# EVALUATING WINDOW INSULATION FOR COLD CLIMATES

Robbin Garber-Slaght[1] and Colin Craven[1]


## INTRODUCTION

*In cold climates, a large amount of heat is lost through windows during the winter. For instance, a double-pane window might allow as much as 10 times the amount of heat to leave a house compared to the same area of a typical 2 × 6 wall. It makes sense to upgrade or insulate windows in order to improve the thermal envelope of a home, especially in an area with a long heating season; however, 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 often resort to cheaper methods to reduce heat loss, such as shutters or curtains. 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, the Cold Climate Housing Research Center (CCHRC) in Fairbanks, Alaska, conducted a study of common window insulation methods and compared them in terms of thermal effectiveness, affordability, ease of installation, durability, functionality, and condensation resistance. The purpose of the study was to inform homeowners about the various advantages and disadvantages of different window treatments. As part of the research, 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 with Therm 6.3, a modeling program, to help explain more generally how they can help homeowners.*



## KEYWORDS

windows, insulation, cold climate, heat loss, condensation, U-value, R-value


## TEST METHODS

This study was designed to examine retrofit methods of improving window performance and to compare them in terms of thermal 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 in real-life situations.

[1]Cold Climate Housing Research Center, Fairbanks, AK. www.cchrc.org

*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. Product names herein do not constitute an endorsement.

**TABLE 1.** Window Treatments Tested.

| Treatment | Window Type |
|---|---|
| Exterior foam shutters | Double-pane, wood frame, casement |
| Exterior mechanical shutters | Triple-pane, vinyl, casement |
| Exterior storm window | Double-pane, wood frame, vertical sliding |
| Interior insulated blinds | Double-pane, no frame, fixed |
| Interior storm window | Single-pane, wood frame, fixed |
| Interior curtain | Triple-pane, vinyl, fixed |
| Interior curtain | Triple-pane, vinyl, casement |
| Interior plastic film | Triple-pane, vinyl, fixed |
| Interior plastic film | Triple-pane, vinyl, casement |
| Interior sliding shutters | Triple-pane, fiberglass, casement |

CCHRC also modeled the retrofit window treatments to help explain more generally how they can help homeowners.

In order to get the best information about alternative window insulation methods, CCHRC turned to Fairbanks homeowners who had been using various 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.

### *Test Objectives*

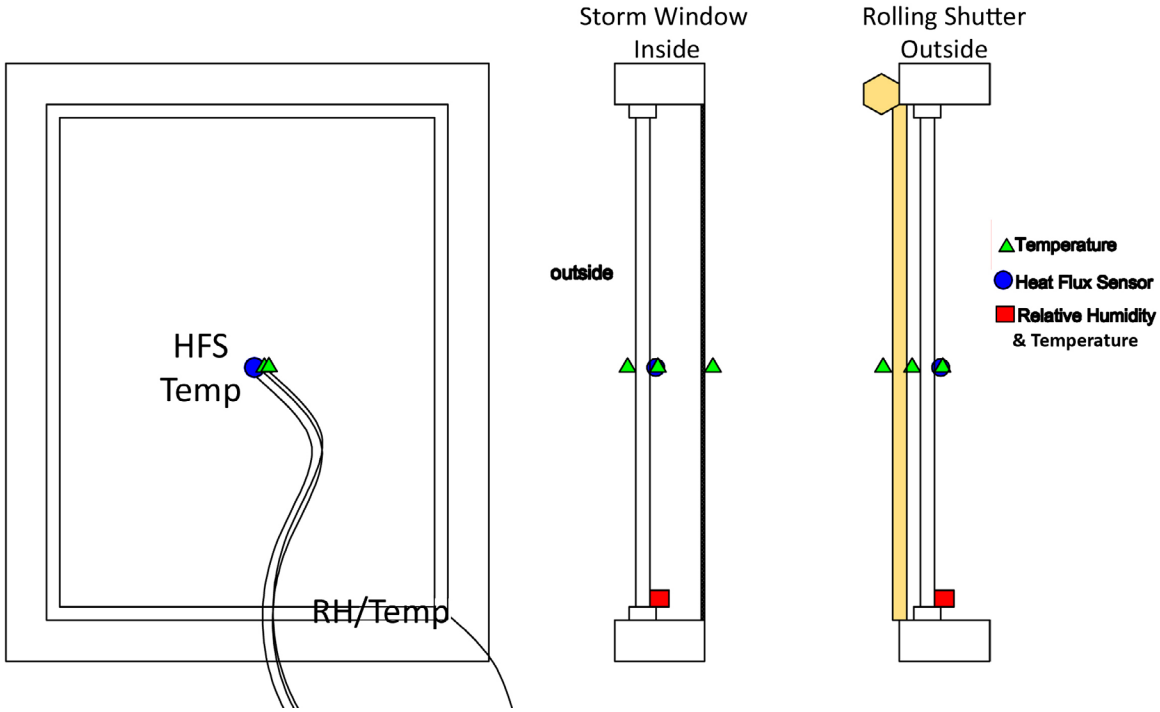
The tests were designed to evaluate the various window treatments by:

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.

### *In-Situ Thermal Performance*

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 with thermally-conductive paste. A relative humidity (RH) sensor was placed on the bottom corner of the window glass, as close to the window glass as possible. Usually one window was monitored at a time, but where two windows were close enough together, both windows were

**FIGURE 1.** Sensor Placement. The temperature and heat flux sensors form a line across the window and the added insulation.




monitored. Figure 1 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 photographs and infrared thermograms were taken to document the changes in the sensors and window with and without the treatment (Figure 2).

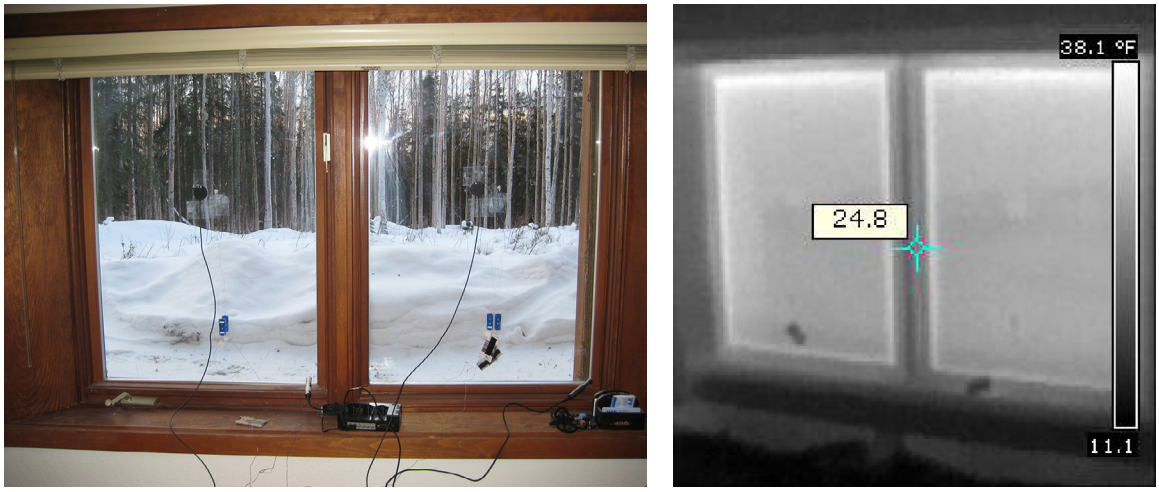
The R-value of the glass and the treatment were calculated using the temperature difference from the inside to the outside and the heat flux through the window.

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

The temperature gradient was assessed from inner to outer surfaces to avoid assumptions on the thermal resistance of air films. 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 condensation would form on the window. The colder the interior surface of the glass, the more likely there would be condensation, unless the introduced treatment was sealed to prevent water vapor from reaching the glass.

**FIGURE 2.** Pictures of sensor placement in a case study home. The photo on the right shows an infrared image of the case study window.




### *Modeled Thermal Performance*

THERM 6.3 is a two-dimensional heat transfer modeling program for building sections. It can model window and wall sections. THERM 6.3 allowed for the creation of a standard-reference window that was used to apply different treatments. Then the difference in the thermal performance of the window was analyzed and the condensation line was studied to see if it moved to a location that allowed for condensation (Figure 3).

The standard-reference window (Figure 3 left) had 2 clear panes of glass, spaced ½ inch apart with an aluminum spacer. It was a non-operable window set in a solid wood frame. The overall U-value of this window is 0.48 (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 3, center), when the outside temperature was modeled at 0°F. This means that if the relative humidity in the house reaches 40% and the outside temperature drops to 0°F, condensation will form on the glass near the corners of this window.

This base window was used as a standard reference point to evaluate different movable window insulations. Figure 3 (right) shows the standard-reference window with exterior foam added to the outside, similar to the sliding exterior shutter case study. Note that the dew point has moved completely to the outside of the window, so there is no chance of condensation under these conditions. Thermal modeling results are presented in Table 2. These results were used to inform the comparative rankings in the Window Insulation Comparison chart in the Summary of Findings section (Figure 6).

### *Condensation Resistance*

Condensation on windows is a serious problem in cold climates. Water vapor can condense and drain into window openings and the underlying wall. That moisture can cause mold growth and rot of wood framing and trim. There is also the potential for moisture to freeze, preventing window operability and causing damage to the window. Analysis of the relative humidity and temperature near the glass was used to evaluate if the condensation resistance of the window was changed by the addition of the window treatment.

**FIGURE 3.** 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 extruded polystyrene (XPS) insulation.

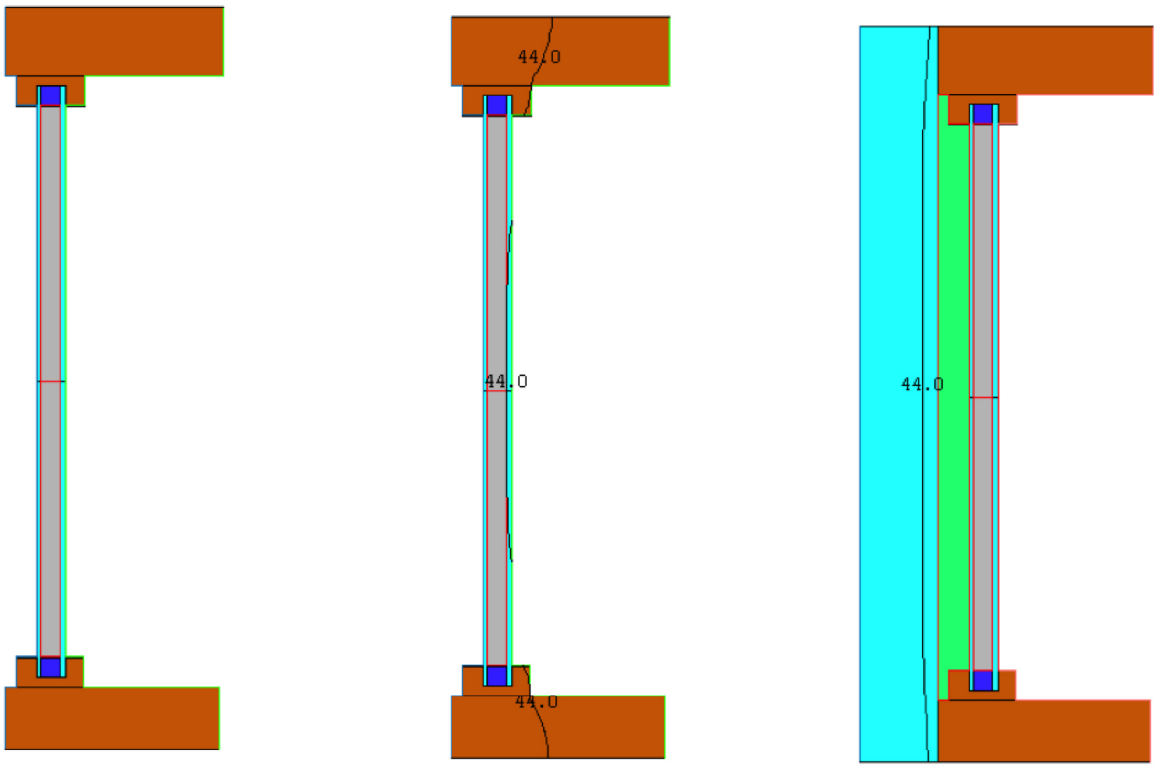



**TABLE 2.** Results of THERM modeling. The U-value results were converted to R-values and the difference between the basic window R-value and the treatment was used to calculate the percentage improvement.

| | U-value[2] | R-value | Difference | Improvement |
|---|---|---|---|---|
| Basic Window | 0.483 | 2.07 | | |
| *Added Window Insulation* | | | | |
| Exterior foam shutters (2 inches) | 0.076 | 13.1 | 11.0 | 532% |
| Exterior mechanical shutters | 0.320 | 3.13 | 1.05 | 51% |
| Exterior storm window | 0.218 | 4.58 | 2.51 | 121% |
| Interior insulated blinds | 0.420 | 2.38 | 0.31 | 15% |
| Interior storm window | 0.312 | 3.20 | 1.13 | 55% |
| Interior curtain | 0.349 | 2.86 | 0.79 | 38% |
| Interior plastic film | 0.388 | 2.58 | 0.51 | 24% |
| Interior sliding shutters | 0.061 | 16.5 | 14.3 | 692% |

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

## QUALITATIVE EVALUATION

Thermal performance and condensation resistance are just two of several important factors when deciding the value of each treatment. Each treatment was also evaluated in terms of affordability, ease of installation, durability, and functionality.

These four factors were rated 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 on which it is applied. For example, adding a treatment to a triple-pane window may not show as much improvement as adding the same treatment to a double-pane window.

## RESULTS

### *U-values and R-values: Measuring Thermal Performance*

There are a few different systems when describing how well windows, walls, ceilings, and floors resist heat loss. Most familiar to people 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 an insulation product alone in reducing heat transfer. A higher R-value indicates a more effective insulation.

The more useful term for windows is "U-value," or "U-factor," which is the ability of the entire window (including glass, framing, air spaces, glazing spacers) to resist the movement of heat.

$$\text{U-value} = \frac{1}{\text{R-value}}$$

The lower the U-value, the more effective the window is at insulating. Windows have various components that have different thermal properties (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; therefore, U-values have become the accepted way of describing the thermal performance of windows. 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 center of the insulated glass unit 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[3]-certified 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.

[3]National Fenestration Rating Council, www.nfrc.org/label.aspx

### *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) when movable insulation of varying R-values was installed for half a day (i.e., overnight). The shape of the curve in Figure 4 indicates that window insulation between R-1 and R-5 greatly improves 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, it's equal to foam insulation about 4 to 5 inches thick.

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. In this sense, they are analogous to upgrading to a higher performance window, although the retrofitted window system will almost certainly not enjoy all the benefits of operability, transparency, and aesthetics of a new window.

**FIGURE 4.** Reduction in heat loss for a window with U-value 0.5 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.

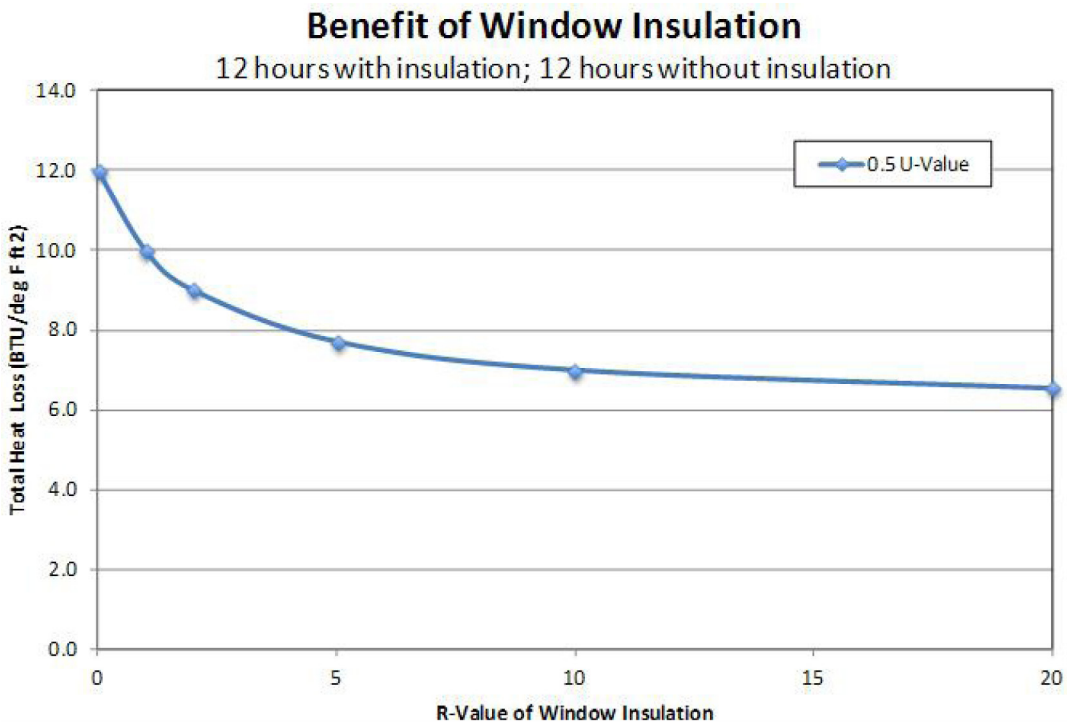


**FIGURE 5.** Reduction in heat loss for multiple grades of windows with varying amounts of movable insulation. The displayed values are for the insulation deployed for 12 hours and removed for 12 hours.

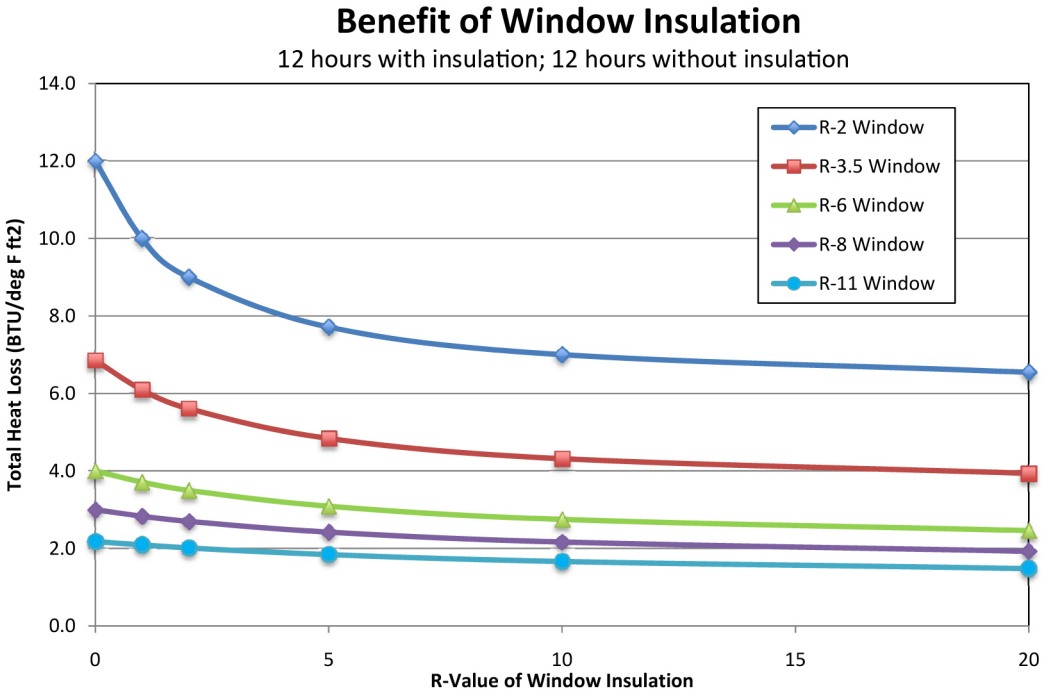



Figure 5 demonstrates the effect of moveable window insulation on windows of different thermal performance, showing that lower-performing windows have more to gain from moveable window insulation. It also illustrates that higher-performance windows often better meet the goal of reducing heat loss than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

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, better windows 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 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.

### *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 window treatment. The chart (Figure 6) summarizes the relative strengths and weaknesses of each window insulation method in CCHRC's case studies to help guide homeowners in these decisions.

**FIGURE 6.** Window Treatments. 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 to homeowners. 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 that will change some of the rankings. The best way to use this chart is to evaluate which parameters are most important and choose the best option based on these preferences.

| Insulation Type | Condensation Resistance* | Insulation Value | Affordability | Ease of Installation | Durability | Functionality |
|---|---|---|---|---|---|---|
| Exterior foam shutters | | | | | | |
| Exterior mechanical shutters | | | | | | |
| Exterior storm window | | | | | | |
| Interior insulated blinds | | | | | | |
| Interior storm window | | | | | | |
| Interior curtain | | | | | | |
| Interior plastic film | | | | | | |
| Interior sliding shutter | | | | | | |

*Condensation Resistance
Bad → Worst  Low → High

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. In order to provide a standardized analysis of the thermal performance, U-value improvements were estimated using THERM 6.3.
- **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 and whether the option is permanent or must 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.

## CASE STUDIES

The following eight case studies were performed in Fairbanks, Alaska, during the winters of 2010 and 2011. The case studies are specific to each house and window studied. The goal was to evaluate a broad range of window insulation options; therefore, 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 varied substantially.

In an effort to standardize the thermal results across the case studies, CCHRC modeled each moveable insulation type using THERM 6.3 to compare the thermal improvement to a double-pane reference window. In some of the case studies there is a significant difference between the *monitored* improvement value and the *modeled* improvement value. There are a few reasons for this: the monitored values are for the center-of-glass R-value and the modeled values are for the whole window U-value; and windows with higher thermal performance do not benefit as much from insulation as windows with lower thermal performance.

The case studies are divided into interior and exterior insulation options. 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. Minor condensation, which is typically found on the bottom

of the glass where it meets the frame, is not a significant problem; however, major condensation can lead to ice formation and drainage that can freeze operable windows shut and cause moisture infiltration into walls. These can create hazards such as lack of emergency egress and potential for mold and rot growth, respectively.

### *Exterior Foam Shutters on Double-Pane Windows*

Exterior shutters (Figure 7) involve placing one or more 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 tended to close them for extended periods of time, he typically filled the gaps around the edges with small pieces of fiberglass 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, as shown in Table 3. The center-of-glass R-value jumped from 1.5 to 7.7 when the blinds were deployed, a thermal improvement of 410%. The modeled U-value improvement for the standard reference window was an impressive 532%.

The cost of exterior shutters is very dependent on the method of construction. Figure 7 shows shutters that were custom built as part of the original home. 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 if not secured well. The biggest drawback of exterior shutters is the effective loss of the window providing a connection to the outside. This can be partially overcome if a homeowner frequently makes the effort to open and close the window shutters. When deployed, the shutters block emergency egress. The monitored window for this case study was close to ground level, making operation of the shutter possible without additional equipment; however, the second-floor windows require the use of a custom-made rod or a ladder in order to operate the shutters.

**FIGURE 7.** Exterior foam shutter system.

**TABLE 3.** Exterior Foam Shutters

| | |
|---|---|
| Condensation resistance | Very beneficial |
| Insulation improvement | 410% |
| Affordability | Moderate |
| Ease of installation | Moderate |
| Durability | Tough |
| Functionality | Challenging |
| Modeled U-value improvement | 532% |
| Blocks egress | Yes |

### *Exterior Mechanical 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.

**FIGURE 8.** Exterior rolling shutter system.

This case study evaluated a commercially available exterior rolling shutter system (Tucson Rolling Shutters®, shown in Figure 8) 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, warming the outside of the window.

**TABLE 4.** Exterior Mechanical Shutters

| | |
|---|---|
| Condensation resistance | More beneficial |
| Insulation improvement | 30% |
| Affordability | Expensive |
| Ease of installation | Professional level |
| Durability | Sturdy |
| Functionality | Excellent |
| Modeled U-value improvement | 51% |
| Blocks egress | Yes |

The shutters increased the center-of-glass R-value for triple-pane windows from 5.3 to 6.9, a thermal improvement of 30% (see Table 4). On a less efficient window the thermal improvement could be even better. The modeled U-value improvement for the standard reference window was 51%.

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 cycled above and below freezing, the shutters occasionally froze in place due to ice formation in the bottom channel.

### *Exterior Storm Window on a Double-Pane Window*

This window was a 1970s-era double-pane window with vertically-sliding sashes. An exterior storm window is added in the winter by the homeowners in this case study. 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% (see Table 5). This is closely matched by the modeled

U-value improvement for the standard reference window of 121%, partially due to the close match between the case study and standard reference window construction.

Because this window is in the bathroom, it is exposed to high humidity conditions for short periods of time. The storm window improved 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 allows for emergency egress.

Storm windows are a very good option to increase the insulation value of windows without causing condensation problems or substantially reducing visibility. More modern versions are available that have low emittance ("low-e") coatings that further improve insulating value more than the storm windows tested in this case study, which also would improve their resistance to condensation. A study conducted in Chicago on homes with single-pane windows found that installing clear glass storm windows reduced heating loads by 13% and installing low-e storm windows reduced heating loads by 21% (Drumheller et al, 2007).

### *Interior Insulated Blinds on a Double-Pane Window*

"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 and insulation. They are easy to operate from the inside of the house and are similar to typical house blinds (see Figure 9).

The window center-of-glass R-value was about 3.5, and the shades increased the center-of-glass R-value to 5.6, an increase of 60% (see Table 6). This is substantially better than the

**TABLE 5.** 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% |
| Blocks egress | Depends on window |

**FIGURE 9.** The insulated blinds in the case study home have a sensor in place in this photo.

**TABLE 6.** Interior insulated blinds

| | |
|---|---|
| Condensation resistance | Problematic |
| Insulation improvement | 60% |
| Affordability | Moderate |
| Ease of installation | Easy |
| Durability | Sturdy |
| Functionality | Efficient |
| Modeled U-value improvement | 15% |
| Blocks egress | No |

15% predicted by modeling the U-value improvement for the standard reference window, as the U-value takes into account the heat lost around the frame. 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.

Because they do not block air movement around the window, the insulating blinds allow for the introduction of water vapor between the blinds and the window; therefore, closing the blinds increases the condensation potential on 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 increase the price and the installation complexity.

### *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 had become a second pane for this window. The storm window increased the center-of-glass R-value of the window by 72% (see Table 7). 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. The modeled U-value improvement for the standard reference window was 55%.

With the storm window removed, the window iced over immediately because the outside temperature was approximately –20°F. This ice 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 pane iced up again, because a thin layer of warm moist air trapped between the two panes was cooled. A week after the storm window had been put back into place, there was still some ice on the single pane inner surface, but it was steadily decreasing in extent.

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 Figure 10, 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 Figure 10. While

**TABLE 7.** 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% |
| Blocks egress | No |

**FIGURE 10.** This storm window has weatherstripping to prevent moisture transfer.

the case study window was fixed, operable versions using this interior storm window system retain their operability and do not have an appreciable change in visible light transmittance.

### *Interior Curtain on a Triple-Pane Window*

Curtains are commonly used to provide privacy and block unwanted light, but also can be used to reduce heat escaping from windows. They are cheap, easy to install and use, and fairly durable; however, curtains lower the temperature of the window surfaces behind them, creating the potential for condensation. As with most interior window insulations, unless they seal to prevent the movement of warm moist air and stop 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.

In this study of a triple-pane window, a simple fleece blanket curtain improved the center-of-glass R-value from 5.4 to 6.3 (see Table 8). The modeled U-value improvement for the standard reference window was 38%. These improvements are small relative to 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 firmly 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.

**TABLE 8.** Interior Curtain

| | |
|---|---|
| Condensation resistance | More problematic |
| Insulation improvement | 17% |
| Affordability | Inexpensive |
| Ease of installation | Simple |
| Durability | Sturdy |
| Functionality | Excellent |
| Modeled U-value improvement | 38% |
| Blocks egress | No |

### *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 (see Figure 11). 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 for small and moderately sized windows. 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 this case study, it changed the center-of-glass R-value for a triple-pane window from 5.4 to 7.2, a 33% improvement. The modeled U-value improvement for the standard reference window was 24% (see Table 9).

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 retarder and prevents warm, moist air from reaching the cooler glass. So

**TABLE 9.** Interior plastic film

| | |
|---|---|
| Condensation resistance | Problematic |
| Insulation improvement | 33% |
| Affordability | Cheap |
| Ease of installation | Easy |
| Durability | Fragile |
| Functionality | Efficient |
| Modeled U-value improvement | 24% |
| Blocks egress | No |

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.

### *Interior Sliding Shutters on a Triple-Pane Window*

Interior shutters involve placing one or more solid panels of insulation over the window opening from the inside. 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 were custom-designed and integrated during construction with triple-glazed windows. The shutters are made of 3-inch thick polyisocyanurate foam insulation framed in ½-inch medium density fiberboard and encased in fiber reinforced plastic. Two sets of weather-stripping are installed along the perimeter of the shutters (see Figure 12) to seal the window sill and jambs from the ambient interior 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

**FIGURE 11.** Interior plastic film on a case study window.

**FIGURE 12.** This interior shutter has weatherstripping to seal the window sill.

increased the center-of-glass R-value by an impressive 147%, from 5.3 to 13.2. The modeled U-value improvement for the standard reference window was a remarkable 696% (see Table 10).

The effectiveness of the interior shutter at insulating the window also creates ample potential for condensation and ice formation. The weather-stripping around the interior shutter was not capable of sealing out water vapor from the interior house, so condensation formed on the window and drained to the window sill during the evaluation period (March–April 2011).

**TABLE 10.** Interior sliding shutters

| | |
|---|---|
| Condensation resistance | Very problematic |
| Insulation improvement | 147% |
| Affordability | Moderate |
| Ease of installation | Moderate |
| Durability | Moderate |
| Functionality | Moderate |
| Modeled U-value improvement | 696% |
| Blocks egress | No |

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. An exterior shutter system would avoid this problem if left deployed in summer, as the insulation would shield the window instead of creating a heat trap.

## CONCLUSION

In selecting a window insulation strategy that is most appropriate, it is easy to focus on cost and thermal performance. Because window insulation requires homeowner involvement, it is also important to fit the insulation strategy to homeowner preferences. The willingness and ability of homeowners to frequently move or maintain window insulation are fundamental considerations in selecting a system. Extremely diligent behavior, such as daily opening and closing of window insulation, should not be expected except for the most motivated homeowners. The duration of insulation deployment over a heating season is a crucial factor in determining the true potential for reducing heat loss.

While interior and exterior insulation methods can be equally effective at insulating windows, exterior insulation methods do not need to be airtight in order to improve condensation resistance. If interior insulation methods are not airtight and water vapor impermeable, they will worsen condensation problems. This places a more stringent burden on interior insulation strategies, as the installation method and durability of the materials must maintain these properties over their intended life span if condensation is to be avoided.

## REFERENCES

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

## ACKNOWLEDGEMENTS

Thanks to Terry Cruikshank, John Cruikshank, and Ned Rozell for their valuable comments and contributions to this report. Thanks to the Alaska Housing Finance Corporation, who provided the funding for this project.