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Manual Determination of Shade R-Values

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***Abstract*— The purpose of this experiment was to find a way to manually determine the unknown R-value of any shade. In heating seasons, shades can decrease the heat loss through a window system. In cooling seasons, a shade can keep unwanted solar heat from entering a space. The temperatures of the outside air, outside side of glass, interior side of glass, outside facing side of shade, inside facing side of shade, and the interior temperature were measured. Using these temperatures and the known R-value of a pane of glass, the rate of heat flow could be calculated and therefore the R-value of the shade could be found. Unfortunately, the experiment did not produce reliable results. General patterns could be observed though.**

***Index Terms*—Shade, R-value, Solar heat gain.**

I. INTRODUCTION

The way buildings interact with the environment has a huge impact on industries, individuals, and the environment itself. Specifically, window systems have lots of potential to decrease heating and cooling costs/energy use. Shades are a relatively simple and feasible way to reach a goal of less energy use/costs associated. This R-value determination would then lead to an accurate calculation of how much energy is saved by using a type of shade and therefore how much money is saved.

A common issue in building assemblies is the cost and energy associated with heating and cooling. The cost can put a strain on building owners, and the energy use on the environment. The majority of heat loss and gain is through windows. This can be seen through R-values. For example, a wall in Michigan has to have a minimum of R-13 according to code [1]. A basic single-pane window only has a value of R-1 [1]. R-value is a unit of measurement that quantifies the heat flow through a material. Specifically, the R-value = thickness of material (m) / thermal conductivity (W/m K) [2]. So, a higher R-value of a material indicates a lower rate of heat transfer or a higher amount of insulating properties.

Shades can add a range of R-values to that base R-1 value of the glass. Many sources outline R-values of shades, but this differs with a multitude of factors, hence this experiment. These factors include, but are not limited to, infiltration, gaps, seals, and vapor barriers [1]. According to the Washington Energy Extension Service, "without an edge seal, an insulated window cover loses up to 40 percent of its effectiveness" [3]. Adding seals on shades is such a simple way to save energy. If that isn't feasible, just adding a one layer polyester insulated quilt to a double pane window can bring the R-value up to R-4.55 [1]. This can have a significant impact, especially in extreme climates. Other commonly used window treatments are insulation boards, removable panels, shutters, drapery, quilts, comforters, roller shades, and cellular shades [1, 2]. Adding insulated shutters to a double pane can increase the R value to R-9.50+ [1]. Cellular shades are considered to be the best though. The honeycomb shape traps air and therefore is insulating [4]. This experiment compares a double cell shade, a single cell shade, and a thin drape. Like stated before, there are values stated online for every type of shade. The values could fluctuate for different brands and assemblies, though.

ASTM, the American Society for Testing Materials, has released many different guidelines regarding R-values. The study closely related to this experiment has been published as the "Standard Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions" [5].

II. METHODS

To try and obtain my experimental value, I first taped a piece of white paper onto the inside of the window and another piece on a different window pane outside. I allowed these pieces of paper to sit for 30 minutes, to hopefully adjust to the temperature of the glass. This was done because the reflection on the glass was producing an inaccurate temperature reading. Once the time elapsed, I took the temperature of the inside pane of glass with the temperature gun and the outside temperature of the glass with the thermal gun. I then closed the shade and allowed it to adjust for 30 minutes. Again, after the time elapsed I recorded the temperatures. The temperature of an interior wall and exterior temperature was also recorded. The space between the window and shade was noted. Other shade characteristics were observed like thickness, color, gap between side of shade and frame, and whether it had cells. I also took thermal pictures of the window to judge the quality of the window.

Comparing the three windows, I determined which one was the leakiest or had the most cold streaks. I recorded other information like the building type, location, orientation, date/time, and weather conditions. All these factors could influence the calculation of the unknown R-value. Since light also contributes to heat gain, I measured the light outside, through the window, and through the shade with a light meter. Then, a calculation of the reflectance of the shade could be done. Yet another factor affecting heat loss and gain.

Experiment Process:

1. Tape a piece of white paper on the inside and outside of the window on different panes. Allow to sit for 30 minutes.

2. Meanwhile, write down the following observations and measurements:

a. Building type (residential, office, medical, school, etc)

b. Location of building

c. Date and time of experiment

d. Window orientation

e. Weather conditions (sun, wind, etc)

f. Shade characteristics

i. Thickness

ii. Color

iii. Type of shade? (fabric, cellular, if so how many cells)

iv. Does the shade feel like it is insulating? If you put your hand right next to the window and then next to the other side of shade do you feel a temperature difference?

v. Gap between the side of shade and frame

g. Window characteristics

i. Gap between window and shade (both these gaps cause a decrease in R value of the system)

ii. How tight is the seal? When you close and lock the window do you feel the seal getting tighter? Can you feel a draft?

iii. Leaky? Related to how tight the seal is, also can create an opinion based on thermal images. A high amount of cold streaking can be labeled as leaky. (insert photos)

iv. Quality: Based off of the 2 previous observations and how the window looks

v. Film/Tint? Can you physically see a tint? Is there fine print on the glass saying there is a low emissivity coating?

vi. Can you access the window from outside?

vii. How many panes of glass?

h. Any other factors that could affect your results? For example, the recording tools, a nearby radiator, etc.

3. After the paper has sat for 30 minutes, start taking temperatures. Record to one decimal place.

a. Interior (temperature gun): Take the temperature on an interior wall that exemplifies the interior temperature correctly.

b. Inside of the glass (temperature gun)

c. Outside of glass (thermal gun)

d. Outside (thermal gun)

4. Now, put down the shade and wait another 30 minutes. Then take the last two temperatures.

a. Side of shade facing room: Take the temperature in the middle of the shade

b. Side of shade facing window: Take the temperature in the middle of the shade

5. Now, take these temperatures into excel to find the heat flow rate between each aspect of the system.

III. Results

Figures 1-6 and Tables 1-3 show photos of windows 1-3, sample calculations to attempt to make the R-Value analysis coherent, and tables of results.

For Window 1, there were quite differing rates of heat flow between the trials. Trial 1 was done on a warmer day. Trial 2 and 3 were done on a very cold, windy, and snowy day. This could account for the higher heat flow rate during Trial 2 and 3. There was a greater temperature differential between inside and outside, so the flow of heat was faster. To try to find the R-value of the shade, I adjusted the values of other parts of the assembly to account for high wind speeds. With all these differences, it was hard to find a consistent R-value for the double cell shade.

For Window 2, there was a consistent heat flow rate. The temperature difference between the outside of glass and the inside was not consistent though. These trials were on the same day, so they should have aligned more accurately. The white paper method of measuring the glass temperature could have caused these inconsistencies. A trend can be seen that the thin fabric shade has a much lower R-value than a cellular shade, although this could not be quantified.

For Window 3, a consistent shade R-value could again not be found. A pattern could be detected though. The double cell shade on Window 1 had the strongest insulating properties. The single cell shade on Window 3 was intermediate and the fabric shade on Window 2 was the least effective.

IV. Conclusions

In conclusion, this experiment could be feasible with more accurate tools. It has great potential to advise commercial building owners on what the best shade system is for them. Looking at predetermined R-values to guide the choice, the experiment could narrow down the options to the most efficient system. Although cellular shades are the most insulating, maybe the building owner has a different goal. If cellular shade is the right choice, there are many other characteristics that can be chosen. For example, the brand of shade, amount of cells, seal type, and shade color. If this process could be made easier, I think many commercial businesses would put time and money into adjusting window systems.

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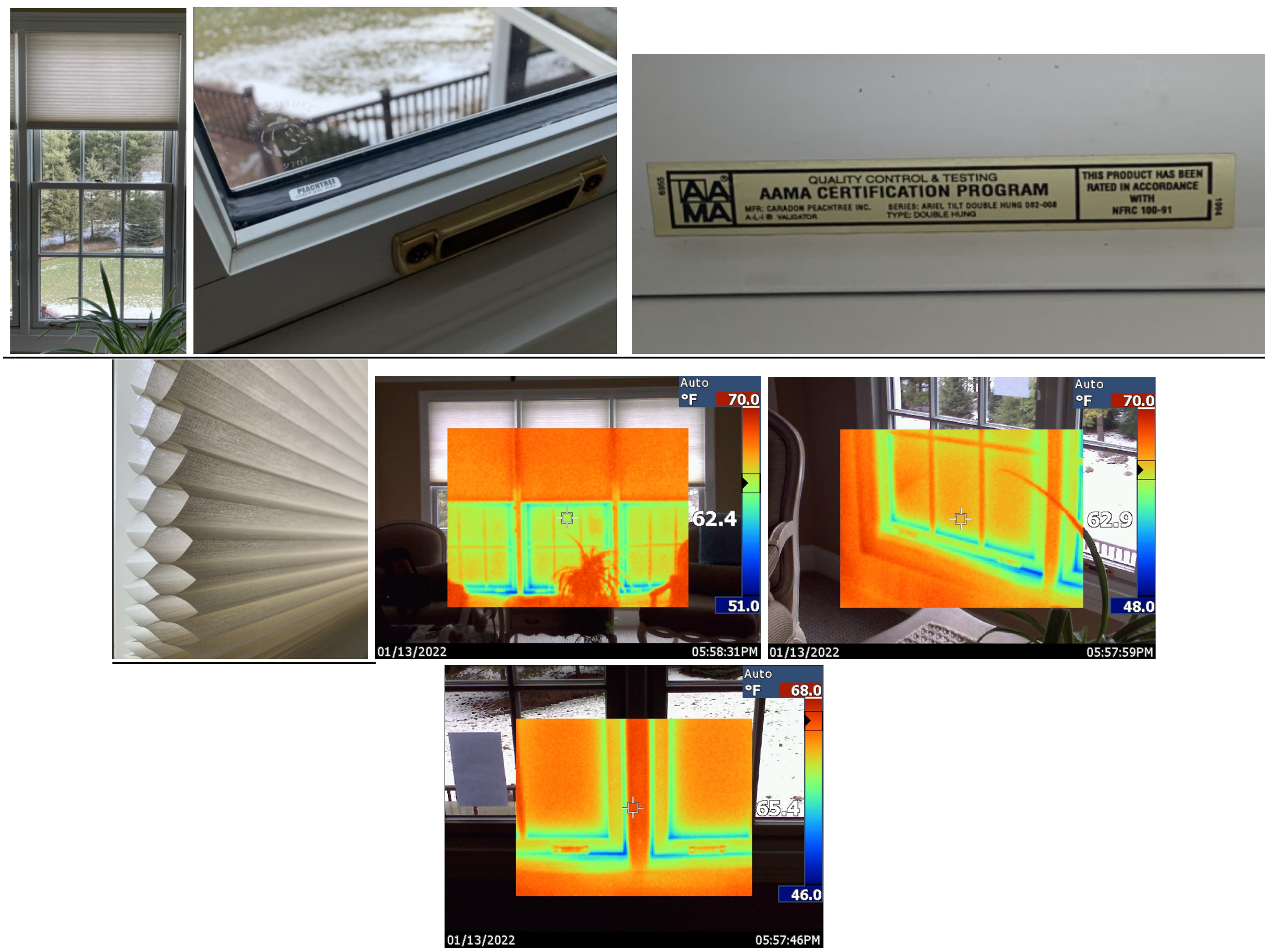

Figure 1 a.-g. Window 1

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Trial 1:

gap				outside air		dbl pane		air 3"		shade 1.77"		air-interior				
2" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	33	(left)adju	39		49		60		64		67.8		34.8	
date		R		0.68	(left)char	0.9		1.32		0.48		0.68			4.06	
location: home										TBD						
wind: 6 mph		delta T		6		10		11		4		3.8				
		rate		8.823529		11.11111		8.333333		8.333333		5.588235			8.344227	8.349673

Trial 2:

gap				outside air		dbl pane		air 3"		shade 1.77"		air-interior				
2" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	18.2		22.8		39.6		42.2		50.7		65.6		47.4	
date		R		0.28		0.9		0.17		0.48		0.68			2.51	
location: home										TBD						
wind: 18.4 mph		delta T		4.6		16.8		2.6		8.5		14.9				
		rate		16.42857		18.66667		15.29412		17.70833		21.91176			18.62418	20.28922

Trial 3:

gap				outside air		dbl pane		air 3"		shade 1.77"		air-interior				
2" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	18.1		23.6		33.2		41.5		53.7		65.4		47.3	
date		R		0.68	changed	0.9		1.32	(left) cha	1		0.68			4.58	
location: home										TBD						
wind: 18.4 mph		delta T		5.5		9.6		8.3		12.2		11.7				
		rate		8.088235		10.66667		6.287879		12.2		17.20588			11.38681	13.93627

Figure 2 a-c. Sample Trial calculations for window 1

Table 1. Window 1 results.

Trial #	1	2	3
Building Type	Residential	Residential	Residential
Location	Northville, MI	Northville, MI	Northville, MI
Date & Time	1/13/22; 2:00pm	2/3/22; 2:00pm	2/3/22; 2:00pm
Where is room/window located	Bedroom, SE corner	Bedroom, SE corner	Bedroom, SE corner
Window Orientation	East	East	East
Sun Condition	Cloudy	Cloudy, sun reflecting off snow	Cloudy, sun reflecting off snow
Shade Characteristics			
Thickness	4.55 cm	4.55 cm	4.55 cm
Color	White	White	White
Multi-cell?	Yes	Yes	Yes
Feel insulated?	Yes	Yes	Yes
Gap btw side of shade and frame	0.3 cm	0.3 cm	0.3 cm
Window Characteristics			
Gap btw window and shade	8.5 cm (top 1/2) 5 cm (bottom 1/2)	8.5 cm (top 1/2)5 cm (bottom 1/2)	8.5 cm (top 1/2)5 cm (bottom 1/2)
Quality	high	high	high
How tight is the seal?	high	high	high
Leaky?	Not leaky	Not Leaky	Not Leaky
Film/Tint?	No	No	No
Reflectance	41%	32%	33%
Access from outside?	Yes	Yes	Yes
How many panes of glass?	2	2	2
Other			
Wind speed/direction	6 mph NE	18.4 mph NNE	18.4 mph NNE
Opening of shade	Closed	Closed	Closed
Factors affecting experiment (i.e radiator)	No	Snow reflection, big room, 7 windows	Snow reflection, big room, 7 windows
Calculations			
Outside temp away from building	30°	18.2°	18.1°
Outside temp of glass	39°	22.8°	23.6°
Inside temp of glass	49°	39.6°	33.2°
Outside temp of shade	60°	42.2°	41.5°
Inside temp of shade	64°	50.7°	53.7°
Room temp on interior wall	67.8°	65.6°	65.4°

Figure 3. a.-c. Window 2.

Table 2. Window 2 Results

Trial #	1	2
Building Type	Residential	Residential
Location	Northville, MI	Northville, MI
Date & Time	2/3/22; 2:00pm	2/3/22; 2:00pm
Where is room/window located	Laundry, East	Laundry, East
Window Orientation	East	East
Sun Condition	Cloudy, sun reflecting off snow	Cloudy, sun reflecting off snow
Shade Characteristics		
Thickness	0.35 cm	0.35 cm
Color	Beige	Beige
Multi-cell?	No, fabric	No, fabric
Feel insulated?	No	No
Gap btw side of shade and frame	None	None
Window Characteristics		
Gap btw window and shade	9.75 cm(top 1/2) 5.45 cm(bottom 1/2)	9.75 cm(top 1/2) 5.45 cm(bottom 1/2)
Quality	Medium	Medium
How tight is the seal?	Medium	Medium
Leaky?	slightly leaky	slightly leaky
Film/Tint?	no	no
Reflectance	42%	43%
Access from outside?	yes	yes
How many panes of glass?	2	2
Other		
Wind speed/direction	18.4 mph NNE	18.4 mph NNE
Opening of shade	Closed	Closed
Factors affecting experiment (i.e radiator)	Snow reflection, small room, vent below window, one window	Snow reflection, small room, vent below window, one window
Calculations		
Outside temp away from building	19.8°	19.9°
Outside temp of glass	22.6°	20.9°
Inside temp of glass	46.6°	31.7°
Outside temp of shade	45.5°	46.7°
Inside temp of shade	47°	50.2°
Room temp on interior wall	69.8°	69.4°

Trial 4:

gap				outside air		dbl pane		air 3"		shade 0.15"		air-interior				
0.15" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	19.8		22.6		46.6		45.5		47		69.8		50	
date		R		0.17		0.9		1.32		0.1		0.68			3.17	
location: home										TBD						
wind: 18.4 mph		delta T		2.8		24		-1.1		1.5		22.8				
		rate		16.47059		26.66667		-0.83333		15		33.52941			19.78758	30.09804

Trial 5:

gap				outside air		dbl pane		air 3"		shade 0.15"		air-interior				
0.15" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	19.9		20.9		31.7		46.7		50.2		69.4		49.5	
date		R		0.1		0.9		1.32		0.3		0.68			3.3	
location: home										TBD						
wind: 18.4 mph		delta T		1		10.8		15		3.5		19.2				
		rate		10		12		11.36364		11.66667		28.23529			17.19964	20.11765

Figure 4. a.-b. Sample Calculations for Window 2.

Figure 5. a-d. Window 4.

Table 3. Results for Window 4.

Trial #	1	2	3
Building Type	Residential	Residential	Residential
Location	Northville, MI	Northville, MI	Northville, MI
Date & Time	2/3/22; 2:00pm	2/3/22; 2:00pm	2/8/22; 4:00pm
Where is room/window located	Bedroom, NW corner	Bedroom, NW corner	Bedroom, NW corner
Window Orientation	West	West	West
Sun Condition	Cloudy, sun reflecting off snow	Cloudy, sun reflecting off snow	Partly Cloudy
Shade Characteristics			
Thickness	1.45 cm	1.45 cm	1.45 cm
Color	White	White	White
Multi-cell?	One cell	One cell	One cell
Feel insulated?	Yes, lower than multi cell	Yes, lower than multi cell	Yes, lower than multi cell
Gap btw side of shade and frame	0.85 cm	0.85 cm	0.85 cm
Window Characteristics			
Gap btw window and shade	6.75 cm(top 1/2) 1.75 cm(bottom 1/2)	6.75 cm(top 1/2) 1.75 cm(bottom 1/2)	6.75 cm(top 1/2) 1.75 cm(bottom 1/2)
Quality	Low, lots of streaking	Low, lots of streaking	Low, lots of streaking
How tight is the seal?	Low	Low	Low
Leaky?	Very leaky	Very leaky	Very leaky
Film/Tint?	Yes; low e smart sun	Yes; low e smart sun	Yes; low e smart sun
Reflectance	40%	41%	44%
Access from outside?	Yes	Yes	Yes
How many panes of glass?	2	2	2
Other			
Wind speed/direction	18.4 mph NNE	18.4 mph NNE	4 mph E
Opening of shade	Closed	Closed	Closed
Factors affecting experiment (i.e radiator)	Snow reflection,medium sized room, two windows	Snow reflection,medium sized room, two windows	
Calculations			
Outside temp away from building	18.8°	18.4°	38.4°
Outside temp of glass	21.3°	21.8°	40.1°
Inside temp of glass	46.7°	40.1°	51.3°
Outside temp of shade	46.5°	41.6°	60.4°
Inside temp of shade	52.6°	46.1°	64.2°
Room temp on interior wall	61.4°	59.9°	65.1°

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Trial 6:

gap				outside air		dbl pane		air 3"		shade 0.6 "		air-interior				
.6" shade			outside		on glass		inside of glass		inside of shade		outside of shade		room		total	
		T	18.8		21.3		46.7		46.5		52.6		61.4		42.6	
date		R		0.17		0.9		1.32		0.48		0.68			3.55	
location: home										TBD						
wind: 18.4 mph		delta T		2.5		25.4		-0.2		6.1		8.8				
		rate		14.70588		28.22222		-0.15152		12.70833		12.94118			13.67063	20.5817

Figure 6. Sample Calculations for Window 4.