Cold Climate Housing Research Center
CCHRC

Product Test

Reflective Insulation in Cold Climates

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Abstract

Reflective insulation is a type of thermal insulation with at least one reflective surface that is installed so that the surface faces an air gap. It is used in attics of homes in hotter climates to reduce the solar heat gain within a building. To determine if reflective insulation is effective in cold climate construction, CCHRC conducted a literature review of research on its use in cold climates and performed tests using two foam insulations with reflective facers. These findings are preceded by a summary on radiative heat transfer to provide relevant background. CCHRC concludes that for well-insulated buildings in cold climates, the use of reflective insulation adds very little to the overall R-value of the building envelope.

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Disclaimer: The research conducted or products tested used the methodologies described in this report. CCHRC cautions that different results might be obtained using different test methodologies. CCHRC suggests caution in drawing inferences regarding the research or products beyond the circumstances described in this report.

Reducing heat loss in buildings is one of the best ways to save on energy costs, ensure comfort, and avoid problems due to moisture in cold regions. To provide these benefits, thermal insulation must be installed correctly and in sufficient amounts. Insulation must also be selected to target the appropriate mechanisms of heat transfer.

There are three types of heat transfer: conduction, convection, and radiation.

- Heat moves through solid materials in direct contact by means of conduction. Fiberglass insulation placed between studs and blown into attics is primarily effective at reducing heat loss due to conduction.
- Convection is heat transfer from fluid motion, where air is the fluid of interest in most buildings. Heat loss due to convection is minimized by having tight air sealing of the building envelope, usually achieved in Alaska by using polyethylene sheeting in combination with sealant and tape. Some insulations are specifically formulated to address both conductive and convective heat transfer simultaneously. One such application is the use of spray applied foam insulation in rim joist areas where it provides both air sealing and reduces conductive heat losses.
- Radiation is less commonly addressed in home insulation for cold climates, and is perhaps the least understood heat transfer mechanism in building science. Heat that travels by radiation does so in electromagnetic waves, similar to visible light, but in a different frequency spectrum. Heat losses from a house due to radiation are the hardest to quantify, and few construction methods directly address radiative losses for cold climates.

Reflective insulations are designed to reduce radiative heat transfer by placement of one or more reflective surfaces in combination with an air gap. The reflective surface reflects most of the thermal radiation toward the air space, preventing it from being transmitted or absorbed by the material. The air gap ensures that there is little or no heat transfer by conduction in that space, which would be the dominant heat transfer mechanism if the air gap was filled. A familiar application of reflective surfaces is in the attics of homes in warm climates, where reducing the radiative heat transfer from hot roof decking to the underlying attic insulation lessens air conditioner loads. Despite the effectiveness of reflective surfaces in this context, it has not been demonstrated that radiative heat transfer from homes in cold climates is significant enough to merit use of reflective insulation. Furthermore, reflective insulation can affect water vapor transmission because they are commonly strong vapor retarders and can induce condensation by reducing surface temperatures (ASHRAE, 2009). Therefore the use of reflective insulation requires consideration beyond the need for thermal insulation.

Nevertheless, some insulation product manufacturers make substantial claims about the magnitude of heat loss due to radiation, and therefore assert a potentially significant role for reflective insulation in cold climate construction. One example comes from the manufacturer of an expanded polystyrene (EPS) insulation, claiming in promotional material that “typically 50-75% of heat loss in a building is through radiation” in the winter (P2000, ND). While this compares well to the other estimates, such as 60% of heat loss made by Desjarlais and Tye (1990), this estimate was based on uninsulated building cavities, a very uncommon scenario for heated structures in Alaska.

At the request of the Alaska Housing Finance Corporation, CCHRC tested the thermal performance of P2000 Insulation Systems EPS insulation and conducted a review of pertinent literature to help determine the potential benefits of reflective insulation in cold climate construction. This report presents an overview of the physics of radiative heat transfer followed by a literature review of pertinent documents relating to reflective insulation. The final section of this report presents the laboratory methods and findings for an experimental study that CCHRC conducted on reflective insulations.

The Elements of Radiative Heat Transfer

To understand the potential contribution of reflective insulation in cold climate construction, it is helpful to first explain some key elements of radiative heat transfer. Thermal radiation is emitted by all materials and is transferred by electromagnetic waves without the need of a transport medium (Modest, 2003). For example, sunlight reaches the earth through the vacuum of space. Objects at room temperature, such as the furniture in a house, also emit thermal radiation, but at a far lower emissive power and not in the spectrum of visible light. In the context of cold climate housing, a familiar example would be a hot wood stove, which will emit abundant thermal radiation into a room. The radiation emitted by the stove is then absorbed by surrounding surfaces, causing their temperatures to increase. A substantial amount of room heating will also result from convective heat transfer to the air in the room. The thermal radiation emitted from the stove spans a range of wavelengths largely dependent on the stove's temperature. After leaving the stove the radiation will be absorbed by, reflected by or transmitted through other materials it encounters.

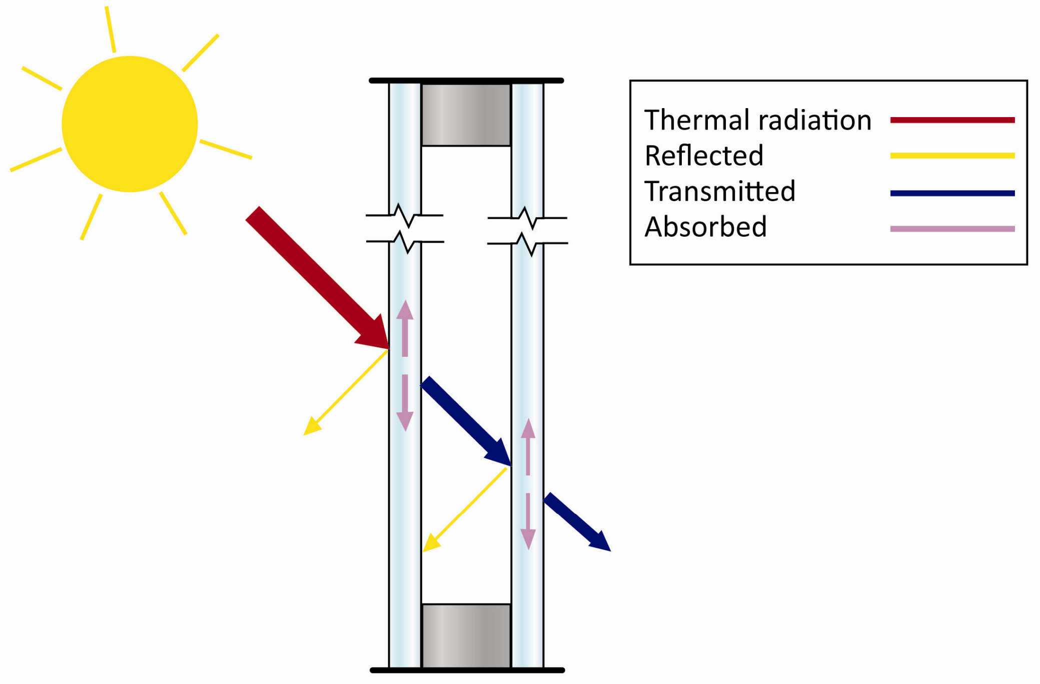

Figure 1. Generalized behavior of thermal radiation from sunlight encountering transparent objects. This example of the behavior of thermal radiation involves transparent objects: sunlight shining on a multi-pane window. For clear glass, roughly 84% of the sunlight will be transmitted through the outer pane, while 8% is reflected and 8% is absorbed (Carmody, 2007).

The three properties of reflectance, absorptance and transmittance balance the total direct energy input from the sunlight (Figure 1). In general terms, all thermal radiation emitted from a source is accounted for by the amount reflected from, absorbed by or transmitted through surrounding surfaces, depending on the composition of the materials encountered, e.g., window glass versus a wall painted with dark colors.

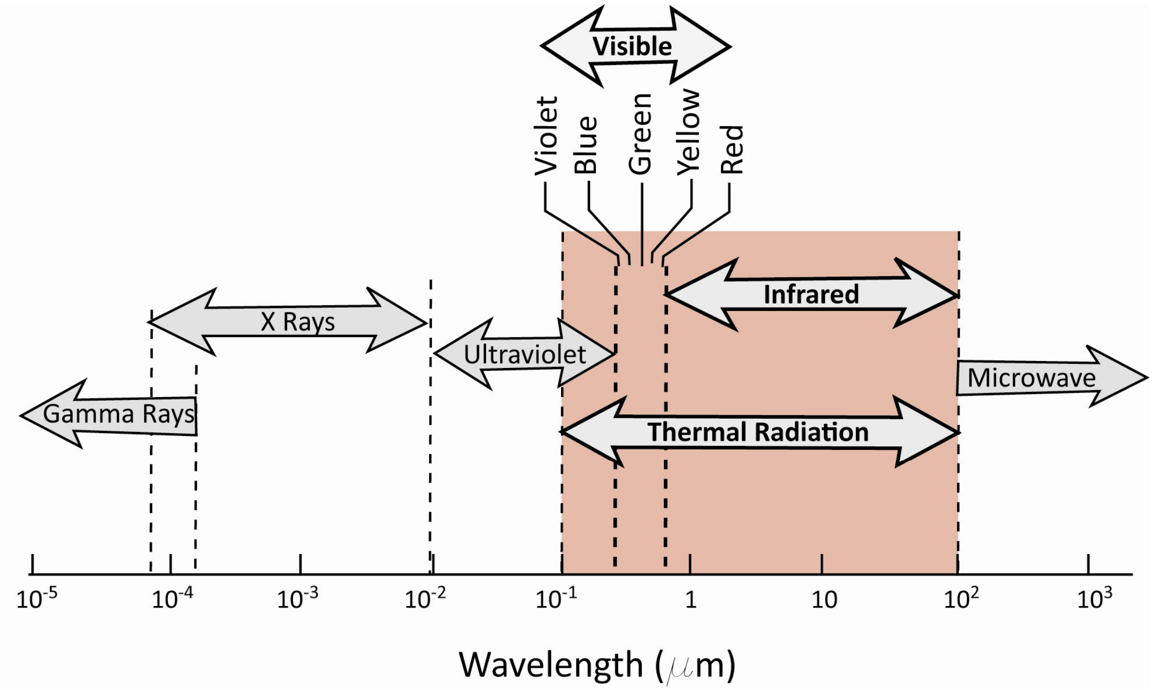

Figure 2. Thermal radiation within the electromagnetic spectrum, shown as a function of wavelength (adapted from Incropera et al., 2007). Human perception is limited to the visible light spectrum which is part of the thermal radiation spectrum.

Windows can be used to help illustrate another important aspect of radiative heat transfer: the process depends on the wavelength of the thermal radiation. Figure 2 shows the common designations for bands of the electromagnetic spectrum, including the ranges for thermal and visible radiation. In our perception, windows are transparent because the majority of the visible light spectrum is transmitted through the glass. However, glass is almost completely opaque to the long-wavelength infrared region (Ozisik, 1973). This phenomenon is illustrated in Figure 3, where a visible light photo shows the outdoors when viewing the window from the inside, whereas an infrared thermogram reveals the reflected indoor conditions. Modern windows are commonly provided with coatings that further tune the spectrum of the electromagnetic radiation that is transmitted or reflected. Some windows transmit most of the solar spectrum (“high solar heat gain” windows), while others block transmission of the short-wavelength infrared region to reduce heating of the home interior (“low solar heat gain” windows).

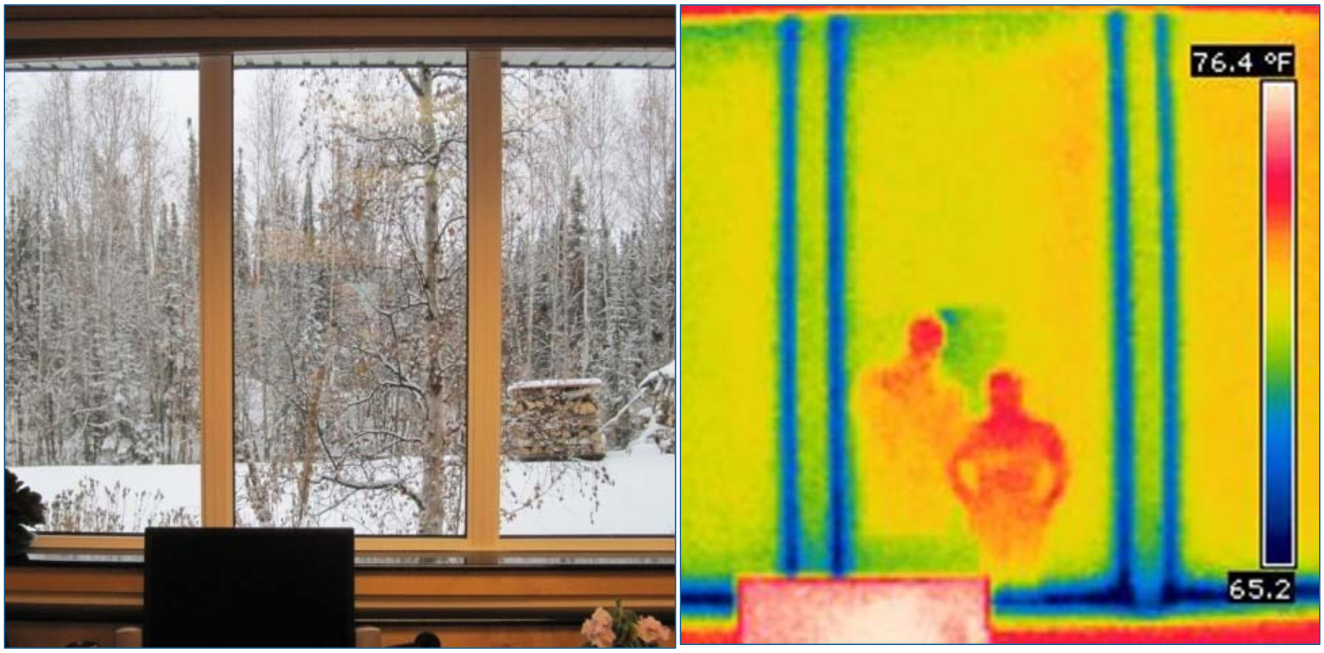

Figure 3. Visible light (left) and infrared thermogram using false color (right) of a window. This example shows how the visible light spectrum compares to the infrared spectrum (7.5 – 13 µm). The false color of the infrared thermogram corresponds with surface temperatures of the window and wall. The temperature scale is on the right.

Radiative heat transfer is somewhat simplified for other parts of the building envelope. For opaque materials, such as drywall or fiberglass insulation, no thermal radiation is transmitted and so radiative heat transfer occurs only by absorptance and reflectance. However, it is important to recognize that all surfaces both absorb and emit thermal radiation. The amount of thermal radiation a surface emits relative to the maximum amount possible (at a specific temperature) is called the "emittance" (Modest, 2003) also called "emissivity." Theoretically, emittance can vary from 0 to 1, where 1 is a perfect emitter, and 0 means that no thermal radiation is emitted. Most building materials have an emittance of approximately 0.9 (ASHRAE, 2009), meaning that they don't deviate significantly from that of a perfect emitter. In contrast, shiny metal surfaces, such as aluminum foil, have emittances around 0.05 – 0.1 (ASHRAE, 2009), signifying that such materials have the potential to retard radiative heat transfer. Low emittance surfaces reduce radiative heat transfer by inhibiting the emission and absorption of thermal radiation. In rough terms, "highly reflective" and "low emittance" are equivalent descriptions. Such surfaces affect heat transfer by minimizing emittance of the material and reflecting (inhibiting absorption of) thermal radiation. If a stud cavity in a wall were only partially filled with insulation and an air gap existed between the insulation and interior paneling, the placement of a low emittance reflective surface such as foil on either the insulation or the interior paneling would have the same effect on heat transfer through radiation. Within this stud cavity, the relative placement of the low emittance reflective surface has the same net effect on the net heat flow (Estes et. al., 1988).

The emittance of a material will match its absorptance for a specific wavelength of thermal radiation and at a constant temperature (Desjarlais and Tye, 1990). This is an adequate approximation for a reflective surface in the cold climate construction example described above, as both surfaces on either side of the air gap are at a relatively similar temperature and therefore both emit thermal radiation of approximately the same wavelength. This will not be the case for thermal radiation of different wavelengths. Using the sun shining on light-colored house siding as an example, the siding will absorb only some of the incoming solar radiation, as most of the radiation in the solar spectrum (concentrated in the short-wave infrared) is reflected. However, whatever solar radiation is absorbed will be readily emitted because common building products have a high emittance of long-wavelength infrared thermal radiation. In the siding example, the simplification that "emittance equals absorptance" is not valid since the thermal radiation being absorbed or reflected is different than the thermal radiation being emitted; this concept is illustrated in Figure 4. The solar infrared radiation is in the shorter wavelength region as compared to objects at or near room temperature. This is an important distinction, as products designed to have high solar reflectivity will not necessarily be relevant for reducing heat transfer in cold climate construction.

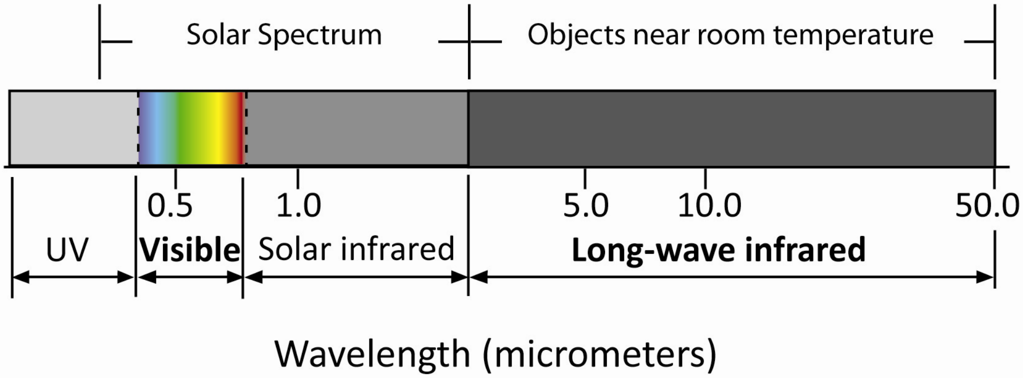

Figure 4. Approximate distributions of thermal radiation for sunlight versus objects at room temperature (adapted from Carmody et al., 2007). Solar infrared radiation has shorter wavelengths when compared to objects at or near room temperature.

Because materials with reflective surfaces have been developed into insulation products, it is important that the nomenclature regarding those products be specific and clear. "Reflective insulation" is defined by the Reflective Insulation Manufacturers Association International (RIMA-I) as "thermal insulation consisting of one or more low-emittance surfaces, bounding one or more enclosed air spaces" (RIMA-I, 2002). In contrast, RIMA-I specifies that a "radiant barrier" is the low-emittance surface that faces an open space. A common example in home construction is the use of radiant barriers in vented attics to reduce radiative heat transfer between the roof sheeting and the underlying ceiling insulation. ASTM International is more specific by requiring that reflective insulations "derive their thermal performance from surfaces with an emittance of 0.1 or less, facing enclosed air spaces" (ASTM C 1224-03).

Reflective insulation needs to face an air space in order to be effective. Radiant barriers like aluminum foil will not create a reflective insulation if both faces are in contact with other building envelope materials. The low emittance of aluminum foil is not effective in reducing heat transfer if sandwiched between two solid objects. In such a configuration, the thermal conductivity of the foil will be the dominant property determining its thermal resistance. A caveat to this statement is on a microscopic scale, where radiative heat transfer occurs across the air pockets within insulation.. Radiative heat transfer in fibrous insulation becomes more significant as the mean temperature of the insulation increases to several hundred degrees (Hass et al., 1997), which can also partially explain the temperature dependence of R-values in rigid foam insulation (Straube, 2007).

Other characteristics of radiative heat transfer help explain the relevance of reflective insulation in cold climate construction. In comparison to conductive or convective heat transfer, which vary linearly based on the temperature difference between two points of reference (such as the interior and exterior air temperatures), the rate of radiative heat transfer is dependent on the difference between two temperatures raised to the fourth power (Modest, 2003).

$$E = \varepsilon\sigma(T_o^4 - T_i^4)$$

E = Radiative heat transfer rate (W/m^2)
ε = Emittance of the object (0 to 1)
σ = Stefan-Boltzmann Constant ($5.67 \times 10^{-8}\ W/m^2K^4$)
T_o = Temperature of the object (in Kelvin)
T_i = Surrounding temperature (in Kelvin)

This means that large temperature differences between objects, such as a wood-burning heating appliance and the surrounding room, will result in much more radiative heat transfer than that between objects near room temperature, such as between a reflective surface within the wall cavity and interior paneling for a wall reflective insulation system. Figure 5 demonstrates an estimate of the temperatures within the wall cavity.

Finally, the efficacy of reflective insulation can be quantified using R-values, both for reflective insulation as an individual product and as installed within a larger system. Federal Trade Commission (FTC, 2009) regulations state the acceptable means for representing the R-value of single-layer reflective insulation (16 C.F.R. §460.5[b]), multiple-layer reflective insulation (16 C.F.R. §460.5[c], 2009), and insulation with a reflective facing (16 C.F.R. §460.5[d], 2009). An example of how R-values can include the contribution of reflective insulation is shown in the technical data for Insulfoam® R-Tech® expanded polystyrene insulation. For a mean temperature of 40ºF, a one inch thick section of R-Tech® has an R-value of 4.17 hr·ft^2·°F/BTU, which increases to 7.17 hr·ft^2·°F/BTU when installed with the foil-covered side facing a dead air space of 0.75 to 3.5 inches in depth (Insulfoam®, 2009). The dead air space adds to the overall R-value of system whether or not a reflective surface is installed (see Table 2, Appendix A). This comparison is roughly consistent with the data presented in ASHRAE (2009) for calculating overall thermal resistances. While the calculation method presented in ASHRAE (2009) is known to exaggerate the actual performance, as discussed below, this approximation accounts for all modes of heat transfer within the hypothetical system.

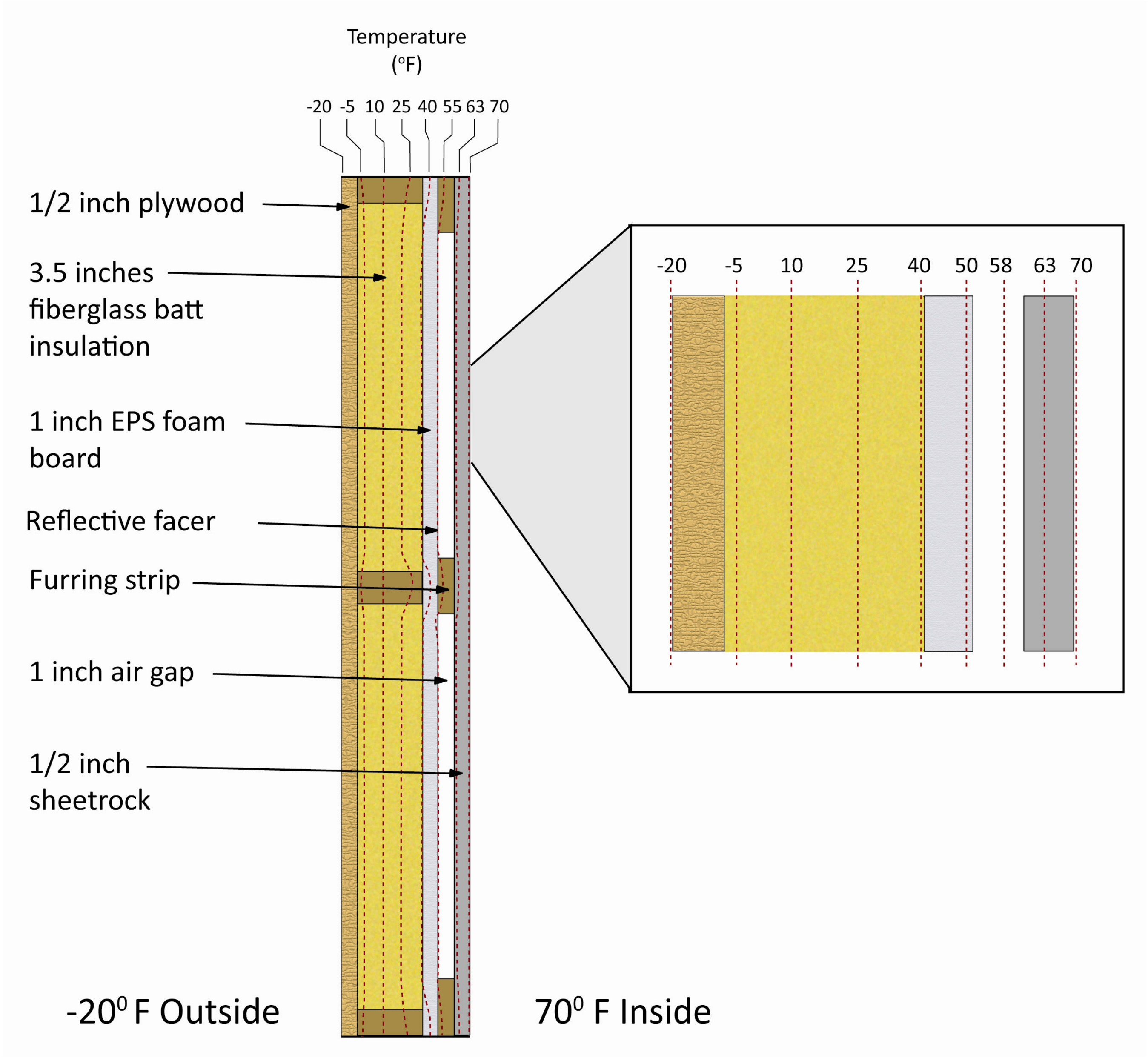

Figure 5. Estimated temperatures within a wall cross-section. The temperature differences across an air gap inside a wall cross section are relatively small, making the radiative heat transfer relatively insignificant (data generated using LBNL Therm 6.3 software).

Review of Literature and Synthesis

The most relevant prior research that examined the significance of reflective insulation under simulated cold climate conditions was conducted by the University of Alaska Fairbanks and the State of Alaska Department of Transportation and Public Facilities in a study using a building envelope test apparatus known as a “guarded hot box” (Estes et al., 1988). In comparing nominal 2x6 frame construction wall sections with 4 inches of insulation and a 1.5 inch air gap in the stud cavities, Estes et al. (1988) found that the wall sections that included reflective insulation, a foil faced cardboard baffle facing an enclosed air space, increased the overall thermal resistance by roughly 10-20% when compared to wall sections with the same air gap but no radiant barrier. Because the wall sections in the Estes et al. (1988) study had relatively low amounts of stud-fill insulation for cold climates, approximately R-15hr·ft^2·°F/BTU, these results are not unexpected.

As summarized in the editorial comments of Estes et al. (1988), the more significant the role of the radiative component of heat flux through a given system, the more effective a reflective insulation will be in reducing heat flux. Therefore, the more insulated a building envelope component, the lesser the potential for a reflective insulation to reduce heat loss because the difference in temperature across an air gap within a well-insulated assembly will be small. Thus, adding a reflective insulation to highly insulated walls and ceilings are expected to show little improvement in thermal resistance. Conversely, components of the building envelope with low overall insulative value, such as windows, can have a relatively high temperature difference between panes, and show a substantial benefit when a reflective surface (i.e., a “low-e” coating) is included. Carmody et al. (2007) estimate that a low-e coating in a multi-pane window will reduce heat loss as much as adding another pane, which could be as much as a 50% reduction in thermal transmittance. This relative benefit is substantial when compared to the gains in thermal resistance reported by Estes et al. (1988) for partially insulated wall assemblies.

In summarizing the significance of radiant barriers in cold climates, Estes et al. (1988) concluded that radiant barriers should be considered if the construction methods chosen for a building provide an air gap in which reflective insulation could be installed, however, it is not worth a reduction in traditional insulation to create an air gap. A caveat to this recommendation is that most reflective surfaces are highly impermeable to water vapor, so they should be considered as the equivalent of adding a strong vapor retarder to a building assembly.

In a prior literature review, Goss and Miller (1989) summarize some fundamental characteristics of reflective insulation that have been well established:

- The placement of a reflective surface on the warm or cool side of the airspace doesn’t change the rate of heat transmission.
- The emittance of surfaces within reflective insulation is important for determining radiative heat transfer, but does not change convective or conductive heat transfer.
- The width of the airspace and the temperature difference across it are significant factors in determining the thermal resistance of a reflective insulation.

An important detail which applies to the last finding is that the width of an enclosed airspace changes the rate of convective heat transfer, but not the rate of radiative heat transfer, which is largely unaffected by the separation distance between the parallel surfaces (Desjarlais and Tye, 1990).

Due to convection within the air gap the direction of heat flow across an air gap strongly influences the thermal resistance of a reflective insulation. For example, the thermal resistance of an air space with downward heat flow can be many times greater than for the same air space in which heat flows upward, as a system with downward heat flow encourages a relatively stable stratification of air due to differences in buoyancy. Heat flow perpendicular to an air gap, such as in walls and windows, is intermediate to these extremes. Figure 6 provides measured values for the R-value of the air space for three different heat flow patterns. To place these R-values in context, they are substantially lower than if the air spaces were filled with common thermal insulations (e.g. fiberglass or cellulose).

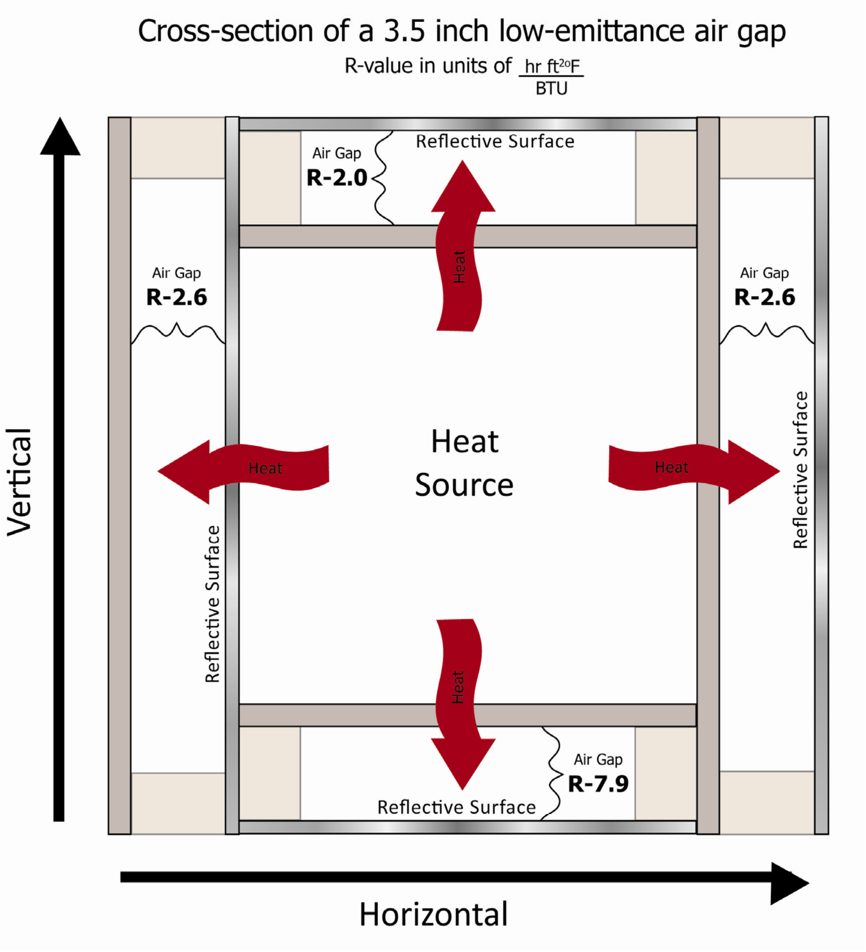

Figure 6. Measured reflective insulation R-values based in the direction of heat flow (adapted from Desjarlais, et al., 1990). The R-value of an air gap with a reflective facer is dependent on orientation, with the highest R-value in the downward heat flow direction.

It should be noted that measured values of thermal resistance are important for accurately characterizing reflective insulation, as theoretical methods of calculation tend to overestimate the thermal resistance of air spaces with one or more low-emittance surface (ASHRAE, 2009; Goss and Miller, 1989; Desjarlais and Tye, 1990). Furthermore, the performance of reflective insulation significantly declines when gaps interrupt the continuity of the low-emittance surface (Goss and Miller, 1989). Because of the differences in measured performance and calculated theoretical performance, multiple studies have established that using well-accepted methods for calculating reflective insulation product performance (e.g. ASHRAE Handbook data), could result in overestimates of thermal performance by approximately 90% to 300% (Goss and Miller, 1989).

Goss and Miller (1989) summarize measurement methods used to quantify the thermal resistance of reflective insulations. They noted that thermal conductivity analyzers cannot completely characterize a reflective insulation thermal resistance because of the differences in edge effects and the aspect ratio of an analyzed sample compared to an actual system. Preferred methods include the use of a calibrated or guarded hot box (Goss and Miller, 1989). Desjarlais and Tye (1990) state that the best method of measuring insulation performance is to install the reflective insulation within the structural framework under consideration, measure the system R-value by means of a guarded or calibrated hot box method, then subtract the contribution of the structural framing by calculation methods such as those developed by ASHRAE. However, such efforts are further complicated because the direction of heat flow strongly influences the performance of reflective insulation, and it is often difficult to achieve reproducible results (Desjarlais and Tye, 1990).

Another consideration in the performance of reflective insulation is the ability of reflective surfaces to retain their initial properties. While the initial surface oxidation of aluminum foils is rapid and already accounted for in reported emittance values (Cook et al., 1989), the accumulation of dust and other contaminants after installation can degrade performance by increasing the emittance of the reflective surface. Cook et al. (1989) conducted laboratory experiments to simulate the accumulation of dust on horizontal foil faces to determine the effect on reflective insulation performance. They found that the emittance of foil faces increases significantly as dust accumulates from an initial value of under 0.05 to an apparent asymptote ranging from 0.67 to 0.85, depending on the type of dust.

Reflective Insulation Testing

Test Objectives

As summarized above, the fundamentals of heat transfer are well understood and the expected contribution of reflective insulation to the building envelope in cold climate construction is bounded by prior research. In this context, CCHRC evaluated the thermal resistance of P2000in various configurations to determine whether the product exhibited qualities significantly different than other similar expanded polystyrene (EPS) products. To help with the interpretation of the data, CCHRC evaluated another EPS product (Insulfoam® R-Tech®) using the same evaluation techniques. CCHRC's evaluation of both EPS products included a particular focus on the significance of the reflective facer material. The tests conducted by CCHRC were designed to evaluate the thermal resistance of the EPS foams and the reflective surfaces by testing the insulations in many different configurations using ASTM Test Method C518.

Product Background

P2000 is a product of Proactive Technology based in Newport, NY. It is an EPS foam insulation that is covered with a metalized plastic facer (see Figure 7). The metalized facer can cover one or both sides of the product, CCHRC's samples all had the facers on both sides. P2000 is advertised as an insulation that reduces all three forms of heat transfer. While the use of rigid foam insulation in a structure can contribute to the restriction of airflow through the building envelope, CCHRC's evaluation was restricted to the product's thermal performance in the absence of air flow both with and without an accompanying air gap. Therefore, CCHRC did not directly address the ability of P2000 to reduce energy losses from a structure due to air leakage.

R-Tech® was chosen as the EPS comparison product because of its common use and availability in Alaska. R-Tech® is a product of Insulfoam®, a Carlisle Company. The type I R-Tech® used in this test was produced at the Insulfoam® plant in Anchorage, Alaska. The R-Tech® EPS has a polymeric laminate facer on both sides. One side is metalized and the other is white.

Figure 7. EPS samples with reflective facers (top) and with facing removed (lower) over plywood.

Method Overview

CCHRC used a FOX-314 heat flux meter to perform tests of thermal conductivity on the products using the ASTM C 518-04 standard test method. The heat flux meter accommodates product samples up to 12 inches in width and length, and thicknesses up to 4 inches. The sample is placed between two horizontal plates, as shown in

Figure 8, where the meter tests samples for thermal conductivity at a constant temperature difference between the upper and lower plates. The meter records heat added or removed to keep the plates at the specified temperatures. This information is then used to determine the thermal conductivity of the sample. In all of the tests, the direction of heat flow was upward, as this configuration that allowed for the most reproducible results (results could vary greatly in other orientations). The FOX-314 also measures the sample thickness, which can be used to normalize the sample thermal conductivity to a per-unit-thickness basis. Referred to as "thermal conductance," this is the inverse of thermal resistance, commonly referred to as R-value. Each sample and configuration was tested three times, with a few exceptions, to document the precision of the results.

After characterizing the two EPS insulations in varying thicknesses and with modifications to the facer material, the ASTM C 518-04 standard test method was modified to allow for a one-inch air gap below the reflective facer material. The modification, depicted in Figure 9, was made in order to study the thermal resistance added to the sample by creating a reflective insulation component. The support structure for the air gap was a hollowed piece of EPS, cut in such a way that the exposed center air space, not the edges of the EPS spacer, was situated over the heat exchange elements of the heat flux meter plates. The air space was approximately 8 by 8 inches in area.

All of the tests were performed at an average temperature of 75°F, with plate temperatures of 55°F and 95°F, as per the Federal Trade Commission regulations on labeling home insulation (16 C.F.R.§ 460.5). While this temperature is not typical in Alaska, its selection connects our test results to industry standards.

Figure 8. FOX-314 heat flux meter with a one-inch thick EPS sample between the plates. The heat flux meter tests the material for its thermal conductivity by maintaining a temperature difference across the sample and monitoring the energy required to maintain that temperature difference.

While use of the thermal conductivity analyzer was convenient and provided reproducible results, prior research has shown that the use of hot box instrumentation is preferred over the use of thermal conductivity analyzers, as noted previously in the literature review, e.g., Goss and Miller (1989). This is partly due to the disparity in scale between conductivity analyzer samples and actual construction. Furthermore, the thermal resistances of air spaces are strongly dependent on the direction of heat flow, as summarized above. Therefore results for heat flow in one direction will not necessarily be similar for applications where the direction of heat flow is different. Nevertheless, for the purpose of comparing P2000 to another EPS product under standard and modified test method conditions, a thermal conductivity analyzer provides sufficient information to draw conclusions on its performance as an insulation product. Detailed construction-scale testing is helpful for evaluating assembly designs, but is not necessary for comparing basic material properties.

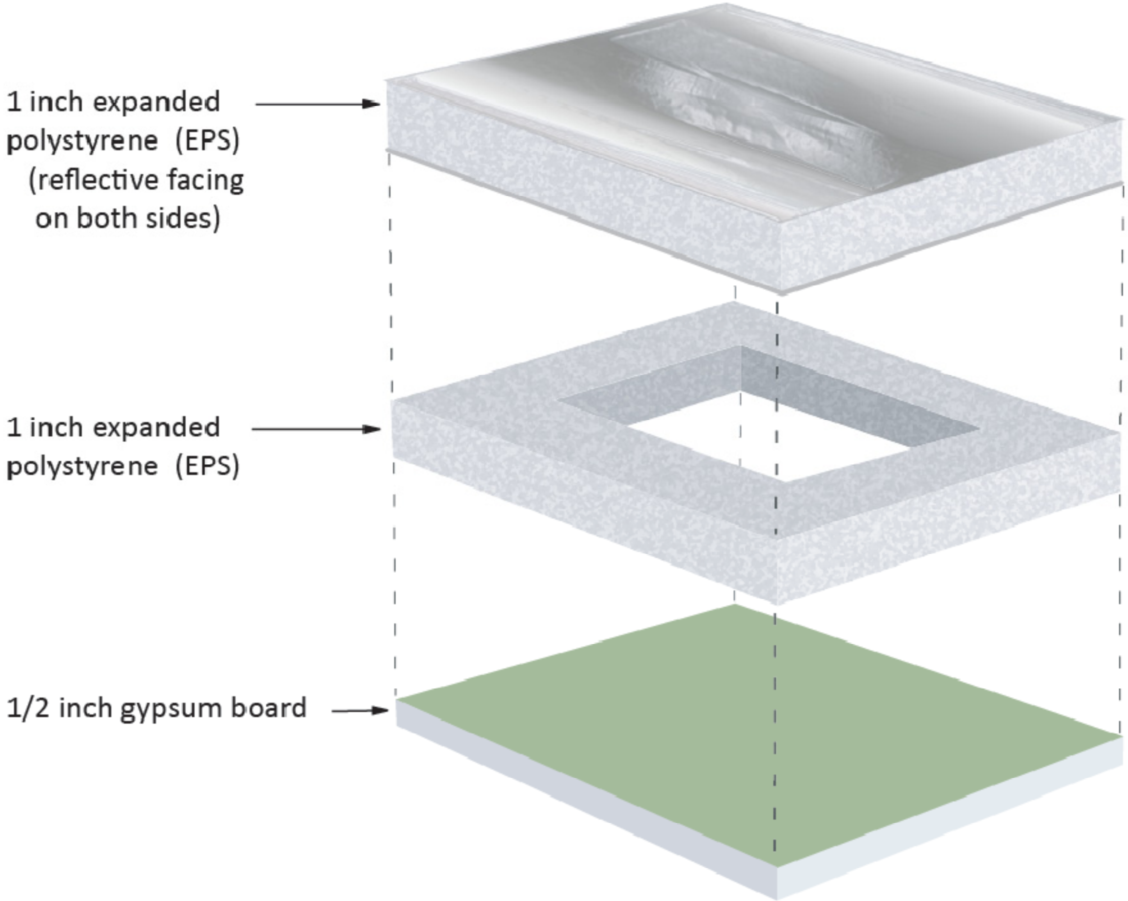

Figure 9. Expanded view of the experimental set up used in testing reflective insulation systems. The 12 by 12 inch samples were designed to fit precisely into the FOX 314. The air gap was 1 inch deep and 8 by 8 inches in area, which placed the air gap over the measuring element of the FOX 314.

Results and Discussion

The average R-value per inch of P2000 was 4.02 while R-Tech® was 3.87hr·ft^2·°F/BTU, both of which compared well with the manufacturer's stated values of 4.17 and 3.85hr·ft^2·°F/BTU respectively. Tests were also conducted in order to compare the EPS products with reflective facers removed or altered, which produced some noteworthy results. Once the facer materials were removed from the EPS samples, the R-value per inch dropped slightly to 3.72 hr·ft^2·°F/BTU for P2000 and 3.79hr·ft^2·°F/BTU for R-Tech®. The results are summarized in Table 2 and complete results and units for the experiments are presented in Appendix A.

Table 2. R-value per Inch (hr·ft^2·°F/BTU)Comparisons for EPS Products

	Manufacturer Data	Test Results	Test Results without Facers	Change in Thermal Resistance
P2000	4.17	4.02	3.72	7.5%
R-Tech®	3.85	3.87	3.79	2.1%

Additional tests were performed to help determine whether this reduction in thermal resistance was primarily due to an increase in radiative or convective heat transfer. In theory, the facer material should have no effect on the thermal conductivity of the insulation samples. Because the facer material acts as both a reflective surface and has a low air permeance, other materials were substituted for the facer material that also had low air permeance, but with varying emittances. The low emittance material, a fresh sheet of aluminum foil, was placed between two "skinned" samples of P2000. This increased the R-value per unit thickness from 3.72 hr·ft^2·°F/BTU to 3.95hr·ft^2·°F/BTU. This value is slightly less than the P2000 sample with intact reflective facers, and may be attributed to the fact that the P2000 samples had facers on both sides of the EPS sample. In contrast, the high emittance material, a six-mil sheet of polyethylene, was placed between two "skinned" samples of P2000. This had a lesser effect, increasing the R-value per unit thickness from 3.72 hr·ft^2·°F/BTU to 3.76hr·ft^2·°F/BTU. Because both the aluminum foil and polyethylene are highly air impermeable, although only the foil surface has a low emittance, these results indicate that the reflective facers on the EPS products create a slight increase in the overall R-value primarily by reducing radiative heat transfer.

Table 3. R-values per Inch (hr·ft^2·°F/BTU) for altered P2000 samples

	Without Facer	Foil Added	Polyethylene Added	Painted -One Side	Painted - Both Sides
P2000	3.72	3.95	3.76	4.04	3.97

A separate test to determine the R-value contribution of the facer involved painting both sides of P2000 samples with latex paint to alter the facer emittance from approximately 0.3 to 0.9, the emittance of most construction materials. Painting one facer actually lead to a slight increase in thermal resistance per unit thickness (4.04hr·ft^2·°F/BTU), which may be attributable to variation in EPS samples, as the difference was small but beyond the margin of error. After painting the other side of the EPS sample the thermal resistance per unit thickness declined slightly to 3.97hr·ft^2·°F/BTU. The lack of a significant decline in the P2000 thermal resistance might be explained by the fact that both sides of the reflective facers have similar properties, whereas only the exposed faces were painted. Because radiative heat transfer would be unchanged by the paint in the air cavities immediately adjacent to the reflective facers, i.e., insulation pore spaces, for samples in the heat flow meter, the painted exterior could only potentially affect incidental air spaces between the heat flux plates and the EPS sample created by imperfections in the insulation surface. A complicating factor for these experiments was the behavior of the latex paint applied to the EPS facer sample, which coated the surface in a highly uneven manner.

Greater potential exists for reflective surfaces to increase thermal resistance when the reflective surfaces face a continuous air gap. Because it is likely in residential construction that the reflective surface would face the backside of an interior paneling, a sample stack was prepared to separate the EPS reflective surface from 0.5-inch gypsum wall board. Our test results show that a stack with a 1.0-inch air gap between the reflective-faced P2000 and gypsum board exhibited an insulative value 1.69 hr·ft^2·°F/BTU higher than a similar stack with no air gap. Data tables in Appendix A provide a summary of the R-values of the products with and without the R-value of the air gap, along with the predicted R-value of the air gap from the most analogous experimental conditions from ASHRAE (2009). Our measured R-values are consistently less than the ASHRAE values, which is possibly due to the fact that our tests did not match the experimental conditions from ASHRAE (2009), but instead to the Federal Trade Commission requirements for temperature conditions. Tests were also conducted in an attempt to quantify the contribution of the reflective facer when an air gap is present. The sample stack was tested with the air gap and sheetrock, but with the reflective facers painted. The entire stack with P2000 and the facers had an R-value of 6.11 hr·ft^2·°F/BTU and with the faces painted the value dropped to 5.35hr·ft^2·°F/BTU. The difference in the measured R-values of the two test stacks estimates the contribution of the reflective surface.

Conclusions

P2000 is an EPS insulation with reflective facers that has a thermal resistance within general expectations for this type of foam insulation. Samples analyzed at CCHRC using ASTM Standard Test Method C 518-04 provided an R-value per inch of 4.02hr·ft^2·°F/BTU. This compares well to the manufacturer's stated R-value per inch of 4.17hr·ft^2·°F/BTU. Introducing a one-inch air gap between gypsum board and one inch of P2000 with the reflective surface facing the air gap increased the R-value by 1.69 hr·ft^2·°F/BTU to 5.71hr·ft^2·°F/BTU. This increase in thermal resistance introduced by the reflective insulation component is slightly less than predicted by common reference sources. R-Tech® EPS insulation was evaluated using the same methods.. The sample of R-Tech® analyzed at CCHRC was found to have an R-value per inch of 3.87hr·ft^2·°F/BTU, very close to the manufacturer's stated R-value of 3.85hr·ft^2·°F/BTU. When an air gap was introduced, as described above, the R-value increased by 1.64 to 5.51hr·ft^2·°F/BTU. In terms of the overall R-value of a wall assembly, this is a relatively insignificant contribution, especially in cold climates like Alaska where the minimum prescriptive R-values for wall construction range from R- 20 to R-35 (AHFC, 2010). Based on samples analyzed by CCHRC, there was no evidence that P2000 would deliver substantially greater thermal performance than expected for typical EPS insulation.

In cold climate construction, when considering the use of reflective insulation to reduce heat loss, the potential is very modest. In a tightly controlled laboratory setting, where the temperature difference is 40°F and the heat flow direction is up, the reflective facer adds a small increase to the R-value. When there is an air gap present, the reflective facer has a greater effect on the R-value of the structure by creating a “reflective insulation” as defined by RIMA-I (2002). The actual R-value of an installed reflective insulation is hard to determine reliably, and common calculation methods grossly overestimate R-values. Additionally, maintaining thermal performance means ensuring the reflective surfaces are protected from penetration or surface contamination. Using reflective insulation in cold climate construction is also complicated by the vapor impermeability of the reflective surfaces, which adds potential moisture control problems to a structure if not placed properly. Simply put, the contribution of reflective insulation to the building envelope in cold climate construction is minimal, especially when viewed in the context of the total R-value of the building envelope.

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Appendix A – Data Tables

Results for Experimental Configurations, No Air Gap Included

Sample Description	Sample Depth (in)	k (BTU in/hr ft^{2}F)	R-value (hr ft^{2}F/BTU)	R-value/inch	Average R-value	Standard Deviation
1.0 inch P2000	0.998	0.2484	4.02	4.03	4.02	0.005
	1.001	0.2488	4.023	4.019		
3.0 inches P2000	2.996	0.2494	12.01	4.010	4.015	0.006
	2.993	0.2491	12.01	4.014		
	2.992	0.2487	12.03	4.021		
1.0 inch P2000 with foil facer removed	0.990	0.2687	3.68	3.72	3.72	0.003
	0.990	0.2691	3.68	3.72		
	0.988	0.2690	3.67	3.72		
2.0 inch P2000 with foil facer removed	1.984	0.2681	7.400	3.730	3.723	0.006
	1.998	0.2690	7.428	3.717		
	1.986	0.2687	7.391	3.722		
3.0 inch P2000 with foil facer removed	2.976	0.2750	10.82	3.636	3.647	0.009
	2.973	0.2740	10.85	3.650		
	2.972	0.2737	10.86	3.654		
1.0 inch R-Tech®	1.007	0.2574	3.912	3.885	3.87	0.009
	1.007	0.2582	3.900	3.873		
	0.995	0.2586	3.85	3.87		
1.0 inch R-Tech® with foil facer removed	1.003	0.2642	3.796	3.785	3.79	0.009
	0.999	0.2632	3.79	3.80		
	1.004	0.2643	3.799	3.784		
2.0 inches P2000 with one layer aluminum foil between	1.987	0.2529	7.857	3.954	3.954	0.002
	1.986	0.2531	7.847	3.951		
	1.986	0.2528	7.856	3.956		
2.0 inches P2000 with one layer polyethylene between	1.991	0.2660	7.485	3.759	3.761	0.002
	1.991	0.2658	7.491	3.762		
	1.991	0.2658	7.491	3.762		
1.0 inch P2000 with one coat of paint	0.992	0.2478	4.00	4.04	4.04	0.002
	0.993	0.2477	4.01	4.04		
	0.993	0.2479	4.01	4.03		
1.0 inch P2000 with two coats of paint	0.998	0.2525	3.95	3.96	3.97	0.007
	0.999	0.2519	3.97	3.97		
	0.998	0.2517	3.96	3.97		

Results for Experimental Configurations with an Air Gap

Sample Cross Section	Sample Depth (in)	k (BTU in/hr ft^2F)	R-value (hr ft^2F/BTU)	Average	Air space R-value	Average	Predicted Air Space R-Value*
1.0 inch P2000 and 0.5 inch gypsum	1.497	0.3384	4.424	4.42	--	--	--
1.0 inch P2000, 1.0 inch air gap, 0.5 inch gypsum	2.484	0.3942	6.301	6.11	1.878	1.69	2.22[1]
	2.478	0.4162	5.954		1.530		
	2.476	0.4068	6.087		1.663		
1.0 inch P2000 with foil facer removed, 1.0 inch air gap, 0.5 inch gypsum	2.471	0.5271	4.688	4.67	0.564	0.549	0.75[2]
	2.466	0.5314	4.641		0.517		
	2.465	0.5257	4.689		0.565		
1.0 inch P2000 with one coat of paint, one inch air gap, 0.5 inch gypsum	2.468	0.4659	5.297	5.34	0.854	0.898	1.04 - 1.61[3]
	2.478	0.4552	5.444		1.000		
	2.474	0.4682	5.284		0.840		
1.0 inch P2000 with two coats of paint, one inch air gap, 0.5 inch gypsum	2.477	0.4639	5.340	5.35	0.966	0.976	1.04 - 1.61[3]
	2.481	0.4602	5.391		1.017		
	2.486	0.4673	5.320		0.946		
2.0 inches P2000, one inch air gap, 0.5 inch gypsum	3.467	0.3527	9.830	9.93	1.386	1.485	2.22[1]
	3.463	0.3473	9.971		1.527		
	3.463	0.3468	9.986		1.542		
2.0 inches P2000 with foil facer removed, one inch air gap, 0.5 inch gypsum	3.454	0.4146	8.331	8.25	0.487	0.404	0.75[2]
	3.456	0.4162	8.304		0.460		
	3.456	0.4262	8.109		0.265		
1.0 inch R-Tech®, 1.0 inch air gap, 0.5 inch gypsum	2.482	0.4164	5.961	5.92	1.687	1.643	2.22[1]
	2.481	0.4187	5.925		1.652		
	2.473	0.4217	5.864		1.591		

Table 2.

* ASHRAE (2009)

[1] Mean temperature: 90 deg F, temperature difference: 10 deg F, effective emittance: 0.05, air space thickness: 0.75 inches

[2] Mean temperature: 90 deg F, temperature difference: 10 deg F, effective emittance: 0.82, air space thickness: 0.75 inches

[3] Mean temperature: 90 deg F, temperature difference: 10 deg F, effective emittance: between 0.2 and 0.5, air space thickness: 0.75 inches