SELECTION AND IMPROVEMENT OF SHGC AND U-VALUE IN LOCATIONS WITH COLD WINTER AND WARM SUMMER

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ABSTRACT

The climate is changing in Canada, and this change is affecting homes and buildings, making it hard to decide how to select a proper SHGC for new windows or improve the current windows. The number of days with warm summer temperatures is increasing in Canada. For a city like Windsor, we expect more than 30 days above 35°C (95°F) in the summer, and winter gets as cold as -20°C (-4°F).

Higher solar heat gain can provide free winter heating in colder climates, but can lead to overheating and occupant discomfort in warm seasons and afternoons. Overheating is a very important issue in buildings because it has a direct effect on energy consumption, indoor comfort, and the aesthetic of the façade.

This paper considers several kinds of windows and glazing systems, different designs, orientation, shading conditions, and other devices to find an effective material and design to achieve an optimum solar heat gain for climates with a high temperature in summer and low temperature in winter.

The widely recognized NFRC 200 procedure (SHGC rating method) is used to determine the solar heat gain coefficient (SHGC) and visible transmittance of curtain-wall systems. THERM 7.4 2D, WINDOW 7.4, Resfen5, and EnergyGaugeUSA5 software are used to model the windows.

INTRODUCTION:

Most new projects in Canada use double- or even triple-glazed windows with one or two layers of low-emissivity coating, but overheating is still a big concern for occupant comfort and building energy consumption. Finding a proper window and IGU isn't so easy when there are so many parameters that designers should consider and involve in their decisions.

On the other hand, we have gotten used to change in many parts of our lives as the seasons change, but building facades and enclosures don't change in response to the changing seasons. We change our car tires, windshield-washer fluid, clothes, shoes, ventilation systems, and so on, but we don't change anything in our building facades – often the part of building with the highest rate of energy use.

In this paper, Windsor, Ontario has been selected as a city with warm summers and cold winters. It is Ontario's warmest city, although the winters are still severe. Snow depth in this city is greater than 1cm for about 53 days each year compared with 10 days per year in Vancouver. We will review different windows and glazing options, and other solutions for improvement, to find the best options for Windsor.

CLIMATE CHANGE AND ITS EFFECT ON WINDOW SELECTION:

Canada, like the rest of the world, is seeing significant climate change, and projections show that this will continue in the future. These changes affect human and natural systems, as well as buildings and the construction industry. It impacts building designers and their design methods. Figure 1 shows that the temperature in Canada has increased by almost 1.3°C (2.3°F) since 1948. This rate is high– almost twice the global average warming trend.

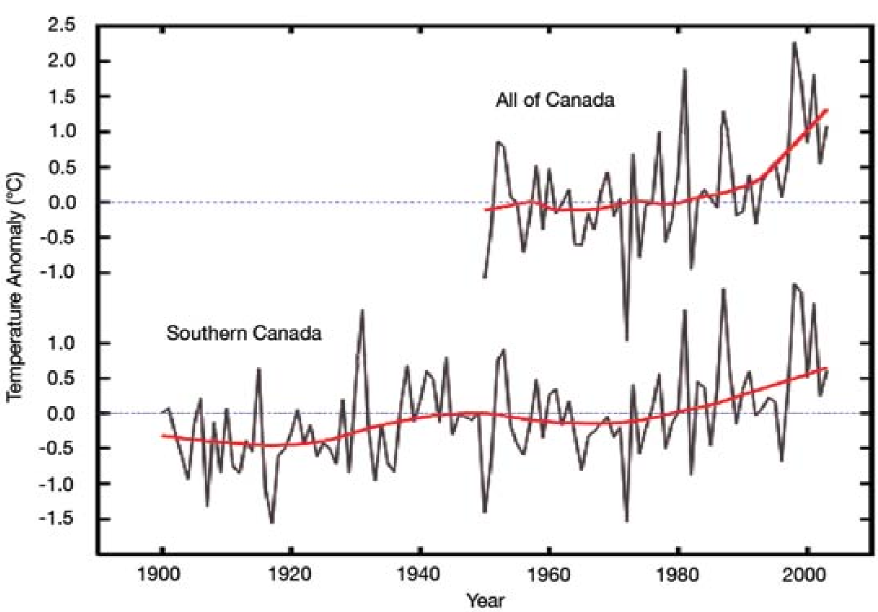


Figure 1: Annual national temperature excursions and long-term trend, 1948 to 2006 (Environment Canada, 2006)

All regions of Canada have warmed in recent years, and some parts have seen a reversal in the trend from cooling to warming starting in the 1990s. Figure 2 shows seasonal temperatures in Canadian regions. Summer warming is more consistent in all regions, even if temperatures are different for each region in other seasons.

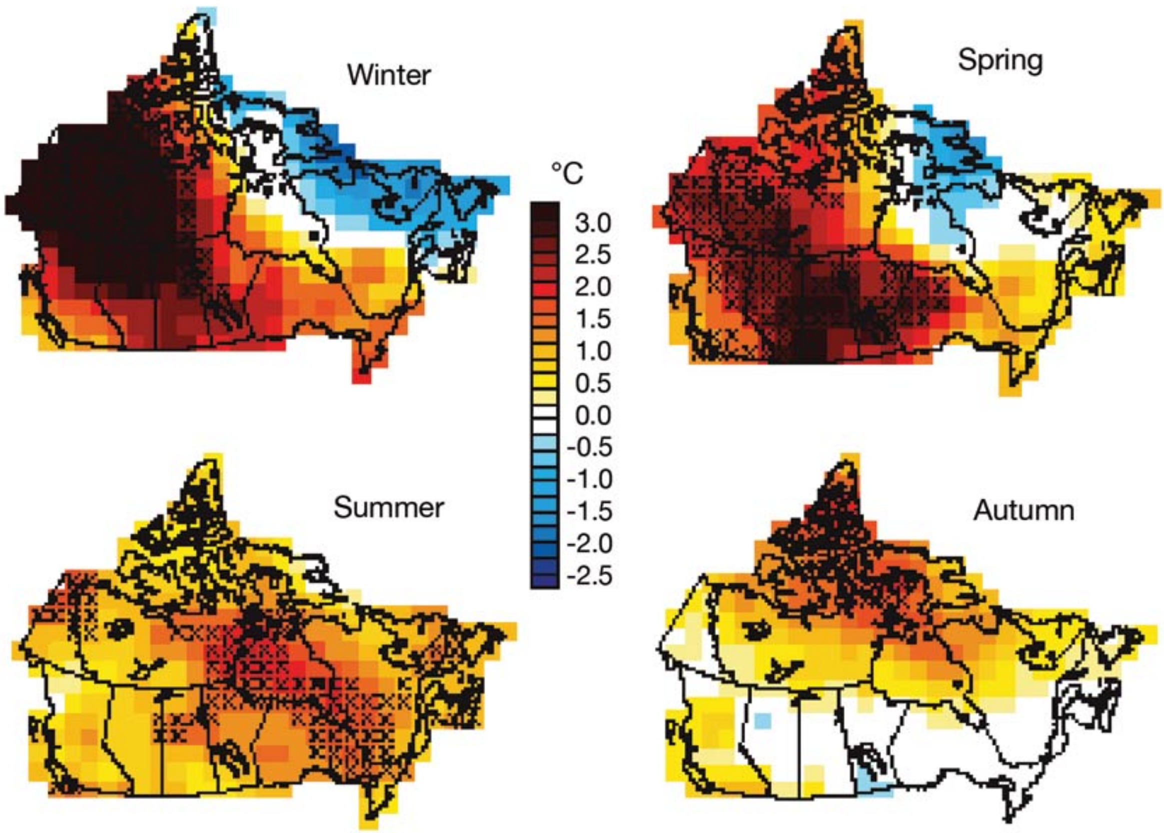


Figure 2: Regional distribution of linear temperature trends (°C) observed across Canada between 1948 and 2003, by season. The "X" symbols indicate areas where the trends are statistically significant (Hengeveld et al 2005).

The frequency of extremely warm summers is increasing, and heat waves are projected to become more frequent in Canada. The number of days with temperature above 30°C (86°F) exceeds 30 days in some cities and expecting to exceed 60 days in the future, according to Figure 3. This chart shows the expected temperature in the years 2020 to 2100, and the number of hot days will triple in most Canadian cities.

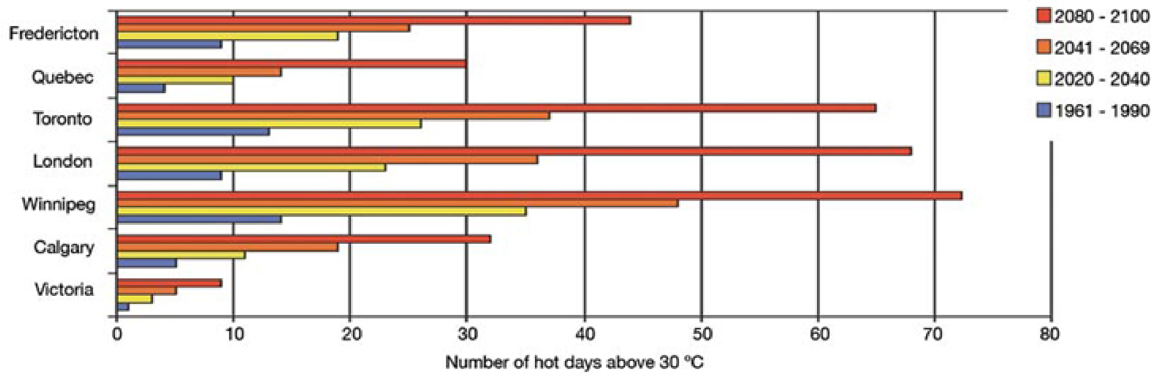


Figure 3: Number of days with temperatures exceeding 30°C (86°F), during observed (1961-1990) and future (2020-2040; 2041-2069; and 2080-2100) time periods. (Hengeveld et al 2005).

Twenty-five years of data for cooling degree-days (CDD) and heating degree-days (HDD) have been gathered for Windsor. The month of July has been chosen to represent cooling degree-days, and the trend lines show a significant increase in CDD, whereas HDD decreased slightly. Figure 4 shows HDD for Windsor from July 1992 to July 2016. These data show that the summer season in Windsor has been warmer, and show how much cooling is needed to reach the balance-point temperature to 18ºC (65°F).

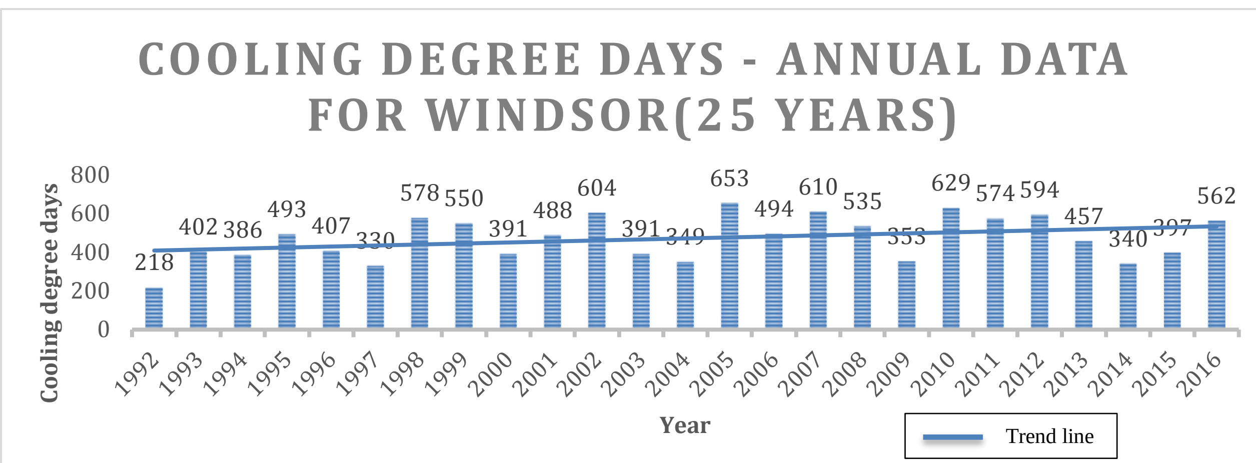


Figure 4: Annual Cooling Degree-Days for Windsor (25 years). ***Source:*** **http://weatherstats.ca**

On other hand, heating degree-days have been gently trending downward for 25 years (Figure 5), which means that heating demand to increase the daily balance-point temperature up to 18ºC (65°F) is decreasing.

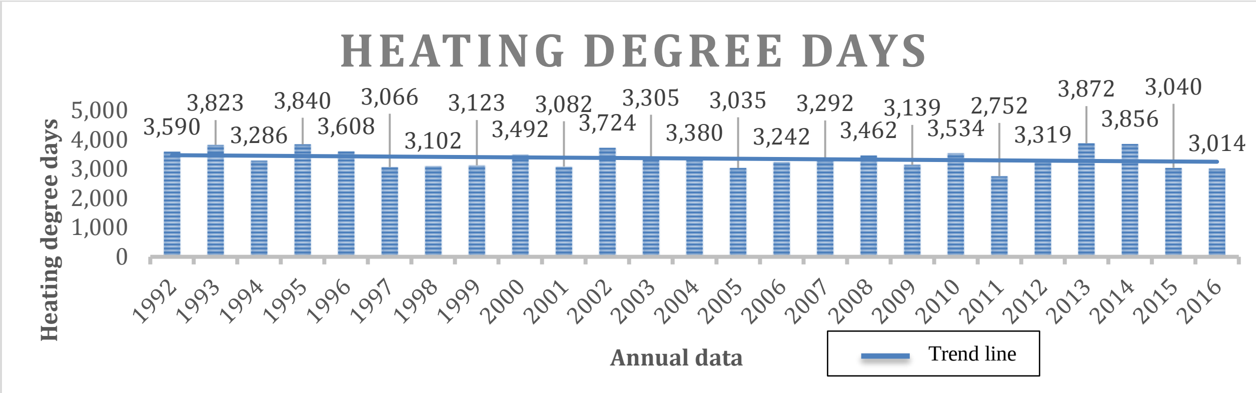


Figure 5: Heating Degree Days- Annual data for Windsor (25 years). ***Source:*** **http://weatherstats.ca**

In this study, different window products were compared to find an energy-consumption trend line affected by U-value and SHGC. Windows were selected from the Resfen5 database with U-values between 1.03 W/m^2-°C (0.182 Btu/h-ft^2-°F) and 6.58 W/m^2-°C (1.159 Btu/h-ft^2-°F), and SHGC between 0.333 and 0.756. The house is a two-storey, 280-m^2 (3000-ft^2) residence in Windsor. All elevations have 9.3 m^2 (100 ft^2) of window area, and a 2.3-m^2 (25-ft^2) skylight has been considered.

Table 1 : Windows selected from the Resfen5 database

window ID	Window name	U-value (Btu/h-ft^2-°F)	SHGC	Heating (kWh)	Cooling (kWh)	Total (kWh)
241	ATB 2 SS Low-E	0.47	0.333	16544	880	17424
351	W/V 3 HT Super	0.285	0.382	14424	1028	15452
451	INS 3 HT Super	0.182	0.402	13175	1134	14309
211	ATB 2 Clear	0.634	0.62	16501	1488	17989
201	ATB 1 Clr	1.00	0.696	19316	1549	20865
101	AL 1 Clr	1.159	0.756	20226	1652	21878
413	INS 2 SS Tint	0.444	0.405	15755	1058	16813
412	INS 2 Bronze	0.444	0.492	15366	1232	16598
411	INS 2 Clear	0.444	0.596	14813	1503	16316

When SHGC increases, the cooling energy consumption increases accordingly (Figure 6). It is important to note that the U-value is not constant in Figure 6, and part of the energy consumption relates to U-value.

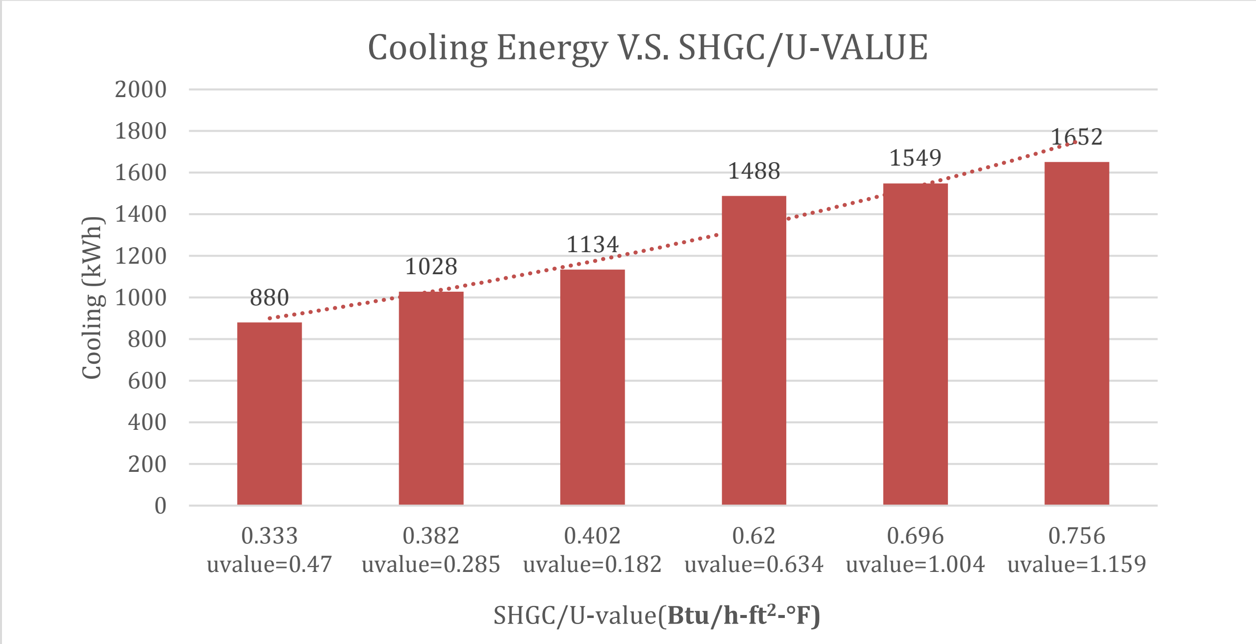


Figure 6: Cooling energy VS. SHGC/U-value (Btu/h-ft^2-°F)

In Figure 7, the U-value is held constant, and with SHGC changing from 0.405 to 0.596 the cooling energy changes from 1058 kWh to 1503 kWh, an increase of 445kWh.

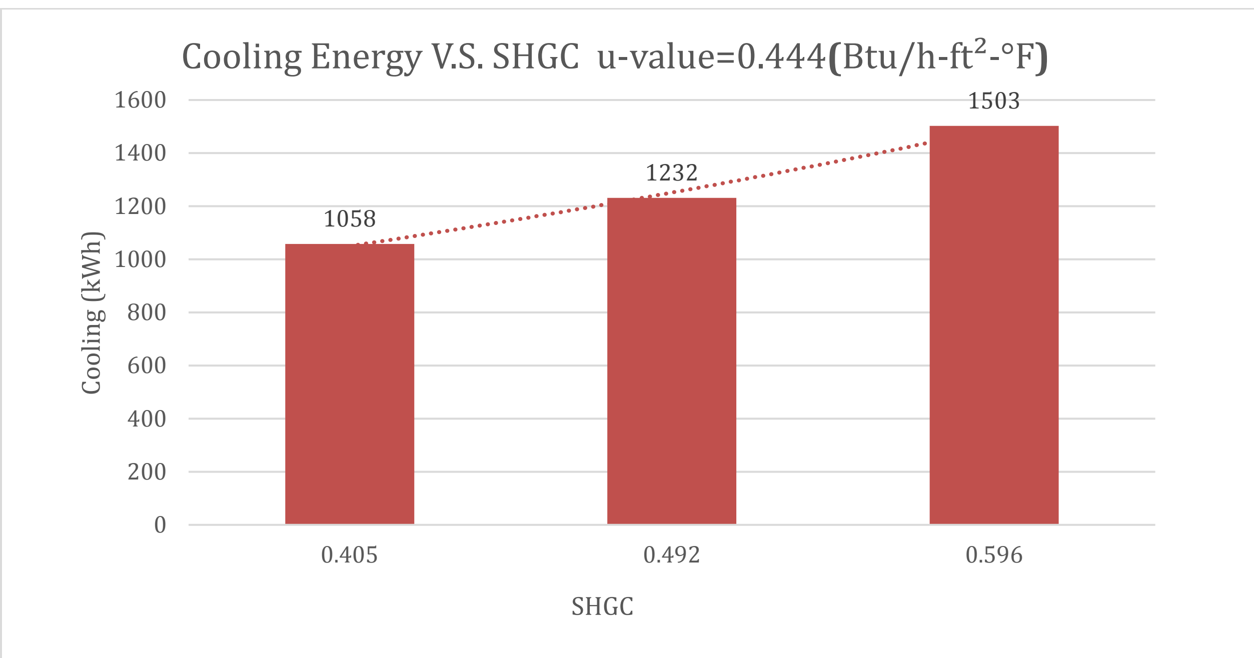


Figure 7: Cooling energy VS. SHGC (U-value= 0.444 Btu/h-ft^2-°F)

Overall, Figures 6 and 7 show that the lower U-value and SHGC yields greater energy efficiency for the Windsor climate. For a more refined comparison, a greater variety of windows was selected from window-selection tools provided by the Efficient Window Collaborative website. Table 2 shows a list of windows with a range of U-values and SHGCs, along with heating and cooling and total costs. In this case, the house is a new 240-m^2 (2600-ft^2) two-storey building in Windsor with equal wall and window areas on all sides. The window area is more than 20% in each orientation, and window have no canopies or overhangs.

Table 2: Windows selected from the Efficient Window Collaborative window-selection tool

window ID	Window name	U-value (Btu/h-ft²-°F)	SHGC	Heating cost	Cooling cost	Total cost
1-6	2 pan LSG Low-E Metal	0.56-0.70	≤0.25	$590	$135	$725
2-11	2 pan LSG Low-E Metal, Improved	0.41-0.55	≤0.25	$534	$132	$665
3-18	3 pan HSG Low-E Non-metal, Improved	≤0.22	0.41-0.60	$372	$222	$594
4-19	3 pan MSG Low-E Non-metal, Improved	≤0.22	0.26-0.40	$422	$156	$578
5-20	3 pan LSG Low-E Non-metal, Improved	≤0.22	≤0.25	$454	$122	$575
6-23	2 pan LSG Low-E Non-metal, Improved	0.23-0.30	≤0.25	$461	$129	$590

Figure 8 shows four windows with SHGC ≤ 0.25 and U-values ranging from 1.25 to 3.97 W/m2-°C (0.22 to 0.70 Btu/h-ft2-°F). Annual cost for both heating and cooling increases as U-value increases, although cooling energy doesn't show a huge difference. The best window will decrease total cost to $575 per year.

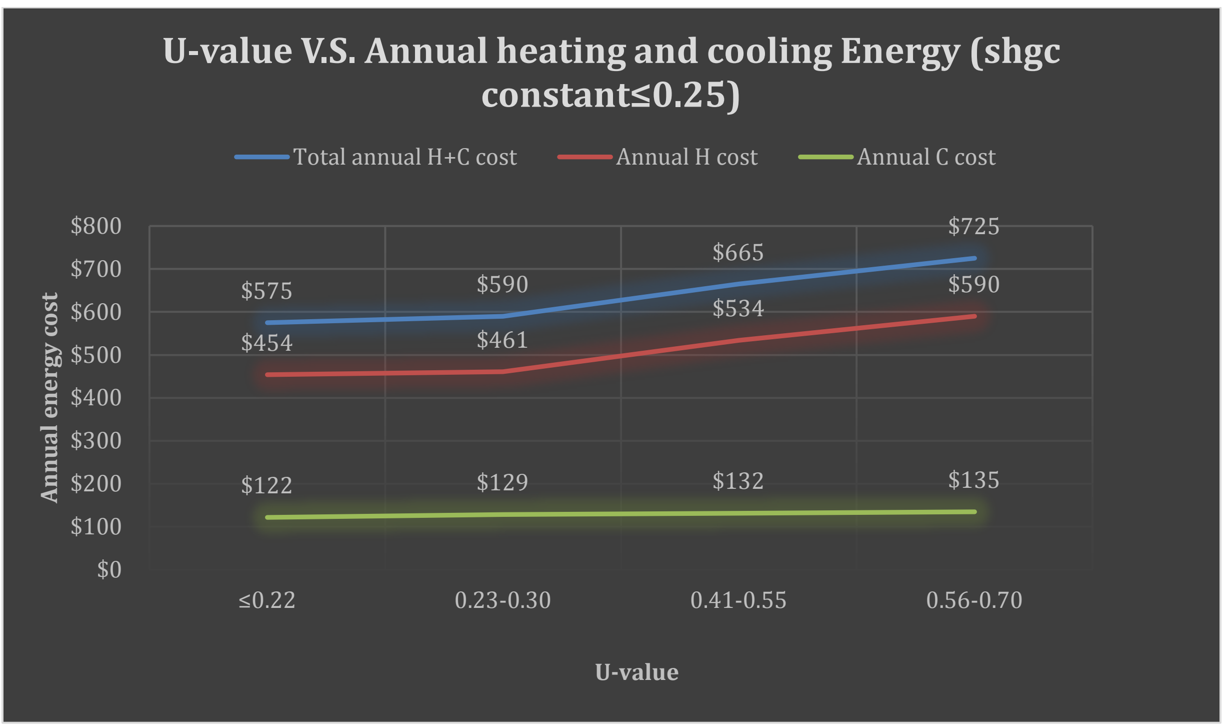


Figure 8: U-value V.S. Annual heating and cooling energy (SHGC constant ≤ 0.25)

With a constant U-value ≤ 1.25 W/m^2-°C (0.22 BTU/hr-ft^2-°F) and changing the SHGC, the cooling energy cost increases more than the heating energy cost (see Figure 9).

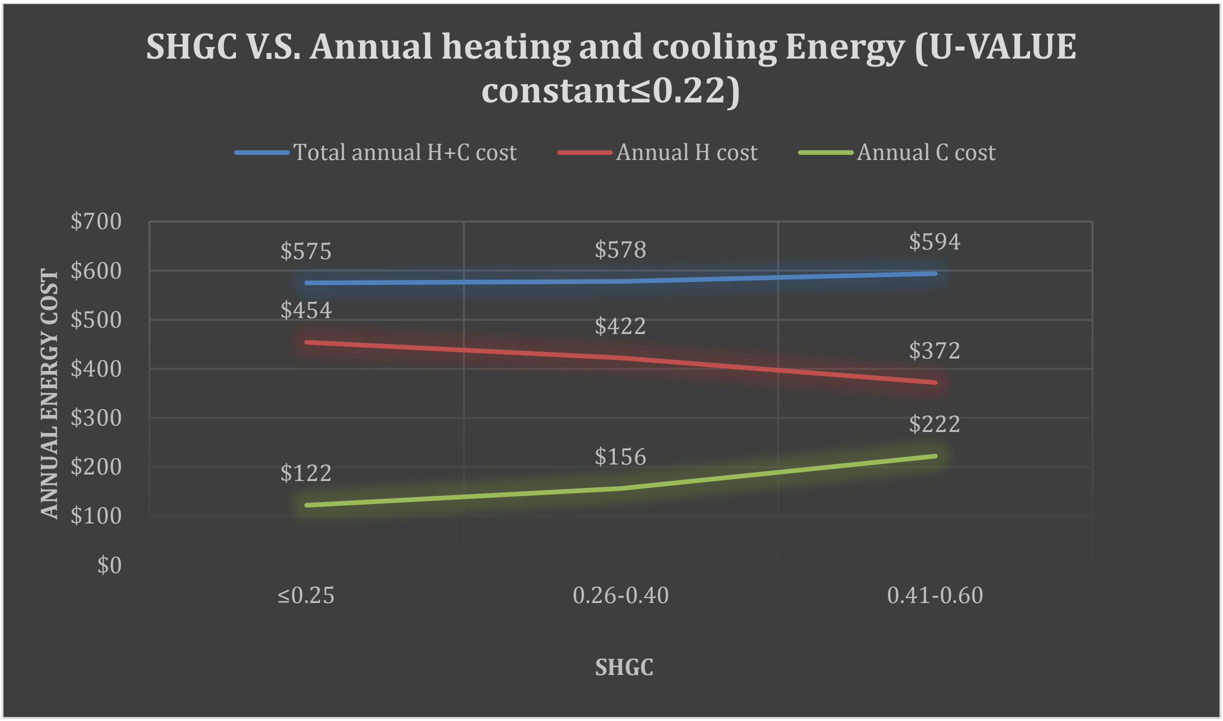


Figure 9: SHGC V.S. Annual heating and cooling energy (U-value constant ≤ 0.22)

Therefore annual energy costs with the best window in this study would be $575 ($454 is for heating and $122 for cooling). Some improvement methods were considered to decrease this cost even further. Some of these solutions are not associated with an increased cost, but are simple design changes.

IMPROVEMENT OF SHGC AND U-VALUE:

Using removable shading systems

A shading system that can be removed in winter and installed in summer, decreases energy cost:

Table 3: list of windows with lowest and highest SHGC from window selection tool

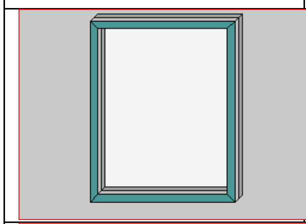
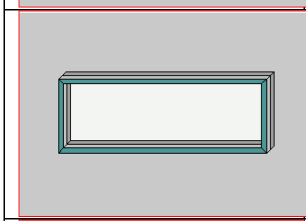
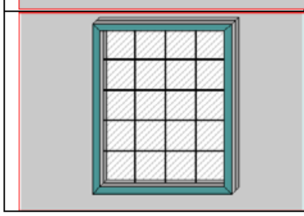
Window ID	U-Factor (Btu/h-ft²-°F)	SHGC	VT	Total Cost	Heating Cost	Cooling Cost
5-20	≤0.22	≤0.25	≤0.40	$575	$454	$122
3-18	≤0.22	0.41-0.60	0.41-0.50	$594	$372	$222

The total energy cost for this system would be $122 + $372= $ 494, which is $81 lower than a window with U-factor ≤ 1.25 W/m^2-°C (0.22 BTU/hr-ft^2-°F) and SHGC ≤ 0.25. in this example, we only need to change window SHGC from SHGC ≤ 0.25 in summer to SHGC = 0.41-0.60 in winter.

Window design

Using a different geometry with the same window area can produce different performance in windows. This design change doesn't necessarily affect the cost of the window, but it can optimize annual energy cost. In table 4, three windows with the same IGU and profiles have been modeled in WINDOW software. The window area is constant at 2.25 m^2 (24.2 ft^2) but the shape and design changes. The results show square windows have a better thermal performance than rectangular ones. Even in square shape, using the divider will increase the U-value dramatically. SHGC and VT differences depend on the profile sections and system properties.

Table 4: list of windows with the same area and different geometry

Window figure	Dimension	Operation	Area (m^2)	U-value	SHGC	VT
	1500x1500	Fixed vinyl window	2.25	1.603 W/m^2-°C	0.232	0.540
	2500X900	Fixed vinyl window	2.25	1.637 W/m^2-°C	0.226	0.524
	1500x1500	Fixed vinyl window	2.25	1.733 W/m^2-°C	0.208	0.471

Window orientation

Selecting a proper SHGC and U-value based on the orientation of the window is also important. Table 5 shows different SHGC and U-values that have the best performance based on the wall orientation.

Table 5: SHGC and U-value based on building elevation

Window facing	For cold climate, choose:	For warm climate, choose:
North	Lowest U-factor	Low U-factor
South	Highest SHGC, Lowest U-factor	Low SHGC and shading
East	Low SHGC or shaded	Low SHGC, Low U-factor
West	Low SHGC or shaded	Low SHGC, Low U-factor

Storm windows

Storm windows greatly affect SHGC and U-value for existing windows. Table 6 shows different kinds of windows with attached storm windows. In the worst case, storm windows improve U-value by 25-35%, and decrease SHGC by 8-20%. Locations with cold winters and warm summers require U-values ≤ 1.25 W/m^2-°C (0.22 BTU/hr-ft^2-°F) and SHGC ≤ 0.25, so storm windows can help improve window performance.

Table 6: Effect of storm windows on metal-framed windows (KA Cort, Pacific North West national laboratory, 2015)

Base Window	Storm Type	U-factor, W/m2-°C (Btu/h-ft2-°F)	SHGC	VT
Aluminum double hung, single glazed	None	6.36 (1.12)	0.61	0.65
Worst case mounting	Clear, Exterior	3.81 (0.67)	0.56	0.58
Thermally broken mounting	Low-e, Exterior	2.50 (0.44)	0.48	0.54
Aluminum double hung, double glazed	None	4.26 (0.75)	0.58	0.6
Worst case mounting	Clear, Exterior	3.12 (0.55)	0.51	0.54
Thermally broken mounting	Low-e, Exterior	2.04 (0.36)	0.44	0.5
Aluminum fixed, single glazed	None	6.02 (1.06)	0.72	0.77
Worst case mounting	Clear, Exterior	3.52 (0.62)	0.59	0.62
Thermally broken mounting	Low-e, Exterior	2.38 (0.42)	0.52	0.59
Aluminum fixed, double glazed	None	3.52 (0.62)	0.67	0.71
Worst case mounting	Clear, Exterior	2.67 (0.47)	0.54	0.58
Thermally broken mounting	Low-e, Exterior	1.87 (0.33)	0.48	0.55

Dynamic facades and systems

These systems work based on weather condition and adjust visible transmittance and solar heat gain for occupant comfort as well as heating and cooling energy consumption in different seasons. Table 7 shows the results of a study by View Dynamic Glass, conducted for workplaces in five U.S. locations with different climates: Atlanta, Miami, Phoenix, New York, and San Francisco. This table shows the difference in energy consumption between Low-e and Dynamic glass based on various end uses.

Table 7: Energy benefits on Dynamic glass in workplace (View Dynamic Glass)

	Average	
End use	Low-emissivity glass (Mbtu)	Dynamic glazing (Mbtu)
Space cooling	575	494
Vent fans	98	78
Pumps	15	14
Miscellaneous Equip	666	666
Area lights	670	518
Space heating	133	163
Hot water	89	90
Total	2246	2021

Although these systems are very effective, they require more design consideration for controls, interaction with other systems, and operating costs. More savings could be achieved if the electric lighting is also controlled with this system.

Operable shading layers

These shading layers or blinds are installed between glazing layers or in front of the window. They prevent overheating but decrease occupant comfort. While these layers decrease cooling energy, electricity consumption increases as natural light is replaced with artificial electric lights. Horizontal blinds or louvers can transmit daylight and provide more view to the exterior. These blinds are efficient for privacy and personal security, but not an efficient option for reducing cooling-energy costs.

Double-skin façades

Control of solar heat gain through shading systems between two layers of the building enclosure is one of the most advance design improvements. Typically, either motorized or manual blinds between the skins is used to reduce SHGC, and venting the air cavity. Based on a study at Zhejiang University, double-skin façades can provide significant reduction of the cooling load. In this study, the cooling load was calculated for both double- and single-skin façades for different orientations of a building and detailed CFD simulation was used to find the energy savings from using a double-skin façade.

Table 8: Annual cooling load saving (Shu, He, Zhang and Bai, 2011)

	Annual cooling load for double-skin façade			
Orientation	East	South	West	North
Double-skin façade (kWh/m²)	42.16	40.51	63.73	32.86
Single-skin façade (kWh/m²)	51.19	49.2	77.19	39.98
Energy saving (kWh/m²)	9.03	8.69	13.46	7.12
Energy saving percentage %	17.6	17.7	17.4	17.8

External shading devices

Shading devices can reduce solar gains in glazed buildings. Installation cost and safety considerations can be a concern, but external shading devices can reduce overheating by preventing solar gains from entering the conditioned space. These devices are usually fixed and not able to block sunlight from all angles, especially at low angles at the beginning and end of the day.

According to a study conducted (Diane Bastien, Andreas K. Athienitis, 2015) on different exterior devices under NFRC conditions, exterior shades can improve the glazing U-value by 25%. In this study a new methodology was used for window U-value calculation:

$Uw= \frac{\sum UgAg+\sum UfAf+\sum I\psi\Psi}{At}$, where Iψ is the vision area perimeter and Ψ is linear thermal transmittance in this equation.

CONCLUSION

In this paper we consider many tools and methods to select the best SHGC and U-value for a window and optimize for the best performance (i.e., reduced energy consumption and increased occupant comfort).

Windsor, Ontario, was used as an example of a location with warm summers and cold winters. The study shows that U-factor ≤ 1.25 W/m^2-°C (0.22 BTU/hr-ft^2-°F) and SHGC ≤ 0.25 is the best choice for this city, but in case further improvements are needed we reviewed other possible design choices.

In terms of U-value and SHGC improvement, many methods have been considered: removable shading systems, window configuration, storm windows, dynamic façades and systems, operable shading layers, double-skin facades, and external shading devices. Each method is considered individually, and advantages and disadvantages are shown for each option.

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