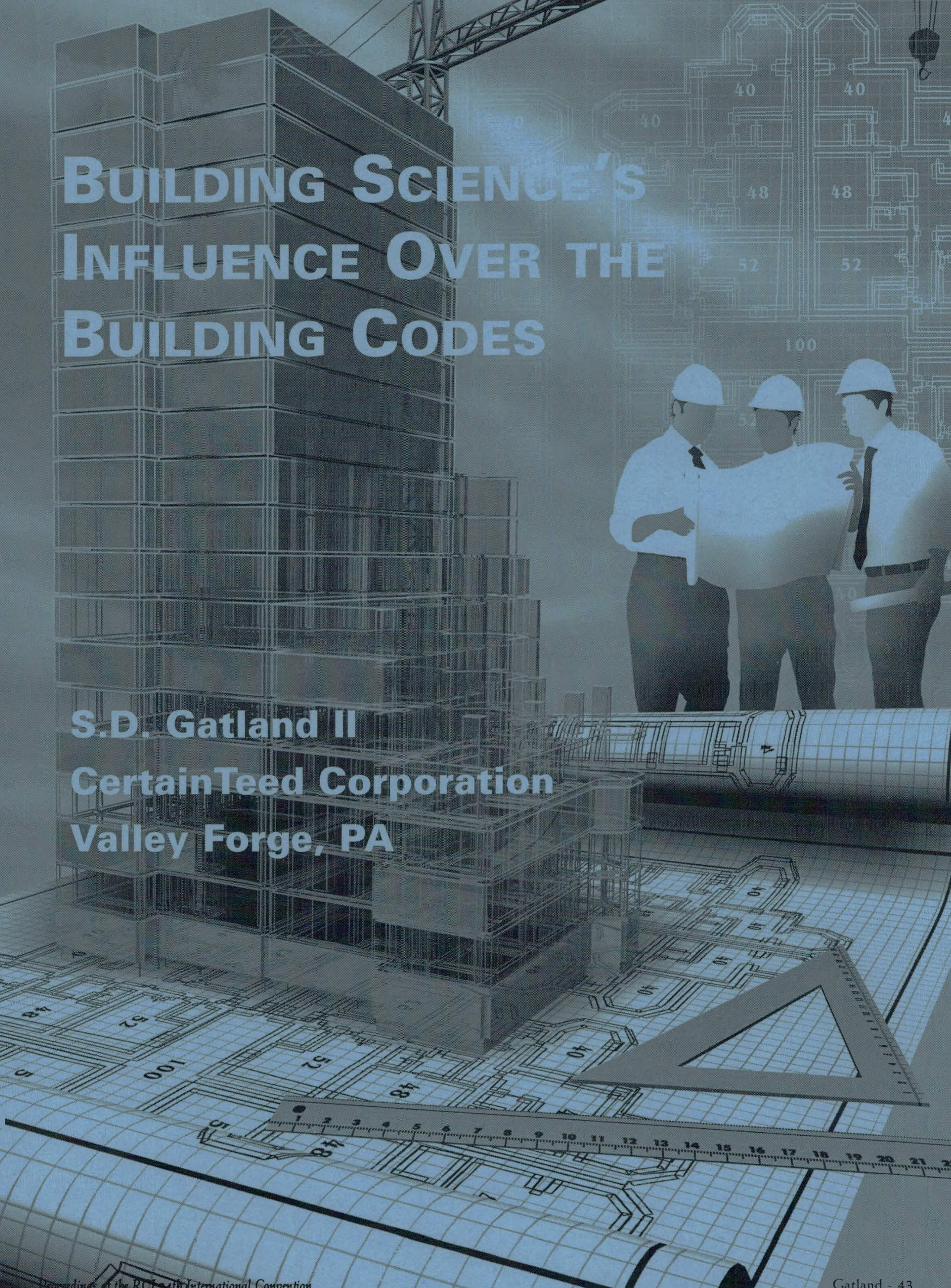

BUILDING SCIENCE'S INFLUENCE OVER THE BUILDING CODES

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ABSTRACT

Many changes to the International Residential Code are related to building envelope design recommendations based on recent climate zone designations provided by the International Energy Conservation Code. The building science technical community has long recognized the influence of temperature, precipitation, and humidity on building envelope performance, as well as material selection and placement in the assembly. Historical construction practices regarding interior vapor retarder use and placement, air barrier specifications, roof system ventilation, and crawl space ventilation have changed from traditional recommendations to practices not allowed until recently.

The purpose of this paper is to provide an overview of the building envelope research and analysis conducted to support the various changes to the code language. Vapor retarder and air barrier requirements will be reviewed, as well as the allowance of unvented attic and crawl space assemblies. A thorough technical literature review detailing issues related to energy efficiency, moisture management, and building envelope performance will be discussed.

SPEAKER

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Building Science's Influence Over the Building Codes

ABSTRACT

Many changes to the International Building Code (IBC) and International Residential Code (IRC) are related to building envelope design recommendations based on recent climate-zone designations provided by the International Energy Conservation Code (IECC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1. The building science technical community has long recognized the influence of temperature, precipitation, and humidity on building envelope performance, as well as material selection and placement in the assembly. Historical construction practices regarding interior vapor-retarder use and placement, air-barrier specifications, and roof-system ventilation have changed from traditional recommendations to practices not allowed until recently.

The purpose of this paper is to provide an overview of the building envelope research and analysis conducted to support the various changes to the code language. Vapor-retarder and air-barrier requirements will be reviewed, as well as the allowance of unvented attic and cathedral roof/ceiling assemblies. A technical literature review detailing issues related to energy efficiency, moisture management, and building envelope performance will be discussed. In addition, the concept of hygrothermal analysis will be presented as a method for predicting building envelope performance.

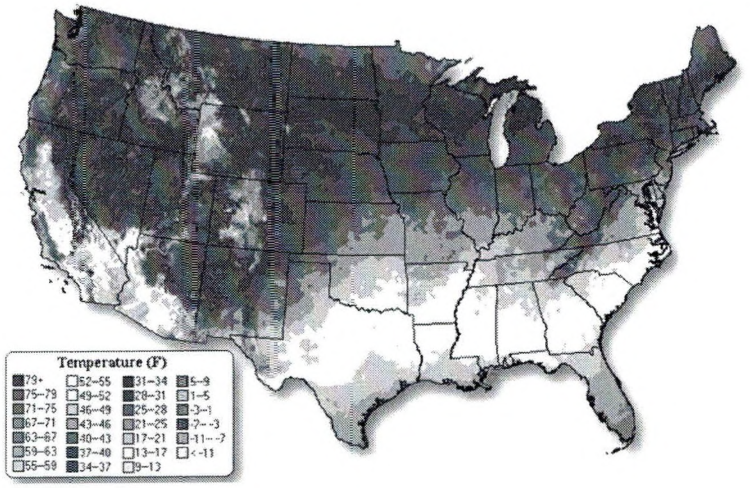


Figure 1 – Average minimum air temperature based on annual climatology data between 1971 and 2000 (Copyright © 2004, Spatial Climate Analysis Service, Oregon State University, www.ww.ocs.oregonstate.edu/prism. Map created Feb 20, 2004.)

INTRODUCTION – CLIMATE CONSIDERATIONS

New climate classifications proposed by Briggs et. al (2003), were incorporated into the 2003 IECC and ASHRAE Standard 90.1 (ASHRAE 2004). The changes categorize the U.S. into several hygrothermal regions, which take into account exterior air temperature, relative humidity, and precipitation. Historical geographic weather data were used to define air temperature extremes that determine energy efficiency requirements (*Figure 1*).

In addition, historical precipitation data were used to further define moisture-related building envelope requirements (*Figure 2*). Lstiburek (2002) categorized North America into several hygrothermal regions, which take into account exterior temperature, relative humidity, and precipitation. The combination of geographical weather information creates a climate zone map (*Figure 3*).

Generally speaking, building envelope design in cold and extreme cold climate zones focuses on heating systems, while building envelope design in hot/dry and hot/humid climates focuses on air conditioning systems. These climate zones also dictate how construction must focus on moisture loads and in keeping moisture out of buildings. Areas labeled "mixed" experience both hot and cold climates and often can be heating- or cooling-

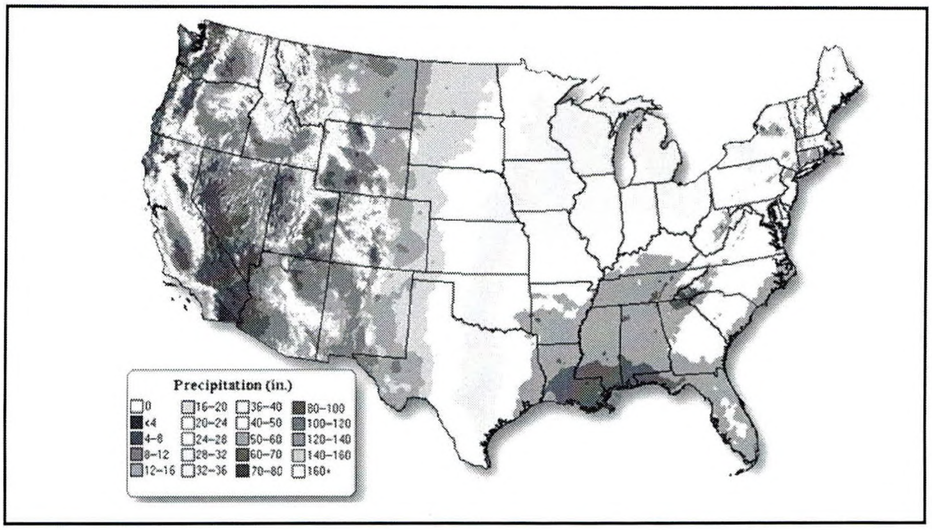


Figure 2 – Average precipitation based on annual climatology data between 1971 and 2000 (Copyright © 2004, Spatial Climate Analysis Service, Oregon State University, www.ww.ocs.oregonstate.edu/prism. Map created Feb 20, 2004.)

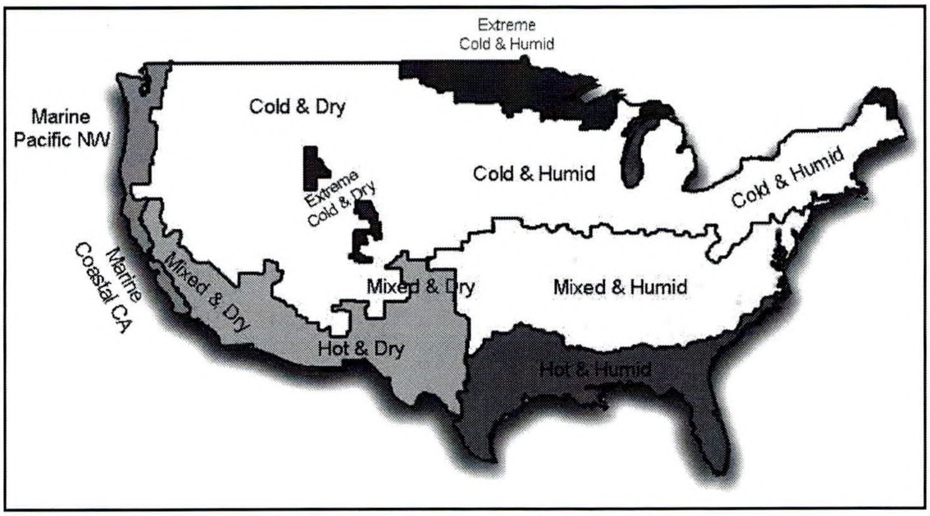


Figure 3 – United States climate zone designations. (Source: DOE Building America Program.)

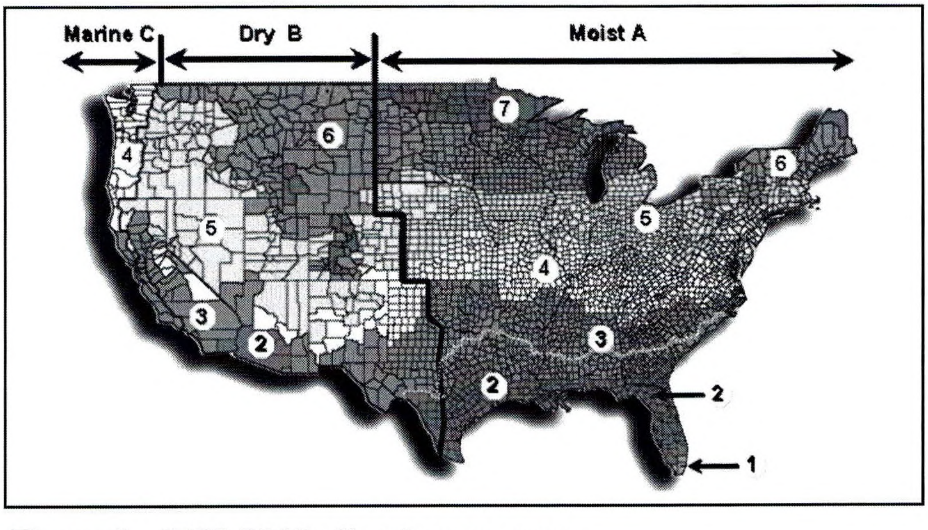


Figure 4 – IECC 2003 climate zone map.

dominated. The IECC (2003, 2006) and ASHRAE Standard 90.1 (2004) climate zone maps divide the continental United States into seven climate zones for energy efficiency and moisture control. Regions of Alaska are considered climate zone 8.

The purpose of this paper is to provide an overview of the building envelope research and analysis conducted to support the various changes to the code language. Vapor-retarder and air-barrier requirements will be reviewed, as well as the allowance of unvented attic and cathedral roof/ceiling assemblies.

VAPOR RETARDERS

Water vapor will move or diffuse through building materials when areas of high vapor pressure and low vapor pressure exist on opposite sides of that material. The movement is from the high-vapor pressure side to the low-pressure side (*Figure 5*). Historically, two North American building codes – the International Code Council (ICC 2003) and the National Building Code of Canada (Canadian Commission on Building and Fire Codes 2005) require that vapor retarders have a water vapor permeance of 1 perm or less when tested in accordance with the American Society for Testing and Materials (ASTM) standard test method ASTM E 96 (2005) using standard, dry-cup conditions of 0 and 50 percent relative humidity, creating a mean relative humidity of 25 percent (*Figure 6*).

Gatland (2005) presented experimental water vapor permeance results for several common interior building materials over a wide range of mean relative humidities. *Figure 7* displays a simplified version of the data between 25 and 95 percent. The permeance data were plotted on a log scale in order to visualize the differences between materials. If building materials are placed into

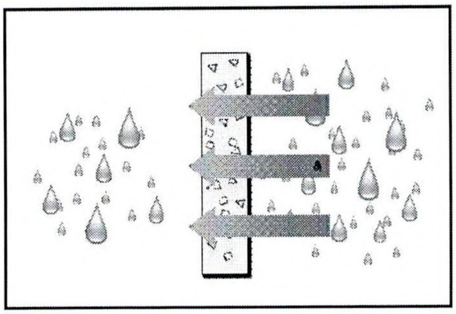


Figure 5 – Concept of water vapor diffusion.

Figure 6 – ASTM E 96 cup test samples.

four categories with respect to water vapor permeance, vapor barrier (0.1 perm or less), vapor retarder (1 perm or less), semi-permeable (1 to 10 perms), and permeable (greater than 10 perms), then products can be described as fitting into one or several categories.

Historically, interior vapor retarders were required in many of the mixed heating- and cooling-dominated climates (Figure 3) of the U.S. In 2003, the IRC and the IECC adopted changes to interior vapor retarder requirements based on numerous U.S. Department of Energy-funded research programs and the support of the building science technical community. After 2003, climate zones 1 through 3, 4A, and 4B, would not require an interior vapor retarder (see *Figure 8*). Building envelopes in climate zone 4C (the Pacific Northwest) would still require an interior vapor retarder, based on research conducted on various wall assemblies located in the Seattle, Washington, region (Tichy *et. al*, 2003; Gatland *et. al*, 2007).

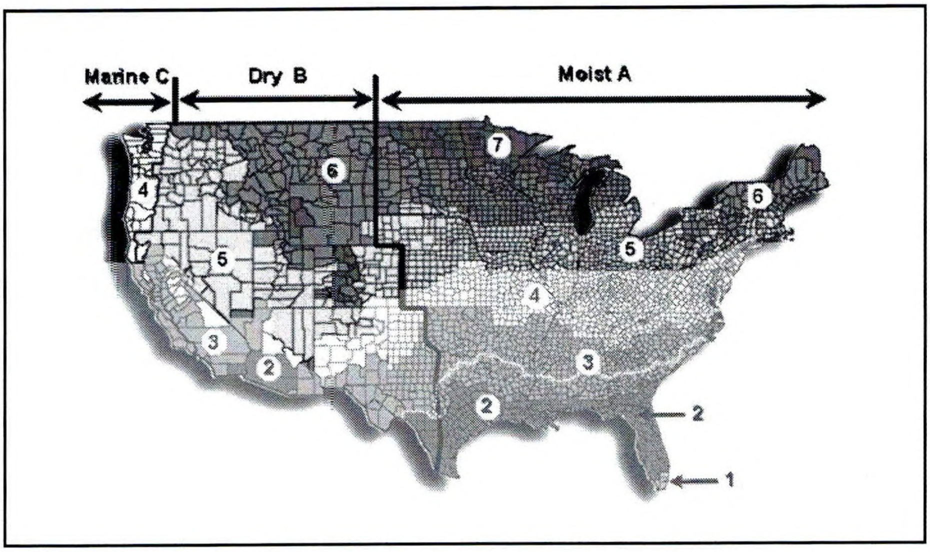


Figure 8 – IECC (2003) interior vapor retarder requirements – climate zones 4C, 5, 6, 7, and 8.

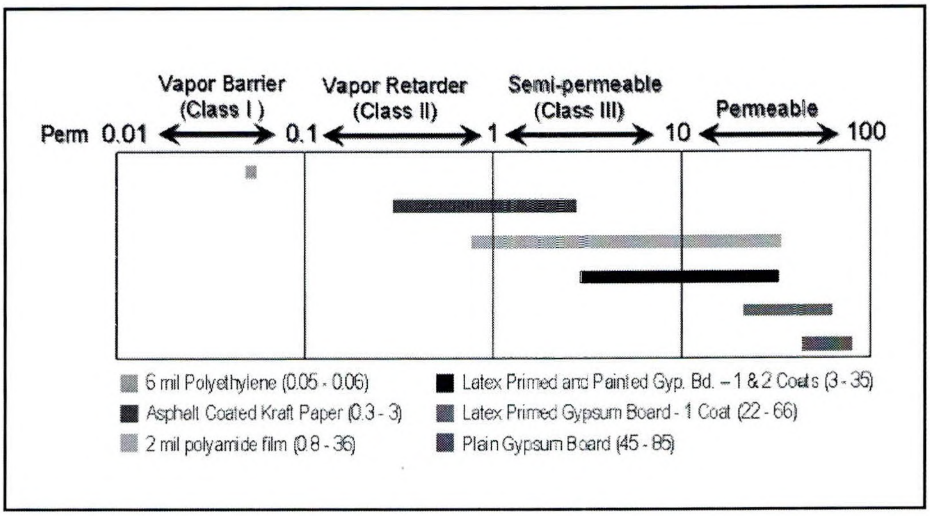


Figure 7 – Common interior building materials' water vapor permeance range.

Joint research conducted by Pennsylvania State University, Oak Ridge National Laboratory, and the University of Waterloo examined the benefits of ventilation spaces between wall claddings and water-resistive barriers in wood-framed wall assemblies (Burnett 2004). Based on this research and numerous hygrothermal simulations of wall assemblies with variations on cladding type, cladding ventilation, and exterior sheathing type (Karagiozis and Desjarlais, 2005) in geographic locations covering all of the climate regions in the continental United States, Lstiburek (2004) proposed changes to the 2006 IECC that provided minimum interior vapor retarder requirements dictated by wall design.

Section 402.5 "Vapor Retarder Class" of the proposed 2006 IECC

Climate Zone	Allowance of Class III Vapor Retarder
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ R2.5 over a 2 x 4 wall Insulated sheathing with R-value ≥ R3.75 over a 2 x 6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ R5 over a 2 x 4 wall Insulated sheathing with R-value ≥ R7.5 over a 2 x 6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with R-value ≥ R7.5 over a 2 x 4 wall Insulated sheathing with R-value ≥ R11.25 over a 2 x 6 wall
7 and 8	Insulated sheathing with R-value ≥ R10 over a 2 x 4 wall Insulated sheathing with R-value ≥ R15 over a 2 x 6 wall

Table 1 – 2006 IECC Table 402.5.1, Class III vapor retarders.

code language classifies vapor retarders into three categories: I (0.1 perm or less), II (0.1 to 1.0 perm), and III (1.0 to 10 perm). See *Figure 7.* Vapor retarders are classified using the ASTM E 96 desiccant method or Procedure A. Class I and II vapor retarders are required in climate zones 4C, 5, 6, 7, and 8. Exceptions are provided for basement walls, below-grade wall sections, and construction in which moisture or freezing conditions will not damage the building materials.

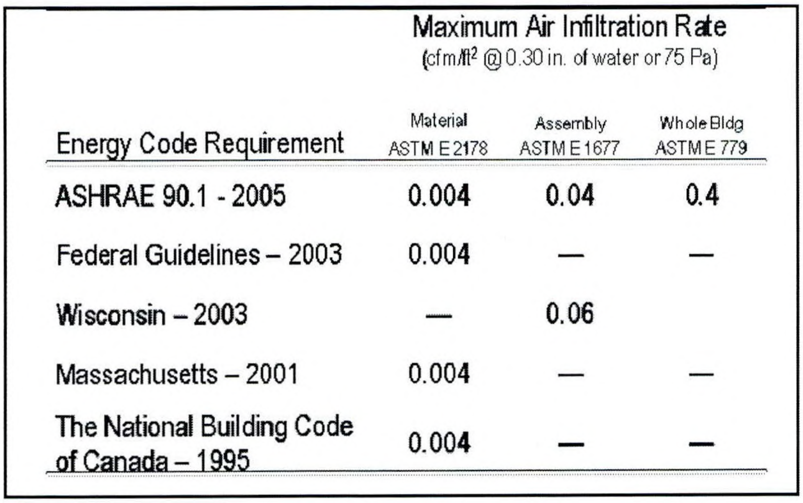
Guidance is provided for the allowance of Class III vapor retarders when design conditions exist that promote drying through the use of ventilated claddings or reduce closed-cavity condensation potential through the use of exterior insulating sheathings. One acceptable Class III vapor retarder would be latex-painted, interior gypsum board. *Table 1* summarizes the climate-zone-specific combinations of vented claddings, exterior sheathing materials, and insulated sheathings that permit the use of Class III vapor retarders.

Vented claddings include vinyl lap or horizontal aluminum siding applied over an approved weather-resistive barrier. Additional claddings, such as brick veneer, require a 1- to 2-inch clear airspace with vented openings as specified by Section R703.7.4.2 of the IRC.

BUILDING ENVELOPE AIR-TIGHTNESS

Unrestricted flow of air against or through a building can have an enormous impact on the building's temperature and energy efficiency. In cold months, warm air leakage to the exterior and thrust of cold winds against the exterior surface of a building can cause interior temperatures to lower, requiring extra work from the heating system and additional utility bills to keep the interior warm. The same is true with cool air leakage and warm air intrusion in summer months. Like heat flow, air flow has a strong impact on the building envelope.

Air flow occurs only when there is a difference between the exterior and interior of a building. Air will flow from a region of high pressure to one of low pressure —



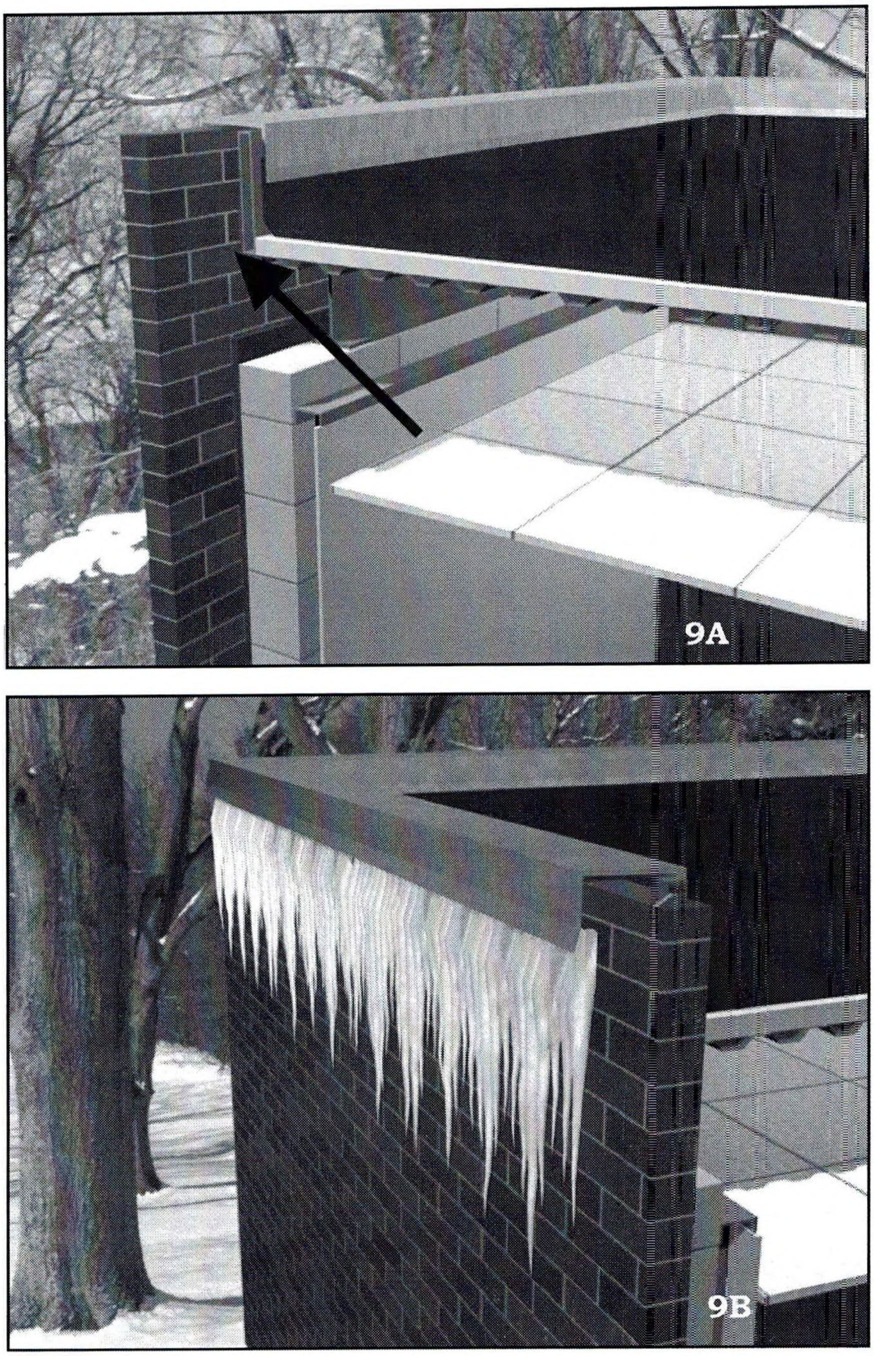
	Maximum Air Infiltration Rate (cfm/ft² @ 0.30 in. of water or 75 Pa)		
Energy Code Requirement	Material ASTM E 2178	Assembly ASTM E 1677	Whole Bldg ASTM E 779
ASHRAE 90.1 - 2005	0.004	0.04	0.4
Federal Guidelines – 2003	0.004	—	—
Wisconsin – 2003	—	0.06	
Massachusetts – 2001	0.004	—	—
The National Building Code of Canada – 1995	0.004	—	—

Table 2 – Summary of commercial building air barrer requirements.

the bigger the difference, the faster the flow. Air-pressure differentials are thus the driving force behind air flow. There are three air-pressure differentials — wind pressure caused by external forces, stack pressure created by warm air rising, and mechanical pressure created by a building's mechanical systems.

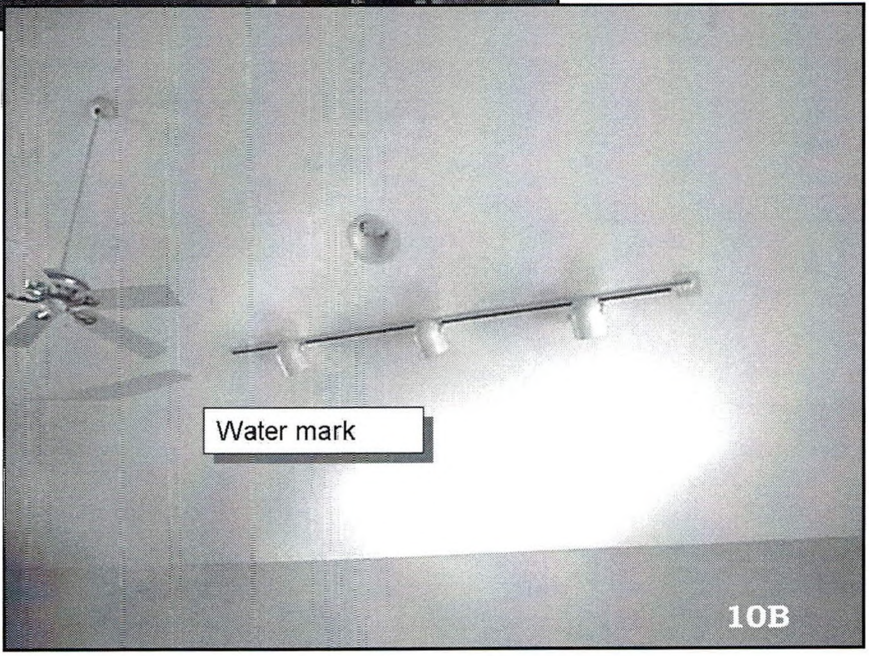
Designing an airtight building envelope is extremely important to a building's performance. Also, adaptive reuse and building renovation projects require special considerations to meet airtightness challenges. Airtight building envelopes help control heat and sound energy, as well as airborne moisture flow and airborne contaminants. Airtight building envelopes even help to control the spread of fire if cavities are properly blocked. In short, airtight building envelopes create more energy-efficient, healthy buildings, which are more durable and require less maintenance. The best way to make an airtight building envelope is by incorporating an air barrier system into the building envelope.

A building material must meet a range of requirements before it can be approved as an air barrier. The most important requirement for air barriers is air impermeability, or not allowing any air to pass through it. Air barrier systems must also be continuous, as well as strong and durable, to stand the test of time and weather of all kinds. Air barriers installed on the exterior of buildings must be able to withstand ultraviolet light in addition to precipitation, freezing, and thawing.



Figures 9A and 9B – Air exfiltration through suspended acoustical ceiling that penetrates the building envelope at the roof parapet and wall interface (9A) causes airborne moisture to deposit at the roof-wall intersection, creating icicle formation during the winter season (9B).

ASHRAE 90.1-2004, Section 5.4.3 – "Air Leakage," describes how to seal the building envelope to minimize air leakage. Areas highlighted for treatment are joints around fenestration and door frames, building envelope intersections (walls, foundations, structural floors, building corners, roofs), building envelope utility penetrations, site-built fenestration and doors, building-integrated ducts or plenums, vapor retarder discontinuities, and all other openings in the building envelope. ASHRAE 90.1 has code-specific requirements for the material alone, the material in an assembly, and for the whole building (*Table 2*). Many of the recommendations are based on research (Anis *et. al,* 2005, Emmerich *et. al,* 2005) and specifications from the Air Barrier Association of America



Figures 10A and 10B – Snow melt on roof due to air leakage (left) and cathedral ceiling surface staining (below) due to surface condensation on the light fixture from airborne moisture transport.

(**www.airbarrier.org**).

When the goal is to control air flow, efforts should be made to compartmentalize the building as much as possible. The purpose of compartmentalization is to isolate connecting spaces and minimize the impact of the stack effect. Disconnect occupied building spaces from the foundation and the roof, as well as rooms next to connecting corridors.

Effective air barriers require special attention at all penetrations. Areas of discontinuity in the building are where many problems can begin. These include roof decks and parapets, windows and doors, wall and floor intersections, at expansion joints, wherever there are brick ties, and at all façade supports.

Figure 9 shows an example of what can happen when air exfiltration carries moisture through poorly sealed crevices in a building all the way to the roof parapet, causing ice damming at the top.

The 2006 IECC, Section 402.4.1 – "Building thermal envelope," describes how to seal the building envelope to limit infiltration. Many of the requirements duplicate specifications outlined in ASHRAE 90.1. Special considerations are described for residential applications, such as dropped ceilings or chases adjacent to the thermal envelope, knee walls, building envelopes separating the garage from conditioned spaces, tubs and showers on exterior walls, multfamily dwelling common walls, and attic hatches.

Common problems with the roof/attic ceiling system are condensation and surface staining. *Figure 10* illustrates the problems that occur with an air-leaky, uninsulated recessed light. Roof snow melt (*10A*) is a symptom of a heat transfer problem due to air movement and the lack of thermal insulation. Condensation accumulating on the light fixture due to airborne moisture transport runs down the slope of the cathedral ceiling, pooling and creating stains at the seams (*10B*), which is visible to the inside.

UNVENTED ROOFING SYSTEMS

As the sizes of homes have increased over the years, traditional attic ventilation has become more and more difficult to achieve, due to architectural details that include open attics, vaulted ceilings, and cathedral ceilings (*Figure 11*). TenWolde and Rose (1999) described the climate-based hygrothermal performance issues related to traditional ventilation techniques. Subsequently, the U.S. Department of Energy's Building America Program funded many research projects related to identifying and measuring the performance benefits of constructing unvented attic applications in warm/humid, warm/dry and mixed/dry climates (Hendron *et. al*, 2003; Parker, 2005; Lstiburek, 2006). Quarles and TenWolde (2004) examined the implications of attic ventilation for homes located in urban wildlife areas at risk for forest fires. The Florida Solar Energy Center (Parker 2005) evaluated the impact and need for attic ventilation in Florida homes through a very extensive and thorough technical literature review.

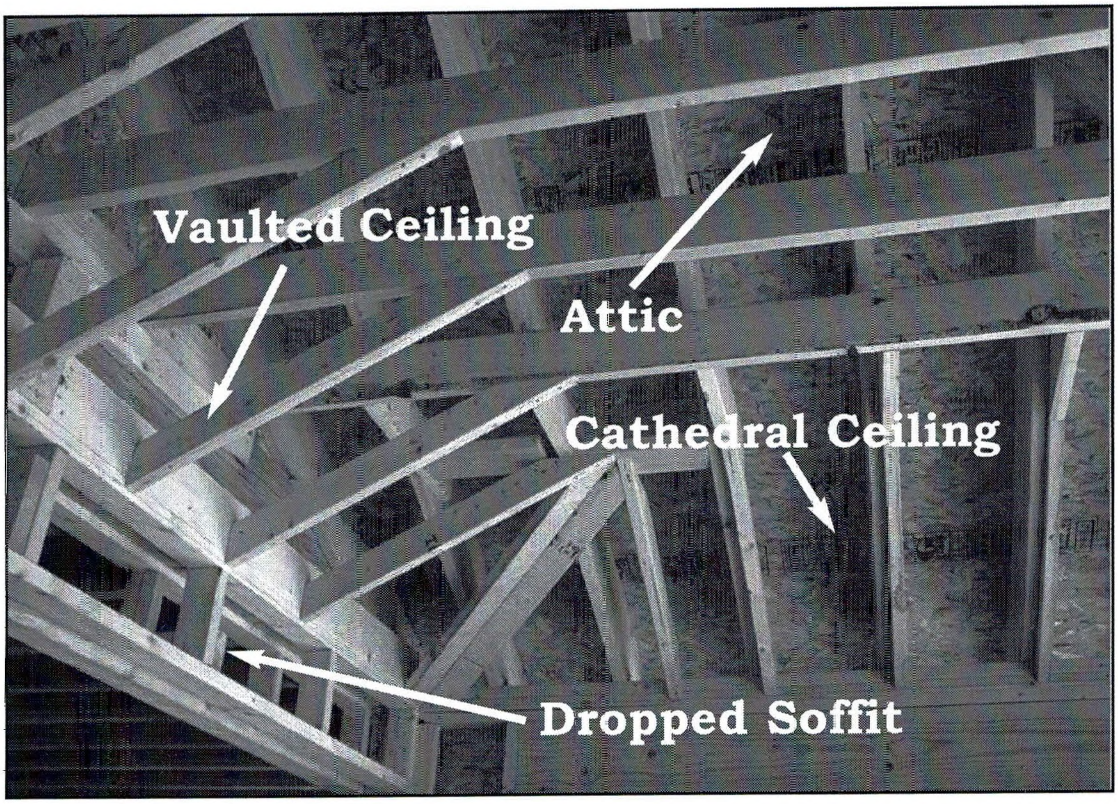
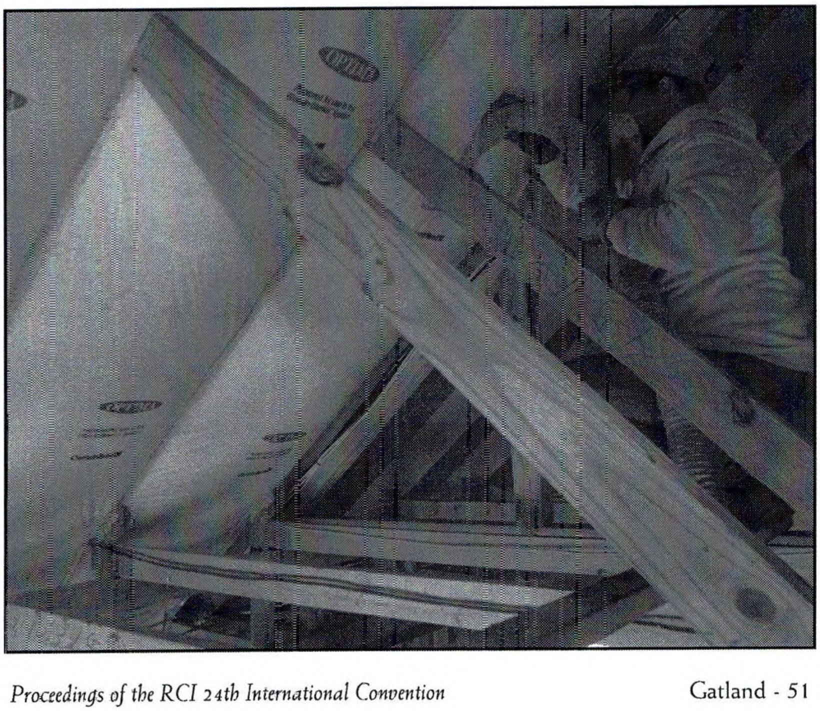


Figure 11 – Difficulties creating traditional attic ventilation.

In 2003, the International Residential Code adopted language allowing unvented attic-assembly design strategies. Section 806.4 – "Unvented attic assemblies" – describes the space between ceiling joists of the top story and the roof rafters as the attic area. Unvented attic assemblies require that the space is completely contained within the building thermal envelope (*Figure 12*). No interior vapor retarders are installed on the ceiling side (attic floor) of the unvented attic assembly. Wood shingle or shake roofs require a minimum ¼-in vented air space between the



Figures 12A and 12 – Warm- and humid-climate, air-impermeable insulation at the underside of roof-deck application (above). Warm- or mixed- and dry-climate, air-permeable insulation at the underside of tile roof deck application (right).

Climate Zone	Minimum Rigid Board or Air-Impermeable Insulation R-value
2B and 3B tile roof only	0 (none required)
1A, 2A, 2B, 3A, 3B	R-5
4C	R-10
4A, 4B	R-15
5	R-20
6	R-25
7	R-30
8	R-35

Table 3 – 2003 IRC Table R806.4, Insulation for Condensation Control.

shingle or shake and the roofing underlayment above the roof deck.

The unvented attic assembly requires that air-impermeable insulation be installed directly under the structural roof sheathing. In climate zones 5, 6, 7, and 8, any installed air-impermeable insulation is required to be a vapor retarder or have a vapor retarder coating or covering in direct contact with the underside of the insulation.

Hybrid insulation systems that include both air-impermeable and air-permeable insulation require that the air-impermeable insulation's thermal resistance (R-value) be great enough to control condensation at the air-impermeable surface throughout the year. The air-impermeable insulation shall be applied in direct contact to the underside of the structural roof sheathing. *Table 3* outlines the minimum thermal resistance necessary for condensation control in all climate zones for hybrid insulation systems. The air-permeable insulation shall be installed directly under the air-impermeable insulation.

Unvented cathedral-roof/ceiling assemblies are not covered by the recent code language. The application has become a common design option in many of the cold/dry and extreme cold/dry regions of the country. One of the reasons for the system's success is that dry climates are much more forgiving than humid environments. In addition, interior air-barrier systems, typically consisting of continuous, smart, vapor retarder or polyethylene films, combined with finished gypsum-board ceilings are necessary for the assemblies to perform satisfactorily (*Figure 13*). Many of the regional building-code officials require transient heat and moisture transfer (hygrothermal) analysis of each unvented cathedral ceiling assembly to predict the acceptable long-term performance of the system with respect to moisture management.

HYGROTHERMAL ANALYSIS

When designing a building envelope, one of the best tools for predicting its moisture management performance is hygrothermal analysis. A large amount of research related to developing transient heat and moisture transfer (hygrothermal) analysis methods (Trechsel, 2001; Straube et. al, 2001) and measuring the hygrothermal properties of building materials (Hens *et. al*, 1996; Kumaran, 2001; ASHRAE, 2005) has been conducted and published in recent years.

Hygrothermal analysis predicts the impact of transient heat and moisture transfer on building envelopes over time. It may be used in planning construction projects and on existing buildings with moisture problems. Specialized software helps the user visualize such factors as surface condensation and mold growth potential, the wetting and drying potential of the building envelope, and the moisture content of building components. This analysis helps building designers evaluate potential preconstruction moisture risks and also helps analyze and solve moisture problems after construction. The resulting reports should conform to ASHRAE 2006, Standard 160 P, "Design Criteria for Moisture Control in Buildings." Hygrothermal analysis takes into consideration both the geographic location and the building's orientation. Vapor retarder and unvented roofing system building-code language changes previously discussed were supported by hygrothermal modeling (Karagiozis and Desjarlais, 2005; Lstiburek, 2006).

Figure 13 – Airtight unvented cathedral-roof/-ceiling assembly with air-permeable insulation in an extreme cold and dry climate.

CONCLUSION

Building science technology and practices will continue to influence changes to future building envelope design and energy efficiency code requirements. As more and more tools are developed, such as hygrothermal analysis software, we will develop a greater understanding of the dynamic relationships among the building envelope, the occupants, the mechanical systems, and the surrounding environment. Integrating products and systems that help control heat, air, and moisture transport in the building envelope will ultimately create more energy-efficient, comfortable, durable, and sustainable buildings.

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