QUANTIFYING COMFORT TO ASSIST IN THE WINDOW SELECTION PROCESS

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ABSTRACT

"Generally, windows are not the key element affecting the comfort of a building's occupants. However under more extreme conditions, where a window is hot or cold and/or the occupant is very close to the window, they become most influential." (Lyons, 1999)

The Efficient Windows Collaborative's (EWC) web-based Window Selection Tool provides performance metrics for windows and skylights for cities in North America. Certain metrics, such as energy and peak demand, are rather easy to quantify because simulation and other methodologies are readily established. The EWC has developed a comparative comfort analysis based on the principles presented by Mr. Lyons in previous research papers.

The EWC comfort analysis was performed using weather files for nearly 100 locations in the U.S. and Canada to determine how often the winter night and summer day night comfort levels are compromised. The analysis accounts for the effect of cold roomside window surface temperatures in the winter and direct solar radiation in the summer. The comfort analysis should apply to most any conditioned space, whether residential or commercial.

Discomfort hours as a function of climate were determined for a set of 20 generic windows. Products ranged from single pane clear glass in a metal frame (high heat loss and high solar gain) to best available technology for low U-factor and low solar heat gain. Qualitative rankings of **Cold – Cool – Neutral** were established for winter weather and **Hot – Warm – Neutral** were used for the summer conditions. A simple graphical display for each location allows for quick comparisons within the range of window products.

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Keywords: windows, comfort, discomfort, thermal comfort analysis, comfort metric, direct solar radiation, glass surface temperature, SHGC, U-factor

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The Efficient Windows Collaborative (EWC) is a nonprofit organization that promotes energy-efficient fenestration products by providing unbiased information on the energy efficiency, technical, and human considerations that influence window and façade design, selection, and use to consumers, designers, and fenestration industry professionals. The Window Selection Tool, for new and replacement windows, on the EWC website (http://www.efficientwindows.org) provides performance metrics for windows and skylights across the United States and Canada. Energy metrics are rather easy to quantify as building energy simulation methodologies are readily established. Metrics involving a human response, such as comfort, are not as easily measured. This paper details the efforts employed by the EWC to develop a comparative metric for the human comfort response to windows.

THE EWC WINDOW SET

The EWC 20-window set is made up of generic market-available products. The windows were simulated using Lawrence Berkeley National Laboratory's (LBNL) WINDOW program. The performance data was used for energy simulations for the EWC web site and for providing glass surface temperatures.

ID	Glazing Layers	Glazing Type	Argon Fill	Frame Type	U-Factor	SHGC	VT
1	Single	Clear	—	Metal	1.29	0.73	0.69
2	Double	Clear	No	Metal	0.83	0.65	0.63
3	Double	Tint	No	Metal	0.83	0.54	0.47
4	Double	Low-E, High SHGC	Yes	Metal	0.65	0.58	0.61
5	Double	Low-E, Med SHGC	Yes	Metal	0.64	0.38	0.56
6	Double	Low-E, Low SHGC	Yes	Metal	0.63	0.26	0.49
7	Double	Clear	No	Metal, Thermal Break	0.60	0.62	0.63
8	Double	Tint	No	Metal, Thermal Break	0.60	0.51	0.47
9	Double	Low-E, High SHGC	Yes	Metal, Thermal Break	0.42	0.55	0.61
10	Double	Low-E, Med SHGC	Yes	Metal, Thermal Break	0.42	0.35	0.56
11	Double	Low-E, Low SHGC	Yes	Metal, Thermal Break	0.41	0.23	0.49
12	Single	Clear	—	Non-Metal	0.88	0.64	0.65
13	Double	Clear	No	Non-Metal	0.52	0.57	0.59
14	Double	Tint	No	Non-Metal	0.52	0.47	0.44
15	Double	Low-E, High SHGC	Yes	Non-Metal	0.29	0.50	0.57
16	Double	Low-E, Med SHGC	Yes	Non-Metal	0.28	0.31	0.52
17	Double	Low-E, Low SHGC	Yes	Non-Metal	0.27	0.20	0.46
18	Triple	Low-E, High SHGC	Yes	Non-Metal	0.20	0.41	0.50
19	Triple	Low-E, Med SHGC	Yes	Non-Metal	0.19	0.28	0.45
20	Triple	Low-E, Low SHGC	Yes	Non-Metal	0.19	0.18	0.37

Table 1. EWC 20 Window Set

AN OVERVIEW OF THERMAL COMFORT ANALYSIS

Thermal comfort is that condition of mind that expresses satisfaction with the thermal environment. There are large variations, both physiologically and psychologically, from person to person, so it is difficult to satisfy everyone in a space. The science of comfort analysis employs statistical relationships to express the level of thermal “satisfaction” (or dissatisfaction) for a broad segment of the population. More importantly is the ability to use the comfort prediction in a comparative manner: is condition A vs. condition B more or less comfortable.

The thermal sensation scale, which is used to quantify thermal comfort, is defined as follows:

-3	**-2**	**-1**	**0**	**+1**	**+2**	**+3**
cold	**cool**	**slightly cool**	**neutral**	**slightly warm**	**warm**	**hot**

When a group of people exposed to the same conditions rate their comfort sensation the results are analyzed as “predicted mean vote” or PMV. Comfort research suggests there is an exponential response of the dissatisfaction level to the thermal sensation vote. The term PPD, or predicted percentage dissatisfied is the statistical outcome. In any design scenario the goal then is to provide the lowest possible PPD which then minimizes the risk of comfort complaints.

The following plot is from ASHRAE Standard 55. Note the symmetry of the dissatisfaction for cold and hot sensations, and also that the lowest PPD is 5%.

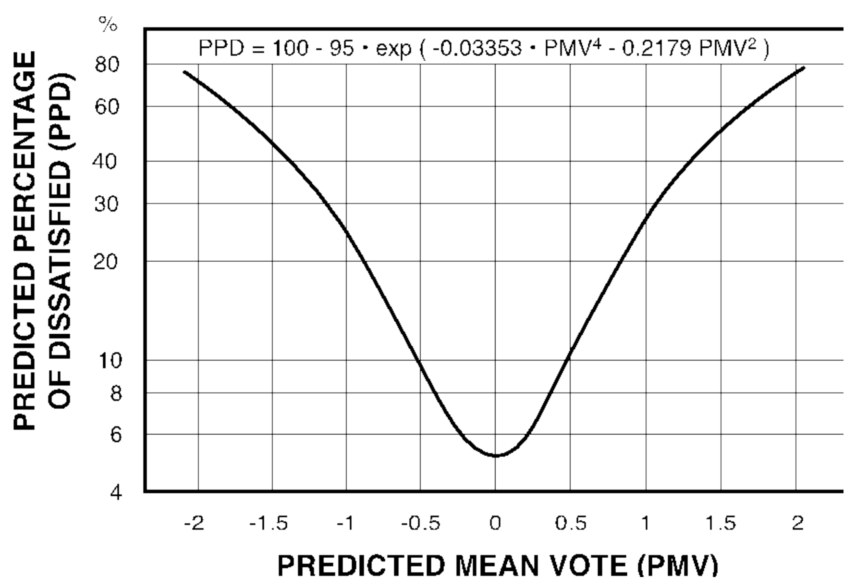


Figure 1. Predicted Percentage of Dissatisfied vs. Predicted Mean Vote (From ASHRAE Standard 55-2010)

The four primary factors that must be addressed when defining thermal comfort conditions for windows are:

1. Metabolic Rate (activity level)
2. Clothing Insulation
3. Air speed and Relative Humidity (draft response)
4. Mean Radiant Temperature (MRT)

For this research we follow the precedents suggested in ASHRAE Standard 55 for a person seated (quiet activity level), clothed with seasonal attire, and standard conditions for air movement and indoor humidity. Our MRT calculation will position the occupant at 3 feet away from a moderate sized window (representative of a picture window or patio door).

WINTER CONDITONS AND COLD SURFACE THRESHOLDS

Windows generally do not insulate as well as opaque wall elements. In winter when outdoor temperatures are cold, window roomside surfaces will be cooler than the adjacent wall. As an example, the chart below shows the roomside surface temperatures of a broad set of windows when analyzed at 0°F outdoors with two different wind speeds. Note that windows with U-factors greater than 0.30 see additional temperature drop when exposed to wind. For the EWC comfort analysis we will use this worst-case condition of wind to form the basis of our cold weather ranking.

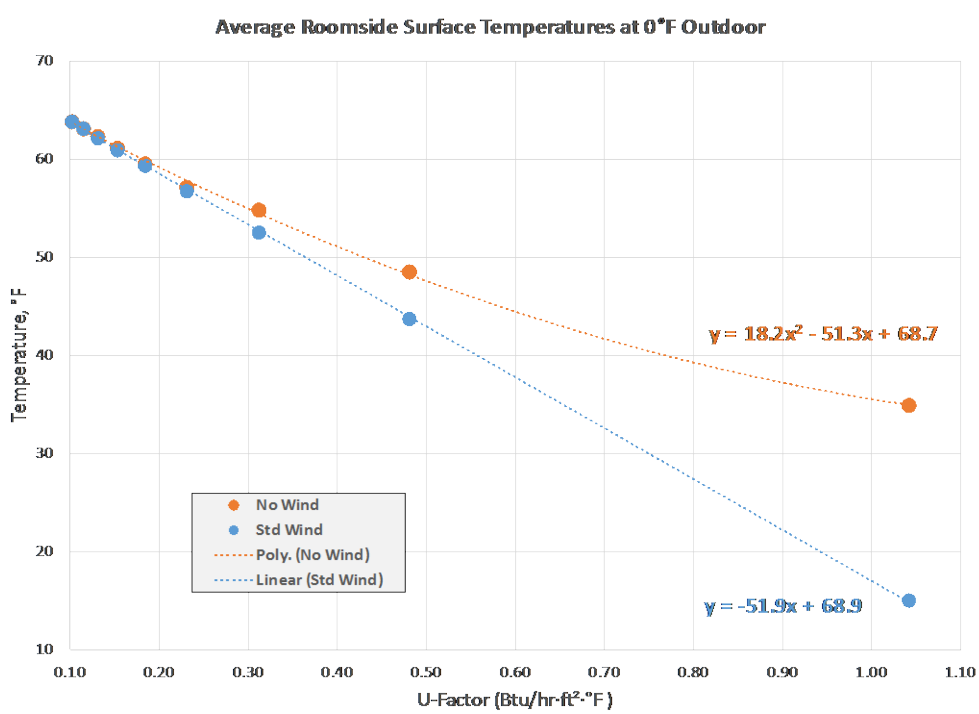


Figure 2. Window Roomside Surface Temperature vs. U-Factor

The roomside surface temperature depression for a given window is linear with the indoor-outdoor temperature differential. For example, if the roomside temp is depressed by 20°F at 0°F outdoor (a 70°F differential) the temperature depression at half that differential (outdoor temp of 35°F) would be 10°F.

The next issue to address is window size and occupant proximity to the window. Windows can range in size from small (e.g. single operable window about 15 ft^2) to medium (e.g. patio door or picture window about 40 ft^2) to large (all glass wall). In the authors experience we have noted that occupants tend to gravitate towards larger windows. Desiring the connection to the outside world this exposes the occupant to greater risk of discomfort.

The next plot shows the comfort offsets for three different window exposure conditions:

- Small window (operator size) with occupant 3 foot away
- Medium size (patio door) with occupant 3 foot away
- Medium size (patio door) with occupant 6 foot away

Note that the comfort response is nearly the same for the small window at 3' and the medium size at 6' away. Given the more severe response for the medium size at 3' proximity we've chosen this as the benchmark for our analysis.

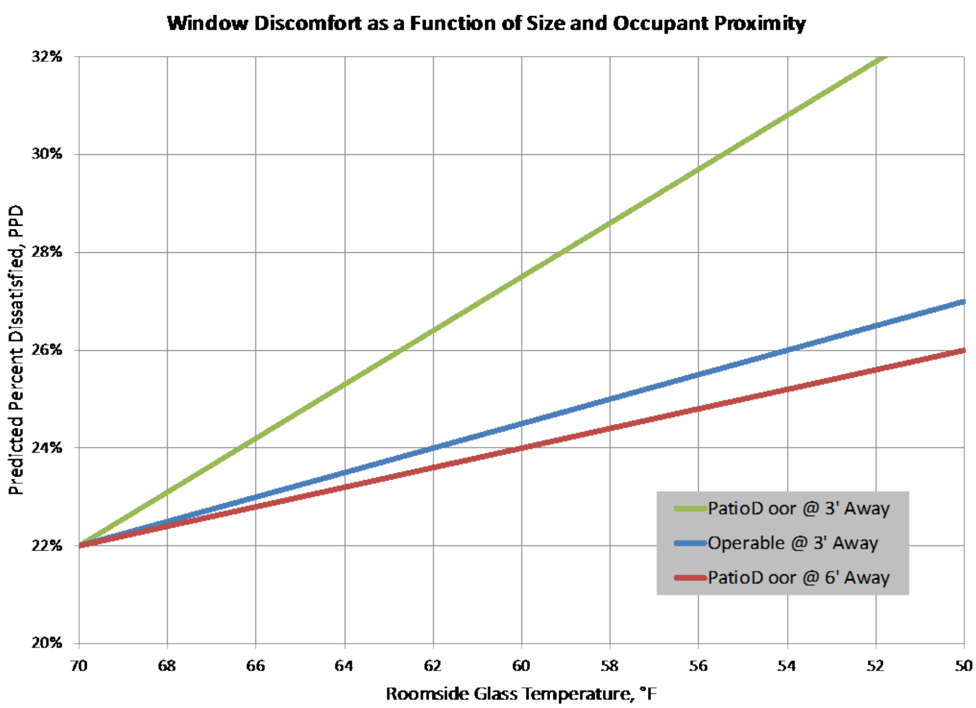


Figure 3. Predicted Percent Dissatisfied vs. Window Size, Temperature, and Occupant Proximity

In practice every window in the EWC set will lower cold weather comfort to some level, we just need to select a threshold point that matches with typical building practice. Two windows, representing code U-Factor (double pane w/low-E) and better than code (triple pane w/low-E) were analyzed in Minneapolis at three threshold levels of roomside temperature. The hours of discomfort are tabulated below:

Hours of Discomfort in Minneapolis

Comfort Threshold	Window U = 0.32	Window U = 0.20
52°F	2	0
56°F	193	3
60°F	727	212

Table 4: Evaluation of Discomfort Ranking

With current market practice we concluded that the 60°F threshold is too high: there is no evidence to suggest that double pane low-E gets 700+ hours a winter in comfort complaints. The 52°F number was deemed too low: there is little suggestion for improvement beyond double pane low-E and *Figure 3* also suggests this correlates to a 32% dissatisfaction level.

The EWC cold weather comparative analysis will use 56°F roomside surface temperature as the threshold for pass-fail on the question of whether a particular hour in the weather data file qualifies the window as uncomfortable. On the EWC website we present this graphic to explain discomfort for a variety of glazing options:

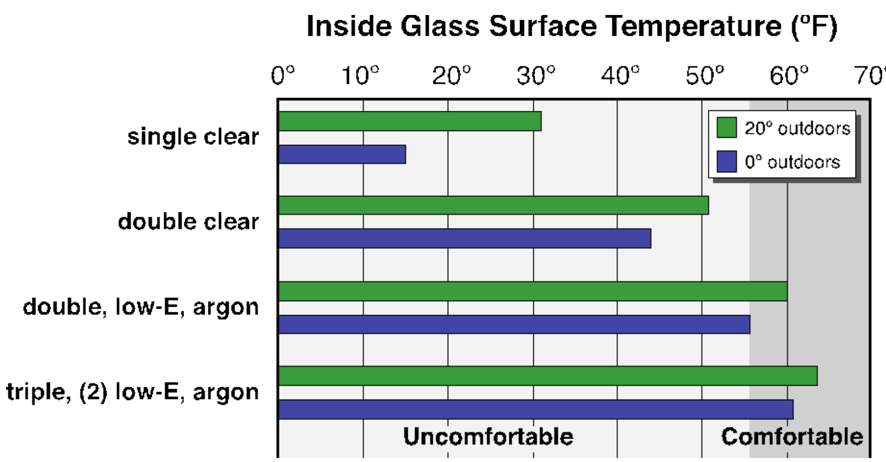


Figure 5. EWC Window Uncomfortable-Comfortable Threshold

SUMMER CONDITIONS AND DIRECT SOLAR RADIATION

Direct sun has obvious impacts on thermal comfort. During cold periods, limited solar radiation can be a pleasant sensation. But during warm or hot weather, it invariably causes discomfort. Just as people turn up the heat to compensate for cold windows in winter, they may use more air-conditioning to counter the effects of warm window surfaces and sunlight in summer.

This methodology takes into account the effects of solar radiation. Lyons and Arasteh adapted the estimation of Percent People Dissatisfied (PPD) when direct solar radiation was present and these correlations where incorporated into the hour-by-hour analysis. The method uses a linearized algorithm to predict the change in the predicted comfort vote (PMV) as a function of direct solar gain (Figure 6). The PPD is calculated from the net Predicted Mean Vote (PMV) (Lyons, 1999).

To determine the solar PMV affects for the Window Selection Tool, Energy Plus weather data was used in conjunction with a National Oceanic & Atmospheric Administration Solar Calculator to determine the angle of incidence on west facing vertical windows and thus the direct beam radiation on that elevation. While it's possible to get solar overheat in a space during the swing seasons of spring and fall, we set an outdoor temperature threshold at > 70°F to ensure the analysis looked only at air-conditioning hours. Following the protocols from the Lyons work a solar offset of 0.5 PMV points established when an hour of summer discomfort occurred.

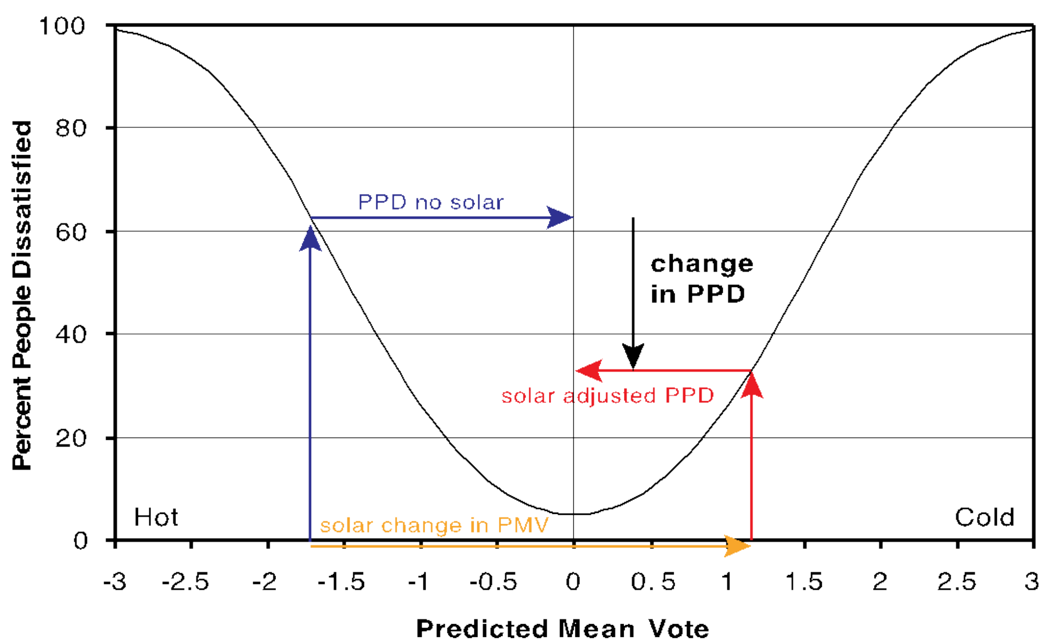


Figure 6. Fanger PPD-PMV relationship showing adjustment for solar load (Lyons, 1999).

COMFORT DISPLAY IN THE EWC WINDOW SELECTION TOOL

There are 98 North American locations in the EWC window selection tool. Weather data files from the Energy Plus program provide 8,760 hours of temperature and solar radiation in each location. For each location we determined hours of winter window discomfort using the 56°F threshold and summer window discomfort with the 0.5 PMV offset.

Windows below a level of 88 discomfort hours received a “neutral” rating. The neutral level is approximately 1% of the hours in a year. HVAC equipment sizing also use the 1% thresholds on weather conditions.

Looking at the graphical analysis of the window set across a variety of climates we selected 800 discomfort hours as the breakpoint between Cold and Cool while 200 hours is used for the Hot – Warm ranking.

The figures below illustrates hours of winter and summer discomfort for each of the 20 windows in Minneapolis. The winter ranking levels show code windows (#15, #16, #17) as “cool” and the triple pane products (#18, #19, #20) as “neutral”. Note also how the cool glass options 15–17 in a non-metal frame turn deliver a cold rank in a metal frame. The summer ranking levels matchup well with solar heat gain. An SHGC below 0.25 will be neutral and SHGC greater than 0.50 will be hot.

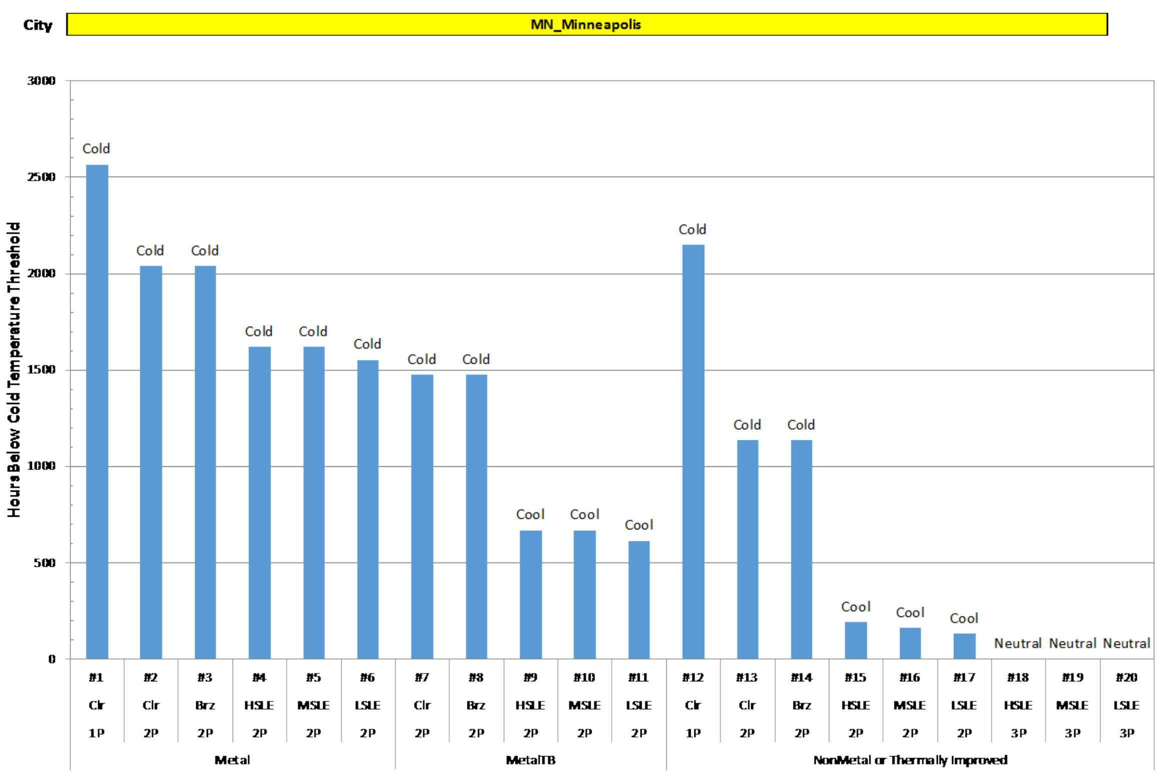


Figure 7. Winter Comfort Rankings of EWC Window Set in Minneapolis

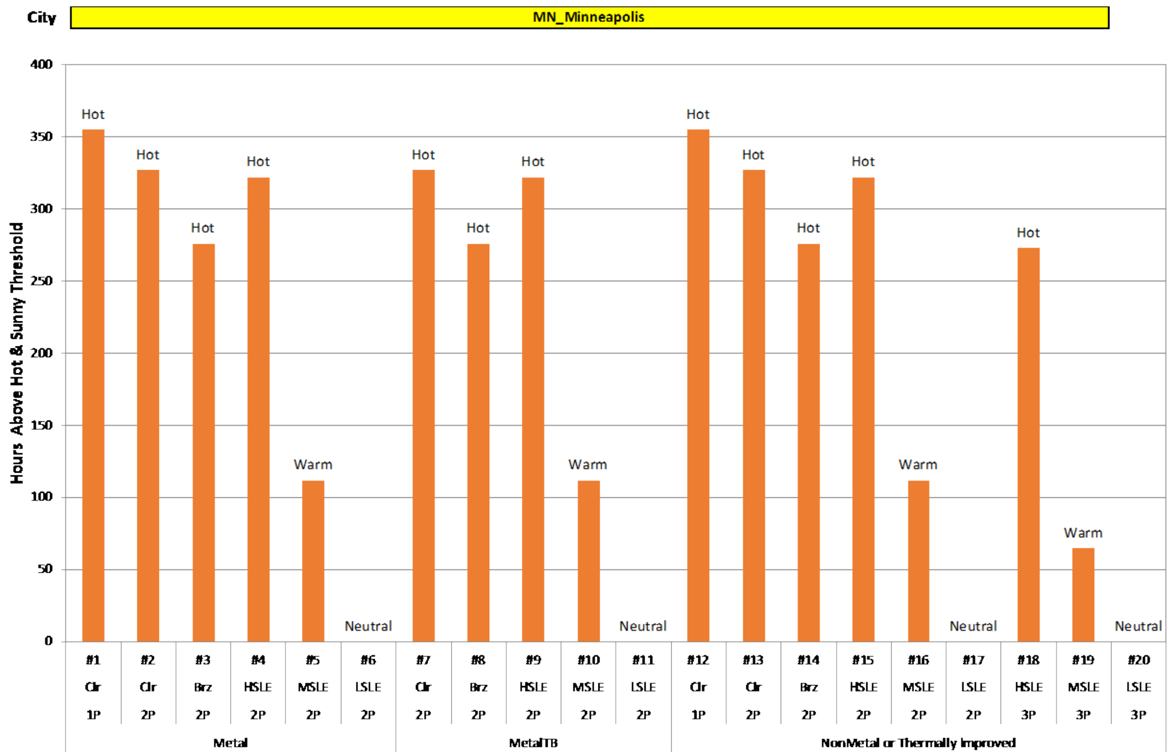


Figure 8. Summer Comfort Rankings of EWC Window Set in Minneapolis

In Houston the summer trends are nearly identical to Minneapolis while the neutral point for winter can be hit with U-factors as high as 0.65. The trends make sense, as the summer design temperatures in Houston are only about 5 degrees higher than Minneapolis while Houston winter design temperatures are about 40 degrees warmer than Minneapolis!

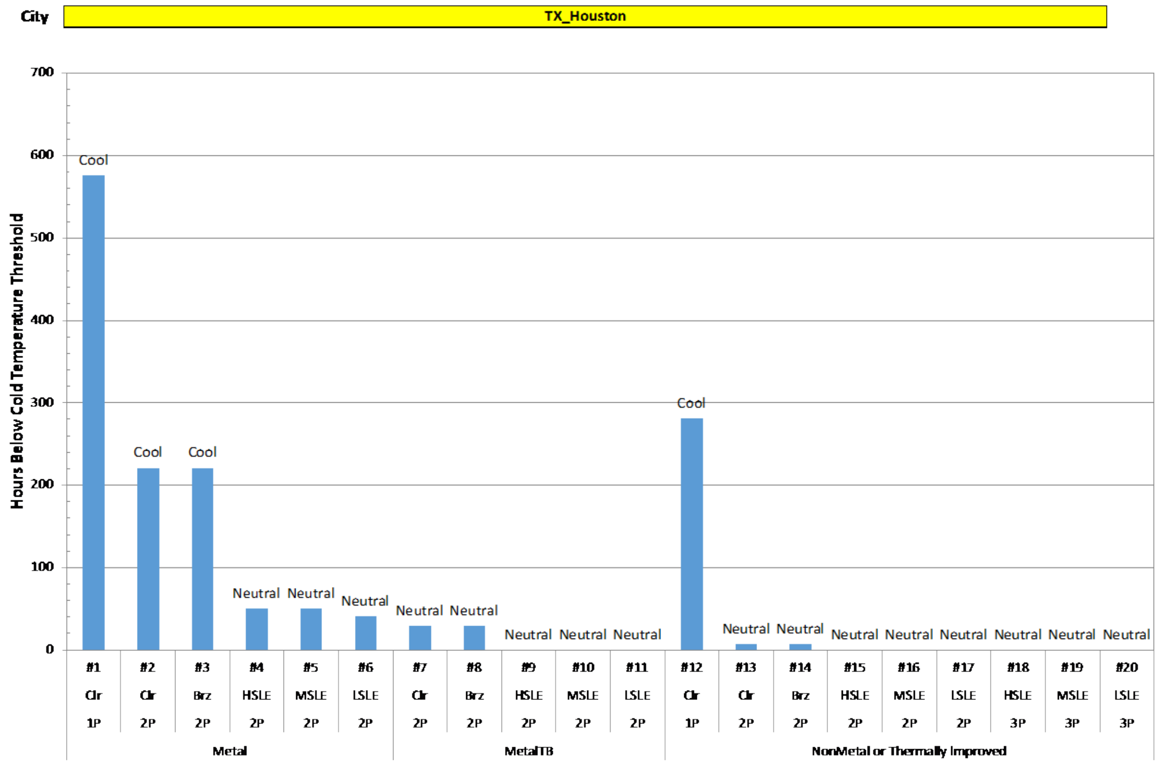


Figure 9. Winter Comfort Rankings of EWC Window Set in Houston

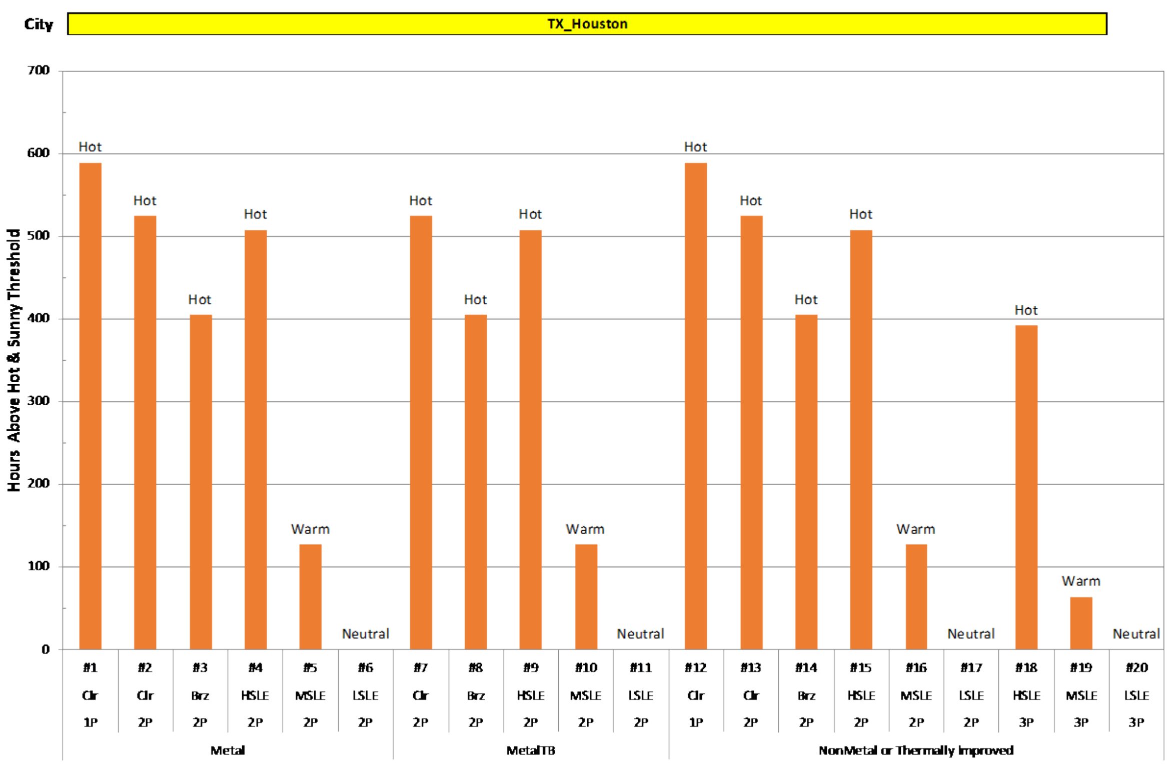
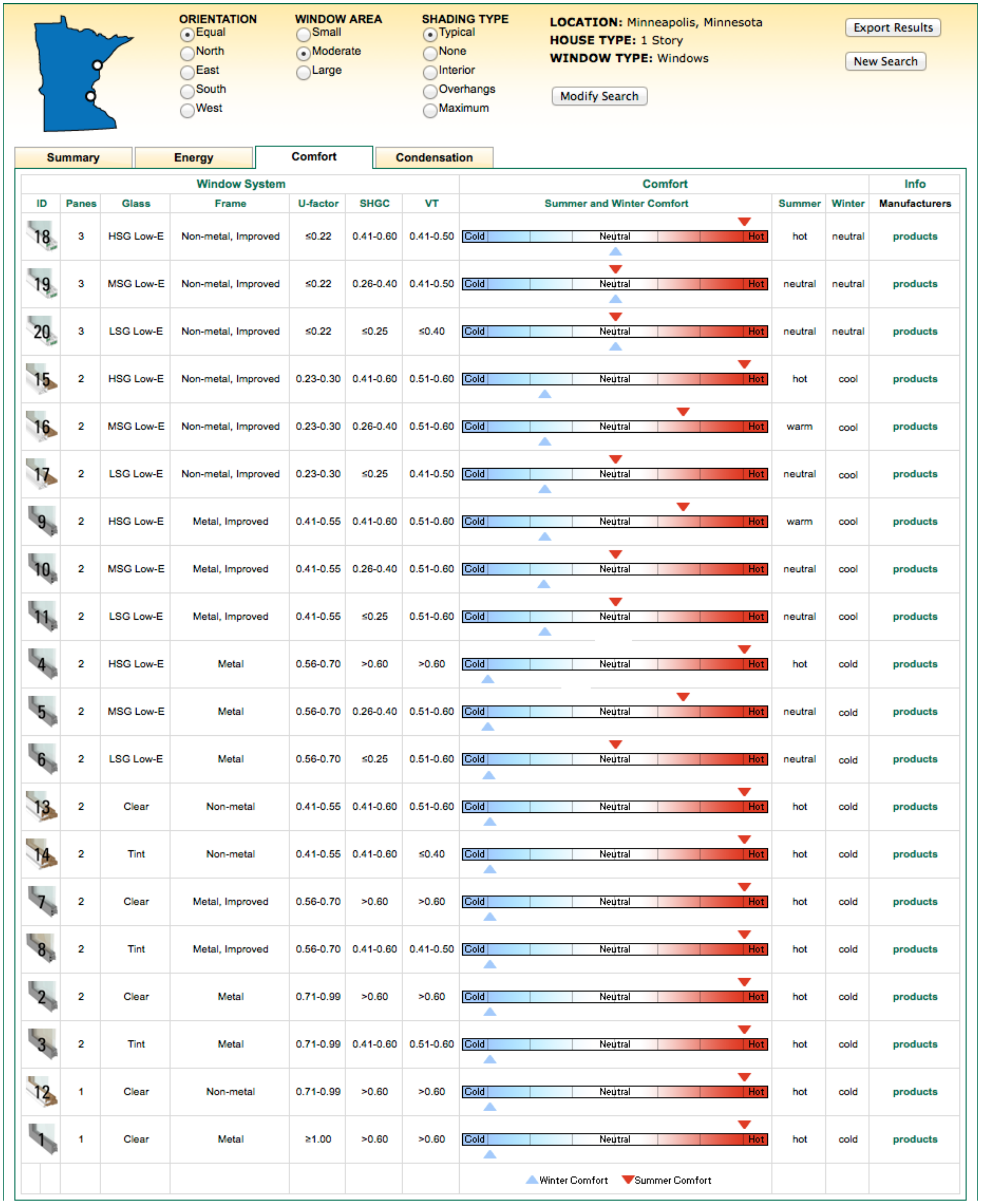


Figure 10. Summer Comfort Rankings of EWC Window Set in Houston



Window System							Comfort			Info
ID	Panes	Glass	Frame	U-factor	SHGC	VT	Summer and Winter Comfort	Summer	Winter	Manufacturers
18	3	HSG Low-E	Non-metal, Improved	≤0.22	0.41-0.60	0.41-0.50	Cold Neutral Hot	hot	neutral	products
19	3	MSG Low-E	Non-metal, Improved	≤0.22	0.26-0.40	0.41-0.50	Cold Neutral Hot	neutral	neutral	products
20	3	LSG Low-E	Non-metal, Improved	≤0.22	≤0.25	≤0.40	Cold Neutral Hot	neutral	neutral	products
15	2	HSG Low-E	Non-metal, Improved	0.23-0.30	0.41-0.60	0.51-0.60	Cold Neutral Hot	hot	cool	products
16	2	MSG Low-E	Non-metal, Improved	0.23-0.30	0.26-0.40	0.51-0.60	Cold Neutral Hot	warm	cool	products
17	2	LSG Low-E	Non-metal, Improved	0.23-0.30	≤0.25	0.41-0.50	Cold Neutral Hot	neutral	cool	products
9	2	HSG Low-E	Metal, Improved	0.41-0.55	0.41-0.60	0.51-0.60	Cold Neutral Hot	warm	cool	products
10	2	MSG Low-E	Metal, Improved	0.41-0.55	0.26-0.40	0.51-0.60	Cold Neutral Hot	neutral	cool	products
11	2	LSG Low-E	Metal, Improved	0.41-0.55	≤0.25	0.51-0.60	Cold Neutral Hot	neutral	cool	products
4	2	HSG Low-E	Metal	0.56-0.70	>0.60	>0.60	Cold Neutral Hot	hot	cold	products
5	2	MSG Low-E	Metal	0.56-0.70	0.26-0.40	0.51-0.60	Cold Neutral Hot	neutral	cold	products
6	2	LSG Low-E	Metal	0.56-0.70	≤0.25	0.51-0.60	Cold Neutral Hot	neutral	cold	products
13	2	Clear	Non-metal	0.41-0.55	0.41-0.60	0.51-0.60	Cold Neutral Hot	hot	cold	products
14	2	Tint	Non-metal	0.41-0.55	0.41-0.60	≤0.40	Cold Neutral Hot	hot	cold	products
7	2	Clear	Metal, Improved	0.56-0.70	>0.60	>0.60	Cold Neutral Hot	hot	cold	products
8	2	Tint	Metal, Improved	0.56-0.70	0.41-0.60	0.41-0.50	Cold Neutral Hot	hot	cold	products
2	2	Clear	Metal	0.71-0.99	>0.60	>0.60	Cold Neutral Hot	hot	cold	products
3	2	Tint	Metal	0.71-0.99	0.41-0.60	0.51-0.60	Cold Neutral Hot	hot	cold	products
12	1	Clear	Non-metal	0.71-0.99	>0.60	>0.60	Cold Neutral Hot	hot	cold	products
1	1	Clear	Metal	≥1.00	>0.60	>0.60	Cold Neutral Hot	hot	cold	products

Figure 11. EWC Window Selection Tool comfort metric for windows in Minneapolis

ORIENTATION
- Equal (selected)
- North
- East
- South
- West

WINDOW AREA
- Small
- Moderate (selected)
- Large

SHADING TYPE
- Typical (selected)
- None
- Interior
- Overhangs
- Maximum

LOCATION: Houston, Texas
HOUSE TYPE: 1 Story
WINDOW TYPE: Windows

Modify Search

Export Results

New Search

Summary | Energy | **Comfort** | Condensation

Window System							Comfort			Info
ID	Panes	Glass	Frame	U-factor	SHGC	VT	Summer and Winter Comfort	Summer	Winter	Manufacturers
20	3	LSG Low-E	Non-metal, Improved	≤0.22	≤0.25	≤0.40	Cold Neutral Hot	neutral	neutral	products
17	2	LSG Low-E	Non-metal, Improved	0.23-0.30	≤0.25	0.41-0.50	Cold Neutral Hot	neutral	neutral	products
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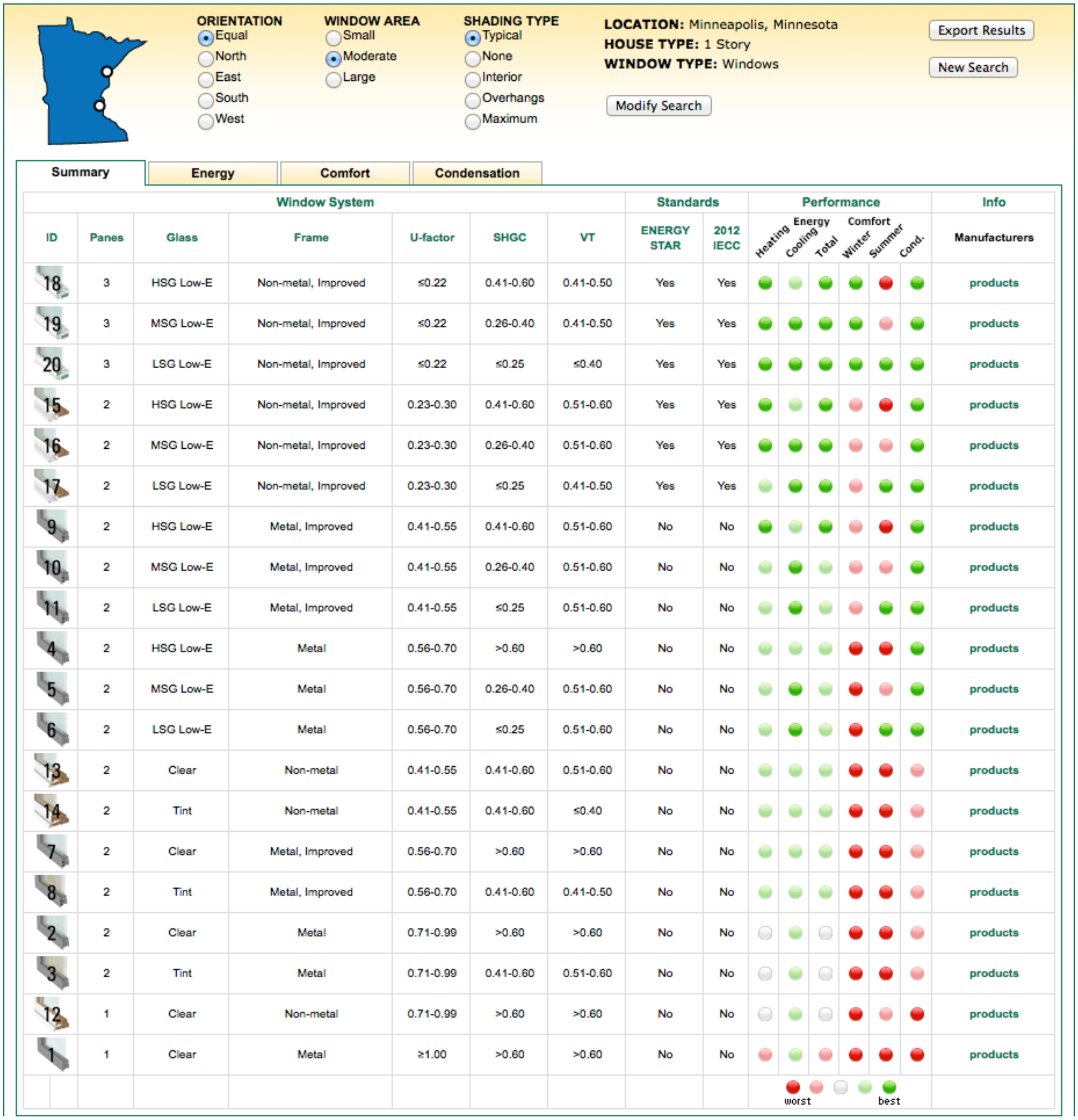
1	1	Clear	Metal	≥1.00	>0.60	>0.60	Cold Neutral Hot	hot	cold	products
							Winter Comfort / Summer Comfort			

Figure 12. EWC Window Selection Tool comfort metric for windows in Houston

CONCLUSIONS

The EWC Window Selection Tool provides a methodology to rank the winter and summer comfort for a variety of window options. Figure 13 shows an example of a summary where the comfort rankings can quickly be compared to the energy performance rankings for the 20 windows. The comfort ranking will provide insights beyond the traditional energy analyses into the window performance.



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8	2	Tint	Metal, Improved	0.56-0.70	0.41-0.60	0.41-0.50	No	No	products
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Figure 13. EWC Window Selection Tool performance summary metrics for windows in Minneapolis

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TABLES AND FIGURES

BIOGRAPHIES

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Ms. Haglund has a Bachelor and Master of Architecture from the University of Minnesota. Kerry was Senior Research Fellow at the Center for Sustainable Building Research (CSBR) at the University of Minnesota for 15 years but is now focusing her efforts on consulting and the Efficient Windows Collaborative. Her work focuses on windows and glazings research, decision-making tool development, and information design and dissemination. Kerry currently sits on the Board of Directors for the National Fenestration Rating Council (NFRC) and is an active participant of NFRC's committees as well as other window industry associations. She was named in Glass Magazine's 2012 List of Most Influential Individuals Impacting the Glass and Metal Industry.

Jim Larsen, Director, Technology Marketing
Cardinal Glass Industries
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Mr. Larsen is a mechanical engineer by training with 30+ years of experience in the research and development of glass products for windows. Today, Jim's principle job responsibility is supporting the recognition of efficient windows through building energy codes. He also provides product support through website development (www.cardinalcorp.com), product brochures, customer training, and building energy research.

Jim has been involved with the National Fenestration Rating Council (NFRC) since its inception, has chaired many of the technical committees and currently sits on the NFRC board or directors. Mr. Larsen has also been a board member of the Energy and Environmental Building Association (EEBA) and the Midwest Energy Efficiency Alliance (MEEA). He has been a member of the state energy code committees in Florida and Minnesota, and has testified on behalf of efficient windows for numerous state and national code activities. Jim currently sits on the ASHRAE 90.2 committee for residential building energy performance. Jim is a frequent presenter at energy efficiency conferences such as EEBA, Affordable Comfort, BETEC, DOE Envelope Conference, etc.

Under Jim's direction, Cardinal Glass has built and monitored multiple test houses across the country to evaluate the energy impacts of new glass technologies. These fully instrumented real world test houses have also been utilized by Building America research partners. The integration of the latest glass technologies with improvements to the performance of other building components is demonstrating the efficiencies possible in today's buildings and provides validation on the building practices needed to reduce energy consumption by 50% and more.