Evaluating Window Insulation

Curtains, Blinds, Shutters & More

Cold Climate Housing Research Center

CCHRC

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Introduction

Windows are a very expensive component of the building envelope to replace. Replacing a single window can cost several hundred to more than a thousand dollars. Therefore people in cold climates often resort to cheaper methods, such as shutters or curtains, to reduce heat loss. Others may already have high performance windows, but want to reduce heat loss even further by placing movable insulation over their windows during the cold winter nights.

To help guide these decisions, CCHRC conducted a study of common window insulation methods and compared them in terms of effectiveness, affordability, ease of installation, durability, and functionality. CCHRC studied a variety of methods and windows in volunteers' homes to understand how the methods work in real-life situations. CCHRC also modeled the retrofit window treatments to help explain more generally how they can help homeowners.

Before ranking the window insulation methods or discussing the case studies, some simple background information will help to explain the terminology and relevant variables. After the findings, a general discussion follows that helps explain the significance of window insulation in reducing heat loss.

Condensation

Condensation refers to the water droplets that form on a cold surface when it is exposed to warm, humid air. Water vapor in the air turns into liquid when it touches a cold surface that is below the dew point, the temperature at which moisture condenses. The dew point is based on the temperature of the air and the amount of moisture in the air (the humidity). If the temperature in your house is 70°F and the humidity is 40% the dew point will be 44°F. If the surface of your window is 44°F then water droplets will form on the surface; as the temperature drops, more surfaces on the window will reach the dew point, and more water vapor will condense. The water can freeze when the temperature drops below freezing on the surface (Figure 1). If a window becomes frozen shut, it can become a safety hazard if the window provided a necessary emergency exit.

Figure 1. Water and ice on a window due to condensation. When the window warms to the point where this ice can melt, water will run down to the window sill, creating the potential for mold and rot.

Water that collects on the window surface has the potential to cause rot and mold on the window frame and sill. Homeowners should be careful about how they try to insulate their existing windows, because some treatments, especially those that go on the inside of the window, can lower the temperature of the window's surface below the dew point (Figure 2). Some treatments will lower the surface temperature of the window but they also seal the warm, humid air away from the cold surface of the window.

A well-sealed plastic layer can move the dew point to the inside of the glass, but the moisture in the air does not condense on the glass because it does not move through the plastic. In contrast, insulating blinds and curtains allow moisture to reach the cold window glass, as the air moves by the edges or as the moisture migrates through the fabric.

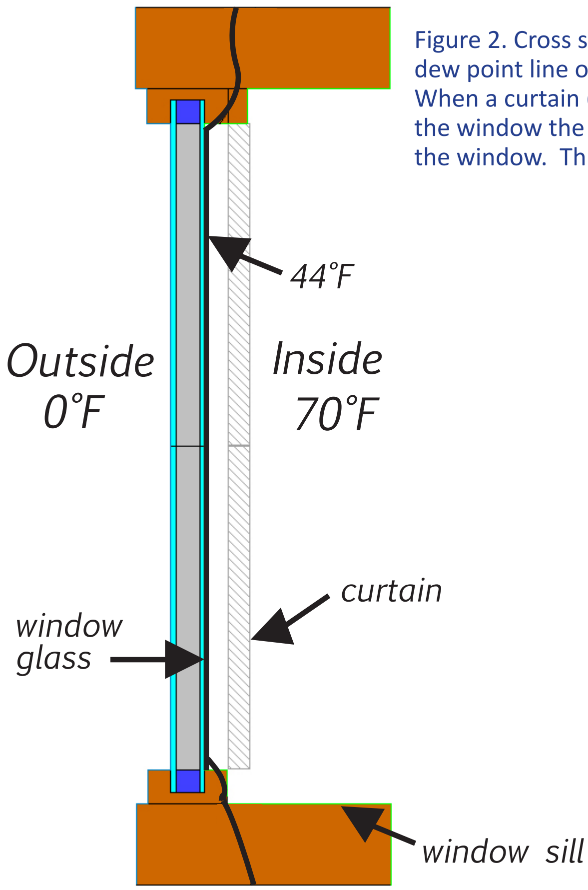
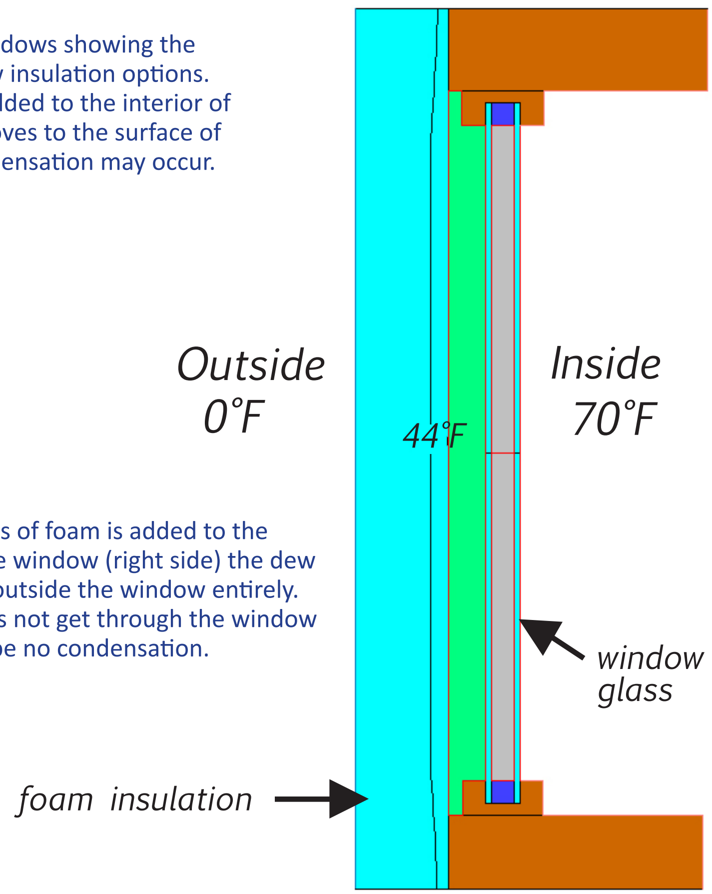


Figure 2. Cross sections of windows showing the dew point line on two window insulation options. When a curtain (left side) is added to the interior of the window the dew point moves to the surface of the window. This means condensation may occur.



When 2 inches of foam is added to the exterior of the window (right side) the dew point moves outside the window entirely. Moisture does not get through the window so there will be no condensation.

U-values and R-values: Measuring Thermal Performance

There are a few different systems that describe how well windows, walls, ceilings, and floors resist heat loss. Most familiar is the term "R-value," which is commonly seen on insulation products like sheets of foam or rolls of fiberglass batts. R-value describes the ability of that insulation product in resisting the movement of heat. The higher the R-value, the more effective the insulation. It's common to hear about an R-19[1] fiberglass batt or an R-10 sheet of polystyrene foam. If you put the R-19 batt over the R-10 foam, it's safe to say you have an R-29 insulation combination.

When it comes to windows, everything literally gets turned upside down. The correct term for windows is "U-value," which is the ability of the entire window (including glass and framing) to conduct heat.

$$U_{value} = \frac{1}{R_{value}}$$

[1] Throughout this report, the units for R-value are $ft^2hr°F/BTU$ and U-value units are the inverse, $BTU/ft^2hr°F$.

The lower the U-value, the more effective the window at insulating, so it sounds just like R-value turned upside down. Why the complication? Windows have various parts that have different R-values (for example, the frame and the glass) that sit side by side in parallel instead of in series, so they can't be simply added together like the insulation example. Therefore U-values have become the accepted way of describing the thermal performance when customers are ready to buy a window. The term "center-of-glass R-value" is used occasionally, which is a valuable part of understanding the performance of a window. However, it's only a part of the total, and the glass is often the best performing part of the window. In other words, center-of-glass R-value may be overly optimistic for the whole window performance, so consumers need to ask for the NFRC-certified[2] U-value.

As long as the parts are added together correctly, a window with a U-value of 0.5 is the same as a window with an overall R-value of 2.0. Or a window with a U-value of 0.25 is the same as a window with an overall R-value of 4.0. Looking for the certified U-value helps provide assurance that the value characterizes the whole window performance.

Summary of Findings

There are simple, cost-effective ways to reduce the heat loss from windows. There are also more complicated and highly effective options that cost more and place higher demands on the homeowner to operate. Each option has its pros and cons. The best choice for homeowners should be based on what they are willing to do to maintain their window and their window treatment. The chart (Figure 3) summarizes the relative strengths and weaknesses of each window insulation method to help guide homeowners in these decisions, based on CCHRC's case studies.

The different window insulation methods were evaluated in comparison to one another, based on the following metrics:

- **Condensation Resistance**–Exterior window treatments helped reduce condensation by keeping the window warmer, whereas some interior treatments increased condensation problems by making the surface of the window colder while not blocking sources of interior moisture.
- **Insulation Value**–All the window treatments increased the insulation value of the window, but some had a much greater effect than others. The case studies only looked at the center-of-glass R-value, because evaluating the overall window U-value was not practical (the methodology for determining the R-value is available in the Appendix). In order to do a better analysis of the thermal performance, U-value improvements were estimated using THERM 6.3, a thermal modeling program.
- **Affordability–**Affordability is an estimate of the relative cost for materials and installation for a window insulation method similar to those shown in the case studies. Some insulation methods could have a wide range of costs depending on the window size and complexity of moving parts.
- **Ease of Installation**–The ease of installation was ranked based on a qualitative estimate of which insulation seemed easier to install (we were not able to perform the installation on all of the options) and whether the option is permanent or has to be installed every year.
- **Durability**–The durability of each treatment was also ranked based on qualitative observations of which treatment seemed most likely to hold up longer to common wear and tear.
- **Functionality**–The functionality of the insulation option was ranked based on how easy it was for researchers to operate the window insulation and how the insulation affected window transparency and operability.

[2] NFRC is the National Fenestration Rating Council. They certify window performance and apply a label, http://www.nfrc.org/label.aspx.

Case Study Summary

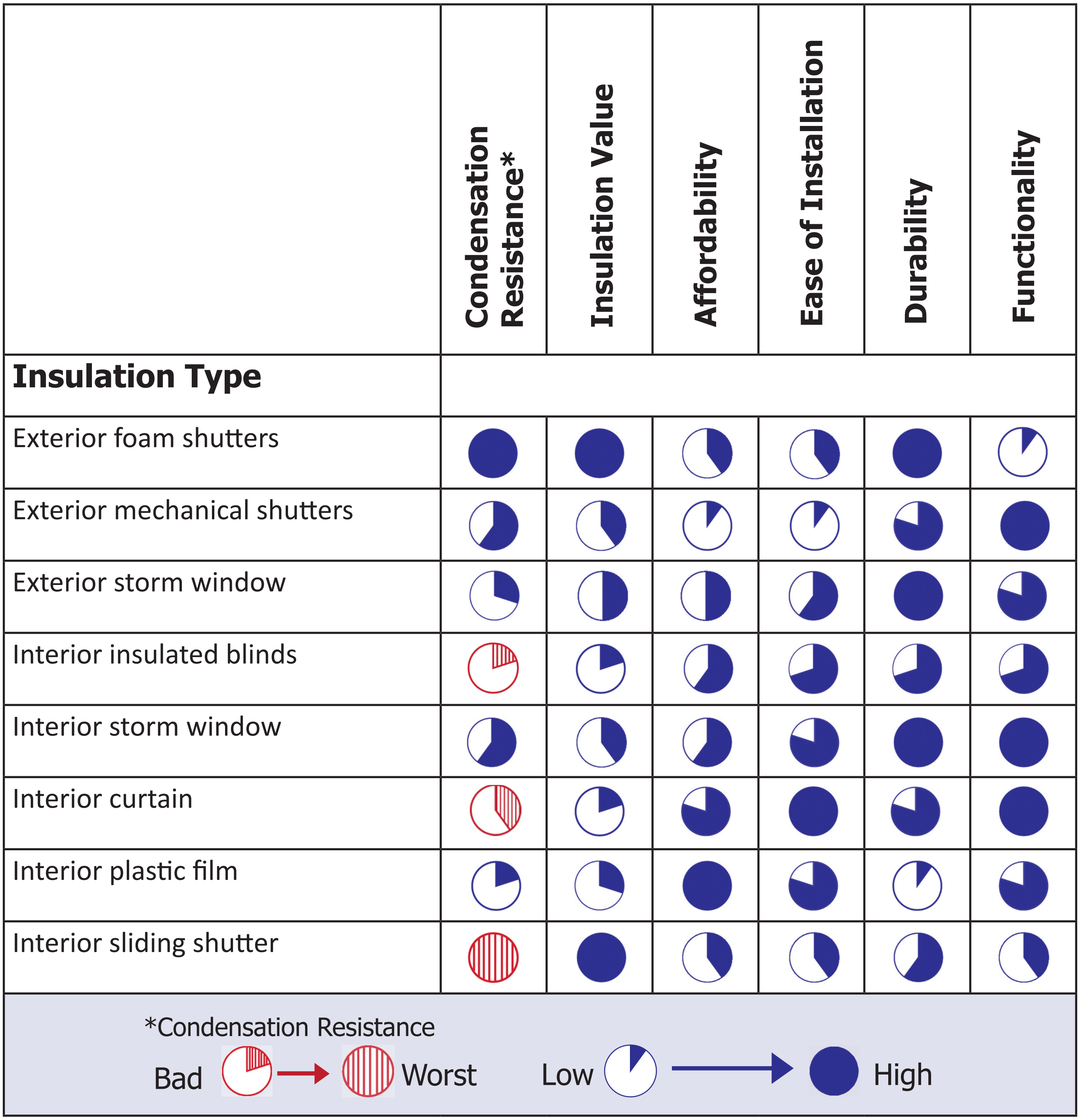


Figure 3. The various window insulations are ranked here based on six testing criteria. There is no overall best to worst ranking for the window insulations, because it is difficult to determine which testing criterion is most important. For example, the case study with the best insulation value had the worst condensation problems. Additionally, these rankings are based on case studies; each homeowner will have a different implementation of window insulation which will change some of the rankings. The best way to use this chart is to evaluate which parameters are most important to you and choose the best option based on your preferences.

Case Studies

The following 8 case studies were performed in Fairbanks during the winters of 2010 and 2011. The case studies are specific to each house and window studied. Volunteers for the study were chosen based on what kind of movable insulation they were using; the interior home conditions and the types of windows were all very different.

In an effort to standardize the thermal results across every treatment, CCHRC modeled each moveable insulation using THERM 6.3 to compare the thermal improvement to a common double pane reference window. In some of the case studies there is a significant difference between the recorded improvement value and the modeled improvement value. There are a few reasons for this: the recorded values are for the center-of-glass R-value and the modeled values are for the whole window U-value; and higher-quality windows do not benefit as much from insulation as lower-quality windows. A full description of the study methodology is provided in Appendix A.

The case studies are divided into interior and exterior insulation options. Each option is different and in these case studies it is particular to the window and house we studied. In general, interior insulation options can cause or worsen condensation problems, whereas exterior insulation options tend to reduce condensation problems. Homeowners should try to avoid condensation as much as possible and consider the potential of window condensation when choosing a type of window insulation.

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Exterior Shutters

Exterior Shutters on Double-Pane Windows

Exterior shutters involve placing a single or multiple solid panels of insulation over the window's exterior. Exterior shutters operate by a variety of methods: they can slide on tracks, fold to the side, or swing from the top.

The case study exterior shutters are part of the original home and were installed when the house was built. The shutters are made of a foam insulation core surrounded by plywood on the exterior and set in a track so they roll in front of the window. The shutter is not airtight, but because the homeowner tends to close them for extended periods of time, he can fill the gaps around the edges with small pieces of insulation to improve the seal. When insulating from the exterior, it is not necessary for the movable insulation to be airtight in order to reduce heat loss and improve the condensation resistance of the window.

The shutters provide excellent insulation value and condensation resistance. The center of glass R-value jumped from 1.5 to 7.7 when the blinds were deployed, a thermal improvement of 410%.

Exterior Shutters	
Condensation resistance	very beneficial
Insulation improvement	410%
Affordability	moderate
Ease of installation	moderate
Durability	tough
Functionality	challenging

Case study of an exterior shutter system

The cost of exterior shutters is very dependent on method of construction. The pictured examples show shutters that were custom built as part of the original homes. Placing a sheet of rigid foam as a friction fit over the window exterior can offer similar thermal and condensation improvements, although it will not be as aesthetically pleasing or durable and may fall out easily if not secured well. The biggest drawback of exterior shutters is the effective loss of the window providing a connection to the outside, unless you frequently go outside to open and close the window shutters.

Modeled U-value improvement **532%**

Exterior Rolling Shutters

Exterior Shutters on Triple-Pane Windows

Exterior rolling shutters are a unique shuttering system that avoids the hassle of moving and storing large, solid insulating panels. The shutters instead have many slats that can be rolled together like a blind when stored, and then connect to form a single unit when unrolled. The primary disadvantage of this approach is that the slats need to be thinner than other exterior shutter systems to allow for practical application, which means a lower thermal performance.

This case study evaluated a commercially available exterior rolling shutter system (Tucson Rolling Shutters®) that can be installed on the exterior of a house during or after construction. The shutters are easily operated from the inside using a remote control. The shutters are guided by tracks with weatherstripping and seated in a bottom channel that has drains to minimize water accumulation. While not airtight, this shutter system greatly reduces air movement around the outside of the window.

Exterior Rolling Shutters	
Condensation resistance	more beneficial
Insulation improvement	30%
Affordability	expensive
Ease of installation	professional level
Durability	sturdy
Functionality	excellent

Modeled U-value improvement 51%

The case study's exterior rolling shutter system

The shutters increased the center of glass R-value for triple-pane windows from 5.3 to 6.9, a thermal improvement of 30%. On a less efficient window the thermal improvement would be even better.

These shutters are more expensive and require professional installation and knowledge of electrical wiring. In one year of testing at CCHRC, the motors operated without difficulty; although on days when temperatures were near freezing, the shutters occasionally froze in place due to ice formation in the bottom channel.

Exterior Storm Window

Exterior Storm Window on a Double-Pane Window

This window was a 1970s-era double-pane window with vertical opening sashes. An exterior storm window is added in the winter. The storm window has two glass sashes and fits into a track that is outside the main window. The homeowners remove the storm window in the summer and replace it with an insect screen.

CCHRC monitored each sash of the window separately to get a better understanding of their individual thermal performance. The lower pane had a center-of-glass R-value of 1.4 without the storm window and 3 with the storm window. The upper pane had a center of glass R-value of 2 without the storm window and a value of 2.7 with the storm. The average insulation improvement was 110%.

Because this window is in the bathroom, it deals with extreme humidity for short periods of time. The storm window increased the condensation resistance of the window, but this window will still likely develop condensation when the shower is running. This storm window can be moved twice a year, or left in place permanently. It is very durable and relatively easy to install. Installation for a larger window might be more difficult. Care should be taken when using storm windows in bedrooms; they should be a type that opens to allow for emergency egress.

Exterior storm window from the case study home

Storm windows are a very good option to increase the insulation value of your glass without causing condensation problems or substantially reducing visibility. More modern versions are available that have “low-e” coatings that improve insulating value, and also improves their ability to reduce condensation problems.

Exterior Storm Window	
Condensation resistance	more beneficial
Insulation improvement	110%
Affordability	moderate
Ease of installation	moderate
Durability	tough
Functionality	efficient

Modeled U-value improvement 121%

Interior Insulated Blinds

Interior Insulated Blinds on a Double-Pane Window

Insulated blinds from case study home with sensors in place

"Double cell cellar" shades were installed by the homeowner on a very large double-pane picture window. The shades are a light-colored fabric with dual "cells" for air entrapment. They are easy to operate from the inside of the house and are similar to typical house blinds.

The window center of glass R-value is about 3.5, and the shade increases the center of glass R-value to 5.6. That is an increase of 60% in the center-of-glass R-value. Window shades move with the air currents in the room and do not form a seal to prevent air movement between the shades and the window glass. The shades also do not improve the air tightness of the window; air can leak past the window frame or past the weatherstripping.

Interior Insulated Blinds	
Condensation resistance	problematic
Insulation improvement	60%
Affordability	moderate
Ease of installation	easy
Durability	sturdy
Functionality	efficient

Modeled
U-value
improvement
15%

Because they do not form an area of still air around the window, the insulating blinds allow for the introduction of water vapor between the blinds and the window. Therefore closing the blind increases the condensation potential of the window. At colder temperatures, condensation and eventually ice forms along the bottom of the window. If the blinds sealed out water vapor, condensation would be less of a factor, but that would probably increase the price and the installation complexity.

Insulated blind system at Cold Climate Housing Research Center

Interior Storm Window

Interior Storm Window on a Single-Pane Window

Single pane windows are becoming rare in Alaska, especially as the cost of heating rises. However, this case study is an example of a single pane picture window with a storm window that had been in place since the owners moved in. In effect the storm window has become a second pane for this window. The storm window increased the center of glass R-value of the window by 72%. This single pane window had a center of glass R-value that averaged 0.4, and with the storm window in place it averaged 0.7.

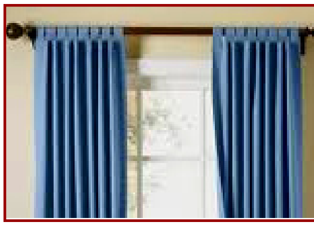
With the storm window removed, the window iced over immediately when the outside temperature was -20 °F and didn't clear up for some time. This was partly because the interior storm window had been keeping the glass of the single pane cooler than the dew point, but it was also preventing moist air from reaching the exterior window. When the storm window was put back into place the exterior glass iced up again, because a thin layer of warm moist air between the two windows cooled again. A week after the storm window had been put back into place, there was still some ice on the single pane surface, but it was decreasing every day.

Case study window with interior storm window attached. Note the layer of frozen condensation at the bottom.

Interior Storm Windows	
Condensation resistance	more beneficial
Insulation improvement	72%
Affordability	moderate
Ease of installation	easy
Durability	tough
Functionality	excellent

Modeled U-value improvement 55%

The storm window is highly durable and simple to install because the window was designed to accommodate it. The weatherstripping between the storm window and the window sash, shown in the photo, prevents moisture from migrating between the window panes. There are other options for interior storm windows, including glass or clear plastic installed in a track, with tape or magnets. The storm window in this case study is held in place by several metal tabs visible in the photo below.



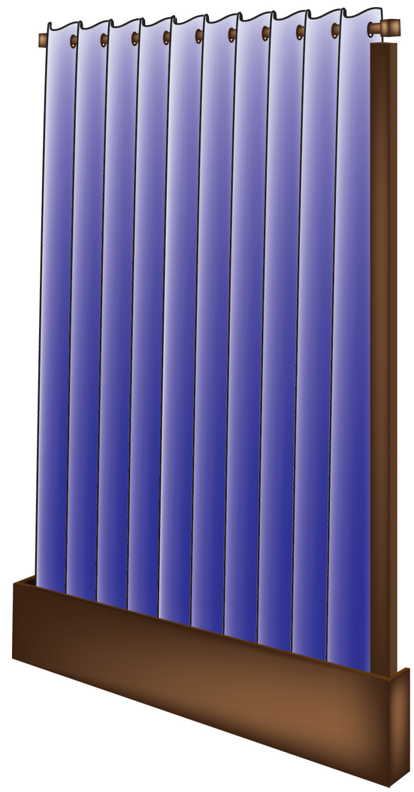
Interior Curtain

Interior Curtain on a Triple-Pane Window

Curtains are commonly used to provide privacy and block out unwanted light, but also can be used to reduce heat escaping from windows. They are cheap, easy to install and use, and fairly tough. However, curtains lower the temperature of the window surfaces behind them, creating the potential for condensation. Condensation on the windows can cause moisture problems on the window sill and further down the wall and could possibly crack the seal of the window. As with most interior window insulations, unless they seal to prevent the movement of warm moist air and prevent the flow of moisture through the material, condensation will form on the window glass. Over the course of a winter, that condensation can cause quite a bit of damage to the window and sill, especially if either is wood.

Insulating curtain from the case study home

Interior Curtain	
Condensation resistance	more problematic
Insulation improvement	17%
Affordability	inexpensive
Ease of installation	simple
Durability	sturdy
Functionality	excellent



An example of how a curtain can block air movement (although not vapor)

In our study of a triple pane window, a simple fleece curtain improved the center of glass R-value from 5.4 to 6.3. This is a small change for the potential problems a curtain can cause. Curtains come in a large variety and some will have a much greater effect on R-value than others. The curtain system monitored in the case study home was well attached to the window head and side trim and extended well past the window sill; however, the curtain did not provide an airtight seal.

Curtains can be more effective at slowing air leakage around the window frame than other movable insulations. While this may help improve homeowner comfort by shielding occupants from cold drafts, the relatively minimal insulation improvement usually does not make up for the condensation problems that are likely to arise.

Modeled U-value improvement **38%**

Interior Plastic Film

Interior Plastic Film on a Triple-Pane Window

Adding a thin plastic film to the inside of a window is a common practice with old, leaky windows. The plastic film is commonly available and comes in large sheets that can be cut to size. The plastic is stretched over the window and held in place with double-sided tape. Once it is firmly affixed, a hair dryer is used to tighten the plastic, which smoothes out the wrinkles since the film is a “heat shrink” or “shrink wrap.” While not as simple as a curtain, the plastic film is fairly easy to install. The film usually lasts one winter, but is fragile and susceptible to puncture if in a high-traffic area. The tape also tends to fail over time, undermining the effectiveness of the window treatment.

The plastic film provides a thermal improvement roughly equivalent to adding another window pane. In our case study, it changed the center-of-glass R-value for a triple-pane window from 5.4 to 7.2, a 33% improvement.

Depending on where the plastic is placed, the film can also reduce air leakage around the frame of the window. The plastic film cools the surface temperature of the glass, but it also acts as a vapor barrier and prevents warm, moist air from reaching the cooler glass. So while the glass may fall below the dew point, moisture is blocked from reaching the cooler surface, preventing condensation. If installed well, plastic film is one of the few interior treatments that doesn’t increase the condensation on the interior of the window.

Case study home with interior plastic film

Modeled
U-value
improvement
24%

Interior Plastic Film	
Condensation resistance	problematic
Insulation improvement	33%
Affordability	cheap
Ease of installation	easy
Durability	fragile
Functionality	efficient

Installing plastic film in the case study home

Interior Shutters

Interior Shutters on a Triple-Pane Window

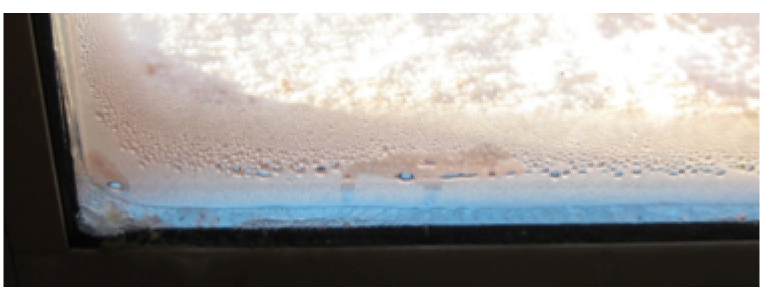
Interior shutters involve placing a single or multiple solid panels of insulation over the window opening. Interior shutters operate by a variety of methods: they can slide on tracks, fold to the side, or swing from the top. The interior shutters studied by CCHRC were custom-designed and integrated during construction with triple-glazed windows. The shutters are made of three-inch thick polyisocyanurate foam insulation framed in 1/2-inch medium density fiberboard and encased in fiber reinforced plastic. Two sets of weather-stripping are installed along the perimeter of the shutters (see photo) to seal the window sill and jams from the ambient interior house moisture; this effort was intended to reduce the potential for condensation and ice formation between the window and the interior shutter. The shutters slide in and out of a compartment built into the adjacent wall and are accessed by hinged doors built into the window side jamb. This is very similar in concept to a pocket door commonly seen in many homes. The shutters increased the center-of-glass R-value by an impressive 147%, from 5.3 to 13.2.

Modeled U-value improvement **696%**

Interior Curtain	
Condensation resistance	very problematic
Insulation improvement	147%
Affordability	moderate
Ease of installation	moderate
Durability	moderate
Functionality	moderate

The effectiveness of the interior shutter at insulating the window also creates ample potential for condensation and ice formation, as shown in the photo. The weather-stripping around the interior shutter was not capable of sealing out ambient interior house moisture and condensation formed on the window and window sill during the evaluation period (March-April 2011).

An additional precaution is overheating in the summer. In July 2011, the interior shutter was inadvertently left closed during the daytime. The result was that the sunlight heated the air space between the shutter and the window got hot enough to cause the window to break.



Condensation and ice on an exterior door covered with an interior shutter in the case study home

Weather stripping on the interior

Potential in Reducing Heat Loss

Homeowners interested in reducing heat loss from their windows should have a basic understanding of the potential benefits of moveable window insulation. Figure 4 illustrates the heat loss per unit area of a relatively low-performing window (0.5 U-value)[3] when movable insulation of varying R-values was installed for half a day. The shape of the curve in Figure 4 indicates that window insulation between R-1 and R-5 greatly improve the thermal performance of our hypothetical 0.5 U-value window. Window insulation of R-1 reduces heat loss by 17%, while R-5 insulation reduces heat loss by 36%.

Window insulation methods above R-5 provide increasingly diminishing returns, as the majority of the heat loss occurs during the 12 hours when the insulation is not in place. For example, window insulation of R-10 would reduce heat loss by 42%, and R-20 insulation reduces heat loss by 46%. This is important, as it is far more practical and affordable to implement movable insulation methods between R-1 and R-5. To visualize, R-20 is equal to foam insulation 4 to 5 inches thick.

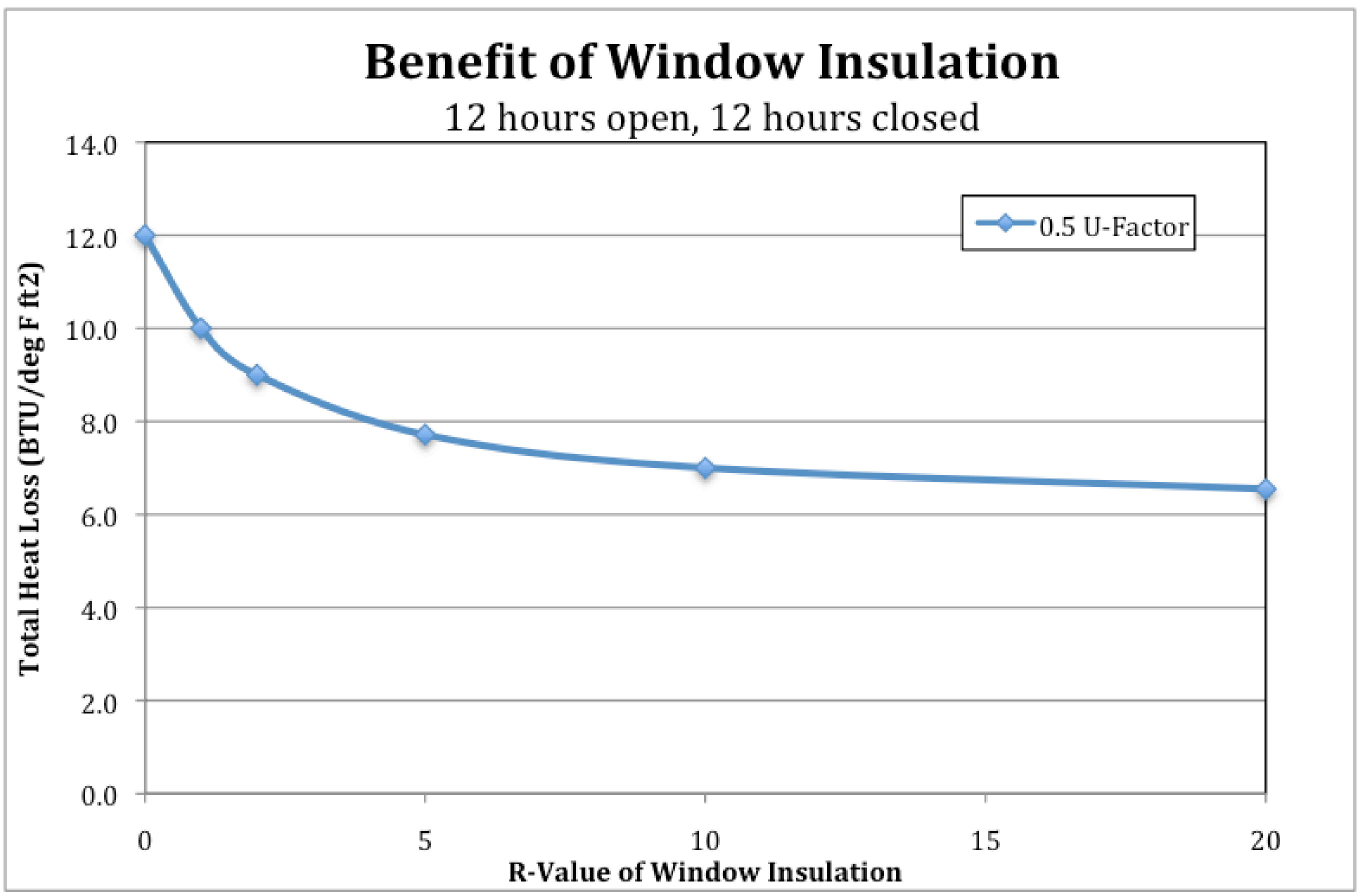


Figure 4. Reduction in heat loss for a 0.5 U-value window with varying amounts of movable insulation. The displayed values are for the insulation deployed for 12 hours and removed for 12 hours, simulating a movable insulation strategy like shutters, curtains, or blinds.

[3] The units R-value are ft²hr°F/BTU and U-value units are the inverse, BTU/ ft²hr°F.

Some insulation strategies are transparent and deployed throughout the heating season, such as storm windows or heat shrink films. These insulations serve to reduce heat loss 24 hours per day, removing the variability of deployment common to strategies that require attention daily from the homeowner. In this sense, they are analogous to upgrading to a higher performance window, although the retrofitted window system will probably not enjoy all the benefits of operability, transparency, aesthetics, and quality of a new window.

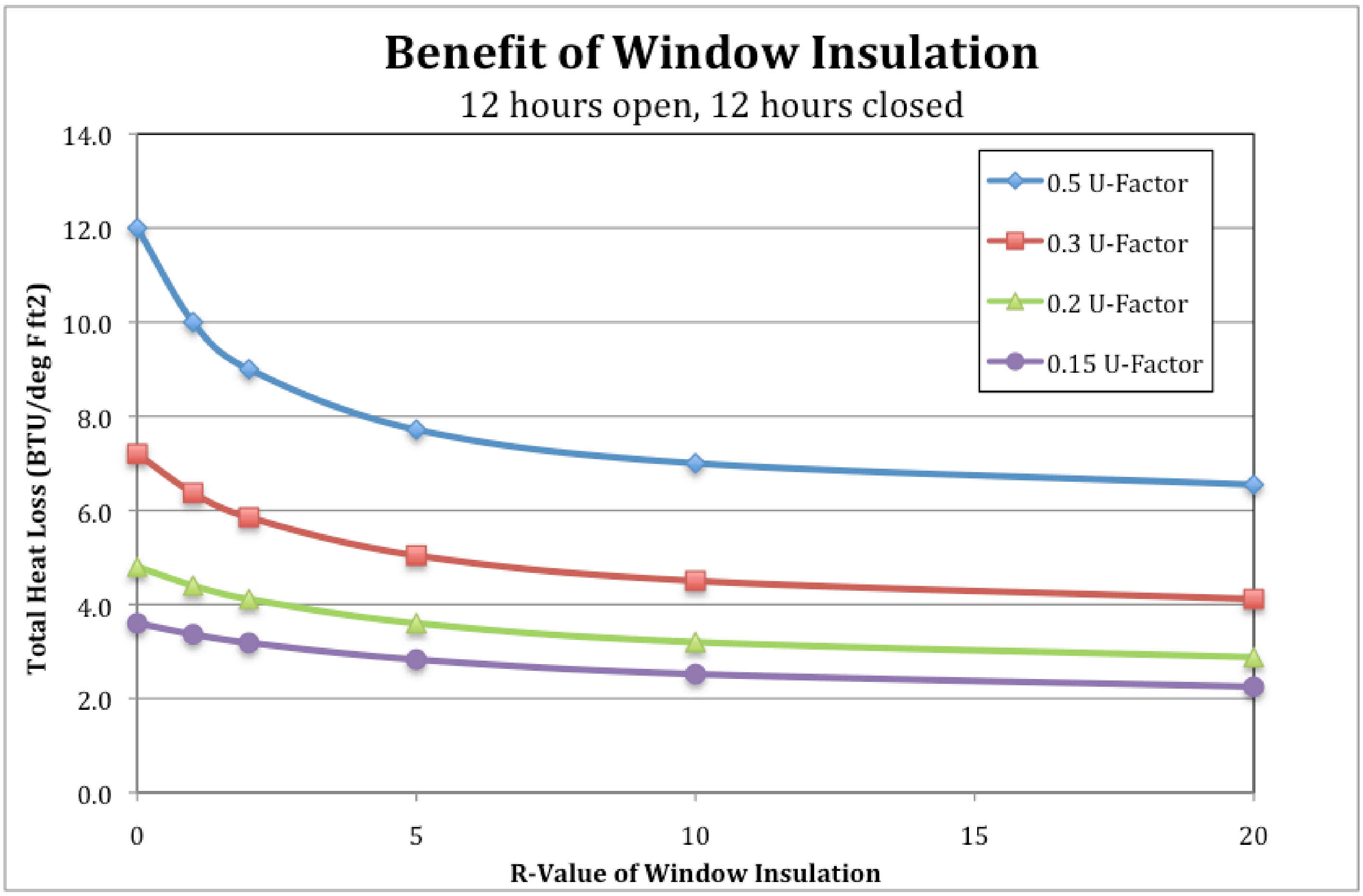


Figure 5. Reduction in heat loss for multiple grades of windows with varying amounts of movable insulation. The displayed values are for the insulation deployed for 12 hours and removed for 12 hours.

Figure 5 demonstrates the effect of moveable window insulation on windows of different thermal performance while also showing that lower-performing windows have more to gain from moveable window insulation. It also illustrates that higher-performance windows often better meet the goal of reducing heat loss.

As an example, a 0.5 U-value window requires approximately R-8 insulation deployed for 12 hours daily to equal the heat loss from a 0.3 U-value window with no movable insulation. The 0.5 U-value window can never catch up with a 0.2 U-value window in terms of heat loss, no matter how much insulation is placed in front of it at night. Similarly, a 0.3 U-value window requires about R-7 insulation in place for half the day to equal the heat loss from a 0.2 U-value window with no insulation. The 0.3 U-value window can never catch up with a 0.15 U-value no matter how much insulation is placed in front of it at night.

While placing movable insulation in front of a window of any quality will reduce heat loss to some degree, windows that perform better will reduce the significance of that work. This is illustrated by the 0.15 U-value window in Figure 5, a very high-quality window by today's standards. The magnitude of heat loss reduction from adding insulation is very modest compared to the 0.3 and 0.5 U-value windows, shown by the increasingly flatter curves as the thermal performance of the window improves.

This discussion only includes heat loss through the window to focus on the benefit of window insulation. While older windows with higher U-values tend to have higher air leakage rates, and could benefit further from movable insulation that inhibits air flow, such considerations are not included in this analysis. Furthermore, the potential for passive solar gain through windows was not considered, as this is strongly a function of window orientation, glazing coatings, and integration into the overall home design, and can be evaluated separately from the potential contribution of movable insulation. This is an important consideration, as the heat losses during the day can be more than compensated for by passive solar gains during times of the year when heating is needed and the sun provides sufficient radiation.

Appendix A: Test Methods

This study was designed to examine retrofit methods of improving window performance that are cheaper than replacing windows and compare them in terms of effectiveness, affordability, ease of installation, durability, functionality, and condensation resistance. CCHRC studied a variety of methods and windows in volunteers' homes to understand how the methods work outside the lab. CCHRC also modeled the retrofit window treatments to help explain more generally how they can help homeowners.

Test Objectives

The tests were designed to evaluate the various window treatments by:

1. Estimating the center-of-glass resistance to heat loss of the window;
2. Estimating the center-of-glass resistance to heat loss with the window treatments in place;
3. Comparing the two center-of-glass resistances to heat loss;
4. Estimating the condensation potential of the treatment by monitoring the relative humidity close to the window glass and observing condensation;
5. Valuing the ease of use and costs through informal discussion with homeowners and researcher use of the treatments;
6. Modeling the overall U-value changes created by the window treatments on a reference window.

Method Overview

In order to get the best information about alternative window insulation methods CCHRC turned to Fairbanks homeowners who have been using varying window treatments for years. Researchers took a sensor kit to case study homes and monitored windows with and without the treatment for one to two weeks. CCHRC selected volunteers mainly through word-of-mouth and by talking to local energy auditors. Table 1 shows a list of the various treatments and window type combinations.

Table 1. Window Treatments Tested

Treatment	Window type
Interior insulated blinds	double-pane, no frame, fixed
Interior storm window	single-pane, wood frame, fixed
Exterior shutters	double-pane, wood frame, casement
Mechanical exterior shutters	triple-pane, vinyl, casement
Interior plastic film	triple-pane, vinyl, casement
Interior curtain	triple-pane, vinyl, casement
Interior plastic film	triple-pane, vinyl, fixed
Interior curtain	triple-pane, vinyl, fixed
Exterior storm window	double-pane, wood frame, vertical sliding
Interior shutters	triple-pane, fiberglass

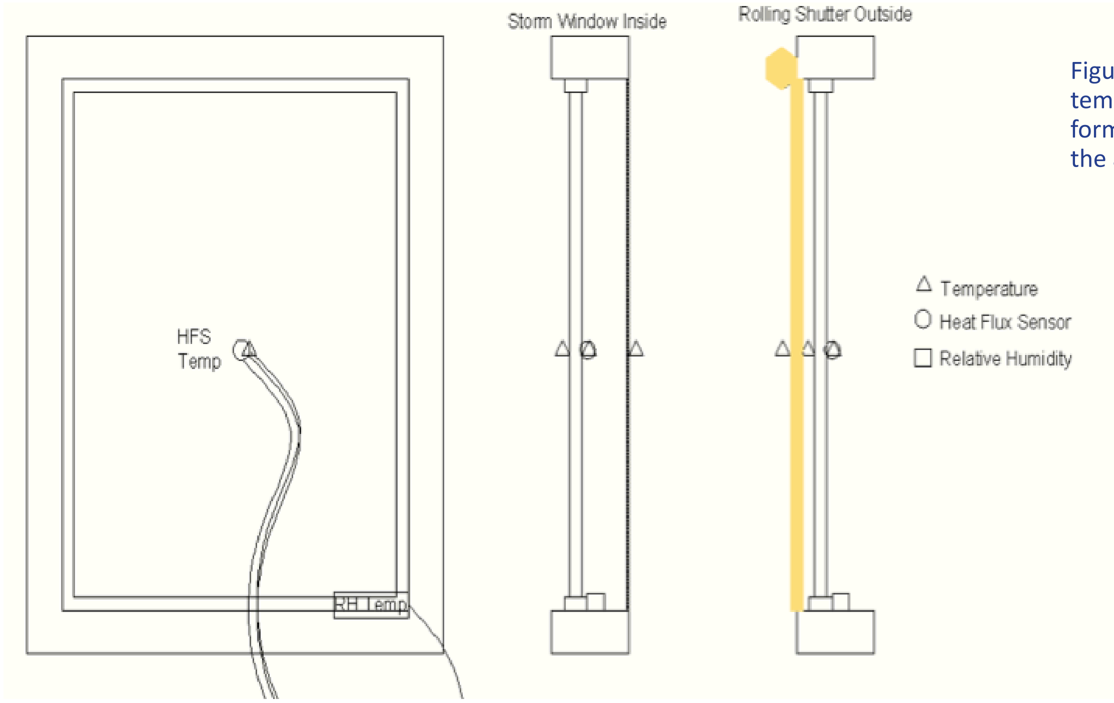


Figure 6. Sensor placement. The temperature and heat flux sensors form a line across the window and the added insulation.

The windows were equipped with a string of temperature sensors on the center of the glass; inside the glass, outside the glass, and on the treatment on the opposite side from the glass. A REBS heat flux sensor was affixed to the inside of the glass beside the interior thermocouple. A relative humidity (RH) sensor was placed on the sill at the bottom of the window, as close to the window as possible. Usually one window was monitored at a time, but where two windows were close enough together, both windows were monitored. Figure 6 shows a layout of the sensors. The system was monitored for one to two weeks and detailed notes were taken about the location of the treatment over time. Visible light and infrared pictures were taken to document the changes in the sensors and window with and without the treatment (Figure 7).

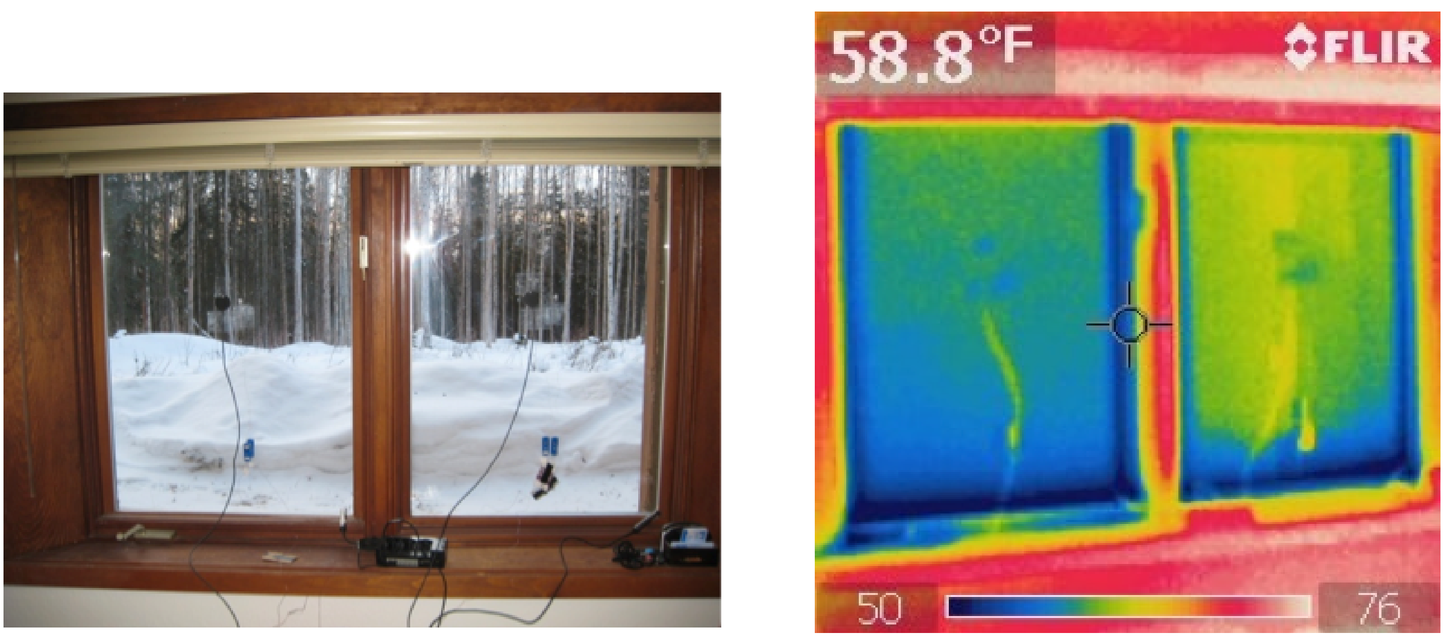


Figure 7. Pictures of sensor placement in a case study home. The photo on the right shows an infrared image of the case study window.

Discussion

The data were analyzed to determine the center of glass R-value with and without the treatment. However, the R-value is just one of several important parameters when deciding the value of each treatment. All of the treatments were evaluated in terms of insulation value, condensation resistance, affordability, ease of installation, durability, and functionality.

The R-value of the glass and the treatment were calculated using the temperature difference from the inside to the outside and the heat flux through the window.

$$\text{R-value} = \frac{T_{in} - T_{out}}{\text{heat flux}}$$

The R-value is a function of the outside temperature, assuming the inside temperature is relatively stable, so the R-values from this study are variable depending on the weather. We chose to average the calculated R-value for each window over the length of study. Then we calculated the percentage increase in the R-value with the treatment to determine the insulating value of the treatment.

The condensation improvement was determined by the relative humidity of the air directly beside the window and the temperature of the inside of the glass. The higher the humidity the more likely the window would have condensation on it. The colder the interior surface of the glass, the more likely there will be condensation, unless the introduced treatment is sealed to prevent water vapor from reaching the glass.

The affordability, ease of installation, durability, and functionality ratings were estimated by conversations with the homeowners and actual use of the treatment by the researchers.

For simplicity, the different treatments were rated in each category on a 1 to 10 scale, with 10 being the best. The ratings are comparative across the different treatments, and could change if other treatments are studied at a later date. The performance of each treatment is also dependent on the type of window that it is applied to; adding a treatment to a triple-pane window may not show as much improvement as adding the same treatment to a double-pane window.

THERM Analysis

THERM 6.3 is a 2-dimensional heat transfer modeling program for building sections. It can model window and wall sections. THERM 6.3 allowed us to create a standard-reference window and apply different treatments to that window. Then we analyzed the difference in the thermal performance of the window and noted whether the dew point moved to a location that allowed for condensation.

The base window (Figure 8, left) had 2 clear panes of glass, spaced 1/2 inch apart with an aluminum spacer. It was non-operable window set in a solid wood frame. The overall U-value of this window is 0.4826 (an R-value of about 2), which is typical for double-pane windows without low-e coatings. The aluminum spacers caused the 44°F dew point line (interior 70°F and 40% RH) to fall on the inside of the window at the corners (Figure 8, center), when the outside temperature was modeled at 0°F. This means that if the humidity in the house reaches 40% and the outside temperature drops below 0°F, condensation will form on the corners of this window.

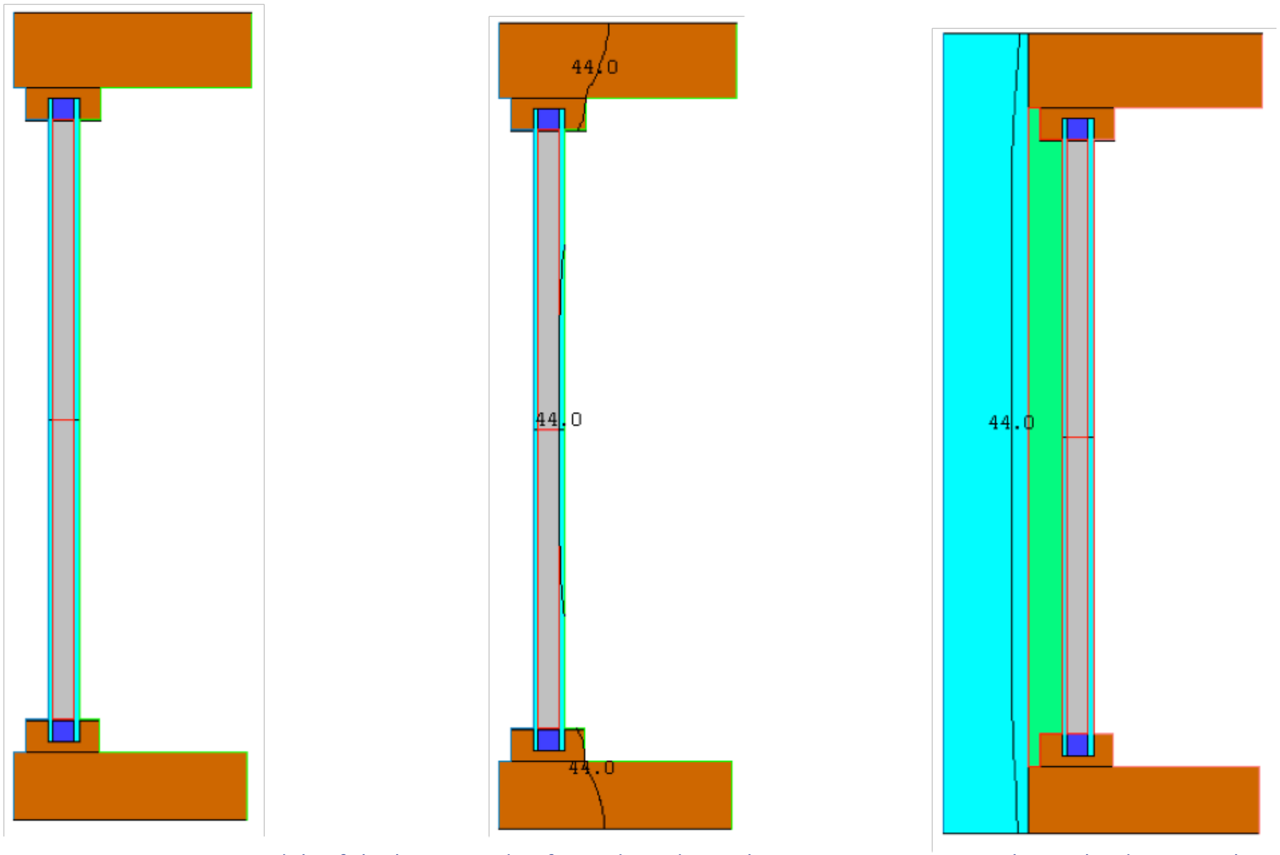


Figure 8. THERM 6.3 models of the base wooden framed window. The center cross section shows the dew point line of the basic window. The right figure shows a window with 2 inches of exterior XPS insulation.

We used this base window to add different movable window insulations. Figure 8 (right) shows the basic window with exterior foam added to the outside, similar to the sliding exterior shutter in our case study. Notice how the dew point has moved completely to the outside of this window, so there is very little chance of condensation is this scenario. All of the thermal results are presented in Table 2. These results were used to inform the comparative rankings in the Window Insulation Comparison chart (Figure 3).

	U-value[4]	R-value	Difference	Improvement
Basic window	0.483	2.07		
Added Window Insulation				
2 inches exterior foam	0.076	13.1	11.0	532%
Interior shutter	0.061	16.5	14.4	696%
Exterior storm	0.218	4.58	2.51	121%
Interior storm	0.312	3.20	1.13	55%
Exterior rolling shutter	0.320	3.13	1.05	51%
Curtain	0.349	2.86	0.79	38%
Plastic film	0.388	2.58	0.51	24%
Interior shade	0.420	2.38	0.31	15%

Table 2. Results of THERM modeling. The U-value results were converted to R-values and the difference between the basic window R-value and the treatment was used to calculate the percentage improvement.

4 The units R-value are $ft^2hr°F/BTU$ and U-value units are the inverse, $BTU/\ ft^2hr°F$.

Further Reading

Coffin, D. (2008). Insulated window treatments and coverings. Retrieved from http://umaine.edu/publications/7214e/

Drumheller, S., Kohler, C., Minen, S. (2007). Field evaluation of low-E storm windows. Retrieved from http://www.ornl.gov/sci/buildings/2010/Session%20PDFs/22_New.pdf

Langdon, William K. (1980). *Movable insulation*. Emmaus, PA: Rodale Press.

Mattinson, B. DePaloa, R. Arasteh, D. (2002) What should I do about my windows? Window retrofit decision will be made easier with a little help from an advisory tool. *Home Energy.* (July/August) 24-31.

U.S. Department of Energy. (1984). Window Insulation, how to sort through the options (Contract No. DE-AC01-82E15095). Washington DC: Government Printing Office.

U.S. Department of Energy, Energy Efficiency and Renewable Energy (2011, February 9). Storm windows. Retrieved from http://www.energysavers.gov/your_home/windows_doors_skylights/index.cfm/mytopic=13490