Cold Climate Housing Research Center
CCHRC

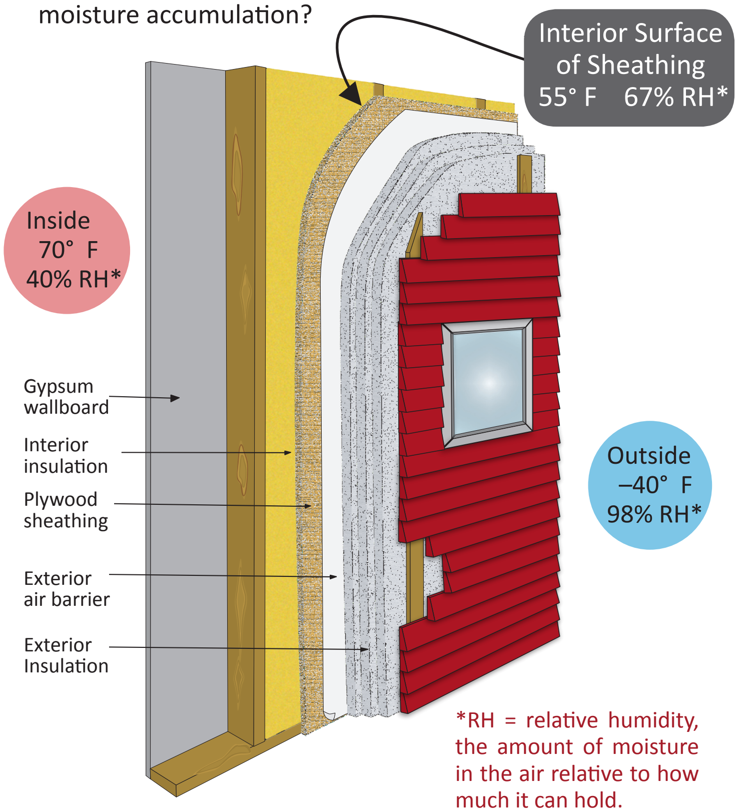
Safe and Effective Exterior Insulation Retrofits: Phase II

by Colin Craven and Robbin Garber-Slaght

January 15, 2012

Moisture control in cold climate housing is a critical concern, as moisture accumulation in the building envelope can lead to mold and rot. As homeowners in Interior Alaska add exterior foam insulation to their walls to make their homes more energy efficient, they can create the potential for moisture damage by reducing the ability of the wall assembly to release moisture. To better understand this risk, CCHRC conducted experiments on exterior wall retrofits from October 2009 through May 2011. The study, summarized in the Mobile Test Lab Phase 1 Snapshot, was designed to determine the significance of vapor retarders in retrofit construction and the potential for moisture accumulation. CCHRC designed the study to answer the following questions:

- Does the presence of a vapor retarder and exterior foam insulation create a “double vapor barrier” that can cause moisture accumulation?



*RH = relative humidity, the amount of moisture in the air relative to how much it can hold.

Figure 1. A general depiction of the wall system used in this study (not to scale). Variables across the nine wall sections include the presence or absence of an interior vapor retarder, 2x4 or 2x6 stud construction, and the amount of interior and exterior insulation. Note that interior insulation is placed in the stud cavities and exterior insulation is between the structural sheathing and the siding.

Exterior of the Mobile Test Lab at the end of the 2-year study, with the siding and insulation removed.

- What distributions of interior-to-exterior insulation prevent moisture accumulation within retrofitted walls?

To answer these questions, CCHRC conducted experiments with nine test walls in the Mobile Test Laboratory (MTL) through two Fairbanks winters with levels of interior humidity and pressure that ranged from normal to extreme (see Table 1). CCHRC monitored the nine test walls for relative humidity in the stud cavities and the moisture content of the wood framing. CCHRC also modeled the test wall constructions for these variables over a 10-year period using WUFI® Pro 5.1.

In the summer of 2011, the MTL test walls were disassembled and inspected. Some of the test walls had varying degrees of mold and water damage on the wood components. Note that rot would take longer to develop, so the observations summarized here are limited to measured data and visible mold. CCHRC found that the monitoring and inspection results can be largely explained based on the presence or absence of an interior vapor retarder and the distribution of interior-to-exterior insulation.

In short, adding exterior foam slows the release of accumulated moisture, but a “double vapor barrier” effect is only likely in walls with thin exterior insulation (30 % or less of total wall

Table 1. Interior Conditions in the Mobile Test Lab

	Temperature	Humidity	Pressurization
1st Winter (2009-2010)	70° F	40%	Positive
Summer (2010)	Ambient	Ambient	Neutral
2nd Winter (2010-2011)	70° F	25%	Neutral
Summer (2011)	Ambient	Ambient	Neutral

R-value) under extreme humidity and temperature conditions. Walls with thick exterior insulation (roughly 65% or more of the total wall R-value) make for greater durability by avoiding moisture accumulation.

Moisture Problems
Mold growth on building materials is typically only limited by the availability of moisture. Once a water source is available, such as condensation of water vapor, mold growth will follow if the water is present for a sufficient period of time (as shown in Figure 2). For the test walls studied, the most widespread mold was observed for walls with no vapor retarder and less than 65% of the total wall R-value as exterior insulation. The walls with no signs of moisture damage were those with the thickest exterior insulation. A summary of our visual observations is provided in Table 2 (page 4).

Insufficient exterior insulation means that the sheathing can become colder than the dew point in winter, allowing water vapor to condense on the inside sheathing surface (see sidebar, Dew Point and Humidity). If this occurs frequently, it can lead to mold growth and eventually rot. Ideally, the wall will have sufficient exterior insulation so that the sheathing remains above the dew point. This is illustrated by the green line in Figure 3, where the test wall with the most exterior insulation remained above the dew point for almost the entire test period. Correspondingly, this test wall was free of visible mold after the two-year experiment.

In contrast, the test wall with thin exterior insulation (the red line) remained below the dew point for almost all of the first winter and most of the second winter. Correspondingly, this test wall had abundant mold after the two-year experiment. The test wall with no exterior insulation (the blue line) had the coldest sheathing. In fact, sheathing on this test wall was below freezing for almost the entire winter. Interestingly, this test wall had only small areas of visible mold, so colder sheathing and dew point analysis alone is not sufficient to explain our observations. One explanation is that the continuous subfreezing temperatures inhibited the ability of mold to grow. Also, the plywood sheathing without exterior foam provided an effective path for condensation to later evaporate to the outside air. The combination of these factors allowed for this test wall to escape with only minor amounts of mold.


Figure 2. Mold on the sheathing behind the fiberglass on a wall with thin exterior insulation.

The test walls with a vapor retarder, while not perfectly sealed, had substantially less mold growth. Mold in these test walls tended to be concentrated close to unsealed penetrations in the vapor retarder. For test walls with thick exterior insulation (65% – 70% of the total R-value on the exterior), the presence or absence of a vapor retarder was not of great significance. All of the walls with exterior insulation less than 65% had mold growing on the sheathing to some degree. The mold tended to be localized on test walls with a vapor retarder and widespread in test walls without a vapor retarder.

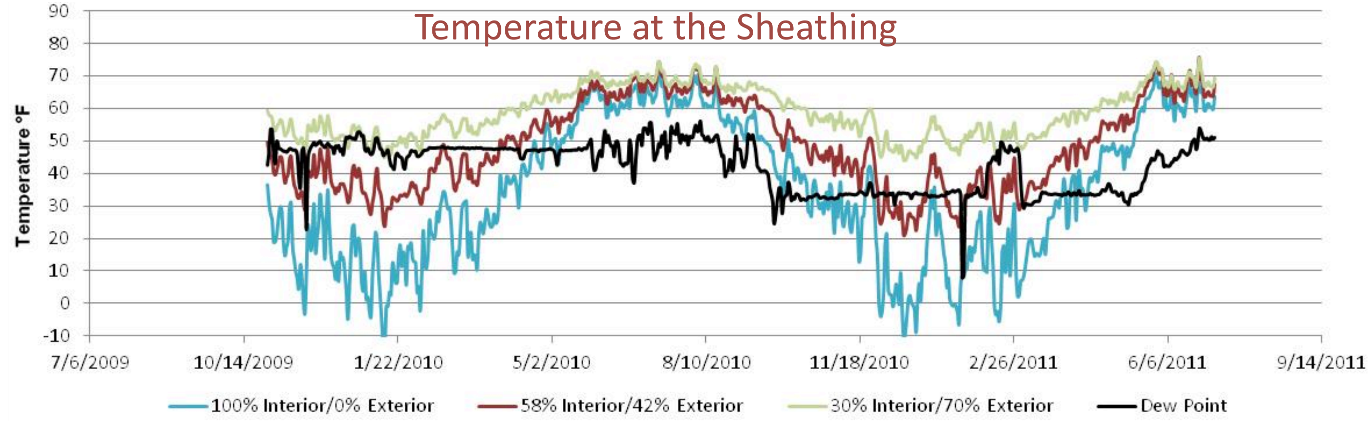


Figure 3. Temperatures at the sheathing plane. The test wall with the most exterior insulation stayed above the dew point for both winters, successfully avoiding condensation on the sheathing.

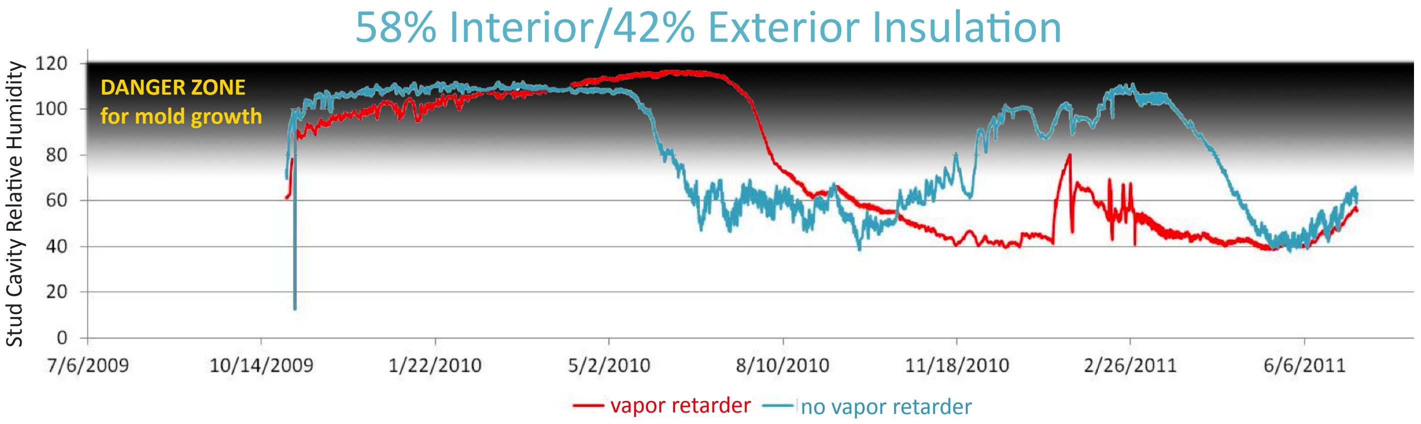


Figure 4. Relative humidity in the stud cavity of the thin exterior insulation walls. The wall with a vapor retarder took longer to dry during Summer 2011, while better controlling moisture in Winter 2010/2011.

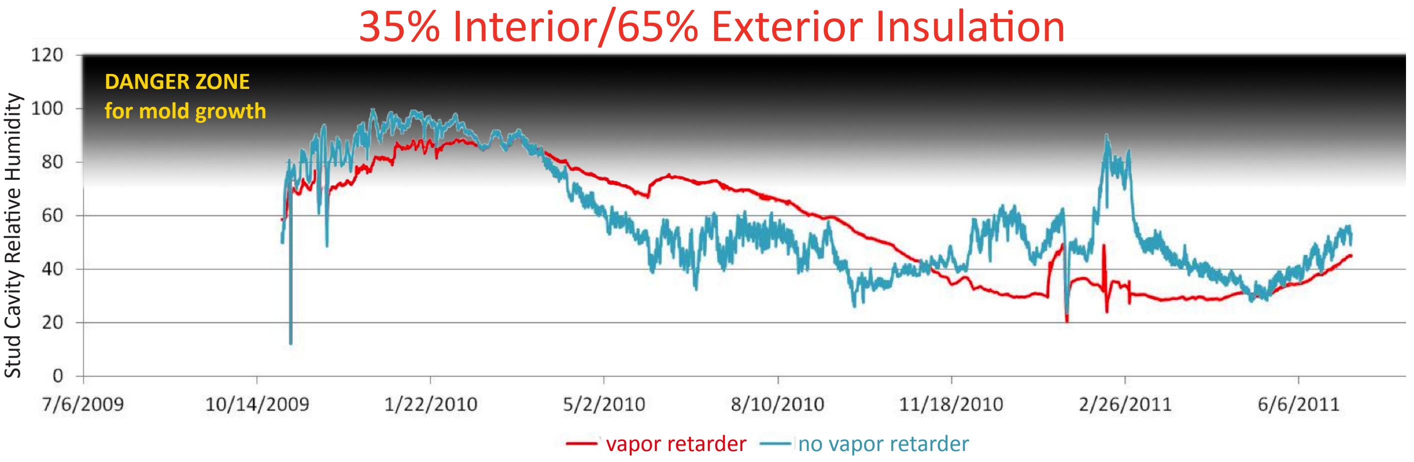


Figure 5. Relative humidity in the stud cavity of the walls with thick exterior insulation. While the RH entered the danger zone for several months, no visible mold was observed.

Moisture Control

While critical, avoiding condensation is not sufficient, as very high humidity in the wall cavity over time can also lead to mold growth. This is dependent on temperature and the type of material (for example, plywood versus OSB sheathing), so there is no absolute threshold humidity for concern. Instead the danger zone for mold growth in most residential construction is above 75% relative humidity (World Health Organization, 2009).

The interior humidity of the MTL ranged from 25%-40% in the winter, however, the humidity at the sheathing plane was typically much higher because the fiberglass insulation reduced the temperature of the sheathing while not inhibiting the flow of air and water vapor. The warmer the sheathing is kept by exterior insulation, the lower the humidity at the sheathing plane (see Figure 1).

The humidity at the sheathing was very high for all test walls during the first winter (40% interior RH and positive pressure). However, there is significant difference between 75% and

Dew Point and Humidity

If the interior temperature of the house is 70°F and the interior relative humidity is 40%, the dew point is 44°F. At any surface in the wall that is 44°F or colder the water will condense out of the warm moist interior air. This is very visible and common on windows on colder days. If you've ever seen condensation on a window in the winter, imagine that kind of moisture inside your walls.

In order to prevent this type of condensation, walls in cold climates are typically constructed with an interior vapor retarder (6 mil polyethylene plastic) behind the drywall. Regardless of construction type, homeowners need to manage interior relative humidity. Humidity levels can be kept in check with a mechanical ventilation strategy that changes the air in the house on a regular basis.

If the interior humidity is kept at 25%, the dew point drops to 32°F. This substantially reduces the potential for condensation while not being too dry for most people's preferences.

100% relative humidity in terms of potential for mold growth. The higher the humidity, the less time it takes for visible mold growth to become established (Viitanen, 1994). The walls with thin exterior insulation were essentially at 100% humidity all of the first winter, with or without a vapor barrier (Figure 4). In contrast, the walls with thick exterior insulation were able to stay under 100% relative humidity (Figure 5). The test wall with 65% exterior insulation and a vapor retarder was even able to remain under 90% relative humidity. Notable for both graphs is that the test walls with a vapor retarder took longer to dry during the summer than the test walls without a vapor retarder. This matches expectations, as walls without vapor retarders can dry more easily to the inside. However, this drying capability did not spare the test walls without vapor retarders from abundant mold growth on the sheathing.

During the second winter when humidity and pressure within the MTL were more representative of typical home conditions (25% RH and neutral pressure), the contribution of an interior vapor retarder was more apparent. Humidity was consistently higher for the test walls without vapor retarders. The test walls with a vapor retarder stayed safely under 80% relative humidity at the sheathing, as long as 42% or more of the wall R-value was exterior to the sheathing. The test wall with 30% exterior insulation had high humidity at the sheathing plane (data not shown), and demonstrated the most widespread mold growth of all the test walls with a vapor retarder.

Implications

Based on the MTL experiments and WUFI® simulations, retrofitting walls with foam insulation is safest when 65% or more of the total wall R-value is exterior to the sheathing. However, the "double vapor barrier" effect only seems to be a concern for wall systems with approximately 30% or less of their R-value exterior to the sheathing coupled with relatively high interior humidity. While only one of the test walls fit that description, it is common for residential retrofits to have less than 30% of the wall's R-value exterior to the sheathing. In such cases, the home envelope durability becomes largely a function of occupant behavior. Decisions on home ventilation or humidification can determine whether or not such wall systems will provide a long service life.

Consider Ventilation Needs

Retrofitting a home with foam insulation will tighten up the envelope, resulting in a reduction in air leakage that is often counted on to provide ventilation. Mechanical ventilation by a heat recovery ventilator is the common solution in Alaska.

While any wall system is safer with low interior humidity (less than 25%), people are generally happiest with a moderate relative humidity (30% – 50%). Because more ventilation means higher energy costs and greater irritation to people related to low humidity, current residential applications must seek to balance these competing interests. CCHRC plans to conduct more research on building envelope designs that can withstand higher humidity without risk of mold, to help improve the health of homes in the North.

Most homes in Alaska already have plastic sheeting as a vapor retarder, and it is reasonable to assume that in most cases electrical outlets, renovations, and other disturbances are not well sealed. Correspondingly, the test walls monitored in the MTL and simulated by WUFI® included unsealed holes in the vapor retarder that allowed for air leakage into the stud cavity. Even in an imperfect state, this vapor retarder was found to provide substantial protection by reducing the relative humidity at the sheathing plane and the incidence of visible mold growth when compared to test walls that lacked a vapor retarder.

A full research report on this study will be available at www.cchrc.org later in 2012.

References: Vitanen, H. (1994). Factors affecting the development of biodeterioration in wooden constructions. *Materials and Structures*, 27, 483 - 493.

World Health Organization (2009). *WHO guidelines for indoor air quality: dampness and mold*. Retrieved from: http://www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf

Table 2: Observations from the Mobile Test Lab Walls

Interior Insulation	Exterior Insulation	Insulation Distribution	Vapor Retarder	Visible Observations of the Interior Sheathing Surface (for interior conditions, see Table 1)
R-11	--	100 % Interior	Present	One small area of visible mold, several areas of discoloration
R-19	R-8	70% Interior/ 30% Exterior	Present	Several small areas of visible mold
R-11	R-8	58% Interior/ 42% Exterior	Present	Visible mold close to hole in vapor retarder
			Absent	Visible mold covering all of the sheathing
R-11	R-16	41% Interior/ 59% Exterior	Present	Visible mold close to hole in vapor retarder
			Absent	Visible mold covering most of the sheathing
R-11, R-19	R-24, R-36	30-35% Interior/ 65-70% Exterior	Present	No visible mold
			Absent	No visible mold

Alaska Housing FINANCE CORPORATION

This snapshot was created with funding from the Alaska Housing Finance Corporation. The opinions, findings, and conclusions expressed within are those of the authors and not necessarily those held by AHFC.