Lessons from Visualizing the Functions of the Building Enclosure

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ABSTRACT: A study completed in 2012, by the author, surveyed designers and builders about their use and understanding of the air barrier system in residential construction. Results show that a larger percentage of builders than designers reported *always* performing blower door tests on their projects. The study also showed that a larger percentage of builders than designers believe that an air barrier system must be continuous to be effective. It is well known that an air barrier system must be continuous to be completely effective and it is hypothesized that more builders believe this because they have first hand, visual experience of air infiltration. Blower door tests depressurize a building to expose air leaks through the enclosure. If visualization of air infiltration has convinced more builders of the importance of the air barrier system, what other visual and experiential tests of the building enclosure could be devised for building professionals to reinforce the importance of other enclosure components?

This paper explores possibilities for new experiential tests for a highly misunderstood layer of the enclosure, the vapor retarder. Reasons for its misunderstanding are numerous: placement is climate based, it is sometimes only millimeters thick, it is made of many parts, information on the topic is often unreliable and it is generally a confusing topic. For these reasons, the vapor retarder is often misused within the enclosure creating potential problems for structural rot and mold within walls. Is there an onsite testing option for this layer that would provide the same visual feedback that the blower door test gives for the air barrier system? This paper seeks to identify possible methods to teach building professionals using hands on experience and visualization about the function of the vapor retarder.

KEYWORDS: Building Enclosure, Experiential Learning Theory, Vapor Retarder, Air Barrier System

INTRODUCTION

I know the difficulty of understanding the invisible functions of the building enclosure. Without understanding these invisible functions, intelligent design decisions about the composition of the enclosure are difficult to make. I based my graduate thesis on this issue. As a design professional, I often wondered if I was correctly positioning the vapor retarder and what constitutes an air barrier system. Clear answers to my questions were almost impossible to find in books and on the internet, and other designers seemed to be just as confused. Although these parts of the enclosure are thin and difficult to see, they are important to a properly functioning enclosure.

It is commonly known that a correctly designed air barrier system prevents air infiltration which preserves heating and cooling and stops vapor transmission. A correctly placed vapor retarder reduces interstitial condensation which prevents mold and rot within wall cavities. Both are essential to an efficient and healthy building. Although it is obvious they are needed, the use and placement of these parts are often confused because they are challenging to draw and communicate between designers and builders, they are usually only millimeters thick, and the scientific nature of their function is difficult to understand. For instance, an air barrier system is the combination of many parts of the enclosure – not just a layer of house wrap. Air barrier systems are three dimensional, therefore include the caulked joint from the window to house wrap and taped joint between each layer of house wrap. Insulation, drywall, sheathing, and other building materials, at times, serve as parts of the air barrier system. Vapor retarders sometimes serve as part of the air barrier system.

Vapor retarder placement is determined by climate and differs depending on wall type. The air barrier system must be completely continuous to be effective whereas the vapor retarder does not (Lstiburek 2001.) Because of their sometimes shared functions and sometimes very different placement requirements, it can be a confusing task to design and install these systems. An intimate understanding of both is necessary for effective use.

My graduate thesis completed at the University of Oregon in 2012, titled *A Comparative Study of Climate Based Design of Building Enclosures*, concentrated on common use and understanding of the vapor retarder and the air barrier system in residential construction. I attempted, through research, to determine if the contradicting information and confused terminology I discovered in practice had a negative effect on the performance of buildings. Through a national on-line survey, I asked building professionals where they learn about vapor retarders and air barrier systems and if they find the information confusing. I wanted to know what resources others were using for answers and what practices for design they used. I also asked specific questions about their understanding of and where they place vapor retarders and air barrier systems. This information could help me to determine if what is being built is flawed. I hypothesized that common practice of enclosure design differed from best practice. This paper uses two interesting points of data derived from my thesis and applies them to ideas about better ways to teach building professionals about the building enclosure.

The results of the survey revealed that a large percentage of builders "strongly agree" that an air barrier system must be continuous to be effective; whereas, a significantly smaller number of designers believe this statement to be true. Why do more builders believe in the importance of a continuous air barrier system? Could it be because more builders report always performing blower door tests on their projects (McGlohn 2012?) Is it possible that builders understand the importance of a continuous air barrier system because they have visually experienced the effects of a discontinuous system and had to fix the problem? Can it be concluded that hands-on experiential learning methods like blower door testing are better for teaching building professionals about the functions of the building enclosure? This paper considers alternative ways to learn using Experiential Learning Theory as a vehicle for teaching design professionals about the invisible functions of the building enclosure.

Section one gives a short overview of my master's thesis including the problem, methodology and conclusions gathered. The information this paper focuses on is discussed in section two. Section three introduces Kolb and Kolb's Experiential Learning Theory (ELT) and relates this theory to the results of my thesis' survey. Section four explores the possibly of applying ELT to other lessons about the building enclosure such as vapor retarder function.

1.0 A COMPARATIVE STUDY OF CLIMATE BASED DESIGN OF BUILDING ENCLOSURES

The thesis referred to in this paper was completed in March of 2012 in partial fulfillment for the degree of Master of Architecture awarded by the University of Oregon. An online survey approved by the Institutional Review Board (IRB) was issued to designers and builders of residential construction in 4 states from October 07, 2011 to November 04, 2011. In this thesis designers are defined as ". . . an architect, an architectural intern, or designer/builder (McGlohn 2012, 71.)" Builders are defined as "someone directly related to the construction of a house in a decision making role (McGlohn 2012, 71.)" From the results two interesting points related to teaching methods are highlighted for this paper and considered for future research.

1.1 Problem statement and hypothesis

As mentioned in the introduction, air barrier systems and vapor retarders are often confusing to building professionals. This is supported by the following quote from building science experts, Straube and Burnett in their text book *Building Science for Building Enclosures*.

> . . . much of the older literature (and a remarkable proportion of current documentation) 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 (Straube and Burnett 2005.)

Considering this, the first objective of my research was to determine if common practice of residential design and construction was negatively affected by the documented confusion. Do designers and builders detail their enclosures so that air can infiltrate and water vapor can condense within the wall? Other objectives were to find out where building professionals learn about the vapor retarder and air barrier system and if the resources they use are reliable.

I hypothesized that building professionals do not follow best practice and make mistakes in detailing. I also hypothesized that the internet is the first place building professionals go when they have a question pertaining to the building enclosure.

1.2 Methodology

To answer these questions I designed a 17 question on-line survey that was approved by the University of Oregon's Human Subjects Office. Many aspects of enclosure design are climate based; therefore, 4 states in 4 different climate zones were selected for the survey. States were selected based on their use of shared and mandated International Residential Code and International Energy Conservation Code. Through the use of the American Institute of Architects (AIA) and the National Association of Homebuilders online databases of members, I randomly selected 80 architecture firms and 80 homebuilders to contact and ask to take the survey. One hundred sixty phone calls and emails were sent to potential respondents across the country. Personal contacts in the selected states were also used to distribute the survey. Two hundred twenty responses were collected but after cleaning the data only 152 were used.

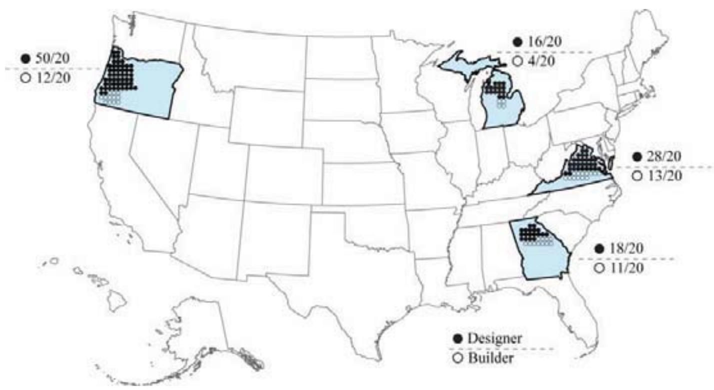

Figure 1: State selection and response numbers from each.

Above, Figure 1 illustrates the states selected for the survey and how many responses were received. Oregon represents a marine climate, Michigan a cold climate, Georgia a hot-humid climate, and Virginia a mixed climate.

1.2 Results pertinent to this paper

The complete results of the referenced thesis will not be discussed; however, two interesting points from the results make the basis for this paper. A question was included in the survey that was designed to help determine if building professionals understand the importance of a continuous air barrier system. They were asked to respond to the statement “A continuous air barrier system is essential for proper function of the building enclosure” by selecting one of the following: “strongly disagree,” “disagree,” “neither agree nor disagree,” “agree,” “strongly agree,” or “not sure.” The results showed that, alarmingly, only 65% of designers “strongly agree” that an air barrier system must be continuous to be effective (McGlohn 2012.) This is a surprisingly low percentage because it is a well-known fact that an air barrier system must be completely continuous to be effective. On the other hand, 83% of builders “strongly agree” with this statement (McGlohn 2012.) Why do more builders believe in the importance of a continuous air barrier system? A follow-up question asked “how often is a blower door test performed on your buildings?” with the choices of “never,” “rarely,” “sometimes,” “always,” and “not sure.” A blower door test identifies areas of air infiltration. Twenty-five percent of builders reported they “always” perform blower door tests (McGlohn 2012.) Designers report “always” performing blower door tests only 6% of the time (McGlohn 2012.) Figure 2 graphically depicts these results. Is it possible that more builders believe in the importance of continuity of the air barrier system because they more often perform blower door tests?

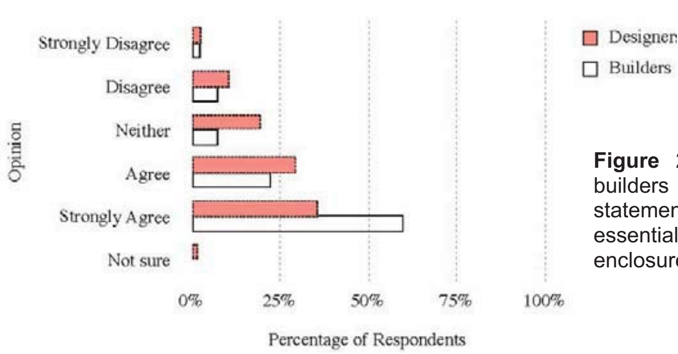

Figure 2: Percentages of designers and builders who responded to the following statement: A continuous air barrier system is essential for proper function of the building enclosure” (McGlohn 44.)

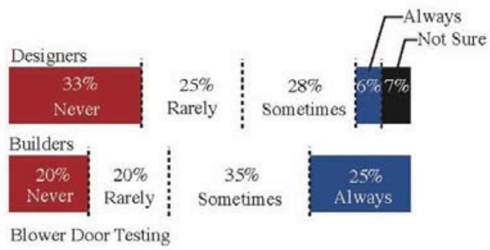

Figure 3: Percentages of designers and builders reporting how often they perform blower door tests on their projects (McGlohn 44.)

These two points from the results are the basis for this paper. One conclusion that can be made from the information presented above is that more builders believe an air barrier system must be continuous to be effective because more builders preform blower door tests. Blower door tests depressurize a house in order to measure the air infiltration through the enclosure. Air changes per hour (ACH) are then calculated with the results. A house with a low ACH number has low air infiltration. Conversely, a high ACH indicates many cracks and crevices that air is able to pass through the enclosure. Often builders use blower door tests during construction to insure a tightly sealed and energy efficient house. Air leaks are identified with smoke sticks or infrared cameras so they can be sealed. Does this process of testing air tightness, identifying the problem, and fixing the problem teach builders about air barrier system functionality? If this is the case, it can be concluded that design professionals' understanding of the building enclosure can be improved with the use of other experiential based testing methods.

2.0 Experiential Learning Theory

One well known theory presented by Kolb and Kolb that supports the learning process identified above is the Experiential Learning Theory. This theory defines learning as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience" (as cited in Kolb and Kolb 2005.) This theory supports that learning is enhanced by having a "concrete experience" that can be thought about and then used to draw conclusions on the event (Kolb and Kolb 2005.) The conclusions are then used to adjust future attempts to learn in order to improve a second "concrete experience" (Kolb and Kolb 2005.)

2.1 Experiential Learning Theory applied to air infiltration

Builders report testing the performance of the enclosures they build with blower door tests more often than dsigners and more builders also believe in the importance of a continuous air barrier system. My conclusion for these results is that builders, unknowingly, participated in experiential learning. They constructed an enclosure, tested its effectiveness through depressurization which identified their mistakes, assessed the leaky situation, fixed the mistakes and probably tested the enclosure again. The following chart (figure 4) adapted from Kolb and Kolb's journal article *The Learning Way: Meta-cognitive Aspects of Experiential Learning,* diagrams the process.

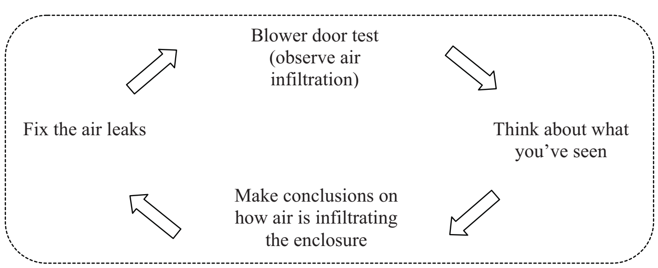

Figure 4: Experiential Learning Theory applied to testing air infiltration in a house (Kolb and Kolb 2009.) Through each cycle, knowledge is increased because the end result is experienced, adjusted, and refined.

2.1 How Experiential Learning Theory can be applied to vapor diffusion

Many builders, carpenters, architects and designers learn their trades through first hand experiences. "On the job" was ranked number 1 when building professionals were asked "where did you first learn about vapor retarders and air barrier systems?" (McGlohn 35.) Experiential Learning Theory is discussed in earlier sections and highlighted by the relationship between blower door testing and comprehension of the continuity of an air barrier system. Through on-site testing and adjusting, builders teach themselves about air infiltration and how to fix problems. This is significant because preventing air infiltration is important to energy efficient and healthy homes. Another invisible action within the enclosure is vapor diffusion. Generally, more water vapor is held in warm air; therefore, buildings in hot-humid climates have more water vapor on the exterior most of the year and buildings in cold climates have more water vapor on the interior most of the year. The higher concentration of water vapor seeks to balance with the air in the lower concentration of water vapor. This happens by vapor diffusion through the enclosure and this process will cause problems if the water vapor collides with a surface below the dew point within the wall cavity. Vapor retarders are placed within the enclosure at climate specific locations to slow down water vapor diffusion which prevents interstitial condensation.

The function of a vapor retarder is invisible. Is there a mechanism that can be devised, similar to a blower door test that can visually demonstrate how a vapor retarder works to builders and designers? Can the Experiential Learning Theory be applied to learning about vapor retarder function?

2.2 WUFI-ORNL/IBP

One method of learning about vapor diffusion thorough the material of an enclosure is a software program developed by the Oak Ridge National Laboratory (ORNL) called WUFI-ORNL/IBP or WUFI for short. WUFI is creates a "realistic calculation of the transient hygrothermal behaviour of multi-layer building components exposed to natural climate conditions" as stated on the ORNL Building Technology Center's website. This program allows a user to define the composition of a building's wall, apply climate specific conditions to the exterior and interior of the wall, and simulate climate conditions for a two year period. The results show if the wall, over time, will accumulate moisture or if the wall will dry over time. Although this is a relatively simple program and one version is free, most people in the field will never be exposed to this way of demonstrating vapor movement. My research has shown that an on-site demonstration that shows measurable water vapor movement would be more beneficial.

2.3 ORNL Rotatable Guarded Hotbox

Another testing method the Oak Ridge National Laboratory's Building Technology Center has developed is the Rotatable Guarded Hotbox. Wall assemblies are tested according to ASTM C1363 – 11 Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus ("Oak Ridge.") This dual chamber system controls temperature on two sides of a wall assembly sample and measures levels of thermal resistance through the sample. One side of the chamber is warm and one is cold. Although measuring vapor diffusion is not a goal of this research it is an aspect. Relative humidity is controllable in the Large Scale Climate Simulator, the roof and attic assembly testing simulator ("Oak Ridge.") A system similar to this is one possibility for demonstrating the use of vapor retarders. The Rotatable Guarded Hotbox and the Large Scale Climate Simulator are huge, stationary, and not appropriate for on-site demonstrations to carpenters, builders, designers, and architects.

3.0 The vapor diffusion experience

This paper is the beginning of a larger and more in-depth research effort. The broadest question that arises from the discussion above is, "can vapor diffusion be measured through a building's enclosure?" Unlike air infiltration, there are few onsite tests that exist to measure how much water vapor passes through an enclosure and identifies problematic areas of condensation. Because interstitial condensation is the major concern, access to the inner layers of the enclosure would be necessary to measure moisture accumulation. Also, because interstitial condensation is dependent on the climate conditions of the exterior and interior of the building, temperature control would be necessary to accurately identify the consequences of a misplaced vapor retarder. Furthermore, the amount of water vapor in the air, relative humidity, would also need a control mechanism. These obstacles present a few major problems with testing an entire building's vapor retarder function. But is testing the entire building necessary? The continuity and the quality of installation of the vapor retarder is not as important and the continuity and quality of installation of the air barrier system. From the book *Builder's Guide: Mixed-Humid Climates*, Lstiburek explains that a vapor retarder that is 90% complete, blocks 90% of vapor diffusion (109.) I believe understanding the basic function and climatic placement of a vapor retarder can be taught with an on-site module that contains all the controls necessary to simulate climatic conditions necessary to affect vapor diffusion.

3.1 Proposed on-site vapor diffusion demonstrations

Below, in Table 1, the components a vapor diffusion teaching module would need are listed.

Table 1: Components needed for dual chamber vapor diffusion simulator

Component	Function
Sealed, dual chamber container	An air tight chamber is needed to isolate climate specific simulations. Air infiltration must be avoided to prevent water vapor from entering through air infiltration.
Mechanism to control heat and relative humidity on side 1 of dual chamber container.	Simulate winter conditions on the interior of a cold-climate wall assembly and summer conditions on the exterior of a hot-humid wall assembly.
Mechanism to control air conditioning and relative humidity of side 2 of dual chamber container.	Simulate winter conditions on the exterior of a cold-climate wall assembly and summer conditions on the interior of a hot-humid wall assembly.
Desiccant	Moisture absorbing material that allows water vapor to be measured as it diffuses from one side of the chamber to the other.
Visual indicator	A visual component that allows the user to see water vapor move through the wall assembly would be ideal. Although, at this time I am unsure what this mechanism is.
Wall assembly divider	The two chambers must be divided by the wall assembly in question.
Data loggers	Data logger sensors are needed within the wall assembly to measure temperature, relative humidity, and dew point. It is necessary to determine if condensation has formed within the wall.

Although there are simulation methods that exist for testing vapor diffusion, I believe that to improve education of the installers and designers, a traveling simulator is necessary. Ideally, it would be simple to use for on-site experimentation. Temperature and relative humidity set points can be specified, the sample wall assembly can be inserted, and water vapor diffusion can be measured. Admittedly, this is a simplification of the proposed machine. Technically, I am proposing a complicated module; however, I believe that an experience such as this would be beneficial to those designing the location and installing vapor retarders.

CONCLUSION

My research has highlighted a practical fact that most educators already know, having hands-on learning experiences solidifies the lesson for a student. As building technologies change and become more complicated, we must find ways to continue to educate ourselves and the people hired to build what is designed. The quality and functionality of our buildings depends on it. Learning environments are different for individuals involved with the design and construction of buildings. A classroom setting is not always available and arguably not the best learning environment for these subjects. Most lessons for these trades are learned on-site, through hands-on experiences. The blower door test is one example of how builders and designers are learning about air infiltration and energy efficiency. This exemplifies the Experiential Learning Theory. Air infiltration is only one of many invisible and important subjects within the building enclosure. Vapor diffusion is also problematic when it is not properly controlled with a good understanding of how to use vapor retarders. Is there an on-site method for teaching about vapor diffusion that would provide installers and designers with an experience that teaches them how a vapor retarder works? With on-site experiential learning simulations, building technology education can be enhanced, building performance can be improved, and lasting impressions can be made on builders and designers. Confusion on this topic can be reduced; therefore, more efficient and healthier homes will be designed and constructed.

There is much more to do to make this idea a reality. More research is necessary to determine what components are needed for an on-site vapor diffusion chamber. I have only proposed general elements. Consultation with other researchers involved in similar research will be helpful to determine where overlap may occur and where joint efforts can take place. A feasibly study that outlines costs, time line, educational curriculum, and documented interest from the industry will also be necessary. A final product is in the distant future but the need for improving on-site building enclosure education is immediate.

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