

Building Techniques for Cold Climates
©Wisdom & Associates, Inc.
PO Box 3413, Kenai Alaska 99611
(907) 283-0629 ph. (907) 283-9188 fx
www.WisdomAndAssociates.com

First Printing

Publication Date: August, 2019

COPYRIGHT© 2019

By

Wisdom & Associates, Inc.

(Printed January 15, 2015)

Copyright © 2019 by Wisdom & Associates, Inc.

7984 Kenai Spur Highway

Kenai, Alaska 99611, (907) 283-0629

Authored by: Robert Moss

Technical Assistance: Steven Wisdom

All rights reserved. No part of the material protected by this copyright notice may be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without the express written consent of Wisdom and Associates, Inc.

Table of Contents

Introduction ---- **6**
Heat ---- **7**
Purchased Energy ---- 7
Solar Energy ---- 7
Dwelling Energy ---- 7
Thermodynamics ---- **7**
Radiation ---- 7
Convection ---- 8
Conduction ---- 7
Controlling Heat Loss ---- 7
Introduction to Insulation ---- **8**
Batt Insulation ---- 9
Loose Fill Insulation ---- 10
Foam Insulation ---- 12
Describing Heat Loss ---- **14**
British Thermal Units ---- 14
R-Value ---- 14
Heating Degree Days ---- 17
Heating Load ---- 18
Air ---- **20**
Stack Effect ---- 20
Wind Effect ---- 22
Point Source Effect ---- 22
Duct Leakage Effect ---- 23
Interior Door Closure ---- 24
Pressure Imbalances ---- 26
Methods of Controlling Air Leakage ---- **26**
Managing Supply and Exhaust ---- 26
Balanced Duct System ---- 27
Exterior Weather Resistant Barrier ---- 28
Interior Vapor Retarder ---- 29
Caulking & Sealants ---- 30
Gaskets ---- 30
Tapes ---- 31
Moisture - Vapor ---- **32**
Condensation ---- 32
Psychometric Chart ---- 33
Vapor Retarder Materials ---- 34
Vapor Retarder Placement ---- 35
Moisture - Bulk ---- **38**
Weather Resistant Barrier ---- 38
Capillary Breaks ---- 39
Air Gaps ---- 40
Pressure Equalization ---- 40
Eliminate Direct Openings ---- 40
Flashing ---- 40
Grading and Drainage ---- 40
Roof Gutters ---- 41
Heating Fuel ---- **42**
Heat Content ---- 42
Equalizing Fuel Costs ---- 42

Cost Per BTU ----43
Heating Efficiency ----44
Steady State Efficiency----44
AFUE----45
COP ----45
Heating Appliance Types----47
Open Combustion----47
Closed Combustion ----48
Natural Draft ----48
Assisted Draft ----48
Forced Draft ----49
Cold Climate Considerations ----49
Heating Appliance Sizing ----50
Modulating Heating Systems----50
Domestic Water Heating ----51
Energy Factor ----51
Open Combustion Water Heaters ----52
Sealed Combustion Water Heaters----52
Electric Tank Water Heaters----52
Tankless/On Demand ----53
Combi-Boiler ----53
Boiler Mate ----53
Heat Pump Water Heaters----54
Gallons Per Minute ----55
First Hour Rating ----55
Electrical ----56
kWh Costs----56
Lighting Efficiency----56
Color Rendering Index ----56
Lighting Cost----57
Fans & Pumps----58
Home Appliances----59
Cost Effectiveness----60
Payback Period ----60
SIR----61
Ventilation ----62
Ventilation Strategies ----62
Ventilation System Types ----63
Supply Only Ventilation----64
Exhaust Only Ventilation ----64
Balanced Ventilation ----65
Heat Recovery Ventilation ----66
Indoor Air Quality----68
Carbon Monoxide----68
Radon ----70
Mold----72
Garages----73
Alaska Specific Concerns ----74
Snow Loads ----76
Seismic Design ----78
Wind Design ----78
Building Orientation----78

Building Shape ---- 78
Foundations ---- 80
Slab Foundations ---- 80
Basement/Crawlspace ---- 83
Piling Foundations ---- 84
Multi-Point Foundations ---- 86
Materials - Concrete ---- 87
Materials - Wood ---- 88
Site Considerations ---- 88
Permafrost ---- 92
Frost Depth ---- 94
Foundation Insulation ---- 95
Foundation Air Sealing ---- 98
Foundation Vapor Retarders ---- 99
Floors ---- 100
Floor System Vapor Retarders ---- 102
Cantilevers ---- 103
Floor System Air Leakage ---- 104
Rim Joist ---- 104
Above Grade Walls ---- 106
Advanced Framing Techniques ---- 106
Single Stud Walls ---- 112
Strapped Stud Walls ---- 114
Double Walls ---- 115
Stand-Off Walls ---- 116
SIPS Panels ---- 117
Log Walls ---- 118
Masonry/Concrete Walls ---- 119
REMOTE Walls ---- 120
Vapor Retarders ---- 121
Roof/Ceiling Construction ---- 126
Hot Roofs ---- 126
Cold Roofs ---- 126
Ice Dams ---- 129
Vapor Retarders ---- 130
Attic Access ---- 135
Truss Uplift ---- 138
Windows ---- 140
Frame Materials ---- 140
Efficiency ---- 142
Energy Star ---- 143
NFRC Ratings ---- 144
Installation ---- 145
Flashing ---- 148
Doors ---- 149
Door Materials ---- 149
Weather-Stripping & Air Sealing ---- 150
Glossary ---- 154

Introduction

The purpose of this manual is to provide an outline of the fundamentals of building and construction techniques for cold climates. The goal of this manual is to prepare readers with the knowledge and critical thinking skills to make informed decisions about the building materials, techniques and construction types.

The underlying theme for this manual is that a "house is s system". This is a term that has been in the industry for some time, but is a true now as it was when it was first coined. It reminds us that any decision made in the construction process can have consequences later in the building process or when the home is occupied. Some outcomes may happen during or immediately after construction, and some may not show up for many years. Most building failures are a symptom of larger issues that came about during the construction process. With the proper knowledge and well thought out plan, a comfortable, safe, and energy efficient house can be constructed that will last for generations.

Alaska encompasses a very large area with many diverse climates and building challenges. From rain forest to permafrost, the unique and varied landscape requires the home builder to think critically about building performance and longevity. One size does not always fit all, and this is certainly true about cold climate construction in Alaska. Methods, materials and practices that are successful in one region of the state will fail miserably in another. The reader of this manual is encouraged to approach each home as a unique and complex undertaking where each component of the building is evaluated and optimized for the site conditions.



Alaska has some of the most challenging conditions for cold climate construction in North America.

Heat

Heat is energy in one form or another, and there are three methods of energy movement; radiation, convection, and conduction. The principals of building science seek to address the three methods of energy transfer. Insulation is the primary tool used to reduce heat loss, and the amount of heat loss can be described and measured

Purchased Energy

There are three types of energy to be considered in relation to home construction. The first type is purchased energy. Purchased energy is energy that has been paid for, either through money or physical labor, to be consumed in the home for heating, lighting, appliance use, or through other means. Purchased energy makes up the largest energy input into a building. Purchased energy most commonly refers to utilities such as natural gas, electricity, or fuel oil, but purchased energy can also refer to wood, coal, or solar electric for example. When money is exchanged for energy, that energy is considered purchased energy even if all the cost is paid upfront such as with renewable systems.

Solar Energy

The second kind of energy related to building science is solar energy. Solar energy is energy from sunlight, typically in the form of heat gain through windows and skylights. Solar energy in this context is energy that is not paid for, but can be captured through strategic use of building orientation and glazing types to maximize heat gain in northern climates.

Dwelling Energy

The third type of energy is dwelling energy. Dwelling energy is energy produced by the occupants of the home through normal household activities. Dwelling energy is a small fraction of the overall energy input into the home. The average person will emit about 300 BTU per hour.

Thermodynamics

When considering the movement of heat energy in a home or dwelling, the law of thermodynamics must be taken into account. The law of thermodynamics states that energy always flows from hot to cold. This is a particularly important concept in cold climate construction, where energy typically flows from inside to outside. There are three methods of energy movement. Radiation, convection, and conduction are the methods by which energy moves, and in cold climates the way in which energy or heat leaves the building. By addressing each means of energy movement with construction techniques and efficient design, heat loss in cold climates can be greatly reduced.

Radiation

Radiation is the transfer of heat via electromagnetic waves. Radiation is invisible, but is easily felt with bare skin. Electric heaters, incandescent lamps, and sunlight are all examples of radiation energy traveling from the source outwards. In the context of cold climate construction, capturing radiant energy from the sun, while at the same time limiting the amount of radiant energy loss through windows or other glazings is the goal.

Radiant energy escapes through clear assemblies such as windows and skylights. Radiant energy does not travel through opaque assemblies such as floors, walls, or ceilings.

Radiation is a property of the transparency of the material. The more transparent a material is, the more radiant energy is let through. Window manufacturers understand this, and have designed products that can increase or limit the emissivity or solar radiation allowed through based on the climate the window is designed for. Cold climate construction techniques seek to reduce radiant heat loss from a building. Reducing radiant heat loss can be accomplished several different ways, including through the

use of low-e or low emissivity coatings on the glass panes of windows. The type and orientation of emissivity coating can greatly affect the amount of solar radiation allowed to pass through a window.

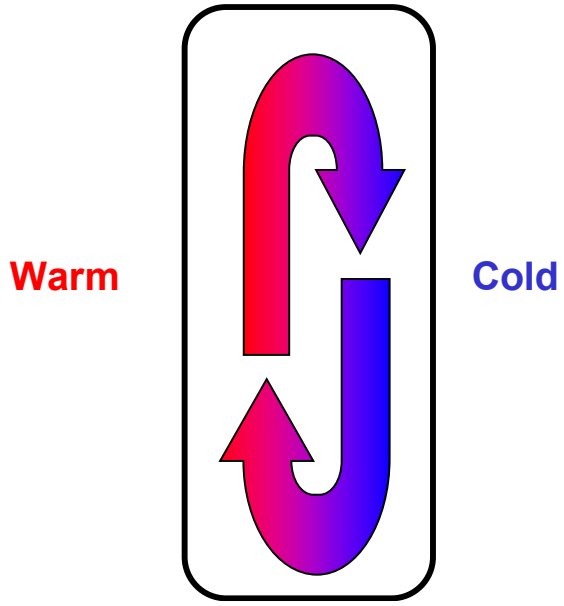
The addition of more than one glazing to an assembly affects the amount of radiation that passes through, particularly if more than one glazing surface has a low emissivity coating.

Lastly, proprietary mylar products such as heat mirror are used inside window assemblies to mimic the effects of an additional pane of low-e coated glass with less weight and expense.

Convection

The second method of energy movement is through convection. Convection is the transfer of heat energy from a warmer area to a cooler area via movement of a gas or liquid.

The process of convection, or the "convective loop", efficiently transfers heat from inside buildings to the outside with air movement. Convective loops can be very large or very small, and occur wherever there is a difference in temperature and space in which air can move.



A convective loop transfers heat efficiently.

The loss of heat through convection is a property of air movement. It is the still, trapped air inside a building assembly which performs the primary insulating role. The ability of the insulation to trap air and how well the insulation is installed to prevent air movement are essential to preventing heat loss by convective air movement.

Convective loops can be any size. An example of a large convective loop would be a heating radiator or baseboard. As air is warmed, it rises and draws cool air in from the underside in a continual process. Convective loops can also be quite small. A void or handprint in an insulated cavity can set up a small convective loop that will draw heat outside.

Proper installation of insulating materials is key to reducing convective heat loss, particularly with hand installed insulation such as batting. Insulation works by trapping air and reducing air movement. Insulation should be in contact with all six sides of an assembly such as a floor joists or wall stud cavities to prevent air pockets which result in convection.

Insulation should be installed to full depth of the product. No efficiency is gained by over-filling a cavity with a higher rated product which would cause the insulation to be compressed. As insulation is compressed air pockets are reduced, but conductive heat loss is increased at the same time.

Conduction

The third method of energy movement is via conduction, or the transfer of heat through a solid material. Heat loss is a property of conductance, which is how efficient a material is at transferring heat from warmer areas to cooler areas.

High conductance materials are those which are efficient at transferring heat. In terms of building materials, metal, concrete, and wood products are considered to be good conductors of heat.

It can be difficult to avoid using materials with high conductance in the building envelope or a part of a thermal boundary assembly, since those same materials are often the ones that provide the required structure of the building. However, the use of a "thermal break" or interruption between the interior and exterior of a conductive material can reduce heat loss.

The conductance of a building materials is measured and compared by using R-value. The R-value of a material making up a building assembly is a measure of the resistance to heat loss. The higher an product's R-value rating, the lower the conductance of the material and the more resistant to heat loss that product is.

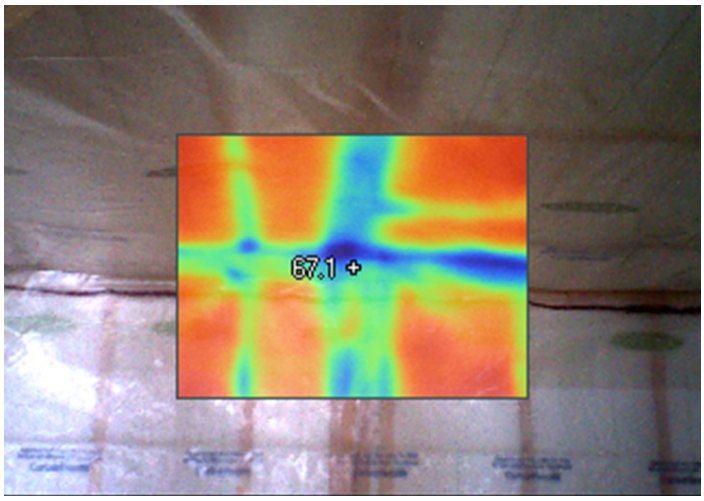
From a building science standpoint, reducing conductive heat loss can be accomplished in two different ways.

The first way is to use materials with lower conductance whenever possible. For example while both wood and concrete are considered conductive, wood is relatively less conductive than concrete and will result is less heat loss at the same given thickness of material.

The second strategy is to utilize thermal breaks as part of the building assembly whenever possible. Low conductance materials such as insulation can be used to cover higher conductance materials such as wood or concrete to reduce the rate of heat loss significantly.

Controlling Heat Loss

Controlling heat loss is a primary goal of energy efficient building. Slowing down heat transfer from inside of the building to the outside reduces energy costs. By addressing each method of heat loss with proper materials and installation practices, an energy efficient building envelope can be constructed.



Conductive heat loss as seen through an infrared camera.



Examples of conductivity of building materials

Introduction to Insulation

Before examining the properties of different types of insulation, it is important to understand where the insulation should be applied for maximum effectiveness. The thermal boundary of a building must be defined at the beginning of construction.

The thermal boundary is the assembly that separates the heated or conditioned space of the building from the exterior of unconditioned space surrounding the building.

Understanding where the thermal boundary is located is key to maximizing the effectiveness of the insulating effort. Insulation that is used inside the thermal envelope, such as in knee walls or between floor joists, is ineffective at slowing heat loss if the thermal boundary is the ceiling or the basement wall for example.

In all cases the thermal boundary, which is defined by the location of the insulation, should be aligned with the pressure boundary, which is the location of the vapor retarder. The pressure boundary reduces air movement which degrades insulation performance, and the thermal boundary reduces heat loss from radiation, convection, and conduction. If the insulation and the vapor retarder are not aligned, air movement through the insulation will greatly reduce its effectiveness.

Insulation Types

There are three common types of insulation; batt insulation, loose fill insulation, and foam insulation. Each type of insulation has unique properties that must be understood to get efficient performance from the thermal envelope of a building.

The properties of an insulation must be examined to make the correct choice for the intended application. How rigid or soft the material is affects how and where the product may be installed. Care must be taken with soft materials such as batts or loos fill products to prevent compression which reduces effectiveness.

The R-value of an insulation must be considered in conjunction with the space available in the building assembly. Higher R-value products can fit in smaller spaces than lower R-value products of the same thickness, but usually at an increased cost.

The moisture resistance of an insulation product must be weighed depending on the use, particularly in exterior, basement, or crawlspace applications.

The permeability of an insulation affects the requirements for an additional vapor retarder. Certain low permeance materials may double as an effective vapor retarder which can be a benefit.

Batt Insulation

Batt insulation is a soft material that is generally sold in pre-cut strips or rolls. The R-value of batt material varies by type and by density and is stated on the product by the manufacturer. Batt insulation is typically somewhat moisture resistant since it is usually composed of inorganic material such as fiberglass or rockwool. Batt insulation is permeable to both air and moisture and must rely on a separate vapor retarder and exterior air barrier to prevent moisture and air intrusion which degrades performance. Fiberglass and rockwool are the two most common materials used for batt insulation.

Batt insulation must be cut to fit inside a cavity or assembly. Batts are not self supporting, and are easily compressed if not cut to fit correctly. Batt insulation is susceptible to voids and compressions during the installation process. It is a soft material, and care must be take to install batts at the manufacturer's rated thickness to get proper performance. Small compressions from tucking batts behind wiring or piping, over-sizing the batt, or even handprints will negatively affect the insulating performance.



Poorly installed insulation results in a lifetime of heat loss and energy waste.

Lumber Size	Cavity Depth	R-Value When Compressed in Cavity											
2X12	11-1/4"	37	38										
2X10	9-1/4"	32	35	28									
2X8	7-1/4"	27	29	25	27	24							
2X6	5-1/2"			21	22	20	19	21	18				
2X4	3-1/2"						14	15	13	15	13	11	
2X3	3-1/2"									11	10	8.9	8
2X2	1-1/2"										6.6	6.1	5.7
2X1	3/4"												3.3
Product R-value		R-38	R-38C	R-30	R-30C	R-25	R-22	R-21	R-19	R-15	R-13	R-11	R-8
Product Thickness		12"	10-1/4"	9-1/2"	8-1/4"	8"	6-3/4"	5-1/2"	6-1/4"	3-1/2"	3-1/2"	3-1/2"	2-1/2"

This chart illustrates that installing a thicker or higher R-value batt in a cavity that is too small does not gain any insulation value. Batts are rated to provide insulation at a certain installed thickness and there is no advantage to using a batt that is too large for the assembly. For example, using an R-25 batt which is rated for a 2X8 wall cavity in a 2X6 wall cavity instead results in less R-value than if a properly sized R-21 batt were used in the first place.

Loose Fill Insulation

Loose fill insulation is a soft insulating material that typically consists of small, chopped up pieces of insulation sold in compressed bags.

Loose fill insulation is rated by R-value per inch of material at a given thickness and/or density. For unenclosed applications such as in the attic space, the insulation product may be rated at an initial installed thickness and R-value, and a settled installed thickness and R-value. The settled thickness and R-value rating recognizes that some products will naturally settle over time and this provides a more accurate picture of the long-term insulating value of the product.

Loose fill insulation can be installed in two ways. Loose fill insulation that is designed to be installed in a cavity such as a stud bay or floor joist is installed at certain density to prevent settling which would leave voids in the cavity that promote heat loss. Loose fill insulation installed in an attic of other unenclosed space is installed at a lower density to allow greater thickness and R-value. The R-value per inch is different for each application, even with the same product.

Loose fill insulations may be somewhat moisture resistant, dependent on the product type. Loose fill insulation made from organic materials such as cellulose are less moisture resistant than insulations may from inorganic materials such as fiberglass. In either case loose fill insulation is not designed for continuous wetting or submersion. Loose fill insulations are permeable to both moisture and air, and must be protected with vapor retarders and air barriers to prevent wind washing from the exterior and vapor/warm air passage from the interior.

Fiberglass in various forms and cellulose are the two most common blown in insulation products. Other materials such as rockwool and denim are also available although less common.

The installation of loose fill insulation should always be accompanied by a receipt from the installer. The receipt should include important details about the installation.

The measured coverage area for the product should be included. Without knowing the square footage of the area to be insulated, there is no way to accurately count bags and install the product to desired thickness. The initial installed thickness of the product should also be included. Many loose fill insulations are recognized to settle after the initial install, particularly cellulose insulation. Conversely, the minimum settled thickness should be noted as well. This is the long term insulation level that will be present in the home for the remainder of the product lifespan, and reflects the actual efficiency and R-value of the installation. The R-value of the installation must be recorded on the receipt as well. If the product has both an initial and settled thickness, the R-value of the settled thickness is more accurate. Finally, the number of bags used for the installation should be included. The number of bags can be checked against the square footage of the install to determine if the thickness or R-value of the installation is correct. This is a good way to check that the insulation blower has been calibrated and the product has been installed correctly.



Insulation depth markers such as the one shown in this photo help the contractor install the proper amount of loose fill insulation in an attic space, and offer easy verification of insulation thickness and R-value after the fact.



Loose fill insulation can be installed as an uncompressed blown-in product on the attic floor, or as a compressed insulation contained in a cavity known as "densepack". Loose fill insulations installed in enclosed cavities must be installed at a specific pounds per cubic foot density to achieve rated R-value and to prevent settling and voids in the cavity over time.

Foam Insulation

Rigid insulation materials are hard materials that maintain their shape unsupported. Rigid insulation is most commonly a foam product, although there are some fiberglass products available. Rigid materials are typically board stock or are spray applied in the field. Rigid materials are rated as an R-value per inch of material thickness.

Rigid insulation materials may be open or closed cell type. Open cell materials may absorb water, and closed cell materials are typically moisture resistant. The PSI rating of board products can also affect the moisture absorption properties of the product.

Most rigid insulating materials are impermeable to air and moisture. Check with the manufacturer for the permeance ratings of a particular product to verify that it will work for the intended application.

Rigid foam insulations are subject to ultraviolet decay from sunlight, and must always be covered in an outdoor application. Foam products must also be protected from physical damage if installed outside.

There are four commonly used rigid foam insulation materials. Expanded polystyrene, extruded polystyrene, and polyisocyanurate are board stock products available in various pre-cut thicknesses and sizes. Polyurethane foam and its many variants are a spray applied product that is mixed and installed in the field.

Expanded Polystyrene Insulation

Expanded polystyrene, or EPS, is a board stock foam available in several different densities or grades. Lower density products typically have a lower R-value and are not suited for ground contact or below grade use as they may absorb moisture. A minimum of 25 psi is needed to prevent moisture absorption.

EPS is an open cell foam, which makes it vulnerable to water absorption at the lower densities. The open cells are filled with air, which is slightly less efficient that closed cell foams which may be gas filled and achieve a higher R-value rating per inch.

EPS foam by itself does not usually qualify as a vapor retarder, especially at lower densities and thicknesses. The product is often skinned with a polyethylene and/or aluminized vapor retarder on one or both sides which can qualify the product as a vapor retarder and at the same time help the product hold its shape. EPS foam is usually rated at R-4 per inch of thickness.



EPS (Expanded Polystyrene) foam placed on grade and ready for concrete. Not all EPS foams are rated for below grade use, check manufacturer specifications.

Extruded Polystyrene Insulation

Extruded polystyrene, or XPS, is also available in different grades or densities. XPS foams are available in higher densities than EPS foams, usually starting at 40 psi. XPS foams are suitable for below grade use as these products exceed the 25 psi minimum needed to prevent water absorption and to withstand soil pressure.

XPS differs from EPS in that it is a closed cell foam rather than open cell, which allows it to qualify as a vapor retarder in most applications. Due to the rigidity and low permeance of this product from the higher psi formulations, XPS foam is not usually skinned. XPS has a higher R-value per inch than EPS, rating at a typical R-value of 5 per inch.

Polyisocyanurate Insulation

Polyisocyanurate foam boards, or PISO, is a closed cell foam product. PISO foam board is usually skinned on both sides. The foil facing qualifies PISO as a vapor retarder and helps maintain the integrity of the product which is more easily subject to physical damage than the other foam boards.

The density of PISO foam board is much lower than XPS and it is not suitable for below grade or ground contact use. The R-value of PISO foam is the highest per inch of the three common foam board stock types at R-7 per inch.

Spray Foam Insulation

Spray applied foam insulation is available as a one- or two-part formula. Spray foam insulation is typically a polyurethane product, although many variations in mixtures are available. Sp

Spray applied foam can be open or closed cell, depending on the mix type. One-part products are typically open cell, and two part products are typically closed cell.

Spray applied foam may or may not qualify as a vapor retarder. This often depends on the installed thickness of the product, and the integrity of the "skin" that forms on the surface of the foam as it cures. Check with the manufacturer's specifications to determine the permeance of the product.

Spray applied foams have a variable R-value depending on the manufacturer, but an R-value of 6 to 8 per inch is standard.



Spray polyurethane foam may be considered a vapor retarder if applied at the correct thickness and if the outer skin remains intact, check manufacturer specifications.

Describing Heat Loss

British Thermal Unit

The British Thermal Unit is the most common unit of measure to describe an amount of energy and is used nearly universally by contractors, designers, and manufacturers in the construction industry. A BTU is the amount of energy needed to raise one pound of water one degree Fahrenheit.

A lot of BTUs are needed to heat a home over the course of a year, so the terms “Therm” and “MMBTU” are used as a shorthand way or describing large amounts of BTUs. 100,000 BTUs is called a therm, and 1,000,000 BTUs is described as MMBTU.

Heat loss from buildings is measured at a rate, or a certain amount of loss in a discrete amount of time. BTU per hour, or British Thermal Units per hour, is the most commonly used unit of measure to describe the rate of heat loss through a particular building assembly or even from a whole building.

R-Value

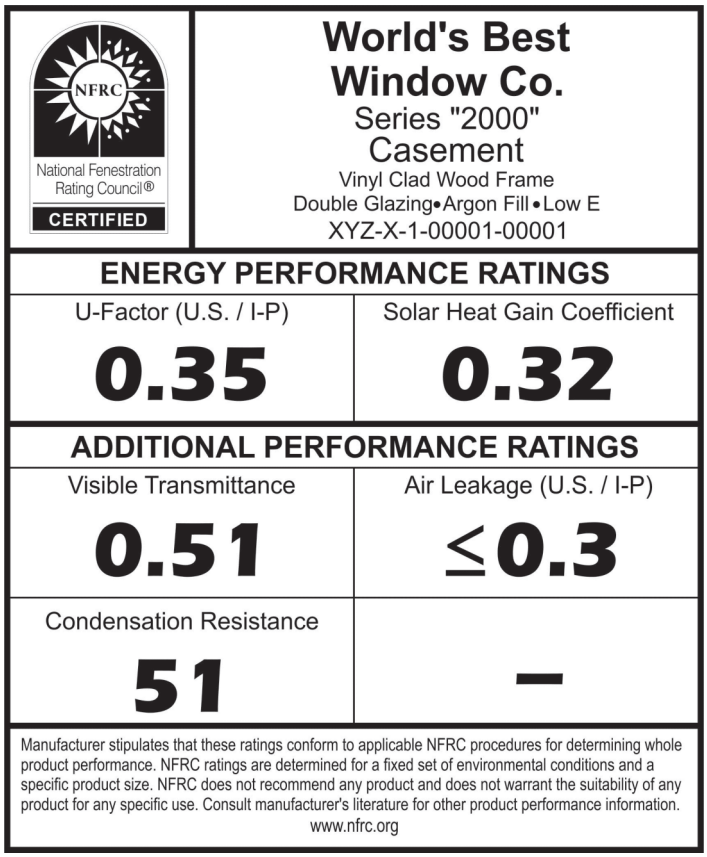
Heat loss from a building is directly related to the R-value of the components of that building. The higher the R-value, or resistance to heat loss, the less BTUs per hour escape to the outside.

U-factor is also a measure of resistance to heat loss; however U-factor is the opposite of R-value. The lower the U-factor of a building product, the higher the resistance to heat loss and the less BTUs per hour escape outside.

Most common building products use the R-value and U-factor designations to rate their resistance to heat loss and building energy codes now usually require that products be rated with these designations.



Building insulation products are required to have listed R-values. The thicker the product, the higher the R-value and resistance to heat loss.



Window and door product insulation is rated by U-value

Resistance to Heat Loss

R-value and U-factor are the primary means of describing the resistance to heat loss of a given product, and R-value and U-factor as also interchangeable. If the R-value of a product is known, the U-factor can be determined, and vice-versa.

To determine the U-factor from the R-value, divide the number 1 by the R-value. This is what is known as taking the inverse. Conversely, to determine the R-value from a U-factor, divide the number 1 by the U-factor.

Being able to convert from R-value to U-factor and back is useful for comparing different building products with different rating types equally. For example, windows and doors are rated in U-factor, and insulation is rated in R-value. Being able to convert back and forth allows an entire assembly of differently rated products to be added together and summed up into one single R-value or U-factor for the purposes of determining overall heat loss of an assembly.

Resistance to Heat Loss - Example 1

- A window is rated at 0.33 U-factor, what is the R-Value?
- 1 / 0.33 = R-3.03

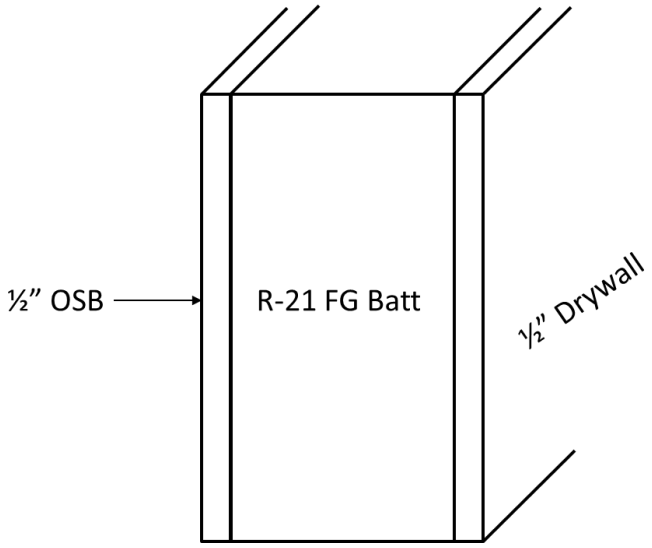
Resistance to Heat Loss - Example 2

- A foam board product is rated at R-8, what is the U-factor?
- 1 / 8.0 = U-0.125

Resistance to Heat Loss - Exercise 1

What is the composite R-value of the entire assembly?

_____



R-Value of Selected Building Components	
½" Drywall	R-0.45
½" OSB	R-0.625

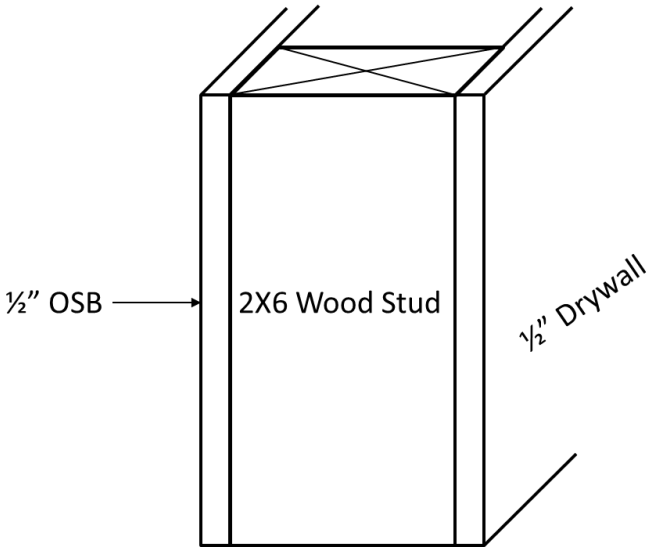
Resistance to Heat Loss - Exercise 2

What is the composite R-value of the entire assembly?

_____

If a wall is 15% studs & plates, and 85% insulation, what is the R-value of 100 square feet of wall?

_____



R-Value of Selected Building Components	
½" Drywall	R-0.45
½" OSB	R-0.625
Wood Stud	R-1.25 per inch

Heating Degree Days

Heating degree days, or HDD, is the measure of the heat load in a single location over the course of one year.

Heating degree days are typically figured at a base of 65 degrees. As such, the mean or average daily temperature is subtracted from 65 and that is the heating degree days for that day. The mean daily temperature is subtracted from 65 every day of the year. All days are then added together to determine the heating degree days for a location.

Heating degree days can be used to estimate the annual heat loss of separate components that make up a building, or even the entire building itself.

Using heating degree days to determine the harshness of the climate at a location and the amount of heat loss over a year is the first step in determining the cost effectiveness of building component choices.

Annual Mean Temperature - Selected Cities

Station	Annual	HDD	Station	Annual	HDD
ADAK	41.1	8724	KING SALMON AP	35.2	10877
ANCHORAGE INTL AP	37.1	10184	KLAWOCK AP	45.5	7118
BARROW WSO AP	11.8	19418	KOBE HILL	28	13505
BETHEL AP	30.7	12520	KODIAK AP	40.9	8797
CANTWELL 2 E	26.7	13980	KOTZEBUE WSO AP	22.9	15367
COLD BAY AP	38.8	9563	MCGRATH AP	27.4	13724
COOPER LANDING 5 W	36.2	10512	NOME WSO AP	27.4	13724
CORDOVA AP	39.7	9235	NORTH POLE	26.9	13907
CRAIG	46.1	6899	PALMER AP	36.8	10293
DEADHORSE	11.5	19528	PAXSON	25.9	14272
DELTA JUNCTION 20SE	27.2	13797	PETERSBURG 1	43.2	7957
DILLINGHAM FAA AP	34.3	11206	PRUDHOE BAY	12.1	19309
DUTCH HARBOR	40.9	8797	SALCHA	27.1	13834
EAGLE	25.5	14418	SAND POINT	41.1	8724
EAGLE RIVER 5 SE	36.1	10549	SELDOVIA AP	39	9490
EKLUTNA WTP	36.3	10476	SEWARD	40.5	8943
ELMENDORF AFB	36.3	10476	SITKA JAPONSKI AP	45.3	7191
FAIRBANKS INTL AP	27.7	13615	SKAGWAY	41.9	8432
GALENA	26.1	14199	SOLDOTNA 5SSW	34.1	11279
GULKANA AP	28.2	13432	ST PAUL ISLAND AP	35.4	10804
GUSTAVUS	41.2	8687	TALKEETNA AP	36	10585
HAINES AP	41.1	8724	TOK	25	14600
HEALY 2 NW	29.8	12848	UNIVERSITY EXP STN	28.7	13250
HOMER AP	38.7	9600	VALDEZ AIRPORT	37.7	9965
HOONAH	43.1	7994	WAINWRIGHT	13.9	18652
HOPE	36.7	10330	WALES	21.7	15805
JUNEAU AP	42.1	8359	WASILLA 3 S	37.3	10111
JUNEAU DWTN	43.5	7848	WHITTIER	41.2	8687
KASILOF 3 NW	34.7	11060	WILLOW WEST	32.9	11717
KENAI AP	36.2	10512	WRANGELL AIRPORT	44.6	7446
KETCHIKAN	45.1	7264	YAKUTAT AP	40.3	9016

Heating

This is a list of annual mean temperatures for selected cities around the state of Alaska, based on 1980 to 2010 data. Heating degree days are a useful tool to compare the relative harshness of the climate at a certain location.

Load Heating degree days, as a measure of how cold the climate is in a location, are an integral part of determining the heating load for a home or other building. The heating load is the number of BTUs required to maintain the interior temperature of a dwelling, typically at 65-degrees Fahrenheit.

The annual heating load is the BTU load over the course of one year, which is useful for estimating annual utility costs.

The peak heating load is the BTU load experienced by the building on the coldest day of the year, which is useful for estimating the required size of a heating system to maintain the interior temperature of the building.

Annual Heating Load

The annual heating load is based on three factors; the heating degree days at the location of the building, the R-value of the component or the assembly, and the square footage or size of the component or assembly.

The formula for figuring the annual heat load is square feet times heating degree days times 24 hours in a day which is a constant. This is divided by the R-value of the component or assembly, and the result is the annual heating load in BTUs.

Annual Heating Load Example

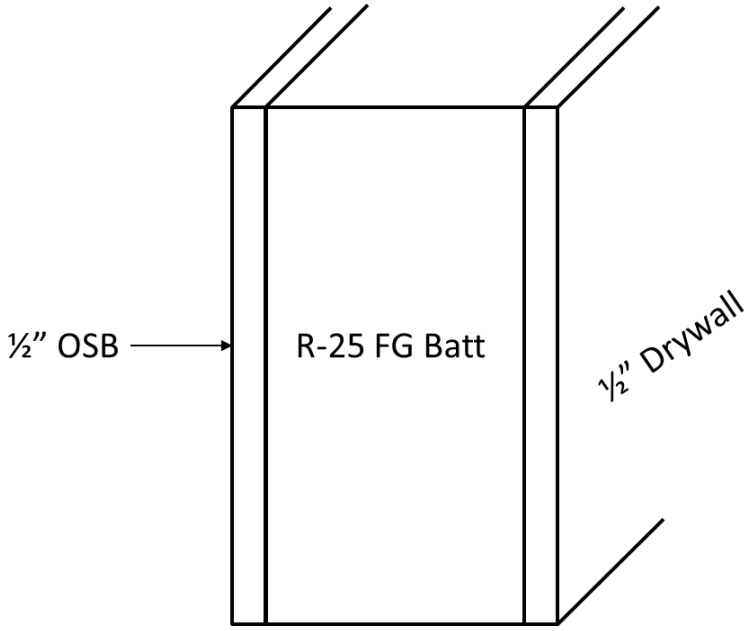
- 100 Square Feet of wall
- R-value of 19.95
- Located in Anchorage (10,184 HDD)
- What is the annual BTU heat loss?

$$\frac{\text{Square feet} * \text{HDD} * 24}{\text{R-Value}} = \text{Annual Heating Load}$$

$$\frac{100 * 10{,}184 * 24}{\text{R-19.95}} = 1{,}225{,}142 \text{ BTU}$$

Annual Heating Load Exercise

- 1000 Square Feet of wall
- 150 SF studs, 850 SF insulation
- Located in Fairbanks (13,615 HDD)
- What is the annual BTU heat loss?



Square feet * HDD * 24 = Annual Heating Load

R-Value

Annual Heat Loss - Insulation:

_____

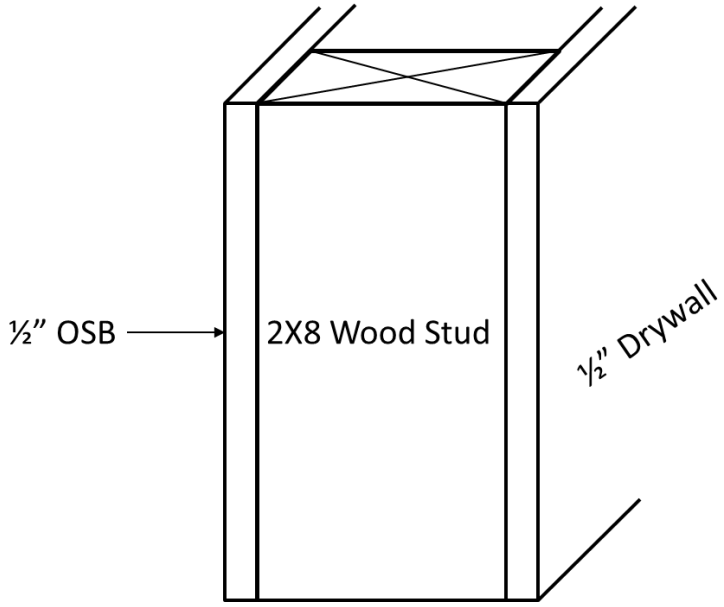
Annual Heat Loss - Studs:

_____

Annual Heat Loss - Total:

_____

R-Value of Selected Building Components	
½" Drywall	R-0.45
½" OSB	R-0.625
Wood Stud	R-1.25 per inch



Air

Air movement into and out of a home is the primary method of heat loss and of moisture transport. Moisture is transported through air movement via humidity, or suspended water vapor in the air. Reducing air movement through the thermal envelope and air barrier is a key to increasing energy efficiency as well as improving building longevity.

Air Movement

In order for air movement to occur into or out of a home, there must be two conditions present. The first condition is a hole or a crack in the building assembly that can allow air passage. Holes and cracks in the vapor retarder, whether intentional or unintentional, will allow air leakage if there is a pressure differential present. A well sealed vapor retarder is an important line of defense against uncontrolled air movement into and out of a building. The second condition required for air to move into or out of a home is a pressure difference across the assembly. Pressure differences drive air movement through the gaps and cracks in the vapor retarder.

For every cubic foot of air that exits the building, one cubic foot of air must enter the building from somewhere else. Pressure imbalances always seek to equalize, and the amount of air inside of a home always remains the same.

There are five primary causes of pressure difference or pressure imbalance that cause air movement in a building. These drivers of air movement are stack effect, wind effect, point source, duct leakage, and interior door closure. One or more of these five primary causes are typically responsible for air movement and heat loss.

Stack Effect

Stack effect occurs when there is a temperature difference between the interior and exterior of a building. In most locations in Alaska the outside of the building is considerably cooler than the interior of the building, which means stack effect is a nearly constant cause of pressure imbalance and air leakage in homes.

As it is typically colder outside than inside, warm air rises to the top of the interior of the home or structure where positive air pressure causes leakage. Positive pressure at the top of the building causes heated air to exfiltrate through any gaps in the vapor retarder. At the same time, negative air pressure is created at the bottom of the structure, and for every cubic foot of air that escapes at the top of the building, one cubic foot is drawn in at the bottom.

A home of building can be thought of a chimney in a sense. The taller a building, the greater the stack effect and the greater the pressure difference between interior and exterior, just like a chimney. A taller chimney has a greater draft than a shorter chimney all things being equal, and there will be more positive pressure at the top and more negative pressure at the bottom.

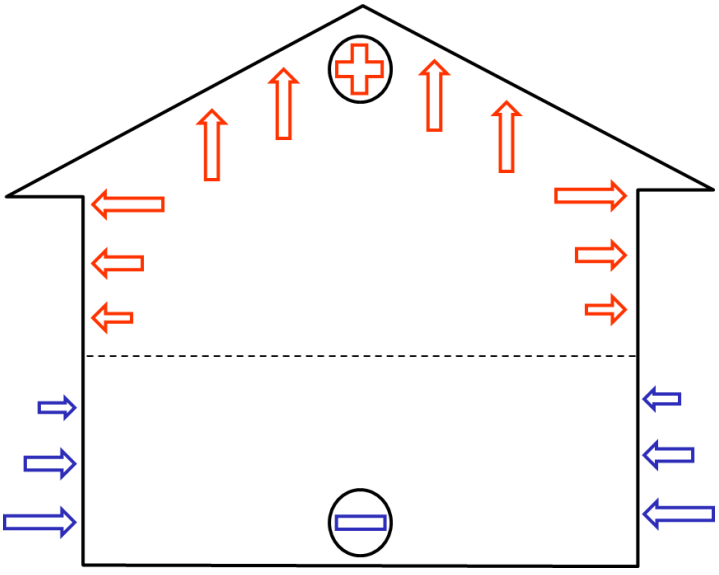
Greater temperature differences between the interior and the exterior of a home will also cause greater stack effect and pressure differences all other things being equal. The closer the outdoor temperature matches the indoor temperature; the less stack effect will be present inside the building.

From a building science standpoint, stack effect cannot be controlled since the outdoor temperature cannot be controlled, and the indoor environment must be maintained at a livable temperature. Limiting building height is not really practical either, since most residential construction is three stories or less.

The optimum solution for mitigating stack effect is to limit the gaps from which conditioned air can escape from the building. A well sealed vapor retarder with limited penetrations is the best strategy to reduce air leakage from stack effect escaping outdoors.



This picture shows the real life result of stack effect. Consistent escape of heated air through the upper half of the building has caused moisture vapor to condensate on the cold exterior surfaces through which interior air has escaped. Over time the heat loss and moisture transfer has decayed the wood adjacent to the leakage points and resulted in water damage and mold growth.



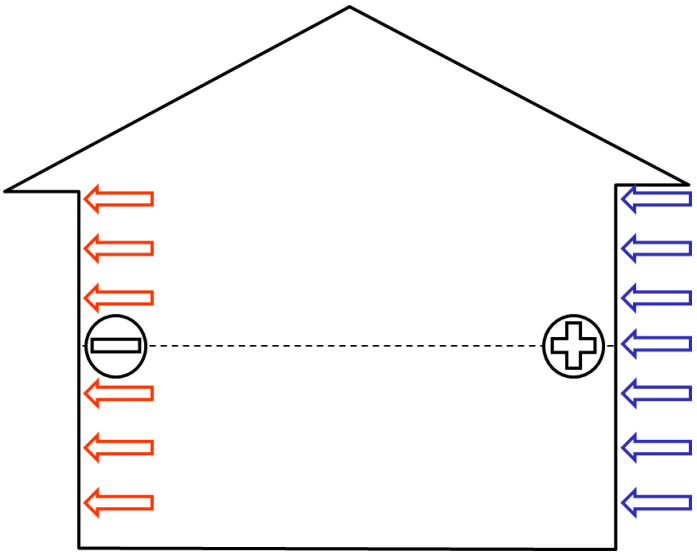
This illustration shows how stack effect interacts with the building. The pressure differences are the greatest at the highest and lowest points of the building, and at the middle of the building there is essential zero pressure difference. Air seeks to exfiltrate or escape through the top half of the building, and infiltrate through the bottom half of the building.

Wind Effect

The second driver of air movement in homes is wind effect. Wind effect is as simple as it sounds, it results from wind blowing on the building.

Outdoor air enters the building on the windward or positive pressure side. Conditioned air exits the building on the leeward side. For every cubic foot of air that enters the building, another cubic foot is pushed out.

Wind effect is a product of the outdoor environment, and little can be done to change the intensity of direction of wind, which is the root cause of air leakage from wind effect. Instead, the there are two strategies to address air movement from wind effect. The first is a well sealed vapor retarder on the warm in winter side of the building assembly, which limits air movement and resulting heat loss and moisture transport from the interior of the building. The second is complete air barrier on the underside of the siding which prevents air infiltration into the insulated cavity while still allowing any water vapor that escapes into the insulated cavity to escape.

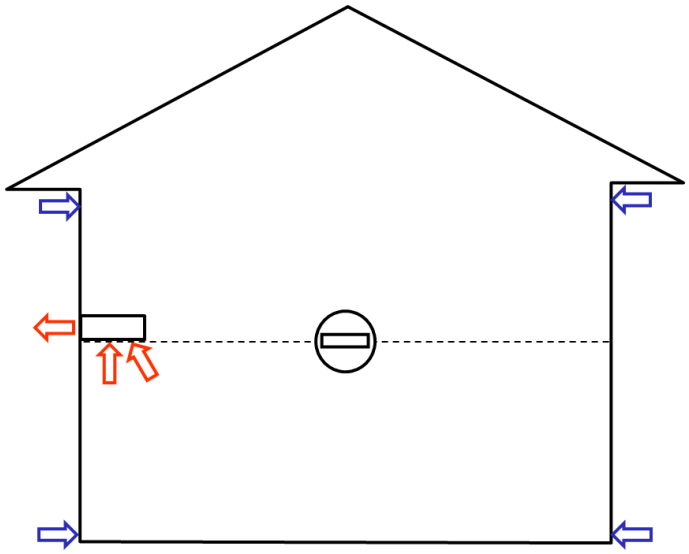


This illustration shows how wind effect pushes outdoor air into the building on the windward side, and conditioned air is pushed out through the leeward side.

Point Source Effect

The third driver of air movement into and out of buildings is the point source effect, which comes from air exhausting appliances inside the home. Appliances such as kitchen range exhaust fans, bathroom exhaust fans, crawlspace exhaust fans, and clothes dryers all remove air from the building when operating.

This removal of air from the building causes a negative pressure imbalance inside the building which causes air to infiltrate from the exterior. Every cubic foot of air that is exhausted from the building must be replaced with a cubic foot of unconditioned air from outdoors.



This illustration shows the effect of point source ventilation inside the home. As air is removed from the home by the exhausting appliance, a negative pressure is created which draws in outdoor air.

In the process of making homes more efficient, building codes and practices require that homes become more air tight. In an air tight environment, exhausting appliances can have a dramatic effect on pressure imbalances which is some cases can cause adverse conditions to occur, including the back-drafting of combustion appliances. The building codes do require exhaust ventilation for areas such as bathrooms and kitchens along with a minimum flow rate, and most homes have a clothes dryer. The amount of exhaust can be controlled somewhat, and limited to the code minimums which reduces the amount of negative pressure inside the home and the resulting infiltration.

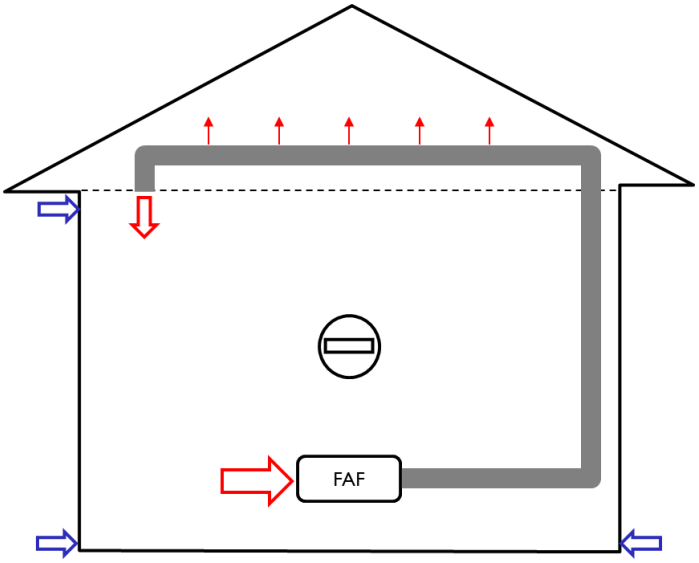
The installation of sealed combustion appliances in air tight homes can offset some of the issues regarding excessive negative pressure inside the home. Sealed combustion appliances are closed to the interior of the home and are much more resistant to excessive negative air pressure than conventional combustion appliances.

Duct Leakage Effect

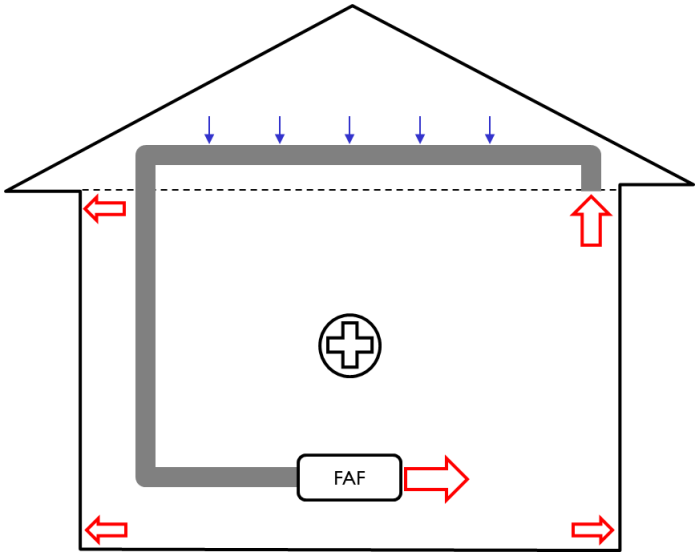
Duct leakage from forced air systems can cause pressure imbalances inside the home. This most notably occurs with forced air furnace configurations where some part of the ductwork is outside of the thermal boundary. Poorly sealed or disconnected ducts contribute to this problem. Pressure inside the ductwork may force air out through gaps of cracks in the ductwork, or the venturi effect of air moving through the ductwork can draw air outside of the duct into the duct through cracks or gaps in the ductwork.

Leakage from the supply side of forced air ductwork may cause negative air pressure inside the building. As air exits the ductwork to the exterior, air must enter the home to make up for the imbalance.

Leakage from the return side of forced air ductwork may cause positive air pressure inside the building. As air enters the ductwork it is added to the inside of the home.



This illustration shows how duct leakage to the exterior on the supply side of a forced air system causes a negative pressure the building.



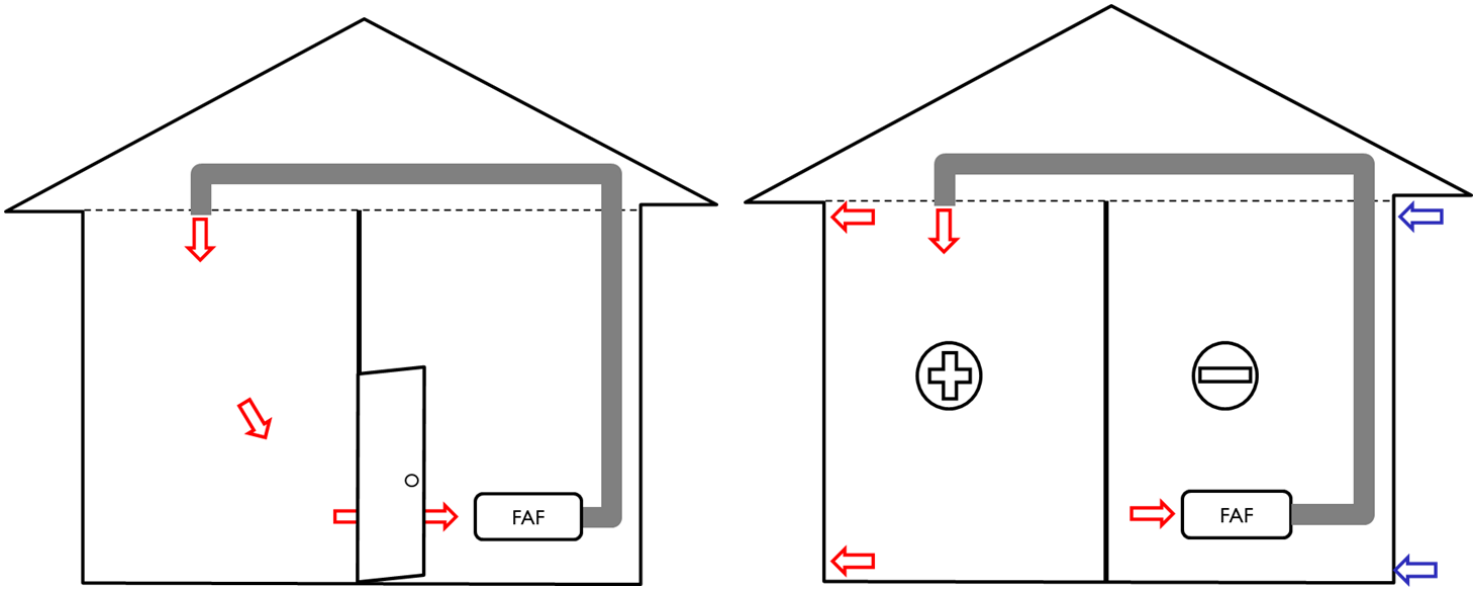
The illustration shows the effect of duct leakage on the return side of forced air ductwork. Air is drawn into the ductwork by the venturi effect. This air is added to the interior of the house.

Interior Door Closure

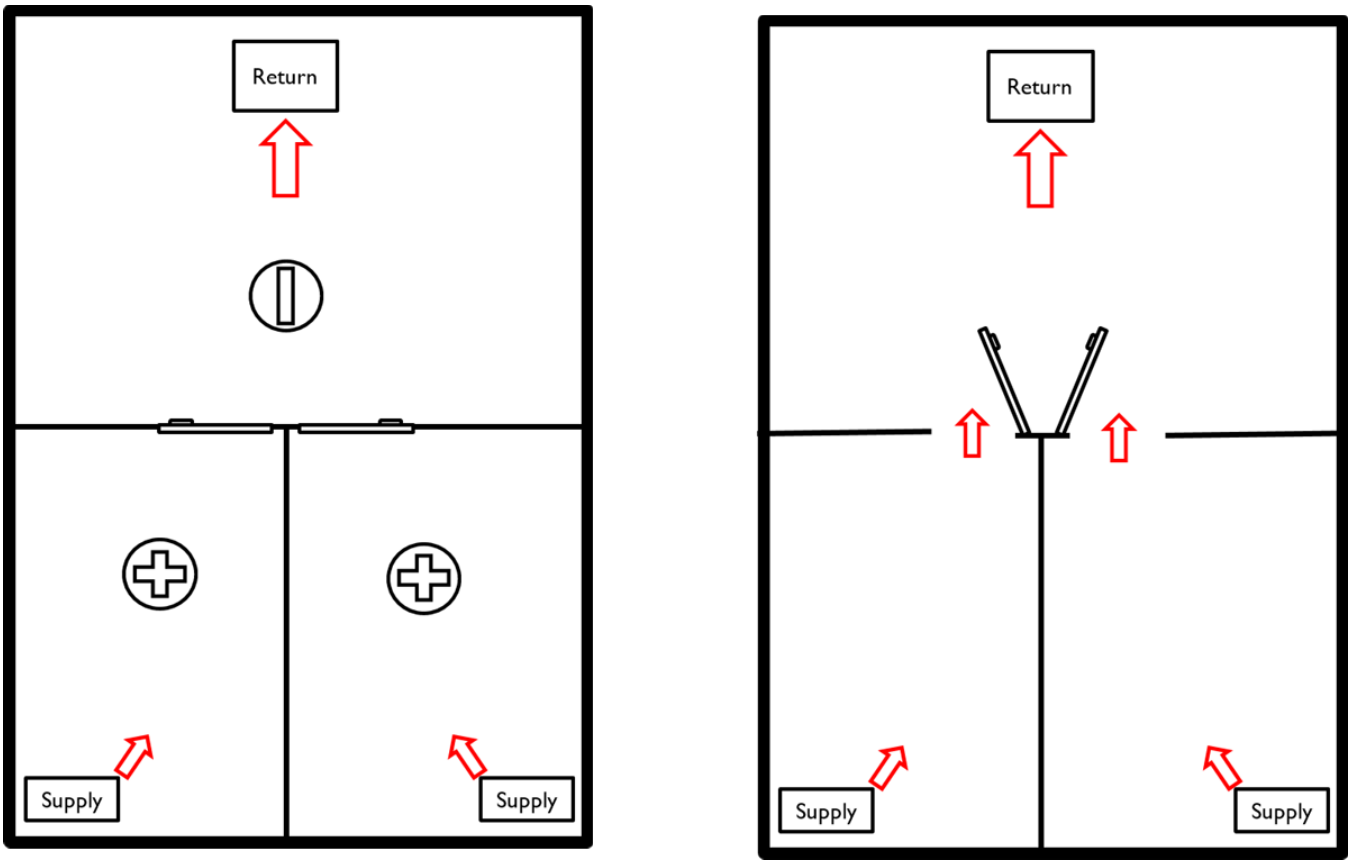
The final significant cause of pressure imbalances inside of a home is through interior door closure. Interior door closure may cause sections of the forced air ductwork to become isolated which cuts off the circulation path of air. Supply registers that are cut off from a return air duct will pressurize the room or space in which they are located. Conversely, the room or space containing the return air duct will depressurize.



This photo shows a real-life example of pressure imbalances from door closure interrupting the air circulation path. This window is in a bedroom that is supplied by a forced air heating system. The only return air for the system is centrally located in the hallway. When the bedroom door is shut, as is often the case, the room becomes pressurized, and air escaping around the window frame causes frost to build up on the siding during cold weather. Frost can often provide a visual clue of air movement out of a building in cold climates by the presence of ice or frost.



This illustration shows the effect of interior door closure which cuts off the air circulation path between a supply duct and a return duct. When the door is in the open position, air can flow freely between the supply and the return and no pressure imbalance is present. However, when the circulation path is restricted, the room or space in which the supply duct is located becomes pressurized, and the room or space in which the return is located becomes depressurized, with reference to the outside.



A plan view of interior door closure shows the pressure imbalance from above. When supply and return ducts are isolated and the air circulation path is restricted, pressure imbalances result.

Positive Pressure Imbalance

When examining pressure imbalances and whether they are negative or positive, it is important to define what they are positive or negative in reference to. In most cases, pressure imbalances are defined in relation to the exterior of the building. For instance, positive pressure imbalances refer to a positive pressure inside the building With Reference To the exterior air pressure.

Positive air pressure imbalances can have many consequences. Increased heat loss from air movement out of the building is a result of a positive pressure imbalance. Another serious consequence of positive pressure imbalance is the transport of moisture and humidity inside the home through the building assemblies to the exterior. In a cold climate, this results in the buildup of frost inside the assemblies as the humidity reaches dew point and turns into liquid water and ice. Over time, the buildup of ice and water inside of the building assembly causes water damage as well as biological growth. Left unchecked, damage can be severe.

Negative Pressure Imbalance

Negative pressure imbalances inside of a home with reference to the outside can also have undesirable effects. Negative pressure imbalances inside the home cause air leakage from outside, which is a heat loss. Negative pressure imbalances can also cause combustion appliances in the home to back-draft, or spill combustion air contaminants including carbon monoxide, into the living space.

Radon and other soil gasses can also be drawn into the home from the suction effect on the ground beneath the home from negative pressure in the home with reference to the outside.

Methods of Controlling Air Leakage

There are many methods of controlling air leakage into and out of a home, which can be grouped into four main categories. The first is to manage the air supplies and exhausts in a home. The second is to balance and seal air handlers and air ducting systems. The third is to utilize exterior weather resistant barriers. The fourth method is to utilize interior vapor retarder and sealants. Using all these methods together will address the significant sources of air leakage in the home.

Pressure Boundary

To effectively control air leakage, the pressure boundary must be identified. The pressure boundary is the plane or assembly that separates conditioned or heated space from unconditioned or unheated space. Air sealing methods and techniques should be applied to the pressure boundary for best results. An example of ineffective air leakage control would be air sealing the roof sheathing if the vapor retarder and insulation are on the ceiling.

For optimum efficiency and effectiveness, the pressure boundary and the thermal boundary should be aligned. In other words, the insulation and the vapor retarder/air barrier should work together on the same plane to stop air leakage and heat loss as a single assembly.

Managing Supply & Exhaust

Managing the supply and exhaust airflows in a home is an important method of controlling air leakage. In cold climates, all powered air supplies that are not part of a balanced ventilation system such as a heat recovery ventilator, must be eliminated. This is good practice as well as part of the model energy code.

For exhausts, it is recommended that the code minimum exhaust airflow rates not be exceed. The minimum intermittent exhaust rates for kitchens is 100 CFM, and the intermittent exhaust rate for bath-

rooms is 50 CFM. Bathroom exhaust may be reduced to 20 CFM for continuously operable exhaust fans. For every cubic foot of heated air that is exhaust from the home, one cubic foot of outdoor air must replace it, making excessive exhaust an energy waste and expensive proposition.

Building codes also require that relief or makeup air be provided for exhausts exceeding certain CFM levels, typically 400 CFM for a kitchen exhaust for example. In this instance there is a double energy penalty for exceeding the minimum requirement and for having a relief or makeup air opening to the outside.

Some of the energy penalty from exhausting heated air from the building can be offset with the use of balanced ventilation with heat recovery. Heat recovery ventilation systems are capable of recovering up to 70% or more of the heat energy from the exhaust air stream and transferring it to the supply air stream. The effectiveness of these systems varies depending on the equipment and the climate.

Balanced Duct System

There are several techniques and strategies for achieving a duct system with a balanced airflow that avoids problems associated with pressure imbalances. First and foremost is a duct system that is properly sized. A properly sized and constructed duct system is much easier to balance than a duct system that is not correctly sized. The most common problem with duct sizing is undersized ducts which cause reduction in airflow. An undersized duct is difficult to correct after it has been installed.

Utilizing multiple air returns is an excellent way to promote balanced airflow. Generally, locating a return in each room or space with a supply duct limits the effect of door closure and the need for other methods of air transfer between spaces.

If adequate air returns are not available or cannot be installed, then the next best method is to provide a way for air to move from each supply to the return point regardless of door closure. Undercut doors and transfer grilles are a way to maintain air circulation paths even when a supply is cut off from a return by door closure. These methods can also be easily used in a retrofit situation where duct system modification is not practical.

In all cases, ducts must be properly sealed at all seams and joints to prevent duct leakage which is inefficient and may contribute to pressure imbalance as well. As pressure in the duct system is increased, the leakage rate is also increased. Joints and seams should be sealed with mastic or approved tapes.



Sealed ductwork prevents leakage which is inefficient and may contribute to pressure imbalance within the home.

Exterior Weather Resistant Barrier

Exterior weather resistant barriers are another method of controlling air leakage into and out of a building. In addition to its primary role of preventing water ingress into the wall system behind exterior siding, weather resistant barriers also block wind infiltration into the wall system. Air movement is a primary driver of heat loss and pressure imbalance, and the weather resistant barriers reduce air movement through the wall assembly.

A discussion of weather resistant barriers as well as interior vapor retarders would not be complete without considering permeability ratings, or how well a material blocks moisture transport. The role of the weather resistant barrier is to block moisture and air movement from the exterior to the interior, but at the same time it must allow water vapor to pass through from the interior to the exterior. To be considered permeable, a weather resistant barrier must be rated at 10 perms or greater.

Perm Ratings

Many building materials are rated in "Perms" which is shorthand for permeability. Permeability is a scientific way of measuring how easily moisture can pass through a material.

Materials through which moisture vapor can pass through easily are said to be permeable, and materials through which water vapor cannot pass through or has great difficulty passing through are said to be impermeable. Depending on the application, the permeability or impermeability of a building material can have great effect on the performance of a building assembly.

Impermeable

Materials which are classified as impermeable do not allow the passage of water vapor. Such materials have a perm rating of 1.0 or less.

Material with a perm rating of 1.0 or less are considered a Class 1 or Class 2 vapor retarder by the building codes. Impermeable materials are placed on the warm in winter or interior side of building assemblies to block the passage of air and moisture through the assembly to the exterior.

Semi Permeable

Materials that are considered semi-permeable have a perm rating of 1.0 perms to 10 perms. These materials allow a small amount of water vapor to pass through them. Materials rated as semi-permeable are not generally satisfactory as an interior vapor retarder or as an exterior weather resistive barrier. Materials with a rating of 1.0 to 10 perms are considered a Class 3 vapor retarder and are only acceptable in warm climates.

Permeable

Materials classified as permeable allow the passage of water vapor through the materials readily. Many materials classified as permeable allow the passage of water vapor while at the same time preventing the passage of liquid water. This is a desirable characteristic when considering the role that the weather resistant barrier fulfills in the wall assembly. Water vapor is allowed to pass through to the exterior, while at the same time liquid water from exterior, such as from wind driven rain, is blocked.

Permeable materials are rated at 10 perms or greater permeability. Permeable materials such as weather resistant barriers are used on the exterior of the wall assembly.

Perm Ratings - Common Materials		
Material	Perm Rating	Vapor Retarder Class
Aluminum Foil	0.05	I
6 Mil Polyethylene	0.06	I
Plywood - Exterior Glue (min. 1/4”)	0.70	II
XPS Foam (2” thick)	0.70	II
OSB (min. 7/16”)	0.91	II
Kraft Faced Insulation	I.0	III
EPS Foam (25 psi, 1” thick)	2.0	III
Drywall - Latex Painted	2.50	III
Drywall - Unpainted	50	III
Housewrap	48-59	III

This chart gives the permeability of many common building materials, and their vapor retarder classification. Class 1 and Class 2 materials would be suitable for use as an interior vapor retarder. Class 3 materials are only acceptable as a vapor retarder in climate zones 1 through 4, which are warm or hot climates.

Exterior Weather Resistant Barrier

Exterior weather resistive barriers are typically required by building codes. The primary purpose is to prevent water intrusion into the above grade wall system as a secondary barrier behind the siding. Weather resistive barrier has a secondary benefit of reducing air infiltration and leakage through the exterior wall assembly. Weather resistive barriers must cover all exterior wall surfaces, this includes gable end walls and other walls that may not be enclosing conditioned space on the interior. Weather resistive barrier is installed in a shingling manner from the bottom of the wall to the top. It is applied in this way to direct water to the exterior of the assembly.

Weather resistive barrier is installed in conjunction with penetrations through the wall such as doors and windows to direct liquid water to the exterior of the assembly.

Interior Vapor Retarder

The fourth primary method of controlling air barriers is with the use of interior vapor retarders. The primary purpose of the interior vapor retarder is to reduce air exfiltration from the interior to the exterior.

The interior vapor retarder must be a Class 1 or 2 vapor retarder, and be rated for less than 1.0 perms. For proper performance of the interior vapor retarder assembly, all edges, seams, and penetrations must be sealed. The interior vapor retarder is required by code to be continuous over the entire above grade wall system, including rim joists.

Caulking & Sealants

The use of caulking and sealants is critical to the performance of the interior vapor retarder system. Caulking and sealants are used to bond two close fitting surfaces to create a continuous membrane or system.

Caulking and sealants are best used in applications where the joint is not expected to experience movement. Caulking and sealants do have some flexibility, but are limited in how large a gap they can be expected to fill and cannot withstand excessive or repeated movement.

Gaskets

In addition to caulking and sealants, gaskets are product that can be used to create a continuous interior vapor retarder. Gaskets are useful for joints that are too large for caulking or will experience repeated movement. Gaskets come in many sizes and are typically compressible and form fitting to maintain a seal even when movement of the assembly is expected. A typical example of large, variable gaps with repeated movement is in log structures, where logs expand and contract seasonally and gaps in the assembly are typically bigger than in stick framing to allow for settlement.

Caulking & Sealant Properties

Type	Indoor/ Outdoor	Lifespan	Notes
Acrylic Latex	Both	8-10 Years	Wood, masonry, drywall. Must be painted on exterior
Silicone	Both	20 Years	Very flexible, durable. Not all can be painted
Butyl	Both	10 Years	For wet areas; concrete, brick, flashings, dissimilar surfaces
Acoustical	Indoor	20+ Years	Never hardens, best choice for polyethylene
Polyurethane	Both	20+ Years	Flexible, long cure time
Single Part Spray Foam	Indoor	20 Years	Expands well

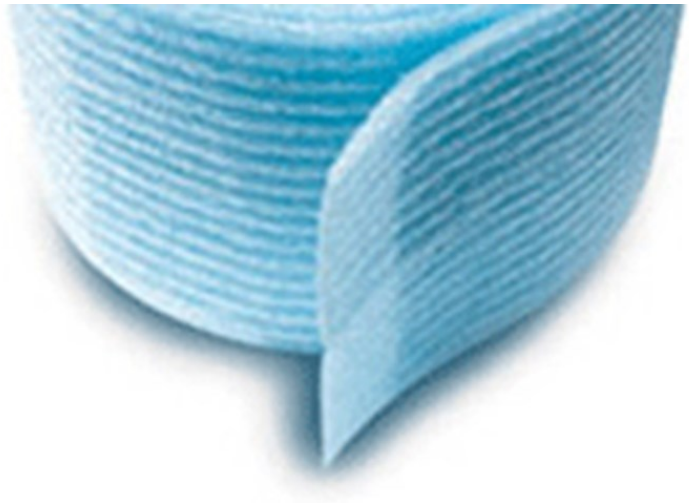
This chart shows the properties of some of the common types of caulking and sealants used in construction. Each type of sealant has strengths and weaknesses depending on the application for which it is used. Check the manufacturer's specifications and compare products to determine which is the right material for the job. Important criteria to consider includes indoor/outdoor rating, lifespan, flexibility, and size of gap that can be filled.

Tapes

Tapes are another useful tool for maintaining a continuous interior vapor retarder or exterior weather resistant barrier. Tapes are typically used for bonding sheet goods such as polyethylene and weather resistant barriers such as house wrap together. For good performance, always match the type of tape to the application.

Gaskets & Tapes Properties	
Type	Notes
Vinyl Tape	Best for polyethylene
Foil Tape	Best for metal, ductwork
Sill Gasket	Closed cell, between plate & foundation
Backer Rod	Larger gaps, between logs
Duct Tape	Not suitable for any use

This chart provides the basic properties of typical tapes and gaskets used in construction. In no case should duct tape be used for sealing, as it tends to creep and fails over time.





Sill seal (left) and backer rod (right) are two effective means of sealing large gaps or gaps where movement is expected.

Moisture - Vapor

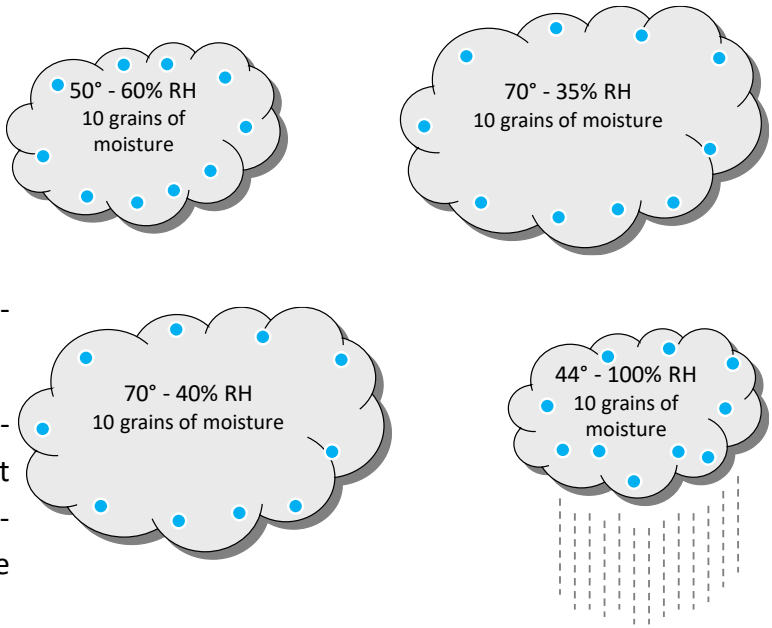
There are several key concepts to understand when considering moisture vapor in building science. The first key concept is that air movement is the primary means of moisture transport in the home. This may seem counter-intuitive at first but controlling air movement also controls the movement of moisture vapor.

The second key concept is the use of the psychometric chart and dew point. Understanding what the dew point is and how it relates to the placement of the interior vapor retarder is critical to the proper performance of a building assembly.

The third key concept, which relates to the dew point concept, is the proper location of the vapor retarder in an assembly. Locating the interior vapor retarder in the wrong spot can cause significant problems with condensation and trapped moisture in the building assembly.

There are two types of moisture that must be considered for cold climate construction, moisture vapor and bulk moisture. This section will deal with moisture vapor, the next section with bulk moisture. Humidity, or water vapor, inside the home and management of dew point and condensation are important to the long-term performance of the exterior building assemblies.

There are two different ways of measuring humidity, relative humidity and absolute humidity. Absolute humidity is that actual physical grains of moisture suspended in the air. Relative humidity is stated as a percentage of water vapor or moisture suspended in the air, relative to the maximum amount of moisture or water vapor the air could hold. Relative humidity, or RH, is the measurement most commonly used in building science applications. The relative humidity or percentage of water vapor that can be suspended in the air varies with the temperature. As temperature increases, the amount of water vapor the air can hold increases and the relative humidity drops. As the temperature decreases, the amount of water vapor the air can hold decreases and the relative humidity increases. At 100% relative humidity, dew point is reached and condensation occurs. Liquid moisture forms out of the air and deposits on nearby surfaces.



Given the same absolute humidity, or actual grains of moisture in the air, relative humidity will decrease as the temperature increases. The amount of moisture in the air remains the same, but the amount of moisture the air could hold increases with the temperature. Conversely, relative humidity will increase at the temperature drops. The actual amount of moisture in the air does not change, but the amount of moisture the air can hold decreases with the temperature.

Condensation

Condensation, or liquid water, will form when relative humidity reaches 100%. Cold surfaces in a building can cause condensation and liquid water to form when relative humidity reaches 100%. This can result in significant problems with water damage and organic growth over time if condensation occurs regularly.

Psychometric Chart

The psychometric chart is a useful tool for determining when dew point will be reached, and condensation will occur. The psychometric chart is based on the interior temperature of the building and the interior relative humidity. Based on this information, the placement of the interior vapor retarder in a building assembly such as an exterior wall can be located such that condensation will not be trapped inside the vapor retarder.

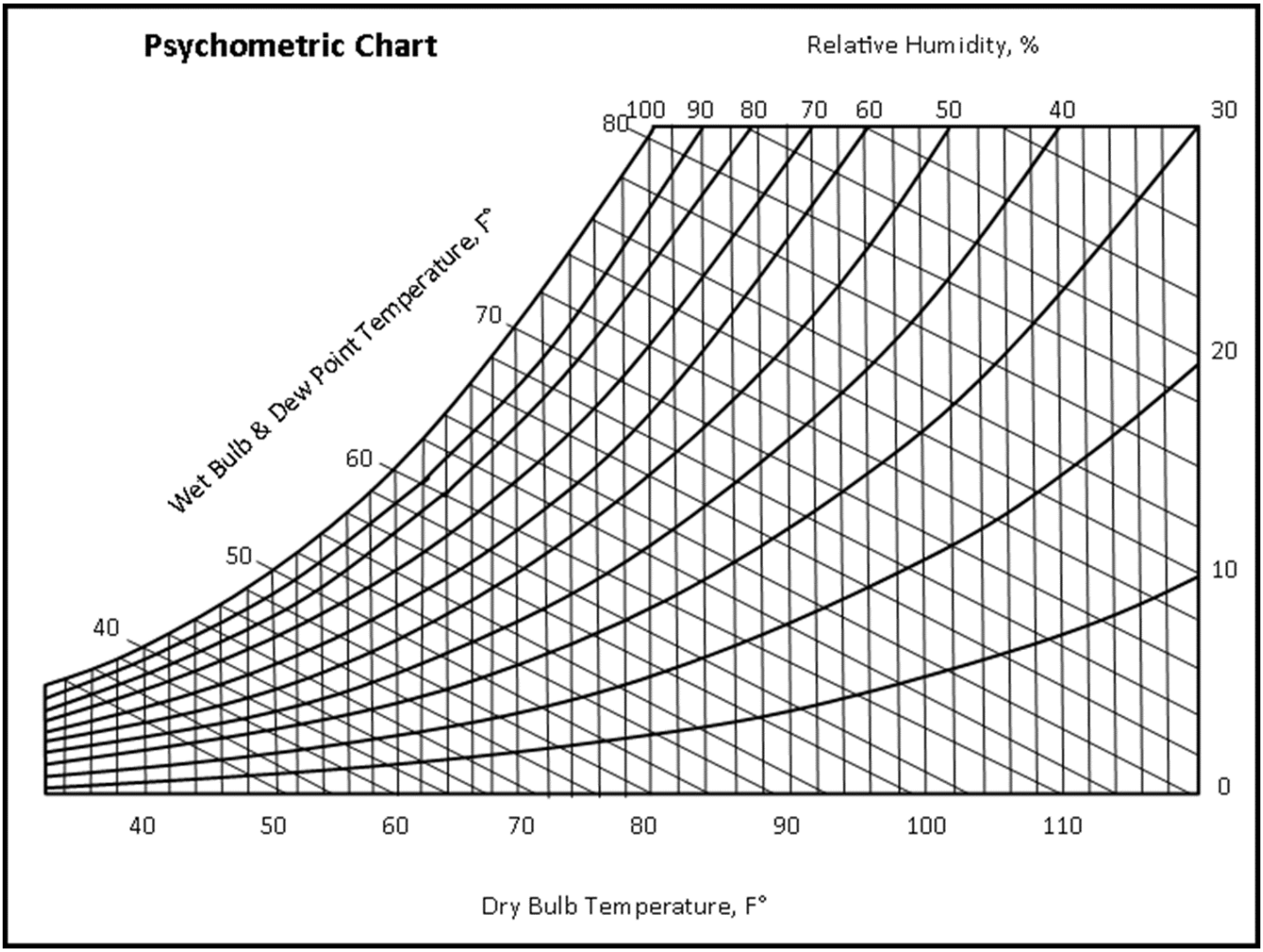
Psychometric Chart Example

Given the example of 70 degree indoor air and 40% relative humidity, condensation will occur when the indoor temperature reaches 44 degrees.

Psychometric Chart Exercise

Given 70 degree indoor air at 60% relative humidity, at what temperature will condensation occur?

_____



Vapor Retarder Materials

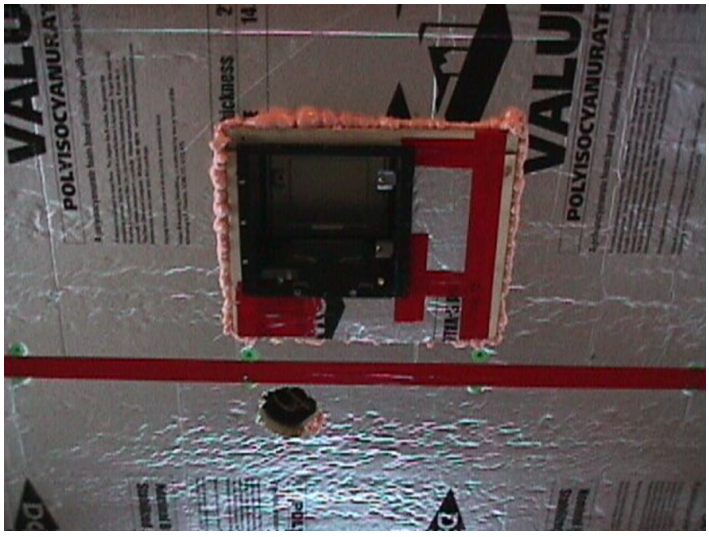
An interior vapor retarder must be an impermeable Class 1 or 2 material. Class 1 and 2 vapor retarders have a permeability of 1.0 perms or less, meaning it is nearly impossible for water vapor to pass through the material. There are several common building materials that fall into the Class 1 and 2 categories, including polyethylene, closed cell foams, and foil facing.

The primary purpose of the interior vapor retarder is to reduce air leakage and the associated moisture transport through the building assembly, which as a result reduces heat loss and potential condensation issues.

Polyethylene is a common vapor retarder material that sees widespread use. 6 mil is the minimum thickness typically used as it meets the perm rating requirements for a Class 1 or 2 material, and it is fairly durable while still being workable.

Foil facing on foam sheet products is another common vapor retarder material. Expanded polystyrene foam is not considered to be impermeable by itself, so foil facing is often added to create a Class 1 or 2 vapor retarder that is acceptable for use in this application. Joints and seams in the sheets are sealed to create a continuous membrane, and no additional material has to be applied over the top. Foil facing on fiberglass batts is not considered acceptable since it is too difficult to adequately seal each batt facing together to create a continuous vapor retarder membrane.

Closed cell foams such as extruded polystyrene are considered a Class 1 vapor retarder material, and can be used as-is with sealing at joints, seams, and penetrations. Spray polyurethane is another foam product that may or may not qualify as a Class 1 vapor retarder, based on the mixture and thickness of the product. Check the manufacturer's specifications, as a minimum two inch thickness is typically required. In many cases 6 mil polyethylene sheeting is still required to cover the inside face of the studs, or caulking must be applied between studs and plates to meet the requirements of a continuous membrane.





Two examples of closed cell foam products being used as a vapor retarder on the interior of a building assembly. The foil facing on the foam in the top photo is the class 1 vapor retarder. Extruded polystyrene foam shown in the bottom photo meets class 2 requirements without an additional skin or film.

Vapor Retarder Placement

Vapor retarder that are located on the wrong or "cold" side of the assembly have the potential to trap condensation or liquid moisture inside of the assembly, where it does not have the opportunity to dry to the exterior.

The psychometric chart can be used to predict where the dew point will occur in an insulated building assembly. With this information, the home builder can place the vapor retarder to the warm side of this dew point which will prevent condensation from being trapped inside the of the assembly. For design purposes, the minimum average January temperature at the location of the building is used. 70 degree indoor air and 40% relative humidity is the standard criteria for indoor conditions.

Based on these criteria, there is a formula that can be used to determine at what R-Value in the assembly the dew point will occur. Measuring by R-value is useful since there are practically an unlimited number of material and design combinations that could be used, and R-value is consistent among all designs. The inside temperature is subtracted from the dew point temperature, and this number is divided by the inside temperature minus the outside temperature. This number is multiplied by the composite R-value of the assembly which yields the dew point position in the assembly by R-value. This is the maximum amount of R-value of insulation that can be placed on the warm side of the vapor retarder.

Vapor Retarder Placement Example

The standard criteria of 70 degree indoor temperature and 40% relative humidity is most often used for design purposes. This yields a dew point temperature of 44 degrees which remains a constant. The outside temperature changes based on location, and in this example the minimum January temperature for Anchorage, AK is used. The composite R-value of the building assembly being tested is 22.07 in this case, but any R-value could be used.

$$\left\{\frac{70-44}{70-11.1}\right\} * \text{R-22.07} = \text{R-9.71}$$

For correct order of operations, 70-44 is divided by 70-11.1 first, and then multiplied by the R-value of 22.07. The result is that the dew point will occur in the assembly at R-9.71. In this example a maximum R-value of 9.71 can be placed on the warm in winter side of the vapor retarder without risking trapping condensation inside the assembly.

Vapor Retarder Placement Exercise

Building located in Barrow: -19.5°

Total R-value of wall assembly: R-30

How much R-value can be placed on the warm side of the vapor retarder?

Answer:_____

$$\left\{\frac{\text{Inside Temperature} - \text{Dew Point Temperature}}{\text{Inside Temperature} - \text{Outside Temperature}}\right\} * \text{R-value} = \text{Dew Point Location}$$

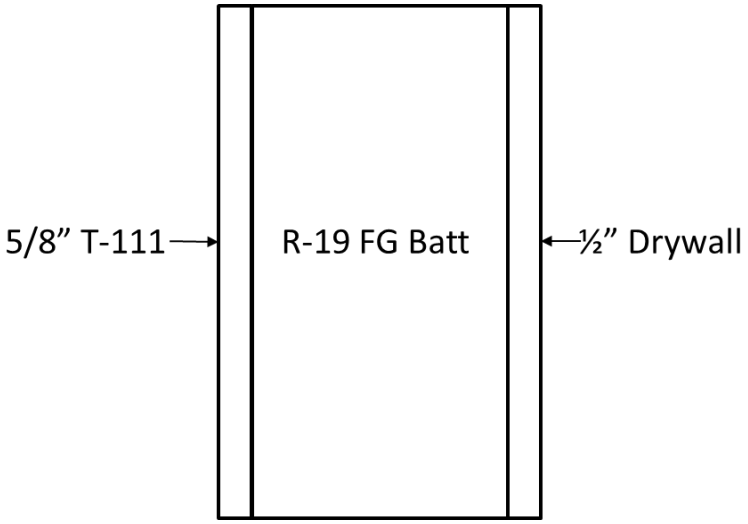
Minimum January Temperature & Vapor Retader Placement - Selected Cities					
Station	Temp.	Max % R-value On Warm Side	Station	Temp.	Max % R-value On Warm Side
ADAK	28	62%	KING SALMON AP	8.8	42%
ANCHORAGE INTL AP	11.1	44%	KLAWOCK AP	31.1	67%
BARROW WSO AP	-19.5	29%	KODIAK AP	25.9	59%
BETHEL AP	0.8	38%	KOTZEBUE WSO AP	-9.5	33%
CANTWELL 2 E	-8.9	33%	MCGRATH AP	-15.3	30%
COLD BAY AP	23.6	56%	NOME WSO AP	-2.8	36%
COOPER LANDING 5 W	8.8	42%	NORTH POLE	-17.2	30%
CORDOVA AP	19.4	51%	PALMER AP	8.5	42%
CRAIG	32.8	70%	PAXSON	-9.1	33%
DEADHORSE	-23.1	28%	PETERSBURG 1	26	59%
DELTA JUNCTION 20SE	-12.5	32%	PRUDHOE BAY	-22.4	28%
DILLINGHAM FAA AP	9.5	43%	SALCHA	-13.6	31%
DUTCH HARBOR	27.7	61%	SAND POINT	28.6	63%
EAGLE	-17.9	30%	SELDOVIA AP	21	53%
EAGLE RIVER 5 SE	7	41%	SEWARD	22.3	55%
EKLUTNA WTP	7.9	42%	SITKA JAPONSKI AP	32.3	69%
FAIRBANKS INTL AP	-16.9	30%	SKAGWAY	21.3	53%
GALENA	-17.6	30%	SOLDOTNA 5SSW	4.3	40%
GULKANA AP	-10.7	32%	ST PAUL ISLAND AP	21.1	53%
GUSTAVUS	22.1	54%	TALKEETNA AP	6.2	41%
HAINES AP	18	50%	TOK	-20.1	29%
HEALY 2 NW	-7.6	34%	VALDEZ AIRPORT	16.1	48%
HOMER AP	18.8	51%	WAINWRIGHT	-17	30%
HOONAH	26.3	59%	WALES	-8	33%
HOPE	11.4	44%	WASILLA 3 S	8.2	42%
JUNEAU AP	23.7	56%	WHITTIER	24.7	57%
KASILOF 3 NW	9.9	43%	WILLOW WEST	-1.3	36%
KENAI AP	8.1	42%	WRANGELL AIRPORT	27.6	61%
KETCHIKAN	30.1	65%	YAKUTAT AP	22.4	55%

This chart gives the minimum January temperature and allowable R-value percentage of a building assembly on the warm in winter side. For determining vapor retarder placement in a building assembly, using R-value percentage charts and scale drawings is useful, particularly for advanced assembly systems with multiple layers of framing and insulation. A significant energy benefit can be captured by placing the vapor retarder inside the wall assembly where it is not subject to utility penetrations or damage from drywall installation.

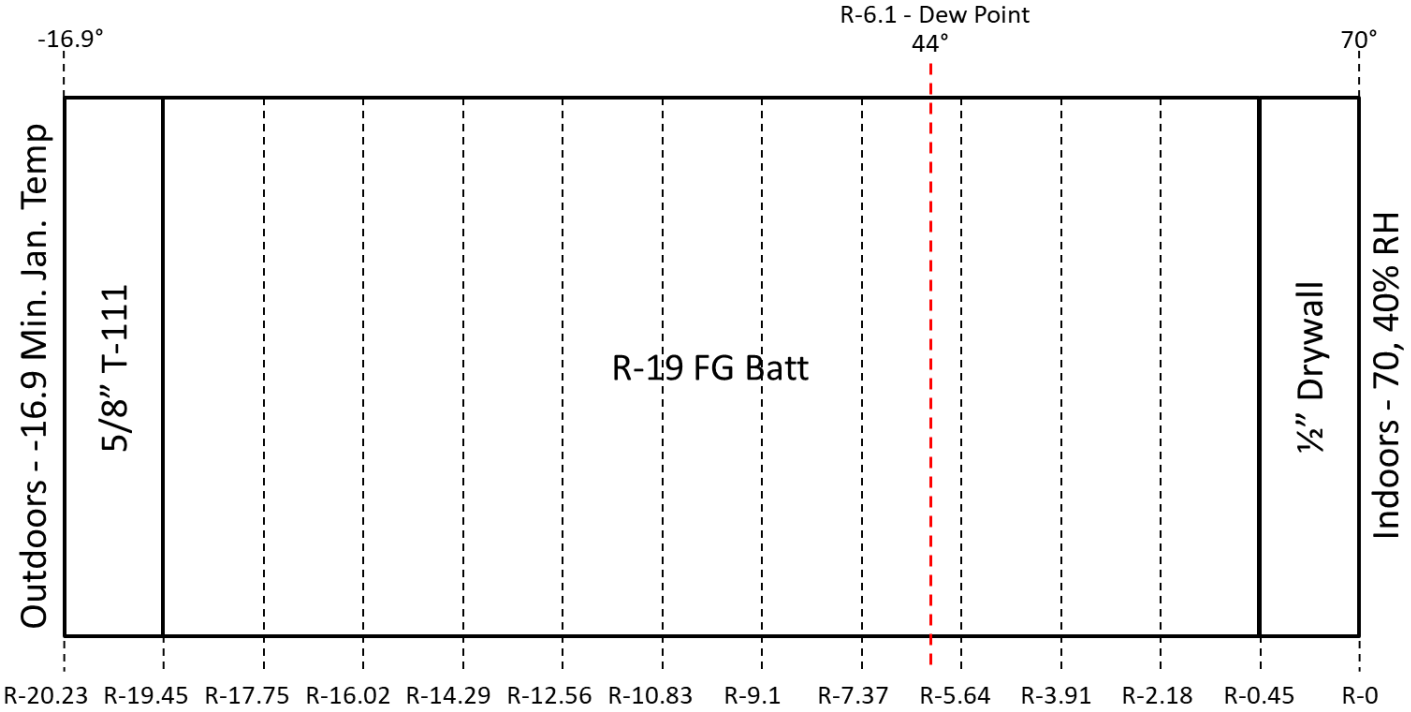
Vapor Retarder Placement Example 2

Standard 2X6 construction, where does the dew point occur in the wall assembly in Fairbanks, AK?

- Cross sectional R-value of 20.23
- -16.9° exterior temperature
- 30% of R-value allowed on warm side of vapor retarder
- 20.23 * 0.30 = 6.1
- Dew point occurs at R-6.1



R-Value of Selected Building Components	
1/2" Drywall	R-0.45
5/8" T-111	R-0.78



Moisture - Bulk

The key concepts for bulk moisture are determining the sources of liquid moisture as they relate to home construction, understanding how liquid moisture moves and migrates within a home, and how to control the liquid moisture so that it does not threaten the structure or occupants of a home.

There are four common sources of liquid moisture that affect home construction. Rain, snowmelt, runoff from rain or snowmelt, and groundwater. By understanding what the sources of liquid water are, strategies to control and mitigate can be used to prevent problems.

Liquid water moves and flows within and around a building by two different means. The primary driver of water flow is of course gravity. Water flows from high to low generally by the path of least resistance.

The second driver of liquid moisture migration is by capillary action and surface tension. Capillary action has the ability to move water sideways or upwards, against the natural pull of gravity. Capillary action, also known as wicking, is caused by the combination of surface tension and the adhesive forces of water molecules. Porous materials such as paper, wood, or concrete, and even non-porous materials such as sand can experience capillary action.

To prevent liquid water from infiltrating buildings, multiple strategies must be employed, sometimes in combination. Strategies for controlling liquid moisture movement in and around a home include use of an exterior weather resistant barrier, capillary breaks, eliminating direct openings, pressure equalization, use of flashing, grading and drainage around the exterior of a structure, and roof gutters.

Exterior Weather Resistant Barrier

The exterior weather resistant barrier is a strategy that applies to all exterior wall types. It is a house wrap type product that covers all vertical exterior wall surfaces. Weather resistant barrier is installed under the exterior siding to act as a secondary layer of protection against rain and wind from the exterior.

It forms a drainage plane behind the siding used to direct liquid water to the exterior. Exterior weather resistant barrier must cover all exterior wall surfaces, even those surfaces that do not enclose conditioned space behind them such as gable ends. Weather resistant barrier stops liquid water from entering the wall assembly from the exterior, while also allowing water vapor to past through the exterior from inside. Weather resistant barriers are considered permeable to water vapor. The installation of weather resistant barrier must follow the manufacturer's specifications. Specific tapes, sealing methods, and overlaps are required for different products.



Weather resistant barrier must be applied behind all types of siding, including T-111, and must cover all exterior wall surface enclosing space behind, including attic gable end walls.

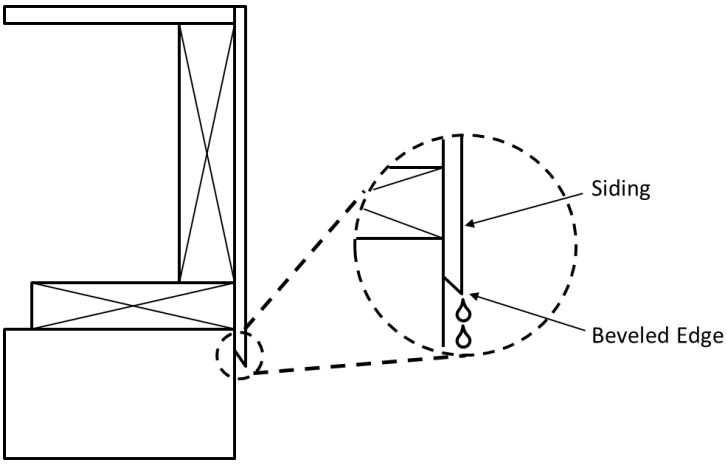
Capillary Breaks

Capillary breaks are used to break surface tension and prevent water from traveling through common building materials. Many common construction materials such as wood and concrete are porous and thus very susceptible to capillary action water movement. Strategies that prevent capillary action through building materials include kerfs, bevel cuts, drip edges, gaskets, and air gaps.

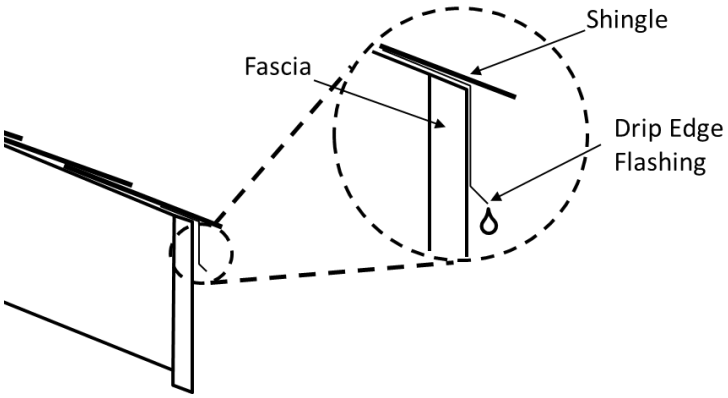
The **kerf** or kerf cut is a simple slit or notch cut by a saw in a building material. A kerf cut makes a recess in the building material which prevents liquid water from migrating further than the edge of the cut. The kerf can also be used to accept the edge of a flashing material to direct water off of and away from the building material. Sills for windows or veneer on the exterior of the building are good places for kerf cuts.

The **beveled edge** is an angled cut at the edge at the bottom of a vertical piece such as siding. The beveled edge is similar to the kerf in that it forces water to drip off rather than travel by capillary action or surface tension. The bottom edge of exterior siding is a good application of a bevel cut.

Drip edge is a type of metal flashing that is angled similar to the edge of a bevel cut. Water that runs down the drip edge flashing is directed away from the building exterior and forced to drip off of the edge. Drip edge flashing is most commonly installed under the exterior edge of the shingles and is used to protect the roof fascia.



The beveled edge siding cut.



Drip edge is a type of metal flashing that is angled similar to the edge of a bevel cut.

Gaskets

Gaskets can provide a capillary break when used to separate materials with an impermeable physical barrier. Common materials that can be used as gasketing materials include closed cell sill seal or 40-60 mil Bituthene, both of which are waterproof. Gaskets work well when separating connections such as sill plates and posts from concrete or other porous material that is subject to capillary action. The gasket provides a capillary break which prevents water from wicking up from concrete into wood.

Air Gap

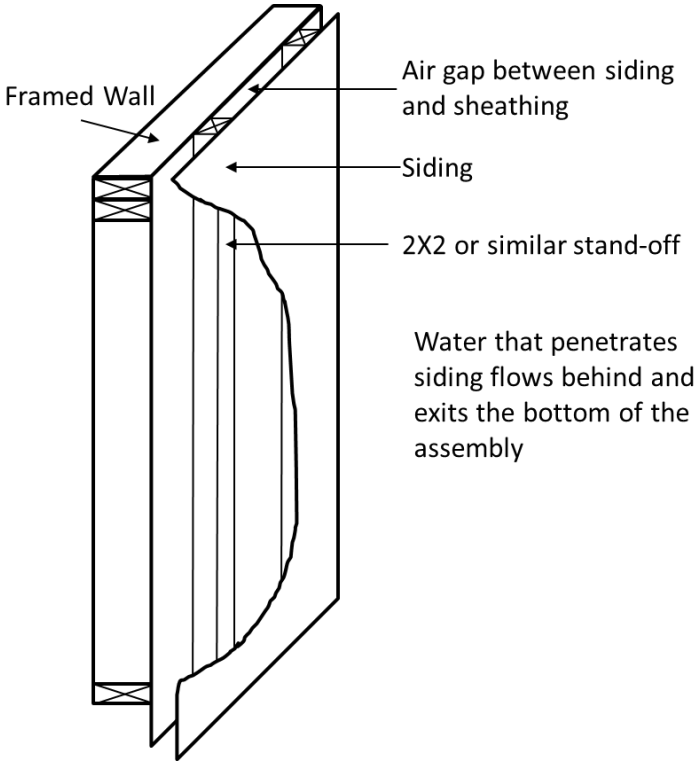
An air gap is a method of construction that provides a physical gap of air the water cannot cross. An air gap is most commonly used as part of the exterior wall siding assembly, particularly in areas of wind driven rain. The air gap is formed by standing the exterior siding off of the wall assembly with spacers. Water that does penetrate the siding runs down the back side of the siding and exits at the bottom of the assembly.

Pressure Equalization

Pressure equalization is a method used in conjunction with the air gap behind exterior siding in areas of wind driven rain. The gap behind the siding is vented so that air pressure on both sides of the siding is equalized. With the pressure on both sides of the exterior siding equalized, then there is no driving force causing rain to penetrate past the weather resistant barrier.

Eliminate Direct Openings

Eliminating direct openings is a simple way to prevent water intrusion into wall assemblies that commonly occurs around utility penetrations such as for gas piping. Direct openings into the siding are caulked or otherwise sealed so that water cannot enter. Other areas of direct opening may be present where exterior siding is tucked behind corner of exterior door or window trim. Lap siding and T-111 grooves may allow direct openings into the wall assembly if not sealed.



An air gap between the siding and exterior sheathing of a building is an effective method of stopping water infiltration into the wall assembly, especially when combined with pressure equalization.

Flashing

Flashing is thin pieces of water impervious materials such as metal or self adhering bituthene used to prevent water infiltration into a building assembly. Flashing is installed so that water is directed to the outside of the assembly with a shingling effect. Any water caught by the flashing is directed outwards.

Grading and Drainage

Grading and drainage around the exterior of buildings is as important as controlling liquid water on the building itself. Improper grading and drainage can cause water infiltration into below grade areas causing rot, water damage, and organic growth. Grading should slope away from all sides of the building, or to a drainage path or street away from the building. The minimum slope of the grade should be not less than 2%.

Roof Gutters

Collection and disposal of roof drainage using roof gutters and downspouts is important for keeping excessive water away from the foundation and enclosed below grade areas. Downspouts should be directed at least 5 feet away from the foundation to an area or drainage path that slopes away from the building.





These photos show the difference a gasket can make in providing a capillary break. The photo on the left show the application of closed cell sill seal gasket between concrete and a wood framing member. The photo on the right shows a wood post supported on a concrete footing. Capillary action has clearly been taking place here as evidenced by the dark streaking coming up from the post base where supported on concrete. An attempt to create a gasket using 15 lbs. felt paper to separate the wood from the concrete was not successful.

Heating Fuel

Heating The key concepts for heating fuel selection relate to the differences in BTU contents of various common heating fuels, the efficiency of the combustion appliances and how that affects costs and fuel consumption, and the difference combustion appliance types and how this relates to the efficiency, health, and safety of the home.

Heating typically represents the largest utility cost to a homeowner. Selection of heating fuel and heating appliance type plays a large role in the affordability and efficiency of housing in cold climates. Common fuels used by combustion appliances for heating and hot water production include natural gas, propane, oil, wood, and electricity.

When selecting a heating fuel, it is important to understand the BTU or heat content of the fuels being compared. The goal is to equalize the cost of heat between all fuel type choices. By equalizing the cost in terms of the heat content of the fuel, a fair comparison between different fuel types can be made.

For comparison purposes, the cost per **therm** is used. A therm is a unit of measurements of heat content which equals 100,000 BTUs. If the cost of different heating fuels per therm is known, then all fuels can be compared equally and the most efficient choice can be made for the situation and location.

Heat Content of Various Fuels

Electricity	1 kWh =	3,413 BTU
#1 Heating Oil 1	Gal. =	134,000 BTU
#2 Heating Oil	1 Gal. =	140,000 BTU
Natural Gas	1 CF =	1,028 BTU
Propane	1 Gal. =	91,330 BTU
Split Wood	1 Cord =	15-20 MMBTU
Wood Pellets	40 lb. Bag =	320,000 BTU

Equalizing Fuel Costs

Once the heat content of each fuel type is known, the number of units of fuel (gallons, cubic feet, etc.) that will add up to one therm, or 100,000 BTUs can be determined. When the units per therm of fuel type are known, and the cost per unit is known, the cost per therm can be determined. Then, the cost per therm of each fuel type is compared on an even basis and the most efficient choice can be made.

Cost Per Them Example 1

Natural Gas $1.05 per ccf

#2 Oil cost $3.25 per gallon

How does the cost per therm compare?

- 1 ccf per Therm (100,000 BTU)
- $1.05 * 1.00 = $1.05 per Therm
- 0.71 Gallons per Therm (100,000 BTU)
- $3.25 * 0.71 = $2.31 per Therm

Cost Per Them Example 2

Electricity cost $0.13 per kWh

Propane cost $3.15 per gallon

How does the cost per therm compare?

- 29.3 kWh per Therm (100,000 BTU)
- $0.13 * 29.3 = $3.80 per Therm
- 1.09 Gallons per Therm (100,000 BTU)
- $3.15 * 1.09 = $3.43 per Therm

Cost Per Them Exercise

What is the cost per therm of the following fuels?

Natural Gas =	$0.95 per ccf	_____
Electricity =	$0.15 per kWh	_____
#2 Fuel Oil =	$2.68 per Gal.	_____
Propane =	$3.46 per Gal.	_____
Split Wood =	$250 per cord	_____
Wood Pellet =	$6.00 per bag	_____

Annual Heat Load Example

Based on the Anchorage, AK annual heat load from earlier, what would the annual heating cost be for 1,225,142 BTUs be at $0.95 per therm?

- 1,225,142 / 100,000 = 12.25 therms
- 12.25 * $0.95 per therm = $11.64 per year

Annual Heat Load Example

What is the cost of heat loss from the Fairbanks, AK annual heat load example from earlier (15,483,498 BTUs), if propane is the heating fuel and the cost is $3.00 per gallon.

Number of Therms: _____

Cost per Therm: _____

Annual heating cost: _____

Cost Per BTU

The cost of heating fuel around the state of Alaska varies depending on the location, sometimes by a significant amount. The cost per therm of the heating fuel is an important factor in determining the best choice.

When considering a fuel source other factors must also be taken into account besides cost, including the reliability of the energy source. Selecting a fuel type for a home or other building is a big commitment, and it is not usually easy or inexpensive to convert from one fuel type to another. A reliable fuel source may have the advantage over slightly less expensive options.

It is difficult to predict the future, but fluctuations in future price can have a huge impact on energy costs. For example, electrical costs are typically more stable than fossil fuels, except in cases where electrical generation must rely on generator backup if peak capacity is exceeded. A consistent fuel cost that meets expectations is a benefit to consumers.

There is no right answer for every situation. The best strategy is to weigh all of the options for a particular building to find one that meets all of the selection criteria as well as possible.

Heating Efficiency

The efficiency of the heating appliance is a large contributing factor to the end user cost. Along with cost per BTU, heating efficiency plays a big role in the economics of heating and domestic hot water consumption.

Heating efficiency is a term that refers to how much heat is actually delivered as heat to the building, versus how much fuel is consumed in the process. Typically for fuel burning combustion appliances, some percentage of the heat produced in the combustion process is lost up the chimney or through other factors. Low efficiency heating appliances waste energy by not turning BTUs into usable heat. There are two types of efficiency to consider for heating appliances, steady state efficiency and AFUE, or Annual Fuel Utilization Efficiency.



This photo of a combustion analyzer shows a heating appliance steady state efficiency of 98.9%

Steady State Efficiency

Steady state efficiency only applies to fuel burning combustion appliances and does not include heat pumps or other "movers" of heat. Steady state efficiency is a measure of the heating appliance in its most efficient burning operation.

Steady state efficiency is a ratio of BTU input to BTU output. Steady state efficiency ignores BTU losses that may occur when the appliance is not in heating mode, such as for pilot lights. Steady state efficiency also does not include chimney losses from warm air escaping up the chimney when the appliance is off.

The steady state efficiency of a combustion appliance is measured when the appliances is fully warmed up and at normal operating temperature. The theoretical maximum for steady state efficiency of a fuel burning combustion appliance is 99%. No combustion appliance converts all the of BTUs burned into usable heat. No fuel burning combustion appliance generates more BTUs than it burns. Steady state efficiency can be measured in the field with a combustion analyzer.

AFUE

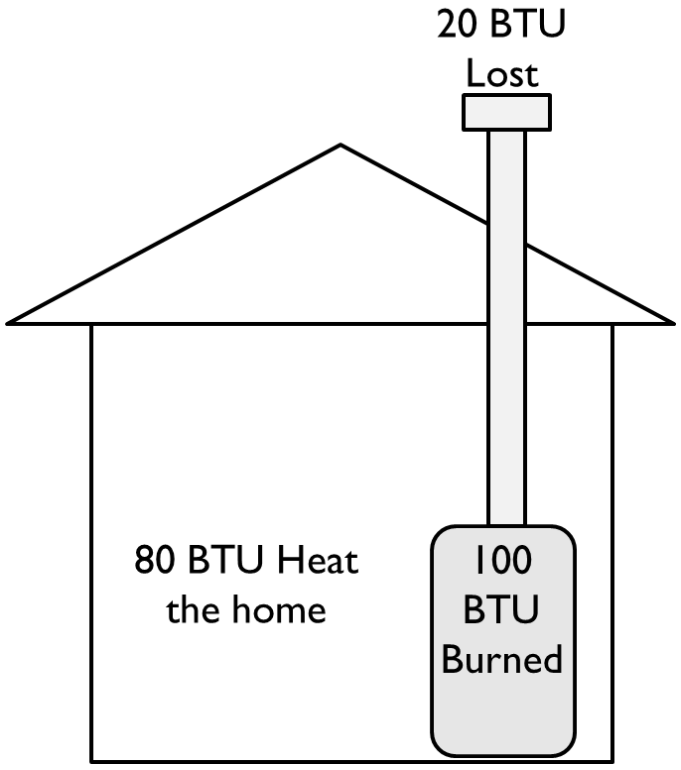
AFUE, or Annual Fuel Utilization Efficiency, is different from steady state efficiency. AFUE applies to both fuel burning combustion appliances and heat pumps. AFUE goes beyond steady state efficiency by accounting for standby losses of the heating system, pilot losses, chimney losses from warm air escape, and start up and cool down inefficiency. AFUE is a more accurate than steady state efficiency for determining annual fuel consumption.

AFUE can reach up to 99% for fuel fired combustion appliances. AFUE often exceeds 100% for heat pumps and other non-combustion heating appliances, reaching up to 500% or more. These types of appliances use the refrigeration cycle to move heat from the exterior to the interior of a building rather than burning a fossil fuel.

COP

AFUE, which is a rating of appliance efficiency, is directly related to COP, or Coefficient of Performance. Heat pumps are usually rated in terms of COP rather than AFUE. The terms AFUE and COP are interchangeable, COP is simply a decimal number and AFUE is a percentage. For example, an AFUE of 100% is equal to a COP of 1.0. A COP of 2.5 is equal to an AFUE of 250%.

Regardless of whether a heating appliance efficiency is rated in AFUE or in COP, either can be combined with the cost per BTU to estimate actual heating costs. There are two steps to this process, the first step is to convert the fuel cost per unit into the cost per therm. The second step is to divide the cost per therm by the AFUE or the COP to get the true cost, accounting for the efficiency of the heating appliance.



Heat appliance efficiency, whether AFUE or COP, is a measure of how many BTUs of heat energy are delivered to a building. For combustion heating appliances, some percentage of the BTUs in the fuel burned is wasted up the chimney in the form of exhaust gasses, pilot lights, or warm air leakage through an open chimney. For example, a combustion heating appliance that is rated at 80% AFUE efficiency is delivering 80% of the BTUs consumed to heat the house. The remaining 20% of BTUs are lost or wasted.

AFUE Example 1

#2 Fuel Oil @ $3.00 per Gal, 85% AFUE

What is the actual cost per therm?

- $3.00 * 0.71 = $2.13 per therm
- $2.13 / 0.85 = $2.50 per therm

AFUE Example 2

Wood Pellets @ $6.00 per bag, 70% AFUE

What is the actual cost per therm?

- $6.00 * 0.31 = $1.86 per therm
- $1.86 / 0.70 = $2.66 per therm

AFUE Exercise

#2 Fuel Oil @ $3.50 per gallon, 85% AFUE

Propane @ $2.75 per gallon, 95% AFUE

What is the actual cost per therm?

Answer: _____

COP

Coefficient of performance can be used the same way as AFUE to more accurately assess the true cost of heating. Heat pumps are rated by COP and use electricity to move BTUs from outside to inside the building. Coefficient of performance ratings typically range from 1.0 on the lower end to 5.0 or greater.

COP Example 1

Electricity @ $0.22 per kWh, 2.7 COP

- 1.$0.22 * 29.3 = $6.45 per therm
- 2.$6.45 / 2.7 = $2.39 per therm

Efficiency Exercise

#2 Heating Oil @ $2.48 per Gal, 87% AFUE

Electricity @ $0.14 per kWh, 3.9 COP ASHP

Which is the least expensive option?

Answer: _____

Heating Appliance Types

Fuel fired combustion heating appliances can be categorized in two different ways; whether they are open or closed combustion, and how they are drafted. Open combustion appliances have some part of the combustion process open to the atmosphere inside the building. Closed combustion appliances are completely sealed to the inside of the building.

Natural draft appliances rely on the heat of combustion to carry exhaust gasses out of the building. Assisted draft and power vented appliances rely partially or completely on a fan to carry exhaust gasses out of the building. Combustion appliances can be any combination of combustion and draft types, and understanding the significance of each of these categories is important to proper selection in an energy efficient home.

Open Combustion

Open combustion appliances have some part of the combustion process open to the atmosphere inside of the building. This opening is typically either at the firebox, or at the draft diverter. Combustion gasses and byproducts have a direct and open path to the interior of the building.

Open combustion appliances are the simplest of the heating appliance types. They may be any of the three draft types, although natural draft is the most common. And are typically also the least expensive.



This photo shows an open combustion, natural draft boiler vented in combination with an open combustion, natural draft water heater. Both appliances have open draft hoods at the top of the appliance.

Closed Combustion

Closed combustion heating appliances are sealed to the exterior of the building, and no part of the combustion process is open to the atmosphere inside the building. Closed combustion appliances can be either natural draft, or power vented. Closed combustion appliances typically have a higher efficiency rating than open combustion appliances, although there are exceptions. Closed combustion appliances are the least prone to back drafting gasses into the building, since there are no openings to the combustion chamber inside the building.

Natural Draft

Natural draft appliances may be either open or closed combustion, although open combustion is more common. Natural draft appliances rely on the positive buoyancy of heated gasses to draft combustion products up the chimney. For this reason, they are typically less efficient that other appliance types since a certain amount of heat loss is needed just for draft purposes.

Natural draft appliances have a negative vent pressure with reference to the room or space in which they are located. This negative vent pressure is what allows the draft diverter or combustion chamber to be open to the atmosphere in open combustion appliances, as the negative pressure in the vent is what draws gasses up the chimney.

Assisted Draft

Assisted draft combustion appliances are similar to natural draft combustion appliances in that they also rely at least partially on the positive buoyancy of warmed air to provide draft of combustion gasses out of the building. However, assisted draft appliances also have a fan which serves two purposes. The primary purpose of the assisted draft fan is to modify the flame shape at the burner to increase the appliance efficiency. The secondary purpose is to assist the combustion gasses up and out of the chimney. This type of combustion appliance will have an inducer fan and no draft diverter at the vent connector.

Also similar to the natural draft appliance, the pressure inside the vent is negative with reference to the room or space in which the appliance is located. Assisted draft combustion appliances are less sensitive to back drafting that natural draft appliances because of the fan, and typically have a higher efficiency rating than natural draft appliances.



This is a picture of a sealed combustion boiler in which no part of the combustion process is open to the atmosphere.

Forced Draft

Forced draft appliances use a fan to assist combustion gasses out of the chimney or vent, similar to the assisted draft combustion appliance. The difference is that forced draft appliances have positive pressure inside the vent with reference to the room of space in which they are located. As such, there are no openings in the vent system to the atmosphere inside the building.

Forced draft appliances must be closed combustion, or combustion gasses would be forced into the building. This type of appliance is the least prone to back drafting. Forced draft appliances are typically more efficient than natural draft appliances, being able to modify the flame shape and utilize multiple heat exchangers that cannot be used on natural draft or assisted draft appliances.

Cold Climate Considerations

When selecting the type of combustion heating appliance in Alaska, it is important to remember that the housing is considered to be of unusually tight construction. Unusually tight construction meets rigorous codes and standards for sealing and air tightness and must typically pass a performance test with a blower door. Buildings of unusually tight construction must follow combustion air codes if open combustion appliances are installed.

Houses of unusually tight construction are subject to greater negative air pressures with reference to the outside than typical construction, making open combustion appliances much more susceptible to back drafting and related issues with combustion gasses such as carbon monoxide. New construction housing codes and standards require that outdoor combustion air be provided for all homes with open combustion appliances installed.



This photo shows a fan assisted, natural draft, open combustion furnace. There is no draft hood, but the furnace firebox is open to the atmosphere in the home. The pressure inside the vent is still negative with reference to the home.

Heating Appliance Sizing

A properly sized heating system offers several benefits to the home builder and the home owner. Properly sized heating systems are more efficient than systems that are oversized or too large for the heating demand. Ideally, a properly sized heating system will run nearly continuously on the coldest day of the year.

Properly sized heating systems operate for longer periods of time when called on to provide heat, maximizing time when the heating appliances is at steady state efficiency. Oversized heating systems spend less time at steady state and more time warming up and cooling off, as the heating demand is met much more quickly. The is known as short cycling, which decreases the overall efficiency of the heating system as steady state is only achieved for short periods or not at all.

Energy codes require that heating systems be sized for new construction applications. A maximum of 125% of the design heat loss for a home is allowed in BTU output for the heating system. If no heating system is available in a particular product line that fits this criteria, the next largest available size is allowed.

There are several methodologies which are permitted for obtaining an acceptable design heat loss number. These methodologies include the AkWarm energy rating software, Manual J from the Air Conditioning Contractors Association, and the ASHRAE Handbook Of Fundamentals. In all cases documentation of the design heat loss BTU number must be provided as part of the commissioning of a new home.

Modulating Heating Systems

When selecting a heating system, it is important to remember that all heating systems are designed for the worst-case cold weather which will be encountered. For 99% of the year, the heating system is oversized for the required heating demand. Even a properly sized system is too large for all but the coldest day of the year.

Modulating heating appliances, which can vary the BTU output based on the actual demand, are available to better match the actual heating load. The heating equipment uses cues such as outdoor temperature, or the return temperature of the air or liquid, along with other factors to better match real time heating conditions.

One method of modulation is the High/Low fire type, which has two BTU outputs. Another method of modulation is step down, or continuously variable firing rates. These systems typically have multiple firing rates to more closely match heating conditions than the simple High/Low fire type. Step down or continuously variable heating appliances can reduce the firing rate to some ratio of the maximum output, usually 5 to 1 or 10 to 1. This means that an appliance rated for 100,000 BTUs of output at the maximum firing rate can reduce or “turn down” the firing rate to as low as 10,000 or 20,000 BTUs.

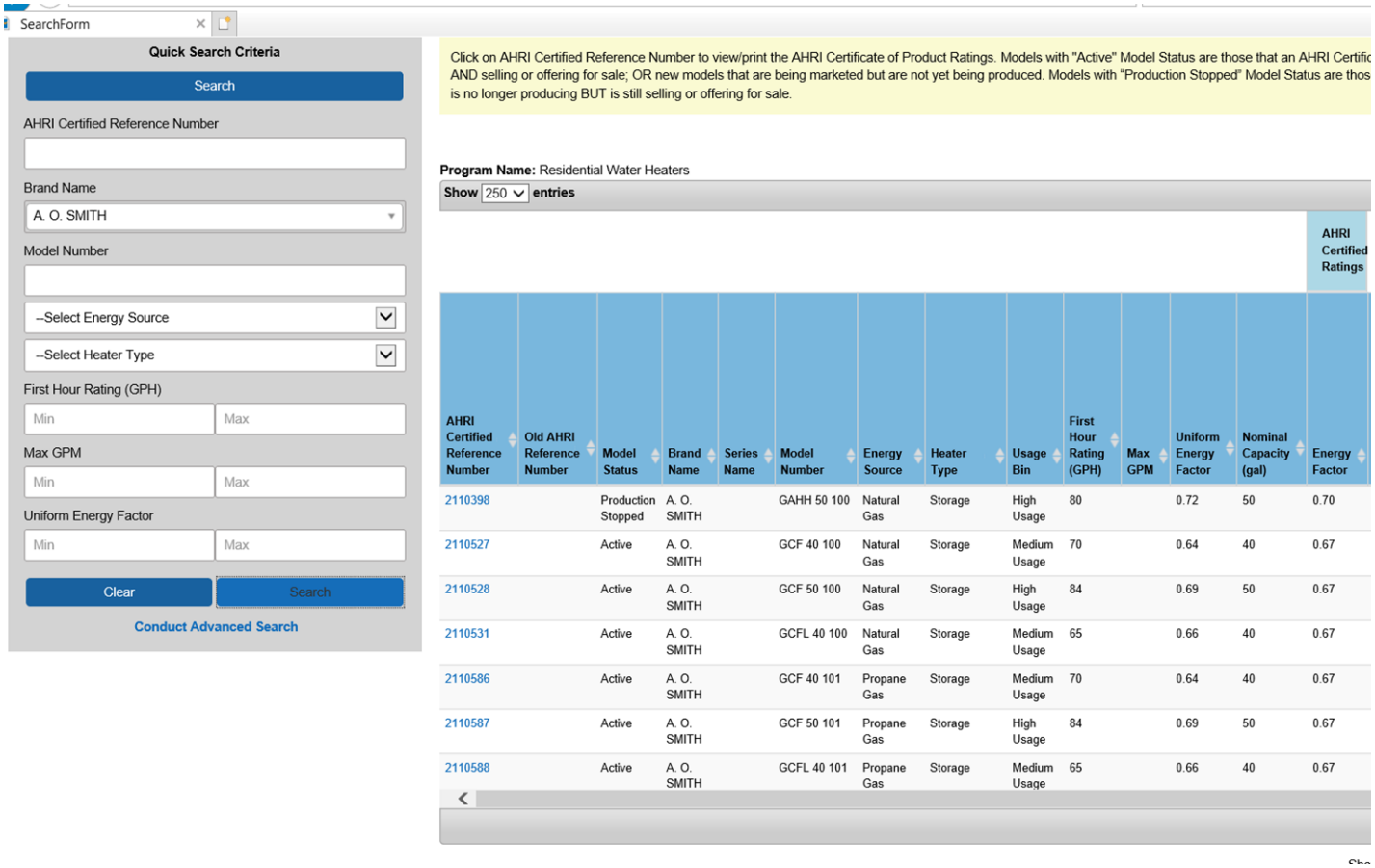
Domestic Water Heating

The key concepts for domestic hot water are energy factor, which is the method of efficiency rating for domestic hot water appliances, gallons per minute, which is how much hot water an appliance can produce on a continuous basis, and the first hour demand, which is how much hot water an appliance can produce in the first hour of operation.

Energy Factor

The energy factor is the means by which domestic water heating appliances are rated in terms of efficiency. The energy factor is a decimal number between 0 and 1, with 0 being the least efficient and 1 being the most efficient. The energy factor decimal number is equal to the percentage efficiency which is more typical of heating appliances. For example, and energy factor of 0.8 is the same as an efficiency rating of 80%. All domestic water heater efficiencies are listed on the AHRI website which can be searched.

The energy factor of water heaters varies. Standard tank style water heaters with no upgrades have at typical energy factor of 0.5 to 0.6. High efficiency water heaters may have an energy factor of up to 0.97. Electric water heaters are typically rated at an energy factor of 0.95 or greater, although higher efficiency does not always equate to better performance or lower costs. Heat pump water heaters may have an energy factor rating exceeding 1.0 or 100%. Similar to heat pump heating appliances, these water heaters move heat rather than create heat, which is how they can achieve high energy factors. As with space heating appliances, energy factor is only the first step in equipment selection. The cost of fuel plays a large role in the long term energy costs of water heating equipment.



AHRI Certified Reference Number	Old AHRI Reference Number	Model Status	Brand Name	Series Name	Model Number	Energy Source	Heater Type	Usage Bin	First Hour Rating (GPH)	Max GPM	Uniform Energy Factor	Nominal Capacity (gal)	Energy Factor
2110398		Production Stopped	A. O. SMITH		GAHH 50 100	Natural Gas	Storage	High Usage	80		0.72	50	0.70
2110527		Active	A. O. SMITH		GCF 40 100	Natural Gas	Storage	Medium Usage	70		0.64	40	0.67
2110528		Active	A. O. SMITH		GCF 50 100	Natural Gas	Storage	High Usage	84		0.69	50	0.67
2110531		Active	A. O. SMITH		GCFL 40 100	Natural Gas	Storage	Medium Usage	65		0.66	40	0.67
2110586		Active	A. O. SMITH		GCF 40 101	Propane Gas	Storage	Medium Usage	70		0.64	40	0.67
2110587		Active	A. O. SMITH		GCF 50 101	Propane Gas	Storage	High Usage	84		0.69	50	0.67
2110588		Active	A. O. SMITH		GCFL 40 101	Propane Gas	Storage	Medium Usage	65		0.66	40	0.67

This screenshot is an excerpt from the AHRI website, showing the energy factor rating for several similar water heaters. These ratings range from 0.70 to 0.67. Water heaters are rated according to their model number, and many model numbers are alike, so search carefully to find the correct rating.

Open Combustion Tank Water Heaters

The standard fuel fired tank water heater is the simplest and typically least expensive domestic water heater. This type of water heater is normally natural draft and open combustion. Tank style water heaters maintain a reserve of hot water that is kept heated at all times, usually 40 to 60 gallons in a residential setting.

The energy factor of this type of water heater is usually on the lower end, at 0.5 to 0.6. Due to its nature as natural draft and open combustion, the standard fuel fired tank water heater is the most sensitive to negative air pressure inside the home and the most prone to back drafting combustion gasses. Outdoor combustion air for these appliances is a must in a new construction home.

Sealed Combustion Tank Water Heaters

The sealed combustion fuel fired tank water heater is a step up in efficiency and cost from the standard tank water heater. The energy factor can be as high as 0.68 or greater. This type of water heater maintains a storage reserve of hot water at all times like the standard tank.

The sealed combustion configuration is less sensitive to negative pressure imbalances within the home and less susceptible to back drafting. These units may be either natural draft or forced draft, but no part of the combustion process is open to the atmosphere inside the building.



Open combustion water heaters are the most sensitive to back drafting.

Electric Tank Water Heaters

Electric tank water heaters differ from the fuel fired tank in that there is no combustion process to heat the water. Water is heated through resistance coils inside the tank. Electric water heaters can claim very high efficiency, with energy factor ratings of 0.95 or greater. Electric water heaters have the added benefit of being immune to pressure imbalance within the home, and no combustion gasses or byproducts are produced when water is heated. However, due to the limitations of electric resistance heating, the recovery rate of this type of water heater is usually much slower than fuel fired water heaters.

Tankless/On Demand Water Heaters

The tankless, or on demand water heater differs from the traditional tank style water heater in that there is very little or no storage of hot water. Hot water is made as needed, which increases the efficiency of the unit. No energy is wasted keeping a reserve of water hot when not needed.

Conversely though, tankless on demand water heaters are limited in how much hot water can be produced at one time. Since hot water is made as needed, there is a limited gallons per minute supply that can be maintained, which is based on the BTU output of the appliance and the incoming water temperature. As the incoming water temperature decreases, so does the gallons per minute capacity.

The energy factor rating is typically higher than that of a tank style water heater, since no energy is wasted maintaining a reserve of hot water at all times.

Combi-Boiler

The combi-boiler is similar to the stand-alone on demand hot water appliance, except that it is integrated with the heating system. There is little or no hot water reserve, hot water is made as needed.

The combi boiler arrangement faces the same difficulty as the stand-alone on demand water heater in that it is limited in gallons per minute output based on the incoming water temperature. Some of the more modern combi boilers have the ability to prioritize domestic hot water production when needed. The efficiency of these units is the same or nearly the same as the rating for the hot water boiler side.



Tankless water heaters have little or no reserve and supply hot water on demand.

Boiler Mate

The boiler mate hot water system is a storage tank that uses the space heating system boiler to indirectly heat a reserve tank of hot water though a heat exchanger. Heat is provided by the boiler through a separate heating zone to maintain a reserve of hot water.

Boiler mate hot water systems have the advantage of the standard tank system by carrying a reserve of heater water while at the same time taking advantage of a typically more efficient space heating system to produce the hot water. Boiler mate efficiency is rated as the same as the heating system, minus 5% for standby losses.

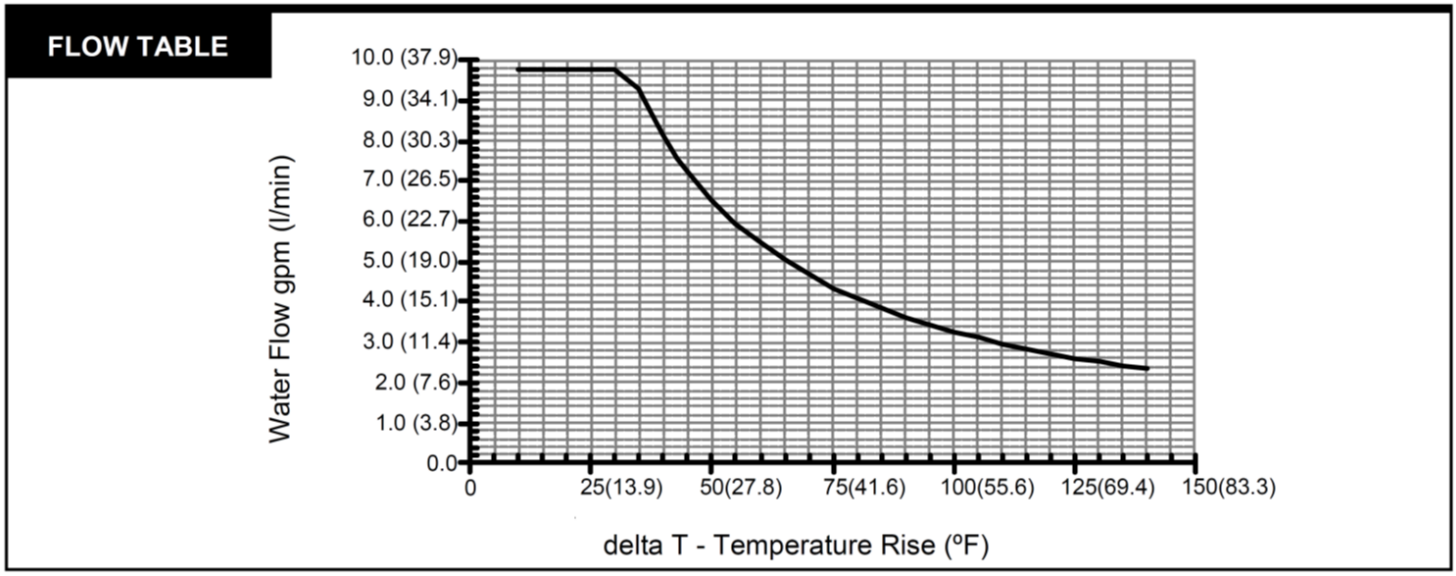
Heat Pump Water Heaters

The heat pump water heater is similar to the electric tank water heater, electricity is the fuel source and there is a reserve tank of hot water. However, rather than using electric resistance to heat water, heat pump water heaters extract heat out of the surrounding indoor air to heat water. Heat pump water heaters operate like a refrigerator in reverse; heat is extracted out of the indoor air and input into the water.

This type of water heater is more efficient than the standard electric tank water heater, with energy factors exceeding 1.0. However, there is no free lunch here, as heated indoor air must be used and must replaced by the heating system to heat the domestic hot water. This type of system makes the most sense when the heating fuel source is much less expensive than the electricity used by the water heater.



Heat pump water heaters extract heat from the indoor air to heat the domestic water supply



As the temperature spread, or difference between incoming water temperature and outgoing water temperature increases, the available gallons per minute decreases. This graphic shows the delta T, or temperature difference, along the bottom axis. As the temperature difference increases moving right, the gallon per minute flow rated decreases. Care must be taken when selecting on demand domestic water heaters to ensure adequate hot water flow rates.

Gallons Per Minute

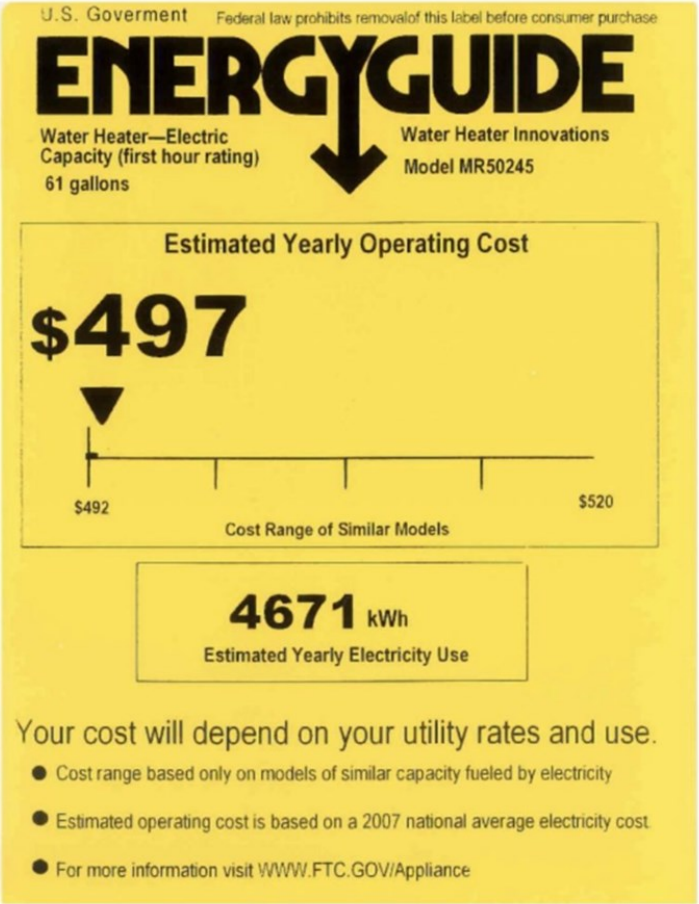
Gallons per minute is an important consideration when selecting an on demand domestic water heating appliance. Gallons per minute refers to the amount of hot water that can be provided by the appliance on a continuous basis. As long as the gallons per minute the appliance can supply is not exceeded, then continuous hot water can be provided. However, the gallons per minute capacity is exceeded, then the output water temperature will be reduced in direct relation.

The gallons per minute rating of on demand water heaters is affected by the incoming water temperature from the street or well, and the outgoing temperature at the unit, which can usually be adjusted somewhat. The incoming water temperature can be a limiting factor in cold climates, where the well or street water service temperature is much lower than the standard rating temperature of this type of appliance.

First Hour Rating

The first hour rating is the maximum gallons of hot water that can be provided by a domestic hot water appliance within the first hour of use. This includes any reserve in a storage tank, as well as how many additional gallons the appliance can make in the first hour.

Electric water heaters typically have lower first hour ratings than fuel fired water heaters. Electric water heaters are usually limited to a smaller BTU/h output because of electrical service size and availability. Tank style water heaters with a storage reserve have higher first hour ratings because of the built-in capacity of the tank.



The US department of energy provides an energy guide sticker on many domestic water heating appliances. Included on this sticker is the first hour rating, and the estimated yearly cost. Note that the estimated yearly cost is based on national average electricity costs and is usually not reflective of actual costs. For a better comparison, multiply the estimated yearly use by the cost at the building location.

Electrical

The key concepts for electrical are the high cost per kilowatt-hour in Alaska, which has some of the highest rates in the nation. Also, lighting accounts for up to 15% of the home energy use, making it an important part of overall energy costs.

kWh Costs

Electricity consumption is measured and billed in terms of kilowatt hours, or kWh. 1000 watts of electricity consumed over the course of one hour equals one kilowatt-hour. To put it another way, if 100 watts was consumed for 10 hours, that would be equivalent to one kilowatt-hour.

The cost of on kilowatt-hour varies greatly around the state of Alaska, from lows in southeast Alaska of $0.08 to highs of over $0.50 in rural areas. Understanding the impact of electrical costs around the state can affect many choices from heating to hot water to lighting and appliance selection.

There are three main categories of electrical use in residential construction; lighting, motors, which includes fans for air circulation and pumps for water circulation, and home appliances.

Lighting Efficiency

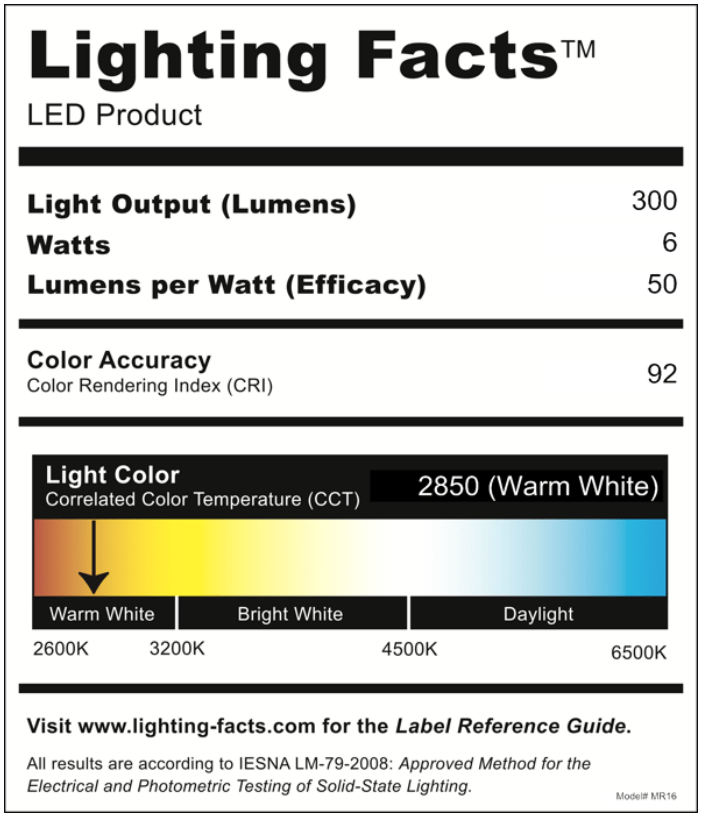
Selection of energy efficient lighting is critical at the outset of construction. Lamp and fixture choices in new homes will influence utility costs for many years in the future. Lighting efficiency is measured in both lumens and watts. Lumens are a measure of light output by a lamp or fixture, i.e. how bright it is.

Watts are a measure of the amount of electricity consumed to produce the light. Lumens per watt is therefore a measure of the efficiency of a lamp or fixture. Lumens per watt compares all fixture and lamp types in terms of how much light is produced per watt of electricity consumed.

Color Rendering Index

CRI, or color rendering index, is a measure of the quality of light that is produced by a lamp or fixture. CRI is based on a scale of 1 to 100, with 100 being the best. 100 is considered to be closest to natural sunlight. For outdoor use, a CRI of 70 or better is recommended. For indoor use, a CRI of 80 of better is recommended.

The higher the CRI rating for a lamp or fixture, the better the quality of light. Better quality light translates into less light output being necessary to perform the same task or to perceive the same brightness.



Lighting Cost

As the efficacy, or lumens per watt, increases so do costs typically. It is worth noting that a larger initial investment in quality lighting can result in longer lifespans of the product, which reduces long term maintenance costs. As electricity prices increase over time, the value of efficient lighting increases as well.

Fixtures and lamp lifespans can vary significantly between bulb types, fixture types, and manufacturers. Selecting products with longer lifespans reduces maintenance and replacement costs. Selecting fixtures and lamps with common base types make maintenance easier and less expensive when the time for replacement comes. Proprietary fixture and base designs can lock consumers into less efficient and more expensive choices down the road, or be forced to replace fixture entirely when products are discontinued.

kWh Cost Example

100w Incandescent ($2) vs. 15w LED ($10)

- 2000 Hrs/yr use
- $0.20 per kWh

What is the annual savings?

- 100w - 15w = 85w per hour savings
- 85w / 1000kW = 0.085 kW
- 0.085 kWh * 2000 hrs = 170 kWh savings
- 170 * $0.20 = $34 year savings

Category	Type	Efficacy (lumens/watt)	Lifespan	CRI
Incandescent				
	Standard A Bulb	10-17	1.5-5K Hours	98-100
	Tungsten Halogen	12-22	1.5K Hours	98-100
Light Emitting Diode				
	LED	80-150	50-100K Hours	80-90
Fluorescent				
	Compact fluorescent	57-72	8-20K Hours	65-88
	T5 Tube w/ electronic ballast	70-100	20-30K Hours	80-90
	T8 tube w/ electronic ballast	80-100	20-30K Hours	80-90
	T12 tube w/ magnetic ballast	60	20-25K Hours	80-90
Gas Discharge				
	Metal halide	65-115	15K Hours	70
	High pressure sodium	85-150	16-24K Hours	25
	Low pressure sodium	100-200	12-18K Hours	>10

This chart categorizes common lamp types and efficiencies along with expected lifespan and CRI. Lighting technology improves regularly, so it is worth staying up to date with new products and review old product specifications to make the best choice.

Fans & Pumps

Residential fans and pump motors are usually single-phase motors that run on standard electrical circuits. The largest electrical usage is fan and pump motors serving heating distribution systems. Forced air heating systems utilize 1/3 to 1 hp motors to circulate heated air through the home. Hydronic heating systems utilize pumps to circulate heated fluid through the home. For either application, the selection of variable speed motors may be a significant energy savings over single speed motors.

Blower Motors

Forced air heating distribution systems may offer a choice between PSC, or permanent split capacitor motors, and ECM, or electrically commutated motors. Permanent split capacitor motors, which are an older technology, have an efficiency rating of around 60% when full loaded. Efficiency drops off rapidly for this type of motor as load is reduced.

Electrically commutated motors have an efficiency of approximately 80% when fully loaded, and are able to maintain better efficiency than PSC motors under partial loads. Selecting a furnace with a ECM motor can save $20 to $50 per year in electrical costs, based on the heat load and the cost per kilowatt-hour of electricity.

Residential Circulation Pumps

Residential hydronic circulation pumps are used to pump heated fluid through baseboards, slabs and fan coils to provide heating. The proper flow rate through the piping is critical for optimum heat transfer without excessive energy use or inadequate heat deliver. Ideally, hydronic circulation pumps are sized to minimize electrical usage, although this can be difficult to do as distribution systems are sized for the worst case coldest day and may be oversized the remainder of the year.

Variable Speed Motors

Variable speed motors, particularly when paired with "smart" boilers that are self adjusting, can greatly reduce the amount of pumping needed to match the required heat load. Electricity savings in excess of 50% are not uncommon with variable speed motors, which can equal more than $100 in utility cost savings per year.

Variable speed motors take advantage of affinity laws, which state that while flow rate (GPM or CFM) is proportional to the speed of the motor. The shaft horsepower used to turn the motor is proportional to the speed or flow (GPM or CFM) cubed. This is how variable speed motors can achieve such large reductions in energy usage in applications where different speeds can be used to match a variable demand such as heating load.

Speed	Shaft HP
30%	3
40%	6
50%	12
60%	22
70%	34
80%	51
90%	73
100%	100

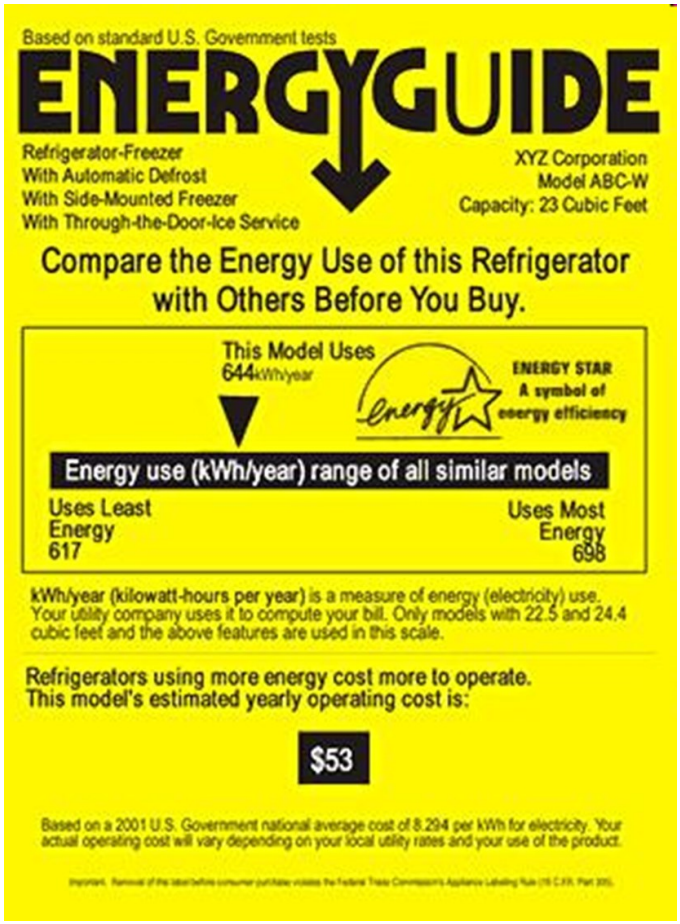
Variable speed motors, whether serving hydronic pumps or forced air motors, can achieve large reductions in energy usage. Energy savings from variable speed motors can only be captured if the application can use variable speed.

Home Appliances

An energy guide label is required on all new home appliances, except for ranges and ovens. The energy guide label provides an estimate of the annual energy consumption in KWH and compares it with the biggest and smallest consumers in the appliance class. The energy star label is a separate designation that signifies an appliance has met guidelines established by the EPA for energy efficiency.

Appliance		Typical Wattage
Aquarium		50 - 1210
Clock Radio		10
Clothes Washer		350-500
Clothes Dryer		1800 - 5000
Dishwasher		1200 - 2400
Dehumidifier		785
Electric Blanket		60/100
Fans		
	Ceiling	65-175
	Window	55-250
	Furnace	750
	Whole House	240 - 750
Hair Dryer		1200 - 1875
Heater (portable)		750 - 1500
Clothes Iron		1000 - 1800
Microwave Oven		750 - 1100
Personal Computer		
	CPU - awake/asleep	120 / 30 or less
	Monitor	150 / 30 or less
	Laptop	150
	Radio	70-400
Refrigerator (forst free, 16 cu ft.)		725
Television		
	19 inch	65 - 110
	27 inch	113
	36 inch	133
	53 - 61 inch projection	170
	Flat Screen	120
Toaster Oven		800 - 1400
VCR / DVD		17-21 / 20-25
Vacuum Cleaner		1000 - 1440
Water Heater (40 gallon)		4500 - 5500
Water Pump (deep well)		250 - 1100
Water bed (with heater, no cover)		120 - 380

The typical wattages shown on this chart reflect the average nameplate ratings of the listed appliance. The expected usage per day is multiplied by the typical wattage to estimate daily energy use.



The Federal Trade Commission requires Energy Guide labels on most home appliances, but not home electronics, such as computers, televisions, and home audio equipment. Energy Guide labels provide an estimate of the product's energy consumption or energy efficiency. They also show the highest and lowest energy consumption or efficiency estimates of similar appliance models. The cost is based on a national average per kilo-watt hour of electricity, and so should only be used as a comparative guide between similar appliances. Multiply the listed kilowatt hour figure on the energy guide by the actual kilowatt hour cost to get a more accurate picture of actual cost of operation.

Cost Effectiveness

Cost effectiveness is a way of determining if a purchase or potential upgrade is a good investment. A cost-effective investment is one that will pay for itself over the lifespan of the product. There are two different tools that can be used to decide if a purchase or upgrade is cost effective; payback period and savings to investment ratio.

The payback period is the amount of time needed to pay back the initial cost of the purchase or upgrade. Payback periods can be applied to new purchases, where two different items can be compared. Payback periods can also be applied to upgrades to existing items by comparing additional savings from an upgrade or improvement against the additional expense incurred.

The formula for calculating the payback period is to divide the initial cost of the purchase or upgrade by the annual savings. This produces a number, in years, that it will take for the purchase or upgrade to "break even" or to pay for the initial cost.

The formula for calculating the savings to investment ratio is the annual savings, multiplied by the expected lifespan of the purchase or improvement, divided by the initial cost. This will yield a number. If the number is greater than 1, the investment will pay for itself in the expected lifespan of the purchase or improvement. If the number is less than 1 it will not pay for itself and should not be considered a good investment.

$$\text{Payback period} = \frac{\text{initial cost}}{\text{annual savings}}$$

$$\text{Savings to Investment Ratio} = \frac{\text{annual savings}*\text{lifespan}}{\text{initial cost}}$$

Payback Period

As a general rule, the shorter the payback period, the faster the investment is recouped and the better investment it is. Between two comparable purchases, the one with the shorter payback period is generally a better investment. In any case, if the payback period exceeds the expected lifespan of the product, then it would be wise to re-evaluate the purchase.

Payback Period Example

Upgrade to more expensive LED lamps

- Initial Cost = $1000
- Annual Savings = $100

What is the payback period?

1000 / 100 = 10 years

Payback Period Exercise

Install more efficient water heater:

- Initial Cost = $2200
- Annual Savings = $175

What is the payback period?

Answer: _____

Savings to Investment Ratio

The SIR, or savings to investment ratio, is a more sophisticated tool to judge the value of an investment. The higher the SIR number, the more cost effective the investment is. In this way, products or investments with different life spans can be compared evenly, so that the better investment can be determined based on the SIR number. An SIR greater than 1 means more money will be saved over the expected lifetime of the purchase or upgrade that was spent originally.

Savings to Investment Ratio Example 1

Upgrade to better windows

- Lifespan = 20 years
- Annual Savings = $40
- Initial Cost = $1000

What is the Savings to Investment Ratio?

40*20 / $1000 = .80 SIR

Cost Effectiveness Exercise 1

Upgrade to more efficient lighting

- Annual kWh lighting usage = 2500
- kWh cost = $0.16
- Cost of lighting upgrades is $1200
- Annual kWh lighting usage after upgrade = 1600

What is the payback period?

Answer:_____

Cost Effectiveness Exercise 2

Upgrade to a more efficient refrigerator

- Existing refrigerator energy consumption = 2117 kWh
- New refrigerator energy consumption = 630 kWh
- Cost per kWh = $0.18
- Cost of new refrigerator $1099
- Expected lifespan of new refrigerator 20 years

What is the Savings to Investment Ratio?

Answer:_____

Ventilation

There are many reasons why it is necessary to mechanically ventilate homes. Modern home construction is much more energy efficient than in the past, increasing the need for adequate airflow to counteract the side effects of air-tight building practices. Some of the challenges that ventilation seeks to mitigate are the buildup of humidity inside the home, to provide odor control in general and specifically in bathroom and kitchen areas, and to dilute and remove particulate buildup and other contaminants and gasses that may otherwise reach unhealthy levels.

Moisture Control

Moisture control is a critical function of mechanical ventilation in the home, particularly in the winter months. Cold outdoor temperatures lower the dew point on interior surfaces such as doors, windows, and outside walls and ceilings which can result in condensation inside the home. The repeated occurrence or buildup of liquid water inside the home leads to organic growth, rot, and water damage.

Ventilation provides moisture control by lowering the relative humidity level inside the home. Warm, moist air is exhausted, and cool, dry outdoor air is brought in to replace it resulting in an overall reduction of interior humidity.

Particulates

Ventilation is also useful for reducing airborne particulates inside the home. Particulates are exhausted outdoors, and the air entering the home serves to dilute the remaining contaminants. Some common particulate issues that may have to be dealt with include the byproducts of fuel burning appliances such as wood stoves, cooking appliances, or heaters, emissions from printers, fax machines, or other office equipment or other sources.

Odor Control

Another benefit of mechanical ventilation is the ability to reduce and control odors within the home. Odors produced through normal household activities such as cooking, cleaning, and the bathroom can be evacuated from the home with whole house and spot ventilation.

Other Contaminants

There are numerous potential pollutants that can be present or may buildup to unhealthy or irritating levels inside the home. The purpose of providing mechanical ventilation isn't to identify or control every single contaminant, but rather to provide a level of air exchange that will keep the indoor environment healthy and acceptable to majority of occupants most of the time.

Ventilation Strategies

When planning a ventilation strategy, there are several important factors that should be considered. The first is that operable windows and doors don't count toward the required ventilation flow rate for a home. The required ventilation flow rate must be provided by the mechanical ventilation system automatically.

Mechanical ventilation systems must be controlled automatically and must be able to be programmed to operate continuously without occupant intervention.

Air supply to interior rooms, whether through exterior wall air inlets or ducting, should be routed to minimum occupant discomfort. Occupants that are bothered by cool air will find a way to disable a ventilation system, so location of supply is critical.

Ventilation air should be circulated into or out of all habitable rooms. Rooms where doors are typically closed such as bedrooms and bathrooms may need undercut doors or transfer grilles to maintain air circulation paths even when the door is shut.

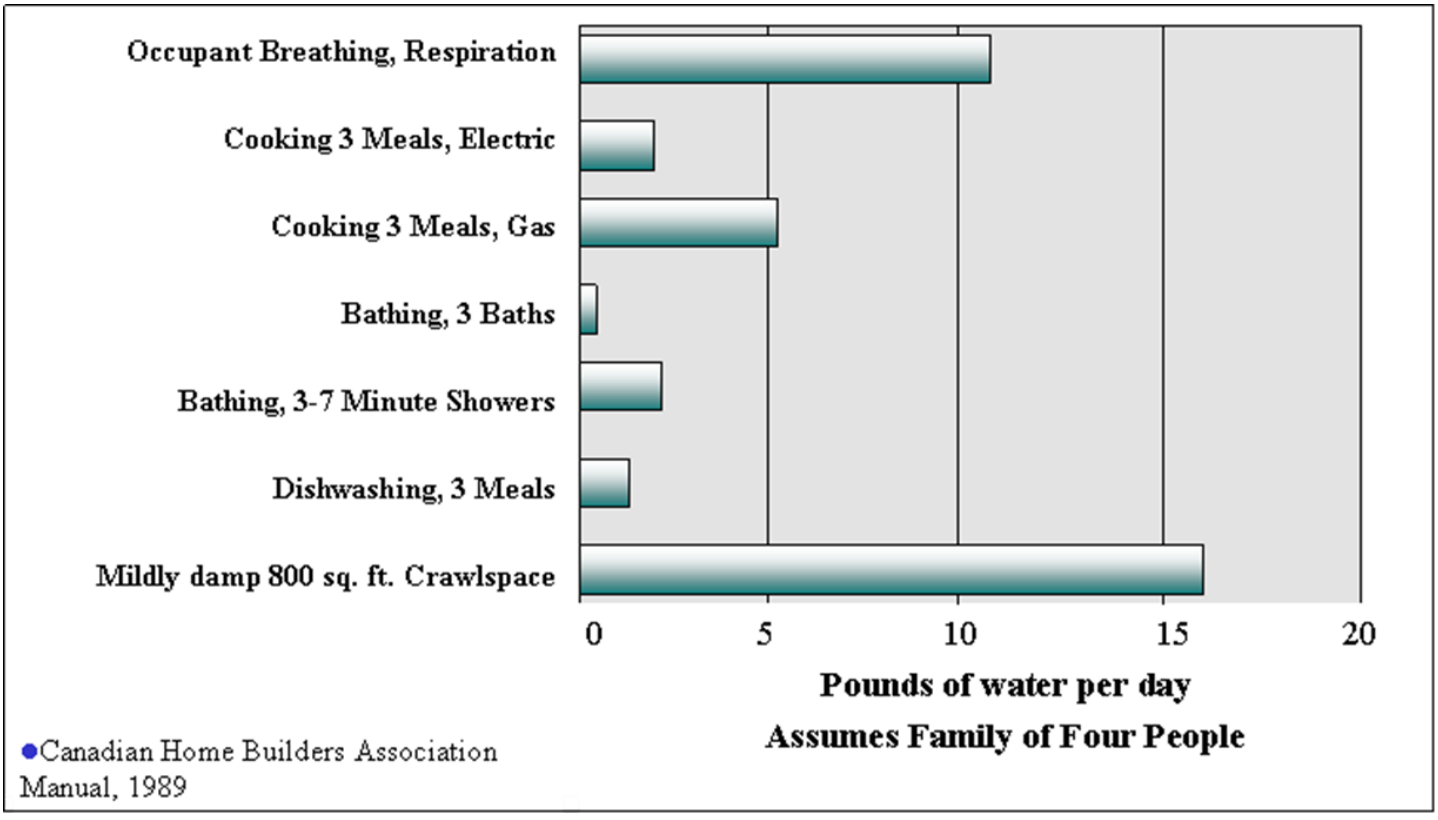
Ventilation System Types

Residential ventilation is defined as one or more air moving fans supplying and/or exhausting air from the building. To qualify as ventilation systems, fans must be automatically controlled to provide air exchange without occupant intervention. Ventilation systems must provide minimum flow rate based on the size and occupancy of the building.

There are three basic types of ventilation systems, supply, exhaust, and balanced. Supply only ventilation systems consist of one or more fans that blows outside air into the building. This type of ventilation system is prohibited in Alaska. Supply only ventilation systems cause positive pressure imbalances which creates problems with condensation inside building cavities.

Exhaust only ventilation systems consist of one or more fans that exhaust or remove air from the building. This is an acceptable ventilation strategy in cold climates, as it does not cause positive pressure imbalances within the structure.

Balanced ventilation systems both supply and exhaust air from the building simultaneously. Ideally, balanced ventilation systems will keep the house at a neutral or slightly negative pressure with reference to the outside. Balanced ventilation affords the opportunity to utilize heat recovery, which can offset some of the cost of exhausting heated air.



This chart form the Canadian home builders shows the amount of water in pounds per day produced in a home. A gallon of water weighs approximately 8.3 pounds, so according to the chart a family of four will produce more than one gallon of water per day into the home through respiration alone. Many normal household activities contribute to the moisture load inside of a home. If a method is not provided for removing this excess moisture the moisture build up can overwhelm the home and cause problems.

Supply Only Ventilation Systems

Supply only ventilation systems are problematic in cold climates since they cause the house to become pressurized with reference to the outside. For every cubic foot of air supplied to the home, one cubic foot of warm, moist air is forced out. The warm, moist air that is forced out through the floors, walls, and ceilings will cool off inside of the building cavities and condensation will occur. As moisture builds up inside the building cavities, organic growth, water damage, and rot may occur. For this reason, the supply only ventilation system is prohibited.

Exhaust Only Ventilation Systems

The exhaust only ventilation strategy consists of a bathroom exhaust fan or other dedicated exhaust fan that meets all the other requirements for ventilation.

The exhaust only ventilation strategy is acceptable since it places the house under a negative pressure with reference to the outside. This is preferable to positive pressure, although excessive negative pressure can cause other issues such as back drafting of combustion appliances and drawing in unwanted air or gasses from other places such as the garage or the crawlspace.

For every cubic foot of air that is exhausted, one cubic foot of air enters the home to replace it. In this way, fresh outdoor air is provided to the living area of the home. Air may be drawn in randomly through gaps or cracks in the building envelope, or dedicated ventilation opening in exterior walls may be used as a path for air movement.

Exhaust Only Advantages

The exhaust only ventilation strategy has several potential advantages that may benefit the home. The exhaust only strategy is the simplest system, relying only on a readily available exhaust fan and possibly a separate control. No ducting or special ventilation units are required.

The exhaust only system can also be the least expensive system, making use of readily available, off the shelf equipment that can be used for more than one purpose. The use of existing exhaust fans such as in the bathroom is allowed, reducing the need for additional fans or equipment on qualifying installations.

The exhaust only system requires minimum maintenance; there are no filter to change and no heat exchangers to clean. Exhaust only ventilation airflow can also be somewhat customized by strategically locating through-wall air inlets in spaces to maximize air circulation.



This is a photo of a common style of though-the-wall fresh air inlet. Fresh air inlets can be strategically placed to direct airflow inside the home. Most through wall outdoor air inlets are capable of being closed off when not needed, and many have a cleanable screen or filter. Locating outdoor air inlets where air circulation can be maximized, and occupant discomfort minimized can increase ventilation effectiveness.

Exhaust Only Disadvantages

There are some disadvantages to the exhaust only ventilation system. Exhaust fans may cause excessive depressurization of the home, which may interfere with the operation of combustion appliance. Depressurization may also draw in unwanted contaminants from the ground, attached garages, or other undesirable areas. Care must be taken in air tight construction to not cause problems associated with negative air pressure inside the home.

Exhaust only ventilation is less effective at directing airflow where it is needed and relies somewhat on random leakage through the building envelope to deliver required ventilation air. Exhaust only ventilation does not afford the opportunity to use heat recovery, which can reduce energy costs and increase occupant comfort. Exhaust only ventilation brings outdoor air directly inside without tempering which can cause discomfort.

Balanced Ventilation Systems

Balanced ventilation is the strategy of both exhausting and supplying ventilation to the home simultaneously. Balanced ventilation systems are typically ducted systems, with ventilation air being directed to and drawn from specific areas of the home. Ductwork used for forced air heating systems is often combined for use with balanced ventilation systems.

Balanced Ventilation Advantages

There are several potential advantages to the balanced ventilation strategy. A properly balanced ventilation system will supply and exhaust equal amounts of ventilation air to the building. This leaves the building at a neutral pressure with reference to outside, which eliminates the drawbacks associated with the supply only and exhaust only systems.

Balanced ventilation is typically a ducted system, which allows airflow to be customized by locating supply and return registers in strategic locations. This is generally superior to relying on random outdoor air leakage as may be the case with exhaust only systems. The balanced ventilation system can be integrated with heat recovery, which can save energy and money in cold climates by extracting heat from the exhaust side airflow. Heat recovery can offset some of the added cost of the equipment and ducting often associated with the balanced ventilation system.

Balanced Ventilation Disadvantages

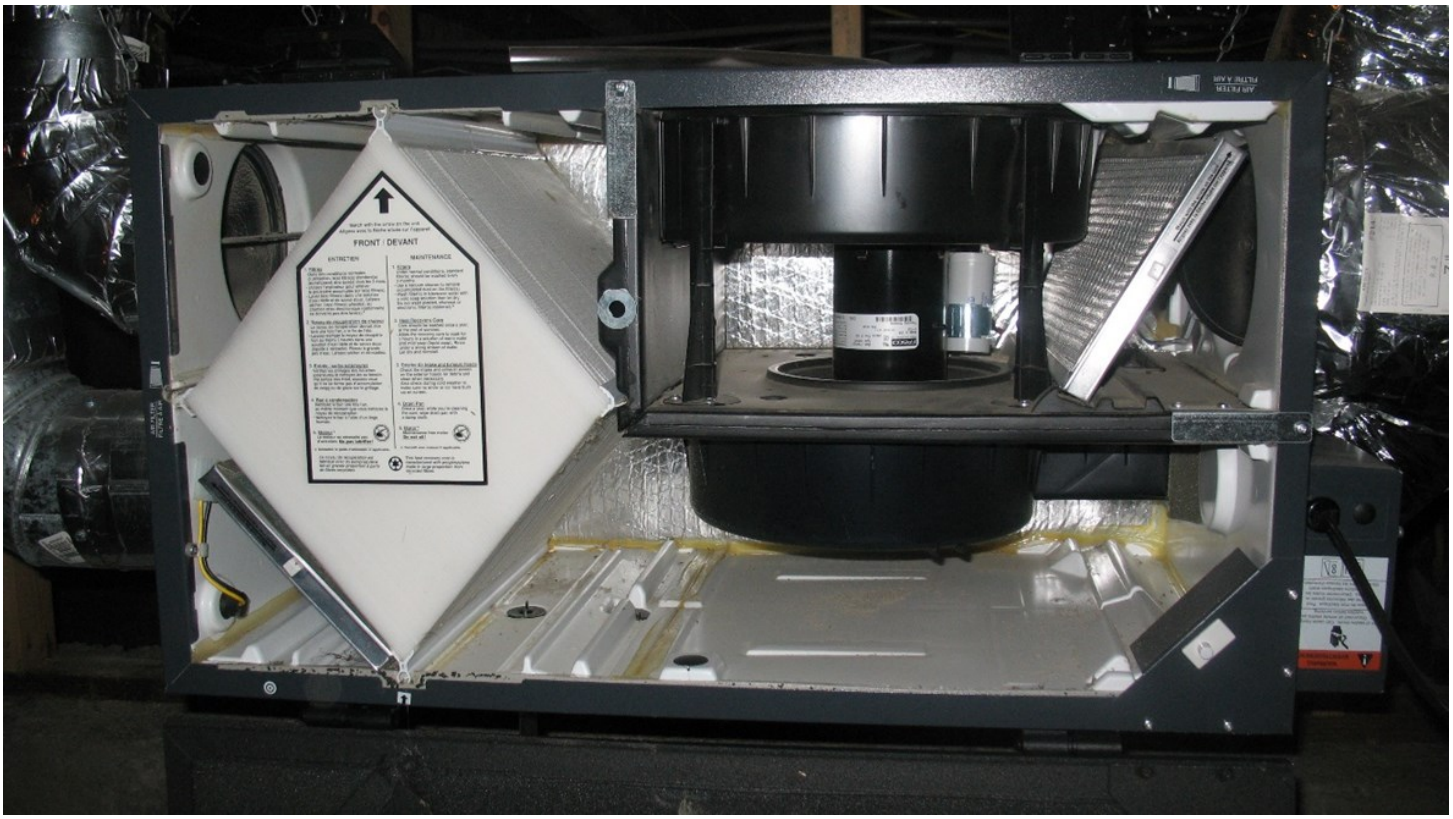
There are disadvantages to the balanced ventilation system as well. The supply and the exhaust flows of the system must be interlocked so that the system cannot positively pressurize the house. For integrated heat recovery units, this is usually a non-issue. For site-built systems such as scuttle air which draw air from outside into a furnace ductwork system, some coordination is needed to ensure that exhaust is provided in an equal amount to the air supply at the same time supply ventilation is occurring.

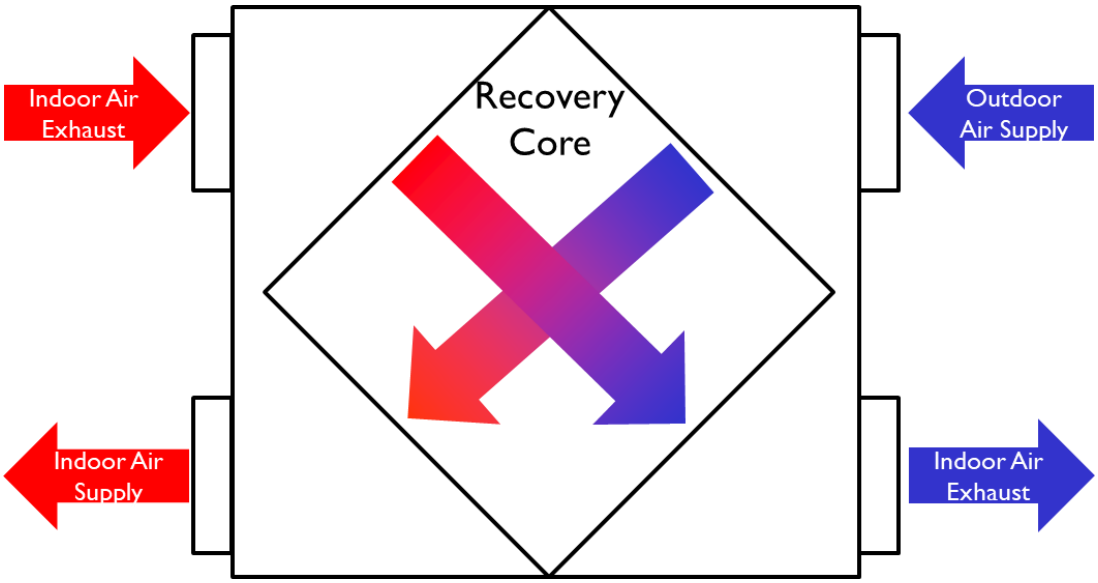
Balanced ventilation systems typically also have one or more screens of filters that must be cleaned and maintained periodically for the system to function properly. Clogged filters and screens can quickly cause a system to become unbalanced or not provide any airflow at all even if the unit is operation.

Balanced ventilation system controls are typically more complex than exhaust only system controls. There is usually both a timer function and a humidity function, which can be overwhelming for some occupants. Some training by the installer is typically needed to inform the occupant about operating the controls.

Heat Recovery Ventilation

Balanced ventilation allows the use of heat recovery, which increases efficiency and lowers fuel costs when correctly maintained and operated. The exhaust air is routed through a heat exchanger, either flat plate or rotary core, which captures some of the heat and transfers it to the supply air stream. Up to 70% or more of the heat may be extracted out of the exhaust and shifted to the supply air. This heat exchange process can save a significant amount of energy and money in cold climates or where heating fuel costs are high. There is also the added benefit of increased occupant comfort as the supply ventilation air is tempered.





This illustration shows a typical flat plate heat exchanger in an integrated heat recovery ventilation unit. Air from outside is pre-heated by the exhaust air from inside.

Heat Recovery Vs. Energy Recovery

There are two types of heat recovery ventilation, although the term heat recovery is usually generically applied to both types. True heat recovery ventilators, which uses the flat plate heat exchanger, recovers sensible heat only. Sensible heat contains no moisture or latent heat.

Energy recovery ventilators, which typically utilize a rotating drum, capture sensible heat and latent heat contained in the moisture in the air. Some studies have shown that energy recovery ventilators are more resistant to freezing in very cold temperatures, check with the manufacturer. Overall, the amount of energy saved between the two types is very similar.

Ventilation Cost Effectiveness

When selecting the ventilation strategy, the cost effectiveness of the type of system should be considered. The cost effectiveness of a particular strategy or system is based on several factors, including the cost of heating fuel. As the cost of heating fuel rises, the cost effectiveness of heat recovery increases as well.

The efficiency of the heating system affects the cost effectiveness as well. Less efficient heating systems increase the cost effectiveness of heat recovery ventilation. The harshness of the climate, i.e. how cold it is also impacts the cost effectiveness of the ventilation system. Colder climates increase the cost effectiveness of heat recovery ventilation.

All of these criteria affect to cost effectiveness of the system. In general, the more expensive it is to heat a home, the more cost-effective heat recovery becomes.

Another key factor in the cost effectiveness and overall effectiveness of ventilation systems is proper sizing. While there may be a temptation to oversize the system and greatly exceed the required air flow, the downside is that money and energy is wasted at the initial install and over the life of the ventilation system. A properly sized system will keep the home free of moisture and contaminants without wasting excessive energy.

Undersized ventilation systems won't provide adequate airflow and will allow a buildup of unhealthy contaminants and moisture. In all cases, the ventilation system controls must be readily accessible to the occupants for adjustment as needed, and must be capable of providing continuous ventilation.

Indoor Air Quality

Air tight homes are susceptible to indoor air quality issues. The house is a system, and it is important to identify the root cause of indoor air quality problems. If the root cause of an indoor air quality issue is addressed rather than a symptom, the solution will be much more effective.

Common IAQ Contaminants

There is a nearly unlimited number of potential indoor air contaminants. However, carbon monoxide, radon, and mold present some of the biggest challenges for healthy indoor air quality.

Carbon monoxide is a combustion air contaminant that is colorless, odorless and tasteless. Carbon monoxide is a product of incomplete combustion during the fuel burning process.

Radon is a naturally occurring soil gas that infiltrates the lower levels of homes in contact with the ground, and may build up to unhealthy levels in air tight homes.

Mold or organic growth is a by-product of excessive humidity or liquid water in the indoor environment. All three of the contaminants can be directly attributed to energy efficient construction techniques to some degree. But, all three can also be mitigated with forethought and planning.

Carbon Monoxide

Carbon monoxide, also known as the silent killer, cannot be seen or smelled and has no visual indicators of its presence.

Carbon monoxide can occur wherever the fuel burning process takes place, which includes common household appliances like heaters, cooking stoves, and fireplaces. Vehicles in attached garages are also a potential source of carbon monoxide.

Carbon monoxide is particularly dangerous because small amounts can accumulate in the blood stream over time, causing chronic health effects.

Carbon monoxide has a long history of causing hospital visits and deaths in Alaska. People are severely injured or killed in their homes nearly every year due to carbon monoxide poisoning. In many cases, faulty heating systems are to blame for the injuries or deaths, which are entirely preventable. Much of the groundwork for preventing injury or death from carbon monoxide and other indoor air contaminants can be laid during the construction phase of a new home. From selecting the right heating appliances to proper ventilation, many indoor air quality problems can be stopped before they start. From 1993 to 2010, 149 people were hospitalized and 4 died from carbon monoxide poisoning in the state of Alaska. That works out to more than 8 reported serious injuries per year.

Carbon monoxide has a half life of 5 hours, which means that if an individual received a dose of 50 parts per million, 5 hours later that person would still have 25 parts per million in their blood stream. Persons spending large amounts of time in the presence of low levels of carbon monoxide may not be able to clear the CO from their bloodstream and can suffer long term adverse health effects.

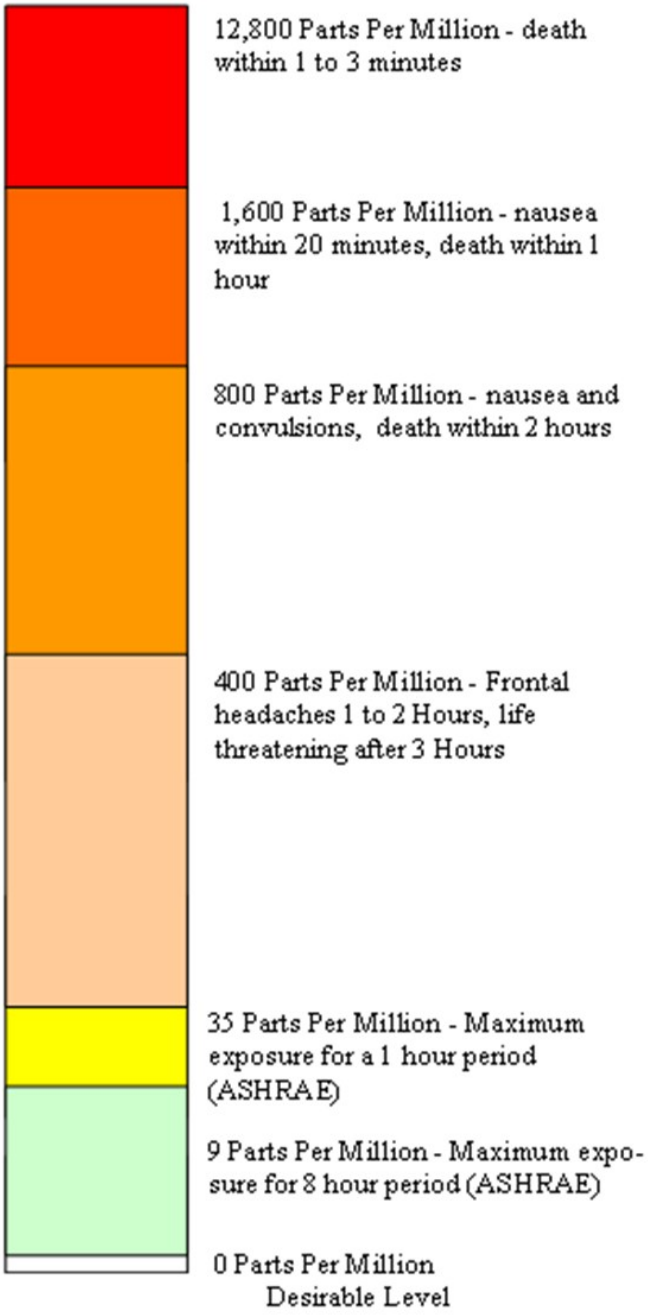
Carbon monoxide is so deadly because the CO molecule has a greater affinity for red blood cells than oxygen. If carbon monoxide is inhaled and enters the blood stream, it takes priority over oxygen and is very difficult to eliminate.

Carbon monoxide is the leading cause of poisoning death in America, which has caused many municipalities to mandate that CO detectors be installed in homes.

There are many potential sources of carbon monoxide in the home. Most of the time, carbon monoxide that is produced by fuel burning appliances is safely carried out of the house by chimney and vents. However, when a chimney or vent is missing, blocked, or not properly installed, the chances of an issue increase greatly.

Open combustion appliances that are natural draft are particularly susceptible to back drafting, which can cause carbon monoxide to enter the living space. Air tight housing and new construction, which can experience significant negative pressure imbalances, does not lend itself to open combustion appliances.

It must be recognized that managing the pressure imbalances within homes, and providing combustion air for open combustion appliances, is mandatory for air tight construction.



The health risks associated with carbon monoxide get progressively worse as levels increase. Zero parts per million is the desired level in all situations. Up to 9 parts per million is considered an acceptable level, although even these levels may cause chronic poisoning. Any levels over 35 parts per million are not acceptable, and levels above 400 parts per million are seriously life threatening.

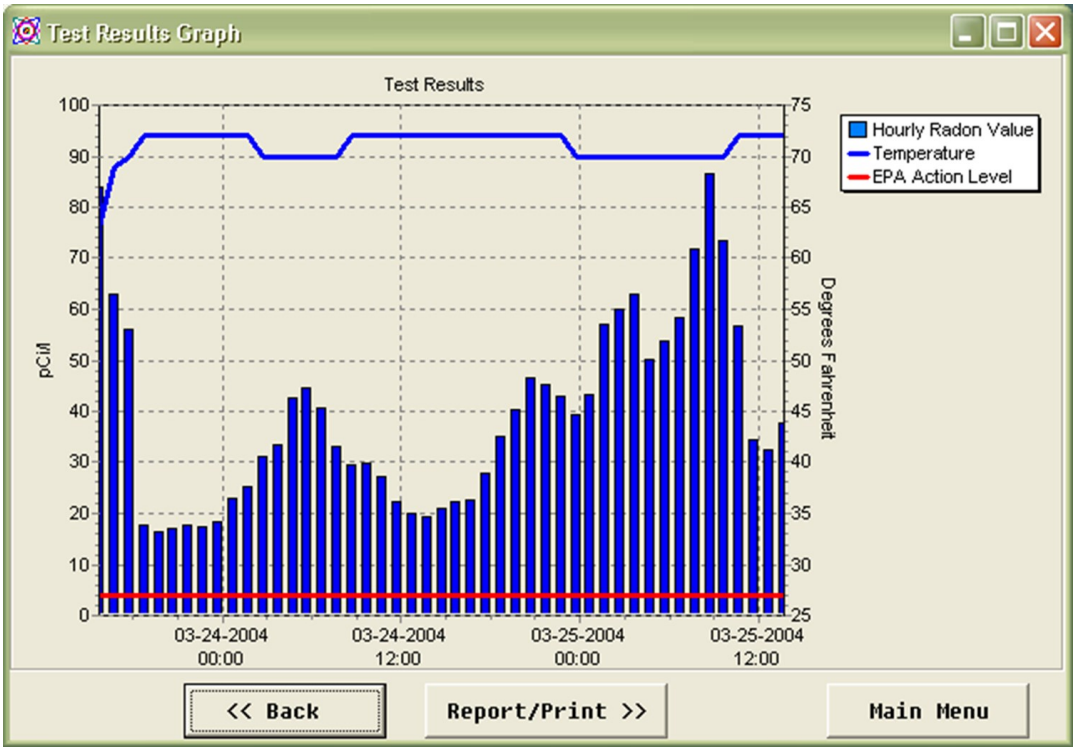
Radon

Radon is a radioactive gas that is colorless, odorless, and tasteless. Radon gas is naturally occurring in the earth's crust and is a byproduct of the decay of uranium and radium elements. Radon is recognized as the second leading cause of lung cancer in America, right behind smoking.

Radon enters buildings through the below grade surfaces such as the foundation, slab, crawlspace, or exposed earth. Radon finds its way through any gaps or cracks in the foundation or vapor retarder. Radon is not a problem outdoors where it naturally dissipates in the air. Radon becomes a problem when it builds up inside the home. This problem is often made worse by negative pressure imbalances in the home. Negative pressure imbalances create a suction on the ground under and surrounding the building, speeding up the rate at which radon enters the building. Air tight homes are particularly vulnerable as they usually experience greater negative pressure imbalances.

There are two driving forces which may naturally draw radon gas into the home; stack effect and appliance effect. Stack effect, which occurs when the outside temperature of a building is less than the inside temperature of a building, causes a negative air pressure at the lower levels. Appliance effect, which is caused by exhausting appliances such as bathroom fans, kitchen fans, clothes dryers, etc. causes a negative air pressure throughout the house including the lower levels where radon can be drawn in.

Because radon gas cannot be seen or smelled, it must be tested for with specialized equipment. Testing periods for radon gas run from 48 hours, which is the minimum allowed for real estate transactions, to a full 90 days. Testing can be done with passive canisters or active monitors. Passive canisters must be sent to a lab for results, active monitors can give readings immediately after testing is complete.



The EPA maximum average allowable radon level is 4 picocuries per liter, represented by the red line in the test graph on the left. Levels reached nearly as high as 70 picocuries during this test.

Radon Mitigation

Radon can be mitigated with good building practices. The number one defense against radon issues is a well sealed vapor retarder covering the below grade surfaces in contact with the earth. Six mil polyethylene is considered the standard for this. All edges of the vapor retarder should be overlapped and taped or sealed to form an air tight seam.

In below grade floor areas, the edges of the vapor retarder should be sealed to the footings and foundation walls at the edges with approved tapes or acoustical sealant. Vapor retarder should be applied under slab on grade floor before concrete is poured and should cover all exposed earth.

Another method of radon mitigation is to reduce negative pressure inside the home with reference to the outside. This can be accomplished by reducing exhaust fan flows to code minimums. Balanced ventilation systems which do not exert negative pressure on the building are preferred. Exhaust only ventilation systems can be improved with the installation of through wall fresh air inlets, which relieve negative pressure and provide controlled air circulation pathways.

In cases where radon levels are significantly elevated, or there is limited ability to reduce negative pressure or seal below grade areas, sub slab depressurization can be a good choice. Sub slab depressurization involves active suction under a basement slab or crawlspace vapor retarder with a dedicated exhaust fan that runs continuously. The suction end of an exhaust pipe is placed below the level of the floor or vapor retarder, ideally in a gravel sump. Radon is drawn to the exhaust fan through negative air pressure below a well sealed slab or vapor retarder. The exhaust piping is run to the exterior, usually discharging above the roof level of the home.



This photo shows continuous polyethylene sheeting under a concrete floor before it is poured. The continuous plastic sheeting acts as a radon and moisture barrier.

Mold

Mold is a living biological organism that occurs naturally in the outdoor environment. Mold is spread through small, lightweight spores which float through the air. Mold has the ability to grow on nearly any cellulose material, which includes common construction materials like drywall and wood, as well as dirt, or paper products. Rapid mold growth on cellulose material is triggered by excessive moisture. Mold growth inside a home is typically a symptom of some type of moisture problem.

Mold spores are always present in the indoor and outdoor environment at relatively low levels, an interior environment cannot be maintained as mold-free. It is high concentrations of mold spores due to overgrowth from moisture which are responsible for most health related issues.

Most houses are made of or contain cellulose material to some degree. Therefore the key strategy to control mold growth is to control moisture inside the home. Moisture comes from two sources; liquid water and humidity. Liquid water from plumbing leaks, condensate drains, and groundwater intrusion are all sources of moisture that can cause mold growth. Water vapor, or humidity is the second source of moisture in the home, and a potential primary driver of mold growth in cold climates. Excessive humidity inside the home causes condensation on cold surfaces, which forms liquid water.

Preventing Mold Growth

Since it would be impossible to eliminate cellulose building materials in homes, the key strategy for preventing mold growth is to reduce or eliminate sources of moisture inside the home.

Steps for reducing moisture include covering all exposed earth inside the home, such as in crawlspaces, with a sealed polyethylene vapor retarder. Proper ventilation of the home is needed to reduce humidity to acceptable levels during winter months, which will reduce condensation potential. Heat must be available or be circulated to all areas of the home. Cold spots collect condensation which will cause mold growth over time. Cold spots must be eliminated, both through proper installment of insulation and reduction of cold air leakage through the building envelope. Moisture control, ventilation, and energy efficient building techniques that reduce cold spots are the primary tools for preventing mold growth inside the home.



This photo courtesy of Alaska Housing Finance Corporation shows mold growth outlining the studs and top plates of the wall. These areas of the wall suffered from greater heat loss that the insulated portion of the wall, and thus condensation occurred in these areas. Mold growth also occurred in the corner where storage prevented air circulation which promoted condensation.

Garages

Garages are a source of a variety of pollutants, including vehicle exhaust, combustion appliances which are often located in the garage, and stored materials such as fuel and cleaning supplies.

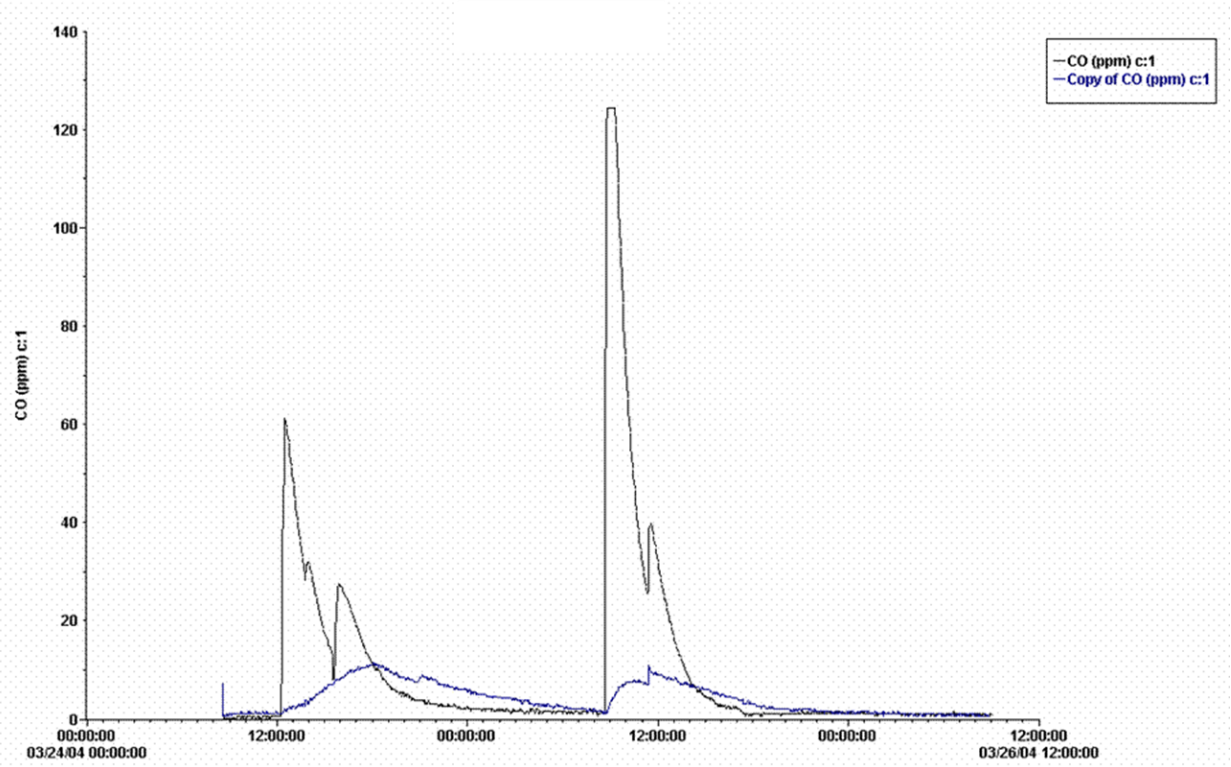
If a garage is attached to a home, it can be assumed that any pollutants present in the garage will migrate into the home. There are many opening and penetrations in the wall that separates the garage from the house, including man doors, piping, and electrical boxes.

The house, which typically contains most of the exhausting appliances, is usually at a negative pressure with reference to the garage. The negative pressure imbalance in the home causes air and pollutants to migrate from the garage into the house.

Summary

The house is an interconnected system of components that must work together to provide safe and efficient place for people to live. When one component of the house fails or does not perform as intended, the consequences may not appear related at first glance.

This is particularly true in terms of indoor air quality issues, where problems are typically a symptom of some larger issue or root cause. Identifying the potential causes of indoor air quality issues at the planning and construction stage can greatly reduce or eliminate future problems. Proper use of energy efficient techniques, air sealing, vapor retarders, combustion air, and mechanical ventilation all play an important part in safe and healthy housing.



In this graph the black line is carbon monoxide level in the garage, and the blue line is the carbon monoxide level in the home. Spikes in the garage carbon monoxide level correspond with times the car was pulled in or out of the garage. Levels reached over 120 parts per million in the garage. Smaller spikes of carbon monoxide occurred in the house immediately after they occurred in the garage, showing the communication between the two areas.

Alaska Specific Concerns

Alaska is home to diverse and extreme climates with many challenges. Acceptable methods and practices in one area of the state will not necessarily be optimal for other areas of the state. Ideally, the builder will take into account the climate, terrain, and available resources to construct an energy efficient house that meets the needs of the occupants and location of the home.

Climate Regions

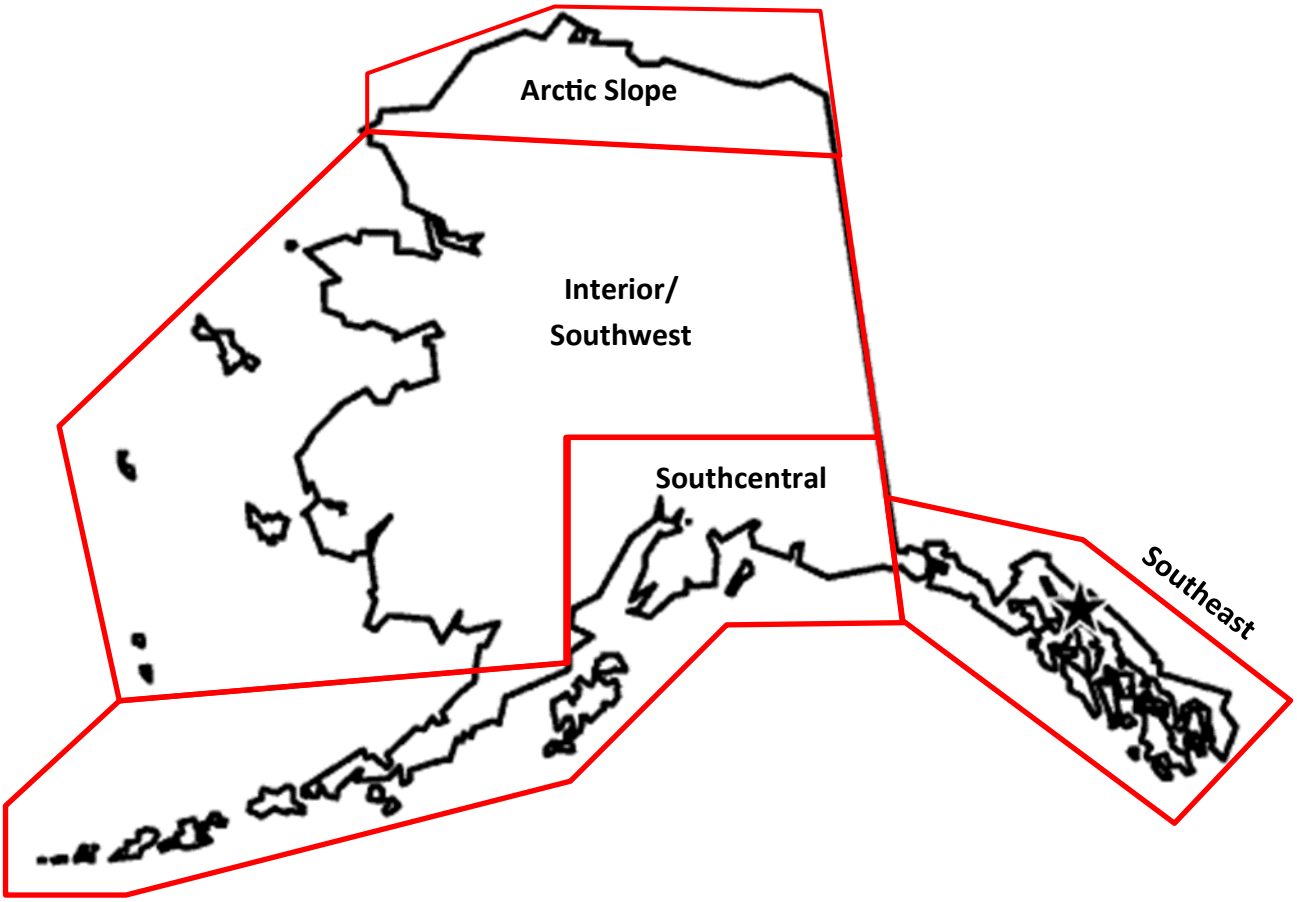
There are four distinct climate regions in Alaska, with diverse need and challenges. The four general climate zones are Southeast Alaska, Southcentral Alaska, the interior and Southwest Alaska, and the Arctic Slope.

Southeast Alaska encompasses the "panhandle" in the southeast corner of the state. Southeast Alaska has a maritime climate, with lots of islands and coastline. This regions is often subject to the jet stream, and experiences heavy rainfall and wind driven rain. This results in extreme humidity and moisture issues from the massive amount of precipitation. In terms of temperature, southeast Alaska has a relatively mild climate, with a heating degree day load ranging from 7,200 to 9,000. Snow loading in this region is moderate, much of the precipitation even in the winter is rain.

Southcentral Alaska encompasses the central part of the state as well as the Aleutian chain to the west. Southcentral Alaska has a mixed climate, with maritime influences along the coast and Aleutian chain, and a transition climate moving inland. The heating degree day load is moderate along coastal areas, and increases moving inland. Snowfall is moderate inland and to the west, increasing to extreme along central and eastern coastal areas, where precipitation falls as snow. The coastal areas and western Aleutian region can be subject to extreme and nearly continuous winds.

Interior and Southwest Alaska is the largest region, reaching from southcentral to the Brooks range in the north, and from Canada to the Bering sea coast in the west. Much of the interior and southwest regions of Alaska are considered a dry or desert climate, with little to moderate rain and snow accumulation. Coastal areas experience a maritime climate, but with much less precipitation than the southeast region. The heating degree day load is higher than the southeast and southcentral regions, bordering on extreme in the norther interior where record freezing temperatures have been set. Much of the interior is characterized by permafrost and unstable soils that are thawing, making foundation construction a challenge. Blowing snow is more of an issue in this region than snow accumulation, with western coastal areas experiencing heavy drifting.

The northern most climate region is the **Arctic Slope**, which extends from the Brooks Range to the arctic ocean. The Arctic slope region is considered a dry or desert climate, with minimum precipitation. This region has the most extreme heating load, with heating degree days ranging from 16,000 to 20,300. The arctic slope region is a heating climate even during summer months, when outdoor temperatures rarely get above 60 degrees. This region is also characterized by permafrost and unstable soils.



The different regions of Alaska encompass a wide variety of climate challenges that must be taken into account for the long term success of energy efficient homes.

Snow Loads

Snow loads are an Alaska specific concern that affects the structural integrity of the building. Snow loads vary widely around the state, ranging from 30 to 300 pounds per square foot. Snow loads can vary considerable even within a single area or community, depending on the elevation, distance from coastline, and how much local shelter is present. Local knowledge of snow loading conditions is highly valuable.

Snow loading criteria is based on several factor. The exposure of the building affects the snow load, sheltered buildings experience greater snow loads than buildings exposed to prevailing winds. Cold roofs which keep snow experience a greater snow load that hot roofs, which melt snow and shed snow load over time. The importance of the building is also part of the calculation. The more important the building is considered, the greater the snow load it must be capable of withstanding. Buildings like hospitals and emergency response centers are considered very important, while uninhabited buildings are not. Residential construction is assigned an importance factor of 1.0.

Snow Load Example

Cold roof residence, located Anchorage, sheltered Category B, what is the snow load?

- Snow Load = 50 psf
- Category B, Sheltered = 1.2
- Cold Roof = 1.1
- Importance Factor = 1.0
- 50 * 1.2 * 1.1 * 1.0 = 66 PSF Ground Snow Load

Snow Load Thermal Factor	
Thermal Condition	**Factor**
Warm roof design	1.0
Cold, ventilated roof design	1.1
Unheated structures	1.2
Continuously heated greenhouses	0.85

The thermal factor assigns a coefficient for snow loading depending on the type of roof construction. Warm roofs, or roofs without ventilation, are assigned a factor of 1.0. Cold or ventilated roofs as assigned 1.1. Unheated structures are assigned a factor of 1.2. Cold roof and unheated structures doe not melt snow and maintain the snow cover, and thus experience more snow buildup and a greater load.

IBC Table 1608.2					
Ground Snow Loads, Pf for Alaskan Locations					
Location	Pounds per Square Foot	Location	Pounds per Square Foot	Location	Pounds per Square Foot
Adak	30	Galena	60	Petersburg	150
Anchorage	50	Gulkana	70	St. Paul Island	40
Angoon	70	Homer	40	Seward	50
Barrow	25	Juneau	60	Shemya	25
Barter Island	35	Kenai	70	Sitka	50
Bethel	40	Kodiak	30	Talkeetna	120
Big Delta	50	Kotzebue	60	Unalakleet	50
Cold Bay	25	McGrath	70	Valdez	160
Cordova	100	Nenana	80	Whittier	300
Fairbanks	60	Nome	70	Wrangell	60
Fort Yukon	60	Palmer	50	Yakutat	150

Ground snow loads in pounds per square foot are given for many communities in Alaska in the building codes but fall short of being comprehensive for the whole state. Local knowledge and experience are very important in design and construction.

Snow Exposure Factor (Based on IBC)			
Terrain Category	**Exposure of Roof**		
	Fully Exposed	**Partially Exposed**	**Sheltered**
Category B - Ubran & suburban areas	0.9	1.0	1.2
Category C - Open area	0.9	1.0	1.1
Category D - Exposed shoreline & plains	0.8	0.9	1
Above treeline in windswept mountain areas	0.7	0.8	N/A
In Alaska in areas without trees within a 2 mile radius	0.7	0.8	N/A
Exposed: Fully exposed with no shetler on all sides Partially Exposed: Any roof not "fully exposed" or "sheltered" Sheltered: Roofs tight among conifer trees			

The snow exposure factor is based on the terrain categories which are the exposure categories B through D. It is also based on the exposure of the roof, whether it is considered fully exposed, partially exposed, or sheltered. When the proper terrain category and exposure of roof are chosen, a coefficient is provided to multiply the ground snow load by. The snow exposure factor is important because this is where the effects of wind are considered in the determination of the snow load for a roof.

Seismic Design

Seismic design, although not directly related to cold weather construction, does directly affect building in Alaska. All seismic categories are present in Alaska, including some of the most severe categories which encompass the most populous areas of the state. It is important to recognize the impact of seismic design on the choice of foundation, which in turn impacts heat loss and efficiency.

Wind Design

Wind design is another aspect of construction in Alaska that affects energy efficient construction choices. All wind categories are present in Alaska. Milder winds are typically present in interior areas, and stronger winds are present in coastal areas. Mountains regions and hillsides or valleys can also have special wind design considerations. Prevailing direction and strength of local winds can affect roof construction when deciding whether to use a vented or unvented roof system. Unvented roof systems may be preferable in areas with heavy blowing snow.

Building Orientation

The orientation of a home on the building site is one area where good design and planning can take advantage of a free resource. Alaska is almost strictly a heating climate, and as such it is beneficial to maximize glass exposure in windows and doors to the south and west to capture heat from sunlight energy.

Rooms that are used during the day, such as living rooms and kitchens, should be placed on the south and west sides. Glass should be limited on the north and east sides of the building where there is little sun exposure or heat gain.

Building Shape

The shape of the building can have a significant impact on the energy efficiency. In general, a low ratio of exposed exterior surface to interior volume is desirable. Heat is lost through the exposed exterior surface, so minimizing the amount of exposed surface area is more energy efficient given the same building volume. This principle lends itself to compact or box like shapes, rather than buildings that have large length to width ratios.

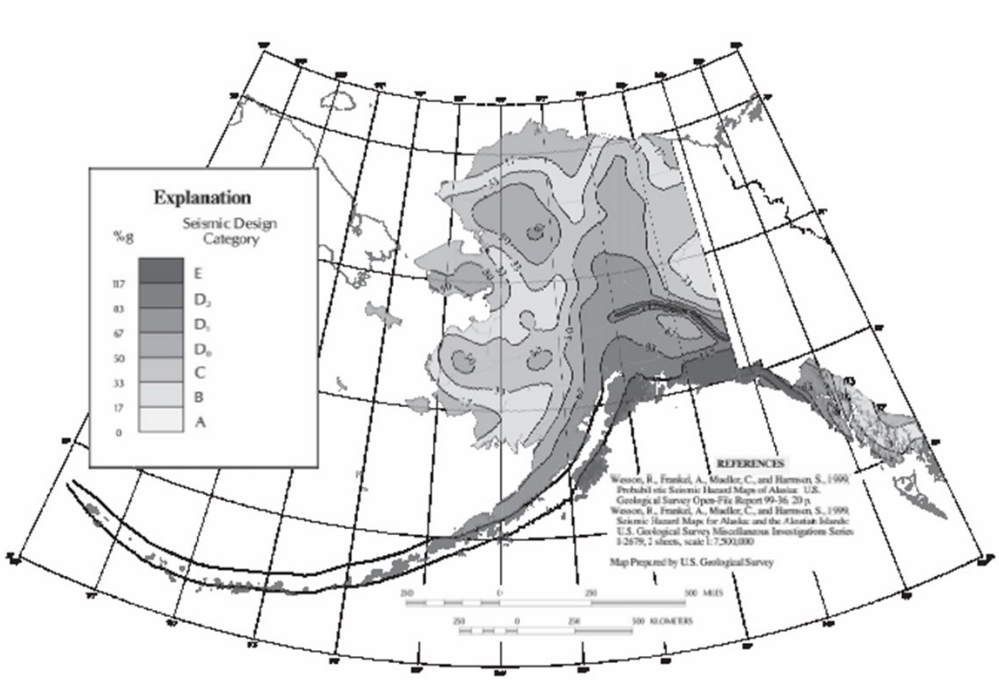
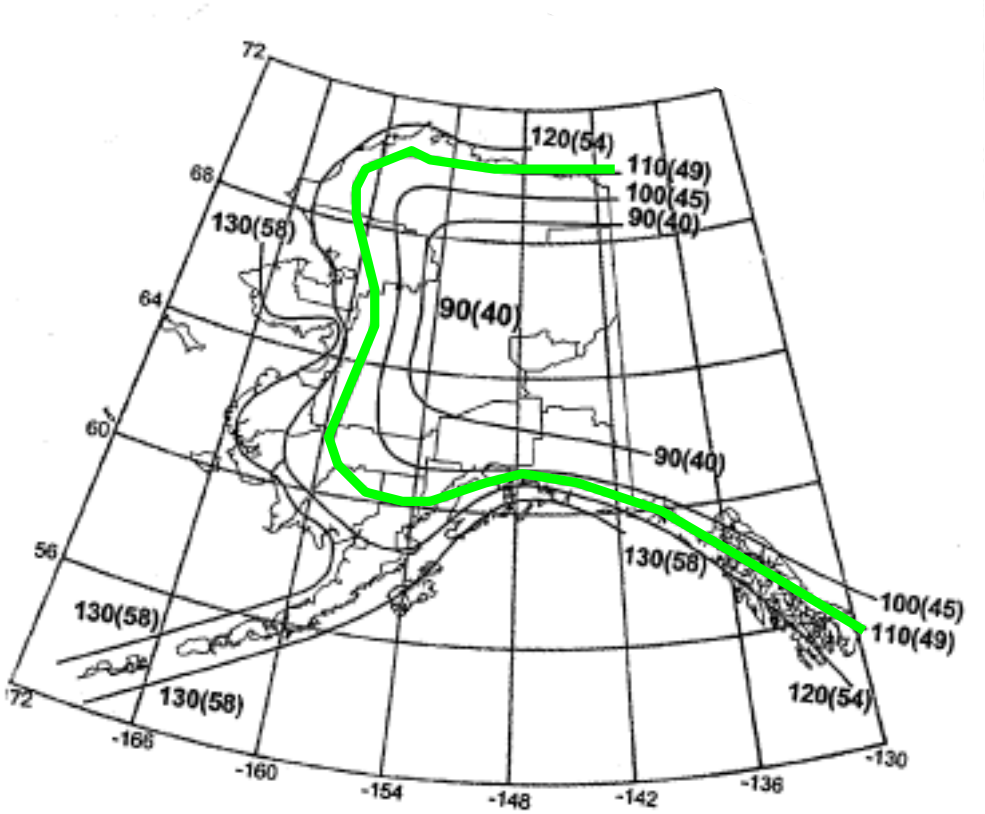


FIGURE R301.2(2)
SEISMIC DESIGN CATEGORIES—SITE CLASS D
(continued)

This graphic from the code book shows the different seismic areas throughout the state. The darker colored areas are the more severe seismic zones. Foundation and exterior wall construction can be greatly affected by hold down and blocking requirements.



Everywhere outside the green line shown on this map of Alaska is considered a high wind region and should be designed accordingly.

Foundations

The key concepts for foundations in cold climates is to maintain structural stability for the conditions present at the building site, to retain heat and be energy efficient, and to keep water out of any below grade areas. Soil conditions and climate challenges can place extreme demands on a building foundation. There are four common foundation types covered in this section. Slab on grade or below grade, stemwall foundations that encloses below grade space, whether crawlspace or basement, piling foundations, and the multipoint foundation.

Slab Foundations

The slab foundation is a concrete floor system poured on the ground. Slabs can be located at grade level, or below grade level as part of a basement. There are two basic types of slab foundations; monolithic or over a stemwall.

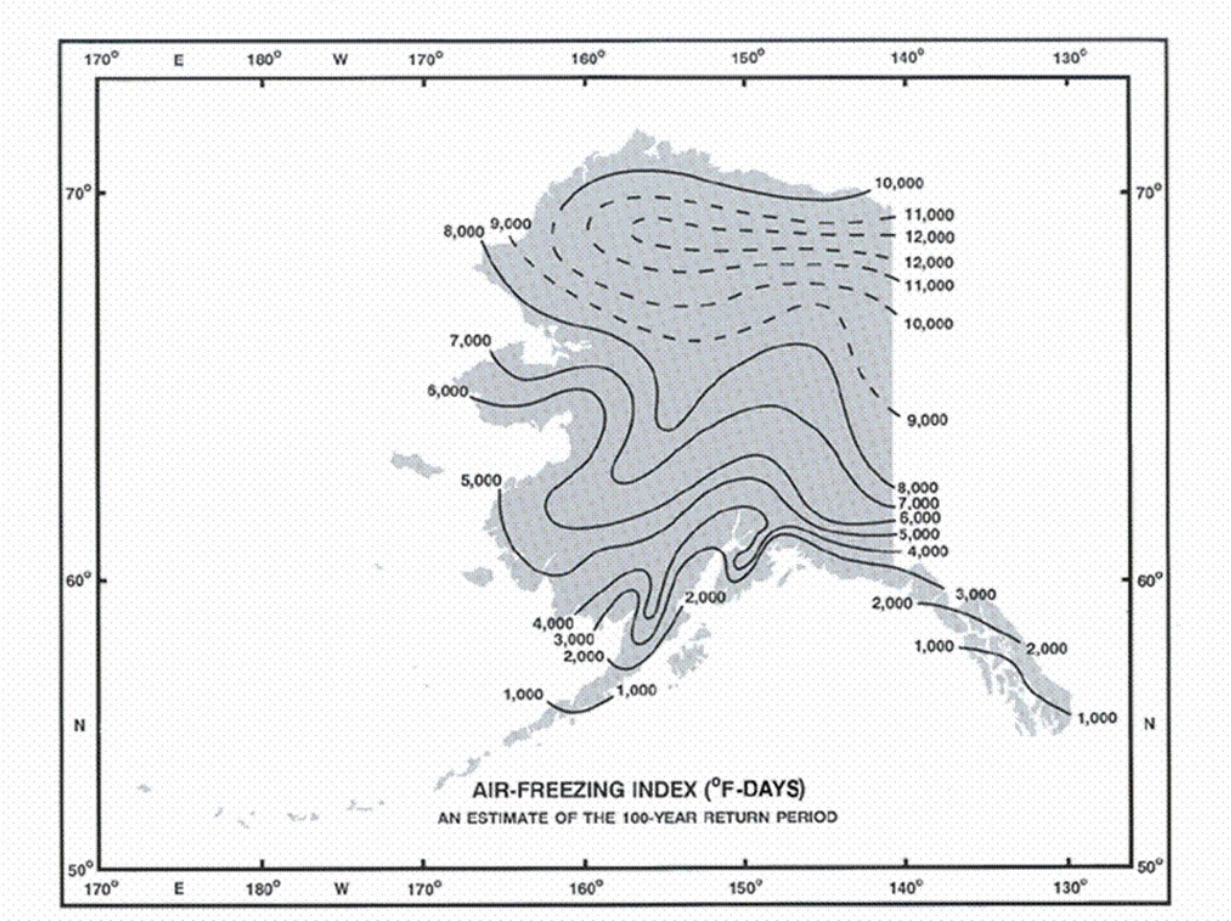
The monolithic slab on grade consists of a footing and floor surface combined into one pour. This type of slab typically does not bear below the frost line and instead uses insulation around the perimeter of the footing to prevent frost heave.

Slabs can also be poured over or inside a traditional stemwall, in which case the slab is supporting only the floor load and the exterior wall and roof bearing is supported by the stemwall.

Monolithic Slabs

The monolithic slab is also known as a frost protected shallow foundation. This type of foundation does not extend below the frost line, which can be an advantage due to reduced excavation costs. In order to prevent the soil under the footing from freezing, a perimeter of foam board insulation is placed along the edge and out from the bottom of the footing. The foam insulation keeps the ground below the footing thawed during below freezing temperatures by forcing heat loss from the building to travel under the foundation footing.

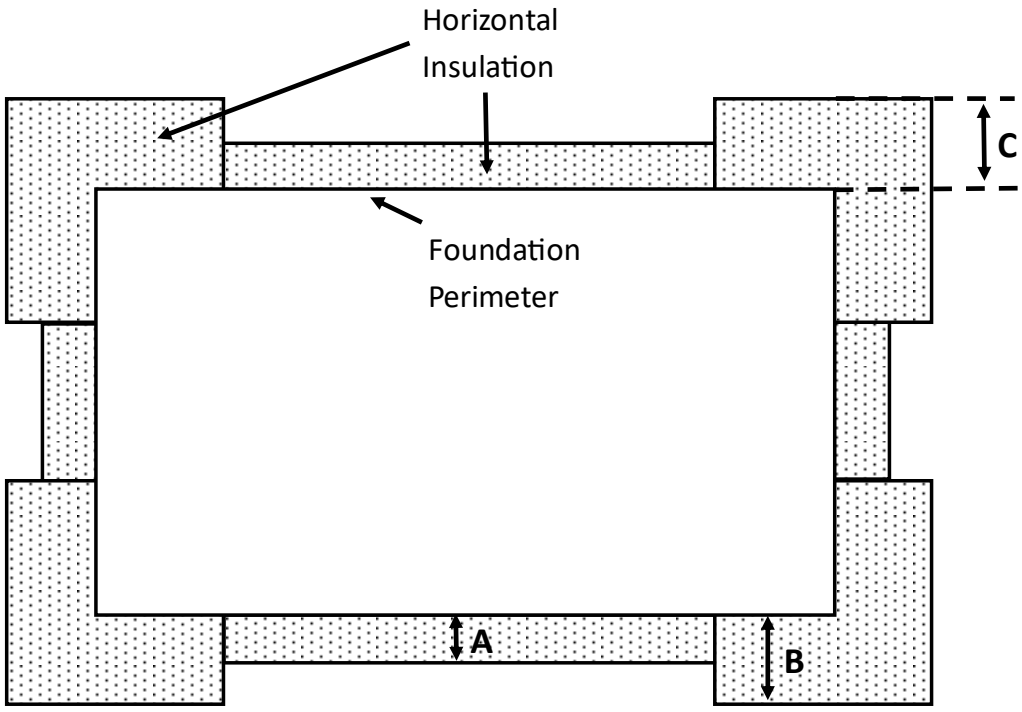
The amount of insulation required for the frost protected shallow foundation to be effective is based on the air freezing index at the location of the building site. The air freezing index is a measure of how cold the climate is in a location. For the frost protected shallow foundation to work, the building must be heated on a year round basis. If the building is not heated during the winter, there is a risk that the soil under the footings will freeze, causing the building to shift and heave. This type of foundation relies on heat loss from the building and for the ground under the building to remain thawed, and is not suitable for use on permafrost.



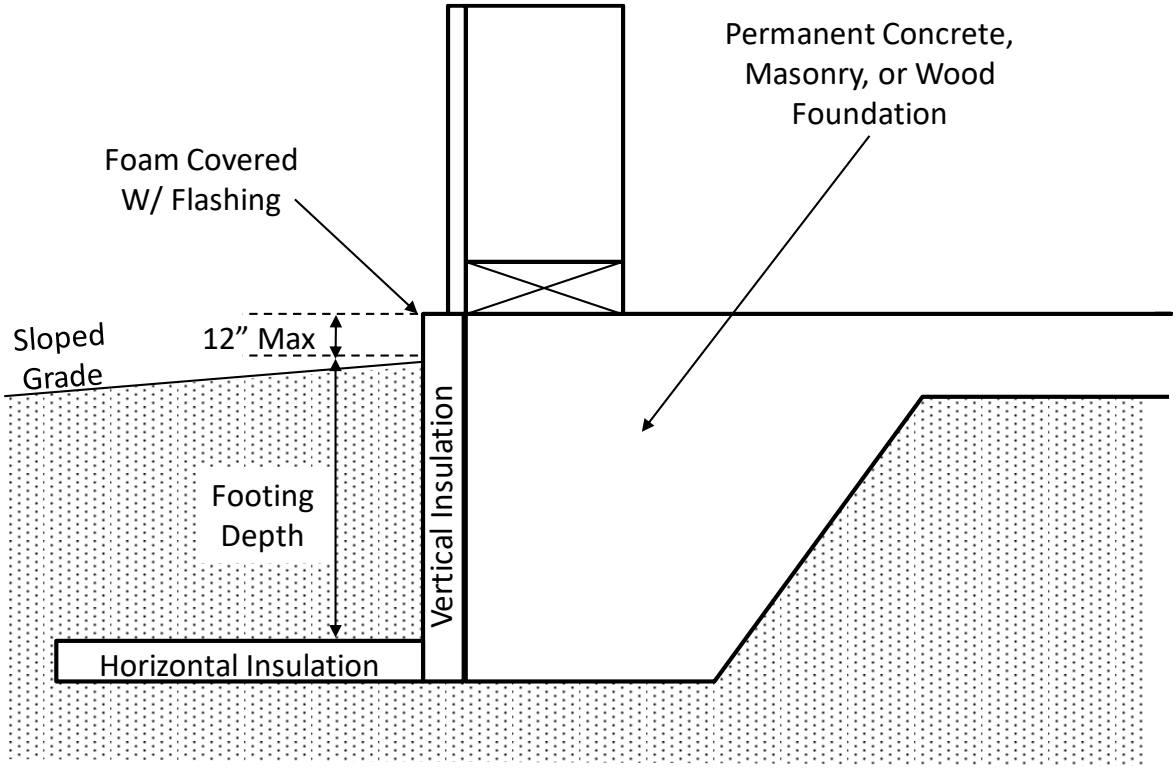
This map indicates the air freezing index for the state of Alaska. The air freezing index ranges from less than 1000 air freezing days to 12,000 air freezing days throughout the state. The depth of the perimeter footing and the amount of insulation required is based on the air freezing index.

Minimum Insulation Requirements for FPSF in Heated Buildings							
Air Freezing Index	**Vertical Insulation R-Value**	**Horizontal Insulation R-Value**		**Horizontal Insulation Dimensions**			**Minimum Footing Depth**
		Along Walls	At Corners	A	B	C	
1500	4.5	NR	NR	NR	NR	NR	12
2000	5.6	NR	NR	NR	NR	NR	14
2500	6.7	1.7	4.9	12	24	40	16
3000	7.8	6.5	8.6	12	24	40	16
3500	9.0	8.0	11.2	24	30	60	16
4000	10.1	10.5	13.1	24	36	60	16
4500	12.0	12.0	15.0	36	48	60	16

A chart in the building code dictates the minimum insulation requirements for frost protected footings in heated buildings. When the air freezing index for an area is established, this table sets out guidelines for vertical insulation value and horizontal insulation values, both along the walls and at corners of the building.



This graphic indicates the dimensions required for the perimeter insulation, based on the previous chart. More insulation is needed in the corners where greater heat loss occurs.



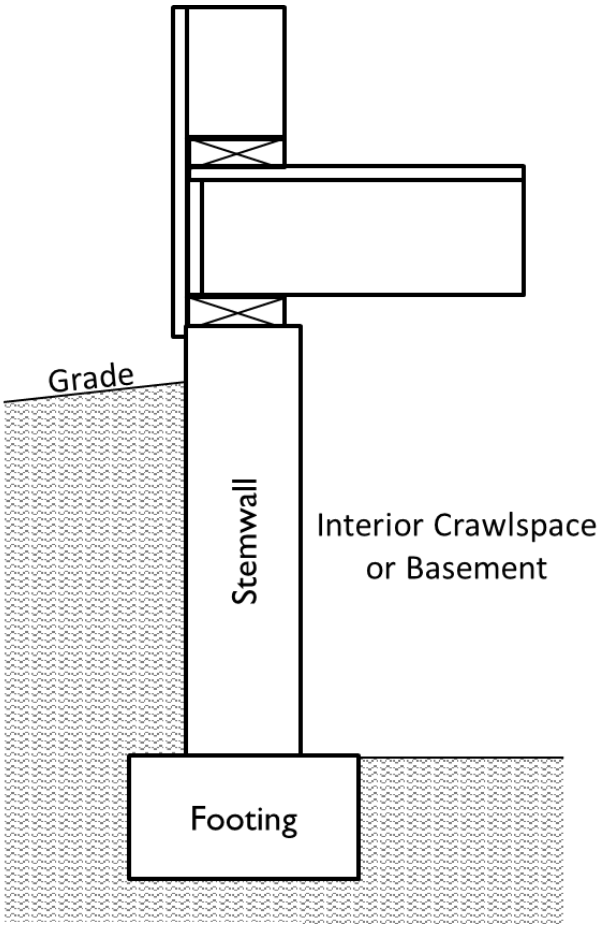
The frost protected shallow foundation principal is most commonly used for poured slab on grade foundations, but is also acceptable for concrete, masonry, or permanent wood foundations. No more than 12" of the perimeter of the foundation can be exposed above grade, and no less than 4 to 6 inches to meet siding to soils requirements listed elsewhere in the code. A granular, free draining base under the footing is required for bearing stability.

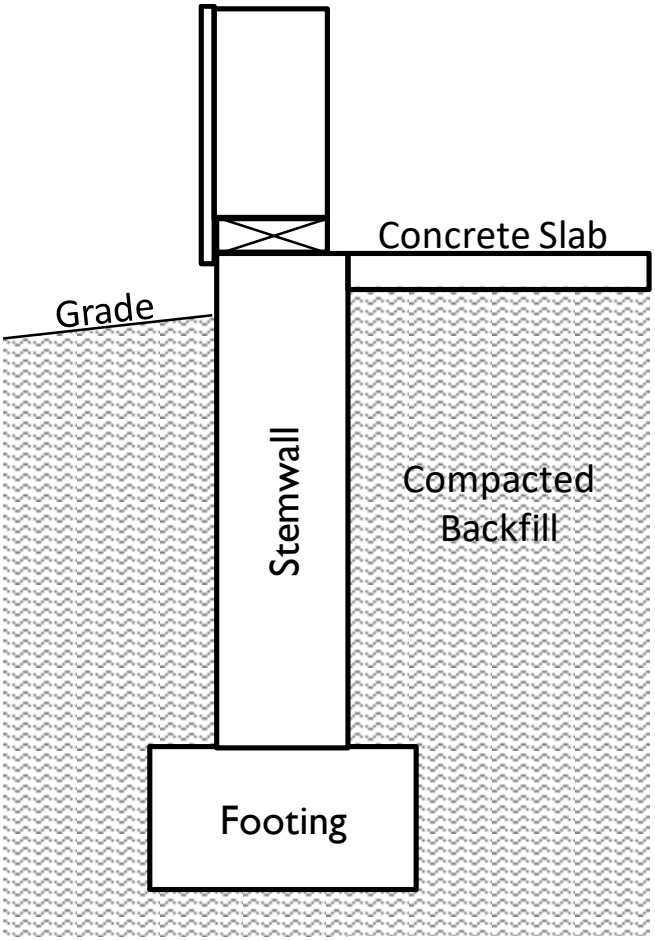
Foundation Types - Basement/ Crawlspace

Basement and crawlspace foundations utilize a stemwall that is partially or fully below grade to enclose space below grade level. The bottom of the stemwall footing is located below the local frost depth.

The stemwall foundation may be backfilled on the inside up to grade level and a slab poured inside the perimeter, but more commonly the enclosed below grade space is used for utilities or additional living space. Poured concrete, masonry, or decay resistant wood are typical stemwall materials.

The graphics on the right illustrate the common types of stemwall foundations. At the top, below grade space is enclosed which can be used as a basement or a crawlspace. On the bottom, the interior of the stemwall is backfilled up to grade level and a slab poured over the top. This method has an advantage over the monolithic frost protected slab foundation, as the footing is below frost line and no additional insulation is required around the perimeter.





Foundation Types - Piling

Piling foundations can be constructed of many different materials. Poured concrete and decay resistant wood piles are not uncommon. Other materials include driven metal well casing, and helical piles which are twisted into the ground like a screw.

Concrete & Wood Piles

Concrete piles are usually poured into tubular concrete forms made of cardboard or thin plastic. The form is only to hold the concrete in place until it is cured and has no structural value.

Wood pilings must be pressure preservatively treated or decay resistant to prevent rot that would occur from contact with the ground. Wood pilings are often augmented with a concrete footing at the base to increase the bearing surface area of the pile.

Similar to the stemwall foundation, the bottom of the wood or concrete pile must be below the local frost line to prevent the soil under the bearing surface of the pile from freezing. Piling are also subject to frost heave from soil friction on the sides of the pile. Frost can “grab” the side of the piling and cause it to raise or shift, even if the bearing soils under the piling remain thawed. This fact highlights the need for a well drained, non frost susceptible fill under and around the pile.

Pilings, by their nature, have limited bearing capacity. It takes numerous pilings to gain the equivalent bearing capacity of a strip footing.

Driven Piles

Driven piles consists of a heavy gauge metal tubing of various diameters being driven into the ground by heavy equipment. Well casing is a common material used for driven pilings.

Piles are typically driven until a minimum resistance is met, which can be measured by specialized pile driving equipment, or be based on the weight of the equipment used to drive the pile. Piping is added on by welding tubing sections together until the minimum resistance met.

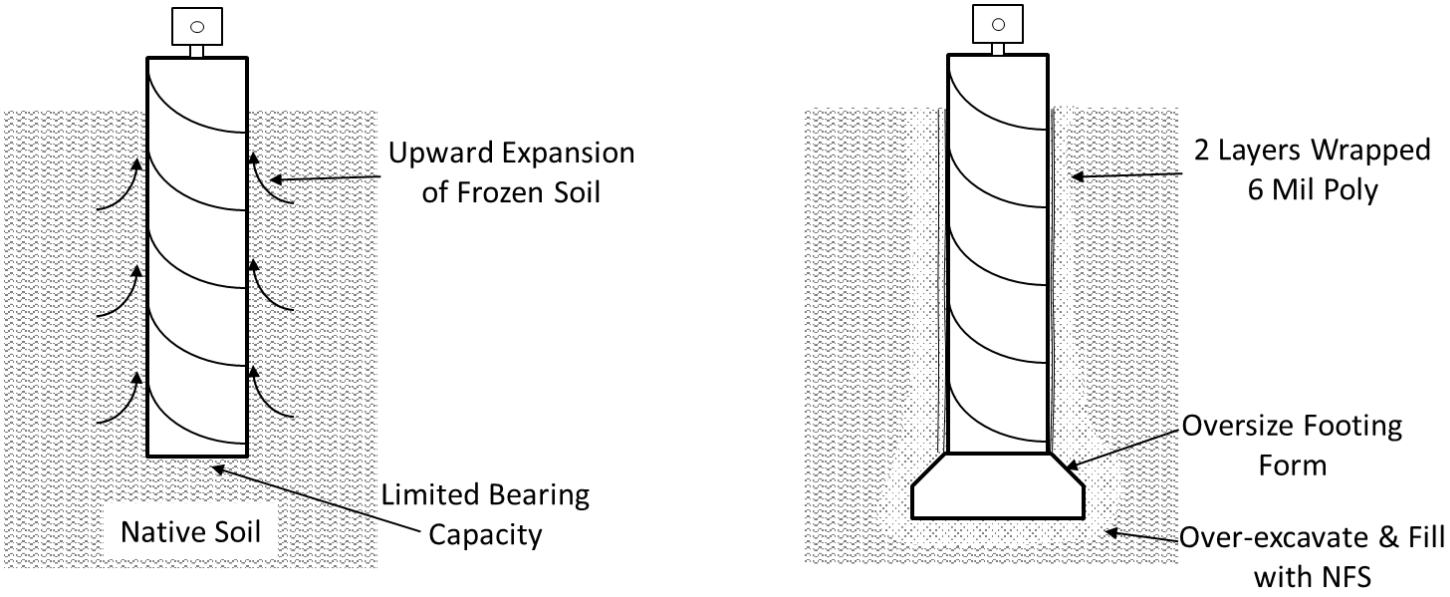
Piling foundations must be capable of withstanding the live and dead loads of the structure above, so careful consideration must be given to how much weight each pile must support. Adequate soil types that can withstand the concentrated weight that bears on a pile is critical to the success of this type of foundation.

Helical Piles

Helical piles differ from other types in that they are twisted into the ground hydraulically like a giant screw. The helical pile bearing is measured by the amount of torque applied by the equipment. Sections can be added onto the top during installation until a minimum torque figure is met.

Heaving

Placed piles, such as formed concrete or wood, have a not undeserved reputation for frost heave and shifting. However, most of this reputation can be blamed on poor installation practices. Over-excavating the piling hole, and then filling it with a non frost susceptible materials such as well drained sand and gravel is good practice for preventing frost heave. Pilings have a limited bearing surface area, so “bigfoots” or enlarged footings can increase the bearing area of pilings significantly. Formed concrete and wood pilings in particular can benefit from being wrapped in at least two layers of 6 mil polyethylene sheeting before being back filled. The polyethylene sheeting allows the soils to slide over the surface of the piling rather than grip the piling and cause displacement.



This illustration shows the difference between good and bad piling installation practices to mitigate frost heaves. The piling on the left is placed in native soils which may not drain properly, and there is limited bearing capacity on the bottom face of the pile. On the right, the piling is wrapped in polyethylene sheeting, an oversized footing has been used, and the soils under and around the pile have been replaced with non frost susceptible material. These steps will greatly reduce the chance of frost heaving or displacement of the piling.



Wood pilings installed in the ground are subject to decay due to moisture in the ground. Wood pilings must be pressure preservatively treated or decay resistant materials for longevity.



The pilings for this structure have been placed in permafrost, where there is a freeze/thaw layer at the surface. These wood pilings have been wrapped in polyethylene sheeting to mitigate movement during freeze/thaw cycles.

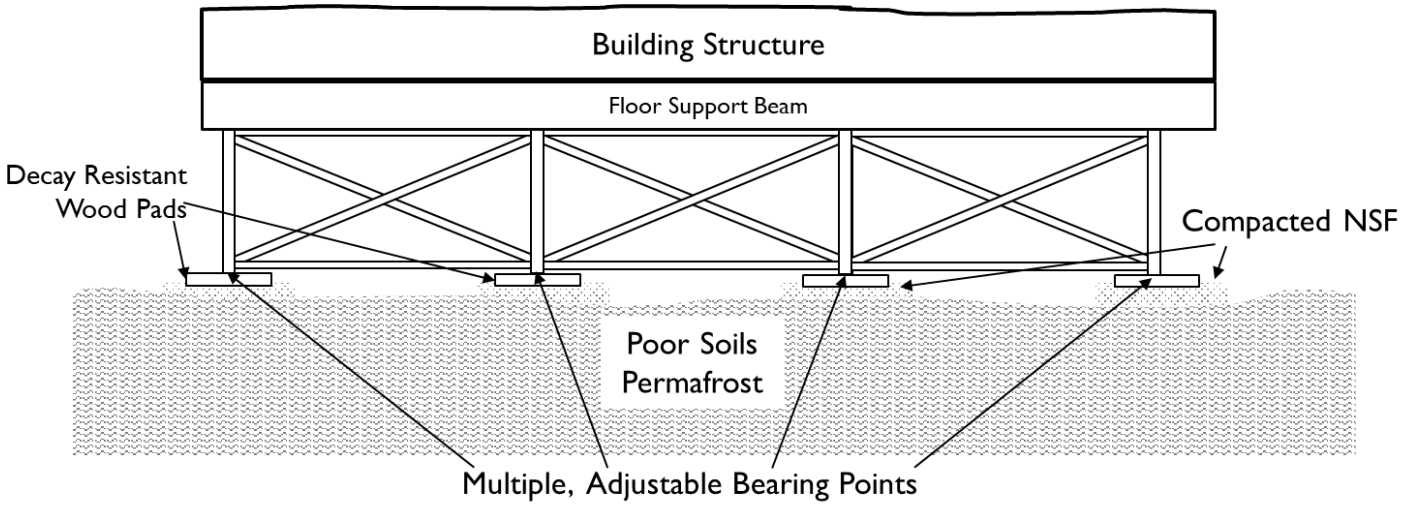
Multi-Point Foundations

Multipoint foundations are an on-grade foundation that has multiple bearing points spread out over the entire footprint of the building. They are a modular tubing system that is light weight and transportable by plane, which can be advantageous for off road system building sites.

Multipoint foundations are adjustable to ground movement. Each bearing point can be adjusted as needed to match changing soil conditions. Multipoint foundations are particularly suited for areas of permafrost or poor soils which change seasonally.



This photo shows a multi-point foundation used to support a four plex building constructed in Western Alaska well off the road system. The multipoint foundation was placed on wood pads at all bearing points and adjusted to level. This type of foundation is well suited for areas where materials transport is difficult and heavy equipment is not available.



The multipoint foundation system bearing points rest on decay resistant wood pads that are constructed on site. Building sites do not have to be perfectly level or stable for this type of foundation to be successful.

Foundation Materials

There are three common foundation material types; concrete, wood, and metal. Each type has advantages and disadvantages and applications where it is the best choice.

Foundation Materials - Concrete

Concrete is the foundation material of choice where available. It is strong, relatively easy to work with, and readily obtainable on the road system. However, concrete does have some shortcomings when used in cold weather construction. Concrete curing in cold weather takes special additives and techniques, and the concrete must be protected from freezing until it reaches a minimum strength. If concrete freezes before a minimum strength is achieved, it is ruined and must be replaced.

All concrete must be protected from freezing until it has reached a minimum strength of 500 pounds per square inch (psi), which typically happens within the first 24 hours. If concrete freezes while it is still fresh or before it has developed sufficient strength to resist the expansive forces associated with the freezing water, ice formation results in the disruption of the cement paste matrix causing an irreparable loss in strength.

Early freezing can result in a reduction of up to 50 percent in the ultimate strength. Once concrete has attained a compressive strength of around 500 psi, it is generally considered to have sufficient strength to resist significant expansion and damage if frozen. Whenever air temperature at the time of concrete placement is below 40 degrees Fahrenheit and freezing temperatures within the first 24 hours after placement are expected, caution is advised.

Steps can be taken to mitigate the risks associated with placing concrete in freezing weather. The water and aggregates can be heated prior to placement which reduces the freezing potential. Concrete curing is an exothermic reaction, some heat is released during the curing process which aids in preventing freezing. Windbreaks and enclosures can be used to protect freshly placed concrete. Moving air cools the surface much faster than still air. Supplementary heat during the initial cure may be needed in very cold conditions. Avoid a sudden cooling of curing concrete, as cracking may occur.



Insulating blankets can help retain the heat of the concrete as it cures, which allows it to build strength. Insulated concrete forms with foam insulation on each side of the concrete can be very effective at retaining heat needed for curing.

Foundation Materials - Wood

Wood can be used as a foundation material if it is decay resistant or pressure preservatively treated for ground contact. Wood must be decay resistant or treated anywhere it is in contact with the ground, anywhere it is used as a sill plate within 6 inches of the ground, or anywhere less than 1 inch above the ground.

Wood in contact with concrete must be decay resistant or treated unless separated by an approved moisture barrier. Concrete is subject to capillary action and will wick moisture into the wood which will cause water damage over time.

Pressure preservatively treated wood comes in multiple ratings of treatment. Wood in contact with the ground must be the higher grade of treatment and is typically an incised product.

Fasteners and brackets used with pressure preservatively wood must be corrosion resistant. Stainless steel or double hot dip galvanizing may be required depending on the application.

Foundation Materials - Metal

Metal used for foundations may either be galvanized, which is moisture resistant, or plain steel. The wall thickness of the metal generally dictates whether galvanizing is needed. Thinner wall material must usually be protected from corrosion by galvanizing. Check with the local inspector or authority having jurisdiction about requirements in a specific location.

Site Considerations

The type and characteristics of the soil on which the building sits has some of the greatest impacts on foundation type and materials choices. Factors that must be considered include the type of soil present on the building site, the bearing capacity of the soil, and the drainage characteristics and expansion potential which will affect the foundation type and materials choices.

The presence of permafrost eliminates many foundation options. If permafrost is encountered or suspected, caution must be taken in foundation selection. Frost depth dictates how far below grade the foundation must extend to prevent frost heave, which is a major structural concern.

Soil Types

Several aspects of soil types must be scrutinized for a successful foundation. First and foremost is the bearing capacity of the soil. Soils with poor bearing capacity do not lend themselves to foundations with small bearing areas such as pilings. Exceeding the bearing capacity of the soil will cause building settlement.

Drainage characteristic of the soil are critical to proper foundation performance. Poor draining soils can cause water intrusion into below grade areas and exert pressure on the foundation. The frost heave potential of the soil is based on how well or poorly it drains, and its volume expansion potential. Soils that retain water are more likely to cause frost heave and foundation displacement.

Soil expansiveness is a characteristic of how much the volume of the soil increases in the presence of water. Soils that are expansive can create a lot of pressure against foundations which may cause displacement.

Bearing Capacity

The bearing capacity of soils ranges from 1500 lbs. per square foot on the low end to 4000+ pounds per square foot on the high end. Bearing capacity is based on undisturbed soils.

The live and dead loads that will be imposed on the foundation by the structure above must be well-thought-out. Live loads include floor loads from occupancy and snow loads on the roof. Dead loads include the weight of structural materials, possessions, and furnishings. The bearing capacity of the soils affects the choice of foundation. The type of foundation must provide adequate load bearing surface area where in contact with the soils for stability of the structure.

Drainage Characteristics

Drainage characteristics are measurement of how well water drains or "perks" through soil. Water may come from rainfall, snow melt, or local runoff. Expect the soils surrounding the foundation to get wet.

When soils hold water and do not drain well, they experience a significant reduction in bearing capacity. As the soils expand due to saturation, pressure is exerted on the foundation which may result in cracking or displacement. Soils that hold water are more likely to cause frost heave, as the water expands in the soil when frozen.

Frost Heave Potential

Poorly drained soils containing clay or other fine materials have a much higher frost heave potential than gravels or sand that allow water to pass through. Water in the soils that should drain away is retained under and around the foundation, causing water intrusion and the potential for frost heave.

The pressure exerted by water as it expands to form ice is tremendous and has been known to crack solid concrete and move entire buildings.

Expansiveness

Poorly drained soils increase in volume as water accumulates. Clay materials absorb water easily and drain slowly. Saturation of the soils can result in a loss of bearing capacity which in turn causes displacement and settlement of the structure. Glacial silt, clay, and organic materials are all subject to expansiveness when wet.

Soil Load Bearing Values	
Class of Material	**Load Bearing Pressure (PSF)**
Bedrock	12000
Sedimentary & Foliated Rock	4000
Sandy Gravel, Gravel	3000
Sand, Silty Sand, Clayey Sand, Silty Gravel, Clayey Gravel	2000
Clay, Sandy Silty Clay, Clayey Silt	1500

The load bearing values of common soil types are listed in this chart. Soils such as clay and silt have very low bearing capacity and require much greater bearing surface area. Sand and gravel with little or no fine materials or clay have a much higher bearing capacity and allow more choices for foundation construction. Rock and bedrock have the highest bearing capacity of any soil type.

Properties of Soils According To The Unified Soil Classification System					
Soil Group	**USC Symbol**	**Description**	**Drainage Charcteristics**	**Frost Heave Potential**	**Volume Change Expansion Potential**
Group 1	GW	Well graded gravels, grave sand mixtures, little or no fines	Good	Low	Low
	GP	Poorly graded gravels or gravel sand misxtures, little or no fines	Good	Low	Low
	SW	Well graded sands, gravelly sands, little or no fines	Good	Low	Low
	SP	Poorly graded sands or gravelly sands, little or no fines	Good	Low	Low
	GM	Silty gravels, gravel sand silt mixtures	Good	Medium	Low
	SM	Silty sand, sand silt mixtures	Good	Medium	Low
Group 2	GC	Clayey gravels, gravel sand clay mixtures	Medium	Medium	Low
	SC	Clayey sands, sandy clay mixture	Medium	Medium	Low
	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Medium	High	Low
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium	Medium	Medium to Low
Group 3	CH	Inorganic clays of high plasticity, fat clays	Poor	Medium	High
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	High	High
Group 4	OL	Organic silts and organic silty clays of low pasticity	Poor	Medium	Medium
	OH	Organic clays or medium to high pasticity, organic silts	Unsatisfactory	Medium	High
	Pt	Peat and other highly organic soils	Unsatisfactory	Medium	High

The unified soil classification system provides groupings of soil types by characteristics including drainage, frost heave potential, and volume change potential for expansion. This chart is useful for determining soil characteristics based on a description of the soils.

Poor Soil Strategies

Areas of poor soils will demand a different approach for satisfactory results. The type of foundation must be considered, as bearing capacity for poor soils is reduced. Additional excavation of poor soils and replacement with better material may be necessary.

Foundation drainage for any below grade areas enclosed by the foundation is required for all soil groups other than Group 1 of the Unified Soil Classification System. Foundation water proofing is also required for any below grade areas enclosed by the foundation for all soil groups other than Group 1.

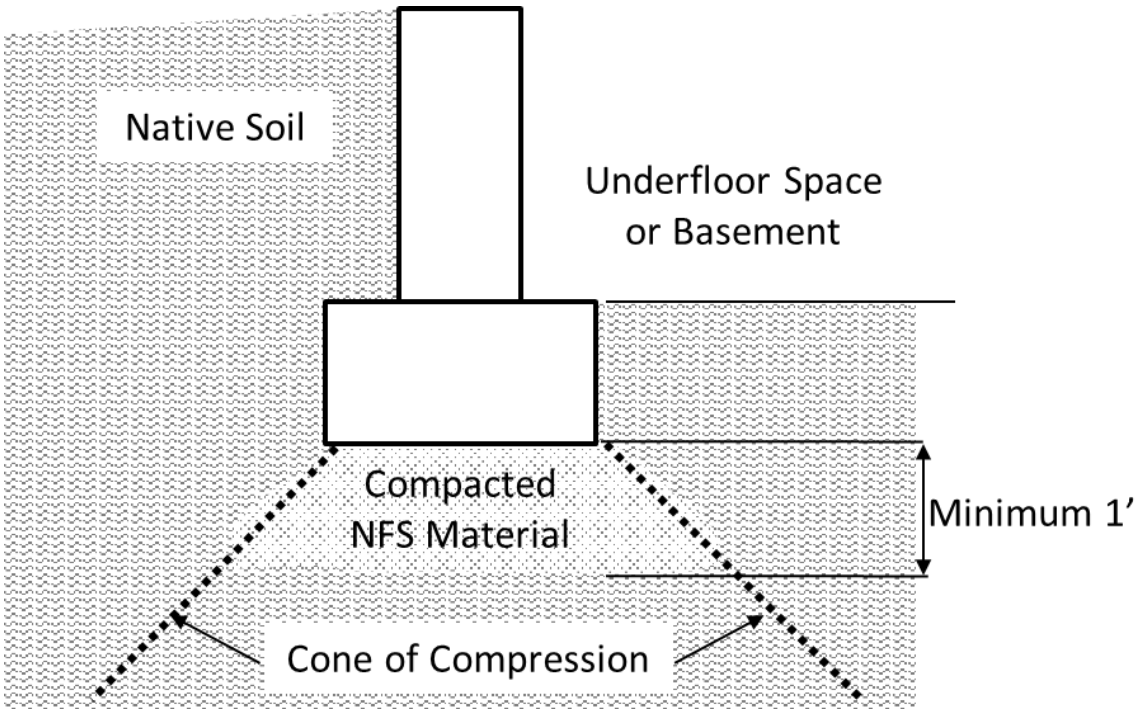
Grading away from the building and capturing roof drainage through gutters and downspouts and directing away from the building are essential in areas of poor soils.

Poor Soil Foundations

Less traditional foundation types may be more suited to poor soil conditions, particularly at off the road system building sites. Driven piling foundations can be driven and added onto until the required resistance is met, ensuring adequate bearing capacity is achieved.

Similarly, helical piles can be driven and added onto until the proper torque specification is met.

Multipoint foundations may be an appropriate choice for areas where excavation is not possible and adjustment to the foundation and building is expected to be necessary over time.



In some situations poor soils can be over excavated and replaced with non frost susceptible materials under the bearing footing. The cone of compression, which is the bearing area under the footing, extends outward at a 45-degree angle from the edges of the footing. Non frost susceptible materials can be used to increase the bearing capacity and bearing width of the footing by replacing poor soils in the cone of compression.

Poor Soil - Foundation Drainage

If usable space is present below grade level that is enclosed by the foundation, a foundation drain system is required for other than Group 1 soils. Usable spaces would include basements and crawlspaces.

The foundation drainage system should be installed at or below the area to be protected, which is the interior floor level. In this way the water level is maintained below the floor level of the below grade space. Foundation drainage must be discharged to an approved area or system.

Foundation Waterproofing

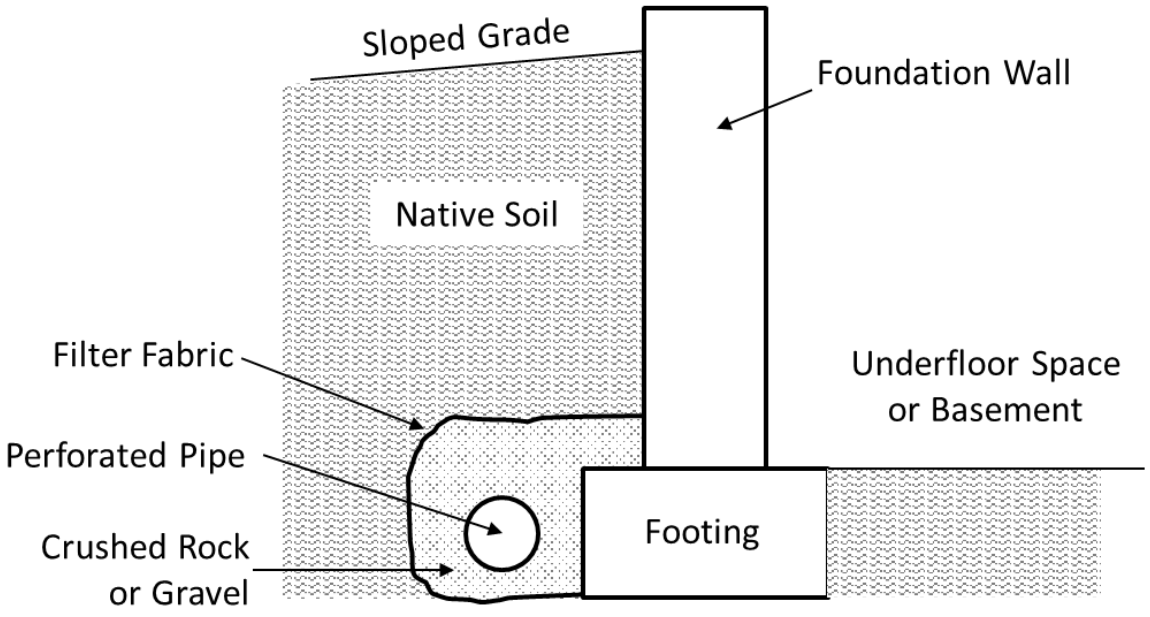
Damp-proofing of foundation is the practice of making them water resistant by coating them with a water-resistant material. All foundations that enclose space below grade must be damp-proofed, even in Group 1 soils.

Foundations must be damp-proofed or waterproofed from the top of the footing to the finished grade level. Best practice is to cover the joint where the foundation is placed on top of or attached to the top of the footing, which is a typical leakage area.

Grading & Drainage

Keeping roof discharge and snow melt away from the foundation is as important as waterproofing and drainage for preventing water intrusion into below grade areas. Soils around the perimeter of the home should slope away at least 6 inches over 10 feet. If 10 feet of slope is not possible, water should be directed to a ditch or swale where it can drain away.

Roof gutter discharge must also be directed away from the foundation. The minimum recommendation is at least 5 feet away from the side of the house.



A drainage system around a conventional footing and stemwall protects the underfloor space by collecting any drainage or runoff water adjacent to the foundation and diverting it elsewhere. The drainage system is composed of a perforated pipe that is covered in clean gravel and wrapped with a filter fabric. The filter fabric prevents silt and debris from clogging the pipe, and the gravel base increases catchment area. Foundation drains are effective for surface water collection but do little to prevent water table or ground water issues from below the foundation.

Permafrost

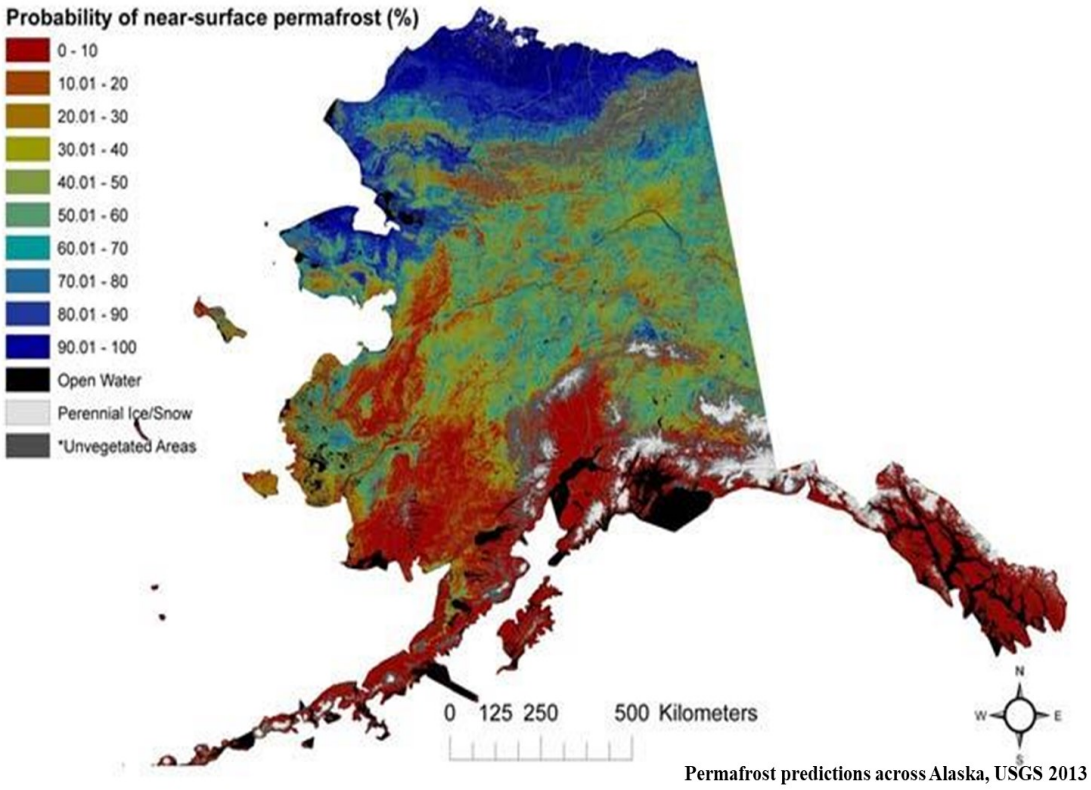
There are three basic strategies for dealing with permafrost. If possible, avoidance is the best and simplest strategy. If permafrost cannot be avoided, but the area of permafrost is limited in size and depth, thawing the frozen area may be an option. Where permafrost is continuous, and there is no possibility of avoidance or thawing, then the permafrost must be kept frozen.

Avoiding areas of permafrost altogether is preferable when selecting a building site. Moving the building site to an area where there is no permafrost present circumvents the issues that arise if the ground thaws. Ensure there is no permafrost present below the footing level that may thaw from building heat loss. Avoidance may not be possible in arctic and northern interior regions. Permafrost becomes more common moving northward.

Shallow lenses of permafrost can be exposed in the summer months and thawed. Heavy equipment can be used to rip up layers of permafrost in the spring, and warm summer temperatures will increase the rate of thaw. Construction on the site can then proceed if the thawed soils are stable enough and of good enough quality, or they can be removed and replaced with non frost susceptible materials.

Frozen permafrost is stable and has good load carrying capabilities. If the building is separated from the ground and outdoor air can flow freely between the floor system and grade, the permafrost will likely stay frozen. For residential applications, foundation systems such as elevated pilings and multipoint foundations can be used to maintain separation between the heated building and the ground. For large scale construction, refrigerated pilings may be feasible.

Care must be taken not to allow heat loss from the building to cause the permafrost to thaw. As temperatures warm, the ability to keep permafrost frozen is increasingly difficult. Heat loss through the floor of the building may accelerate ground thawing.



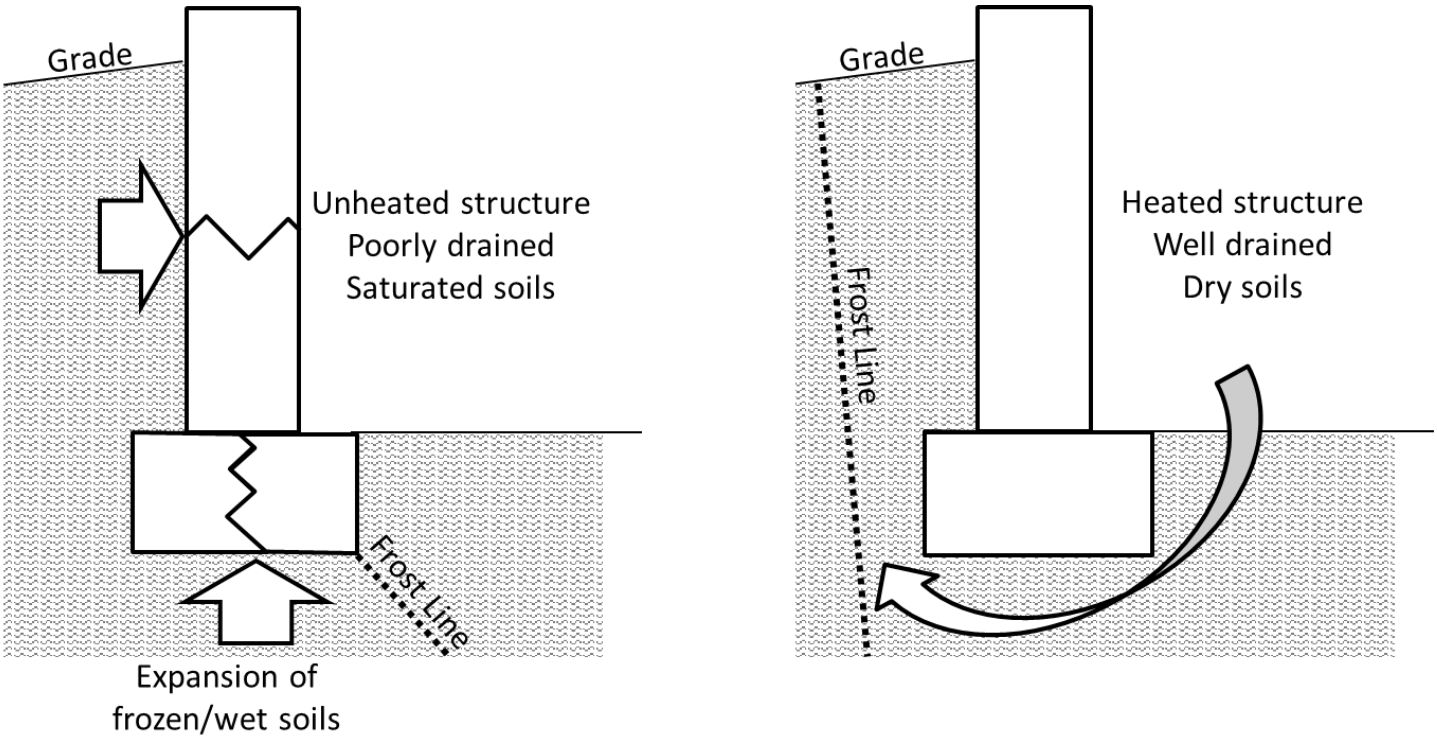
The probability of permafrost is nearly zero in southcentral, southeast, and the Aleutian chain areas of the state. Discontinuous permafrost may be encountered in the interior and southwest Alaska. Permafrost is nearly universal north of the Brooks Range.

Frost Depth

Frost depth is the depth below grade level at which frost is not expected to form under a building. For this reason, the bearing surface of the building footing should be located below this level to minimize the potential of frost heaving of the structure.

Frost depth is typically 42 inches below grade level, although this number may vary based on the location of the building site. Use local knowledge or check with the local building official for specific requirements.

The type of soil, the drainage around the structure, and the heat loss from the foundation are important factors for frost heave potential. Well drained soils and drainage away from the building are nearly as important as the depth below grade level in preventing frost heave. Unheated structures will also have more potential to frost heave than heated structures, which keep the surrounding soils warm.



Unheated structures with poorly drained soils such as clay or silt may be more susceptible to frost heave. Poorly drained soils will hold water, which expands with great force when frozen. Unheated structures do not have heat loss through the foundation which can help maintain the surrounding ground temperature above freezing. Heated structures drive frost out away from the building.

Foundation Insulation

When selecting materials for insulating a foundation, there are many important criteria that must be considered. The insulating material must be rated for the application. Specifically, insulation materials used on the exterior of the foundation must be rated for exposure and/or below grade use. Foam board products of adequate density can be an acceptable choice for exterior use. Lower density foams and fiberglass products are rated for interior use only.

Moisture resistance is a key consideration. Insulating material used on the exterior of the foundation must be rated for moisture resistance. Insulating materials on the interior of the foundation in areas of high-water table or where moisture is anticipated should also be rated for moisture resistance. Again, foam board products of adequate density can offer the required moisture resistance.

Insulation products used on the exterior of the building that are exposed above grade level may also be subject to damage from UV decay. Sunlight will break down foam board products, which must be covered with metal flashing or other materials that will block sunlight and not be subject to decay.

Insulation products used on the inside of the building must be rated as acceptable for interior exposure. Many foam insulation products are considered a fire hazard when exposed to the interior basements or crawlspaces, and special provisions are required for thermal barriers to protect against ignition. Check with the local building department or building official for requirements for covering interior foam, which vary by municipality.

Many foam board insulation products will also qualify as a Class 1 or 2 vapor retarder and can be used in place of 6 mil polyethylene if joints and seams are sealed.

Product	Moisture Resistance	Vapor Retarder	Fire Hazard	UV Decay	Below Grade Exterior Use
Fiberglass Batts	Low	No	No	No	No
EPS Foam Board	High	Only if skinned	Yes	Yes	Minimum 25 psi
XPS Foam Board	High	Yes	Yes	Yes	Minimum 40 psi
Polyisocyanurate Board	Medium	Only if skinned	Yes	Yes	No
Spray Polyurethane	Medium	Depends on thickness	Yes	Yes	No

The chart provides basic guidance on the characteristics of common foundation insulation materials. Moisture resistance, vapor retarder qualification, fire hazard, UV decay resistance, and acceptability for below grade use are given for several foam board types and fiberglass batts.

Interior Foundation Insulation

Foundation insulation may be installed either on the interior or the exterior of the foundation wall. Each method has advantages and drawbacks, and the proper strategy depends on many different considerations. Insulating the foundation on the interior offers a greater choice in the type of insulation used, since both indoor and outdoor rated products are acceptable. However, some foam board products will require covering or other special provisions if exposed on the interior of the building.

Insulating the interior of a foundation wall will expose the foundation to exterior temperatures which will cause the wall to become cold during the winter months. The effect of the cold wall can potentially cause condensation to occur between the interior face of the foundation wall and the insulation, as the interior face of the foundation wall may cool off enough to reach dew point. Insulating only the interior of a foundation wall requires that humidity levels in the below grade space be kept in check with proper ventilation and covering all exposed earth with a sealed vapor retarder.

Exterior Foundation Insulation

Exterior insulation can eliminate the potential condensation issues presented by interior insulation. However, insulating the exterior of the foundation requires the use of insulating materials that are rated for below grade use. Exterior rated insulation that can be used below grade is almost always more expensive than insulation materials that are not exterior rated.

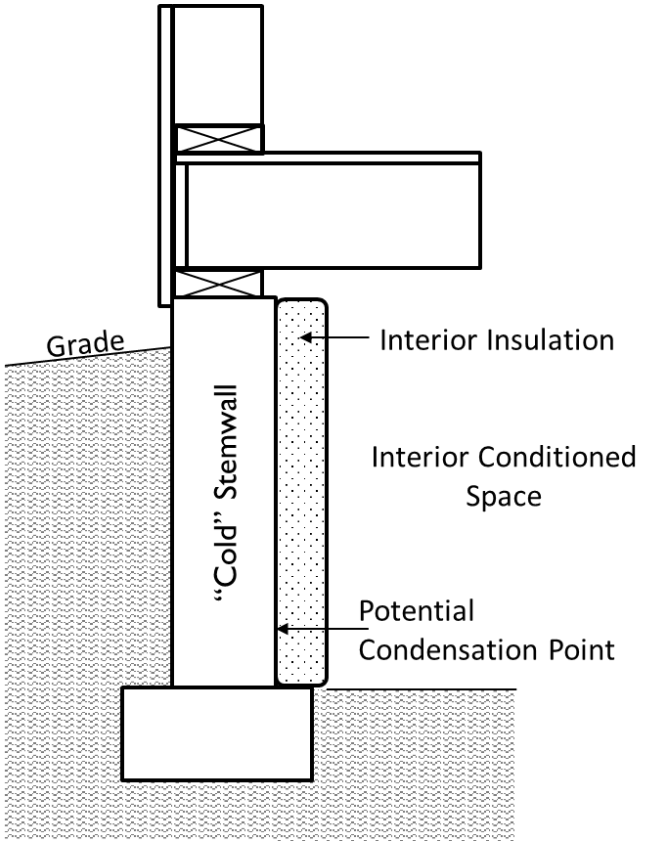
Foam board products, which are most commonly used to insulate the exterior of a foundation, must be covered above grade level to prevent physical damage and UV decay. Exterior insulation keeps the foundation wall inside the thermal envelope, which means the wall stays relatively warm in winter months.

The protentional for the formation of condensation on the interior of the foundation wall is greatly reduced compared to foundation walls that are insulated on the exterior only.

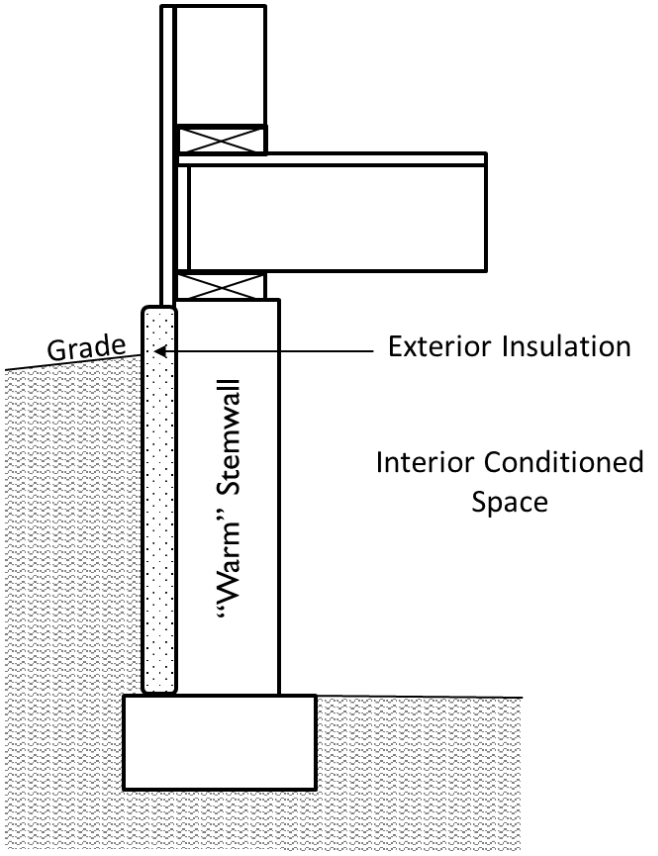
Insulating Both Sides of the Foundation

Insulating both side of a below grade stemwall can utilize advantages of both interior and exterior insulation methods. Less exterior insulation can be used to achieve a comparable R-values by making up the remainder with less expensive interior insulation. At the same time the condensation potential is reduced from a stemwall strictly insulated on the interior. However, insulating both sides does require additional labor.

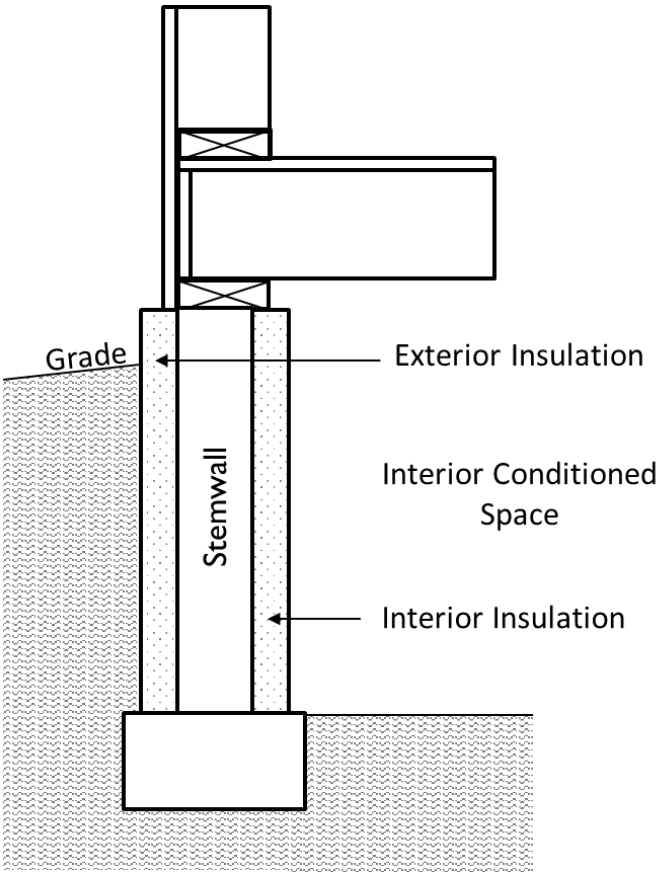
The principle of insulating both sides of the foundation is utilized in insulated concrete forms, which have a layer of foam on the interior and exterior of the wall built in. Insulated concrete forms are an integrated stay-in-place form system with at least two inches of expanded polystyrene foam on each side which holds the rebar and concrete in place to cure. No additional time or labor is required to add insulation, the stemwall is kept warm, and condensation potential on the interior is minimal.



Insulating the foundation wall only on the interior side subjects the foundation wall to outside temperatures. There is a potential for condensation to occur between the interior insulation and interior face of the stemwall.



Exterior insulation offers the advantage of the warm stemwall, but typically comes at an additional cost for below grade rated insulating materials.



The stay in place insulated concrete form system offers the advantages of both interior and exterior insulation arrangements.

Foundation Air Sealing

Foundation walls have essentially no air leakage below grade level, and thus air sealing of the foundation wall itself is not usually necessary. However, where the wall or floor framing attaches to the foundation requires special attention to prevent air leakage.

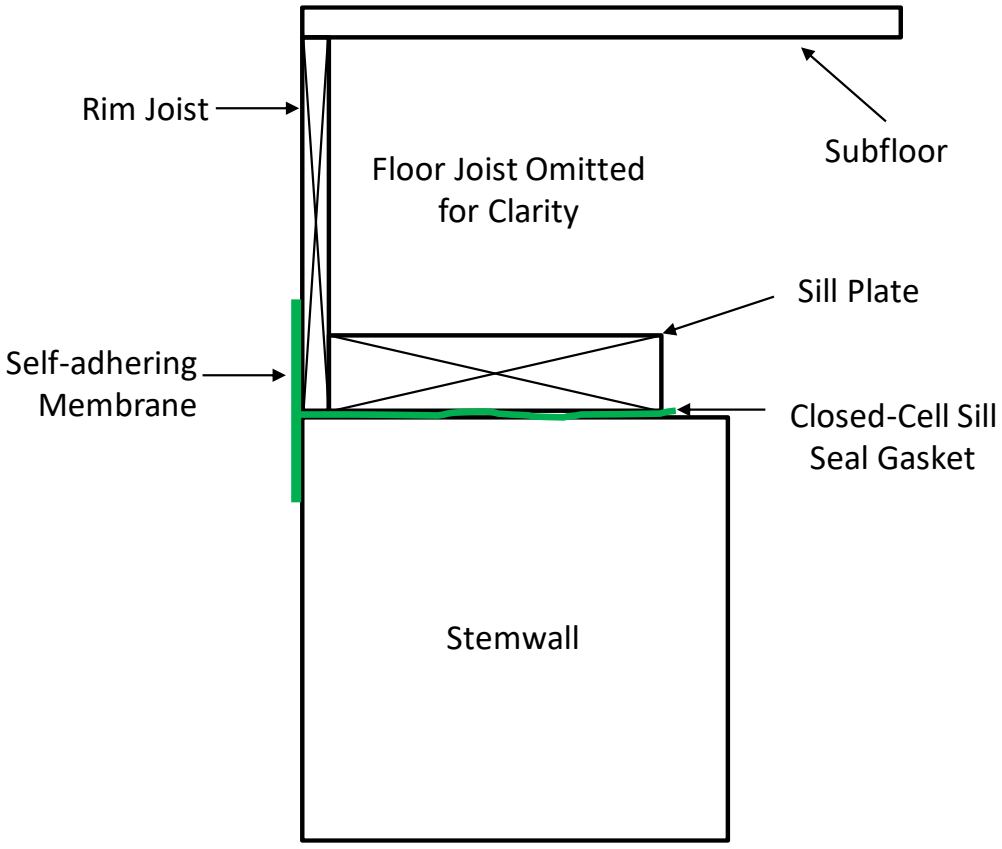
The sill plate and rim joist are areas that require special methods and materials to minimize heat loss and air leakage.

Foundation Sill Plates

The foundation sill plate is the first wood member that rests on top of a typical foundation stemwall. It is bolted in place and the rim joist or wall studs are placed on top. At first glance there may not seem to be much opportunity for air leakage around the sill plate, but in fact the long, thin gap between the sill plate and the top of the foundation can be a significant source of leakage. Warped sill plate materials and un-evenness in the top of the stemwall contribute to this leakage. Gaskets are excellent materials to use to stop air leakage at the sill plate.

Closed cell sill seal is a preferred material, as it is provides a capillary break and is waterproof. The thickness of the material provides some give for movement of or inconsistency in the framing materials.

Another popular method is to use a self-adhering membrane to cover this gap on the exterior side of the foundation wall, similar to what is commonly used as window flashing.



The gap between the sill plate and the top of the stemwall is a common site for air leakage. Closed cell sill seal laid under the sill plate, or self-adhering membrane over the connection between the siding or rim joist and the stemwall are effective methods for stopping air leakage.

Foundation Vapor Retarders

Vapor retarders are not required on the interior side of foundation walls below grade level. This is a departure from the requirement for above grade walls and rim joists areas, which always require a vapor retarder on the warm in winter side of the assembly. Foundation walls that are below grade do not have the ability to dry to the exterior, and there is essentially no air leakage through a below grade wall because they are covered by earth on the outside.

Vapor retarders are required to cover all exposed earth at or below grade level. The vapor retarder must consist of a Class 1 or class 2 materials, with a perm rating less than 1.0 perms.

All edges must be overlapped by at least six inches and sealed. The requirement for overlapped seams makes it difficult to use some foam board products, even though they may be rated as a Class 1 or 2 vapor retarder. Edges of the vapor retarder mush also be attached to the perimeter stemwall and to any interior footings, at least six inches up the wall or footing.

Underfloor Ventilation

Underfloor areas that are conditioned spaces (heated or utilities present) must be ventilated mechanically. Underfloor spaces are those spaces that do not have a finished floor such as concrete or wood or are otherwise not considered habitable space.

Passive vents to the exterior are not permitted. There are three options available for providing mechanical ventilation to an underfloor area.

Continuous exhaust can be provided at the rate of one cubic foot per minute per 50 square feet of floorspace, with an air pathway to a common area.

Conditioned air can be supplied at a rate of one cubic foot per 50 square feet, with an air pathway to a common area. However, this method is essentialy the same as a supply only ventilation system and should not be used on cold climates.

The third option is to provide dehumidification that is sized for 70 points of moisture removal per 1000 square feet of underfloor space.



This photo shows an example of using 6 mil polyethylene to cover exposed earth in the crawlspace. No seams are present in the field. The edges are brought more than six inches up the surrounding foundation wall and are mechanically attached and sealed with acoustical sealant.

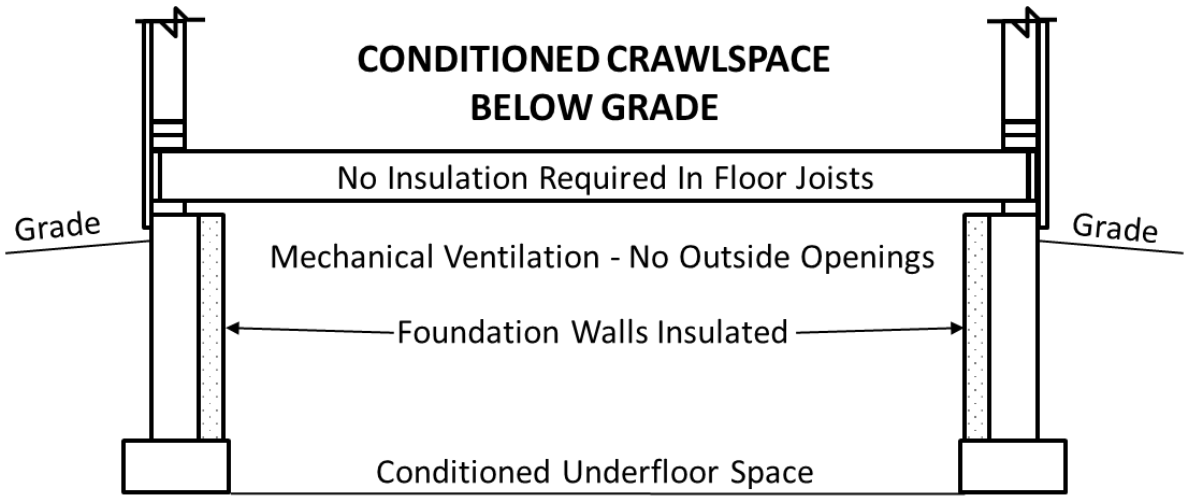
Floors

The key concepts for floor systems in cold climates are to define the location of the thermal boundary, define the location of the vapor retarder, and to identify air leakage points in the floor system.

Floor System Types

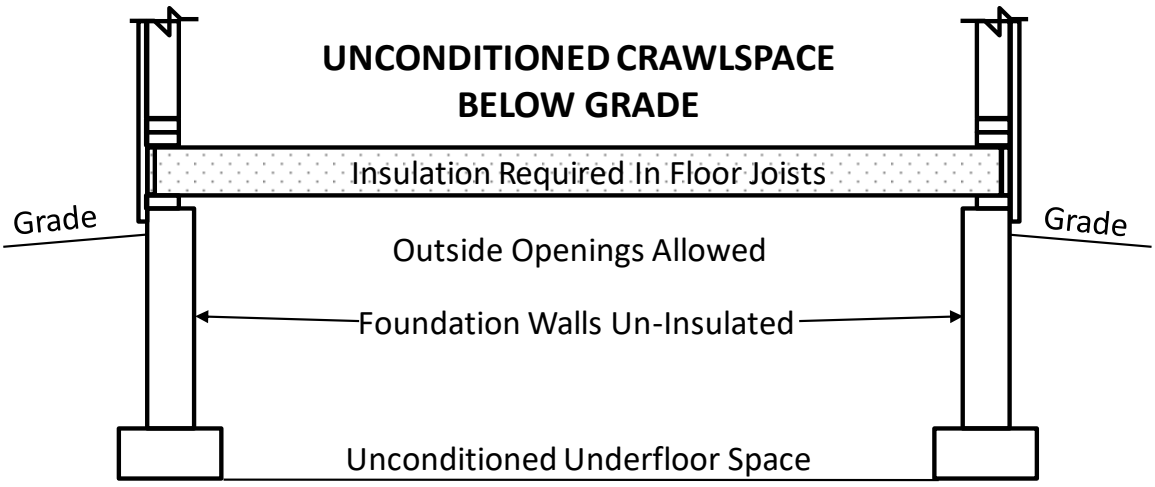
Floor systems fall into two categories that define how they should be approached; unconditioned underfloor space, and conditioned underfloor space. Unconditioned underfloor space is space that is not heated directly or indirectly and does not contain utilities such as plumbing supply, drain, waste, and vent piping. If the underfloor space is unconditioned, then the floor system is part of the thermal boundary and must be treated as such.

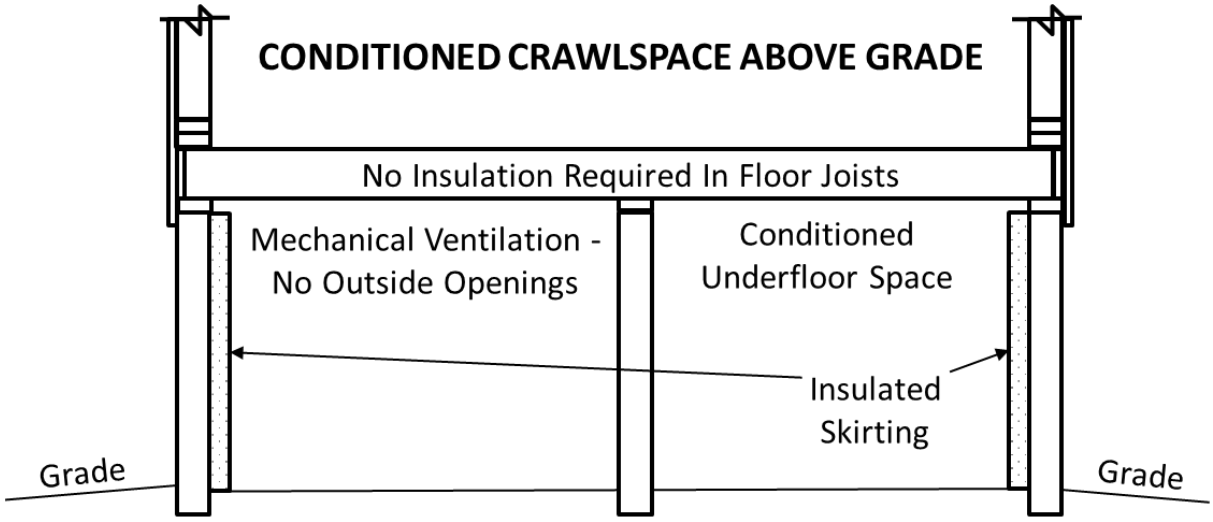
Conditioned underfloor spaces are underfloor spaces that are heated directly or indirectly and may contain pluming utilities. A conditioned underfloor space means that the floor system is within the thermal boundary.

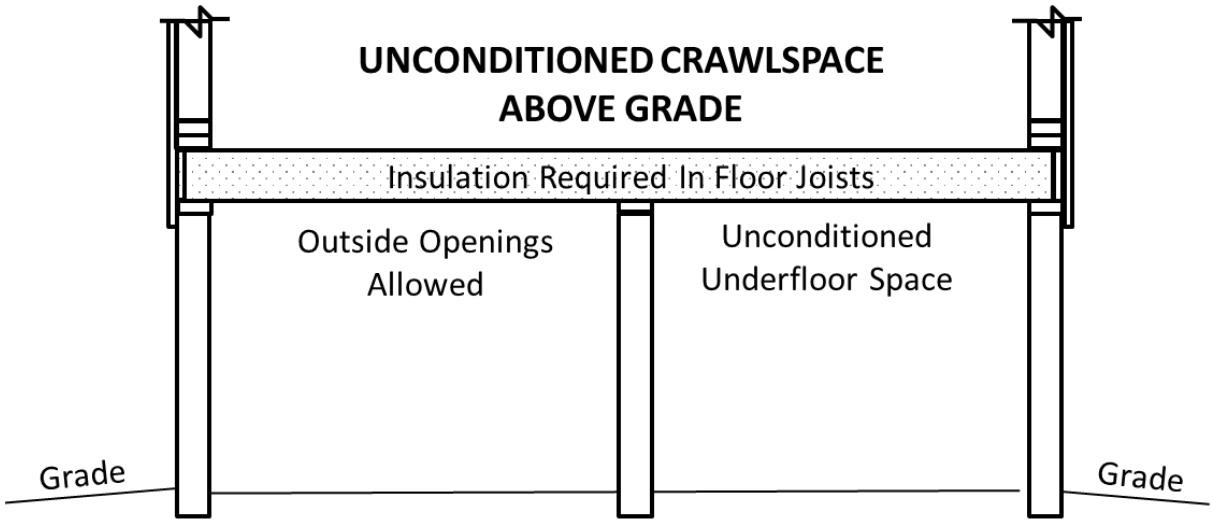


The conditioned crawlspace is an area that is heated either directly or indirectly and is intentionally kept above freezing. The thermal boundary for the conditioned underfloor area is the exterior foundation walls and the ground level. No insulation is required in the floor joist system, although some may be present. No vapor retarder is required in the floor joist system either. Instead, the insulation is placed on the exterior foundation walls and/or on the dirt floor. No vapor retarder is required on the exterior foundation walls if they are below grade level. It is prohibited to used passive ventilation openings for conditioned underfloor spaces, mechanical ventilation is required.

The unconditioned underfloor area is an underfloor space that is not heated and can go below freezing temperature. In this scenario, the floor joists are insulated and are considered part of the thermal boundary. The foundation walls are not insulated. Openings to the outside can be used for ventilation, since the underfloor space is not conditioned and no heated air can escape. A vapor retarder is required on the warm in winter side of the floor joist assembly, which is at the sub-floor level on top of the floor joists.


UNCONDITIONED CRAWLSPACE
BELOW GRADE
Insulation Required In Floor Joists
Grade
Grade
Outside Openings Allowed
Foundation Walls Un-Insulated
Unconditioned Underfloor Space

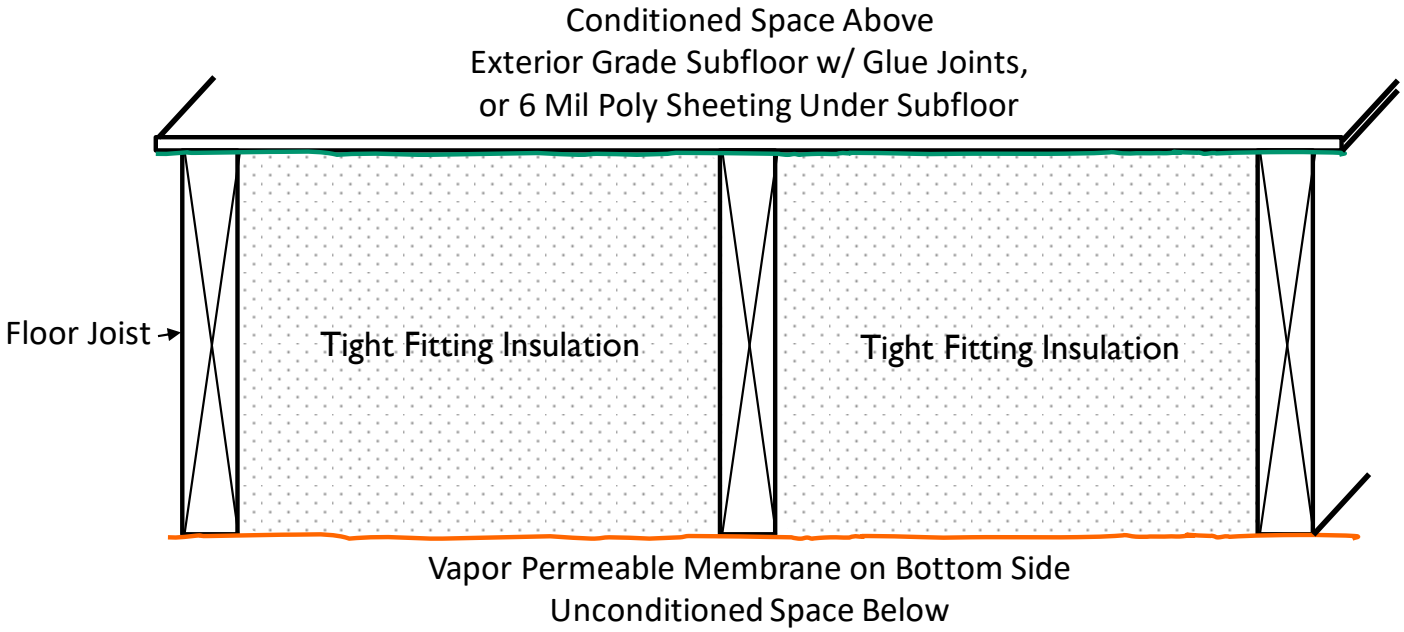

CONDITIONED CRAWLSPACE ABOVE GRADE
No Insulation Required In Floor Joists
Mechanical Ventilation -
No Outside Openings
Conditioned
Underfloor Space
Insulated
Skirting
Grade
Grade


UNCONDITIONED CRAWLSPACE
ABOVE GRADE
Insulation Required In Floor Joists
Outside Openings
Allowed
Unconditioned
Underfloor Space
Grade
Grade

Floor System Vapor Retarders

A floor system that is completely inside the thermal envelope and has a conditioned underfloor space below does not required a vapor retarder in the floor joist system.

A floor system that is part of the building thermal boundary and has unconditioned space below in the underfloor area must have a vapor retarder on the warm in winter side of that assembly.

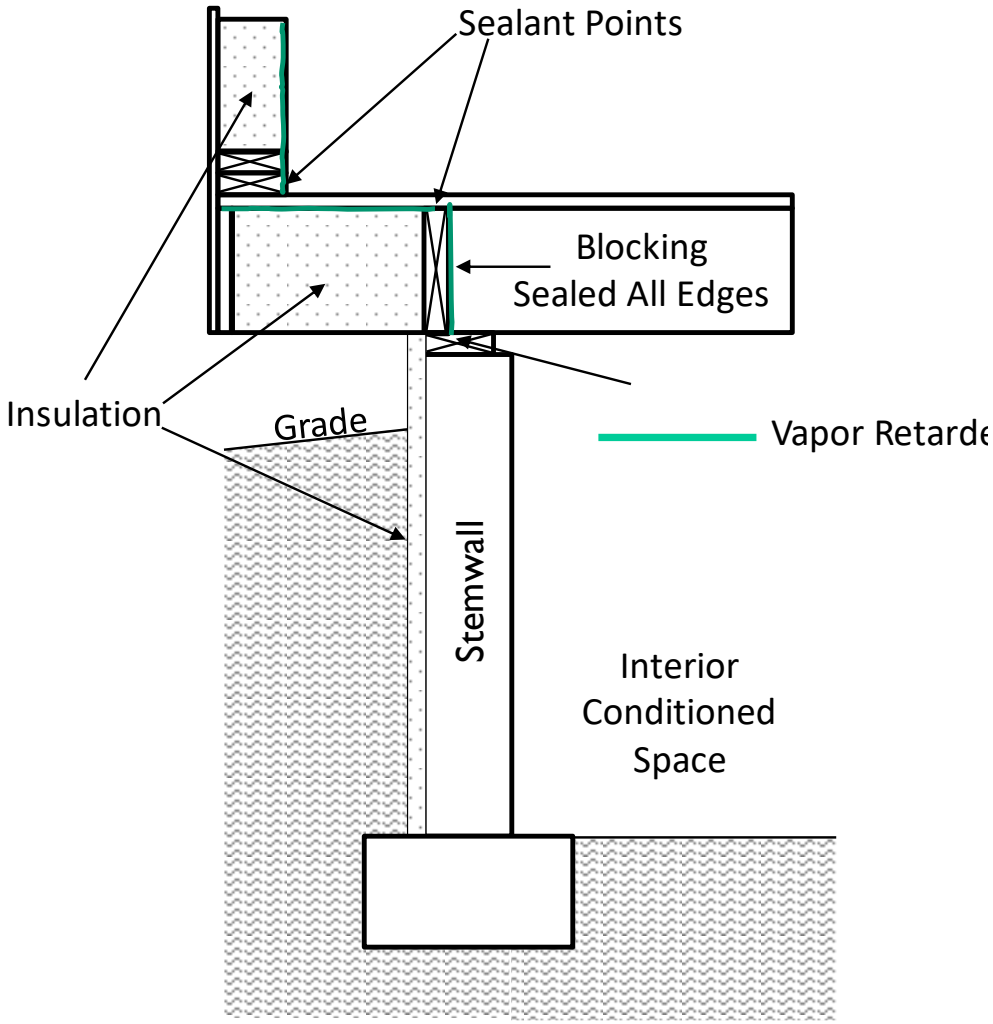


This cutaway view illustrates a floor joists system that is over an unconditioned space below. The vapor retarder must be located on the warm in winter side of the assembly, which is at the subfloor level. The subfloor itself can be used as the vapor retarder, if it is exterior grade with glued joints. If not, 6 mil polyethylene sheathing can be laid over the top of the floor joists. Tight fitting insulation is installed in the joist cavities to the full depth of the joists to eliminate air pockets and convective heat loss. On the bottom of the assembly, a vapor permeable membrane is attached to help hold the insulation in place and to prevent wind washing of the insulation. 6 mil polyethylene or other vapor impermeable materials should not be used on the bottom of this assembly and they can trap moisture in the floor joist system.

Cantilevers and Offsets

Cantilevers and floor offsets follow the same principals of keeping the vapor retarder on the warm in winter side of the assembly as the floor joist system. For cantilevers and offsets over the exterior foundation wall, the floor system is always insulated and part of the thermal boundary of the building.

To maintain continuity of the insulation and the vapor retarders, different materials are used in combination and sealed together to maintain integrity of the thermal boundary.



For a cantilever or offset floor, the thermal boundary must stay aligned from the wall system below up through the floor joists system. The cantilever or offset must be insulated over the unconditioned or outside area below. The vapor retarder starts at the top of the foundation wall at the sill plate and must be maintained up through the cantilever or offset as well. Blocking or foam board products that qualify as a Class 1 or 2 vapor retarder can be used to fill in floor joists at the bearing point over the foundation wall and provide a continuous vapor retarder from the sill plate to the subfloor. From there, the subfloor becomes the vapor retarder until the above grade wall bottom plate is intersected. The cantilevered joist portion from the bearing point to the exterior is treated just like any other floor system over an unconditioned space. The joist cavities are filled with insulation, and a vapor permeable covering is placed on the underside.

Floor System Air Leakage

If the floor system is part of the thermal envelope, special care must be taken to seal off any holes or penetrations through the floor system, particularly where the subfloor is penetrated. This includes any utilities such as plumbing piping or wiring.

Any penetrations through an exterior rim joist must also be sealed, whether the floor system is part of the thermal boundary of the home or not.

For piping and wiring that penetrates the floor system, the annular space around the penetration must be filled. For this application, solid materials or gaskets are the best choice. One or two part expanding foams do a good job of filling in around, above, and below penetrations. Liquid materials are less effective in this application than solid materials or gasket.

Caulking tends to dry out and shrink over time, resulting in gaps and openings. Acoustical sealant, which remains pliable for many years, will slowly drip out of vertical openings such as in a floor assembly.

Rim Joist

The rim joist, while part of the floor joist system, is treated as part of the above grade wall of a building. This is due to the fact that the rim joist is always exposed to the exterior, unlike floor joists which may be inside the thermal envelope. As such, the rim joist is required to have a vapor retarder installed on the warm in winter side of the assembly when there is conditioned space below. The rim joist must be insulated to the same level as the above grade wall, although different materials may be used to achieve a similar R-value.

Polyethylene vapor retarder can be difficult to use and to detail properly in the rim joist, which is often a cramped space with many seams an corners. Spray foam and rigid board foams can be a better choice in this application.

Spray urethane foam can be a good choice for insulating the rim joist area. It expands when applied to fill in gaps and cracks in the framing which common-







These photos show the use of expanding foam to seal penetrations through a floor system. Expanding foam is versatile in this application and can be used to seal many different types of penetrations.

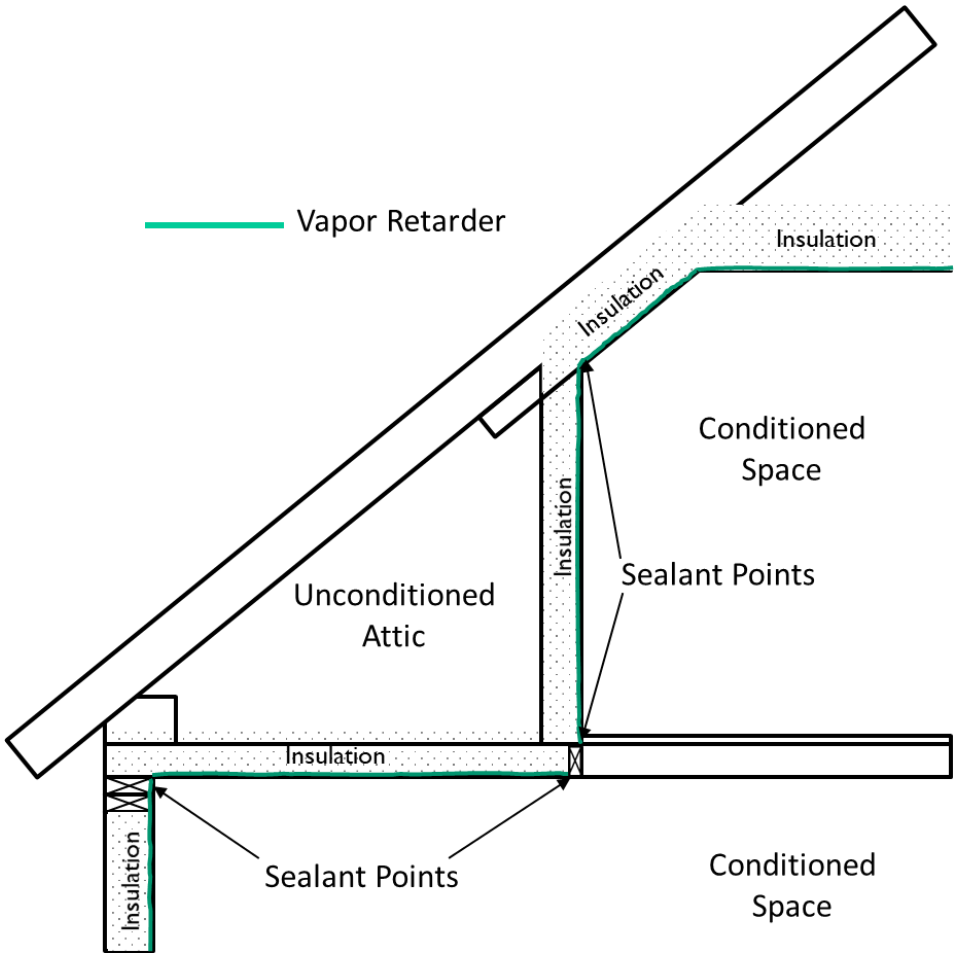
ly occur and provides high R-values per inch of product. Most spray foams require a minimum thickness to be considered a Class 1 or 2 vapor retarder, so always check the manufacturer's specifications.

Alternatively, foam board products can be cut to fit in the rim joist in one or more layers and then sealed around all edges to provide a continuous vapor retarder. Since rim joist openings are all typically the same size, properly sized foam cut outs can be quickly produced with a jig. The foam board used in this application must qualify as a Class 1 or 2 vapor retarder.

"Bonus" Room Rim Joist

Conditioned spaced suspended in a roof truss system, commonly known as "bonus" room, can present a special challenge to insulating and detailing the vapor retarder. Bonus rooms have a ceiling to rim joist to wall connection that is unique to the truss style construction of the room and to some gambrel roof shapes.

The intersection of the ceiling below the insulated wall above is treated very similar to a cantilever or offset floor. Foam board or blocking is used to keep insulation in place and to provide a continuous vapor retarder from the ceiling below to the wall of the bonus room above.



The "bonus" room and some gambrel construction will typically have conditioned space below, an unconditioned space to the side of the room which transitions to a cathedral ceiling at the top, and a typical cold attic overhead. The vapor retarder must be kept continuous at each transition, which means installing blocking of some type below the bonus room exterior wall to carry the vapor retarder to the bonus room wall above.

Above Grade Walls

The key concepts for above grade walls includes locating the vapor retarder in the proper position, especially for advanced wall systems, sealing air leakage points, and resisting water intrusion from the exterior.

Above grade walls have nearly limitless options for designs and strategy to achieve the desired R-value needed for a specific building and location.

There are several important principals to follow to optimize and get the best performance from an above grade wall system, regardless of the design employed. These principals include the use of advanced framing techniques which reduce wood usage and conductive heat loss, proper location of the vapor retarder in the wall assembly to prevent condensation issues, using the proper type of insulation for the intended application, and ensuring there is adequate R-value in the assembly for long term energy savings.

Advanced Framing Techniques

Advanced framing techniques are a set of principals that seek to reduce conductive heat loss through the above grade wall system, while at the same time reducing materials usage. Advanced framing techniques include:

- Insulated headers over doors, window, or other openings
- Eliminating headers where not necessary structurally
- Minimizing the use of jack studs or cripple studs to code minimums and aligning the window and door openings to the existing stud layout.
- Utilizing 2 stud corners to eliminate extra wood
- Stack framing, which reduces the need for double top plates by stacking load bearing member on top of one another
- Stand off interior partition walls which increase exterior wall insulation levels.

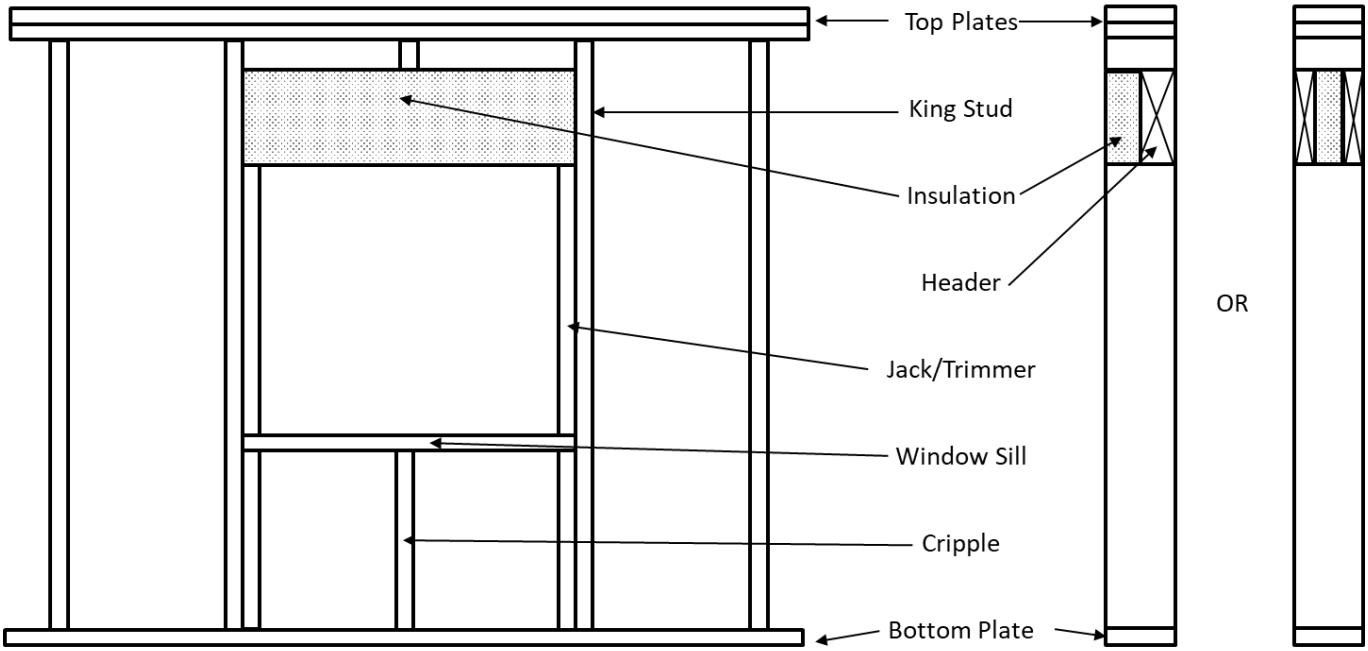
Insulated Headers

Headers are horizontal framing members that carry the load over window and door openings in exterior walls. Using a header that is the full thickness of the wall is usually not necessary to carry the required load and promotes conductive heat loss through the wall. For small and medium sized openings, or openings on non bearing gable end walls, a smaller header which allows filling the remaining width with insulation is much more energy efficient.

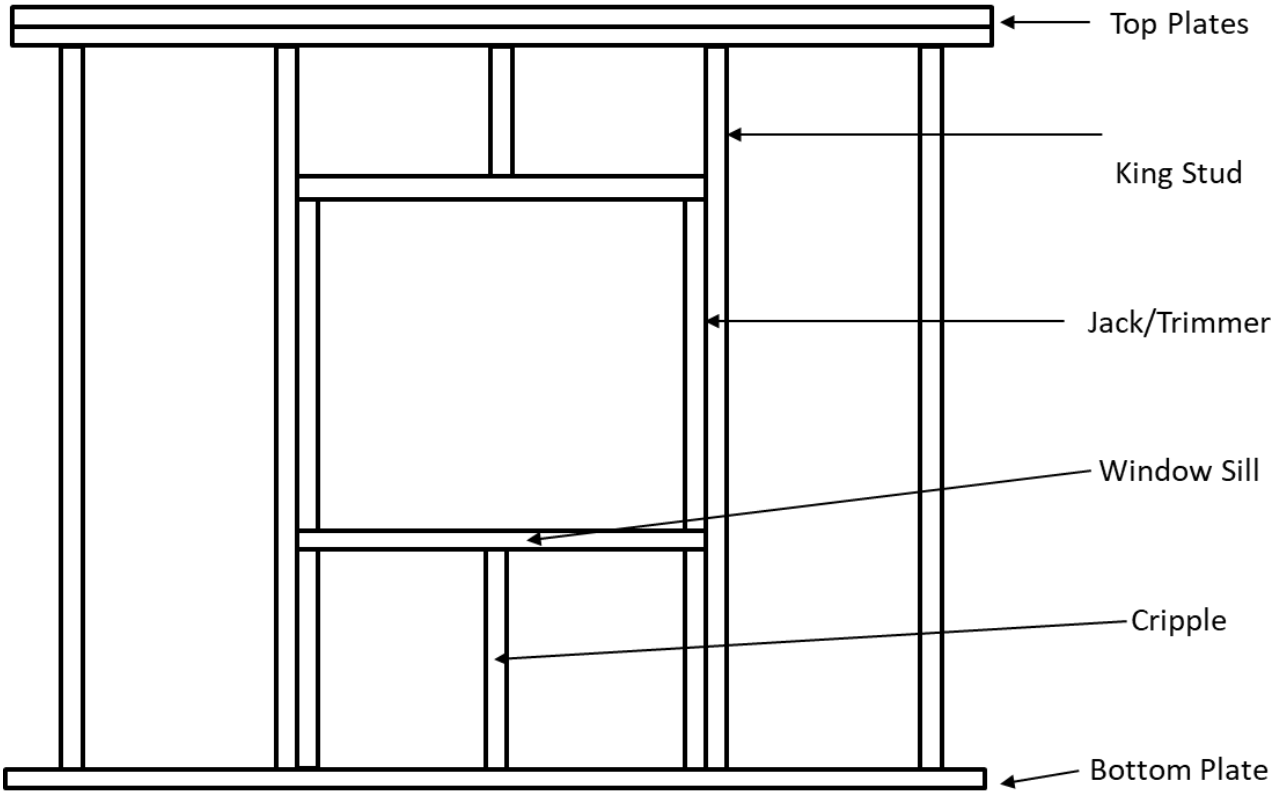
Header materials should be sized to the proper depth for the load they are intended to carry. The reduced size allows for more insulation to be installed in the wall, and at the same time reduces overall materials usage.

Eliminate Headers

Headers, which are designed to support loads from above, are not needed in non-bearing walls. The elimination of unnecessary headers increases insulation in the wall system and reduces materials usage.



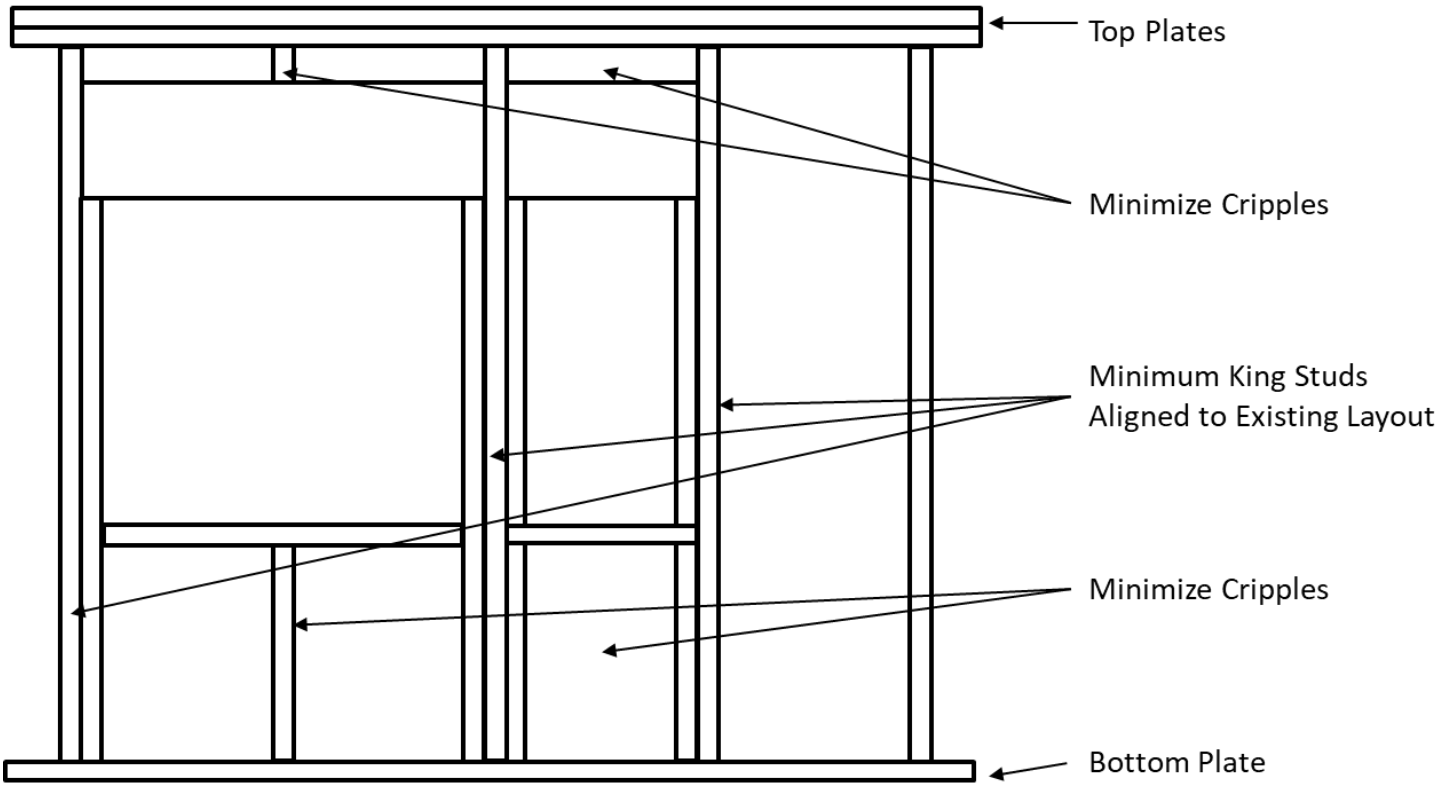
Typical header construction will use a member that is the full width of the wall system, which provides a path for direct conductive heat loss from interior to exterior. Advanced framing techniques call for a properly sized header of reduced width. The remaining width can be filled with insulation which provides a thermal break and decreases the heat loss of the wall system.



Headers are not needed in exterior non bearing walls such as under a gable end where the truss takes the roof load rather than the wall. The space normally used for the header can be filled with insulation instead.

Minimize and Align

During the planning stage, the layout of windows and doors can be arranged to align the openings with existing stud placement. This reduces the number of studs required in the wall, which reduces the amount of conductive heat loss. Using the code minimum number of king studs, jack studs, and cripple studs will also increase insulation and decrease conductive heat loss.

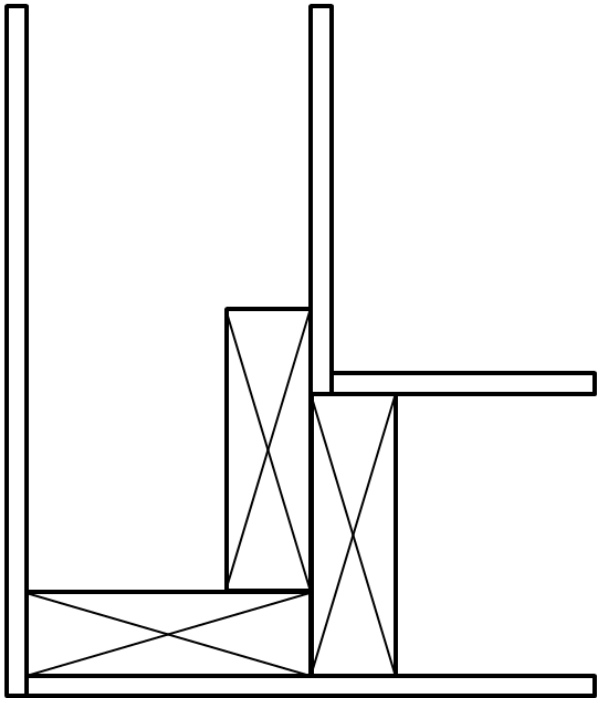


Advanced framing techniques use existing studs to form one or both sides of an opening, reducing the needs for additional studs.

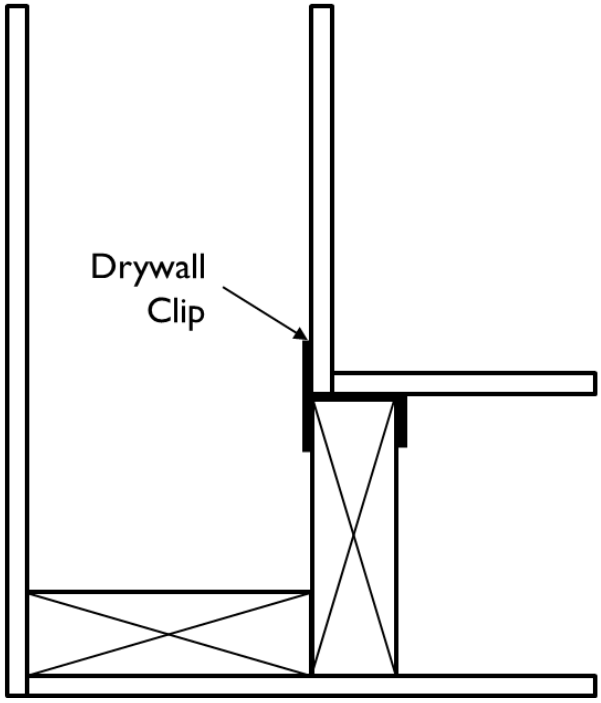
Two Stud Corners

The two-stud corner is a framing technique which reduces the typical practice of using three or four studs to create an exterior wall corner to two. The use of two studs allows for insulation to be installed full-depth in the corner, reducing conductive heat loss, and reducing materials usage. The two-stud corner does require the use of gypsum clips to support the edge of the drywall in the corners.

Traditional 3-Stud Corner



2-Stud Corner w/ Drywall Clip



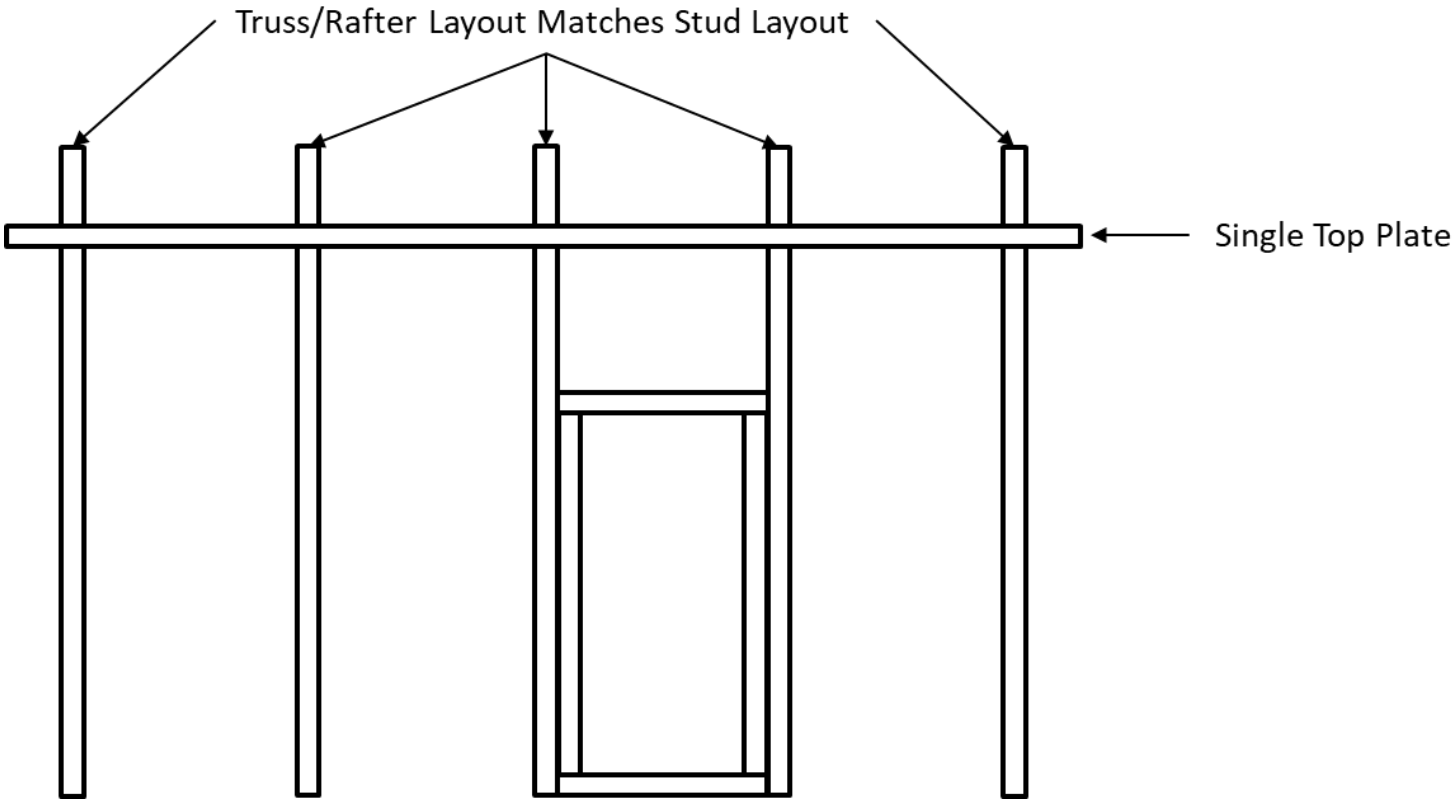
The two-stud corner uses one less stud and instead relies on a drywall clip to support the edge of the drywall rather than a third stud. Less framing materials are needed and more insulation is used, resulting in a more efficient wall system.

Stack Framing

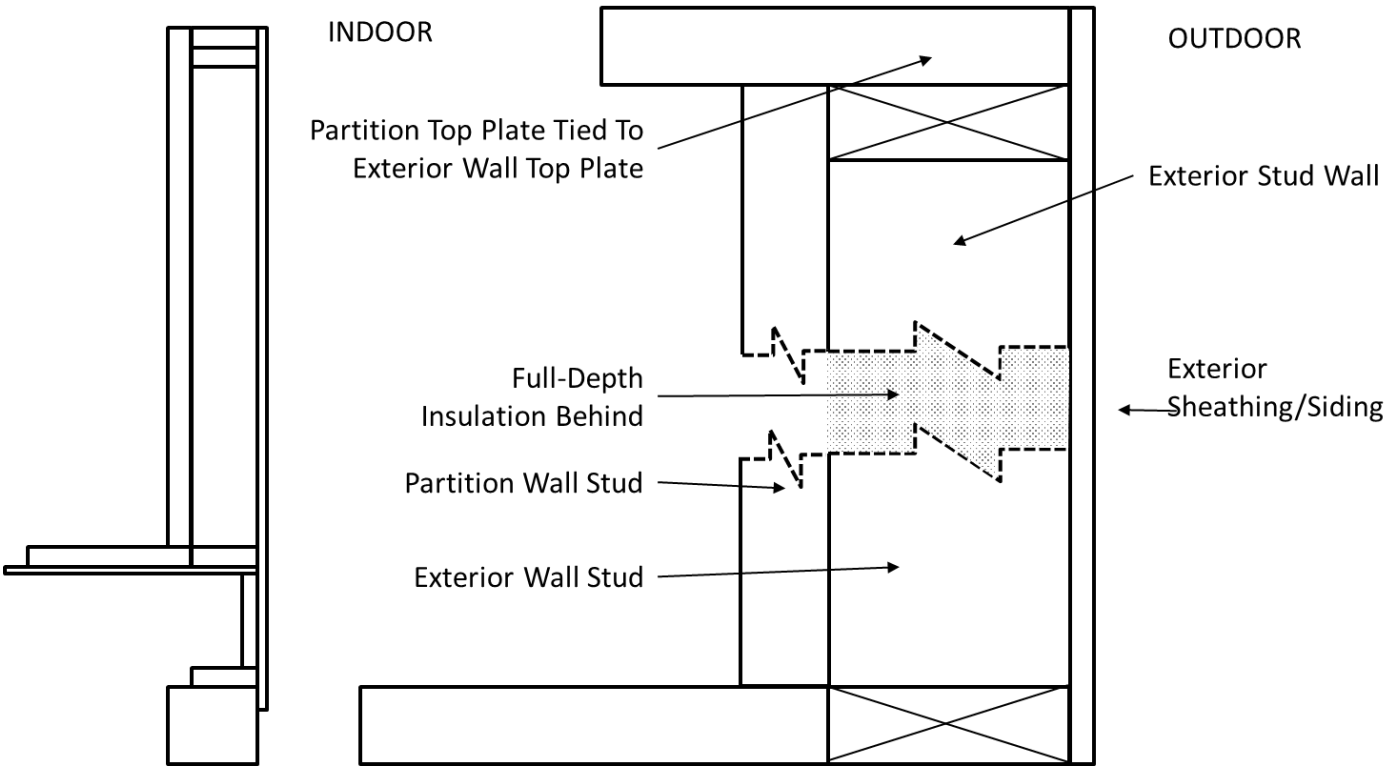
Stack framing is an advanced framing technique that aligns the trusses or rafters for the roof system with the studs in the wall below. By aligning the rafters/ trusses with the studs, the need for two top plates is reduced to a single top plate.

Stand-Off Interior Partitions

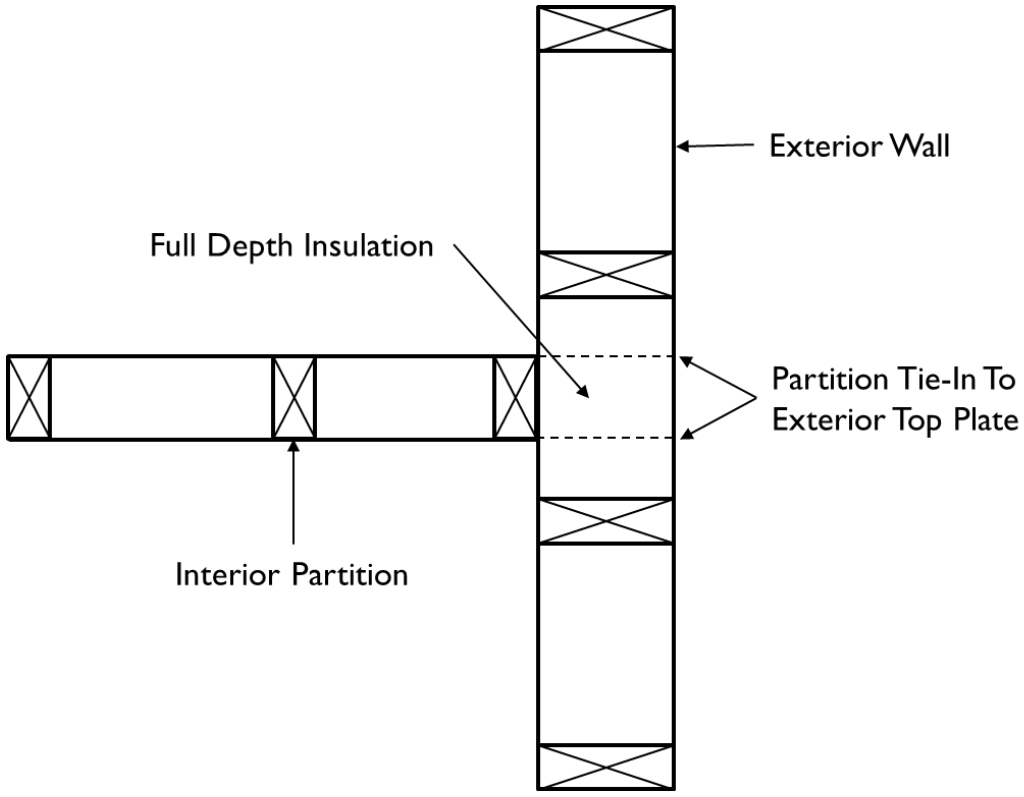
Stand off interior partitions are an advanced framing technique that allows the use of full depth insulation in the exterior wall behind an interior wall partition.



To utilize stack framing, the stud layout must match the truss or rafter spacing, and each stud must be directly under each truss or rafter.



The stand off partition places the interior partition wall stud on the inside face of the exterior wall, rather than inside the exterior wall. Full depth insulation behind the interior partition reduces heat loss.



To utilize the stand off partition, a tie in to the exterior top plate is needed. This can be accomplished on a double tap plate wall system by overlapping the upper interior wall top plate over the exterior wall bottom plate.

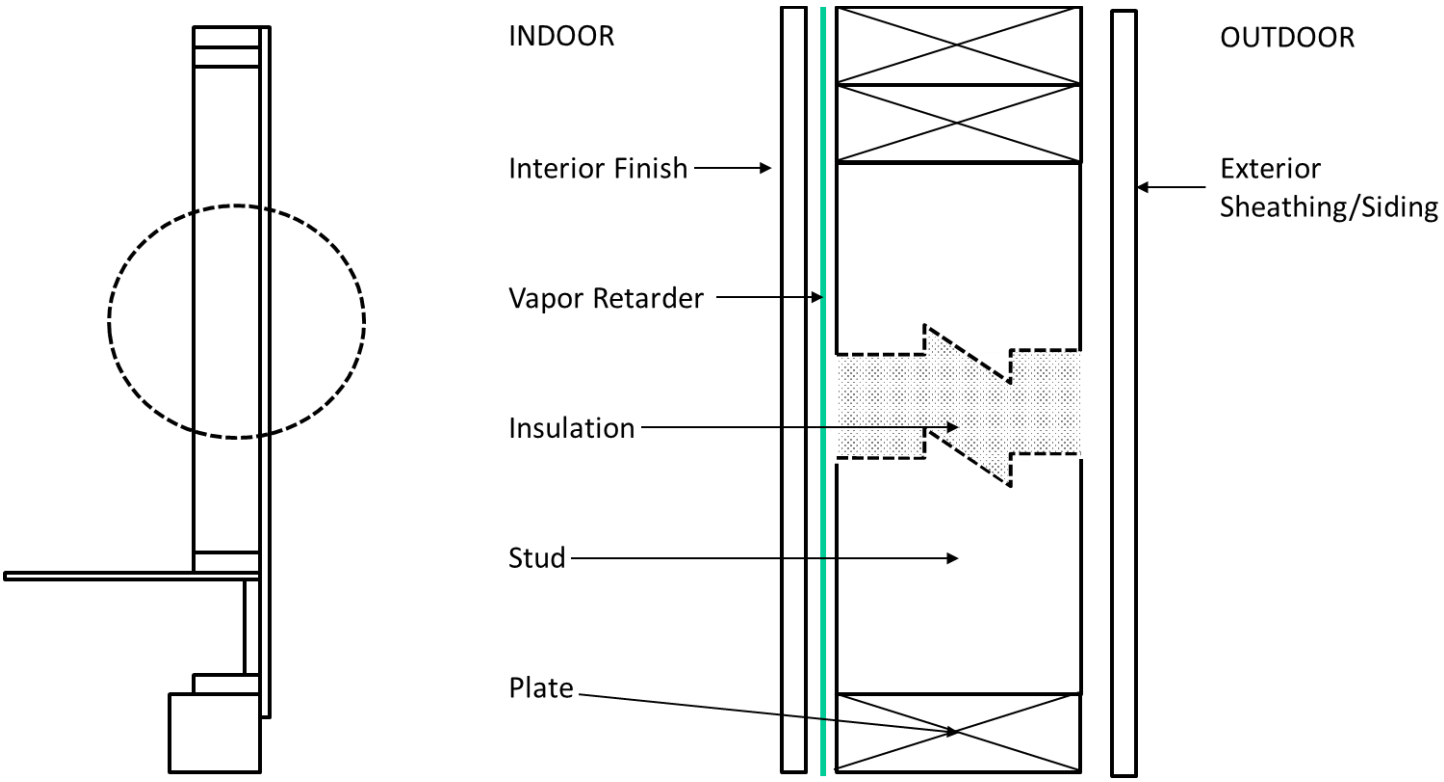
Single Stud Walls

The single stud wall system consists of vertical 2X studs typically spaced 16 inches or 24 inches on center. The vertical studs are capped by top and bottom plates that run horizontally the length of the wall.

There is a vapor retarder which is installed on the interior face of the studs under the drywall or other interior finish material.

The single stud wall system can be sheathed with a thin layer of foam board on the interior or the exterior without additional framing to increase the R-value of the system and reduce conductive heat loss.

The single stud system is the most common framing system in use and has the longest history and is most familiar to tradespeople.

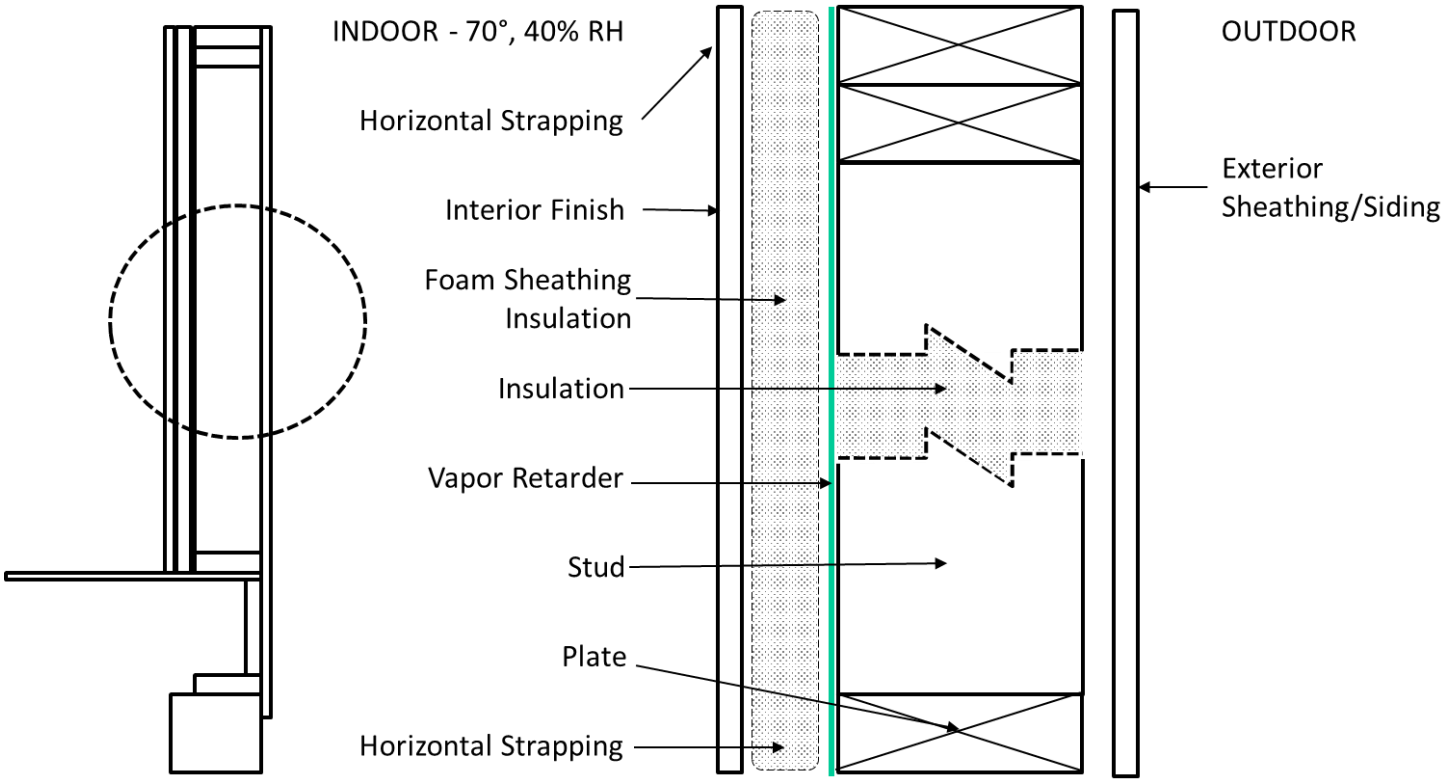


This drawing shows the cross section of a typical single stud wall. 2X6 is the most common size of the vertical stud member, but larger sizes can be used as well to gain efficiency. Fiberglass batts are the most common choice of insulation, but the blown in blanket system can be used to achieve greater R-value for the same thickness. The vapor retarder is located under the interior finish material.

The single stud system is subject to conductive heat loss at every stud and every plate since there is direct contact between the interior and exterior of the wall without thermal break.

To offset the conductive heat loss of this system, thin foam sheathing may be applied to either the interior or the exterior of the wall as a thermal break, without the use of additional framing members or strapping. Interior foam sheathing may result in nail pops as the foam will compress if pressure is applied.

Applying thin foam sheathing to the exterior of a wall system is not recommended, as there is a potential to create a second vapor retarder on the cold side of the assembly which can trap moisture inside the wall.



A variation of the single stud wall that can be used to increase the thermal performance is to use a thin layer of foam sheathing between the interior face of the studs and the finish material. Conductive heat loss is eliminated with the thermal break provided by the foam. A ½ inch thickness is most common, but up to 2 inches of material can be successfully used without additional furring strips. Sandwiching the foam sheathing with drywall does make the wall more susceptible to "nail pops" or drywall fasteners protruding through surface since the interior finish is somewhat compressible.

Strapped Stud Walls

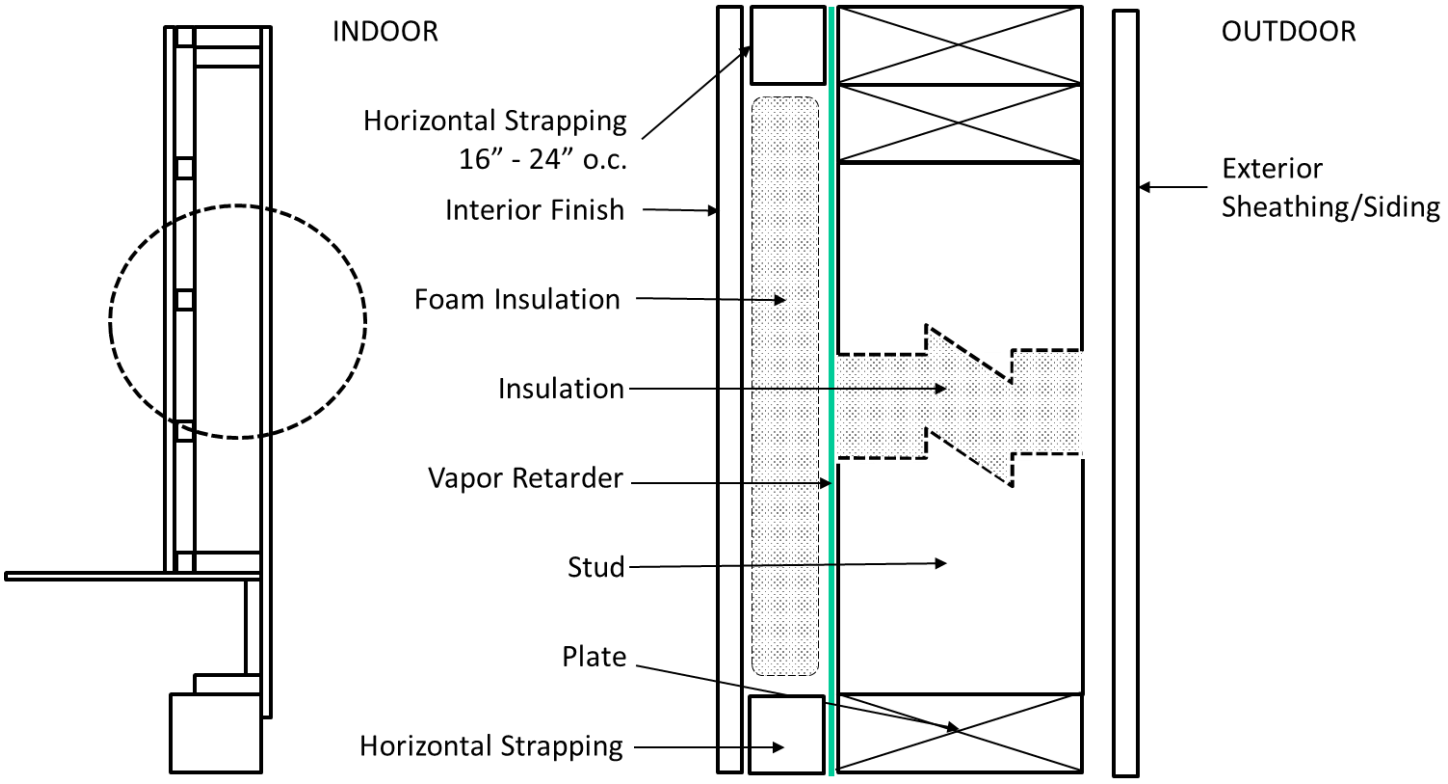
The strapped stud wall is a variation of the single stud wall. Both walls use a vertical 2X stud as the primary framing member, usually 2X6.

The strapped stud wall then has horizontal or vertical strapping applied to the interior or exterior of the primary stud framing, usually 16 inches or 24 inches on center. Conductive heat loss is greatly reduced when the strapping is applied horizontally to the vertical stud wall, with a conductive heat loss path only occurring where the horizontal strapping intersects the vertical studs.

Insulation is typically placed in both the primary and the furred wall cavities, although this is not required. A wall that is strapped on the interior may have the furred cavity left uninsulated and used only as a utility chase to maintain the integrity of the vapor retarder, where the vapor retarder is placed between the studs and the strapping.

The vapor retarder is usually placed either under the interior finish material, or between the strapping and the face of the studs on the interior.

Care must be taken to consider the location of the dew point in the wall so as not to trap condensation. The overall R-value of the wall, the R-value on the warm in winter side of the vapor retarder, and the climate location are all factors in vapor retarder placement.



This drawing shows a typical cross section of a strapped wall, with the strapping on the interior face of the wall. Strapping is typically spaced 16 inches or 24 inches on center to accommodate framing and installation of drywall or other finish materials. Foam insulation or fiberglass batts can be used in the furred cavities, although foam will usually give greater R-value in the same space.

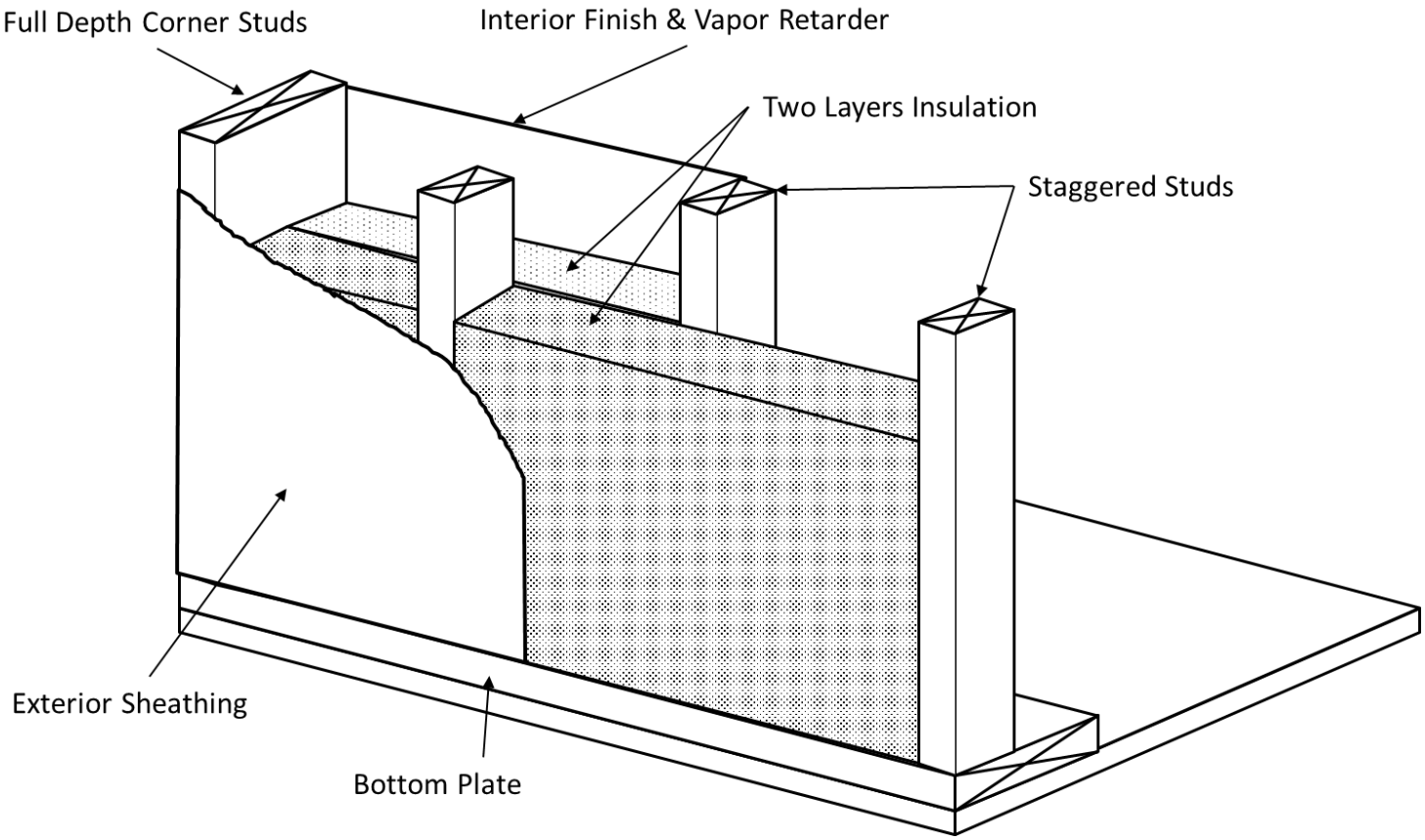
Double Walls

The double wall consists of two sets of vertical 2X studs, offset from each other to eliminate conductive heat loss. There are nearly limitless combinations of studs that can be used for the wall framing, but double 2X4 walls with a 2X8 top plate is common.

The double wall usually has a shared top and bottom plate for structural integrity. Both cavities of the double wall system are filled with insulation. The vapor retarder is placed under the interior finish.

A variation that can be used to further increase the efficiency of the wall system is to add an air space between the inner and outer rows of studs. For example, two rows of 2X4 vertical studs can be spaced about 4 inches apart from each other when used with a 2X12 top and bottom plate.

The main advantage of the double wall system is the offset studs, which eliminate conductive heat loss. For typical 16 inch on center vertical stud space, each set of studs is offset by 8 inches.



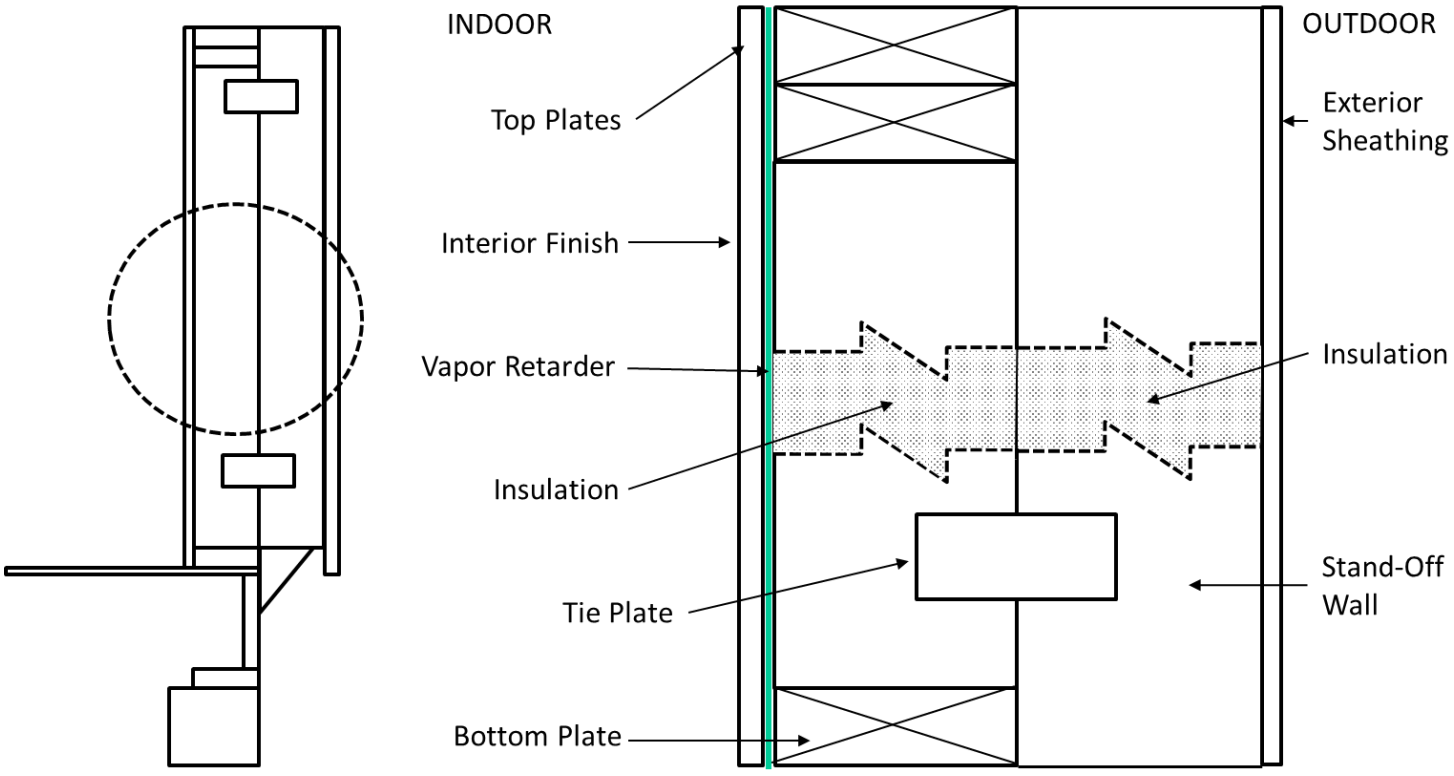
This drawing shows a typical double wall arrangement with two layers of insulation, one between each row of studs. A double 2X4 stud wall with two layers of R-13 will have a greater R-value than a typical 2X8 stud wall for the same thickness, with no conductive loss.

Stand-Off Walls

The stand off wall is a variation on the double stud wall; the stand off wall consists of a load bearing wall with an additional non-load bearing wall framed to the exterior.

The non-load bearing wall acts only as a cavity for additional insulation and to attach siding to the exterior.

The stand off wall offers the ability to achieve very high R-values, the exterior non-bearing wall can be framed with lightweight I-joists to allow for additional insulation.



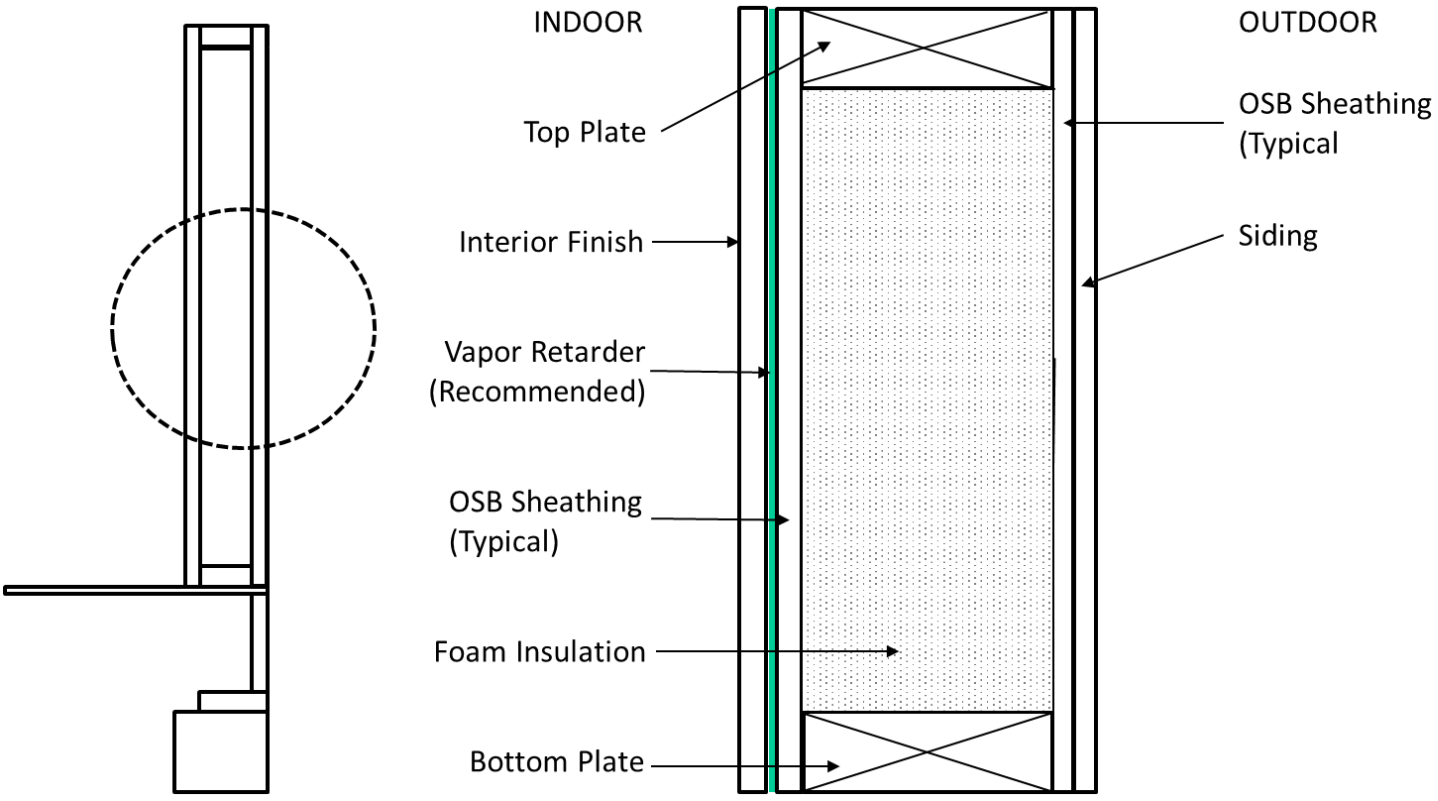
This drawing shows a typical cross section for a stand off wall. The non-load bearing portion of the wall is supported on a ledge at the bottom of the wall against the foundation. Tie plates are used to secure the non-load bearing wall to the bearing studs. The roof load from the trusses or rafters must bear on the interior load bearing wall and foundation.

SIPS Panels

The structural insulated panel, or SIP panel system, is fundamentally different from the typical stick framing system. A SIP panel consists of a foam insulation that is sandwiched between two pieces of wood sheathing, typically OSB or plywood. The SIP panels are pre-fabricated and shipped to the site where they are assembled into the building shell.

The SIP panel utilizes foam insulation which typically has a higher R-value per inch than other insulating products which equals greater insulation for the same overall wall thickness than stick framing systems. The SIP panel also has less conductive heat loss than stick framing; full depth wood members are only present at edges and around window and door opening.

The SIP panel is typically very air tight in and of itself. However, there is a potential for panel failure if the panels are not properly sealed at all edges and seams in the field during installation. Care must be taken to ensure all joints are properly sealed to prevent air leakage and condensation which can lead to significant moisture damage.



This cross section shows typical SIP panel configuration. It is recommended that an interior vapor retarder such as 6-mil polyethylene be used with SIP panels, even if the panel itself qualifies as a vapor retarder. Applying a vapor retarder over the interior face of the panels helps eliminate potential air leakage around edges and joints. SIP panels are available in typical wall widths.

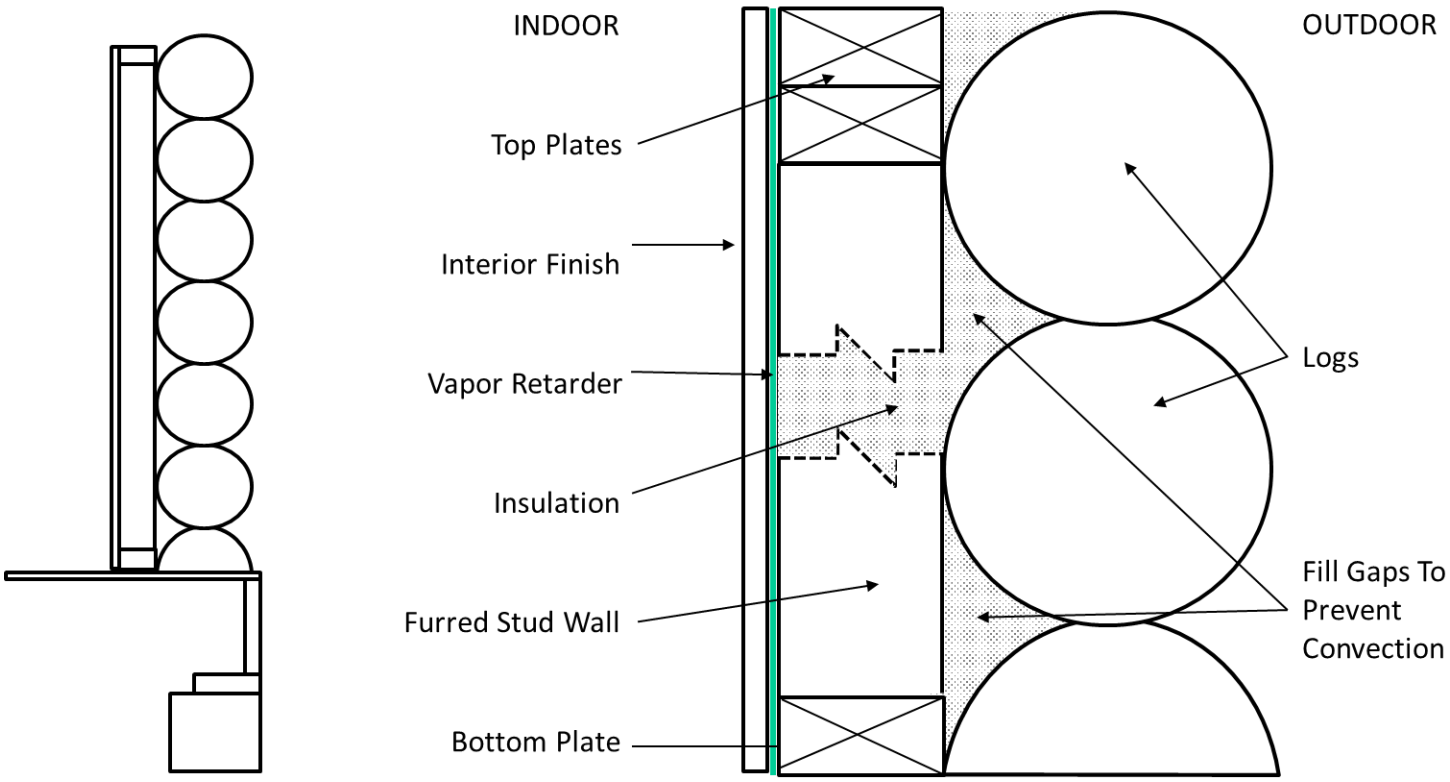
Log Walls

Logs are a natural building material that can be milled into the desired shape or used as felled to build structural exterior walls. To increase the thermal performance of log walls, strapping on the interior can be used to create additional space for insulation and provide a flush surface for an interior vapor retarder.

Log structures tend to shrink, warp, and move over time. There is an initial period of shrinkage for non-kiln dried log members that must be accounted for structurally. After the initial period of shrinkage, logs will expand and shrink seasonally with changing temperatures and humidity levels. This can make air sealing a challenge, especially when considering there is a potential leakage point between each and every log.

Backer rod or other flexible and compressible materials that can fill the natural gaps between logs are a good way to maintain an air seal over time.

Wood itself has a relatively low R-value when compared to traditional insulating materials at just R-1.25 per inch. Even large diameter logs can't compare to other exterior wall types in terms of insulating value and thermal performance.



This is a drawing of a typical log wall cross section with interior furring. Insulating a log wall is challenging due to the variable nature of the logs themselves. Each log must be chinked or sealed. Insulation must be installed to fill in the cavities between the logs.

Masonry/Concrete Walls

Although typical of foundation construction, concrete or masonry can also be used above grade level for the exterior wall. Concrete or masonry walls can be insulated on the interior, the exterior, or both sides. Interior strapping or furring is typically needed to provide a chase for utilities such as wiring or plumbing.

Masonry or concrete exterior walls are typically very air tight, accommodations must be made for proper ventilation and air circulation. There is also a potential risk of condensation if the wall is insulated on the interior only. This leaves the concrete or masonry wall itself subject to the exterior temperature. The interior face of the wall behind the insulation will be nearly the same temperature as the exterior, and any warm, moist air that reaches this point in the wall will be subject to condensation.



Masonry block is available with foam insulation integrated into the interior of the block. Various thickness are available. This system provides an insulated wall assembly that is essentially already finished on both side, although interior furring may still be necessary to wiring and plumbing.

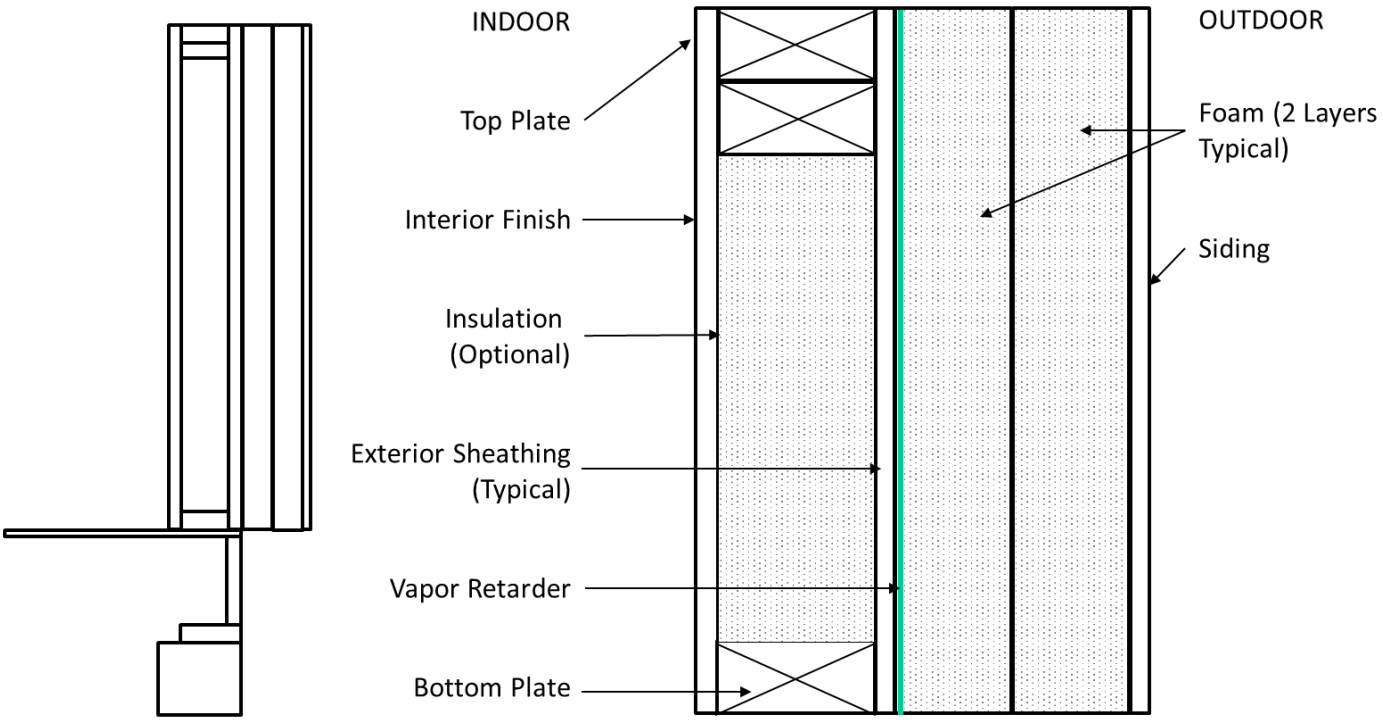
REMOTE Walls

The REMOTE wall system is an advancement on the standard single stud wall using foam sheathing insulation on the exterior of the wall. The REMOTE system relies on using several inches of foam, depending on climate location, on the exterior to prevent condensation issues. The stud wall is load bearing and is essentially a utility chase. Additional insulation can be added to the interior load bearing stud wall if vapor retarder placement rules are followed based on the climate location. In this way a very high R-values can be achieved, and conductive loss is eliminated by the foam sheathing on the exterior.

The vapor retarder is located on the outside face of the exterior wall sheathing. This may seem counter intuitive at first but is acceptable if enough foam sheathing is used on the outside of the vapor retarder. This keeps the vapor retarder on the warm in winter side of the assembly, even though it is on the outside of the stud wall.

The REMOTE wall system can yield very high R-values with a combination of foam insulation on the exterior wall and fiberglass or other batts in the interior bearing wall stud cavities.

The REMOTE wall system is very air tight when constructed properly. Since the vapor retarder is on the outside face of the exterior wall sheathing, there are very few penetrations or interruptions where air leakage can occur. The layers of foam on the exterior also contribute to limiting air leakage. Since the vapor retarder is located in the middle of the assembly between potentially two layers of insulation, the R-value on the warm in winter side of the insulation must be carefully considered. Adequate R-value must be placed on the exterior of the vapor retarder to prevent condensation from occurring inside the interior bearing stud wall. The colder the climate, the more insulation must be placed over the exterior wall sheathing.



This drawing shows typical REMOTE wall construction. A 2X4 stud wall can be used in most situations and there is an option to insulate this cavity. 3 inches to 6 inches of foam is applied to the exterior. Siding is attached to furring strip that are attached through the exterior foam to the stud wall with long screws.

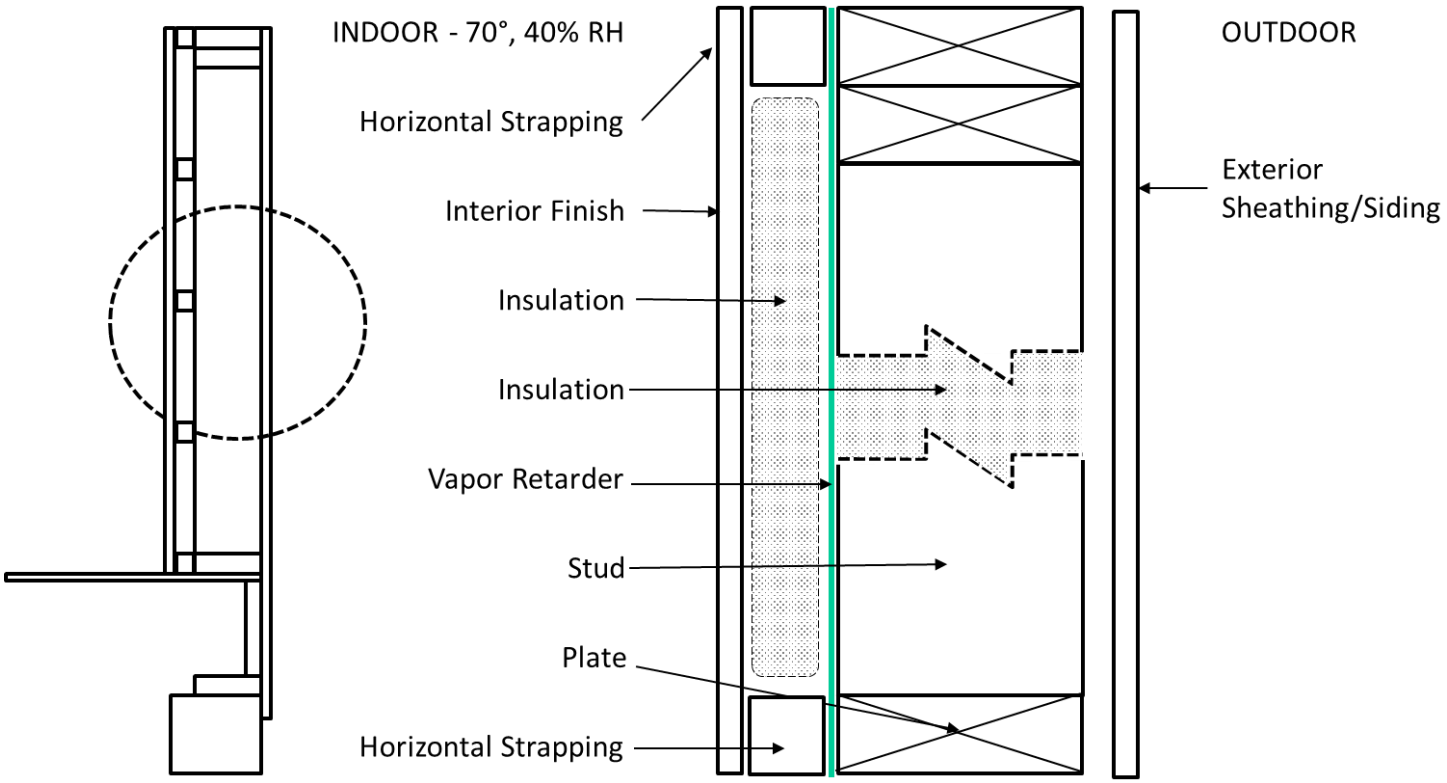
Vapor Retarders

Regardless of the type exterior wall system chosen, the vapor retarder must always be located on the warm in winter side of the assembly. Failure to do so may result in condensation occurring inside the wall system.

Some insulation can be used on the interior of the vapor retarder; how much depends on the climate location of the building. The colder the winter design temperature, the less insulation can be used on the interior side of the vapor retarder. Milder areas of Alaska such as in the Southeast region may allow 50% or more of the wall R-value on the warm in winter side of the vapor retarder. Conversely, very cold climates such as in the Arctic Slope region of Alaska may allow less than 30%. In all cases, the vapor retarder materials must be rated Class 1 or 2, with a permeability rating of less than 1.0.

A select percentage of the overall R-value of the wall assembly may be placed on the warm in winter side of the assembly, dependent on the climate location of the building.

When considering the design of a wall system and vapor retarder placement, always assume that no vapor retarder, no matter how well detailed, is perfect. Some air leakage and moisture transport into the wall will always occur, and there is always the potential for condensation to form inside the wall. Any moisture or condensation inside the wall must not be trapped by the vapor retarder and must have the ability to exfiltrate to the exterior.



Advanced vapor retarder placement is locating the vapor retarder with insulation on both sides. This offers the advantage of less penetrations in the vapor retarder and increased insulation value for a better performing wall assembly.

Advanced Wall Design Challenge

For this challenge, design an advanced wall system, based on one of the four climate regions. Based on the wall design and the climate location, predict where the dew point will occur in the assembly.

Use 1/2" per square scale on the graph paper page provided.

Minimum January Temperature & Vapor Retader Placement - Selected Cities

Station	Temp.	Max % R-value On Warm Side	Station	Temp.	Max % R-value On Warm Side
ADAK	28	62%	**KING SALMON AP**	8.8	42%
ANCHORAGE INTL AP	11.1	44%	**KLAWOCK AP**	31.1	67%
BARROW WSO AP	-19.5	29%	**KODIAK AP**	25.9	59%
BETHEL AP	0.8	38%	**KOTZEBUE WSO AP**	-9.5	33%
CANTWELL 2 E	-8.9	33%	**MCGRATH AP**	-15.3	30%
COLD BAY AP	23.6	56%	**NOME WSO AP**	-2.8	36%
COOPER LANDING 5 W	8.8	42%	**NORTH POLE**	-17.2	30%
CORDOVA AP	19.4	51%	**PALMER AP**	8.5	42%
CRAIG	32.8	70%	**PAXSON**	-9.1	33%
DEADHORSE	-23.1	28%	**PETERSBURG 1**	26	59%
DELTA JUNCTION 20SE	-12.5	32%	**PRUDHOE BAY**	-22.4	28%
DILLINGHAM FAA AP	9.5	43%	**SALCHA**	-13.6	31%
DUTCH HARBOR	27.7	61%	**SAND POINT**	28.6	63%
EAGLE	-17.9	30%	**SELDOVIA AP**	21	53%
EAGLE RIVER 5 SE	7	41%	**SEWARD**	22.3	55%
EKLUTNA WTP	7.9	42%	**SITKA JAPONSKI AP**	32.3	69%
FAIRBANKS INTL AP	-16.9	30%	**SKAGWAY**	21.3	53%
GALENA	-17.6	30%	**SOLDOTNA 5SSW**	4.3	40%
GULKANA AP	-10.7	32%	**ST PAUL ISLAND AP**	21.1	53%
GUSTAVUS	22.1	54%	**TALKEETNA AP**	6.2	41%
HAINES AP	18	50%	**TOK**	-20.1	29%
HEALY 2 NW	-7.6	34%	**VALDEZ AIRPORT**	16.1	48%
HOMER AP	18.8	51%	**WAINWRIGHT**	-17	30%
HOONAH	26.3	59%	**WALES**	-8	33%
HOPE	11.4	44%	**WASILLA 3 S**	8.2	42%
JUNEAU AP	23.7	56%	**WHITTIER**	24.7	57%
KASILOF 3 NW	9.9	43%	**WILLOW WEST**	-1.3	36%
KENAI AP	8.1	42%	**WRANGELL AIRPORT**	27.6	61%
KETCHIKAN	30.1	65%	**YAKUTAT AP**	22.4	55%

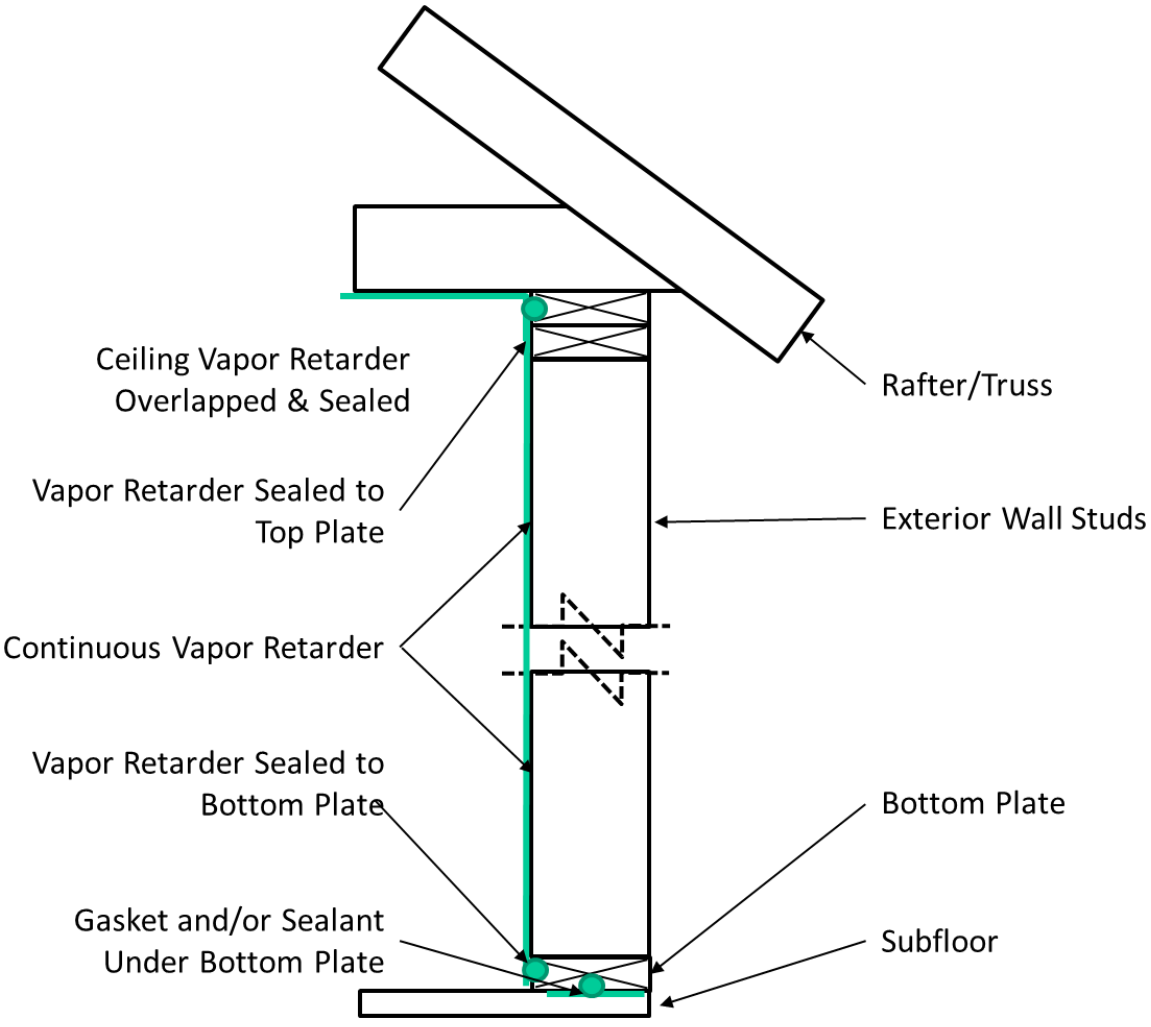
Vapor Retarder Sealing

Sealing the vapor retarder is critical to energy efficiency and long-term performance of the assembly. The vapor retarder is the primary line of defense against warm air and moisture migration into the wall assembly.

The vapor retarder must be continuous from the floor to the ceiling. This includes sealing or overlapping the bottom plate to the subfloor. All seams and edges must be sealed, and all penetrations through the vapor retarder must be sealed.

To provide a continuous seal from the bottom of the wall plate to the subfloor, liquid sealants such as acoustical sealant or caulking can be used, or a gasket material such as sill seal can be used. From the bottom plate to the top plate, a sheet materials such as 6-mil polyethylene or foil faced foam covers the interior side of the wall. At the top or the wall, the wall vapor retarder should be overlapped with the ceiling vapor retarder.

For proper long-term performance, the appropriate type of sealant must be used. For polyethylene sheeting, vinyl tape should be used where there is no



The bottom plate of the wall provides the continuation from the subfloor below to the inside face of the exterior wall. Sealant is applied to each edge and seam. A minimum 6-inch overlap is needed at all seams, but best practice is to overlap one complete stud or truss bay and seal both edges to hard backing.

solid backing behind. Acoustical sealant requires a solid backing behind such as a framing member to provide a good seal. For foil faced products such as foam sheathing, a foil tape is recommended.

Caulking should not be used for sealing the seams or edges of a vapor retarder. Caulking dries out over time, and the seal will break as the building moves and flexes seasonally. A sealant that remains pliable, such as acoustical sealant, is a much better choice.

Duct tape is not suitable for vapor retarder sealing either. Duct tape tends to creep and detaches over time.

All penetrations through the vapor retarder must be sealed. For electrical penetrations, the use of flanged or "vapor" boxes is recommended. The flanged style box provides a gasket and a lip around the outer edge that acoustical sealant can be applied to, which is far superior to the typical rimless electrical box.

Plumbing penetrations must also be sealed. Supply, drain, waste, and vent piping can be wrapped with vinyl tape to secure to the vapor retarder.

Polyethylene, which is the most common vapor retarder sheet good, can be bonded to penetrations with vinyl tape or acoustical sealant.

Bonding to hard plastics such as plumbing piping is best done with vinyl tape. Hard plastic piping that penetrates through a wooden framing member that is part of the continuous vapor retarder assembly can also be sealed with expanding spray foam.

Interior Partition "Tabs"

A method for ensuring the continuity of the vapor retarder around framing member is the use of polyethylene tabs. Tabs are narrow strips of polyethylene, usually 18-24" wide, which are run behind the interrupting framing member such as an interior partition wall. These tabs are installed at the rough framing stage when there is still access behind the framing. The tab allows the polyethylene sheeting to be bonded to the polyethylene tab rather than the wood framing member. This can provide a better seal and brings the interior partition "inside" of the vapor retarder.





There photos show examples of polyethylene "tabs" installed above interior partition walls. Installing tabs does require some fore-thought, as it must be done at the rough framing stage before insulation takes place.

Roof/Ceiling

The key concepts for roof and ceiling construction include the differences between hot roofs and cold roofs, and the proper application of each, details for preventing heat loss through air sealing, and the proper placement of the vapor retarder in the assembly to avoid condensation.

Hot Roofs

There are two types of roof construction. Hot roofs are roof/ceiling assemblies with an unvented attic space or no attic space. Cold roofs are roof/ceiling assemblies with an air space or attic space above the insulation that is vented to the exterior. Each type of roof system is suited for a specific application.

The hot roof, or unvented roof system, is typically not desirable for most applications. The reason is that no vapor retarder is perfect, and some warm air and moisture from inside the building will make its way into the assembly. Stack effect, which is a driving force inside the building during times when it is cooler outside than inside, is constantly pushing warm, moist interior air against the ceiling.

Moisture that enters the roof/ceiling assembly, or any exterior building assembly, must be allowed to dry to the exterior. However, since the hot roof design has no ventilation and is essentially waterproof and vapor proof on the exterior from the roof covering, condensation can easily become trapped inside.

Hot roof assemblies also typically have limited insulation space and limited R-value. The heat loss from a hot roof/ceiling assembly from low insulating value and no ventilation results in the snow covering on the roof melting. Snow melt then runs down to the eave and re-freezes, resulting in ice dams and icicle formation along the lower edges of the roof.

The one advantage offered by hot roof/ceiling construction is the lack of vents to the outside in areas of wind-blown snow. Snow can be blown into the attic space or air space above the insulation and then melt, damaging the roof structure. Therefore, hot roofs are only acceptable in area of extreme wind.

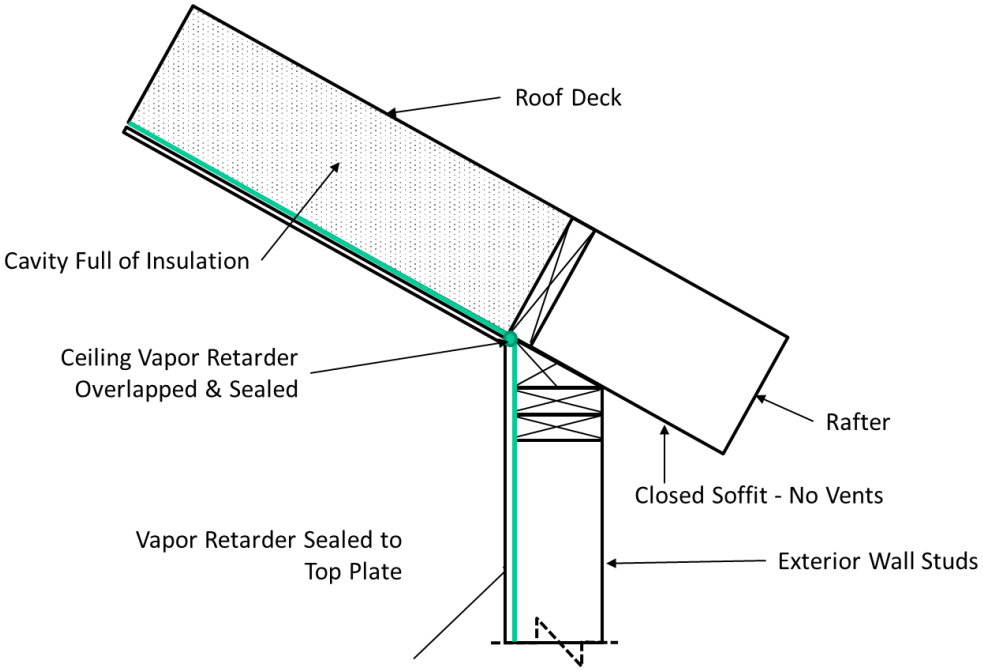
Cold Roofs

The cold roof or vented roof/ceiling assembly has an air space above the top of the insulation. For adequate air circulation, there should be at least 1 square foot of open ventilation area per 150 square feet of cathedral style ceiling, and 1 square foot of venting per 300 square feet of open attic space. Roughly 50% of the venting area should be located at the bottom of the assembly along the soffit, and 50% of the venting area should be located at or near the top of the assembly at the gable ends or along the ridge.

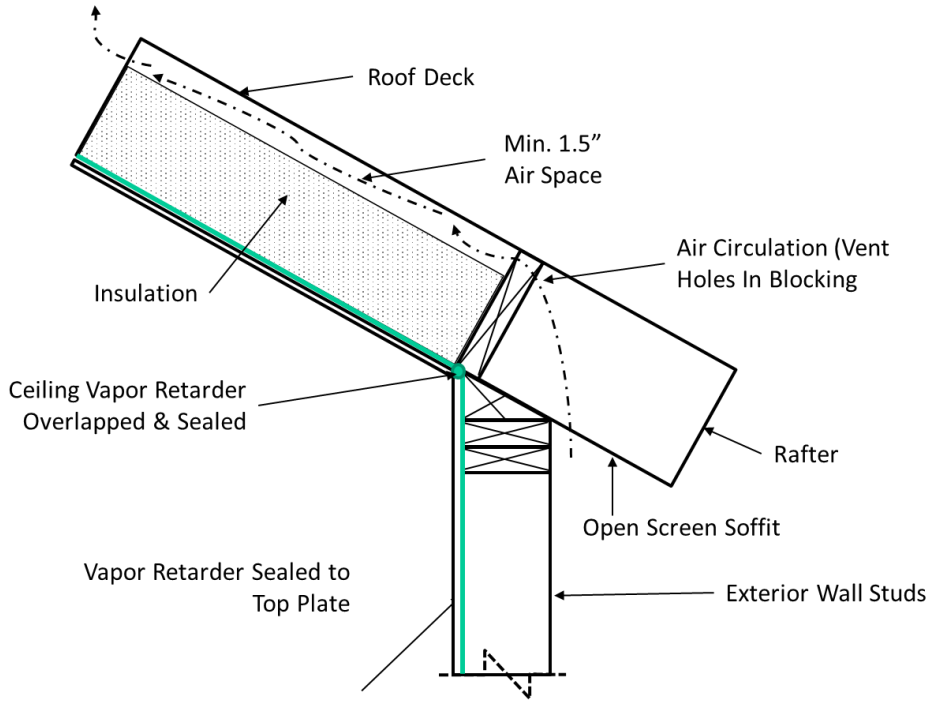
A minimum of 1.5 inches of air space is needed between the top of the insulation and the bottom of the roof sheathing to ensure adequate air circulation. The purpose of the air space is to allow outdoor air circulation to remove any heat or moisture that may accumulate inside the attic or cavity. This lessens the potential of condensation inside the attic space or snow melt off of the roof covering.

Insulation baffles are a best practice for cold roof/ceiling assemblies. Baffles can be used to maintain a minimum air space between the top of the insulation and the bottom of the roof assembly. Baffles are typically made out of cardboard or thin plastic and are secured in place with staples to the bottom side of the roof sheathing.

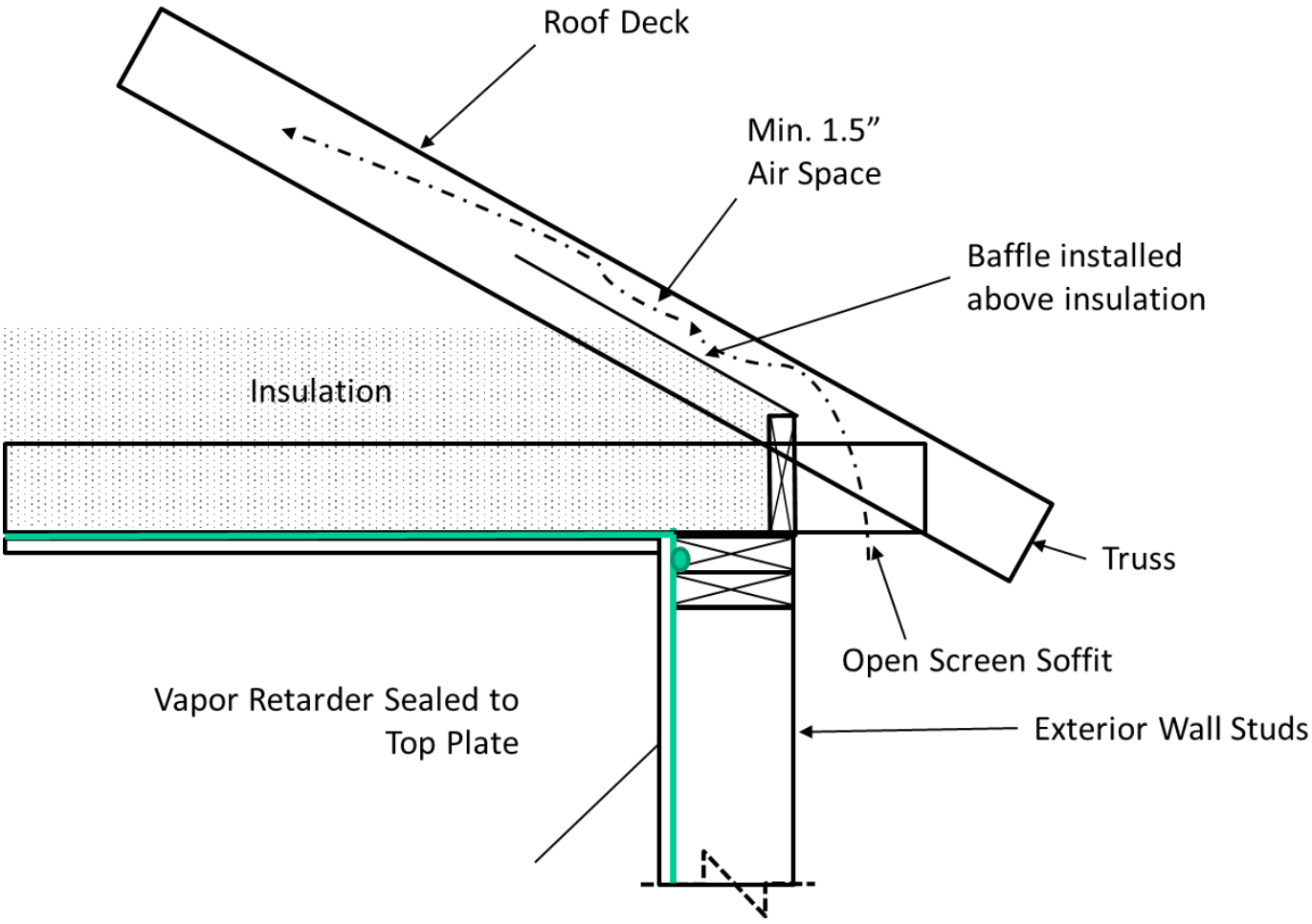
Baffles may also be needed on the exterior side of roof ventilation openings to reduce wind infiltration into the attic, also known as “wind washing”. Wind washing can reduce the effectiveness of the attic insulation.



This drawing shows the typical details of an unvented or "hot" roof system. There is no ventilation openings at the bottom or the top of the assembly, and no air space between the top of the insulation and the roof deck as is typical of a vented or "cold" roof assembly. Extra care must be taken in detailing the vapor retarder to stop the flow of heated air and humidity into the roof cavity, where it may condense into liquid moisture and become trapped.



This drawing shows a typical cold roof detail with a ventilated air space above the insulation. An open screen in the soffit allows air to flow over the top of the insulation. A minimum of 1.5 inches of clear air space is required over the insulation. Baffles may be installed above the insulation to prevent accidentally blocking the air space during insulating.



This drawing illustrates a cold roof design utilizing a truss system with an attic space. Baffles are installed at the eave to provide space for air flow from the soffit into the attic. A minimum of 1.5” of air space is recommended.

Ice Dams

Ice dams are a common affliction in cold climates that can affect both hot and cold roof/ceiling assemblies. Ice dams result when snow melts off of the roof covering and re-freezes at the lower part of the roof eave. Ice damming can be identified by bare spots on otherwise snow covered roofs, or abnormally large icicles forming at the bottom edges of the eaves. Severe ice dams can result in water leaking into the exterior wall at the lower eaves or valleys, causing water damage and mold growth.

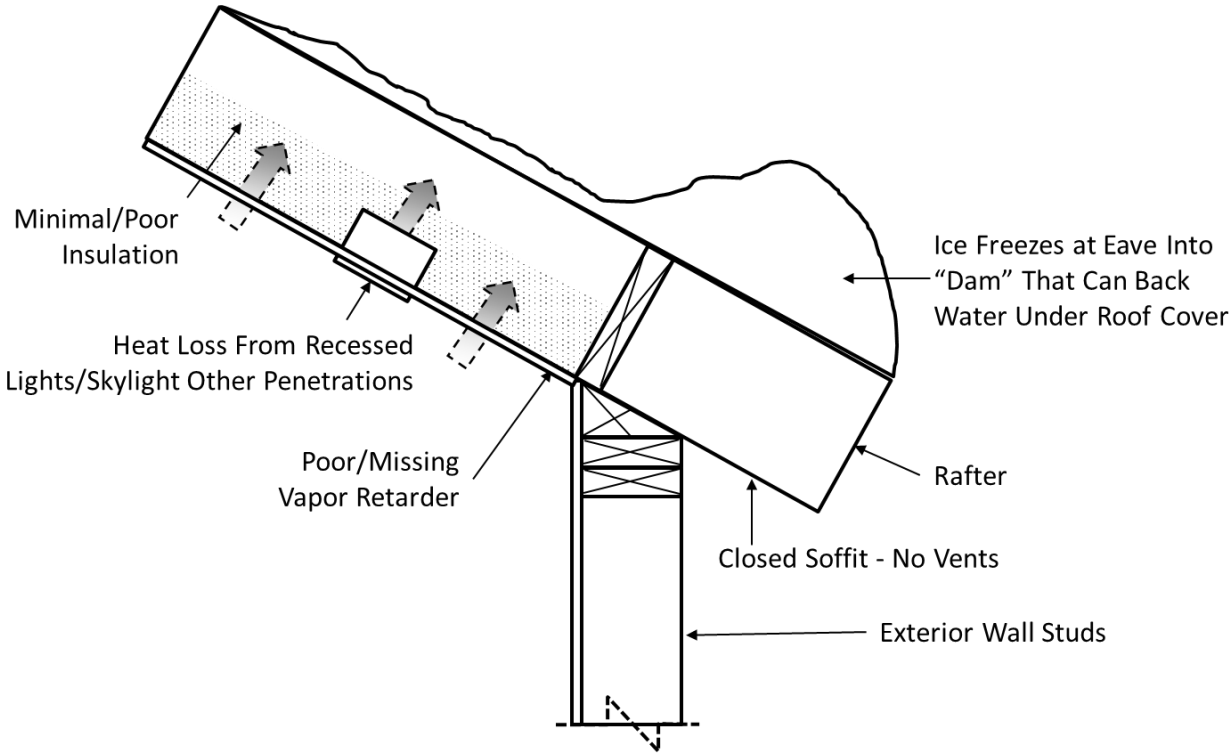
Ice dams are a symptom of heat loss and poor or no ventilation of the roof/ceiling assembly. Ice dams are caused by one or more factors. Lack of insulation in the roof/ceiling assembly can cause ice damming. Heat loss from a lack of insulation causes snow to melt off of the roof covering.

Air movement from heated spaces into the roof/ceiling assembly may also cause ice damming. Warm air leakage is another form of heat loss which results in snow melt off of the roof covering. Lack of proper attic space ventilation can cause or exacerbate ice dams. Heat buildup in the attic from lack of insulation or warm air leakage occurs when no ventilation is present. Insulation can only slow the loss of heat and cannot stop it completely, therefore ventilation is always essential to preventing ice dams.

Ice damming can be prevented. Installing a sealed vapor retarder on the warm in winter side of the roof/ceiling assembly at the construction stage is the first step in keeping ice dams from forming. A properly sealed vapor retarder prevents warm air from escaping into the roof/ceiling assembly. Any penetrations in the roof/ceiling assembly vapor retarder must be sealed. This includes plumbing, wiring, and especially recessed lighting.

Adequate insulation in the attic is also key to slowing heat loss into the roof/ceiling assembly. Check with your local building department for minimum required insulation levels, but R-38 should be considered a minimum for new construction.

Finally, ventilation must be provided for cold roof/ceiling assemblies. An airflow path must be maintained from the bottom to the top of the assembly.



Ceiling Vapor Retarders

The ceiling vapor retarder prevents heat loss and moisture escape from the interior of the building into the roof/ceiling assembly where condensation and ice damming can occur. The ceiling vapor retarder is particularly vulnerable to air leakage since stack effect is nearly always causing a positive pressure at the top of the building.

The ceiling vapor retarder must be continuous from the exterior wall on one side of the building to the exterior wall on the other side of the building, in all four direction. Joints and seams in the vapor retarder must be overlapped and sealed with the proper materials. The ceiling vapor retarder is located on the warm in winter side of the assembly.

Ceiling Air Sealing

Where the ceiling vapor retarder overlaps the wall vapor retarder, don't rely on fastening two edges to a single framing member. Seams should be overlapped wherever possible, and should be located over a hard backing such as a top plate or truss framing member. A solid backing provides additional support to the overlap, making a more durable seal.

All penetrations through the vapor retarder must be properly sealed, including plumbing and electrical utilities. Attic access hatches are considered a penetration that must be sealed as well when not in use.

Sealing Penetrations

All penetrations through the ceiling vapor retarder must be sealed. Electrical penetrations for wiring and fixtures, particularly recessed lighting, must be sealed. Plumbing piping and exhaust fan fixtures must also be sealed.

Chimney penetrations for heat producing appliances must be sealed, but care must be taken to maintain proper fire separation and clearance to combustible materials.

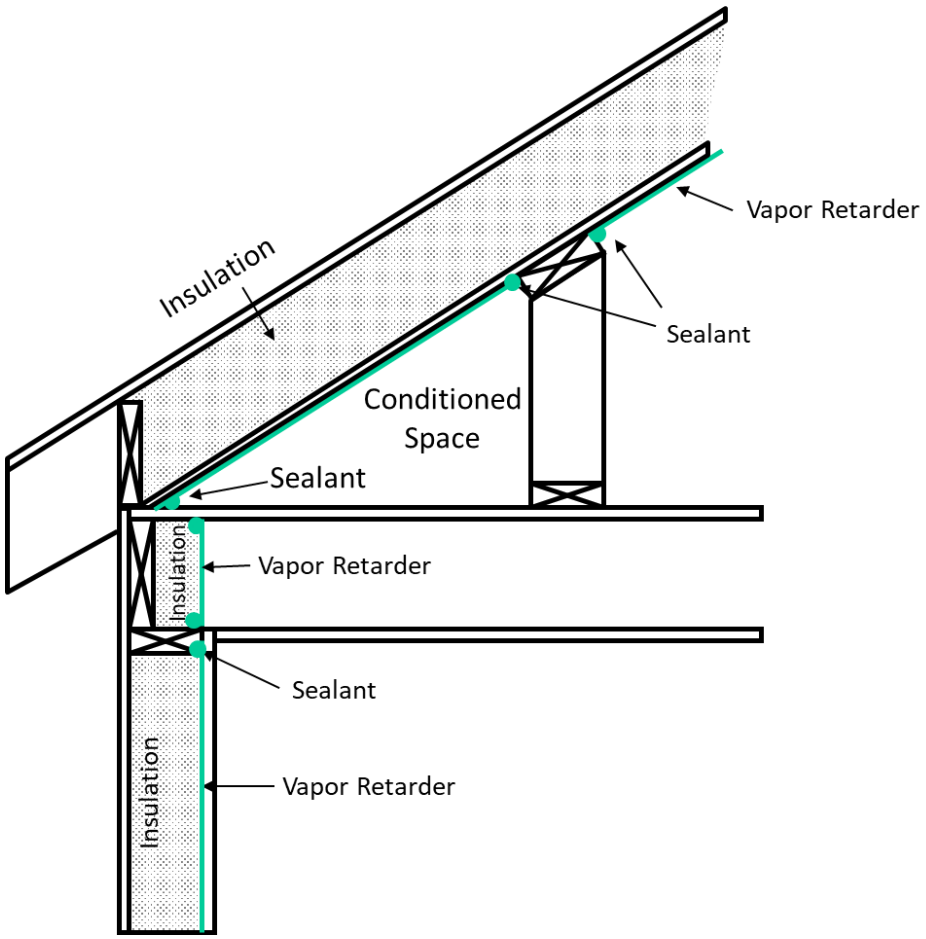
For bonding polyethylene to polyethylene, or polyethylene to a hard-backing material, vinyl tape or acoustical sealant can be used.

For bonding a polyethylene vapor retarder to hard plastic such as ABS, vinyl tape is the best choice. For ABS piping passing through wood framing members, spray foam works well.

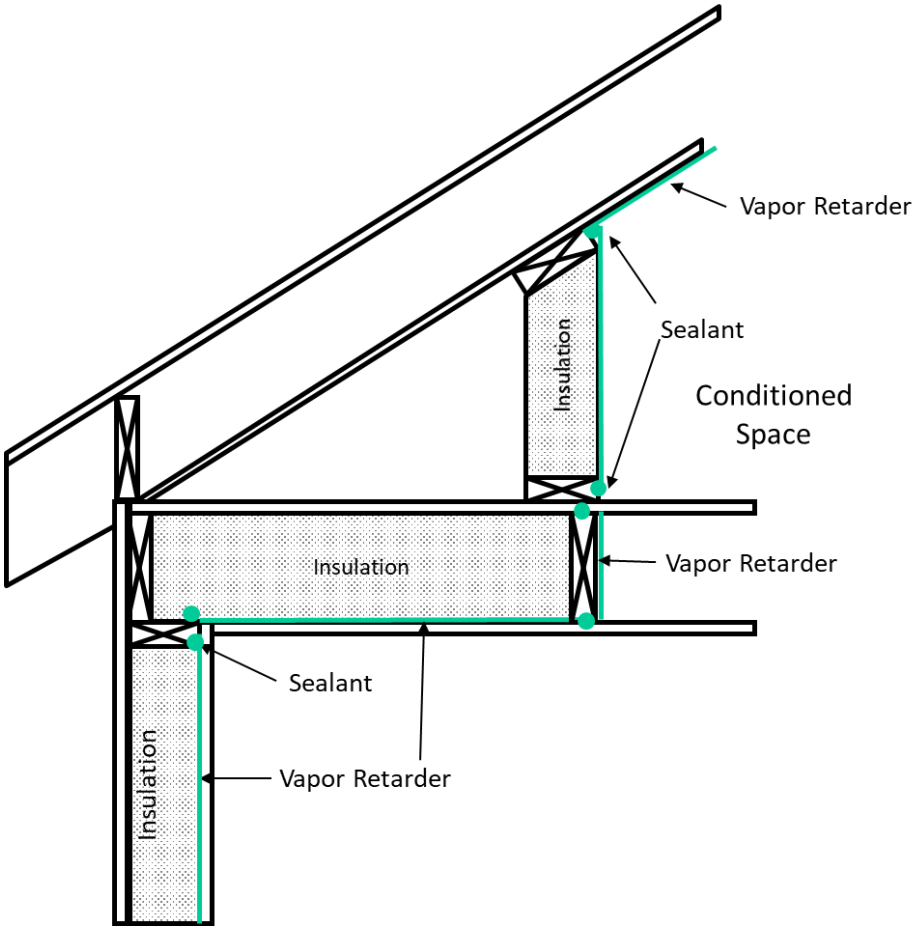
Knee Walls

When addressing attic knee walls, the thermal boundary or insulation must be aligned with the vapor retarder for best performance. To not do so will result in excessive heat loss or condensation issues. It must be established whether the knee wall itself is part of the thermal boundary, or if it is inside the thermal boundary. The insulation and vapor retarder must work together to separate conditioned space from the exterior.

This drawing details an attic knee wall that is inside the conditioned space. In this case the insulation and vapor retarder are continuous from the exterior wall below to the roof/ceiling assembly. The knee wall contains conditioned space behind it and is not insulated. Only the top plate of the knee wall may be part of the vapor retarder.



Conversely, if the knee wall is designed as part of the thermal envelope, it is treated just like an exterior wall. The floor behind the knee wall is treated like a ceiling and is insulated. The space behind the knee wall is unconditioned. The vapor retarder runs from the exterior wall to the underside of the floor behind the knee wall, up the knee wall, and onto the bottom of the ceiling above. Wood or foam blocking under the knee wall is used to keep the knee wall floor insulation in place and to keep the vapor retarder continuous through the floor system.



Electrical Penetrations

Acoustical sealant or vinyl tape can be used with flanged electrical boxes. Recessed lighting, which has a deserved reputation for air leakage, must be sealed even if the fixture is rated as "air tight". Only "IC", or insulation contact rated fixtures should be used. IC rated fixtures allow insulation to be installed right next to and over the top of the fixture. Fixtures that are not IC rated have no place in energy efficient construction. If IC rated fixtures cannot be obtained, or additional air tightness is required, constructing a separate enclosure over the fixture which can be fully insulated and sealed may be the best choice.

Wiring penetrations through framing members are best sealed with spray foam, which will stay in place in a vertical application.



This photo shows a flanged electrical box that has been sealed with vinyl tape around the edge. The flange provides a solid backing.

Plumbing Penetrations

ABS plumbing piping, which is the most common drain, waste, and vent material to penetrate the ceiling, expands and contracts depending on the temperature of the environment. In a venting application where the piping is both inside and outside the thermal envelope, this must be considered when air sealing. Two options for effective air sealing in this situation are gaskets and spray foam. Gaskets and spray foam provide a seal that allows the piping to slide up and down without compromising the seal.

Exhaust fans and ductwork may also penetrate the ceiling vapor retarder. Exhaust fans typically have a surface to seal to that provides a solid backing, and either acoustical sealant or vinyl tape is acceptable. Ductwork does not have a flange or surface to seal to and vinyl tape is the better choice.



This photo shows an ABS plumbing pipe penetrating the top plate of an interior wall leading to the attic space. A generous application of spray foam fills in the annular space.



Even IC rated recessed lighting can be quite leaky. In some cases the best practice is to construct an enclosure for the fixture that seals the fixtures to the inside of the vapor retarder. Thin plywood or OSB can be used to construct the covering. Only the fixture wiring penetrates the enclosure, which is easily be sealed with spray foam.





These photos of exhaust fans show two different ways they can be sealed to the ceiling vapor retarder. Vinyl tape has been used on the right, and acoustical sealant has been used on the left around the mounting flange of the fan.

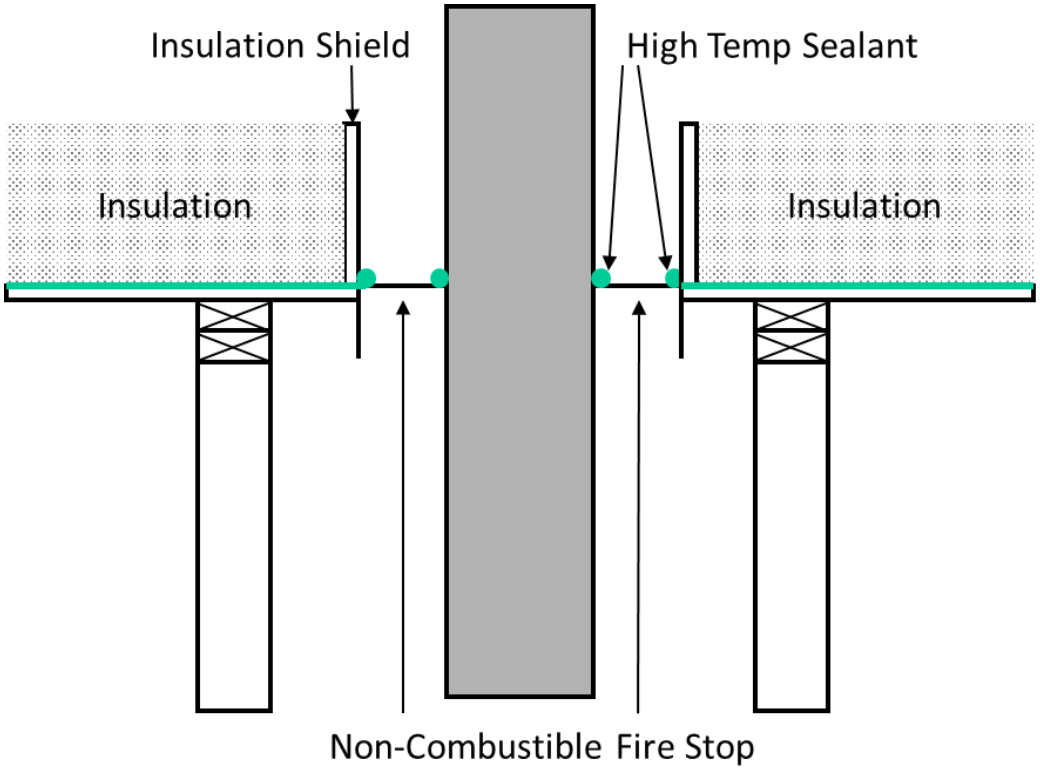
Chimneys

Chimney penetrations through the ceiling vapor retarder require special consideration. Improper installation can result in a potential fire hazard. Many types of insulation are considered combustible, including cellulose and foam products. Combustible clearance requirements extend from the interior finish material to the top of the insulation.

Metal chimneys for fuel fired appliances have specific clearances to combustible materials, depending on the appliance type, the fuel type, and the chimney type. Type B gas vent pipe, which is a double walled metal chimney with an air space, requires a minimum 1-inch clearance. Chimneys for gas fired appliances typically have smaller clearance requirements than for oil or solid fuel appliances.

In all cases, check with the manufacturer of the heating appliance and the chimney to determine the correct clearance to combustible materials. Some type of shield is typically required as well to keep insulation from sloughing or falling against the chimney after installation.

Heating appliances which utilize plastic piping such as ABS or PVC do not have any requirements for clearance to combustible materials and can be sealed as normal.



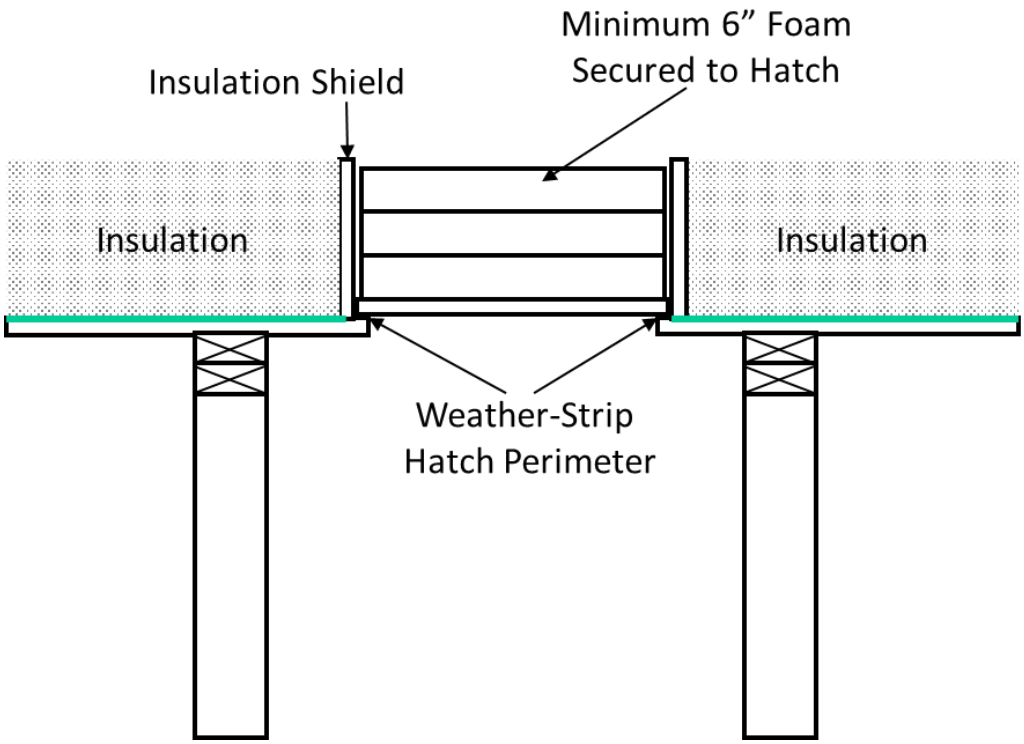
This drawing shows a chimney penetration through the ceiling vapor retarder and insulation assembly. In order to close the gap between the combustible material and the surface of the chimney, non combustible fire stops, made typically of sheet metal, can be used. High temperature sealant may be acceptable by the heating appliance and chimney manufacturer to seal the edges of the fire stop. An insulation shield prevents insulation contact with the piping.

Attic Access

When located in the interior of the building, the attic access hatch is the largest penetration through the ceiling vapor retarder. As such, best practice is to locate the access outside of the thermal envelope if possible. A removable gable end vent can serve as an attic access.

For interior attic accesses, a minimum of 6 inches of foam is recommended to reduce heat loss. Ideally, the R-value of the attic access hatch lid will match the R-value of the surrounding ceiling insulation. Insulation must be secured to the hatch, so it does not fall off when the hatch is used.

A re-closable seal is preferred to a caulking seal that is ruined after the first use. Weather stripping and a suitcase latch or similar positive closure can be re-used many times and still provide a good seal.



This drawing of an interior attic access shows the insulation and air sealing details needed for good performance. Foam board can be cut to fit, layered, and secured to the top of the hatch. An insulation shield around the perimeter of the access is needed when loose fill insulation is present to keep it from falling out when the hatch is opened.

Advanced Ceiling Design Challenge

For this challenge, design an advanced ceiling system, based on one of the four climate regions. Based on the design and the climate location, predict where the dew point will occur in the assembly.

Use 1/2" per square scale on the graph paper page provided.

Minimum January Temperature & Vapor Retader Placement - Selected Cities

Station	Temp.	Max % R-value On	Station	Temp.	Max % R-value On
ADAK	28	62%	KING SALMON AP	8.8	42%
ANCHORAGE INTL AP	11.1	44%	KLAWOCK AP	31.1	67%
BARROW WSO AP	-19.5	29%	KODIAK AP	25.9	59%
BETHEL AP	0.8	38%	KOTZEBUE WSO AP	-9.5	33%
CANTWELL 2 E	-8.9	33%	MCGRATH AP	-15.3	30%
COLD BAY AP	23.6	56%	NOME WSO AP	-2.8	36%
COOPER LANDING 5 W	8.8	42%	NORTH POLE	-17.2	30%
CORDOVA AP	19.4	51%	PALMER AP	8.5	42%
CRAIG	32.8	70%	PAXSON	-9.1	33%
DEADHORSE	-23.1	28%	PETERSBURG 1	26	59%
DELTA JUNCTION 20SE	-12.5	32%	PRUDHOE BAY	-22.4	28%
DILLINGHAM FAA AP	9.5	43%	SALCHA	-13.6	31%
DUTCH HARBOR	27.7	61%	SAND POINT	28.6	63%
EAGLE	-17.9	30%	SELDOVIA AP	21	53%
EAGLE RIVER 5 SE	7	41%	SEWARD	22.3	55%
EKLUTNA WTP	7.9	42%	SITKA JAPONSKI AP	32.3	69%
FAIRBANKS INTL AP	-16.9	30%	SKAGWAY	21.3	53%
GALENA	-17.6	30%	SOLDOTNA 5SSW	4.3	40%
GULKANA AP	-10.7	32%	ST PAUL ISLAND AP	21.1	53%
GUSTAVUS	22.1	54%	TALKEETNA AP	6.2	41%
HAINES AP	18	50%	TOK	-20.1	29%
HEALY 2 NW	-7.6	34%	VALDEZ AIRPORT	16.1	48%
HOMER AP	18.8	51%	WAINWRIGHT	-17	30%
HOONAH	26.3	59%	WALES	-8	33%
HOPE	11.4	44%	WASILLA 3 S	8.2	42%
JUNEAU AP	23.7	56%	WHITTIER	24.7	57%
KASILOF 3 NW	9.9	43%	WILLOW WEST	-1.3	36%
KENAI AP	8.1	42%	WRANGELL AIRPORT	27.6	61%
KETCHIKAN	30.1	65%	YAKUTAT AP	22.4	55%

Truss Uplift

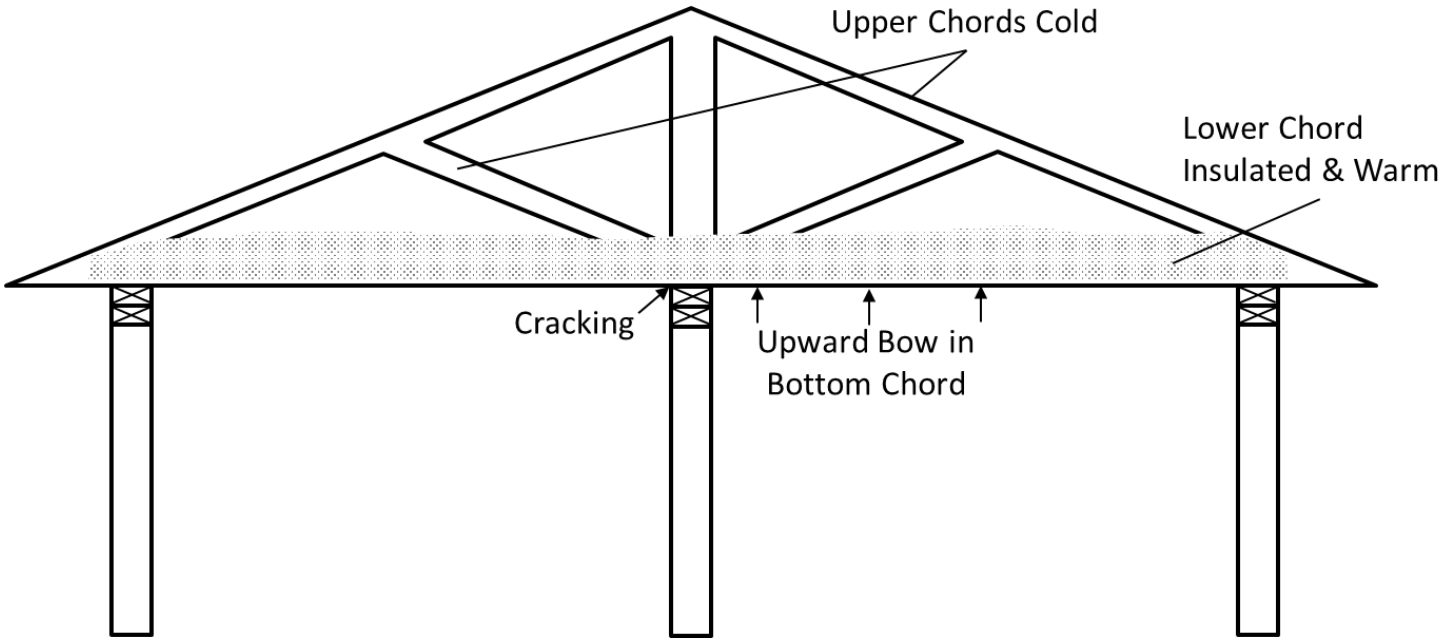
Truss uplift occurs when the bottom chord of the truss is well insulated, and the top chord of the truss is exposed to outdoor temperatures. The bottom chord is "warmer" and expands/contracts at a different rate than the top chord.

The movement is seasonal; truss uplift typically happens in the winter, and settles down in the summer, only to repeat the cycle again the next winter. Trusses with long spans and low slope are more affected by truss uplift than shorter spans and steeper slopes.

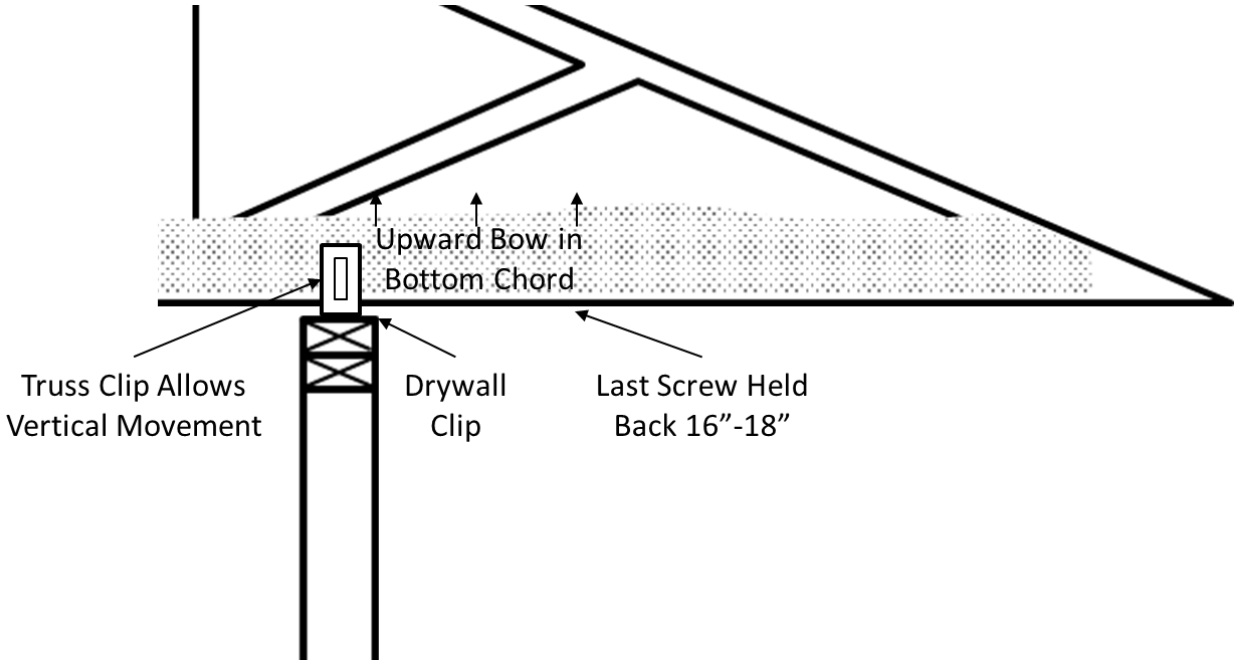
Truss Uplift Solutions

Truss uplift can be easily remedied using truss clips to attach the interior partition walls to the trusses. The truss clip has a nail slot which allows movement of the truss without sacrificing the lateral stability of the partition wall. Drywall fasteners at the ceiling are then held back from the partition wall which allows the drywall to flex, reducing cracking.

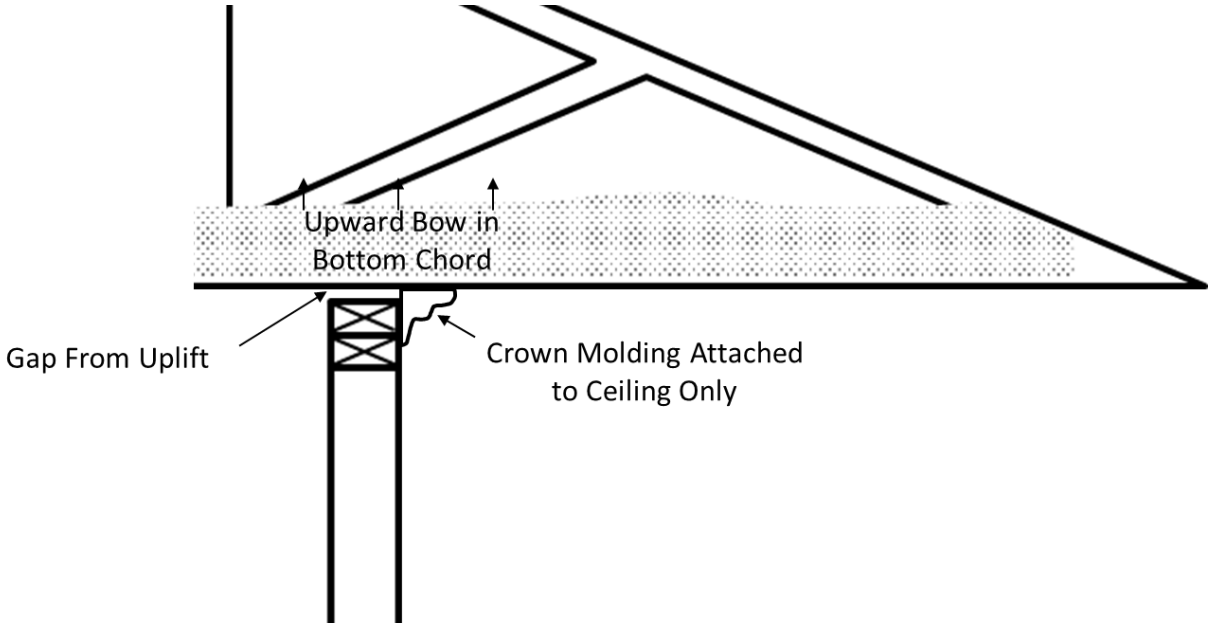
In existing construction, truss uplift can be concealed by using crown molding to cover the recurring cracking at the wall and ceiling intersection.



Truss uplift is a bow upwards in the bottom chord of the truss and does not indicate a structural problem.



The last screw of the drywall sheet that intersects the interior partition is held back 16 to 18 inches to allow the edge to flex with the movement of the truss.



The crown molding is secured to the bottom chord of the truss and not to the partition wall. This allows the crown molding to slide up and down over the interior partition wall, disguising any cracking that may occur.

Windows

The key concepts for windows in cold climates are selecting the proper U-value and solar heat gain coefficient for the application, proper air sealing around the window frame, and effective flashing techniques for keeping water out.

Window Construction

Window construction has many different components, each of which play a role in the durability and efficiency of the window. Window construction considerations include the type of frame, the number of glazings of panes of glass in the frame, the spacing between each glazing, the type of gas fill between the glazings, and the type and orientation of coatings on the glass surface.

Window Frame Materials

There are four common types of window frame material; vinyl, fiberglass, wood, and metal.

Vinyl frame windows are the most common and most readily available. Vinyl frames have many positive attributes that make them popular. The are resistant to decay and moisture damage. Vinyl frame windows take very little maintenance. Vinyl frames are available in a variety of colors, including dark frame colors that are available as an exterior surface or cladding. Previous generations of vinyl windows that were colored all the way through experienced problems with frame warping because they absorbed too much heat. A drawback to vinyl frame as a material choice is the lack of rigidity compared to other frame types.

Similar to vinyl windows, fiberglass frame windows are very decay and moisture resistant and require little or no maintenance over the life of the window. Fiberglass frames are more rigid than vinyl frames, often making fiberglass a better choice for very large windows, or windows with three or four panes. Multiple pane windows increase the overall weight of the unit considerably, and the stiffness of fiberglass can be more suited to this application. Fiberglass window frames can also be filled with foam, which increases the efficiency of the window.

Wood frame windows can offer a different look than vinyl or fiberglass, but there is considerably more maintenance involved. Wood windows will swell and shrink with changes in temperature and humidity and can be subject to water damage or decay. The frames must be painted or stained regularly for protection against moisture.

Metal window frames are the least energy efficient material available. Metal has essentially no insulating value and creates a direct conductive path for heat loss from inside to outside. Metal window frames are the most durable and the strongest, and for applications where there are large glass fronts metal may be necessary for structural reasons. Metal frames are available with thermal breaks which increase the efficiency of the window slightly.

Number of Glazings

The number of glazings or panes of glass in a window has a great effect on the overall efficiency of the window. Generally, the more panes of glass, the greater the insulating value of the window. Without considering special glass coatings or gas fill, each pane of glazing equals an approximate R-value of R-1. However, there is a limit to the number of panes that can be used practically. Larger windows or windows with three or more layers of glazing require a stronger and more robust frame system to handle the weight.

This is a drawing of a typical log wall cross section with interior furring. Insulating a log wall is challenging

Spacing Between Glazings

In addition to the number of glazings, the spacing between each glazing is important to the performance of the window. Optimizing the spacing between each layer of glazing increases the insulating value.

Window panes that are too close together result in excessive conductive heat loss. Many older windows had a very narrow spacing between panes which reduced efficiency.

Window panes that are spaced too far apart will suffer from convective heat loss as the increased width allows for more efficient convective loops to form between panes.

The optimum spacing between layers of glazing is typically between 3/8" and 5/8". The efficiency of the window can be further increased by filling the space between each pane with heavier than air gasses.

Gas Fill

Heavy gasses such as Argon and Krypton reduce convective losses. The heavy gas slows down the convective loop that forms between the panes of glass, which in turn slows down the transfer of heat from inside to outside.

Most modern windows with special gas fill can be identified by visible fill ports between the glazings. Some windows are even assembled in heavier than air gas rooms, eliminating the fill ports altogether.

Glass Coatings

Low emissivity coatings are nearly transparent films that are applied to the inner surface of the panes of glass to increase efficiency. Low emissivity coatings can be identified by shining a flashlight directly into the window. The coating will visible as an extra reflection with a green or bronze tint.

The purpose of these coating is to reflect heat either inside or outside of the building. For heating climates, it is desirable for the window to reflect heat back inside of the building which reduces heat loss. For cooling climates, windows are designed to reflect heat outdoors.

The orientation of the low emissivity coating and whether it is designed for reflecting heat inside or outside of the building affects the Solar Heat Gain Coefficient, or SHGC, dramatically. A high SHGC is desirable in cold climates. Don't assume that windows stocked at the local building supply store are best for cold climates, it is worthwhile to shop around for the best selection.



This photos of a triple pane window shows three very bright double reflections in the front, and several dimmer reflections towards the back. The bright double reflections are each side of each pane of all three panes of glass. The dimmer reflections are from the low emissivity coating on the inside of the panes.

Window Efficiency

All of the previously cited factors add into the overall efficiency of the window unit. The overall resistance to heat loss is measured by the U-value. The amount of heat energy from sunlight the window lets into the building in the form of solar radiation is the SHGC, or solar heat gain coefficient. Window are also rated by the amount of air leakage. Each window type and style is categorized into various Energy Star regions to simplify window selection. All windows used in new construction must be National Fenestration Rating Council, or NFRC, rated.

U-Value

The U-value is a rating of the insulation value of the window as a whole unit, including the glass and the frame. U-value ratings are a numerical value between 0 and 1, and typically range from 0.15 for very good insulating windows to 0.50 for poor insulating windows.

The U-value rating is the inverse of the R-value rating. The U-value can be used to find the R-value and vice versa, which can be helpful for heat loss analysis or comparing building products. The lower the U-value, the greater the insulating value of the window. In cold climate construction, low U-value windows are more efficient and a better choice all other factors being equal.

Solar Heat Gain Coefficient

The SHGC, or solar heat gain coefficient, is a numerical rating of how much heat energy from the sun is allowed into the building. The higher the SHCG, the more heat energy is allowed into the building. In cold climates, high solar heat gain is desirable in almost all residential applications.

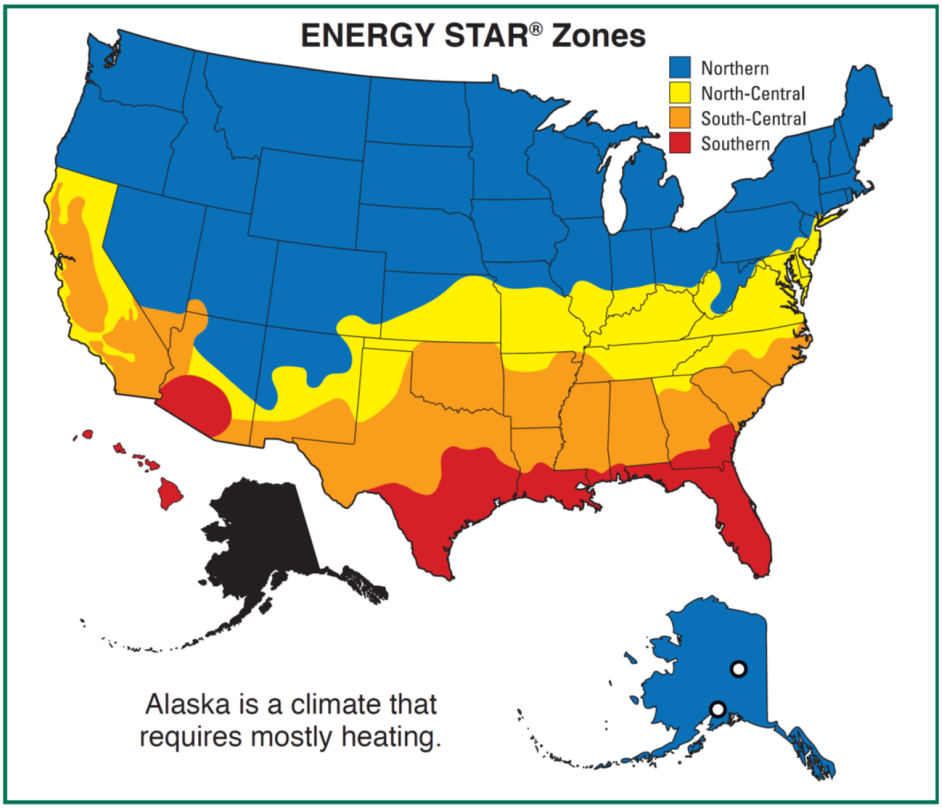
Air Leakage

All windows are rated for how much air the window assembly leaks when tested. This is a numerical value in cubic feet per minute of air leakage at a specific air pressure, based on the size of the window.

Operable windows tend to leak more than fixed windows, and sliding windows tend to leak more than casement style. The quality of the weather-strip and the number of latching mechanisms play a role in the overall air leakage measurement.

Energy Star Categories

Windows are grouped into energy star categories in an effort to simplify selection. However, all categories are sold in Alaska, and the stock window selection may not be optimum for the needs of the project. Northern and north central category windows usually have the best compromise of lower U-value and higher SHGC for cold climate building.



This chart from Energy Star shows which categories are applicable to different regions of the unit states. Alaska is listed as a Northern Energy Star Zone, but North Central rated windows may also be acceptable.

U-factor	SHGC	Air Leakage
Windows: U ≤ 0.27 **Windows: U = 0.28** **Windows: U = 0.29** **Windows: U = 0.30** **Skylights: U ≤ 0.50**	**Windows: Any** **Windows: SHGC ≥ 0.32** **Windows: SHGC ≥ 0.37** **Windows: SHGC ≥ 0.42** **Skylights: Any**	**Windows: AL ≤ 0.30** **Skylights: AL ≤ 0.30**
For superior energy performance, select windows with a U-factor of 0.25 or less. If air conditioning is not a concern, look for a higher Solar Heat Gain Coefficient (SHGC) of 0.35–0.60 so winter solar heat can help offset the heating energy need. If cooling is a significant concern and no shading is available, select windows with a SHGC less than 0.32.		
U-factor	**SHGC**	**Air Leakage**
Windows: U ≤ 0.30 **Skylights: U ≤ 0.53**	**Windows: SHGC ≤ 0.40** **Skylights: SHGC ≤ 0.35**	**Windows: AL ≤ 0.30** **Skylights: AL ≤ 0.30**
The larger your heating bill, the more important a low U-factor becomes. For superior energy performance, select windows with a U-factor of 0.25 or less. A low SHGC value reduces summer cooling demand, but also reduces free winter solar heat gain. If you have significant air conditioning costs or summer overheating issues, look for SHGC values of 0.25 or less.		

Energy Star recommends a U-value of 0.25 or less for best energy performance in a heating climate. Also, if air conditioning is not a concern, then a SHGC of 0.35 to 0.60 is optimal.

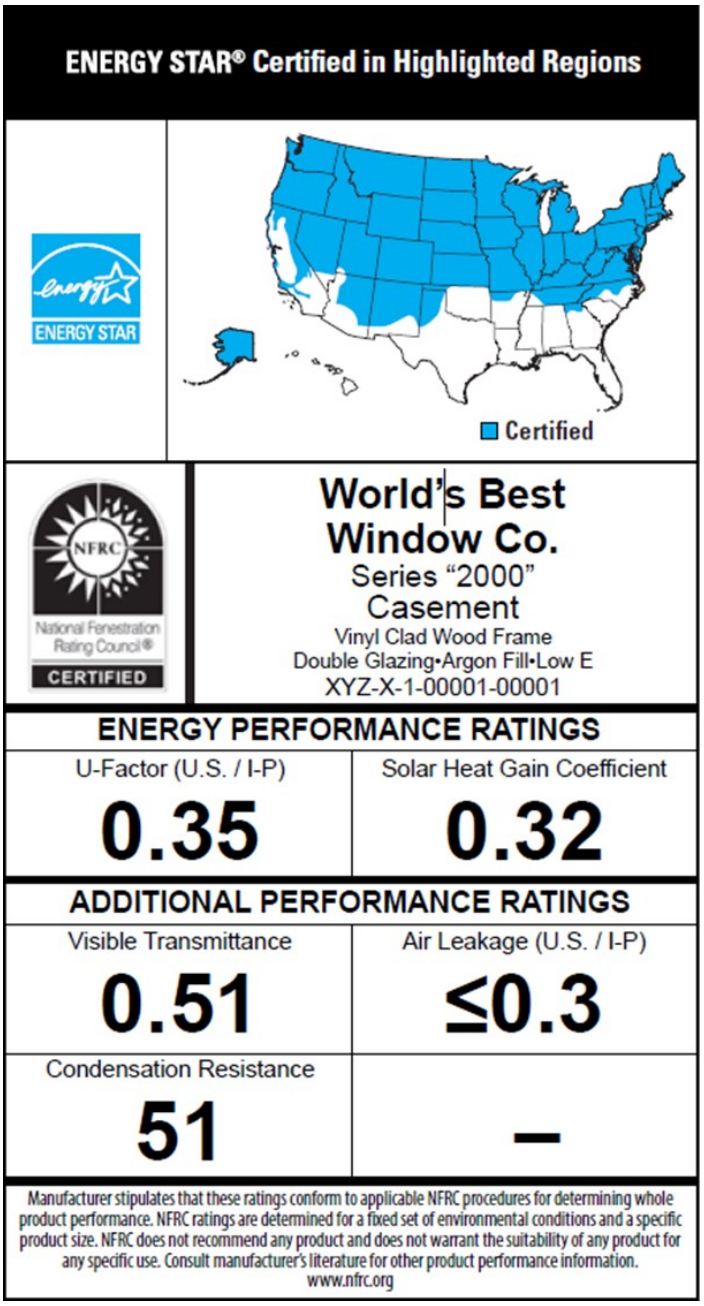
NFRC Ratings

The NFRC, or National Fenestration Rating Council, provides testing and rating for window and door products. The NFRC rating provides a standard comparison for all window and door products in the US.

Each window and door product is labeled with the U-value, the SHGC, visible transmittance, and air leakage. Avoid windows and doors that do not have NFRC ratings, as they likely will not meet energy code requirements.



This photo shows the rough opening of the window filled with foam and ready to be trimmed back.



This is a sample Energy Star rating for a Northern category window. This sticker is applied to the window and allows for comparison of different products. The U-value and the SHGC are listed at the top and are the main criteria for window selection and meeting energy code requirements.

Window Installation

Aside from the window efficiency ratings, window installation technique is important for proper performance. An energy efficient window must be air sealed on the interior to prevent heat loss, and it must be weather sealed on the exterior for durability.

Interior Air Sealing

Interior air sealing of the area between the rough framing opening and the window frame is critical to prevent uncomfortable drafts and heat loss. Low expansion spray foam products designed specifically for window and door installations are available for this application.

Avoid high expansion foams as the foam may warp the frame or even crack the glass as they expand and cure. The use of foam may void some manufacturer window warranties, check the window installation guide. It is recommended that foam be applied in small steps over time rather than trying to fill the entire gap around the window at once. This avoids undue stress on the frame and allows the installer to gauge how much product is necessary.

After expansion of the foam is complete and the product is cured, excess foam can be cut back flush to the interior surface of the framing members.

Exterior Weather Sealing

Exterior weather sealing of the window opening is required for long term durability of the window and the wall framing. The window weather sealing should be integrated into the exterior weather resistant barrier that is required by building code to provide a continuous barrier on the exterior against water penetration.

The window weather sealing should work with the exterior weather resistant barrier to provide a shingling effect that directs any liquid water to the exterior where it can escape from the wall assembly rather than being trapped. The window nailing fins or flanges must be sealed at the top and sides to prevent water infiltration around the rough opening.

The key concept for exterior weather sealing window openings is to never seal over the bottom flange of the window to the siding. Leaving the bottom flange of the window open allows for a drainage path for any water infiltration or condensation that may collect inside the window to escape to the exterior.

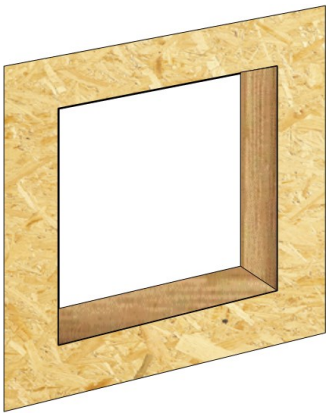
Exterior Weather Sealing & T-111

Installing windows in exterior walls where the sheathing is also the siding, such as with T-111, can present an additional challenge. An acceptable method of weather proofing is to install the windows in the stud wall over the T-11 and caulk and trim over the window flanges. This provides a weather proof assembly, but does not provide a drainage path for any water or condensation on the interior of the window opening to escape.

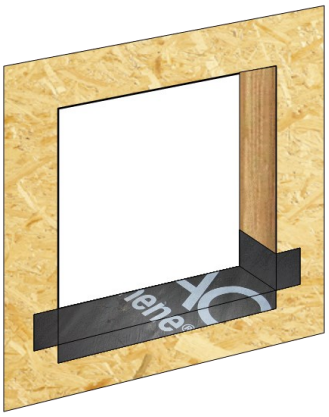
A better practice is to stand up the exterior stud walls and install the weather resistant barrier over the exterior side as normal. Windows are then installed before the T-111 is applies, and so can follow the “after WRB” method of weatherproofing. T-111 is then installed and trim applied around the edges of the window.

Installing a Flanged Window - Before WRB

- Level sill and clean sheathing.



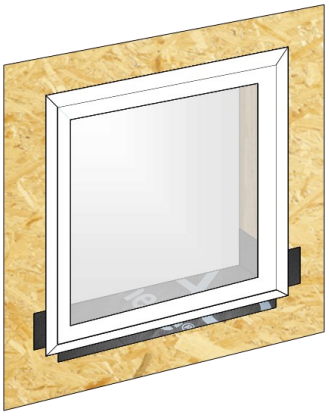
- Install self-adhering waterproofing to sill, bring ends up 6”.



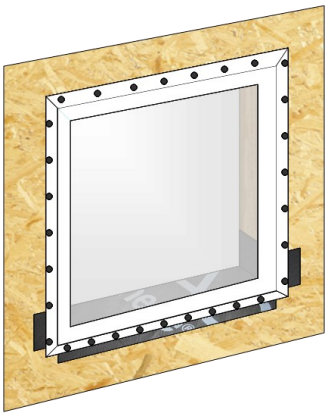
- Caulk outside edges of head and side jambs.



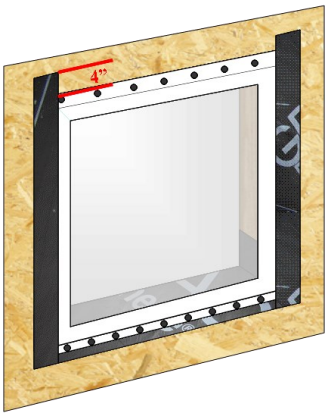
- Install window in opening.



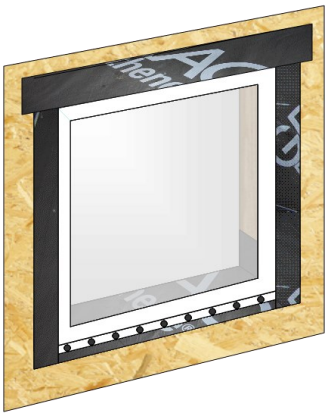
- Check for level and nail or screw (open and close window, adjust spacers, remove shims etc.).



- Install self adhesive waterproofing along sides of jamb, even with bottom flashing and 4” above top of head flange.



- Install self adhesive waterproofing over the top flange, extending 1” beyond sides of jamb flashing.



- Wrap building, including over windows, with WRB. Tape seams at top and side of jamb using same pattern as flashing underneath. DO NOT tape at bottom of window.

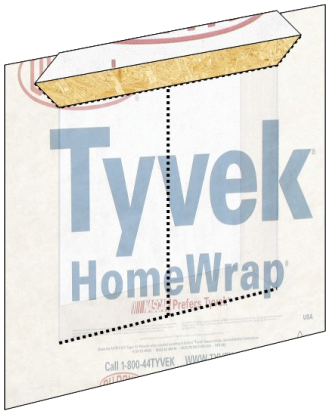


Installing a Flanged Window - After WRB

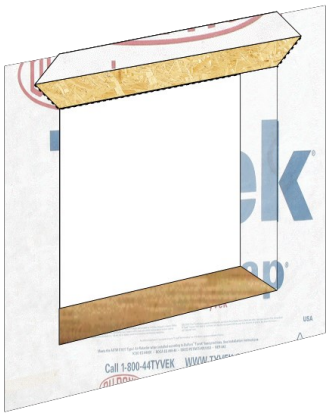
- Make “I-cut” in WRB. 45° slits should be 8” deep to create header flap.



- Roll up header flap and tape in place temporarily.



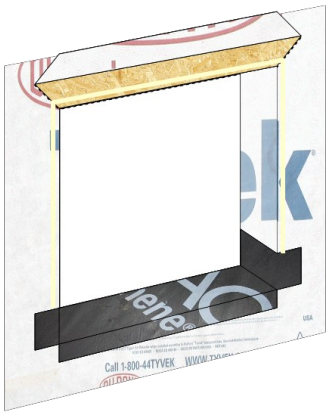
- Fold side flaps into rough opening. Side flaps should cover interior facing framing stud.



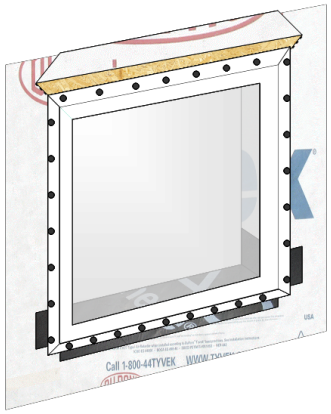
- Fold side flaps into rough opening. Side flaps should cover interior facing framing stud.



- Install self-adhering waterproofing to sill, bring ends up 6”. Caulk outside edges of head and side jamb.



- Install window in opening, check for level and nail or screw.



- Install self adhesive waterproofing along sides of jamb, even with bottom flashing and 4” above top of head flange. Install self-adhesive waterproofing over the top flange, extending 1” beyond sides of jamb flashing.



- Flip down upper flap of WRB and lay flat, tape along all cuts in WRB. DO NOT tape at bottom of window. Seal around window opening at interior.



Drip Cap Flashing

Drip cap flashing is an additional piece of flashing that is installed over the head of the window. The purpose of drip cap flashing is to divert liquid water that might otherwise infiltrate around the window or that is running down the wall from above to the exterior. Drip cap flashing is recommended in areas with reduced or no roof overhang protection, or in very wet climates.

Sill Pan Flashing

Sill pan flashing is a flexible membrane of self adhering waterproof material that is required on all windows. The purpose of the sill pan flashing is to catch any liquid water that occurs inside the wall or window from leakage above or condensation and direct it outward. The sill plan flashing also provides protection for the rough framing from water damage associated with any leakage or condensation.



This photo shows the installation of a drip cap flashing to protect the trim and window below. Drip cap flashing should be placed on the exterior sheathing before the weather resistant barrier so water the penetrates the siding is directed outward.



This photos shows self-adhering membrane applied to the rough opening window sill. The self-adhering water proofing is run up each side of the opening six inches to provide additional protection and prevent leakage at the joint between the sill and the jack stud.

Doors

Exterior doors come is three common material types; wood, steel, and fiberglass. Windows or glazing in exterior doors dramatically reduces their energy efficiency.

Wood Doors

Wood doors are available either as insulated or uninsulated. For cold climate construction, only insulated doors should be considered in an exterior application. Hollow core doors, which are not typically acceptable for exterior use, are rated at approximately R-2. Solid core doors that are wood all the way through are slightly better at R-2 to R-3 insulating value. As a material, wood is subject to water damage and warping. Wood doors require maintenance may not be ideal where directly exposed to weather or where durability is a concern.

Metal Doors

Metal doors are constructed of a thin metal skin surrounding a foam core. A wood stile is typically used for mounting hardware and providing rigidity around exterior edges. Foam core metal doors with no thermal break are rated at an average R-value of R-3. The use of a thermal break, usually wood, around the exterior edges of the door adds additional insulating value to the door and R-values can be as high as R-5.





The door on the left has a wood thermal break around the exterior edge. Although wood is not a great insulator, it is much better than metal and greatly improves the energy efficiency of the assembly. The door on the right has no thermal break. The metal around the edges of the door greatly increases conductive heat loss.

Fiberglass Doors

Fiberglass exterior doors consist of a fiberglass skin over a foam core. Wood inserts are used for hardware mounting. Fiberglass doesn't warp or decay like wood, and is less conductive than metal. Fiberglass doors can achieve R-values of up to R-6.

Weather-Stripping

When weather-stripping doors, choose the appropriate door sweeps and thresholds for the bottom of the doors. Doors should fit snugly with no visible light at the bottom when shut.

Weather-strip the entire door jamb, and apply one continuous strip along each side. Using multiple pieces is less efficient and less durable. Make sure the weather-stripping meets tightly at the corners, as this is the location where air leakage most commonly occurs.

Use a thickness that causes the weather-stripping to tightly press between the door and the door jamb when the door closes, without making it difficult to shut.

Air Sealing Doors

Air sealing exterior door openings is very similar to air sealing window openings. The gap between the rough framing around the door and the door jamb should be filled with expanding foam, and then trimmed back flush with the interior surface of the studs. Fiberglass batts should never be used for air sealing.

Apply foam in small steps to prevent warping the door frame. Overfilling can cause issues with closing the door, and it is difficult to remove cured foam. Low expansion foam meant for windows and doors is recommended. The interior vapor retarder should be ran all the way to the door jamb and sealed with acoustical sealant or vinyl tape as appropriate.



When the door is shut, there should not be any visible light which indicates a path for air leakage.



This photo shows the gap between the rough opening and the door frame has been filled with foam and trimmed back where necessary. Six-mil polyethylene vapor retarder is sealed to the rough opening studs with acoustical sealant, which works well here since it will be sandwiched between the wood and the interior finish material.

Building Design Challenge

For this challenge, select the building components based on one of the four climate regions. For each decision, write down one reason why that particular choice was made:

Climate Zone:_____

Community:_____

Foundation Type:_____

Exterior Wall Type:_____

Roof/Ceiling Type:_____

Heating/Domestic Hot Water:_____

Ventilation System:_____

Glossary

ACH - Air Changer per Hour: ACH is an abbreviation for air changes per hour. Air changes per hour is the number of times in one hour that the entire volume of air inside of a building is exchanged at a particular pressure. Air changes per hour is typically expressed at a neutral pressure for natural air leakage, or at negative 50 pascals of pressure with reference to the outside of the house.

Air, Makeup: Outdoor or transfer air that is replacing exhaust air and exfitration. Not the same as combustion air.

Air, Outdoor: Outdoor air that enters the building through ventilation, infiltration, and/or intentional openings.

Air, Transfer: Indoor air moved from one space to another.

Back Drafting (Spillage): Byproducts from the combustion process, including carbon monoxide, that enter the interior of the building from a heating appliance.

Blower Door: A calibrated fan assembly designed to be placed in an exterior door frame with the purpose of pressurizing or depressurizing the building in order to take readings to determine the air leakage of that bulding.

BTU - British Thermal Unit: The British Thermal Unit is a unit of energy that is commonly used to describe the heat value of home heating fuels, as well as to describe the heat loss through building components. A BTU is the amount of energy required to raise one pound of water one degree Fahrenheit.

CFM - Cubic Feet per Minute: CFM is a unit of measurement that is used to describe airflow. The term CFM is most commonly encountered in regards to fan flows or as an air leakage number from blower door testing.

Conditioned Space: Space within the thermal envelope that is directly or indirectly heated or cooled.

Draft: Pressure difference that compels combustion products to the atmosphere outside the building.

Direct Vent Appliance: All combustion air comes from the exterior, and all combustion gasses are discharged to the exterior. No openings from the appliance or the venting system are present inside of the building.

Flashing: Thin pieces of solid material such as sheet metal or self-adhering modified bitumen that is used to divert water to the exterior of a wall or roof assembly, often in conjunction with underlayment or weather resistant barrier.

Induced Draft: Pressure difference created by the temperature of exhaust gasses, a combustion chamber fan, and the height of the chimney of a combustion appliance. Natural draft appliances have a negative pressure in the vent with reference to the interior of the building.

Infiltration: Infiltration is a term used to describe uncontrolled air leakage into or out of a building. Infiltration is the random air leakage through unintentional openings in the building envelope.

Insulation: Insulation is a material or substance that is used to slow the rate of heat loss through a building assembly. Insulation does not stop the flow of heat, it can only slow down heat loss.

Natural Draft: Pressure difference created by the temperature of exhaust gasses and the height of the chimney of a combustion appliance. Natural draft appliances have a negative pressure in the vent with reference to the interior of the building.

Negative Air Pressure: Negative air pressure is less than atmospheric pressure. In the context of building science, negative air pressure occurs when the pressure inside of a house or dwelling is less than the pressure outside. Negative air pressure promotes air infiltration into a building.

Mechanical Draft: Pressure difference created by the combustion appliance draft fan. Mechanical draft appliances have a positive pressure in the vent with reference to the interior of the building.

Positive Air Pressure: Positive air pressure is greater than atmospheric pressure. In the context of building science, positive air pressure occurs when the pressure inside the house is greater than outside of the house. Positive air pressure inside of a house promotes air exfiltration, or air leaving the house.

Thermal Boundary: The thermal boundary is the space of assembly that separates the conditioned or heated spaces from unconditioned space. The thermal boundary typically occurs where the insulation is located in the building assembly. The thermal boundary may be intentional or unintentionally located in the building. For proper performance from a building science perspective, the thermal boundary should align with the pressure boundary to slow the rate of heat loss from a building.

Pascal: A metric unit of pressure. 50 Pascals equals 0.2 inches of water column.

Pressure Boundary: The pressure boundary is defined as the place in a building assembly where there is more than 50% pressure drop between the conditioned and unconditioned space. The pressure boundary typically occurs where the vapor retarder or air barrier separates the conditioned space from the unconditioned space. A blower door can be used to positively identify the location of a pressure boundary by taking pressure differential measurements on both sides of a building assembly. Ideally, the pressure boundary is aligned with the thermal boundary, so that heat loss and air leakage are effectively reduced.

Vapor Retarder: Material designed to retard the flow of air and moisture vapor. Used on the interior or warm in winter side of building assemblies. There are three classes of vapor retarder materials, based on permeability:

Class 1: 0.1 Perms or less

Class 2: 0.1 Perms to 10 Perms

Class 3: Greater than 10 Perms

Weather Resistant Barrier (WRB): A sheet barrier applied under the exterior siding to resist liquid water infiltration and act as a secondary barrier against exterior moisture, while at the same time allowing water vapor to pass through from the interior. Must exceed 10 perms.

WRT - With Reference To: The amount of pressure in one area WRT another area. Typically negative pressure in the CAZ WRT the outside