# A COMPARATIVE STUDY OF CLIMATE BASED DESIGN OF BUILDING ENCLOSURES

by

EMILY M. McGLOHN

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THESIS APPROVAL PAGE

Student: Emily M. McGlohn

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This thesis has been accepted and approved in partial fulfillment of the requirements for the Master of Architecture degree in the Department of Architecture by:

| | |
|---|---|
| Professor Alison G. Kwok | Chair |
| Associate Professor Virginia Cartwright | Member |
| Associate Professor John Rowell | Member |

and

| | |
|---|---|
| Kimberly Andrews Espy | Vice President for Research & Innovation/ Dean of the Graduate School |

Original approval signatures are on file with the University of Oregon Graduate School.

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THESIS ABSTRACT

Emily M. McGlohn
Master of Architecture
Department of Architecture
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Title: A Comparative Study of Climate Based Design of Building Enclosures

This thesis attempts to determine if misconception about vapor retarders and air barrier systems affects building enclosure design and construction. Literature on this subject is continually evolving and often contradictory, supporting confusion. A survey of designers and builders representing four climate zones within the United States was done. Respondents disclosed where they learned about building enclosures and shared how clear or confusing they think the resources are on this subject and also weighed in on a few basic principles about enclosure design. Results show that most building professionals learn about enclosures through experience or a colleague. The internet is the first written resource they use when questions arise. The most significant misconceptions identified are that in some cases vapor retarder placement does not follow accepted building science or code requirements and that a portion of respondents only consider the air barrier system the vertical surfaces of an enclosure.

# CURRICULUM VITAE

NAME OF AUTHOR: Emily M. McGlohn

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
Auburn University, Auburn, Alabama

DEGREES AWARDED:

Master of Architecture, 2012, University of Oregon
Bachelor of Architecture, 2003, Auburn University

AREAS OF SPECIAL INTEREST:

Building Enclosures
Sustainable Architecture
Vapor Retarders
Air Barrier Systems
Residential Design and Construction
Architectural Education

PROFESSIONAL EXPERIENCE:

Designer, Duet Design Studio, 2009 to present

Designer, BRW Architects, Charlottesville, Virginia, 2009-2010

Designer, William McDonough + Partners, Charlottesville, Virginia, 2006-2008

Instructor, Rural Studio, Auburn University, Newbern, Alabama, 2003-2006

GRANTS, AWARDS, AND HONORS:

Graduate Teaching Fellowship, Department of Architecture, University of Oregon, Eugene, 2010 to present

ASHRAE Student Scholarship, Oregon Chapter of American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2012

Best Paper Award Honorable Mention, American Solar Energy Society Conference, Raleigh, North Carolina, 2011

SBSE Travel Scholarship, Society of Building Science Educators, 2011

Lewis Rosenberg Travel Scholarship, 2011

PUBLICATIONS:

McGlohn, Emily M. "An Attic Full of Hot Air: A Study of Moisture Conditions in a Residential Attic." *Proceedings From the 40th ASES National Solar Conference 2011 (Solar 2011)*. Raliegh, NC, 17-20 May 2011. Red Hook, NY: Curran Associates, Inc., 2011. 48-53.

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# CHAPTER I

# INTRODUCTION

## Introduction

In the fields of residential architecture and construction, proper placement and definition of the vapor retarder and the air barrier system are highly discussed and debated. These two parts of the building enclosure are vital to achieving current performance standards, but they are frequently only millimeters thick or part of another system, making them difficult to understand and communicate amongst designers and builders. Terminology for these layers in commonly available resources is scattered and varies from source to source, and information on their correct use is frequently contradictory. Expert building scientists, Straube and Burnett— the authors of *Building Science for Building Enclosures,* recognize this confusion by noting that "much of the older literature (and a remarkable proportion of current documents) confuses or combines the function of the air barrier system and vapor barriers, and the difference between the two is still one of the most commonly discussed building science issues" (421). Due to the ambiguity of the vapor retarder and air barrier system, confounded terminology, and contradicting information, the confusion that fuels debate about proper design and application has real potential to affect many residential buildings. In a house, 30% or more of heating and cooling costs can be attributed to air infiltration (EPA). A properly detailed air barrier system is designed to eliminate air infiltration, therefore, reducing a home's energy consumption. Effective moisture control in buildings contributes to the health of the occupant, longevity of the building, and energy efficiency.

My interest in this subject stems from personal experience while practicing architecture where I often had questions on the proper use of air barriers and vapor retarders. I was faced with decisions on the design of the building's enclosure, which entailed major performance and financial implications if the correct decision was not made. Answers were difficult to find, and I questioned whether other building professionals were experiencing the same. I believe that designers and builders find the information available on enclosure design confusing and frustrating, and that often, building enclosures are built without complete understanding of their function. This thesis recognizes the documented confusion surrounding air barrier systems and vapor retarders, and aims to determine what effects the confusion may have on common practice of residential design and construction. Methods of research include: a climate specific, online survey of designers and builders that seeks to determine common practice and level of actual confusion among building professionals, a content analysis of commonly available resources that outlines current thought on correct enclosure design, enclosure examples from building professionals to demonstrate their understanding of best practice, and focused interviews of willing respondents to document the thoughts and feelings of a complicated subject. Figure 1.1 summarizes how confusion could affect the quality of what is built.

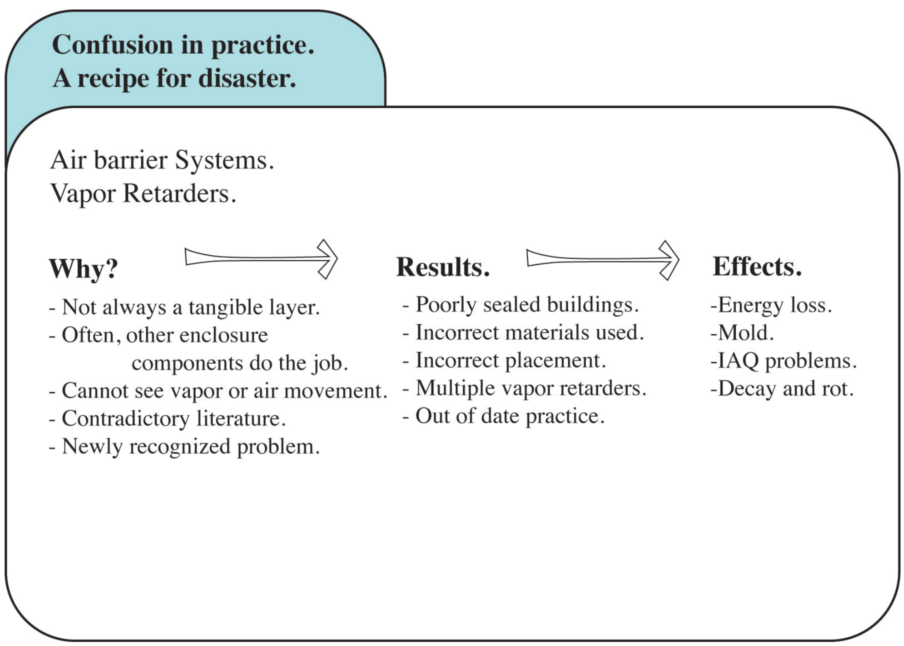



**Figure 1.1.** Illustration of the problem with confusion in practice.

Buildings, specifically residences, play an important role in global energy and resource use as well as the health and financial well being of our population. Over 546,000 single family residential buildings were completed in the United States (U.S.) in 2010; 22% of energy consumption in the U.S. can be attributed to the home and 90% of Americans' time is spent indoors (U.S. Census Bureau, U.S. Energy Information

Administration, EPA). Proper use of the air barrier system increases efficiency of buildings, and protects occupants from convective moisture related problems. Vapor retarders reduce the possibility of condensation within wall cavities thereby reducing the occurrence of mold within a wall and lengthening the life of the building. For maximum effectiveness, it is necessary for these two layers to be designed and installed correctly; therefore, a proper understanding of their application is required.

## Thesis Objectives

It is recognized in building science literature that air barrier systems and vapor retarders are often confused and their proper use is debated, but there is a gap in available research that aims to determine how building professionals perceive the confusion, and how it affects their work. The primary objective of this thesis is to determine what the consequences of the confusion surrounding air barrier systems and vapor retarders may be on common practice of residential design and construction.

The second objective of this thesis aims to discover what resources building professionals most often use when they have questions about the design of the building enclosure, and to determine how comprehensible they think those resources are. This is relevant because often the use of air barrier systems and vapor retarders is learned in practice or in the field, meaning most of what is practiced is not learned in a controlled academic environment.

It is not the intention of this study to suggest new performance criteria for building enclosures or to prove that what has been established is right or wrong due to time constraints. This thesis will not cover all climate zones of the U.S. or survey all parties eligible to design and construct a home due to time constraints. It is also recognized that vapor retarder and air barrier use is dependent of the type of construction. This thesis focuses on frame wall construction because of it prevalence in residential construction.

### *Research Questions*

1. What common practices exist in the design and application of the air barrier system and vapor retarder in residential construction?

2. Which common practices are misconceptions that could lead to significant failure in the air barrier system and vapor retarder?
3. What differences exist in enclosure design between best practice and real practice?
4. Which resources are most commonly used by building professionals when designing an enclosure?
5. How comprehensible do building professionals think the most commonly used resources are?

*Hypotheses*

This thesis predicts that common practice use of vapor retarders and air barrier systems differs from the instruction of commonly available resources.

Secondly, building professionals learn about vapor retarders and air barrier systems through the internet and perceive the available information as incomprehensible.

Thirdly, builders have a better understanding of the function of vapor retarders and air barrier systems than designers.

## Thesis Approach

The single-family residential sector is the focus of this thesis. Architects, designers, contractors, and builders alike are permitted to design and construct homes; therefore, the interpretation and quality of the assembly, beyond code compliance, lies with the individual in many cases. Secondly, the predominate single-family housing type in the United States is light-weight, wood-frame construction. This provides congruency of building knowledge between the majority of designers and builders in homebuilding.

Enclosure design is climate based; therefore, residential designers and builders in four different climate zones in the U.S. are surveyed: warm-humid, mixed, moist-cold and marine. To insure each respondent has a base knowledge of the subject at hand, building professionals in Oregon, Virginia, Georgia and Michigan are surveyed based on the states' shared and mandated energy and building codes. This study is limited to a survey of designers and architects and homebuilders working individually or with a company.

**Organization of Thesis**

This document is organized into five chapters including the introduction. Chapter two is the background information necessary to understand the context of the problem. Similarities and differences between the information provided in these sources will be discussed to provide this thesis with context and a position anchored in the aforementioned confusion. Chapter three discusses the methods employed to carry out this research. The main method of discovery is a questionnaire issued to building professionals in four climate zones in the U.S. that questions common practice, performance standards and information acquisition. Chapter four explains the results from the survey and looks at a content analysis of commonly available resources. Chapter five summarizes with a discussion of the findings and thoughts on further research.

# CHAPTER II
# CONTEXT OF THE BUILDING ENCLOSURE

## Introduction

The following chapter outlines the definition and recent changes of the building enclosure. This chapter also establishes the accepted building science and code compliance for the vapor retarder and air barrier system for this thesis. The contradictions and confusion found in commonly available resources on the air barrier system and vapor retarder will also be presented.

## Background on the Modern Building Enclosure

The primary function of the building enclosure is to "separate interior and exterior environments" (Straube and Burnett 12). Traditionally, the building enclosure was expected to provide safety from intruders, protection from the elements, and admit daylight. Within the last sixty years, the demands of the building enclosure have increased significantly with the standardization of thermal insulation, better methods of construction, and central heating and cooling systems (Lstiburek 3). The history is important because the advances in enclosure design have introduced new problems that call for new solutions, all of which are continually evolving and not easily understood.

### *Insulation and Air Infiltration*

One of the first modern applications of thermal insulation was in the walls of humidified factory buildings in the 1920s. Factory owners observed cold spots on walls caused by air leaks and thermal bridging that subsequently caused condensation on interior walls (Rose 13). Moisture from condensation provided the moisture mold needed to grow. Insulation, added to the walls, kept interior surfaces above dew point and prevented condensation from forming. Although this application of insulation was not for reasons of thermal comfort or energy efficiency, it soon became common in other types of construction as a way to preserve the heating and cooling within the building as mechanical systems became a standard.

It was also recognized that air leaks contributed to moisture problems. Where cold, outside air seeped into warm, insulated walls, water vapor would condense and negate the insulation's value. Therefore, air tight insulation systems were used to block troublesome air leaks (Rose 14). These measures were taken by factory owners that kept intentionally high interior humidity levels, similar conditions to modern mechanically heated buildings.

### *Water Vapor Diffusion*

Prior to the 1930s water vapor was thought to only travel by air infiltration through material pores (Rose 14). The vapor diffusion theory was applied to buildings by the mid 1930s, and soon thereafter, vapor barriers became a regulated part of wood frame construction (Rose 14). In 1942, the U.S. Federal Housing Authority first required vapor barriers in the ceiling of the top floor, within insulated walls, and in walls where an impermeable material was used on the exterior (Rose 16).

### *Building Materials*

The housing boom that followed World War II marked a shift in traditional residential building techniques to current standards; accordingly, insulation for reasons of comfort and energy efficiency became standard, and manufactured panel goods, such as plywood replaced the use of individual boards in flooring and sheathing, reducing air infiltration (Rose 16). Below, Figure 2.1 shows the quantity of housing built after World War II. These new methods improved the quality of the houses, but introduced problematic issues with moisture. In buildings of traditional construction methods the inherent cracks and crevices allowed air to continually pass through the enclosure, drying any accumulated moisture. The use of plywood eliminated these crevices, reducing the buildings' ability to dry. The addition of wall insulation raised indoor temperatures, thereby raising interior absolute humidity levels. Energy conservation and occupant comfort were improved, but higher water vapor levels indoors increased condensation potential in inadequately protected walls. As moisture problems associated with modernized construction techniques threatened the integrity of U.S. housing stock, beginning in 1948 the use of a vapor barrier behind interior plaster became a common solution to outward vapor drive, and it was not until the 1970s that the difference between vapor barrier and vapor retarder was recognized (Rose 17-18).

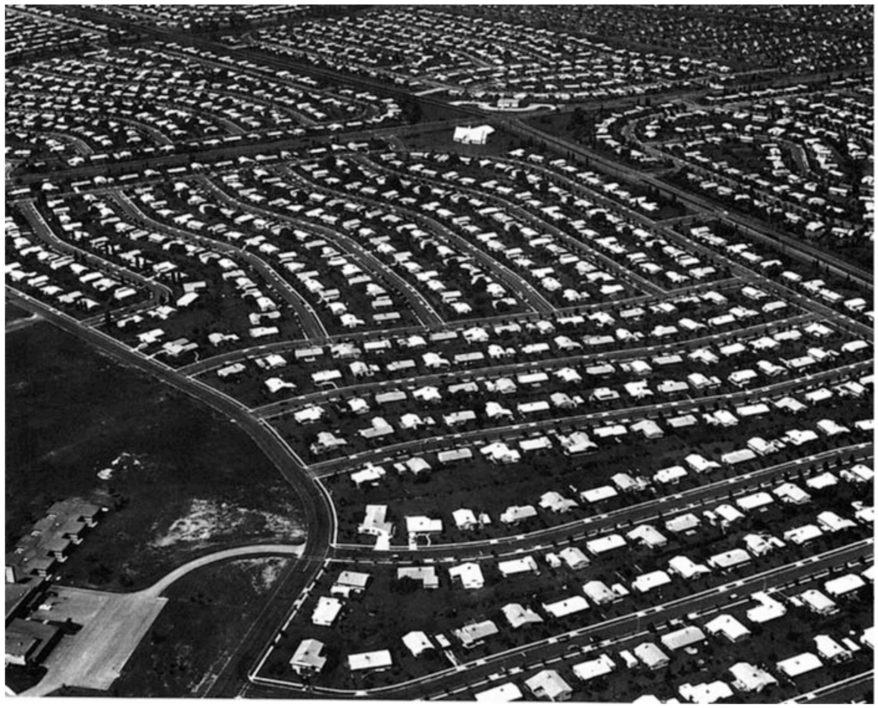


**Figure 2.1.** The post-war housing boom in Levittown, PA ("Levittown").
<http://en.wikipedia.org/wiki/Levittown,_Pennsylvania>

*Air Conditioning*

With the ever-rising demand for air conditioning in homes over the last sixty years, the demands made of the building enclosure have changed, forcing designers and builders to relearn how the systems work (Bomberg and Onysko). From 1978 to 1997 the percent of American homes with a central air-conditioning rose from 23% to 43%; the highest concentration was in the American South at 93% of homes with central air conditioning ("Trends"). The latest Residential Energy Consumption Survey by the by U.S. Energy Information Administration shows that as of 2009, 87% of American homes have air conditioning ("Air Conditioning"). The drier and cooler interior environment air conditioning creates reverses vapor drive; therefore, a reversal in the traditional placement of vapor retarders is required.

## Recent Building Science

In the previous section, there is a description of the sixty-year evolution of current building science. Since the introduction of thermal insulation, tighter buildings, and HVAC, building scientists have reconsidered how buildings interact with their environment, and what the correct methods are for wall construction (Lstiburek 3). Defined above, the building enclosure separates outdoor and indoor environments, but in order for the enclosure to function properly between the two environments, careful thought must be given to specifics of each environment. Two recent improvements to the building enclosure are an air barrier system and the climate-based placement of the vapor retarder. It was established previously in this chapter that air leaks and vapor transport were recognized as problems as early as the 1940s, and one solution included air tight insulation systems. Modern solutions respond to what has been learned within the last sixty years. The following section summarizes the features an effective enclosure must have.

### *Design Principles for Building Enclosures*

According to Straube and Burnett, climate should be the first consideration when designing a building enclosure (393). Three situational climates should be determined: climatic region (which part of the country), micro-climate (condition on the site), and enclosed climate (interior conditions) (393). Each of these factors ultimately determine how the building's enclosure functions as a system. Other design principles for an enclosure are as follows:

> -Be sure to have defined a complete load transfer path.
> -Control rain penetration by proper siting, building shape, surface features and enclosure rain penetration control strategies.
> -Control air flow by using an effective air barrier system.
> -Insulate the structural components of the assembly.
> -Design to accommodate movements and construction tolerances.
> -Control unwanted solar gains.
> -Consider the enclosure as part of the building system.
> -Consider the future. (Straube and Burnett 393-394)

While all of the above principles are essential, the two principles most applicable to this thesis are controlling air flow with an air barrier system and understanding design variables based on climate.

*The Air Barrier System*

The air barrier system is not always a tangible or visible layer; it is "the plane of airflow control" (Straube and Burnett 419). Its main purpose is to prevent air from passing through the building's enclosure by controlling the pressure differential between the exterior and interior. This plane is often a combination of systems, which includes many parts and is affected by how the sheathing, house wrap, insulation, interior gypsum board, and other components are incorporated into the building. An air barrier system can be created by gluing the interior gypsum board to the wall framing, or by properly caulking a window; both differ greatly but are a part of the air barrier system. The air barrier system should be continuous to be effective; therefore, careful and precise application is necessary.

Durability of the air barrier system is important through construction and the life of the building. Any tear, crack, or imperfection in the system diminishes its effectiveness. Given all the options that make the air barrier system, it can be misunderstood in communication between designers and builders. The possibilities of imperfection during application make it difficult to determine on-site if the air barrier system has been correctly constructed. Imperfect air barrier systems result in loss of energy through "infiltration heat loss," and may reduce insulation values due to convection currents in exterior wall cavities (ASHRAE 16.16-17). An imperfect air barrier system also increases chances for interstitial condensation. Where air moves through a tear or crevice in the air barrier system, vapor transport is concentrated, and the likelihood of condensation increases (ASHRAE 26.14). Moisture transport is significantly higher in air infiltration than vapor diffusion. Joseph Lstiburek notes that "in most cold climates over an entire heating season, ⅓ of a quart of water can be collected by diffusion through gypsum board without a vapor retarder; 30 quarts of water can be collected through air leakage" (*Builder's Guide* 119).

Another consequence of interstitial condensation is loss of insulation value. Moisture assists in heat transfer through materials (ASHRAE 25.15). Also, many types of insulation rely on air pockets to function, and air pockets collapse when the insulation is wet, reducing overall thermal performance.

## Products

There are numerous air barrier products used in residential construction that are mechanically fastened. These include board-stock products and the most commonly recognized, house wrap. House wrap functions to stop air infiltration through the building envelope when taped properly. Most house wraps also serve as a backup weather barrier behind the siding but allow the passage of water vapor. House wrap is one of the possible components of a functioning air barrier system. Unfortunately, it is often thought of as a singular solution. Other air barrier products include self-adhered sheets, fluid applied membranes, and sprayed polyurethane foams (ABAA). Most air barrier products are applied to the exterior of the sheathing with the exception of sprayed foam. Foams normally fill the stud cavity, providing thermal insulation and also serving to block all air gaps. See Figure 2.2 for examples of air barrier materials.

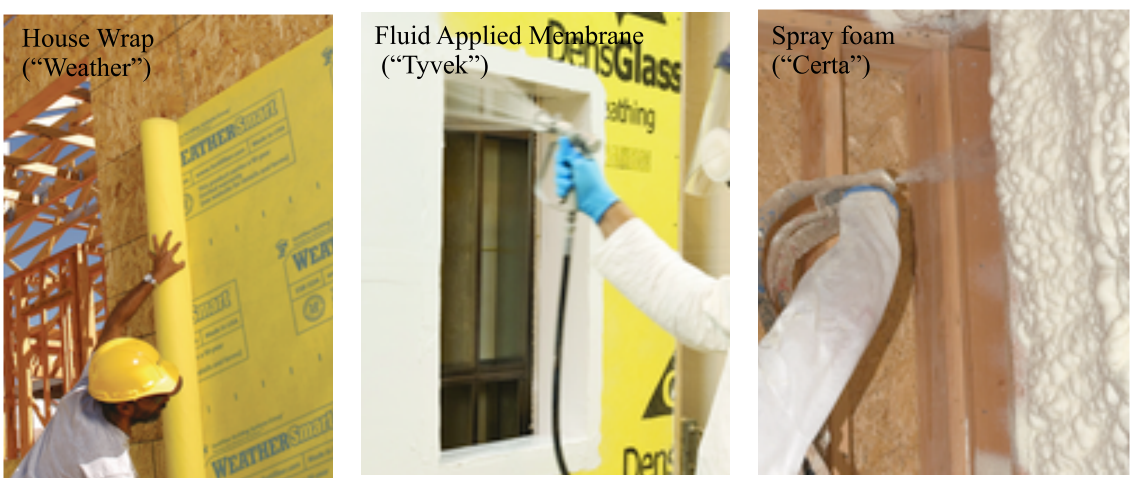



**Figure 2.2.** Air barrier materials.

## Performance and Testing

The most common way air barrier systems are tested is through pressurization and depressurization of the entire house. A blower-door test measures the amount of air needed to maintain a certain pressure difference between the outside and inside of the enclosure. A large fan within a doorway creates the pressure difference, and the volume of air flow needed to maintain the pressure difference tells how much air is passing through the enclosure. A tightly constructed building needs very little air flow to maintain the pressure; the opposite is true for a building with an ineffective air barrier system. The common unit of measurement for a blower-door test is air changes per hour (ACH), which takes into account the volumetric rate of airflow, the volume of the house, and time, usually hours (ASHRAE 16.4).

### *The Vapor Retarder*

Vapor retarders, like air barrier systems are not always an easily understood component of the building enclosure. This is partially due to only recent necessity, the technical nature of the subject, ambiguity of material, and placement dependency on climate and building type. Vapor retarders' primary job is "the control of water vapor diffusion to reduce the occurrence or intensity of condensation" (Straube and Burnett 422). A properly placed vapor retarder slows water vapor diffusion through the building enclosure, which allows time for the enclosure to dry out if any moisture has accumulated. Vapor retarders also prevent water vapor from colliding with surfaces below the dew point, preventing interstitial condensation. A vapor retarder's continuity is not as important as the air barrier system's. Small tears, imperfections, and inconstant coverage only reduces effectiveness by the size of the hole. The percentage of vapor blocked is directly related to the percentage of coverage. Lstiburek explains in his *Builder's Guide to Mixed-Humid Climates*, ". . . if 90 percent of the building enclosure surface area is covered with a vapor retarder, then that vapor retarder is 90 percent effective" (109).

Vapor retarders are defined by their permeance and are categorized into three classes: Class I, II and III. A vapor barrier is a Class I vapor retarder that has 0.1 perm rating or less (ASHRAE 26.14). All building materials have a vapor permeance rating, and the inherent permeance in the enclosure may be sufficient for vapor control, or a separate vapor retarder layer may be needed. Factors that affect vapor retarder use include type of construction and the building's intended use (ASHRAE 26.14). Climate is another major factor that determines permeance and location of the vapor retarder. Water vapor travels from high to low concentrations and is called vapor drive for building purposes. Because warm air can hold more moisture, vapor drive moves from the warm side to the cold of an enclosure. Furthermore, the warm side of the enclosure changes depending on the climate, consequently, vapor drive varies also. Below, Figure 2.3 is the International Energy Efficiency Code's Climate Zone Map that determines where and what type of vapor retarder should be used. There are sixteen different zones within the United States.

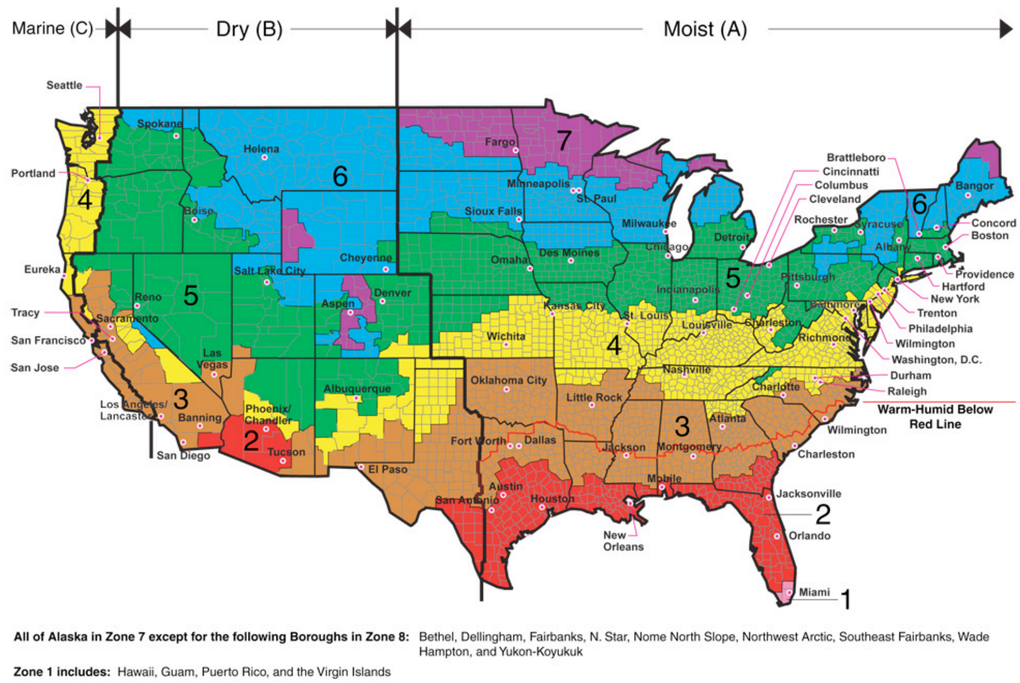



**Figure 2.3.** Climate Zone Map (2009 IECC 10).

A vapor retarder can be understood as the layer in an enclosure with the least amount of permeance (ASHRAE 26.14). All other layers of construction materials on either side of the vapor retarder must have more permeance in order for the enclosure to maintain dryness. A consequence of two vapor retarders with similar permeance in separate locations within an enclosure is a moisture trap. The moisture cannot dry to the outside or the inside. Trapped moisture promotes mold growth and wood decay, both harmful effects. Mold growth has been linked to many health issues such as asthma, headaches, and mucous membrane irritation (Bales and Rose 13). Although it is rare for trapped moisture to cause catastrophic structural failure in a building, it does have the potential to corrode metal fasteners, damage material finishes, and buckle wood products (ASHRAE 25.14-15).

**Products**

A vapor retarder can be a combination of building materials that meet specified permeance requirements, but typically, a vapor retarder is a sheet or coating within the enclosure. Vapor retarders are selected based on the desired permeance. Examples of vapor retarders within the three classes are:

- Class I (0.1 perm or less)—(vapor barrier) sheet polyethylene and foil faced insulation.
- Class II (>0.1 perm but ≤1.0 perm)—craft paper faced insulation batts and extruded polystyrene.
- Class III (>1.0 perm but ≤10 perm)—latex paint and some asphalt impregnated papers.

**Performance and Testing**

The most common way to test for interstitial condensation within an enclosure during the design phase is the Glaser method (ASHRAE 25.13). This method assumes a steady heat and water vapor flow rate through the enclosure and identifies the location where condensation is most likely to occur. This informs the designer of the need for a vapor retarder. A few excluded factors that limit the effectiveness of the Glaser method include: moisture content of materials, rain, and air infiltration (ASHRAE 25.14). Recently, computer aided hygrothermal modeling software has become available. Programs like WUFI-ORNL/IBP improve moisture flow predictions by simulating the three dimensional qualities of an enclosure. Climate specific weather conditions, air infiltration, moisture content in materials, and qualities of construction are a few of the factors included in hygrothermal modeling programs like WUFI-ORNL/IBP

(Karagiozis).

Sensors that measure dew point can be imbedded within the enclosure prior to the completion of construction to verify the performance of the vapor retarder. This is seldom carried out in residential construction.

## The Role of Codes

Since their inception, the International Residential Code (IRC) and International Energy Conservation Code (IECC) have regulated air infiltration and moisture control in varying degrees. The first edition of the IRC, in 2000, requires a vapor retarder on the "warm-in-winter" side of insulation in framed walls, floors, and roofs (or ceilings) with several exceptions*. The same building code requires air leakage to be controlled by sealing sites of infiltration or exfiltration (2000 IRC 283). The 2000 IECC has similar but slightly more descriptive requirements: the vapor retarder can be no more permeable than 1.0 perm. Every three years a revised code is released, and each edition has slightly different requirements for moisture control and air infiltration. The changes are arguably improvements but still prescriptive in many ways, subsequently leaving room for error.

The minimum 2009 IECC compliance for air barrier systems is a visual inspection by a third party (30). Although this requirement recognizes the problem of air leakage and is significantly more stringent than past codes, visually determining air leaks in a building's enclosure is not fail proof. Alternatively, a blower-door test is an option available in the same code section to demonstrate compliance but is not required. Nineteen states now recognize an energy code based on the 2009 IECC ("Residential"). This is a great step forward for energy conservation. The 2006 IECC did not require any testing of the air barrier system.

Code compliance with vapor retarder regulation does not ensure proper design either. The 2006 IRC requires a vapor retarder on the "warm-in-winter" side of insulation in unventilated frame walls, floors, and ceilings (321). Exceptions include moisture resistant construction methods, frame walls, floor, and ceilings in climate zones 1, 2, 3, 4A and 4B, and where other measures to prevent condensation have been taken (2006 IRC 321). This version of the code recognizes the IECC Climate Zones (see Figure 2.1 above) and attempts to improve vapor retarder placement regulation. The prescriptive quality of this section lends itself to mistakes. For instance, climate zone 4C through zone 8 require the vapor retarder placed on the warm side of the insulation in winter. If a second vapor retarder is added to the cold side inadvertently the vapor has no exit increasing the chance of condensation. There is no code regulation for the number of vapor retarding layers within the residential enclosure according to the IRC.

Although the codes are making progress towards providing building professionals with a set of comprehensive guidelines for this confusing topic, more improvements are needed. It is obvious positive change is near. The 2009 IRC dedicates a significant portion of the wall construction section to defining the three classes of vapor retarders and provides much improved flexibility in their use (145). The 2012 IECC has eliminated the "visual inspection" of the air barrier system and now requires a blower-door test (R-33).

### Accepted Practice for this Thesis

Although the 2012 IRC and IECC have been released, for the purposes of this thesis, the 2006 IRC and 2009 IECC are the highest code references. States adopt minimum standards regularly, but implementation takes time, and the states selected for this research comply with at least the 2006 IRC and 2009 IECC.

For air barrier system standards, the 2009 IECC is used as a benchmark for this thesis. Because the building code only dictates vapor retarder use in climate zone 4C-climate zone 8 (Oregon and Michigan), for this thesis, vapor retarder practice for climate zones 4A, 3A, and 2A (Virginia and Georgia) are derived from the *Builder's Guide to Mixed Humid Climates*, a well respected book by Joseph Lstiburek. His suggestion for hot climates, like Georgia, are as follows:

> Hot Climates—Building assemblies need to be protected from getting wet from the exterior, and allowed to dry towards the interior. Accordingly, air barriers and vapor retarders are installed on the exterior of the building assemblies, and building assemblies are allowed to dry towards the interior. . . (111)

Similarly, Lstiburek's suggestions for mixed climates like Virginia are below:

> Mixed Climates—Building assemblies need to be protected from getting wet from both the interior and exterior, and be allowed to dry to either the exterior, interior or both. (112)

This means the vapor retarder in mixed climates should be placed near the center of the wall assembly so that vapor can dry towards the interior and exterior or that a vapor retarder should not be used at all creating a “flow-through” wall assembly (Lstiburek 112).

## Contradictions and Confusion in Resources

The code is not the only document that addresses this topic. Because of its popularity among building professionals there are many websites, discussion groups, videos, and documents available on the internet that attempt to explain this issue. More traditional print resources are also available such as magazines and books that deal with the air barrier system and vapor retarder. Most commonly there are the conversations all building professionals have between each other discussing the proper use of these layers.

### *Terminology*

Terminology is one indicator of the confusing nature of this topic. Often the terms “vapor retarder” and “vapor barrier” are incorrectly interchangeably used, which is one reason for the noted confusion. In a survey of handbooks written specifically to address the design of the building enclosure, the following terms are used to name essentially the same layer, the vapor retarder: “vapor diffusion retarder” (Lstiburek and Carmody 43), “moisture-reduction barrier” (Walker and Felice 171), and “vapor retarder”. The same books named the air barrier system in the following terms: “air retarder” (Lstiburek and Carmody 35), “air infiltration barrier” (Walker and Felice 170), and “air barrier.” Although the definitions for each term defining the vapor retarder or air barrier system may be correct, the variation in terminology is confusing.

### *Contradicting Sources*

The internet provides a wealth of information on vapor retarders and air barriers systems, but explanations are not always consistent. Often discussions arise in comment areas that exemplify the debate that exists. Many building professionals ask questions on clarification or express a disagreeing opinion. Contradictory or unclear information between resources is easy to find.

For example, when dealing with the necessity of a continuous vapor retarder, the U.S. Department of Energy claims on its Energy Efficiency and Renewable Energy website that:

> When installing a vapor diffusion retarder, it should be continuous and as close to perfect as possible. This is especially important in very cold climates and in hot and humid climates. Be sure to completely seal any tears, openings, or punctures that may occur during construction. (EERE)

Conversely, the Air Barrier Association of America's website states very clearly that:

> The vapor barrier does not have to be continuous, does not have to be free of holes, does not have to be lapped, does not have to be sealed, etc. A hole for example in a vapor barrier will simply mean that there will be more vapor diffusion in that area compared to the other areas where the vapor barrier (sic). (ABAA)

Although there may be a reasonable explanation for the statements made by both sources, these two statements seem to contradict each other, possibly confusing the reader.

Another example is the information provided by Johns Manville, an insulation manufacturer, in their informational video titled "What is a Vapor Retarder?" The narrator tells the audience that "generally, in hot-humid areas using a vapor retarder is not recommended" (jmhomeowner). Although this can be interpreted to mean "generally, in hot-humid areas [of the United States] using a vapor retarder [of 0.1 perm or less on the warm-in-winter side of the insulation in a frame wall] is not recommended," there is no other information provided in the video to explain the specifics. It is most likely to be understood that no vapor retarder is needed at all. Contradicting this video, the *Moisture Control Handbook* recommends the use of a vapor retarder, in cooling climates (hot-humid areas) on the outside of a frame wall (Lstiburek and Carmody 35). Again, these statements are not necessarily incorrect, but as they stand, they contradict one another making the information confusing.

### *Questions and Conversations*

Anecdotally, as a practicing designer, I also experienced confusion surrounding this topic. When I had questions about how to detail and specify the air barrier system and vapor retarder, it was difficult to find answers, and I struggled to understand the concepts. Questions that I asked my colleagues were often questions they had also. I was charged with finding resources to answer my questions, but I was not satisfied with the mixed results. I admit that some of my bewilderment was due to inexperience, but I attribute a portion to the contradictory nature of the information available.

Due to the recent science behind modern building enclosures, I feel that building professionals struggle to keep up with current information. Within the practices of architects and builders, knowledge and experience is passed between individuals in conversations, drawings, and building traditions. This way of communicating information builds congruency and cohesion between people and projects but is dangerous if what is being shared is incorrect.

## Summary

Due to the relatively new science of buildings and the technical nature of the information, the design and application of the vapor retarder and air barrier system is a difficult subject to understand. When questions arise, getting answers from available resources is difficult because of the contradictory aspects of the information. Misunderstanding air barrier systems and vapor retarders has the potential to harm occupant health, building life, and energy efficiency. It is important to understand how this confusion is actually perceived by building professionals.

# CHAPTER III
# METHODOLOGY

## Introduction

In this chapter, the research methods chosen to investigate common practice of vapor retarders and air barrier systems and the confusion that surrounds them is presented. Selected study areas and the sample population of the survey are described. The data processing procedure, including how the data was cleaned and sorted is explained as well.

A combination of descriptive quantitative and qualitative methods are used for this thesis. The primary research method is an online survey of residential designers and builders. The survey is designed to discover where building professionals look for information on the building enclosure and to gauge their level of understanding of the use of vapor retarders and air barrier systems. The survey also asks respondents a range of demographic questions in order to categorize level of experience and education, as well as climate zone. Respondents also have the opportunity to submit a detail from their company to exemplify their best practice.

The secondary research method is a content analysis of online resources and handbooks on enclosure design. This data will help to determine how much variation there is in terminology and instructional use of the vapor retarder and air barrier system. This documentation will help support the confusion this thesis recognizes.

## Survey Instrument

### *Human Subjects Protocol*

The first step in using a survey for research was to proceed with the University of Oregon's Human Subjects Protocol. Exemption from a full Institutional Review Board (IRB) review was requested and granted on September 08, 2011 by the Office for Protection of Human Subjects. This thesis was determined to be of minimal risk to participants.

*Survey Design*

A survey was selected to be the primary research method due to the size and distance between sample groups. Aspects of enclosure design are climate dependent; therefore, it was necessary to survey building professionals in four states in different U.S. climate zones in order to compare practices. A survey was also used because it is an appropriate method to collect data on past experiences and opinions, both of which are important to determining how confusing respondents find information on enclosure design (Leedy and Ormrod 187).

The desire to collect data across climate zones posed a serious challenge for distribution. Since most building professionals commonly use email, an online survey was chosen because it is the most efficient way to collect data across such a broad sample. Qualtrics, free software from the University of Oregon's Graduate School, was used to create the survey. An online account was created, the survey was designed using the available tools, a unique URL was created for distribution, and anonymous results were collected, all with Qualtrics.

The survey was designed to be taken in no more than six minutes, asked respondents a total of seventeen questions, and gave an opportunity to add written comments at the end. The introduction screen explained the rights of the respondent, the intent of the survey, and the requirements to participate. Contact information for the primary researcher was offered as well as the incentive of winning one of four, twenty-five dollar gift certificates to either Lowe's or Books-A-Million. Respondents had the opportunity to enter the drawing at the end of the survey. Only one response was possible for all questions. Responses to most questions used a Likert rating scale because they are "useful when a behavior, attitude or other phenomenon of interest needs to be evaluated on a continuum. . ." (Leedy and Ormond 189).

The first two questions asked respondents to rank, in order, the most influential resources when they have questions about enclosure design. Next respondents were asked for a description of the information available on vapor retarder and air barrier system function and placement; a Likert scale from "very confusing" to "very clear" was used. Other questions inquired about climate zone consideration and the use of performance testing in their buildings. Questions seven and eight asked specifically about the placement and function of vapor retarders and air barrier systems. These questions were added as a gauge of knowledge comparable to earlier questions that asked about level of confusion. The remainder of the survey collected demographic data such as primary climate zone, job title, experience, and level of education. Questions fifteen and sixteen asked if respondents would be willing to participate in a phone interview with the primary researcher or submit detail of vapor retarder and air barrier system use at their company. A copy of the final survey is included in Appendix B.

For those willing to send a detail, follow-up emails were sent asking them to email the primary researcher with the detail attached. A follow-up email was also sent to those willing to give an interview that explained if they were chosen for an interview, they would be contacted in a second email.

### *Pretest*

From August 12, 2011 to September 06, 2011 a pretest on the preliminary survey was conducted. Ten people were asked to take the draft survey. The group consisted of current and past school colleagues of the primary researcher and a select group of professors from the University of Oregon. None of the pretest respondents were participants in the official survey that began October 07, 2011. At the end of the pretest respondents were asked to comment on the following items: ease of software use, clarity of wording, logical sequencing, appropriateness of questions, and leading statements. Eleven requests were made and eleven responses were collected. Comments were incorporated into the final survey that was used during the official survey period.

### *Sample*

An important aspect of this thesis is how building professionals adjust enclosure design based on their climate zone. In order to compare data that represents this practice, it was decided at least three climate zones in the U.S. should be surveyed. Although guidelines for sample size suggest that a population of over 5,000 should be represented by at least 400, this was not feasible due to the length of time available for this thesis (Leedy and Ormond 214). Leedy and Ormond also state that sample size depends on how homogenous the population is; increased similarities give reason for a smaller sample size (214). To narrow the the possibilities for sample selection and increase homogeneity, several goals and criteria were established for the process.

To guarantee that each potential respondent would have equal exposure to the material covered in the survey, mandated building and energy codes were cataloged for all fifty states. States that shared codes became contenders for selection. In Figure 3.1 below, shaded states mandate an energy code based on the 2009 IECC ("Residential"). A star represents the mandated use of the 2006, or higher, IRC. (See Chapter II for an explanation of requirements.)The building professionals in shaded states with a star became possible targets for recruitment. The climate map, introduced in Chapter Two as Figure 2.2, was then used to determine which three target states represented a variety of climate zones.

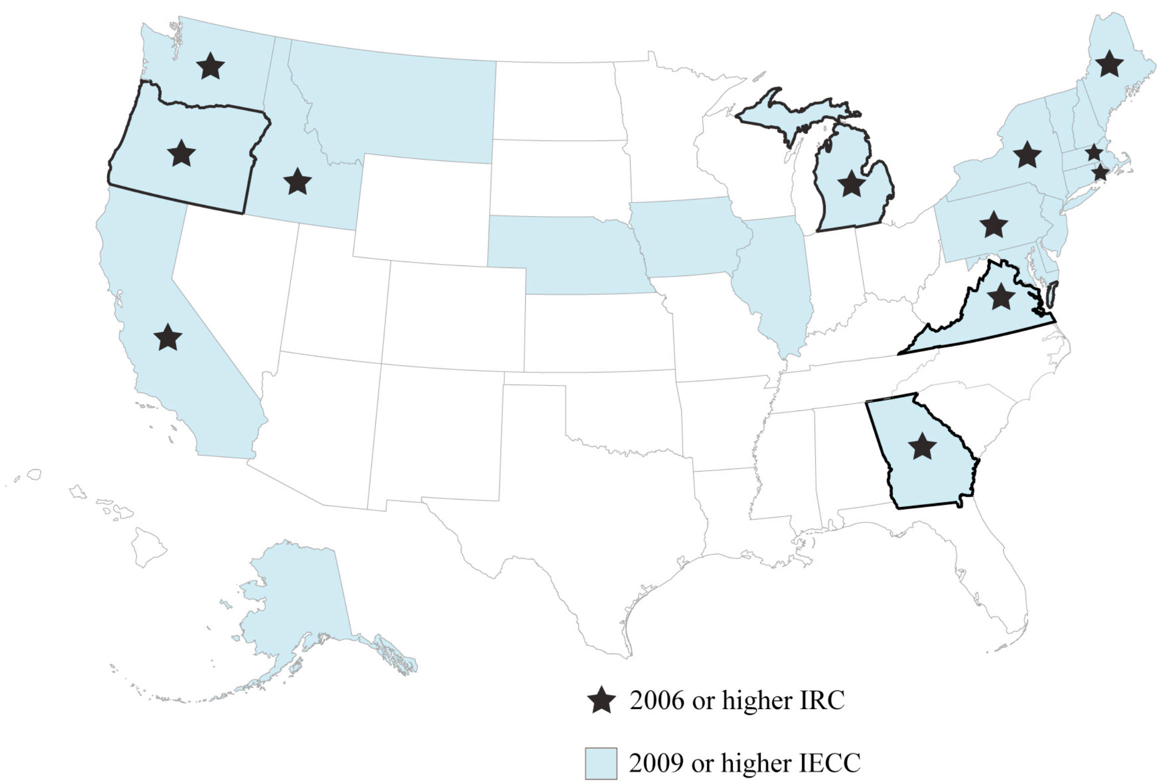



**Figure 3.1.** State selection map.

The following states (darker outline on map above) were selected based on an overlap in mandated building codes and energy codes, and difference of climate zone:

1. Oregon (Willamette Valley) representing a mixed, marine climate.
2. Michigan representing a moist, cold climate.
3. Virginia representing a moist, mixed climate.
4. Georgia representing a moist, warm-humid climate.

Although the goal was to survey three climate zones, Virginia was included to further enrich the data by adding a fourth climate. A sample goal was set of twenty designers and twenty builders in each of the four states, making a total of 160 respondents.

*Recruitment Method*

Two methods of recruitment were utilized. The publicly available, online databases from the American Institute of Architects (AIA) and the National Association of Home Builders (NAHB) were used to randomly select respondents based on the following searchable attributes: country, state and a single-family housing designation. Personal contacts of the primary researcher in the selected states were also used to find participants. Both methods were used to compile a list of twenty designers and twenty builders in each state, and a phone call or an email was sent to all 160 possible recruits.

Prior to any phone calls, the local AIA chapters of possible survey participants were contacted to alert them to the nature of the research in their area. Each chapter was asked if they could be of assistance in helping to recruit their members. Two chapters, Southwestern Oregon and Northern Virginia, of the AIA offered to advertise the survey in their newsletter during the survey period. AIA Portland (Oregon) allowed an in-person presentation to their Committee on the Environment's (COTE) monthly meeting where six contacts were made. The majority of chapters did not respond, or had no means of helping. Next, each prospective respondent received either a phone call asking for participation or an email, including the survey link, asking the same. Messages were left for a portion of the contacts that explained the nature of the call and a request to return the phone call. Willing participants contacted through phone calls were sent an email that included the survey link.

Although a minimum of 160 contacts were made, the online survey had the possibility of reaching many more people. Figure 3.2 illustrates the challenges of executing and controlling a nationwide survey. All respondents were asked, if they felt it was appropriate, to forward the survey link to their colleagues. There is a possibility that a second and third tier of respondents participated in the survey. This collection method was encouraged in order to increase the sample size, yet an attempt to protect data was made through questions within the survey that ask for job title and climate zone location. This allowed any outliers to be identified.

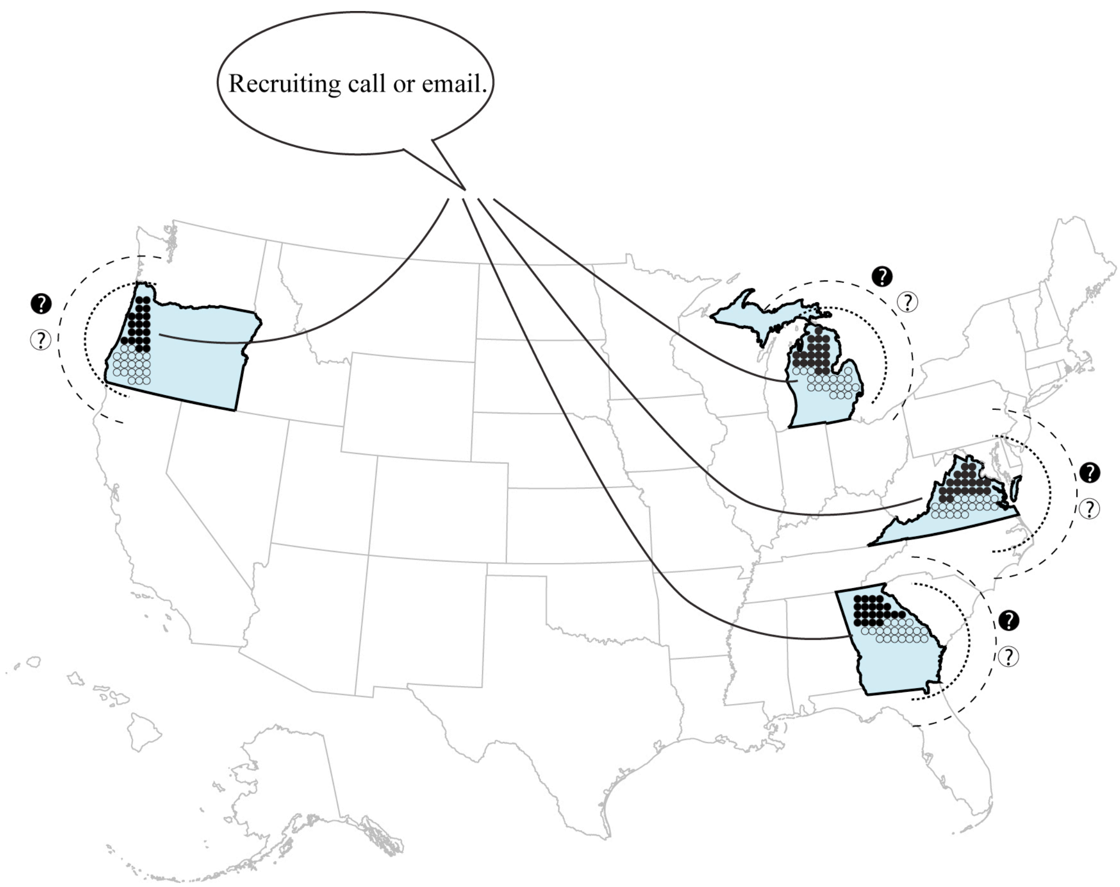



**Figure 3.2.** Recruiting map.

**Possible Sampling Biases**

It is recognized the recruitment method possibly created bias in the data based on the following:

1. Personal contacts may have been more willing to take the survey and distribute it to their colleagues.
2. Not all recruits were contacted in the same way. Both phone calls and emails were used to make the initial request.
3. The AIA and NAHB's databases only provide contact information for members of their associations.
4. People are self selecting. Some are more willing to fill out surveys, or participate in graduate research.

*Survey Period*

The official online survey period ran from October 07, 2011 to November 04, 2011. Any completed surveys collected outside this timeframe were not included in the results of this thesis.

## Content Analysis

A content analysis of design handbooks and online resources about vapor retarders and air barrier systems was conducted to determine variations in the literature available to building professionals. A content analysis is defined by Leedy and Ormond as "a detailed and systematic examination of the contents of a particular body of material for the purpose of identifying patterns, themes, or biases" (144). Hypothesis number two states that a majority building professionals learn about vapor retarders and air barrier systems through the internet. To simulate a typical internet search and to help determine if the internet may play a role in the confusion surround this topic, one portion of the content analysis centers around the top websites that appear when searching for vapor retarder and air barrier system. Using the Google search engine, the terms "vapor retarder" and "air barrier system" were searched for separately. The first ten websites that were presented were analyzed for three characteristics listed below:

1. Definition of searched term.

2. Variation in terminology throughout the article.
3. Information on placement and function.

A second content analysis was completed on *Architectural Graphic Standards,* a popular handbook for architects. Through almost four decades of publications, the book was analyzed for the following characteristics:

1. Terminology and definition of vapor retarder and air barrier system.
2. Usage description of vapor retarder and air barriers system.

The content analysis provided data, comparable to the results of the survey, that helped to identify sources of confusion and demonstrated the evolution of information over relatively short period of time.

**Data Collection Protocol**

1. *Content Analysis:* A review of selected design handbooks and online resources on vapor retarders and air barrier systems was completed in the spring term of 2011.
2. *Survey Draft Pretest:* A combination of classmates and university faculty were asked to participate in a draft survey pretest from August 12, 2011 to September 06, 2011. No pretest respondents participated in the official survey.
3. *Survey Modification:* The official survey was updated to reflect the comments generated from the pretest.
4. *Human Subjects Protocol:* A request for exemption from full IRB review was submitted with the final survey to the Office for Protection of Human Subjects. Exemption was granted on September 08, 2011.
5. *Official Survey Period:* 160 design professionals were contacted and asked to participate from October 07, 2011 to November 04, 2011.
6. *Best Practice Example:* Follow-up emails were sent to respondents willing to submit a best practice example of an enclosure detail. Detail collected through email.
7. *Follow-up Interview:* Follow-up interviews began in December 2011 and continued through January 2012.
8. *Incentive Prizes:* Four, twenty-five dollar gift certificates to Lowe's and Books-A-Million were awarded in January 2012.

## Data Processing Procedure

The results of the survey were downloaded from Qualtrics as two Microsoft Excel files, one of labels and one of values. This provided identical data sets but with the actual answers in one file and coding in the other. Excel was used to make pivot charts (cross tabulations) and all other graphs were made in iWork Numbers. Identical files were used in both programs. Each row represented the anonymous response of one participant and each column was a category for a recorded response. The data was first sorted to determine which responses were valid and which were not. Below in Chapter IV, Table 4.1 outlines the reasons why some were eliminated. After invalid responses were deleted, the data was color coded by climate then separated into two categories, designers and builders. All of the data was left in the same spreadsheet so the columns of questions could be aligned for ease of counting results.

Graphs were made directly in the spreadsheet and organized in order below the data. Graphs that were used in the final document were copied and pasted into the word processing program. Some graphs' appearances were manipulated in Adobe Illustrator. In order to compare designers' and builders', their coded responses were counted and averaged within each category. Bar graphs are predominately used to depict the highest percentages in graphic form. To determine differences between and within categories, pivot charts were made, crossing and recounting the data sets. This allowed for a more in depth understanding of the data based on the demographic information provided by respondents.

Questions that asked respondents to rank a list of options were analyzed by tabulating total selections and weighting their first, second, third, and fourth choices. Only the top four choices were weighted because that was the minimum each respondent was asked to rank.

### *Coding*

A feature of Qualtrics is automatic coding. Qualtrics provides a list of codes for each question's answer and the data can be downloaded as values. These values were counted to determine percentages of either designers, builders, or the group when analyzing the results. Minimal manual coding was necessary for this thesis.

## Summary

This chapter has reviewed the methodology for this thesis and explained the data processing procedure for data collected through an online survey and content analysis. Human Subject Protocol procedures were explained, how respondents were selected, and possible sampling biases were all explained.

# CHAPTER IV
# RESULTS AND ANALYSIS

## Introduction

This chapter outlines the results of the online survey that comprise the majority of the analysis. The best practice examples submitted by building professionals and the follow-up interviews of select respondents are also reviewed. The content analysis is described in this chapter as well. Where helpful, charts are used to graphically show significant findings.

## Survey Results

*Number of Respondents*

A total of 160 recruiting phone calls or emails were sent (twenty designers and twenty builders in each of four states) requesting participation in the online survey. Recruiting calls and emails included a request to forward the survey to colleagues in the individual's office if they felt it was appropriate. As a result there were 220 responses to the online survey but not all are part of the results. After the responses were cleaned and sorted, 152 were valid. Below, Table 4.1 lists the reasons some submissions are not valid.

**Table 4.1.** Summary of invalid responses.

| Number of Respondents | Note |
|---:|---|
| 220 | Total number of surveys returned. |
| -35 | Did not proceed past question 1. |
| -15 | Did not answer questions 10 or 14 (identifies climate zone and profession). |
| -13 | Not designers or builders as defined in this thesis. |
| -5 | Not practicing in a qualifying climate zone for this thesis. |
| **152** | **Total number of surveys used in the data set.** |

The number of respondents after cleaning is 152/220. To better understand the characteristics of the respondent body, designers and builders were separated. Of the eighty designers contacted, 112 actually responded where as only forty builders responded out of the eighty contacted. There are several possible explanations for this difference. One is that designers may be more likely to respond to a survey request by an architecture student because of a shared experience or that designers probably spend more time at a computer throughout the day. Builders are often visiting job sites and may spend less time at a desk. When respondent counts are broken down by state it becomes clear that personal connections played a bigger role in participation than expected. In Virginia and Oregon the respondent counts are highest for both designers and builders. The state with the lowest count is Michigan. Figure 4.1 shows a summary of respondent counts by building professional category and state.

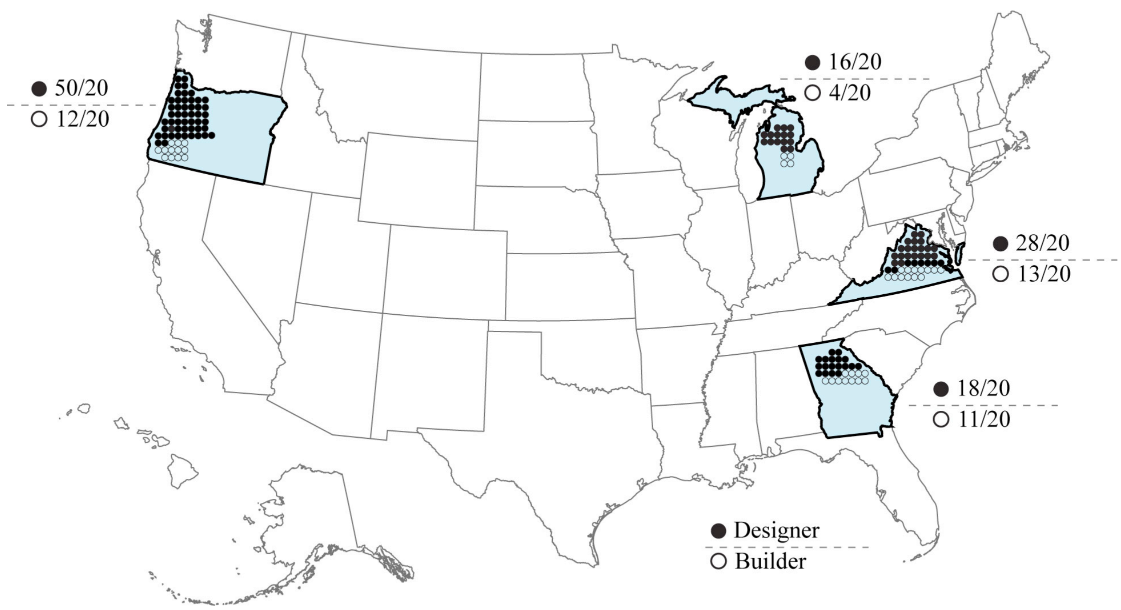



**Figure 4.1.** Number of responses by professional category and state. Recruiting calls or emails were sent to twenty designers and to twenty builders in each selected state.

Approximately 43% of respondents needed six to ten minutes to complete the survey; total duration was slightly underestimated. Thirty-four percent of all respondents agreed to a phone interview, and 20% indicated they would be willing to submit a detail. Of the thirty-one building professionals contacted to send in a best practice detail, seven actually did.

A national survey was an ambitious undertaking, but climate is important to consider when studying building enclosures. Overall, the respondent counts are surprisingly high.

### *Demographics*

All respondents were asked to select a category that best described their job position, how many years of experience they have, and their highest level of education. Because the category of "designer" encompassed registered architects, architectural designers, and architectural interns, all of these responses were grouped together. The "builder" category included general contractors, builders, and carpenters. Below, Table 4.2 summarizes the demographics of the respondents. For a more detailed summary of all demographic information, a chart is included in Appendix C.

**Table 4.2.** The demographics of respondents by state.

| | | **Georgia** | **Michigan** | **Oregon** | **Virginia** | **Total** |
|---|---|---|---|---|---|---|
| **Total by state** | | 29 | 20 | 62 | 41 | **152** |
| **Experience** | 0-5 Years | 5 | 6 | 7 | 2 | **20** |
| | 6-10 Years | 5 | 2 | 14 | 5 | **26** |
| | 11-15 Years | 5 | 1 | 11 | 7 | **24** |
| | 16-20 Years | 2 | 2 | 8 | 6 | **18** |
| | >20 Years | 12 | 9 | 22 | 21 | **64** |
| **Education** | High School/GED | 0 | 0 | 2 | 1 | **3** |
| | Some College | 3 | 0 | 0 | 2 | **5** |
| | Associates | 2 | 0 | 0 | 2 | **3** |
| | Bachelors | 6 | 4 | 10 | 9 | **29** |
| | Prof. Bach. | 10 | 4 | 21 | 13 | **48** |
| | Masters | 8 | 12 | 29 | 14 | **63** |
| | Tech. Cert. | 0 | 0 | 0 | 1 | **1** |

## Experience

Overall, 42% of respondents have more than twenty years of experience. Forty-two percent of designers have more than twenty years experience and 53% of builders have the same amount. Many very experienced people were generous with their time. The second largest category, building professionals with 6-10 years of experience, make up 17% and professionals with 11-15 years of experience make up 16%. The remainder of respondents were divided between 0-5 years (13%) and 16-20 years (12%) of experience.

## Education

The results for level of education are most accurately explained when broken down by professional category. Forty-eight percent of designers reported having a masters degree and another 40% have a professional bachelors degree. This is because most state registration boards require architects to have a National Architectural Accrediting Board (NAAB) accredited degree (“About”). Accredited degrees are usually a professional bachelors of architecture or masters of architecture. For builders, 35% have a bachelors degree, 20% have a professional bachelors degree, and 23% have a masters degree. There is no specific degree requirement for general contractors, builders, or carpenters; therefore, respondents in the “builder” category may have a variety of degree types.

In summary, a large portion of respondents are very experienced and well educated. Designers with more than twenty years of experience and a bachelors degree or higher make up 37% of respondents. Builders with the same qualifications make up 40% of respondents.

*Informational Resources*

## Where did building professionals learn about enclosures?

When asked where they learned about the proper use of air barrier systems and vapor retarders, 28% of designers and 33% of builders ranked “on the job” as number one, making it the most influential resource. Since “on the job” is not a physical resource, this can be interpreted to mean that “experience” is where most designers and builders learn about enclosure design. Below, Figure 4.2 shows the distribution of the number one rankings for most influential resource when they learned about air barrier systems and vapor retarders.

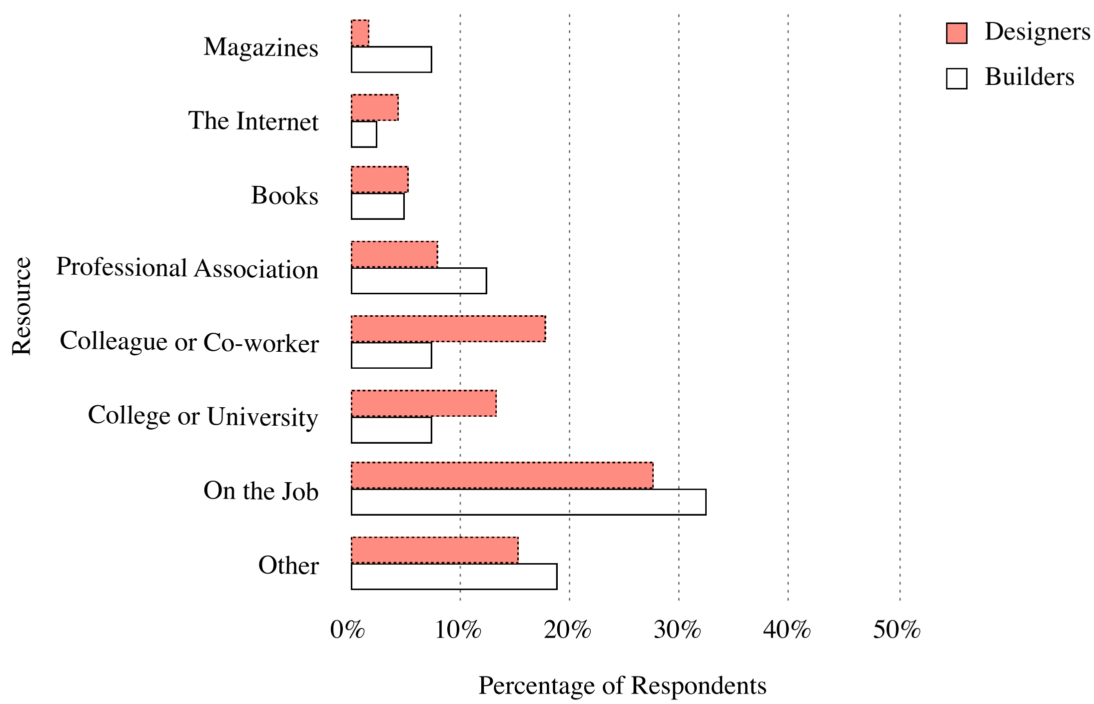



**Figure 4.2.** Most influential resource for designers and builders when they learned about vapor retarders and air barrier systems. This graph depicts the total of respondents' number one selection.

The following Table 4.3, is a list of how building professionals as a group rank the eight options given for where they learned about vapor retarders and air barrier systems. The second ranked option is a "colleague or co-worker." Surprisingly, "books" rank very low in seventh place. When respondents selected "other" they were asked to fill in the unlisted option. The most common filled-in options are consultants and industry representatives. Again, experience and conversation seem to be where most designers and builders initially learned about enclosure design.

**Table 4.3.** A ranked list of resources by building professionals. Where they *learned* about vapor retarders and air barrier systems.

| Rank | Resource | Percentage Rank |
|---|---|---|
| **1** | On the Job | 50.82% |
| **2** | Colleague or Co-worker | 45.07% |
| **3** | The Internet | 25.99% |
| **4 (tie)** | Professional Association | 24.01% |
| **4 (tie)** | University or College | 24.01% |
| **6** | Other | 20.56% |
| **7** | Books | 18.75% |
| **8** | Magazines | 15.13% |

**What resources do building professionals use when they have questions about the enclosure?**

A similar question asked where respondents look for answers when they have questions about air barrier systems and vapor retarders. This question is different because it asks which resource building professionals use to *maintain or update* the knowledge they have gained when learning. Forty-three percent of designers and 33% of builders selected "Colleague or Co-worker" as the number resource used. Again, because "Colleague or Co-worker" is not a written resource, this can be interpreted to mean that many questions are answered through conversation in the office or on a job site. Figure 4.3 depicts the distribution of the number one choice for the resource used when building professionals have questions about enclosure design. It seems that through experience, building professionals learn and continue to learn about the design of the building enclosure. Table 4.4 lists how all respondents rank the given resources. After "Colleague or Co-worker," the second most popular resource is, "The Internet" and, in third place, "Books" rank much higher than in the previous question. It seems building professionals are more likely to maintain their knowledge with written resources only after they have asked their co-workers for an explanation.

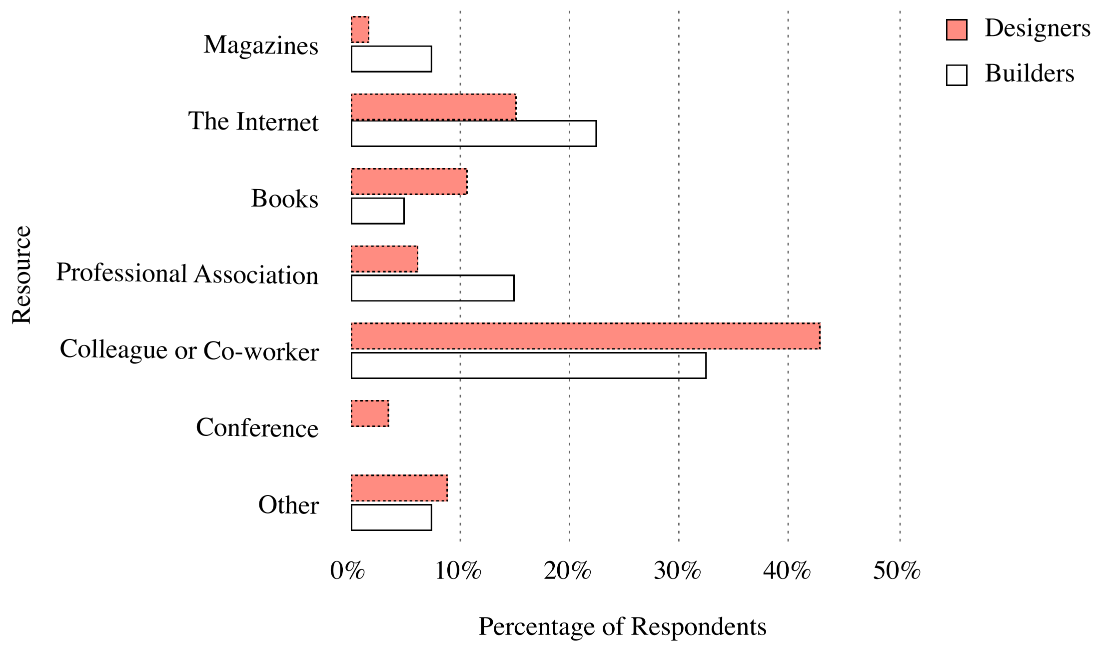



**Figure 4.3.** Most influential resource for designers and builders when they have questions about vapor retarders and air barrier systems. This graph depicts the total of respondents' number one selection.

**Table 4.4.** A ranked list of resources by building professionals. Where they *look* when they have questions about vapor retarders and air barrier systems.

| Rank | Resource | Percentage Rank |
|---|---|---|
| **1** | Colleague or Co-worker | 58.72% |
| **2** | The Internet | 50.16% |
| **3** | Books | 35.2% |
| **4** | Professional Association | 27.96% |
| **5** | Magazines | 21.71% |
| **6** | Conference | 16.12% |
| **7** | Other | 12.5% |

**How comprehendible do building professionals consider the resources?**

*Information About Vapor Retarders*

To follow up on the second question respondents were asked to describe the information available about the *function and placement* of vapor retarders and air barrier systems. This question is intended to help measure how comprehensible building professionals perceive the information on enclosure design. The majority of respondents report they believe the information on the *function* of vapor retarders to be "clear;" accordingly, 42% of designers and 33% of builders thought this. However, in comparison, when asked to describe the information on the *placement* of vapor retarders, both categories of building professionals expressed less clarity. Only 25% of designers reported the information on *placement* as "clear;" incidentally, 22% believe it to be "somewhat confusing." Twenty-three percent of builders described the information on *function* as "clear," and 43% describe it as "somewhat clear." Figures 4.4 and 4.5 depict how building professionals describe the information about vapor retarders.

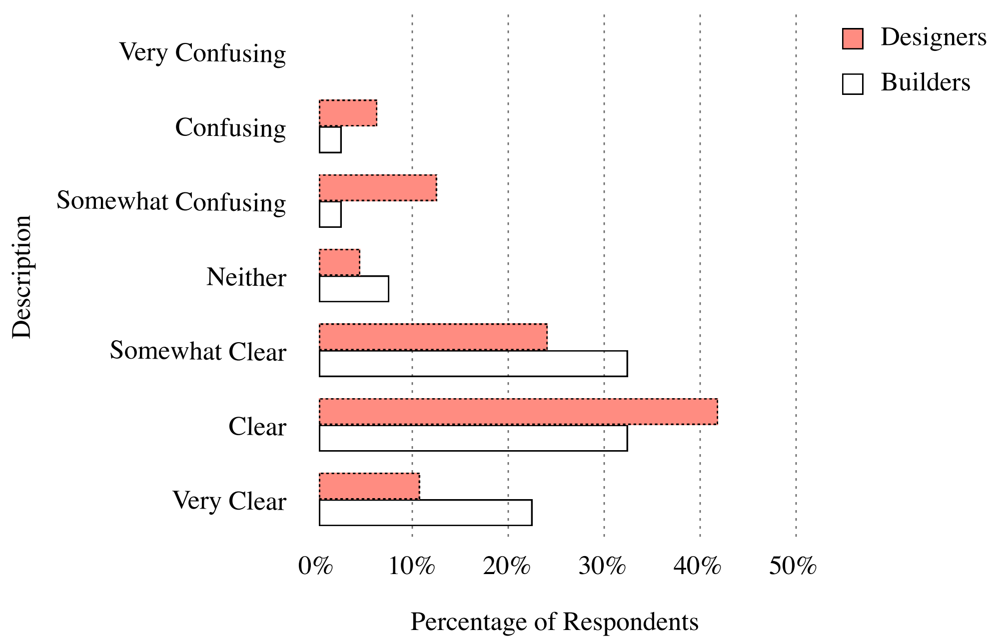



**Figure 4.4.** How designers and builders describe the information about the *function* of vapor retarders.

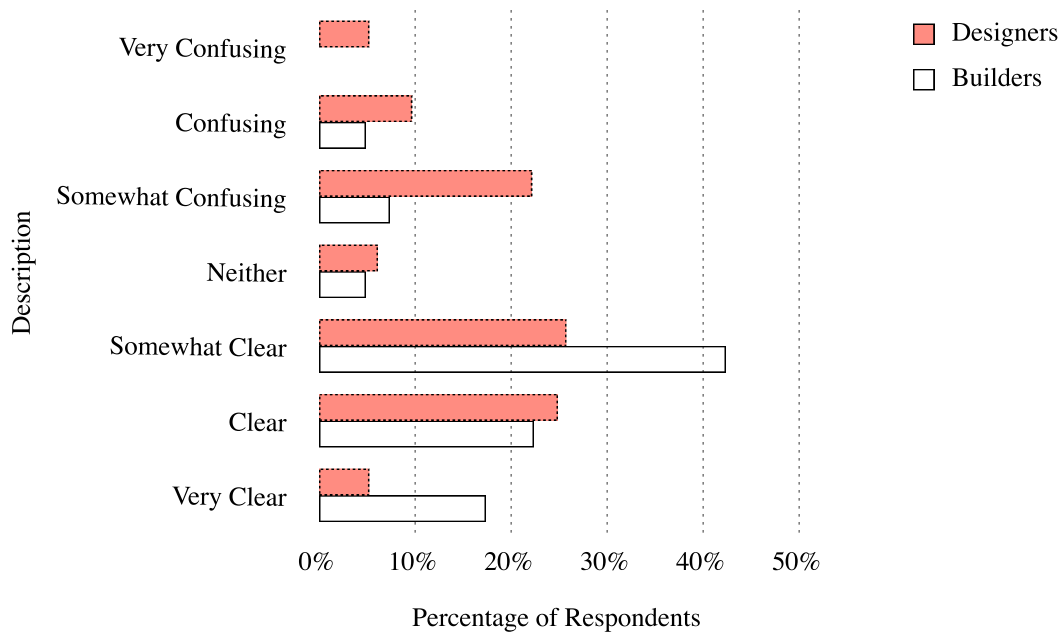



**Figure 4.5.** How designers and builders describe the information about the *placement* of vapor retarders.

Building professionals report the information on the *function* of vapor retarders to be more comprehensible than the information on the *placement* of vapor retarders. Because most respondents report that through experience they learned about vapor retarders and air barrier systems, a cross tabulation of experience and description was created in hopes of finding a relationship between experience and understanding of resources. Figures 4.6 and 4.7 illustrate the results. It is made clear that building professionals with 0-5 years of experience believe the information on *function* to be more clear than the information on *placement*. Building professionals with >20 years of experience show an equal understanding of *function and placement*. It is possible to conclude that as building professionals gain experience, the information becomes increasingly understandable.

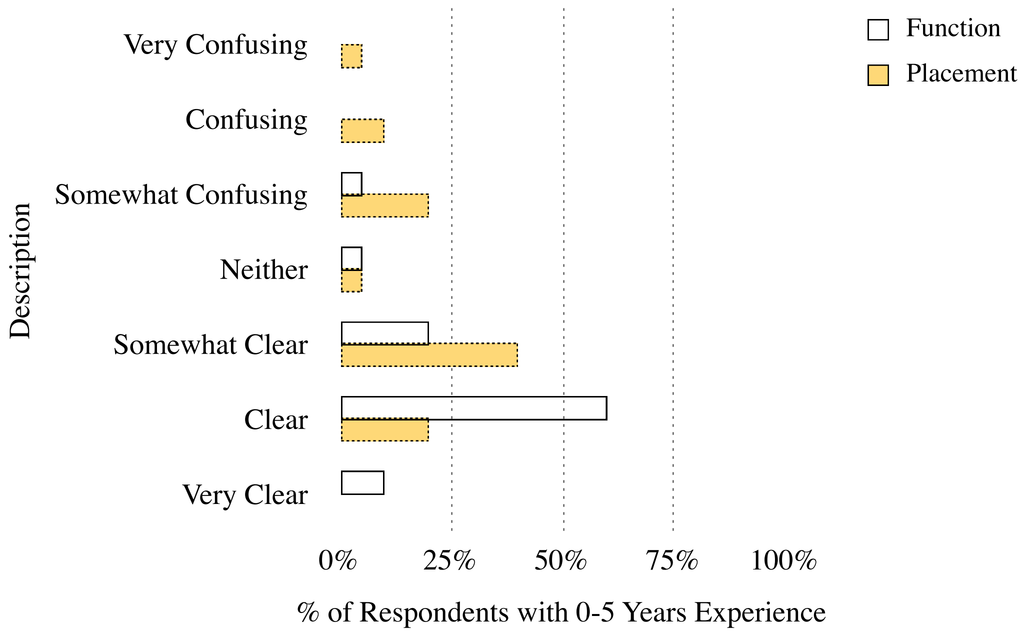



**Figure 4.6.** How designers and builders with 0-5 years of experience describe the information about *function and placement* of vapor retarders.

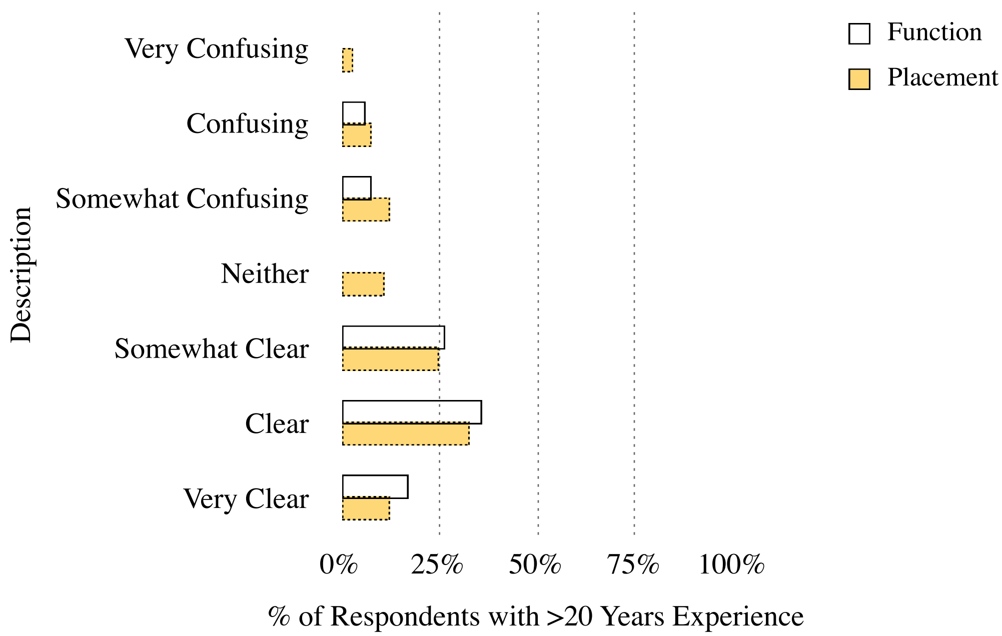



**Figure 4.7.** How designers and builders with >20 years of experience describe the information about *function and placement* of vapor retarders.

*Information About Air Barriers*

In a similar question building professionals were asked to describe the information available on air barrier system *function and placement*. Thirty-four percent of designers described the information about *function* to be “clear” and only 13% said it was “somewhat confusing.” Forty-three percent of builders described the information about *function* as “clear.” Below, Figure 4.8 graphs the respondents’ responses compared to one another. Concerning the information on the *placement* of air barrier systems, more respondents described it as “somewhat clear,” demonstrating a drop in clarity. Twenty-four percent of designers described the information on *placement* to be “clear” and another 24% described it as “somewhat clear.” Incidentally, 21% of designers reported the information to be “somewhat confusing.” Builders were more evenly distributed between “somewhat clear” (33%), “clear” (30%), and “very clear” (23%). Figure 4.9 graphs the comparison of designers and builders and how they describe the information about the *placement* of air barrier systems.

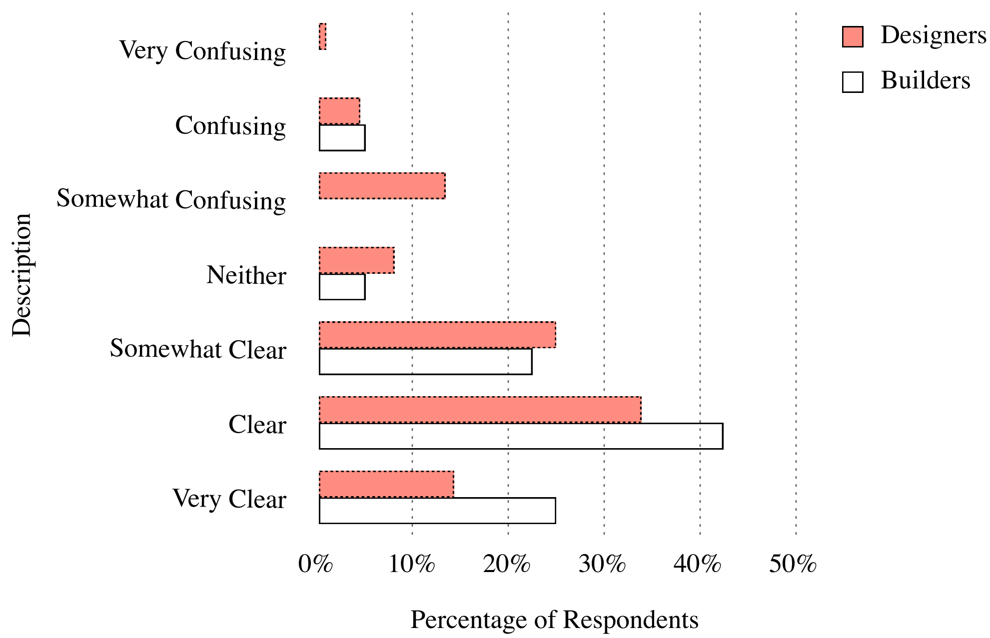



**Figure 4.8.** How designers and builders describe the information about the *function* of air barrier systems.

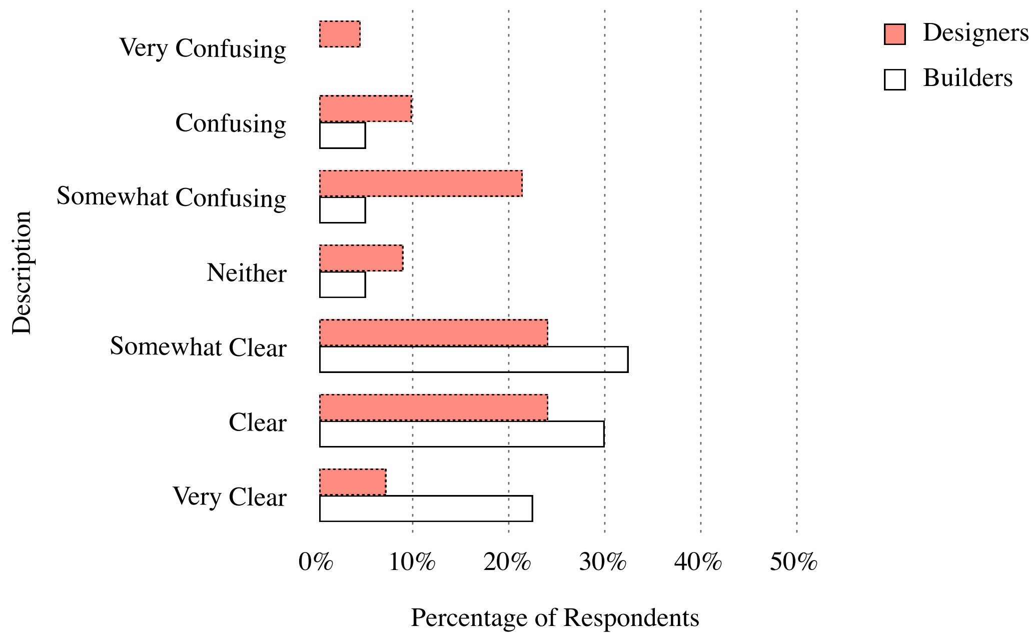



**Figure 4.9.** How designers and builders describe the information about the *placement* of air barrier systems.

Again, it can be concluded that building professionals believe the information about the *function* of air barrier systems is more comprehendible than information about the *placement* of air barrier systems. To determine if experience affects how building professionals describe the information, a cross tabulation of experience and description was created. Figure 4.10 shows how building professionals with 0-5 years of experience describe information about *function and placement* of air barriers. Notice that clarity of *function* trends upwards from “very confusing” to “clear,” yet the description of *placement* spikes over “somewhat confusing.” Figure 4.11 depicts how building professionals with >20 years of experience describe information about *function and placement* of air barriers. The descriptions of *function and placement* steadily rise together from “very confusing” to “clear.”

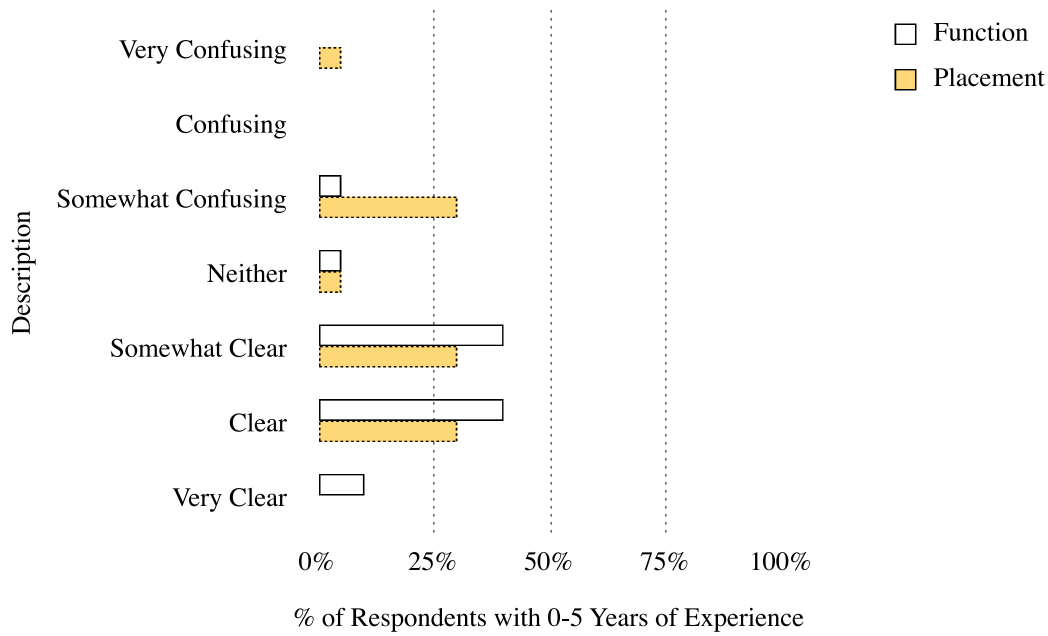



**Figure 4.10.** How designers and builders with 0-5 years of experience describe the information about the *function and placement* of air barrier systems.

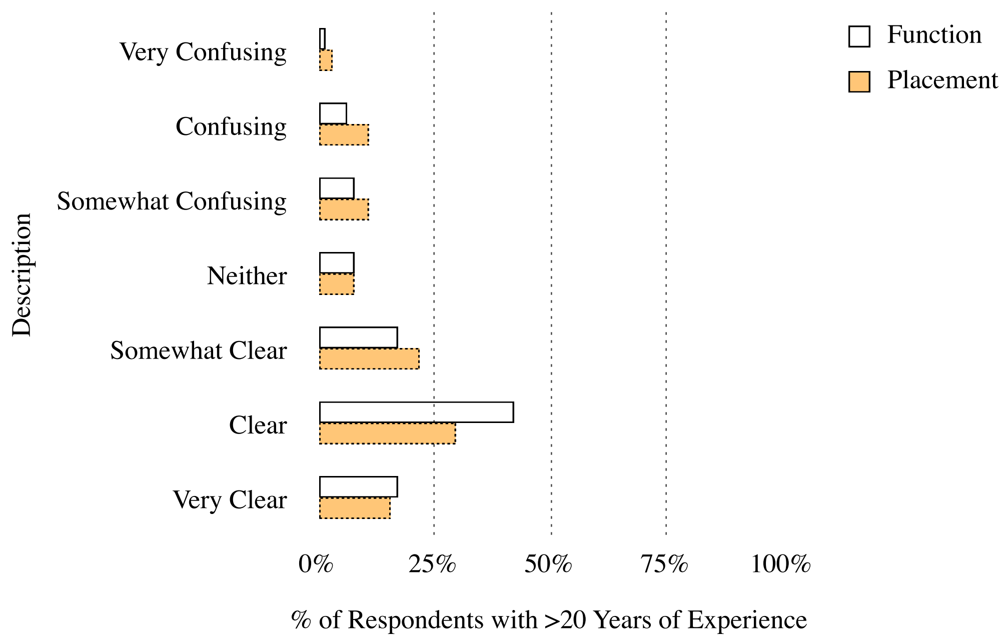



**Figure 4.11.** How designers and builders with > 20 years of experience describe the information about the *function and placement* of air barrier systems.

## Air Barrier System

When asked their opinion on whether or not an air barrier system needs to be continuous for proper function of the enclosure (see Figure 4.12), 65% of designers and 83% of builders selected "strongly agree" or "agree" making those the top picked choices. The importance of a continuous air barrier system was established in Chapter II, and it can be concluded that most building professionals believe in this practice. More builders than designers "strongly agree" or "agree" with this statement. As a control to determine if respondents understood the difference between air barrier system and vapor retarder continuity, respondents were also asked their opinion of the continuity of a vapor retarder. It is not as important for a vapor retarder to be completely continuous to perform its job. Encouragingly, 9% fewer designers selected "agree" or "strongly agree" on this question and 23% fewer builders did the same. Most builders shifted their opinion to "disagree" or "strongly disagree." Twenty-eight percent of builders disagree that a vapor retarder must be continuous for the proper function of the enclosure; yet, only 15% of designers disagreed. These results indicate that builders may have a better understanding of vapor retarder usage. This also seems to indicate a slight misconception between the continuity of air barrier systems and vapor retarders. Figure 4.13 graphs these findings.

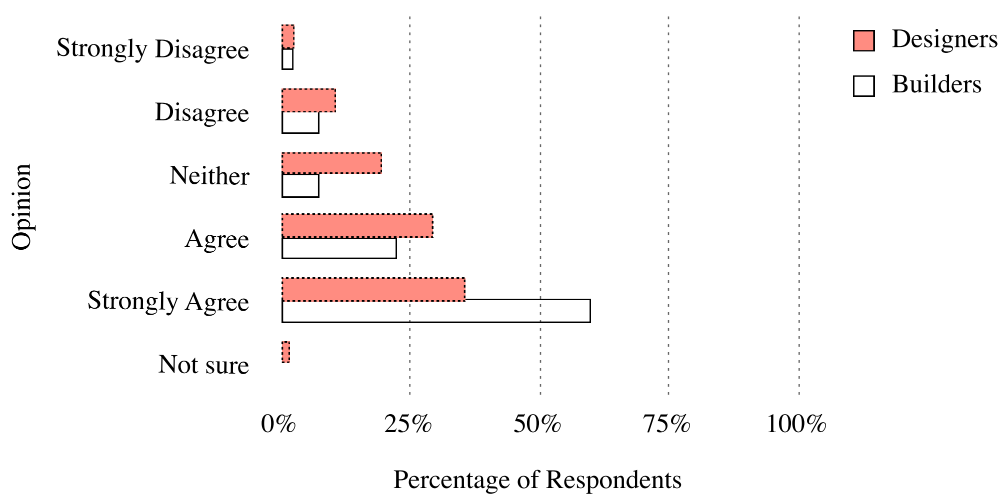



**Figure 4.12.** Designers' and builders' opinions on whether or not an air barrier system must be continuous for proper function of the enclosure.

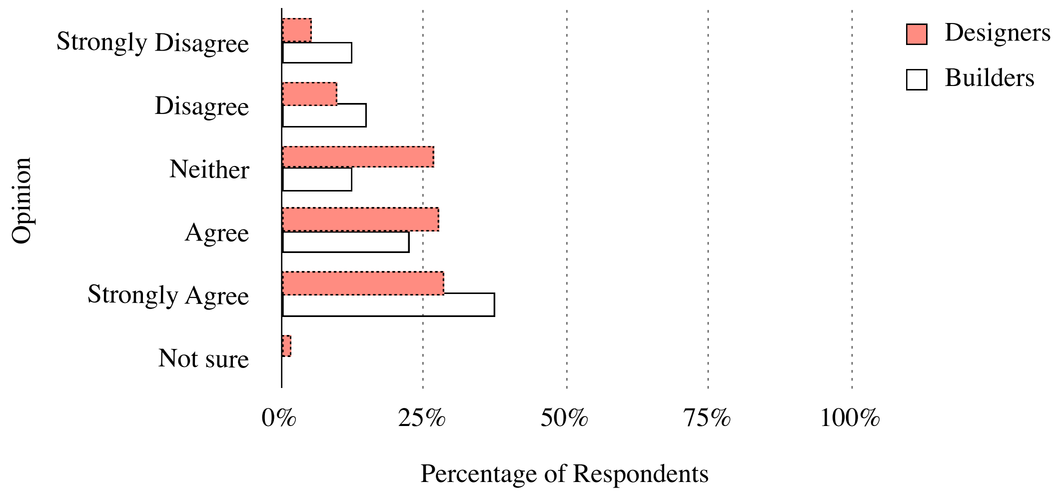



**Figure 4.13.** Designers' and builders' opinions on whether or not a vapor retarder must be continuous for proper function of the enclosure.

To determine if experience may have an affect on builders' strong opinion of air barrier system continuity, a graph comparing how often blower door tests are performed between designers and builders is below (see Figure 4.14). It was established in previous questions that experience is how most building professionals learn about these subjects. Field testing the air barrier system is one hands-on way to experience the effectiveness of a continuous air barrier system. Nineteen percent more builders than designers say they "always" perform a blower door test on the houses they build. Experiencing first-hand, in the field, the effects of a well detailed air barrier system may account for why more builders agree with the importance of continuity. This supports the results from previous questions where building professionals reported they learned about this topic through experience.

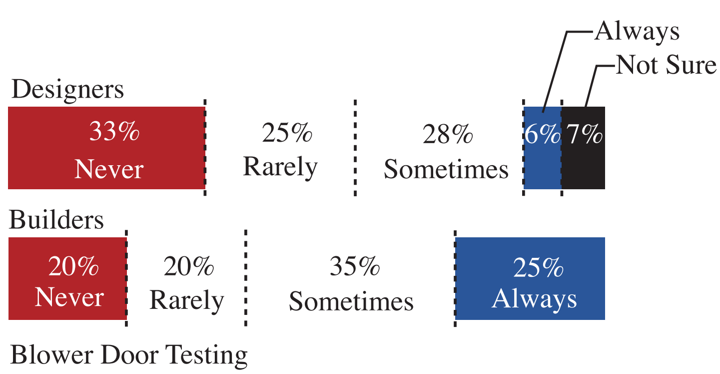



**Figure 4.14.** How often blower door testing is performed between designers and builders.

It has been established that a majority of building professionals believe the continuity of the air barrier system is essential for proper function of the enclosure. This also follows the established convention set forth by codes and other well-respected resources. To determine if the respondents' understanding of "continuous" was the same as convention, they were asked to select air barrier system components from a list of enclosure components. Established in earlier chapters, the air barrier system is made up of a combination of the parts of the enclosure; all the selections of the question were part of the air barrier system. Not surprisingly, 100% of designers and builders selected, "walls" and only a few less picked "windows" and "doors;" however, the choices of "ceiling," "roof," and "floor" were much less popular. This indicates that building professionals clearly understand the air barrier system as the walls and the components of the walls and understand less that the air barrier system is three-dimensional, including all surfaces that touch the outside air. Below, Figure 4.15 graphs these findings.

There are exceptions to what building components make the air barrier system depending on the enclosure's design. This could account for why some choices were picked more than others. However, in general, each selection is a part of the enclosure's defense against air infiltration and should have been selected. It is a misconception to believe that ceilings, roofs, and floors are not part of the air barrier system.

In summary, it is difficult to determine which professional category, designers or builders, knows more about air barrier systems. The most intriguing comparison is that many more builders report "always" performing field testing of air barrier systems. This may account for a larger percentage of builders believing that a continuous air barrier system is essential for proper function of the enclosure. Through experience, more builders have learned the importance of a well-detailed air barrier system.

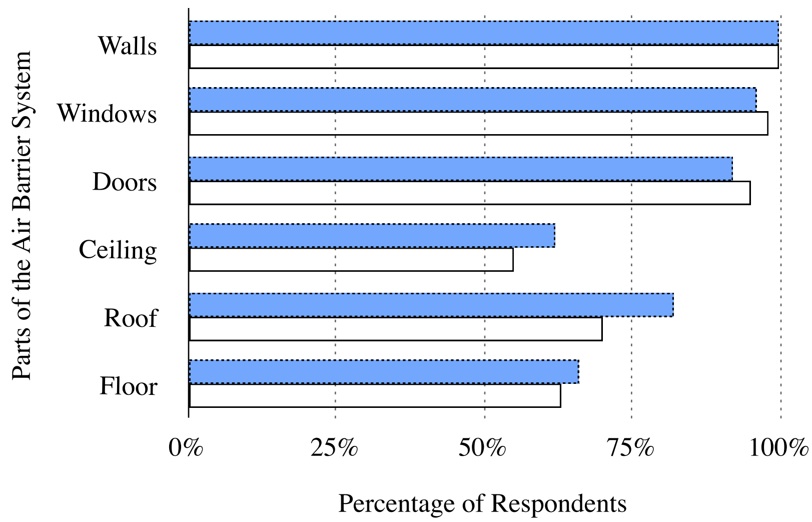



**Figure 4.15.** Which parts of the building building professionals consider to be part of the air barrier system. All selections are actually part of the air barrier system.

## Vapor Retarder

Although 27% of respondents believe the information on the *placement* of vapor retarders to be "somewhat confusing" or worse, an overwhelming amount of respondents report they consider the climate when placing it. This indicates that a majority of building professionals surveyed recognize climate specific vapor drive in enclosure design—a good practice to have. Eighty-six percent of designers and 68% of builders say they "always" consider climate. Figure 4.16 graphs these findings. However 100% of building professionals should have selected "always." The remaining respondents who never, rarely, or sometimes consider climate in vapor retarder design may be operating under a misconception that it is not important.

Understanding that climate plays a major role in placing a vapor retarder is not the whole story. It is also important to understand the characteristics of the individual climate. Below, in Table 4.5, a cross tabulation illustrates where building professionals in each climate zone typically place a vapor retarder. Assuringly, the majority of respondents from Georgia report they place the vapor retarder towards the exterior, and respondents from Michigan almost always place in towards the interior. There are mixed results from Virginia and Oregon. Although code in Oregon requires the vapor retarder to be placed on the "warm side (in winter) of all insulation" in most cases, 23% report they typically put the vapor retarder towards the exterior; this is a significant misconception ("2011 Oregon 11-10"). In Virginia, where code does not regulate vapor retarder placement, 32% of respondents report putting the vapor retarder towards the exterior and 41% say they put it towards the interior. Although it is widely accepted that in mixed climates vapor retarders should be used in the middle of the wall or not at all, Virginian building professionals seem to remain torn between problematic placement, again another possible misconception. Alternatively, the largest percent of respondents that responded with "do not use" (15%) are from Virginia, which is encouraging.

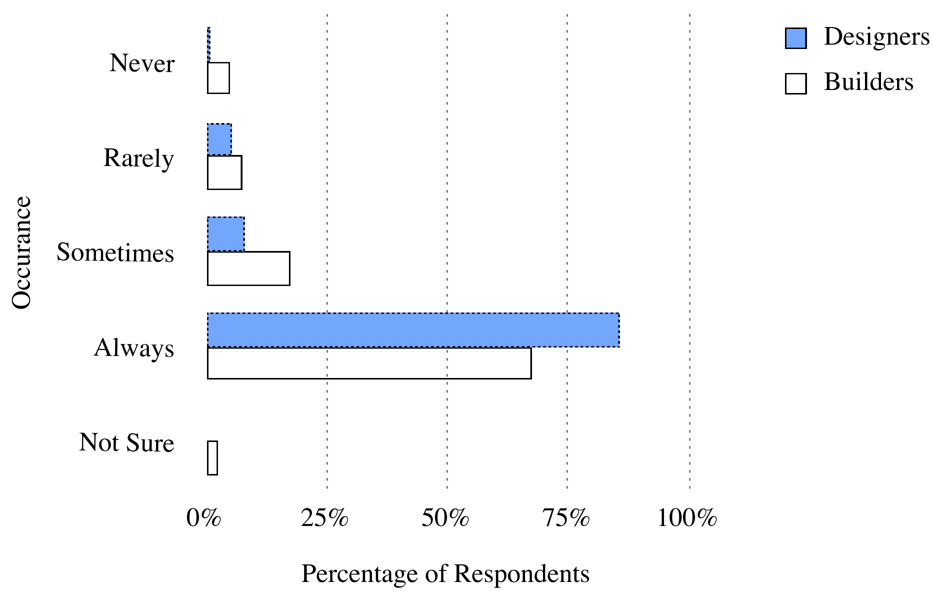



**Figure 4.16.** How often designers and builders consider climate when placing the vapor retarder.

It should be recognized that different construction types and wall assemblies determine vapor retarder placement. The survey was very broad and only asked for a typical placement. Respondents answers could have varied depending on the types of construction they typically build.

**Table 4.5.** Cross tabulation of where building professionals in the six climate zones surveyed typically place vapor retarders.

| Climate Zone (state, characteristic) | Towards the- interior | exterior | middle | Do not use | Not sure | Blank |
|---|---|---|---|---|---|---|
| **Zone 2A (Georgia, warm-humid)** | 0% | 80% | 20% | 0% | 0% | 0% |
| **Zone 3A (Georgia, mixed)** | 13% | 83% | 0% | 4% | 0% | 0% |
| **Zone 4A (Virginia, mixed)** | 41% | 32% | 7% | 15% | 2% | 2% |
| **Zone 4C (Oregon, marine)** | 61% | 23% | 3% | 10% | 2% | 2% |
| **Zone 5A (Michigan, cold)** | 69% | 19% | 6% | 6% | 0% | 0% |
| **Zone 6A (Michigan, cold)** | 100% | 0% | 0% | 0% | 0% | 0% |

## Observed Building Failure

An open-ended question asked building professionals if they had ever experienced building failure due to air infiltration or vapor diffusion; 46% of all respondents said they had experienced building failure and sixty-five comments were gathered on their experiences. The list of building failures was coded by four categories: vapor related issues, air infiltration related issues, flashing or leak related issues, and non-applicable comments.

The results of coding revealed that 55% of the failures were due to a reported issue with vapor. Problems included improper placement of the vapor retarder, two vapor barriers, and no vapor retarder used at all. The most common effect was mold growing within the wall cavity. Reportedly, 19% of vapor related issues were due to high moisture levels within the building caused by internal sources or lack of proper ventilation, and all of these cases happened in the cold, marine, and mixed climates. Only 11% claimed that the improper detailing of an air barrier caused moisture to accumulate within the wall which initiated mold growth, and 15% reported mold or rot issues because of a failure in flashing or a leak. The percentage of reported failure is considerably high, especially with vapor related problems. Although most of the failures are not detrimental to the structural integrity of the building, they are problems that require retrofit to be solved. A summary of all comments by respondents describing the building failure they experienced can be found in Appendix D.

*Example Details*

Building professionals were asked to submit an example of how air barriers and vapor retarders are detailed at their respective companies; these details represent common practice. Seven respondents volunteered a detail but only four are included in this thesis. The submitted details provide this thesis with drawings that demonstrate respondents' understanding of vapor retarders and air barrier systems.

A close inspection of how different designers and builders communicate in drawings was done. Five of the drawings specifically mentioned an air barrier material or portions of an air barrier system, two called out a vapor retarder or barrier, yet only one mentioned a required permeability of a vapor retarder used in the section. All details specified insulation. Each detail was thoughtfully designed. On the following pages, Figures 4.17-4.22 are portions from the details submitted exemplifying common practice of designers and builders.

These details are excellent examples of how enclosure design is typically communicated from designer to builder. Most of the drawings are drawn two dimensionally with notes highlighting material specifications. One set of drawings stood out from the others as an example of the evolution of communication between designers and builders. The architects at PIVOT Architecture and KMD Architects and Planners submitted a three-dimensional series of drawings that steps the builder through the construction of the air barrier system. Clearly drawn and noted, it is a good example of construction documents that consider the difficult nature of this topic. The vapor barrier, air barrier, and flashing are all shown as a system. Figure 4.20 depicts these drawings as submitted by the architect.

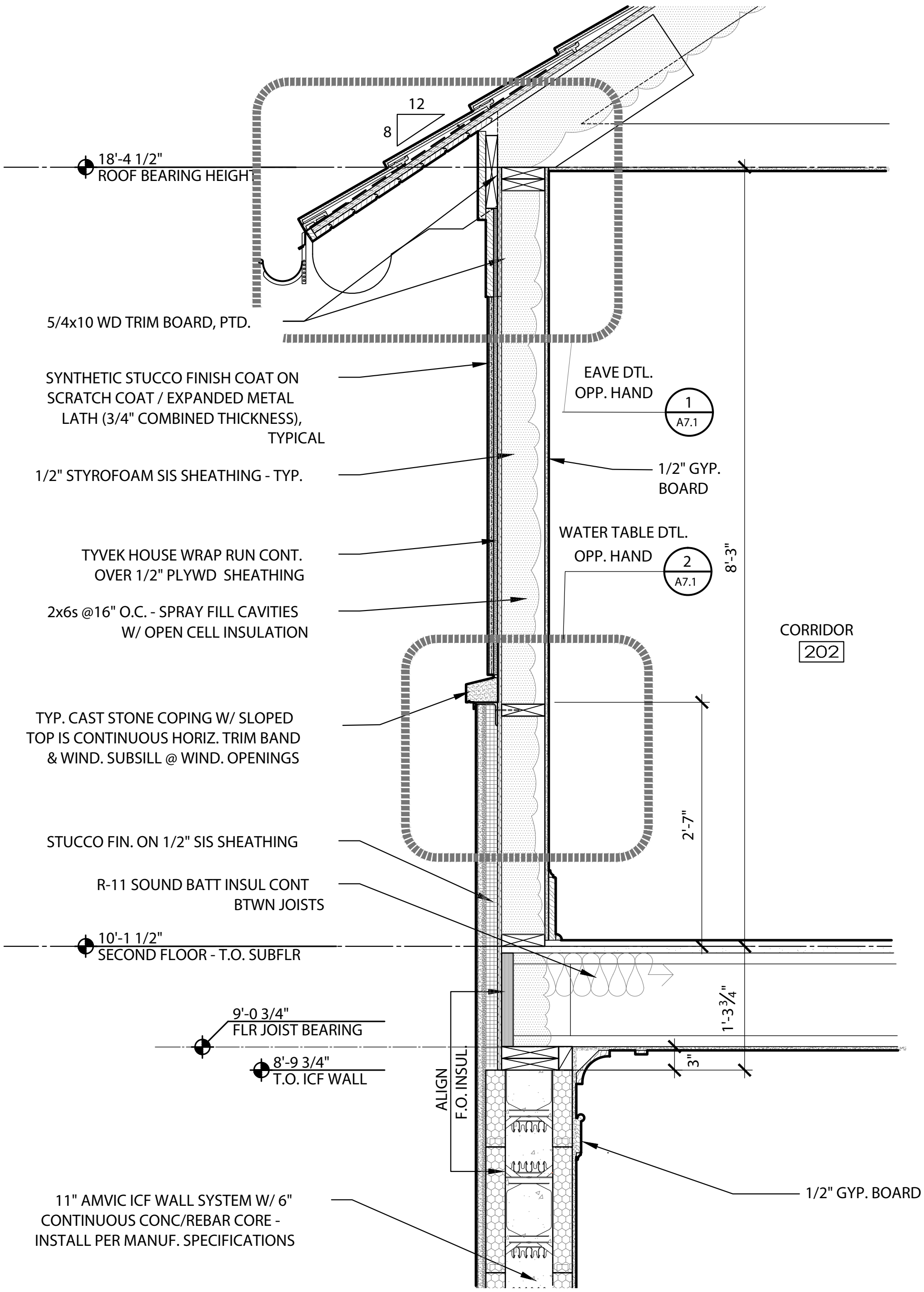



**Figure 4.17.** Residential wall section submitted by **brwa**rchitects in Charlottesville, VA. Notice the designer has used SIS sheathing as a thermal break, called out Tyvek house wrap to run continuously over sheathing, and specified open-cell spray foam insulation (**brwa**rchitects).

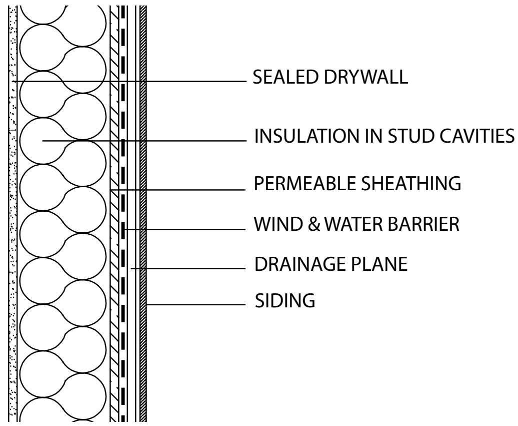



**Figure 4.18.** Residential wall section detail submitted by Wayne Stinnette, a contractor from Charlottesville, VA. Notice the use of a permeable sheathing in recognition of needing a “dry-through” assembly in Virginia’s mixed climate. This respondent has also recognized the gypsum board as part of the air barrier system and called it out as “sealed” (Stinnette).

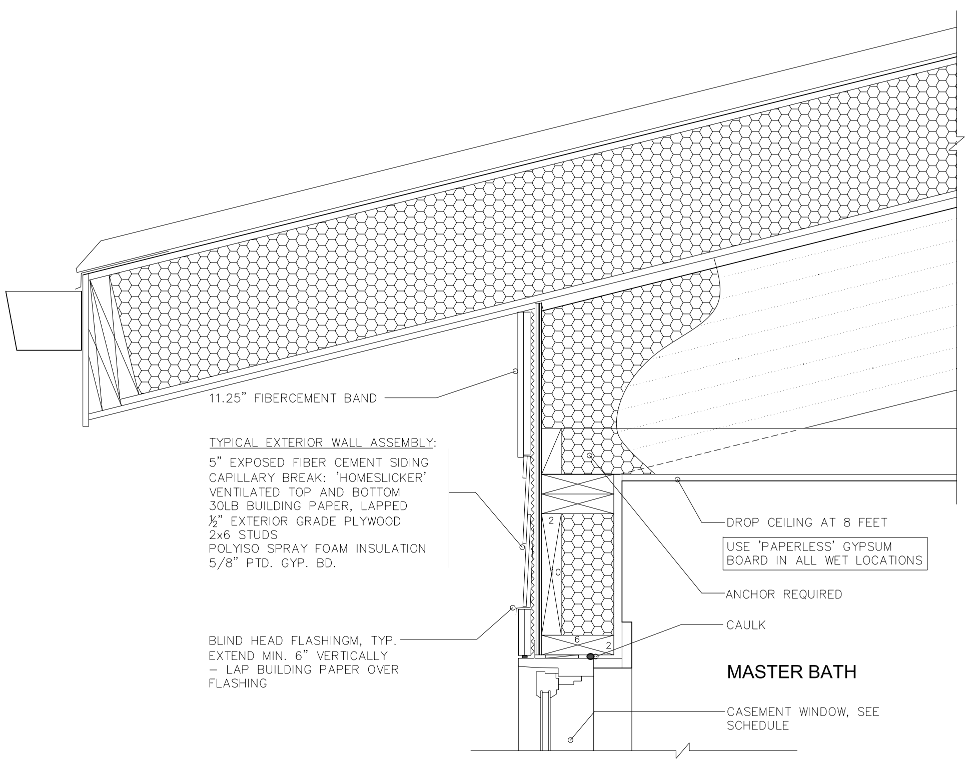



**Figure 4.19.** This residential roof and wall section features polyiso spray foam insulation throughout as the thermal insulation and as the air barrier system. Roof ventilation has been eliminated because spray foam insulation has been installed against the roof sheathing. A rain screen has also been utilized here. This detail complements of SUNBIOSIS from Charlottesville, VA (SUNBIOSIS).

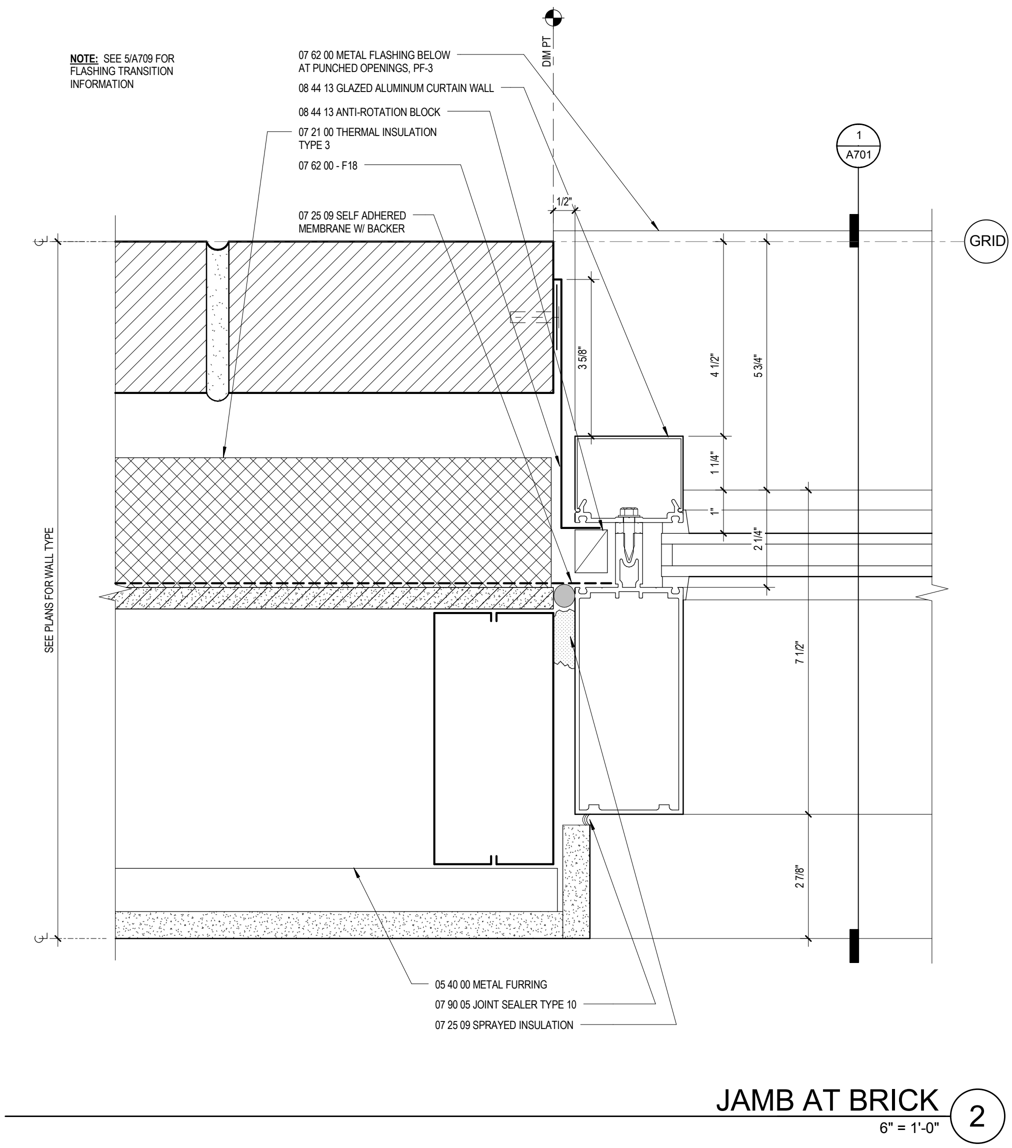



**Figure 4.20.** Although this detail is not from a residential project, it is useful in demonstrating air barrier system details in a brick building. Insulation has been used over the sheathing as a thermal break and a self-adhered membrane over the sheathing. The membrane most likely serves as part of the air barrier system. Where the curtain wall meets the jamb, spray foam insulation is used to block air infiltration. This detail is complements SERA Architects from Portland, OR (SERA Architects).

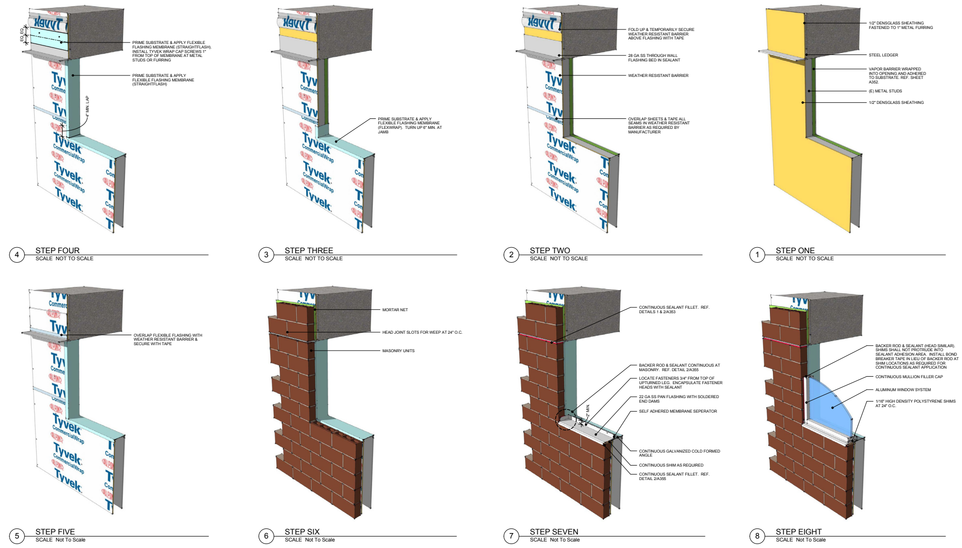



**Figure 4.21.** Exterior envelope sequencing at a window courtesy of PIVOT Architecture and Wiss, Janney, Elstner Associates, Inc. with KMD Architects and Planners. The architects credits the *DuPont™ Tyvek® Weather Barrier Commercial Installation Guidelines* for the inspiration behind the three-dimensional drawings. These drawings could represent an evolution of how designers and builders communicate these complicated systems (PIVOT Architecture and Wiss, Janney, Elstner Associates Inc.).

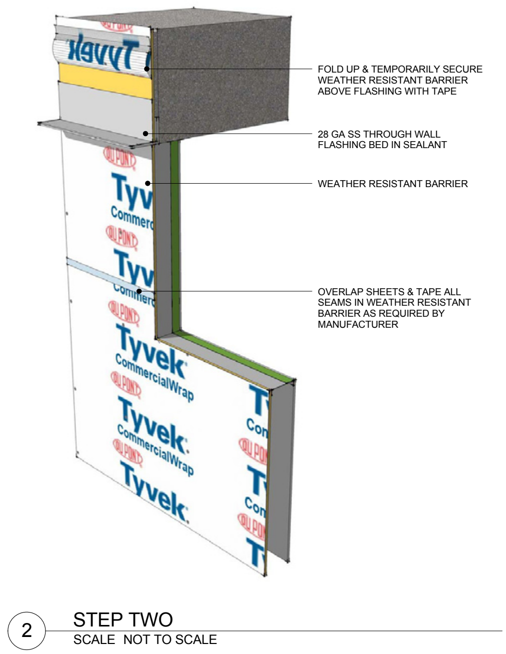



**Figure 4.22.** An enlarged portion of Figure 4.19. Each three-dimensional drawing is a step in the sequence of proper air barrier and flashing placement at a window (PIVOT Architecture and Wiss, Janney, Elstner Associates Inc.).

In summary, the analysis of the common practice details reveals that designers and builders recognize the air barrier system more often than the vapor retarder. This may be because the majority of details were submitted from Virginia, in a mixed climate and vapor retarders are not required there. Thermal bridging is handled with insulative sheathing and rigid insulation outboard of the stud cavity. Interestingly, the sequence of drawings demonstrating a three-dimensional air barrier and flashing assembly was the most informative. Communicating three dimensionally may be the next evolution of architectural drawings to insure proper installation of thin membranes like air barrier systems and vapor retarders. One explanation for this firm's drawing sequence could be their recognition of windows being a problematic location. To properly seal the air barrier at a window, a three dimensional understanding of how the membrane wraps the jambs and seal must be clear. This leads to the question: Are there other problematic intersections within the enclosure that could benefit from three-dimensional assembly drawings? Could better detailing be solved by providing installers with step-by-step, three-dimensional drawings?

### *Interviews*

Because much of how building professionals learn about this subject is verbal, casual phone interviews were held with several willing participants. Four questions were asked of the respondents selected for a anecdotal phone interview. They are as follows:

1. What are your sources for learning about the enclosure?
2. What is the common theory in your firm or company on enclosure design?
3. In your opinion, what are the misconceptions in your field about enclosure design and which do you come across most often?
4. What successful practices have you put into place concerning the building enclosure?

These conversations are intended to provide this thesis with a point of view that may not have been conveyed in the survey alone. Contributors will be identified as Designer 1, Designer 2, Designer 3, Designer 4, Builder 1, and Builder 2. The same number of designers and builders were contacted in each climate; not all responded willingly.

**What are your sources for learning about the enclosure?**

Several similarities between all interviewees surfaced when asked where they go when they have questions about enclosure design. The top four stated resources are the internet, Building Science Corporation, product manufactures websites, and envelope consultants. Designers 1 and 4 explained that when it is possible, envelope consultants are excellent resources for information on the enclosure. They have both had projects where the envelope consultant is part of the design team much like a structural or mechanical engineer and rely on this person for information. Building Science Corporation, specifically Joe Lstiburek, was mentioned twice as an invaluable and trustworthy resource on building enclosure design.

**What is the common theory in your firm or company on enclosure design?**

Answers to this question differed, as expected. Designer 2, from Virginia explained that he firmly believes in a "dry-through" wall assembly. He does not use a vapor barrier and pays attention to the permeability of each material he uses in the enclosure. He also uses spray in place foam insulation in most projects because of its ability to perform as the air barrier. Designer 3 practices in Michigan and follows the rule of placing a vapor barrier on the warm side of the insulation in a house, which is usually 9 mil Visqueen. Designer 4 explains that in her Portland, Oregon practice, the rigid insulation has been moved outside the sheathing and the stud cavity is left empty. This assembly allows them to eliminate the "warm in winter" vapor barrier and use the sheathing as such.

Builder 1's Virginia company almost exclusively insulates the entire envelope, eliminating the need for attic and crawl space ventilation. The spray foam coating applied to the cavity side of the sheathing also creates an effective air barrier. They came to this conclusion over the last decade through reading about the positive aspects of this assembly. Builder 2 is also a designer, and in his practice buildings made to meet Passive House standards are their speciality. They have determined that a vapor open sheathing such as Densglas or fiberboard is the best choice. They tape the sheathing to create the air barrier, therefore combining vapor management, air management, and structural integrity into one layer. Insulation lies outboard of the sheathing so the air barrier is uninterrupted by electrical and plumbing chases.

**In your opinion, what are the misconceptions in your field about enclosure design and which do you come across most often?**

The most common response from designers was that the detailing around windows (air barrier to window, sill pan, etc.) was a problematic area in the field. There are many components connecting at a window and careful installation is imperative. Two designers explained that they have special three-dimensional drawings to explain the sequencing of window installment to contractors (see Figure 4.21). Designer 1 and Designer 4 have experienced contractors applying the weather barrier with a variety of different manufacturers' tape products. It is a misconception that any tape will work with any membrane fabric; they are product specific and will possibly fail over time. Designer 3 explained he has problems with having the vapor barrier installed completely and neatly and often makes a point of being on the job site when it is installed.

Builder 1 has experienced the misconception that attics and crawl spaces need to be ventilated. Because his company almost always insulates the entire envelope, ventilation is not necessary. He also has experienced that vapor impervious membranes are accidentally used or used intentionally when they are not needed. Builder 2 believes one misconception is that many people look for where the dew point is. He thinks a better way of determining if interstitial condensation will occur is to identify the most vapor resistive layer and then identify if its temperature will be below dew point.

**What successful practices have you put into place concerning the building enclosure?**

Most interestingly, a common answer from designers was that they like to establish a personal relationship with the job site superintendent to insure quality workmanship. They believe an open working relationship encourages questions to be asked when a detail is unclear and quick responses to questions increase the likelihood of installation as drawn. All of the designers stressed the importance of preliminary communication with the contractor before construction begins where the intent of the job is explained.

Designer 4 explained that within her office, they perform quality control checks. More eyes catch mistakes and insure a higher quality set of drawings. They also have in-house sessions where lessons learned are shared for the entire office's benefit. Builder 1 believes that advanced systems like SIPs, ICFs, etc. are more likely to be used by a client if a cost benefit analysis is done. They take the time to show their clients what the return on their investment will be to help their decision to use a more sophisticated building system. Builder 2 believes that having contractors perform and experience blower door tests on each project is a powerful tool. He says "there's a big difference between someone who's seen a .6ACH and someone who hasn't" (Builder 2). This statement is evidence for some conclusions made in this thesis.

All of the conversations inadvertently shared the theme of the importance of communication. Several designers expressed frustration with contractors and the issue of buildings not reflecting drawings. One builder suggested that designers should consider simplicity when designing the enclosure to insure congruency in construction. Blaming one another is probably not the solution. Maybe details could be simplified and contractors could follow drawings more carefully, but it could be that a new way of communication is needed. Some successful practices were identified in the interviews like pre-construction meetings and relationships with the guys swinging the hammer. Drawing styles like Figure 4.21 (three-dimensional and sequenced) could be used for other complicated parts of the enclosure.

In conclusion, all of the interviewees were aware of this issue and make attempts to keep their personal knowledge up to date. Resources vary as much as enclosure detailing but a general recognition is shared.

## Content Analysis

### *Architectural Graphic Standards*

In a multi-edition review of the popular design handbook *Architectural Graphic Standards,* it was discovered that over a relatively short period of time (1970-2007), the definitions and thoughts about vapor retarders and air barrier systems have changed significantly. Beginning with the 1970, 6th Edition and ending with the latest edition, 2007, 11th Edition, a close examination of how each edition defines and describes the use of vapor retarders and air barrier systems was performed. A complete summary is included in Appendix E, Table E.1.

The most interesting findings are that the official definition of the membrane in the building's enclosure that manages water vapor migration, in the 1970, 6th edition, was originally called a vapor barrier and that it had a perm rating of one. This definition evolved in the 1994, 9th edition to vapor retarder and explicitly mentions it is no longer known as a vapor barrier. From 1994 to the current edition, vapor retarder is defined as a material with a perm rating less than one; however, the current edition does mention the lack of consensus within the industry about correct usage the terms vapor retarder and vapor barrier. This edition resorts to defining the material by performance standards rather than nomenclature. No definition for an air barrier system is given until the latest edition in 2007, but air movement is recognized as a source of moisture migration beginning in the 1994, 9th edition.

Instructions on placement of the vapor retarder in the 1970, 6th edition are vague at best. This edition recognizes moisture accumulation indoors by way of cooking, breathing, etc. and suggests its migration must be controlled to acceptable rates. The 1988, 8th edition suggests "the vapor barrier be placed as close as possible to the indoor surface of the building" (Ramsey, Sleeper, and Hoke 335). There is no mention of vapor drive or climate considerations. The next edition, 1994, suggests "the vapor retarder should be installed as close as possible to the side of the wall through which moisture enters" (Ramsey, Sleeper, and Hoke 352). Vapor drive has been recognized as conditional and not always from inside to outside like previously thought. Placement for vapor retarders does not change until the 2007 edition where a full explanation of climate based placement is included. It is a much improved explanation including suggestions for placement for all U.S. climate zones.

True instruction on proper air barrier system usage is not included in a *Architectural Graphic Standards* until the latest edition, 2007. Air infiltration is mentioned in previous books and solutions for prevention are: "Plant vegetation to create wind-sheltering building sites. Shape building to minimize exposure to winter wind. Specify weatherstripping and infiltration barrier" (Ramsey, Sleeper, and Hoke 709). These are considered to be inadequate solutions currently.

*The Internet*

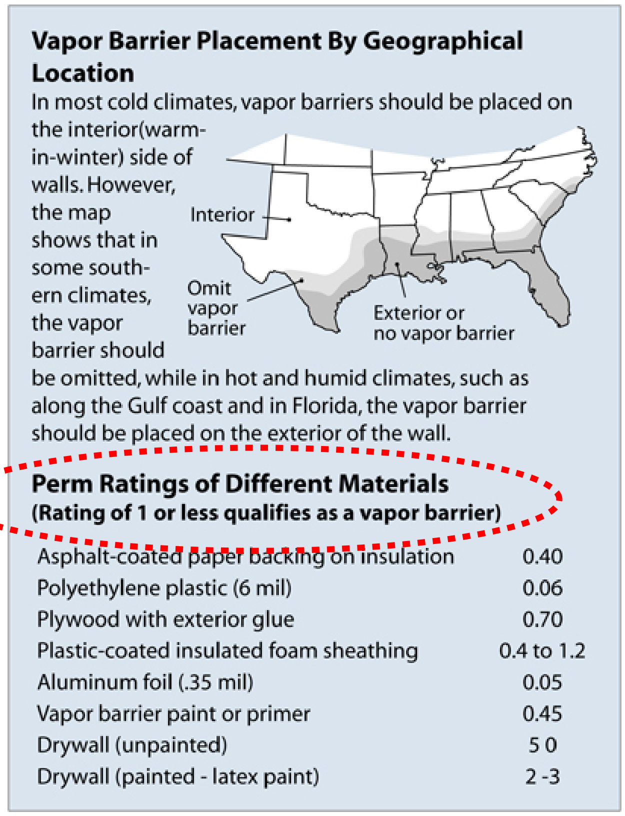
Using the search engine Google, the top ten websites that are presented when the terms “vapor retarder” and “air barrier system” were analyzed for three criteria: definition of the searched term, variation in terminology throughout the article, and information on placement and function. The results are presented in the following subsections and in Table E.2 and Table E.3 in Appendix E.

**Vapor Retarder**

The first article in the results for “vapor retarder” is a Wikipedia article for “vapor barrier.” Vapor retarder is defined with in the article. Results show that seven out of ten websites solely used the term “vapor retarder” throughout the article, and only one website uses an alternative name, “vapor diffusion retarder (VDR).” The lack of variation in terminology in this random search of resources does not support earlier claims of confusion due to confused terms. One reason for this could be the way in which the content analysis was designed. The specific term “vapor retarder” was searched. The definitions of “vapor retarder” are fairly consistent also. Although each website defines vapor retarder slightly differently, they all generally describe it as a layer that reduces vapor diffusion. The definitions from each website are listed in Table E.2 in Appendix E. Commercial product manufacturers, two of which are under-slab vapor retarder companies, sponsor half of the articles and one is a roofing vapor retarder. These various applications of vapor retarders have different standards of permeance requiring specific knowledge of what type of vapor retarder one is looking for.

All of the websites suggest a placement of the vapor retarder. In all but three websites, it is recognized that placement depends on climate. The figure below (4.23) is an image from Wikipedia and the U.S. Department of Energy that depicts vapor barrier placement in the United States. It shows that a vapor barrier should be placed on the interior of walls as far south as lower Mississippi, Alabama, and Georgia. This is a contradiction to most information on placement. Although the IRC does not dictate vapor barrier or vapor retarder placement in mixed and warm climate zones, it does requires the use of a Class I (vapor barrier) or II vapor retarder in climate zones 5, 6, 7, 8, and Marine

4. According to the IRC, climate zone 5 stops above Virginia, much farther north than the suggestion Figure 4.23 makes. Furthermore, in Figure 4.23, a vapor barrier is defined as having a permeance rating of one perm or less (see circled area). This is incorrect. A vapor barrier has a permeance rating of 0.1 perm or less (Lstiburek 108). The U.S. Department of Energy's website, *Energy Savers: Vapor Barriers or Vapor Diffusion Retarders,* also uses Figure 4.23 and alarmingly, in the paragraph directly above the image they define a vapor retarder as having a permeance rating of one or less—this is a direct contradiction on the same webpage.



**Vapor Barrier Placement By Geographical Location**

In most cold climates, vapor barriers should be placed on the interior(warm-in-winter) side of walls. However, the map shows that in some southern climates, the vapor barrier should be omitted, while in hot and humid climates, such as along the Gulf coast and in Florida, the vapor barrier should be placed on the exterior of the wall.



**Perm Ratings of Different Materials**
**(Rating of 1 or less qualifies as a vapor barrier)**

| | |
|---|---|
| Asphalt-coated paper backing on insulation | 0.40 |
| Polyethylene plastic (6 mil) | 0.06 |
| Plywood with exterior glue | 0.70 |
| Plastic-coated insulated foam sheathing | 0.4 to 1.2 |
| Aluminum foil (.35 mil) | 0.05 |
| Vapor barrier paint or primer | 0.45 |
| Drywall (unpainted) | 5 0 |
| Drywall (painted - latex paint) | 2 -3 |

**Figure 4.23.** Vapor Barrier Placement by Geographical Location ("Vapor Barriers"). <http://www.energysavers.gov/your_home insulation_airsealing/index.cfm/ mytopic=11810>.

### Air Barrier System

In the search results for "air barrier system" using Google, the top ten websites produced definitions very similar to one another. Generally, "air barrier system" is defined as an assembly of air barrier materials that resist air infiltration and exfiltration through a building. (For a summary of the top ten websites, see Appendix E, Table E.3) Four out of ten websites are sponsored by a commercial product designed to be an air barrier material and provided a definition for the material not the system.

The suggestions for placement are vague and sometimes confusing. Most describe placement, generally, as continuous throughout the enclosure. The Whole Building Design Guide website does however describe the permeance characteristics an air barrier material must have depending on which side of the enclosure it is placed as follows:

> If it [air barrier] is placed on the predominantly warm, humid side (high vapor pressure side) of the enclosure, it can control diffusion as well, and would be a low-perm vapor barrier material. In that case, it is called an "air and vapor barrier." If placed on the predominantly cool, drier side (low vapor pressure side) of the wall, it should be vapor permeable (5-10 perms or greater) (Anis).

Overall, the definitions for “air barrier system” are fairly consistent and description of placement generally vague. The most confusing aspects of the information are the subtleties between the terms “air barrier system,” “air barrier material,” “air barrier assembly,” and “air barrier component.” The last three terms listed are parts that make up an “air barrier system.” The confusion between these terms is not nearly as damaging as the confusion surrounding “vapor barrier” and “vapor retarder.”

## Summary

This chapter is a summary of the findings from the official survey of designers and builders in the states of Georgia, Michigan, Oregon, and Virginia. Survey findings show that a majority of building professionals learn about enclosure design through experience. Several findings outlined in this chapter can be supported by this discovery. This chapter also describes the results of the content analysis which demonstrate a quickly evolving knowledge about vapor retarders and air barriers as well as often occurring contradicting information.

# CHAPTER V
# DISCUSSION

## Introduction

This chapter reviews the original research questions from Chapter I and a discussion is based on the findings of the research. The depth at which each question can be addressed is affected by how effective the methods of research were in collecting the necessary data. Though the survey did not provide all of the answers as was expected about common practice, it did, provide interesting results on how and where building professionals learn about vapor retarders and air barrier systems. This knowledge could be useful in assisting continuing education programs for builders and designers and informing universities about how learning through experience may extend to technical subjects.

## 1. What Common Practices Exist in the Design and Application of the Air Barrier System and Vapor Retarder in Residential Construction?

### *Vapor Retarder*

Within seventeen broad questions and limited time, the results show that a majority of building professionals in the cold and warm-humid climates place the vapor retarder in the accepted locations. Results show that the placement of the vapor retarder in the marine and mixed climates is not as clearly correct. Building professionals in these climates are torn on where they believed it should be placed: towards the interior, towards the exterior, or in the middle. In the marine climate of Oregon, 23% of respondents claim they place the vapor retarder towards the exterior of the enclosure. This is in direct contradiction to the 2011 Oregon's Residential Specialty Building Code that requires "a one-perm, dry cup rating vapor retarder shall be installed on the warm side (in winter) of all insulation" ("2011" 11-10). In the mixed climate of Virginia, building professionals are divided when placing the vapor retarder. Although no code dictates where a vapor retarder should be placed, research shows the enclosure should be designed to "dry-through;" the vapor retarder should be in the middle of the wall or not used at all. In

Virginia 41% of respondents claim to place the vapor retarder towards the interior and 32% place it towards the exterior. Neither of these locations promote the drying of the enclosure in this swing climate. Although a majority of respondents in the cold climate of Michigan claim to place the vapor retarder towards the interior as accepted, 19% report putting the vapor retarder towards the exterior; this location could potentially cause interstitial condensation in a cold climate.

*Air Barrier System*

When asked which components of the building constitute the air barrier system, 100% of both designers and builders agreed that walls are a part. Only slightly fewer believe windows and doors to be a part of the air barrier system. Vertical surfaces are clearly understood as the air barrier system. However, far fewer thought the ceiling, roof, and floor are parts of the air barrier system. This is problematic because the air barrier system is made of all components of the enclosure that protect the indoor environment. The ceiling, roof, and floor are definitely part of the system. Another point of disagreement is continuity in the air barrier system. Most respondents agreed that a continuous air barrier system is essential for proper enclosure function, but 13% of designers and 10% of builders disagreed that continuity was essential for proper function. This is not a large percentage but still a portion of respondents are operating under a misconception. A significantly larger portion of builders "strongly agreed" or "agreed" that a continuous air barrier system was necessary for proper enclosure function than designers. This could be because 19% more builders report they "always" perform a blower door test on their projects.

### 2. Which Common Practices Are Misconceptions that Could Lead to Significant Failure in the Air Barrier System and Vapor Retarder?

Alarmingly, a significant portion of respondents report placing the vapor retarder in locations that have been proven to cause problems within building enclosures. In Virginia, towards the interior, in Oregon, towards the exterior, and in Michigan, towards the exterior. This may indicate widespread misconception about vapor retarder placement. To be fair, there are many exceptions to vapor retarder placement that this survey did not account for and these results should be understood as a general consensus of common practice.

The misconception in air barrier usage may be that detailing the vertical surfaces is more important in blocking air infiltration when in reality the transitions to horizontal surfaces and the horizontal surfaces themselves need just as much attention. Preventing air infiltration is a three-dimensional problem and should be solved as such.

### 3. What Differences in Enclosure Design Exist Between Best Practice and Common Practice?

This question is difficult to answer because the results of the common practice details are inconclusive. To make an assumption on common practice based on seven submissions would be unfair. It can be said, like in the question above, the varied responses for vapor retarder placement in Virginia and Oregon have the potential to cause damage and seem to contradict best practice. The common practice of vapor retarders in the less extreme climates appears to differ from best practice.

The difference in opinion on the continuity of air barrier systems has the potential to cause damage also. Only 65% percent of designers agree that a continuous air barrier system is necessary for proper enclosure function whereas 82% of builders believe this. The misconception by designers and builders that it is not important to be continuous has the potential to cause mold problems, indoor air quality problems, and energy loss.

### 4. Which Resources Are Most Commonly Used by Building Professionals When Designing an Enclosure?

Of all the research questions, the results for this question are the most interesting and useful. Although it was hypothesized that most building professionals learned, initially, about vapor retarders and air barrier systems from the internet, results show that most learned from experience or "on the job." Results also show that when building professionals have questions about vapor retarders and air barrier systems, their number one resource is a colleague. These findings do not support the hypothesis that confusing and contradicting information promotes bad design. People are learning from each other through hands-on experience or conversation. The down side to this is the possibility of building professionals perpetually sharing bad information by word of mouth or learning from badly designed enclosures. However, it is also possible that building professionals are sharing their mistakes, keeping someone else from doing the same.

### 5. How Comprehensible Do Building Professionals Think the Resources Are?

Established in Chapter IV, a majority of building professionals report learning about vapor retarders and air barrier systems through experience not written resources. However, after ranking the resources, the internet is the second place, after a colleague, building professionals go when they have questions about enclosure design. According to the results, most respondents report the information on the *function* of air barrier systems and vapor retarders to be "clearly" comprehensible. The information on the *placement* of air barrier systems and vapor retarders was less clear to them. There was, however, a difference in how respondents answered depending on their experience level. Building professionals with >20 years experience generally felt the information about *function and placement* is more comprehensible than respondents with 0-5 years of experience. With less experience, the information is "somewhat confusing." This supports the claim that most building professionals learn through experience.

When a building professional turns to the internet or a written resource for information, there is the possibility they will encounter contradicting information. The content analysis of *Architectural Graphic Standards* illustrated how quickly the information about vapor retarders and air barriers is evolving. The analysis of internet resources show direct contradictions of information, sometimes on the same website. This quickly changing and contradictory information has the potential to affect enclosure design.

# CHAPTER VI
# CONCLUSION

## Review of Hypotheses

*This thesis predicts that common practice of vapor retarders and air barrier systems differs from the instruction of commonly available resources.*

Results show that a portion of building professionals' common practice may contradict the instruction of commonly available resources. In the cold and warm-humid states, designers and builders report generally following what is suggested for vapor retarder placement. Those in the marine and mixed climates report contradicting answers, dividing placement between the interior and exterior and creating the potential for the damaging effects of interstitial condensation.

Most building professionals agree that a continuous air barrier system is necessary for proper enclosure function. However, 35% of designers and 18% of builders do not agree. This percentage of building professionals who do not believe continuity is important for an air barrier system are at risk for designing and building enclosures where air infiltration can cause loss of energy, condensation, and uncomfortable indoor environments. A portion of respondents do not believe the ceiling, roof, and floor to be part of the air barrier system. It is a misconception that only vertical surfaces block air infiltration.

*Secondly, building professionals learn about vapor retarders and air barrier systems through the internet and perceive the available information as incomprehensible.*

Building professionals reported their first influence for initially learning about vapor retarders and air barrier systems is not the internet but on the job; the internet has a third place ranking after a colleague. They also report asking a colleague when they have questions about the vapor retarder or air barrier system, and using the internet second when they have questions. This hypothesis is proven incorrect.

Results that describe how comprehensible building professionals think the resources are show that a majority of building professionals with >20 years of experience think it is clear. Building professionals with 0-5 years of experience are somewhat confused by the information about *placement* of air barriers and vapor retarders, but find the information about *function* to be somewhat clear. A content analysis of *Architectural Graphic Standards* and Google results for "vapor retarder" and "air barrier" show a quickly evolving and contradictory body of information about enclosure design. Although most respondents believe the resources they use to be clear, they may be unaware of the inconsistencies that exist and be operating under a false sense of knowledge.

This being said, it is difficult to determine if these perceptions have any effect on how enclosures are detailed. It seems as if the most significant finding is that building professionals learn from one another and that written resources are used less often than first believed. It must remain up to the designers and builders to establish their own beliefs on this subject based on reliable resources.

*Thirdly, builders have a better understanding of the function of vapor retarders and air barrier systems than designers.*

It is difficult to conclusively say that builders understand the function of vapor retarders and air barrier systems better than designers. Some results indicate that builders better understand the importance of a continuous air barrier system and a similar amount report placing a vapor retarder based on climate. If it stands that most building professionals learn about building enclosures through experience, builders may have an advantage due to the hands-on experience they gain from assembling a building. Builders' day-to-day experience in detailing, three dimensionally, while taping, caulking, and glueing the enclosure together may give builders an advantage in understanding the enclosure. This is not to say designers possess less knowledge about the enclosure than builders but that builders are exposed to a hands-on learning experience more often. Encouraging all building professionals to review or perform post-occupancy reports, witness blower door tests, understand moisture diffusion analyses like a WUFI report, and experience other as-built examinations may benefit enclosure design moving forward.

## Conclusion

In the spirit of the tradition of designing and building, it turns out knowledge about vapor retarders and air barrier systems is passed down like most aspects of this industry. This thesis assumed that a technical subject like enclosure design would be more heavily influenced by books, magazines, and other written resources than it actually is. Common practices' main influences are the conversations that happen in offices and on job sites and watching someone with more experience detail or install the components of the enclosure. Best practice is a result of experience.

Misconceptions seem to arise out of the in-between places in this field. Building professionals in climate zones that experience both cold winters and hot summers seem to disagree on where vapor retarders should be placed, and the non-vertical surfaces and intersections of the enclosure are less likely to be seen as part of the air barrier system. More opportunities for building professionals to experience the effects of a properly or an improperly designed enclosure may be helpful in correcting these misconceptions.

To be useful to the industry, this thesis can help identify continuing education practices that will directly affect the profession. Hands-on workshops that demonstrate the functionality of an air barrier system could be one way of teaching the importance of continuity. To expedite experience on the use of vapor retarders, controlled environment mockups could be used to demonstrate the difference in placement. It seems that building professionals learn by doing and seeing, and continuing education could change to fit this. Due to the evolving nature of this topic, exposure to current information is important. Perhaps all building professionals should be required to participate in continuing education courses that address this topic.

Most of an architecture student's education on technical subjects is taught out of books in lecture halls. This research has revealed how practicing professionals learn about technical subjects—through experience—and it is possible that architectural education could adjust to suit this type of learning. Some schools have instituted design/build studios as a way of interactively teaching students how buildings stand; maybe enclosure classes could follow the same path and offer more hands-on lessons about how enclosures operate in their environment. A knowledge based on experience of how effective building enclosures affect energy consumption, moisture migration, and air infiltration could accelerate a new graduate's continuing education in the workforce.

### Suggestions for Future Research

If time permitted, a more detailed survey that delves deeper into common practice of the building enclosure could be useful in determining what is actually being built in order to compare it to best practice. A larger sample size would also more accurately represent the reality of common practice. There are many factors that affect the placement of vapor retarders and the use of air barriers that may not be accounted for in this thesis such as cladding type, construction type, and micro-climate. A more detailed survey would reveal the nuances of enclosure design that this study was not able to address. Focused interviews that try to determine the trends in construction practices may be more revealing. Interviews with faculty at architecture schools, trade schools, and continuing educators could reveal thoughts on how first time students best learn this information. The building material industry also plays a role in this discussion. Often building materials are presented as a way to fix problems and can be used without full understanding. More research could be done on what products are commonly used to solve problems with vapor diffusion and air infiltration to see if they are used correctly.

Although some confusion was identified, a definite answer was not found to whether the contradicting information in written resources has an effect on common practice. It was not within the scope of this project to code the content analysis of design handbooks and internet resources. Next steps for research could include a closer look at the information available about vapor retarders and air barrier systems and to trace its origins. A deeper study into what exact resources building professionals most rely on would be helpful in determining if this is actually an issue.

Now, at the conclusion of this year of research, more questions have been raised on this topic. A continuation in study might ask the following about how design and construction students learn:

1. How are architecture, construction management, and trade schools teaching their students about vapor retarders and air barrier systems?

2. What lessons on vapor retarders and air barrier systems are being taught at architecture, construction management, and trade schools?
3. Are the lessons being taught correct?
4. If architects and builders learn through experience in the field, what lessons can be taught through experience in school?
5. For an architecture school, what is an effective lesson plan for an enclosures course based on learning through experience?

The information on this topic is continually evolving and remains one of the most confusing subjects in design and construction of residential buildings. Through this research, hopefully some useful information on how building professionals learn about vapor retarders and air barrier systems has been identified so that education on this topic may be adjusted to suit these learning styles. A deeper educational foundation on the proper function of building enclosures may be what is needed to reduce the confusion that is evident in professional practice.

## APPENDIX A

## DEFINITION OF TERMS

*Air barrier system*- "the plane of airflow control" (Straube and Burnett 419).

*Builder*- someone directly related to the construction of a house in a decision making role.

*Building performance*- the ability of the enclosure to effectively respond to interior thermal conditions and exterior climatic demands based on the 2006 International Residential Code (IRC) and the 2009 International Energy Conservation Code (IECC).

*Building professional*- key person in the design and construction of a building, either a designer or a builder.

*Designer*- someone involved in the pre-construction process of creating a house, such as an architect, architectural intern, or designer/builder.

*Enclosure*- "the separation between interior and exterior environments" (Straube and Burnett 12).

*Interpretation*- an adaptation or version of the accepted standard.

*U.S. climate zones*- according to the International Energy Conservation Code Climate Map.

*Vapor permeance*- "the time rate of water vapor transmission through unit area of flat material induced by unit water vapor pressure difference between its two surfaces. In inch-pound units, permeance is given in the unit 'perm,' where one perm equals a transmission rate of one grain of water per hour for each square foot of area per inch of mercury." (Trechsel xxiv).

*Vapor barrier*- a Class I vapor retarder. See "vapor retarder."

*Vapor retarder*- functions to "simply control water vapor diffusion to reduce the occurrence or intensity of condensation" (Straube and Burnett 422). The three categories of vapor retarders and their permeance are:

Class I—0.1 perm or less
Class II—1.0 perm or less and greater than 0.1 perm
Class III—10 perms or less and greater than 1.0 perm

# APPENDIX B

# OFFICIAL SURVEY

UNIVERSITY OF OREGON

This is a survey about common building practices of vapor retarders and air barrier systems for my Master's Thesis project at the University of Oregon. I seek your voluntary participation. This survey will take you approximately **5 minutes for 17 questions**. To agree to participate, please select the arrow button at the bottom of this screen.

**WIN 1 OF 4 GIFT CERTIFICATES TO LOWE'S OR BOOKS-A-MILLION!**
You can resister at the end of the survey.

Your responses will remain anonymous and you will not be asked your name or professional association. You must be 18 years or older to participate in this survey. If you have questions, would like more information about the survey, or would like a copy of the final report please contact the primary researcher, Emily McGlohn.

Thank you for your consideration!
Emily McGlohn

emcglohn@uoregon.edu
334-507-0257

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Survey Powered By Qualtrics

UNIVERSITY OF OREGON

**1. Where did you learn about proper use of air barrier systems and vapor retarders?**

Please rank order your top 4 most influential resources.
1 being the most influential, 8 being the least influential.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Magazines | | | | | | | | |
| The internet | | | | | | | | |
| Books | | | | | | | | |
| Professional association | | | | | | | | |
| Colleague/ co-worker | | | | | | | | |
| College or univerisity | | | | | | | | |
| On the job | | | | | | | | |
| Other | | | | | | | | |

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UNIVERSITY OF OREGON

**2. When you have questions about the design or construction of the building enclosure, what resources do you use?**

Please rank order your top 4 resources in which you refer to them.
1 being the most influential, 7 being the least influential.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Magazines | | | | | | | |
| The internet | | | | | | | |
| Books | | | | | | | |
| Professional associaiton | | | | | | | |
| Colleague/ co-worker | | | | | | | |
| Conference | | | | | | | |
| Other | | | | | | | |

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UNIVERSITY OF OREGON

**3. How would you describe the information available on following topics?**

| | Very Confusing | Confusing | Somewhat Confusing | Neither Confusing nor Clear | Somewhat Clear | Clear | Very Clear |
|---|---|---|---|---|---|---|---|
| The **function** of vapor retarders. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| The **function** of air barrier systems. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| The **placement** of vapor retarders. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| The **placement** of air barrier systems. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

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Survey Powered By Qualtrics

UNIVERSITY OF OREGON

**4. Please respond to the following statements.**

| | Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree | Not Sure |
|---|---|---|---|---|---|---|
| A continuous air barrier system is essential for proper function of the building enclosure. | ○ | ○ | ○ | ○ | ○ | ○ |
| A continuous vapor retarder is essential for proper function of the building enclosure. | ○ | ○ | ○ | ○ | ○ | ○ |

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Survey Powered By Qualtrics

UNIVERSITY OF OREGON

**5. When designing or building the enclosure, how often is the climate zone considered in your decisions regarding the listed components?**

| | Never | Rarely | Sometimes | Always | Not Sure |
|---|---|---|---|---|---|
| Air Barrier System | ○ | ○ | ○ | ○ | ○ |
| Vapor Retarder | ○ | ○ | ○ | ○ | ○ |

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Survey Powered By Qualtrics

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**6. How often are the following performance tests done on your projects?**

| | Never | Rarely | Sometimes | Always | Not Sure |
|---|---|---|---|---|---|
| Blower door test | ○ | ○ | ○ | ○ | ○ |
| Thermal gradient simulation (with a program like WUFI) | ○ | ○ | ○ | ○ | ○ |
| Post occupancy evaluation | ○ | ○ | ○ | ○ | ○ |

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**7. When placing a vapor retarder in a wall assembly, you typically place it in which location?**

- Towards the interior of the wall.
- Towards the exterior of the wall.
- In the middle of the wall.
- Do not use a vapor retarder.
- Not sure.

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**8. Please select all that you consider part of the air barrier system.**

- Walls
- Windows
- Doors
- Ceiling
- Roof
- Floor

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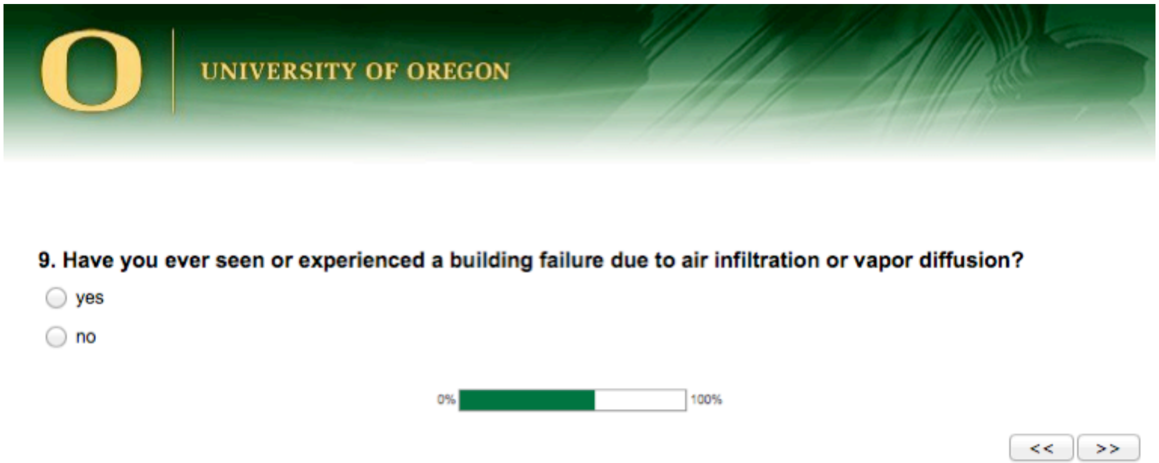
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9. Have you ever seen or experienced a building failure due to air infiltration or vapor diffusion?

- yes
- no

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Please explain the building failure.

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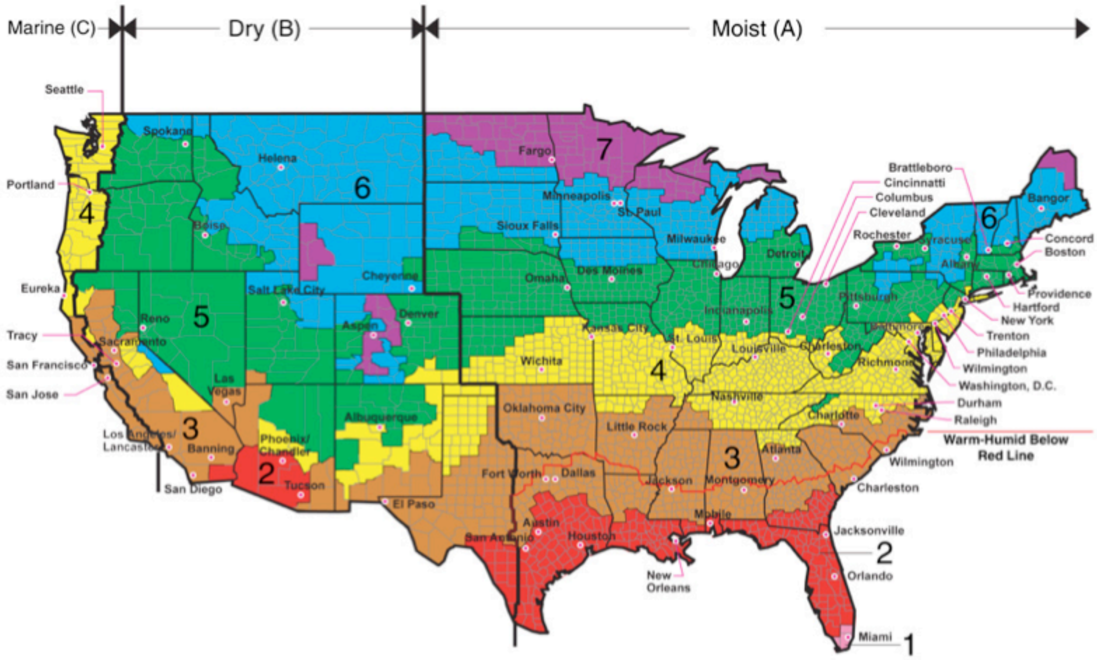
**10. According to the map below, in which climate zone do you typically work?**

Please note the sub-zones at the top of the map: Marine (C), Dry (B), and Moist (A).
For example, if you primarily work in Nashville, TN, you would select 4A from the pull down menu.




**All of Alaska in Zone 7 except for the following Boroughs in Zone 8:** Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

**Zone 1 includes:** Hawaii, Guam, Puerto Rico, and the Virgin Islands

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**11. Please select all the titles that best describe your position.**

- ☐ Registered Architect
- ☐ Licensed contractor
- ☐ Builder
- ☐ Carpenter
- ☐ Designer
- ☐ Professional engineer
- ☐ Other

**12. How long have you been in the building profession?**

- ○ 0-5 years
- ○ 6-10 years
- ○ 11-15 years
- ○ 16-20 years
- ○ more than 20 years

**13. Please select the category of education that fits you best.**

- ○ High school graduate / GED
- ○ Some college
- ○ Associate's degree
- ○ Bachelor's degree
- ○ Professional Bachelor's degree
- ○ Master's degree
- ○ Technical certificate
- ○ Other

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14. If you have any additional comments, please add them in the space below.

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**15. Would you consider participating in a phone interview with the researcher on this topic?**

- ☐ yes
- ☐ no

**16. To help me better understand how building professionals are solving issues related to vapor retarders and air barrier systems, would you be willing to send a best practices wall detail of a vapor retarder and air barrier from your firm or company? Any information sent will remain anonymous and used only for the purposes of research and education.**

**Are you willing to contribute a detail?**

- ○ yes
- ○ no

**17. Would you like to enter the drawing for one of four $25 gift certificates to Lowes and Books-A-Million?**

- ○ yes
- ○ no

If you answered yes to any question above, please provide your contact information, and you will be contacted at a later date.

Thank you for your participation!

Emily McGlohn

emcglohn@uoregon.edu
334-507-0257

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UNIVERSITY OF OREGON

We thank you for your time spent taking this survey.
Your response has been recorded.

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## APPENDIX C

## DEMOGRAPHIC INFORMATION

**Table C.1.** Demographic Information. The chart below summarizes the count of respondents from each state. Small numbers in gray are the totals for the subcategories of designer and builder.

| | | Georgia | | | Michigan | | | Oregon | | | Virginia | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Professional Category | Designer / Builder | 18 | 11 | 29 | 16 | 4 | 20 | 50 | 12 | 62 | 28 | 13 | 41 | 112 | 40 | **152** |
| Experience | 0-5 Years | 4 | 1 | 5 | 5 | 1 | 6 | 7 | 0 | 7 | 2 | 0 | 2 | 18 | 2 | **20** |
| | 6-10 Years | 3 | 2 | 5 | 1 | 1 | 2 | 12 | 2 | 14 | 4 | 1 | 5 | 20 | 6 | **26** |
| | 11-15 Years | 3 | 2 | 5 | 0 | 1 | 1 | 10 | 1 | 11 | 5 | 2 | 7 | 18 | 6 | **24** |
| | 16-20 Years | 1 | 1 | 2 | 2 | 0 | 2 | 6 | 2 | 8 | 4 | 2 | 6 | 13 | 5 | **18** |
| | >20 Years | 7 | 5 | 12 | 8 | 1 | 9 | 15 | 7 | 22 | 13 | 8 | 21 | 48 | 21 | **64** |
| Education | High School/ GED | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 1 | 0 | 3 | **3** |
| | Some College | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 4 | **5** |
| | Associates | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 1 | **3** |
| | Bachelors | 2 | 4 | 6 | 3 | 1 | 4 | 6 | 4 | 10 | 4 | 5 | 9 | 15 | 14 | **29** |
| | Prof. Bach. | 9 | 1 | 10 | 3 | 1 | 4 | 17 | 4 | 21 | 11 | 2 | 13 | 40 | 8 | **48** |
| | Masters | 5 | 3 | 8 | 10 | 2 | 12 | 27 | 2 | 29 | 12 | 2 | 14 | 54 | 9 | **63** |
| | Tech. Cert. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | **1** |

## APPENDIX D

## BUILDING FAILURE COMMENTS

**Table D.1.** Comments submitted by respondents describing a building failure due to air infiltration or vapor diffusion.

| Climate Zone | Comment |
|---|---|
| | **Builders** |
| 5A | Improper installation of air/moisture barrier or water management system resulting in degradation of building components |
| 3A | Usually in the south it is hot moist air getting into the wall assembly and condensing. Wood rot is common in this situation. |
| 4C | Failure resulting in mold, air leakage, energy loss, rot and building envelope performance. |
| 3A | Excessive moisture inside home due to both air and vapor penetration of exterior wall. Result of failure: deterioration of both wall and floor structure. |
| 5A | Improper flashing, moisture entered wall assembly and all cellulose insulation got wet and dropped 18" |
| 4C | Faulty roof assembly without a proper vapor barrier caused structural corrosion and mildew. |
| 3A | No vapor barrier was used at the exterior wall and negative air was used in the building which drew moisture thru the brick to the sheetrock which migrate to wall cover that was unvented and mold proceeded to follow |
| 4A | Rot as a product of air born vapor. |
| 4C | Mold and Mildew was found under the carpet on top of the subfloor. I have also seen buildup of moisture on the exterior side of the drywall due to lack of vapor barrier. |
| 3A | Water inside building. |
| 4C | Moisture was allowed to infiltrate the building envelope and condense on wood framing. Deterioration resulted. |
| 4A | Voids in air barriers invite transmission of moist air between exterior and interior (either direction) often resulting in wood rot and mold growth. In conjunction with negative pressure, even small gaps can allow water vapor and bulk moisture into buildings. |
| 4C | high moisture build up in walls at certain times of year |
| | **Designers** |
| 4A | Various conditions have been seen in my experience on commercial and residential construction. / Discontinuity due to politics of the project or other team "priorities" create barriers that are not technical, but rather influenced by other values on a given design set of decisions. |
| 4C | During renovation of an existing building it was discovered that metal studs in the exterior wall had corroded. The corrosion was attributed to moisture accumulation within the wall. |

| | |
|---|---|
| 4A | Rotting of exterior wall studs of old residential bathrooms, due to lack of internal vapor barrier coupled with external air barrier "sealing" improperly done so as to reduce helpful passage of vapor through wall (and insulation), particularly through sheathing and siding. (Previously renovation apparently including installing foil-faced sheathing, with air barrier, and with vinyl siding trapped moisture inside of wall.) |
| 4C | My front door leaks air all the time - I lose heat during the winter. |
| 4A | mold, rot |
| 4A | Condensation on the interior face of exterior sheathing, trapped by stucco that had been painted, saturated the sheathing, studs, and ultimately the stucco. The paint first peeled, and then the stucco started to crumble off the sheathing. |
| 4C | Dry rot and mold, condensation on the interior |
| 4C | Had to replace interior drywall and carpet due to water build up and saturation from improper vapor barrier usage. |
| 5A | mold growth on exterior wood frame + gypsum board walls (not our design!) |
| 4A | 1. Cold spots in floor plan lead to a post occupancy evaluation that identified poorly installed (large gaps and from poor attachment) air barrier. / / 2. Constant mold growth on interior face on an exterior wall led to an exploratory cut in the siding that revealed no vapor retarder. |
| 4C | I've seen flooring failures from insufficient vapor barrier below slabs. The other way I've seen roof bubbling/failure from interior vapor drive up through the roof. |
| 4A | In research, I have seen super insulated buildings with improper vapor barrier placement lead to mold within the assembly. |
| 2A | condensation / moisture occurrence inside the building envelope resulting in mold |
| 4C | Heat leak through unsealed roof to wall intersection - could see the heat escaping from the building. |
| 4C | interior mold issues in a building with a class 1 vapor retarder at the interior surface located in the Portland area. The buildings were part of a low income housing project and the combination of inadequate ventilation (both mechanical and natural) and tenants who frequently minimized the use of heat lead to increased moisture and condensation inside and over time this created mold. The client originally thought that the exterior siding was failing and that the mold was caused by water from outside, but some demo and exploration into the wall cavity showed no signed of moisture or mold except on the drywall surfaces. |
| 4C | Vapor intrusion through improperly protected concrete floor slabs. |
| 2A | rotting of structural wood members due to water condensation within wall |
| 4C | Mold in the wall stud cavity due to multiple barriers being installed. |
| 4A | Window sealing product failed, allowing moisture into the wall. |
| 4A | I have seen several building failures from air infiltration and/or vapor diffusion. We perform thermal imaging and do facade evaluations. I have seen small holes in exterior walls that led to mold growth. As moist summer air came in contact with colder conditioned air, rain formed, causing mold growth. On another project we found that moist attic air came in contact with cold HVAC ducts, creating “rain” above a ceiling, resulting in mold and rot.. / We have also investigated a project with roof plywood sheathing that failed as a result of air from a shower room being exhausted to the face of the plywood. / |
| 4C | A project in Alaska where there was no vapor barrier on a block wall building, ice would form between the wall and the furred interior wall and then pools would appear in the store when it melted in the spring. |

| | |
|---|---|
| 5A | Not sure exactly what is meant by failure, but I have seen excessive mold growth in garden apartments with improper ventilation and vapor barrier placement. |
| 5A | Usually it is rotting of walls around window openings from water getting stuck in the wrong space because the barriers are detailed incorrectly. |
| 4C | dry rot |
| 3A | The house I bought had rot in the wall that wasn't properly sealed. I had to tear it out and replace all |
| 4C | I have seen examples of mold and rot due to moisture intrusion. |
| 4C | MOLD, DECAY |
| 4C | faulty air barrier - white mold on brick |
| 4A | Vapor infiltration due to poorly installed exterior finishes and window/door penetrations. |
| 4C | Only in photos of trade journals. |
| 4C | rotting wood from infiltration through leaky wood windows |
| 4C | Excess mold |
| 4C | rotting gypsum, wet insulation, moldy wall cavities. |
| 3A | HVAC system running on negative pressure |
| 4C | Moisture in wood members, causing "dry rot" over long term. (And we all know that "dry rot" is an inaccurate term.) |
| 4C | Moisture damage within wall assembly. |
| 4A | A home that had major vapor issue due to the use of a vapor barrier on the interior of the wall. The studs were rotted at the bottoms. The drywall was holding the building together. |
| 4C | mold growth, leaks around fenestrations, etc |
| 3A | moisture penetration into wall system causing extensive rot |
| 5A | Condensation of latent moisture which migrated through the wall and into the insulation. The result was wet insulation which in turn led to heat loss and eventually rotting of the wood. |
| 6A | Decay, wet insulation, and mold in walls and attics. ice damns and melting snow on roofs. |
| 4C | Moisture in wall cavity caused mold and metal stud corrosion |
| 2A | Moisture damage to inside surface of wall like paint peeling off concrete block, or wet stained carpets. |
| 4C | structural damage due to water infiltration which becomes trapped and causes decay |
| 4C | condensation leading to rot and mould |
| 4A | 30 years ago we did sure insulation without considering the thermal bridge or window performance and ended with melting buildings / |
| 4A | Rotted framing due to EIFS barrier system working as vapor retarder in warm humid climate with code required vapor barrier on interior face of wall (North Carolina) |
| 4A | Moisture within a wood stud wall. |

## APPENDIX E

## CONTENT ANALYSIS

**Table E.1.** The summary of the content analysis of *Architectural Graphic Standards'* information on vapor retarders and air barrier systems over a four decade span.

| **Year, edition** | **Vapor retarder definition and usage** | **Air barrier system definition and usage** |
|---|---|---|
| (Ramsey and Sleeper) 1970, 6th Edition | Definition:<br>"Vapor Barrier- a material which does not readily permit passage of water vapor. Normally, an acceptable material is rated at one perm or preferably less in many building applications." (318)<br><br>Usage:<br>"Most moisture problems in residences occur in winter and become increasingly critical as homes are built smaller and tighter. The residences must permit escape or migration of moisture vapor originating from cooking, laundering, . . . (etc.)." (319)<br><br>"This migration must be limited to acceptable rates because moisture in air is a gas which occupies all the space along with the air." (319) | Not mentioned |

| Year, edition | Vapor retarder definition and usage | Air barrier system definition and usage |
|---|---|---|
| (Ramsey, Sleeper, and Hoke)<br>1988, 8th Edition* | Definition:<br>“Vapor Barrier- To control a moderate level of relative humidity in living spaces, vapor resistant membranes must be utilized:<br>1. To control the moisture level within the structure.<br>2. To prevent moisture from passing through the insulation to a cold point where it can condense into water, possibly causing structural damage or rot. Provide condensate drainage.” (334)<br><br>Usage:<br>“Vapor cannot permeate glazed windows or metal doors, but most other building materials are permeable to some extent. Walls are particularly susceptible to the phenomenon, and such migration must be prevented or at least minimized by the use of low permeability membranes known as vapor barriers, which should be installed as close as possible to the indoor surface of the building.” (335) | Definition:<br>None given.<br><br>Usage:<br>“Moisture movement through the building shell must be controlled. It is driven by air leakage (exfiltration) and by vapor diffusion, which is related to temperature differences. . . Plant vegetation to create wind-sheltered building sites. Shape building to minimize exposure to winter wind. Specify weatherstripping and infiltration barrier.” (709) |
| (Ramsey, Sleeper, and Hoke)<br>1994, 9th Edition | Definition:<br>“Vapor cannot permeate glazed windows or metal doors, but most other building materials are permeable to some extent. Walls are particularly susceptible to this phenomenon, and such migration must be prevented or at least minimized by the use of low permeance membranes, called *vapor retarders* (formerly, vapor barriers). They are now called retarders, not barriers, because they do not stop moisture flow completely. A vapor retarder is a material that has a flow rating of one perm or less.” (352)<br><br>Usage:<br>“Vapor retarders should be installed as close as possible to the side of the wall through which moisture enters. Establish the side of moisture entrance in walls of controlled rooms within buildings. However, the beneficial effects of good vapor retarders are lost without adequate air barriers.” (352) | Definition:<br>None given.<br><br>Usage:<br>Same as 1988, 8th Edition. Mentioned in moisture migration chapter (see usage of vapor retarder for 1994, 9th Edition). |

| Year, edition | Vapor retarder definition and usage | Air barrier system definition and usage |
|---|---|---|
| (Ramsey, Sleeper, and Hoke)<br><br>2000, 10th Edition | Same as 1994, 9th Edition. | Definition:<br>None given.<br><br>Usage:<br>“While moisture moves in still air by vapor pressure differences, it is important to recognize that moisture in air is moved by the air. Consequently, the causes of air motion must be considered, especially the infiltration and exfiltration at undesirable leakage rates at window, doors, and other penetrations through the thermal envelope.” (405) |
| (Ramsey and Sleeper) 2007, 11th Edition | Definition:<br>“Vapor barriers and retarders: Without industrywide consensus, materials with a perm rating less than 1 are interchangeable called vapor barriers or vapor retarders (IBC and IEC 2003 use “vapor retarder”). More important that the term is to understand a few basic principles:<br>- Vapor diffusion through materials with perm ratings less than 1 is nearly inconsequential, but even small gaps or holes can easily transport many times as much water vapor.<br>- All materials have some greater or lesser degree of resistance to diffusion, and their placement in an enclosure assembly, whether intended as a retarder or not, will affect wetting and, more importantly, drying of an assembly.” (64)<br><br>Usage:<br>- “Sources of vapor may be in the interior or exterior environment. Vapor retarders have been the traditional method used to control vapor movement, but their use in mixed heating and cooling climates must be carefully evaluated to allow drying.” (66)<br>- “Include only one vapor retarder in a wall assembly, and ensure that all other materials are increasingly permeable for the vapor retarder out.” (66) | Definition:<br>“Materials or combinations of materials that form a continuous envelope around all sides of the conditioned space to resist the passage of air.” (64)<br><br>Usage:<br>“Joints, seams, transitions, penetrations, and gaps must be sealed. The air barrier must be capable of withstanding combined positive and negative wind loads and fan and stack pressure with out damage or displacement. The air barrier must be at least as durable as the overlying construction and be detailed to accommodate anticipated building movement. An air barrier may or may not be a vapor retarder.” (64) |

*The 1981, 7th Edition was unavailable.

**Table E.2.** The summary of the content analysis of the top ten websites when the term “vapor retarder” is searched in Google.

| | Sponsor, Title | Terminology | Definition | Placement |
|---|---|---|---|---|
| 1 | Wikipedia<br><br>“Vapor Barrier.” | vapor barrier<br>vapour barrier<br>vapor retarder<br>vapor diffusion retarder | “A vapor barrier (or vapour barrier) is often used to refer to any material for damp proofing, typically a plastic or foil sheet, that resists diffusion of moisture through wall, ceiling and floor assemblies of buildings and of packaging. Technically, many of these materials are only vapor retarders as they have varying degrees of permeability.” | “For building in most parts of North America, where winter heating conditions predominate, vapor barrier are placed toward the interior, heated side of insulation in the assembly. In humid regions where warm-weather cooling predominates within buildings, the vapor barrier should be located toward the exterior side of insulation. In relatively mild or balanced climates, or where assemblies are designed to minimize condensation conditions, a vapor barrier may not be necessary at all.” |
| 2 | U.S. Department of Energy<br><br>“Energy Savers: Vapor Barriers or Vapor Diffusion Retarders.” | vapor barrier<br>vapor diffusion retarder | “A vapor barrier or vapor diffusion retarder (VDR) is a material that reduces the rate at which water vapor can move through a material. The older term "vapor barrier" is still used even though it may inaccurately imply that the material stops all of the moisture transfer. Since everything allows some water vapor to diffuse through it to some degree, the term "vapor diffusion retarder" is more accurate.” | “In climates with 2,200 or more Heating Degree Days, locate the vapor diffusion retarder on the warm side of the exterior structural assembly.”<br><br>“In climates with fewer than 2,200 Heating Degree Days (cooling-dominated climates) and where the building is near, but not quite in, the 2,200 Heating Degree Days zone (a.k.a. fringe zone), place the vapor diffusion retarder in the same location as climates farther north.”<br><br>“Farther south (about 1,900 Heating Degree Days) it is unimportant where the vapor diffusion retarder goes. For climates even farther south and generally hotter and more humid, some professionals recommend omitting the vapor diffusion retarder completely. This is due to the winter heating loads and summer cooling loads being roughly equal. Any location ends up having the vapor diffusion retarder on the wrong side of the structure during part of the year. However, other building science research indicates that it should be applied directly under the exterior finish and is sometimes itself the exterior finish. A combination air barrier/vapor diffusion retarder may be a better choice for this situation.” |

| | Sponsor, Title | Terminology | Definition | Placement |
|---|---|---|---|---|
| 3 | Certainteed<br><br>"Smart Vapor Retarders: Insulation." | vapor retarder | "The American Society for Testing and Materials (ASTM) defines vapor retarders as materials or systems that adequately retard the transmission of water vapor under specified conditions (ASTM C755)." | "For years, builders have relied on a dual climate-zone classification for the placement of vapor retarders in a home. The prevailing wisdom has called for vapor retarders to be located at the interior in heating-dominated climates and at the exterior in cooling-dominated climates. However, large portions of the United States are considered "mixed-climate," where the moisture drive direction is balanced between winter and summer seasons. In these regions, choice and placement of vapor retarders, air barriers and other materials become critical in minimizing the potential for water vapor condensation, while allowing for drying of wet building materials." |
| 4 | North American Insulation Manufacturers Association<br><br>"Insulation and Vapor Retarders." | vapor retarder | "A vapor retarder is defined as a material or system that adequately retards the transmission of water vapor under specific conditions." | "In areas where the climate is cold in the winter, the vapor retarder should be installed inward toward the warm living space — or on the warm side in winter. In humid climates or areas where there is extensive use of air-conditioning, if a vapor retarder is required, it should be installed on the exterior side of the wall." |
| 5 | Energy Efficient Rehab Advisor (HUD)<br><br>"Vapor Barrier or Vapor Retarder." | vapor retarder | "A vapor retarder is a specially treated paper, thin plastic sheeting, or low permeance paint that prevents condensation of water vapor inside wall or ceiling materials.<br><br>The term 'vapor barrier', which is also commonly used, is somewhat misleading since it does not completely bar the transmission of water vapor. A vapor barrier is actually a vapor-resistant membrane, and is more properly called a 'vapor retarder.'" | "Interior moisture tries to move out of a building. Vapor retarders are important, because they keep this moisture in a warm area where it will not condense. For this reason, vapor retarders should be applied (in colder climates) behind the drywall of a wall or ceiling next to existing insulation and on the warm-in-winter side (between the insulation and the conditioned space) of insulated floor sections over crawl spaces." |

| | Sponsor, Title | Terminology | Definition | Placement |
|---|---|---|---|---|
| 6 | Building Science Corporation<br><br>"Glossary: vapor retarder." | vapor retarder<br>class II vapor control layer | "A vapor retarder is a material that is vapor semi-impermeable. A vapor retarder is a Class II vapor control layer. The test procedure for classifying vapor retarders is ASTM E-96 Test Method A—the desiccant or dry cup method." | "No interior vapor control required on the interior side of framed walls in climate zones 1, 2, 3, 4a, or 4b.<br><br>In hot, humid climates, a Class I or II vapor control layer on the interior of the framing can, and often does, cause premature building enclosure failure due to inward moisture drive condensation (see RR-9302: Humidity Control in the Humid South). BSC recommends avoiding Class I or II vapor control layer on the interior in these zones, or any material that acts inadvertently like a Class I or II vapor control layer such as reflective foil insulations, vinyl wall coverings, glass mirrors and epoxy paints.<br><br>A Class I or Class II vapor control layer is required by the IRC on the interior side of framed walls in Zones 4c, 5, 6, 7, and 8, with the exceptions of basement walls, below grade portion of any wall, and wall construction that is not sensitive to moisture or freezing (e.g. concrete block wall). However, BSC recommends avoiding Class I vapor control layers in general in wall assemblies, except in special use occupancies in cold climates such as indoor pools and spas." |
| 7 | NRMCA<br><br>"CIP 29-Vapor Retarder Under Slabs on Grade." | vapor retarder | "Vapor retarders are materials that will minimize the transmission of water vapor from the sub-slab support system into a concrete slab." | "... include a vapor retarder under every interior floor slab in every building." |
| 8 | Stego Industries<br><br>"What is the Difference between a Vapor Barrier and a Vapor Retarder." | vapor retarder | none listed | Below slab. |

| | Sponsor, Title | Terminology | Definition | Placement |
|---|---|---|---|---|
| 9 | Insulfoam<br><br>“Insulfoam Roofing Manual.” | vapor retarder | “Vapor retarders are used as part of a roof assembly to prevent moisture migration and condensation within that assembly.” | “Vapor retarders are used as part of a roof assembly to prevent moisture migration and condensation within that assembly. Moisture migration or condensation can be a concern within an occupied building and also during building construction. In all cases, the vapor retarders should be installed on the warm side of the insulation.” |
| 10 | Foam-Tech<br><br>“Vapor Retarders.” | vapor retarder | “A vapor retarder is a material that restricts or reduces the rate and volume of water vapor diffusion through the ceilings, walls, and floors of a building.” | “For buildings in a heating climate, the vapor retarder is placed on the inside or the warm side of the building envelope.”<br><br>“In a cooling climate, the vapor retarder should be placed on the outside of the building envelope.” |

**Table E.3.** The summary of the content analysis of the top ten websites when the term “air barrier system” is searched in Google.

| | Sponsor, Citation | Terminology | Definition | Placement |
|---|---|---|---|---|
| 1 | Whole Building Design Guide<br><br>“Air Barrier Systems in Buildings.” | air barrier system<br>air and vapor barrier | “A continuous air barrier system is the combination of interconnected materials, flexible sealed joints and components of the building envelope that provide the airtightness of the building enclosure and separations between conditioned and unconditioned spaces. . .” | “If it (air barrier) is placed on the predominantly warm, humid side (high vapor pressure side) of the enclosure, it can control diffusion as well, and would be a low-perm vapor barrier material. In that case, it is called an "air and vapor barrier." If placed on the predominantly cool, drier side (low vapor pressure side) of the wall, it should be vapor permeable (5-10 perms or greater).” |
| 2 | Air Barrier Association of America<br><br>“About.” | air barrier system | “Air barrier systems are comprised of a number of materials which are assembled together to provide a complete barrier to air leakage through the building enclosure.” | “The building enclosure includes all six sides of the building and may included separations within a building. This system essentially “wraps” the building shell and ensures that it protects the building from the effects of air leakage.” |

| | Sponsor, Citation | Terminology | Definition | Placement |
|---|---|---|---|---|
| 3 | Air Barrier Association of America<br><br>“Commissioning the Air Barrier System.”<br><br>By Wagdy Anis, AIA, Member ASHRAE | air barrier system | “Air barrier systems for a building enclosure are assembled from relatively air-impermeable materials (less than 0.004 cfm/ ft2 at 1.57 lbs/ft2 [0.02 L/s·m2 at 75 Pa]) interconnected to form assemblies and the assemblies (such as opaque walls, windows, etc.) interconnected with flexible joints that can accommodate the expected relative movement of these assemblies.” | “Constructed of relatively air-impermeable materials and assemblies, interconnected with flexible joints;<br>Continuous throughout the enclosure;<br>Structurally supported to withstand positive and negative air pressures (including design wind pressures and gusts, as well as persistent low pressures such as stack effect and fan pressurization) without displacement and failure; and<br>Durable to last the life of the enclosure if inaccessible, or maintainable.” |
| 4 | Air Barrier Association of America<br><br>“About.” | air barrier system | “Air barrier systems are comprised of a number of materials which are assembled together to provide a complete barrier to air leakage through the building enclosure.” | “The building enclosure includes all six sides of the building and may included separations within a building. This system essentially “wraps” the building shell and ensures that it protects the building from the effects of air leakage.” |
| 5 | Poly Wall<br><br>“Waterproofing & Air Barrier Systems.” | air barrier system | “Air barrier systems provide the only effective defense against air leakage and, more importantly, moisture issues.” | Spray on product. |
| 6 | Henry<br><br>“Air Barrier Systems.” | air barrier material | “An air barrier material resists air leakage and is designed to form a continuous plane around a building to prevent uncontrolled air movement in and out of the building envelope.” | Spray on product. |
| 7 | TREMCO Commercial Sealants & Waterproofing<br><br>“Taking the Guesswork out of Air and Moisture Management.” | air barrier | “Air barriers are designed to stop the movement of air (and the water vapor it contains) under pressure. They are only effective, though, when designed as a holistic, continuous system. To be effective, they must be continuous from below-grade to the roof line. Providing continuity at transitions is critical.” | Designing an effective air barrier system starts with understanding the impact of the local climate on vapor drive.<br>This will allow the proper air barrier membrane (air/vapor barrier or vapor permeable) to be selected and located appropriately within the wall in relation to the insulation. |

| | Sponsor, Citation | Terminology | Definition | Placement |
|---|---|---|---|---|
| 8 | Wikipedia<br><br>"Air Barrier." | air barrier<br>air barrier system<br>air barrier components<br>air barrier assemblies<br>air barrier accessory<br>air barrier materials | "Air barrier system – combination of air barrier assemblies and air barrier components, connected by air barrier accessories, that are designed to provide a continuous barrier to the movement of air through an environmental separator and which has an air leakage rate no greater than 2.00 L/(s•$m^2$) at a pressure difference of 75 Pa when tested in accordance with ASTM E 779 or CAN/CGSB 149.10 or CAN/CGSB 149.15." | none listed |
| 9 | Icynene<br><br>"Home page." | air barrier | Spray polyurethane insulating foam. | Usually applied within stud cavity, against sheathing. |
| 10 | International Masonry Institute<br><br>"Air Barrier Systems." | air barrier systems | Air barrier systems are designed to stop moisture-laden air from moving through, under and over wall or roof assemblies. The intent of air barrier systems is to stop air from both infiltrating and exfiltrating buildings. | For single-wythe masonry walls, air barriers still need to be installed on the interior side of the wall insulation. If the wall insulation is inside the wall, then an economical air barrier solution is an air-tight paint assembly on the inside wall surface, applied all the way to the top of the wall with transition material making the connection from the wall to the roof deck or spandrel beam above. |

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