DESIGN STRATEGY FOR LOW E WINDOWS WITH EFFECTIVE INSULATION

Impattern Solutions

<u>Design strategy for Low e windows with effective insulation</u>

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Whether you want to save your wallet, save your planet, or run around naked at home; effective insulation of structures is essential. As always, it is often difficult to sort out the most important issues. In particular, windows are the largest source of heat loss, and there are hundreds of glass choices. This is attempt to demystify window insulation.

Summary

A typical house looses 1-4kW of energy through double pane windows, depending on location. Improving the energy efficiency of windows is a significant cost and energy saving opportunity.

There are 4 different energy bands that determine the effectiveness of a window; visible transmission, solar near IR heating, mid IR re-radiation from structures, and thermal convection. It is desirable to reflect solar near IR in hot climates to reduce A/C bills, and to transmit solar near IR in cold climates to heat the structure.

Each energy band requires it's own mitigation strategy. Thermal convection is reduced by multiple pane windows and filling the gaps between the panes with low conductivity gases. In the mid IR , glass is highly absorbing and passes energy by re-radiation. Mid IR re-radiation is reduced using silver conductive coatings that have very low emissivity. In the near IR and visible, transmission and reflection are engineered using thin multilayer stacks containing the conductive coatings

Analytical model for each energy band was developed so as to understand how the different mitigation strategies interact. Based on the models, a selection criteria for the windows was created for both hot and cold climate windows. For cold climates, the low e silver conductive coating are made very thin and part of a multilayer to make the coating as transparent as possible in both visible and near IR. In hot climates, the multilayer is designed to be filter that is transparent in the visible and reflective in the near IR.

These criteria were applied to glasses in the International Glass Data Base (IDGB), and real windows "built" in the Industry standard "Window" program developed at Lawrence Berkeley Lab.

The optimal windows for hot and cold climates, had an insulating "R" values of 7-10, and had Solar Heat Gain Coefficients of 0.25 and 0.5 respectively. These are improvements over a conventional double pane window of 4-5x in "R", and 3x in Heat Gain for the hot climate window.

The financial impact of the improved window depends on the extremes of the local climate. In Texas, the monthly AC or heating bill is around $100 a month. In Fargo ND, the annual average the bill will be 2x . The payback in Texas on a new house installation is around 1 year and on replacing an existing set of windows around 10 years, half the time in North Dakota. Improved windows are best made as a new house construction decision.

Heat transfer

The goal is a window that must provide effective insulation during both day and night where the thermal conditions change significantly. In the US, the structure can be anywhere from Alaska to Arizona, so different solutions will be needed optimized for the different locations.

Figure 1 below illustrates the important uses cases and the strategies for thermal management. The sketch shows the complete range of energy transfer in the vertical axis; from UV radiation at the top, through visible and near IR down to mid IR, with thermal convection at the bottom. The primary source of radiation is the sun which acts as a hot black body source of photons. Our eyes have evolved with to be sensitive in the "visible" range of 300-700 nm, right at the maximum in solar output. Obviously, the window must be transparent on the visible to be useful !

The case that most people relate to is the desire to reduce air conditioning during the day in hot climates illustrated at the top of Figure 1. In hot climates, the goal is to reduce solar near IR that passes through the window, which is accomplished using spectrally selective coating such as thin silver layers.

Warmed by the sun, the earth and all its structures also act as a black body that re-radiates in the mid IR centered on 10 um. Window glass absorbs in the mid IR, so mid IR is transferred through glass by absorption and re-radiation. Re-radiation is reduced using coatings that have low "emissivity" of black body radiation.

Finally, thermal convection is reduced by using double pane windows with a thin layer of static air that acts as a thermal insulator.

The second use case, is daytime solar heating in cold climates. In this case, the goal is to make the window transparent to the solar near IR so as to heat the structure during the day, while minimizing thermal losses in the mid IR and thermal convection from the warm structure.

The third use case, occurs at night where the structure is much warmer that the environment and the goal is to reduce both re-radiated heat loss in the mid IR, and thermal convection.

The optimal performance of windows designed using commercially available glass is also shown in Figure1.

Hot climates
Goal to reduce solar heating of structure

Cold climates
Goal to allow solar heating during day, while minimizing heat loss from warmer structure.

Cold nights
Goal to reduce heat loss from structure

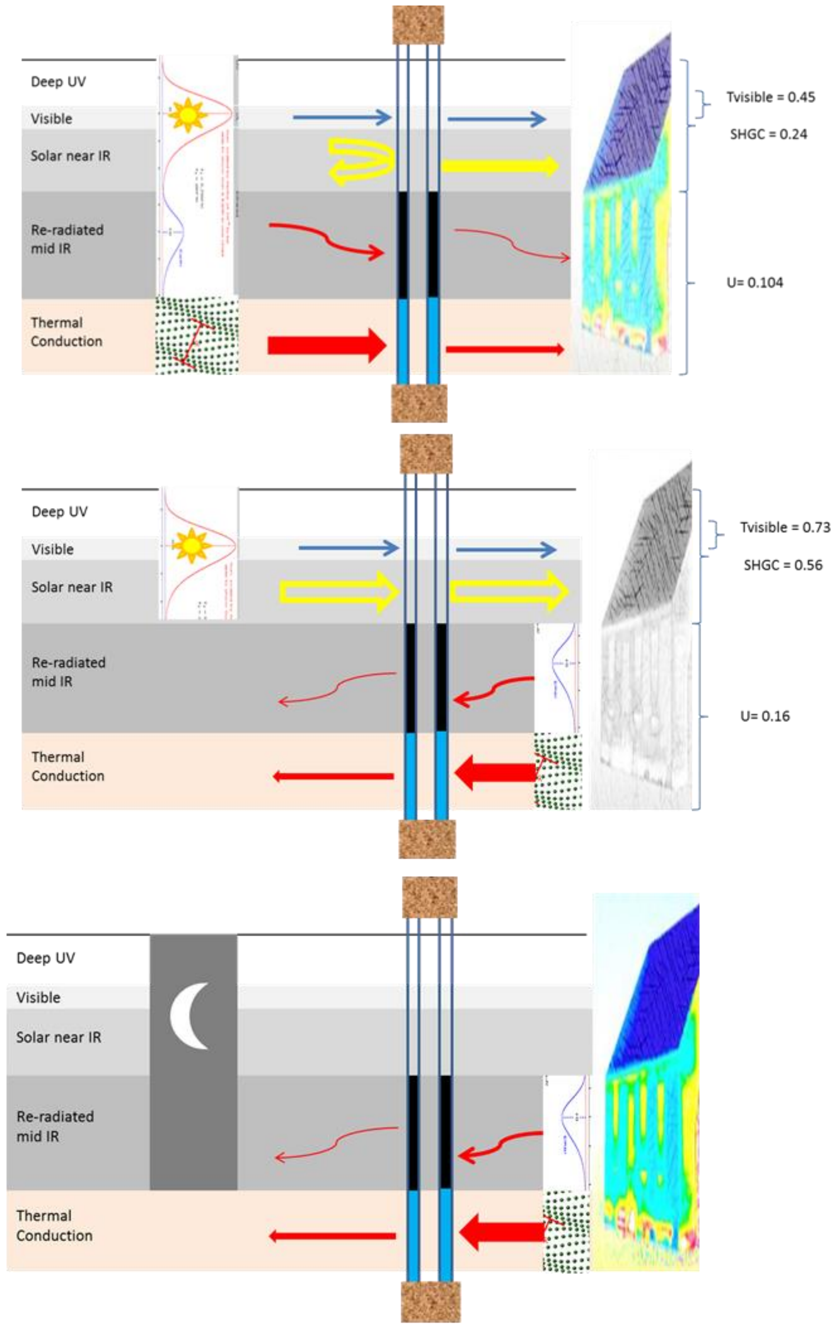


Figure 1 Schematic of energy transfer in hot and cold climates, and at night. The optimal window performance in both climates based on windows designed using selection criteria applied to the IGDB data base of window glass.

Thermally efficient windows are a surprisingly interesting technical challenge, with performance that must be engineered in 4 different energy bands that can be summarized as;

Multiple pane windows for low thermal conductivity

Low emissivity coatings for reduced mid IR re-radiation

Multilayer optical coatings that either maximize or minimize solar near IR radiation, while maximizing visible transparency.

To help build understanding of the important elements of window insulation;

Estimate thermal loads

Analyze energy transport in each energy band

Combine energy bands into window performance metrics

Develop selection criteria for window glasses based on metrics

Apply the selection criteria to obtain optimized windows for both hot and cold climates.

Estimation of typical thermal loads

As a warm blooded species, our body temperature (37C/98F) determines the temperature that we feel most comfortable We are most comfortable in an environment that is just cool enough to remove the heat we generate internally. The heat and air conditioning are used to keep the structure at a constant temperature, around 68F/20C. When the structure is hotter that the environment then energy flows out of the structure. When structure is colder and energy flows into the structure. The bigger the temperature difference, the greater the energy flow. The energy is being exchanged by conduction through the ground, convection from the air and radiation.

The natural variation in energy flows includes the daily and seasonal swings in air and ground temperature, and whether there is cloud cover. The design of the structure needs to be a response to the average environment that structure will see over its useful life. The average annual temperature is direct measure of that environment, and the "city ratings" show that of 140 cities around the US all but 12, have an annual average below the comfort target [1] . The first conclusion is that most US structures are at a net energy deficit, favoring insulation that keeps heat in the building and heat harvesting decisions such as south and west unshaded exposure.

As a general observation for the planet, we know that radiative heating during the day must balance radiative cooling to avoid thermal runaway. In cooler climates, the average temperatures are below comfort and the daily cycle of outside temperature means the night time differential (T comfort – T night) will be greater than day time (T comfort – T day). The larger the differential, the greater the heat transfer. This analysis suggests that night time heat trapping is more important that day time solar heat harvesting for cooler climates.

In hotter climates, avoiding heating during the day is critical. As an example, in Austin Tx, the yearly average 68F is essentially the same as the target comfort temperature. The average mid summer temperature is 85F (+15F from comfort) max 105F (+35F from comfort); average mid winter 48F (-22F) min 32F (-38F). As expected, the summer AC and winter heating bills are very similar.

Heat is primarily transferred through windows by convection and radiation. To develop selection critieria for window glass, convection and radiation will be analyzed separately and then combined together and matched to a commercial simulator.

Estimation of convection insulation of windows

Personal comfort is primarily determined by air temperature, and air temperature is controlled by heat passing through windows, floors, walls and ceiling and changed the air temperature by convection. Convective heat transport between a surface of the house and the outside, include three steps, transfer between air and the surface, conduction through the surface, and transfer to air on the other side.

[1] http://www.cityrating.com/averagetemperature.asp#.UW39FaQo7mI

This model can be easily expanded for double and triple pane windows. The series resistances in a double pane window are;

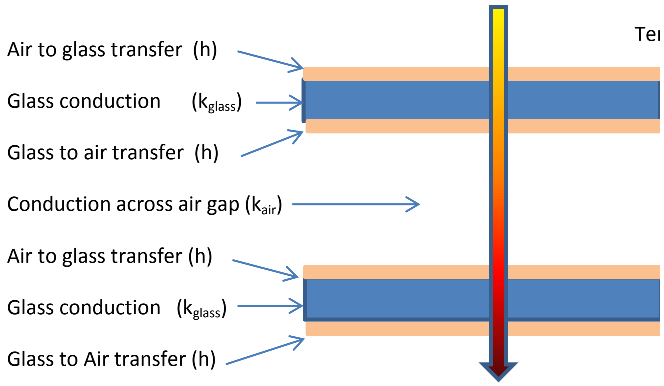
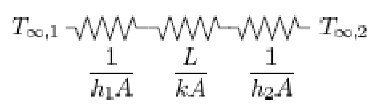


Figure 2

The heat transfer is represented by a set of series resistors shown below:



The heat transfer would simply be given by

$$q = \frac{T_{\infty,1} - T_{\infty,2}}{\sum R} = \frac{T_{\infty,1} - T_{\infty,2}}{1/h_1 A + L/kA + 1/h_2 A}$$

Figure 3. Series resistance model for heat transfer. Temperature (T), heat transfer coefficient (h_1 h_2), area (A), surface thickness L, the conductivity of the surface (k)[2]*.*

The terms $1/h_1A$, L/kA, and $1/h_2A$ at a standard 1 ft^2 are the "R" values for the heat exchange steps. The heat transfer "q" in Figure 3 is generally known as thermal conductance or "U".Added together the series resistances for a double pane window with a unit area are 4*(1/h)+2*($1/k_{glass}$) + ($1/k_{air}$), and for a triple pane window 6*(1/h)+3*($1/k_{glass}$) +2* ($1/k_{air}$).

The approximation for conduction as the principle heat transfer across the air gap between the glass is based on 2 observations. If convection were the mechanism, half the air gap would pick up the heat from one side and the other half would deposit the heat on the other side. The heat capacity of a thin layer of air half the width of the air gap is much smaller than conduction. Secondly, it is generally accepted that larger air gaps are preferable showing that conduction must be the principle mechanism.

[2] http://en.wikipedia.org/wiki/Heat_transfer_coefficient

Estimation of mid IR re-radiation insulation of structures

At wavelengths greater than 3 um (mid infra-red), soda lime window glass is no longer transparent (Figure 4), so the emissivity properties dominate radiant energy transfer.

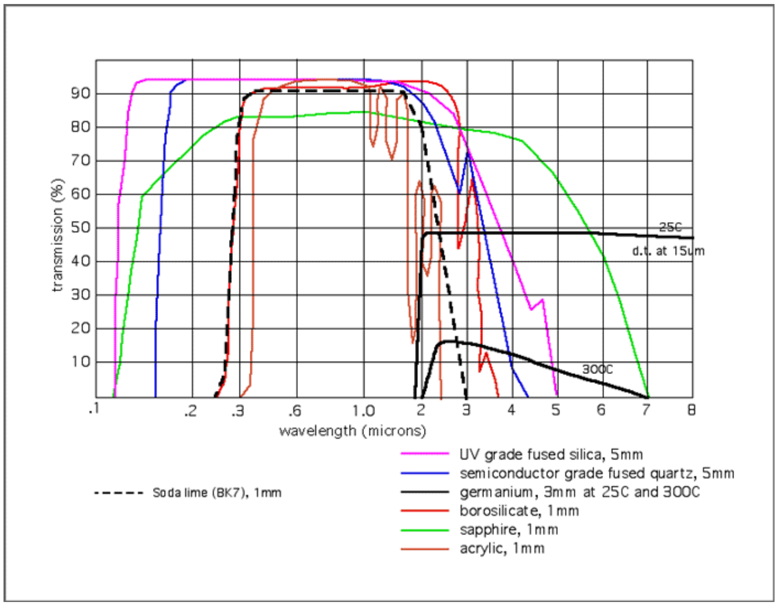


Figure 4 Transmission of different glasses, soda lime glass absorbs a wavelengths > 3 um [3]

The warm glass absorbs the mid IR emitted by the hot side of the glass, and the re-radiates as a black body to the cold side of the glass. The radiation heat transfer from a hot body to cooler surroundings is based on the properties of black bodies.

A single glass pane then re-radiates the absorbed IR to outside absorbing objects. There are a series of paired emission and absorption events between absorbing layers separated by transparent gaps. A double pane glass is shown below, with 3 paired exchanges.

[3] www.rayotek.com

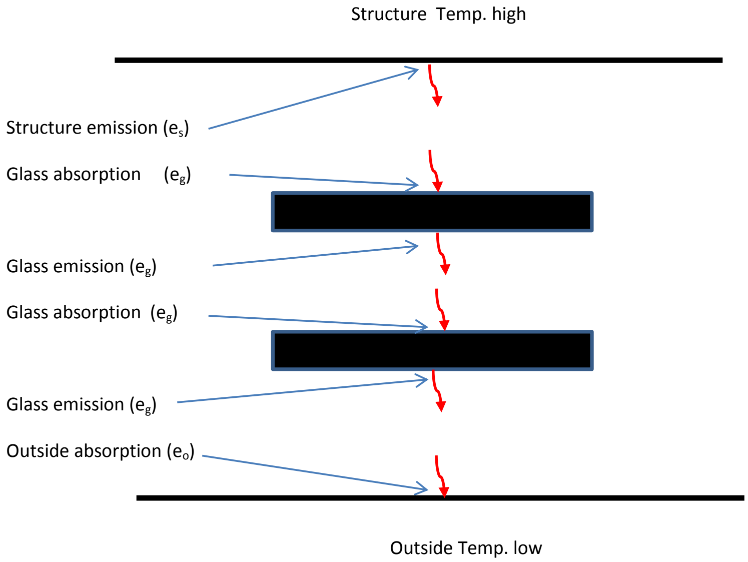


Figure 5 Schematic of paired emission and absorption events in a double pane window

The emission and absorption act as a series of resistances to energy flow. Radiation heat transfer for a single emission – absorption pair is given by;

$$q = \frac{\sigma(T_1^4 - T_2^4)}{\sum_1^{p+1}\left[\frac{1-\epsilon_1}{A_1\epsilon_1} + \frac{1}{A_1 F} + \frac{1-\epsilon_2}{A_2\epsilon_2}\right]}$$

Figure 6 Black body energy transfer for a "p" pane window with p+1 emission – absorption pairs [4]*.*

where T_1 = hot body absolute temperature (K), T_2 = cold surroundings absolute temperature (K), A = area of the object (m^2), ε =emissivity of the surface, F is a shape factor which is 1 for two parallel planes. and σ = Stefan Boltzmann constant 5.7 10^{-8} W/ m^2 K^4. In the case of structure and its surroundings, the temperatures are low and the differences are small, so   when T_1 is 20C (293 K) and T_2 = T_1 +-20C, ($T_1^4 - T_2^4$) approximates to a straight line with a slope 9.5x10^7/C. The radiation heat transfer becomes = 5.5 W/ m^2 C. When its freezing outside and the structure is a typical house with 50 $meter^2$ of windows, the radiation losses are 2.5 kW.

The energy transfer for a multiple pane window is controlled by the series resistance of multiple air gap transfers.

Emissivity is primarily a function of layer conductivity. A window requires the coating to be visibly transparent, which limits the choices. Materials based on tin oxide such as indium Tin Oxide (ITO), or fluorine doped tin oxide (SnO2:F) are used an transparent conductors for displays. Very thin silver (Ag) is partially transparent and used in "partially silvered mirrors".

[4] http://en.wikipedia.org/wiki/Thermal_radiation

Low emissivity surfaces are all good conductors as shown in Figure 7, with silver as the lowest making it an ideal coating for low e windows.

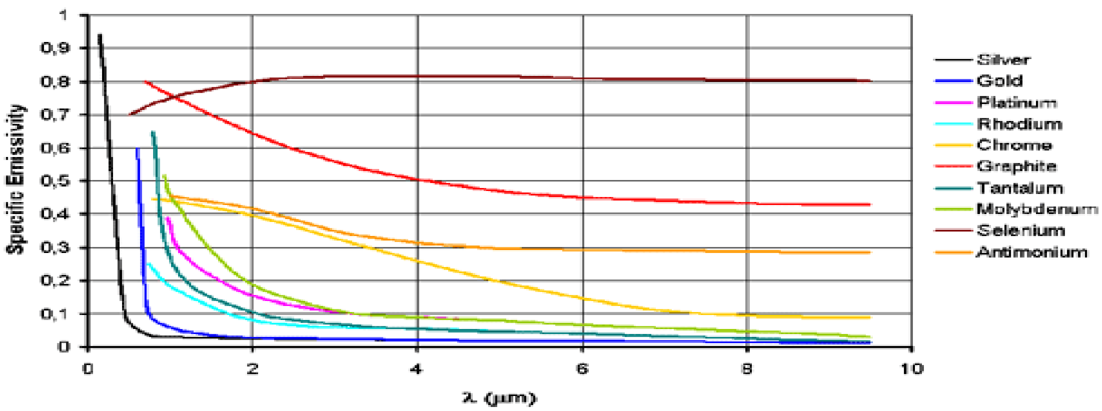


Figure 7 Emissivity of different metals, showing silver as the lowest [5].

SnO2:F has an emissivity of around 0.25.

Combined Thermal insulation radiation and convection

Convection (U_c) and re-radiation (U_{rr})are two energy transfers that occur in parallel through the window, so the thermal conductances (U) get added together. The thermal conductance of the window (U_{window}) as a whole is given by ;

$$U_{total} = U_{rr}+U_{conv}$$

The individual thermal conductivities and emissivities are well known material constants. The heat transfer coefficient of air is a function of wind speed, inside a house the air speed is zero.

The materials constants used to calculate the thermal convection and re-radiation transfers are shown in Figure 8.

[5] http://www.infratec.de/en/thermography/thermography-knowledge/theory.html

Materials	**Heat transfer Coff.**	**Thermal conduction**	**Black body emissivity**
	W /m2/C	W/ m C	
Air	7[6]	0.025[7]	
Krypton		0.01[8]	
Glass, smooth (uncoated)		1.05	0.91[9]
Silver, polished			0.02[10]
SnO2:F			0.25[11]
Inside and outside structure			0.9[12]

Figure 8 Materials constants.

Using the materials constants in Figure 8, the thermal conductance can be calculated. The thermal conductance "U" has units in the US, of Btu in/h ft^2 K. The calculated "U_{conv}" values for various window configurations are shown in Figure 9.

[7] http://en.wikipedia.org/wiki/List_of_thermal_conductivities
[8] windows.lbl.gov/software/optics/optics.html
[9] http://en.wikipedia.org/wiki/Low-emissivity
[10] http://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html
[11] http://www.scientific.net/MSF.658.81
[12] Structure and outside emissivity's were assumed to be 0.9.

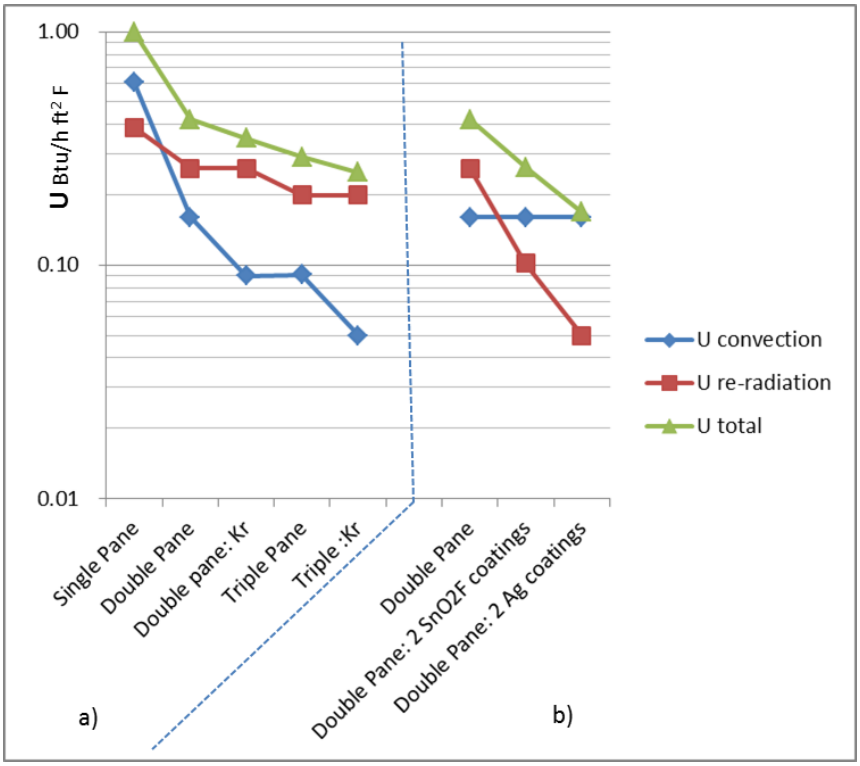


Figure 9 Analytical model results showing the U values for convection and re-radiation components for different window designs in a) and window coatings in b).

The results for the convection component of "U conv" for different windows is shown with the blue points in Figure 9a . The addition of multiple panes and using a lower conductivity gas, Krypton (Kr), reduce the thermal convection through the window.

The calculated Ure-rad for different windows are also shown in Figure 9a. As the number of re-radiation pairs in multiple pane windows increases the re-radiation transfer is reduced. The effect of adding a low emissivity coating is shown in Figure 9b. Commercial low e coatings are limited to SnO2:F and Ag. The conductivity due to re-radiation drops significantly in double pane windows with paired low e coatings.

The combined Uwindow values are also shown in Figure 9. To obtain a low U value of 0.2, requires at least a double pane window and Ag coatings.

The analytical model was checked by comparing with a reference calculation for window performance developed by Lawrence Berkeley Labs to compare different window solutions. The Uwindow values from the analytical model showed the same trends as the reference calculation, but the values were 20% smaller.

Visible and solar near IR

Window glass has excellent transmission to visible and near IR wavelengths, as shown in Figure 4. Transparency to visible light is a basic requirement of the application.   In cold climates, the solar IR acts to warm up the structure saving heating bills. In hot climates, solar IR adds to heat that must be offset by air conditioning. Therefore the goal is to design multilayer filters that either reflects or transmitts solar near IR, depending on climate.

As noted above, there are two materials used for coatings on windows, Flourine doped tin oxide (SnO2:F) a transparent conductor at 1 um thick, and silver which becomes partially transparent in the visible when it is coated in layers that are only 0.03 um or 100 atoms thick.   Both materials are conductors, so they have low radiation emissivity in the mid IR, and controlled transparency in the visible and near IR.

The optical properties of 1 um of SnO2:F are shown in Figure 10.

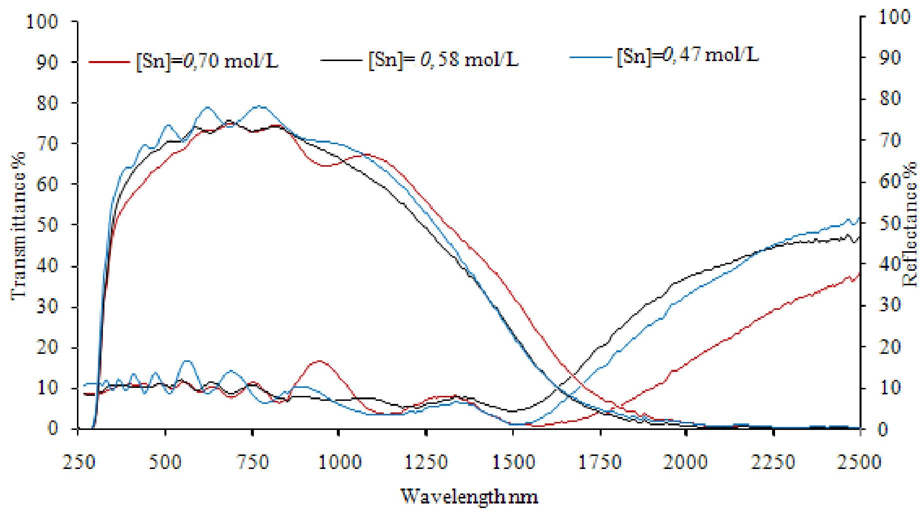


Figure 10. Transmission and reflection of fluorine doped tin oxide approximately 1 um thickness [13].

In this example, flourine doped tin oxide is transmissive from 1750 to 250 nm.

Very thin films of silver become transparent in the visible as   shown in Figure 11.

[13] http://irec.cmerp.net/irec10/papers/REA/Paper%20ID63.pdf

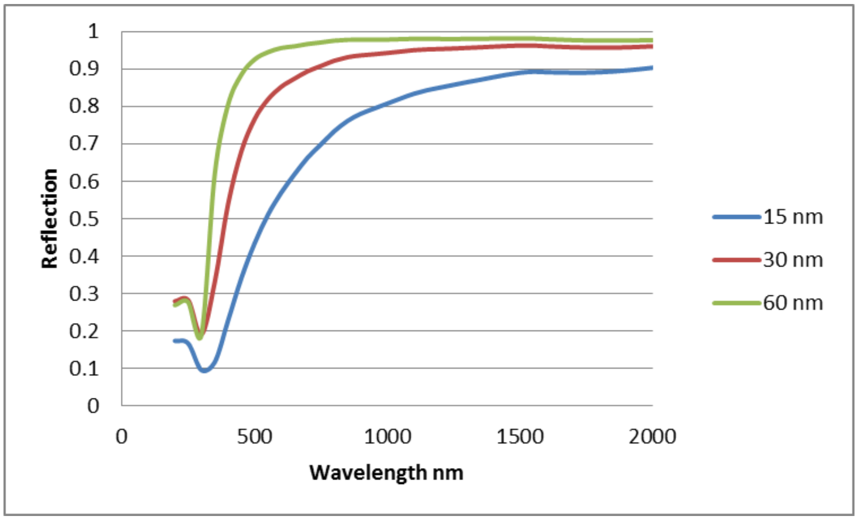


Figure 11 Calculated reflection of silver films of varying thickness from 15 – 60 nm.

Silver has high reflectivity, particularly in the near IR, so the focus is in increasing transparency in the visible. These are combined with high refractive index dielectric layers to maximize transparency as shown in Figure 12 using a classic thin film interference calculation. There is a long history in optics of using repeating multilayer film stacks to increase the transmission and reflection of surfaces. Experimental results show more transmission in the near IR, probably due to non-uniformity in layers[14].

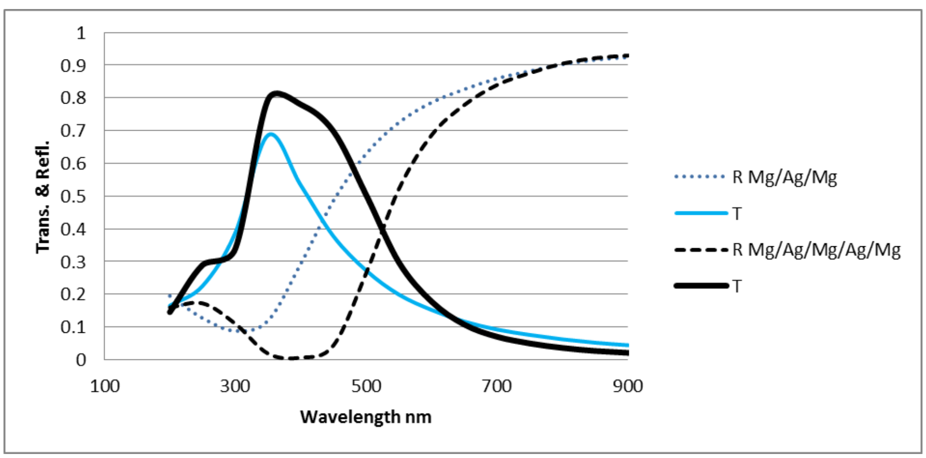


Figure 12 Calculated transmission from multlayer stacks with the same total thickness of silver[15].

The calculated transmission for a 2 silver / magnesium oxide layer stack shows a clear visible window with low transmission in the near IR.

[14] *T. Matar, Egypt. J. Solids, Vol. (31), No. (1), (2008)* Optimization of ZnS/Ag/ZnS Multilayer Thin Film Systems for Heat Mirror Applications

[15] O# Optfilm v.1.1 (C) Fredrik Hansteen 1999

Actual windows with controlled solar gain

The design rules for effective windows, derived from the analytical model, are;

1) Multipane window to reduce convection
2) Low emissivity coating, preferably silver, to reduce mid IR re-radiation
3) Multlayer coating to maximize visible transmission and either increase or reduce near IR transmission.

The optimal window is found using a "bottoms up approach by searching the hundreds of "solar glasses" available today, and suppliers do not disclose the materials they use. The Department of Energy has developed the International Glass Data Base (IGDB) and programs (Window and Optic6) to calculate window performance. These programs are the industry standard for reporting window performance to customers.

The window glasses are characterized by a number of metrics, the selection process will focus on transmission over visible wavelengths, transmission over solar wavelengths and emissivity. In Optic6, the glasses were grouped by visible transmission. For 10 glasses at each 10% increment in transmission, the lowest and highest solar transmission were selected. The lowest solar transmissions all had emissivity below 0.05 indicating that they were Ag films. The highest solar transmissions all has emissivities around 0.2, indicating that they were SnO_2:F films.

In Windows, a double pane window was assembled with both panes made of the same glass, and the coated surfaces oriented inward to a 0.5" air gap. The important metrics for the windows were; thermal conduction "U" that combines conductivity and mid IR emission, visible transmission, and Solar Heat Gain Coefficient (SHGC). The SHGC is effectively the transmission over visible and solar near IR.

An optimal window for hot climates require a high visible transmission with low solar transmission (SHGC), so the results for the selected glasses were plotted as SHGC versus visible transmission in Figure 13.

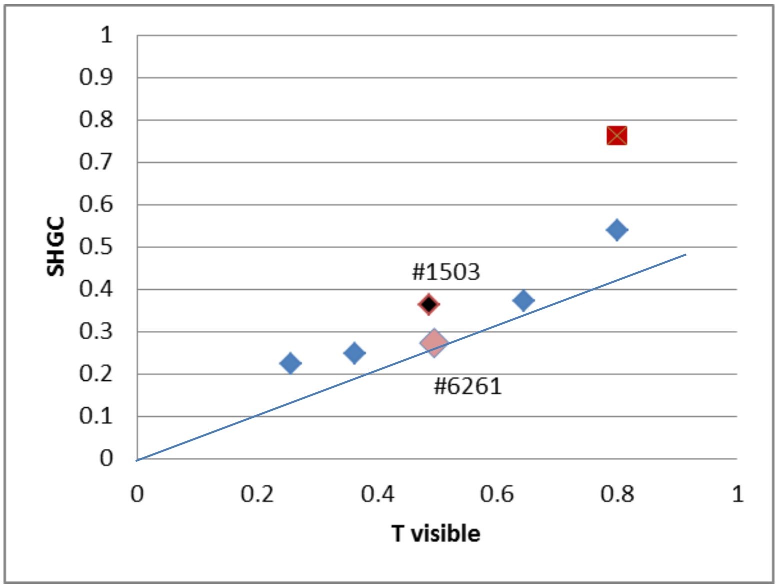


Figure 13 Optimal hot climate window. SHGC drops with T visible, the optimal glass (IGDB#6261) has the lowest SHGC/Tvisible ratio . The red square is a standard double pane window.

The lowest SHGC compared to visible transmission is indicated by the line through the origin and the point marked for the glass IGDB # 6261. The best hot climate window was assembled using glass #6261 with the visible transmission around 0.7, resulting in a double pane window with transmission around 0.5. All the windows in Figure 12 were assembled from low e glass with e=0.02 and had a low U = 0.2 consistent with low emissivity Ag coatings. The optimal window had a SHGC of 0.25, compared to 0.76 for a standard double pane window. For comparison, a triple pane window with an Ag coated plastic film (#1503) as the mid-pane is also shown..

The glass and window metrics are shown in Figure 14.

	Glass					**Window**				
Climate	**IGDB #**	**emissivity**	**T vis**	**T solar**		**Pane**	**Glasses**	**U**	**T vis**	**SHGC**
Std	102	0.84	0.90	0.83		Double	102/102	0.48	0.81	0.76
Hot	6261	0.02	0.70	0.28		Double	6261/6261	0.28	0.50	0.27
Hot						Triple	6261/102/6261	0.16	0.45	0.28
Hot						Triple: Kr	6261/102/6261	0.10	0.45	0.24
Cold	3335	0.30	0.90	0.81		Double	3335/3335	0.34	0.83	0.75
Cold	1506	0.11	0.88	0.63		Triple	3335/1506/3335	0.20	0.73	0.56
Cold						Triple: Kr	3335/1506/3335	0.16	0.73	0.57

Figure 14 Glass and window metrics for the optimal windows.

The transmission spectra of the glasses (Figure 14), show that the optimal glass 6261 has a much narrower band pass for the visible, close to the theory for a 2 layer Ag film as shown in Figure 11.

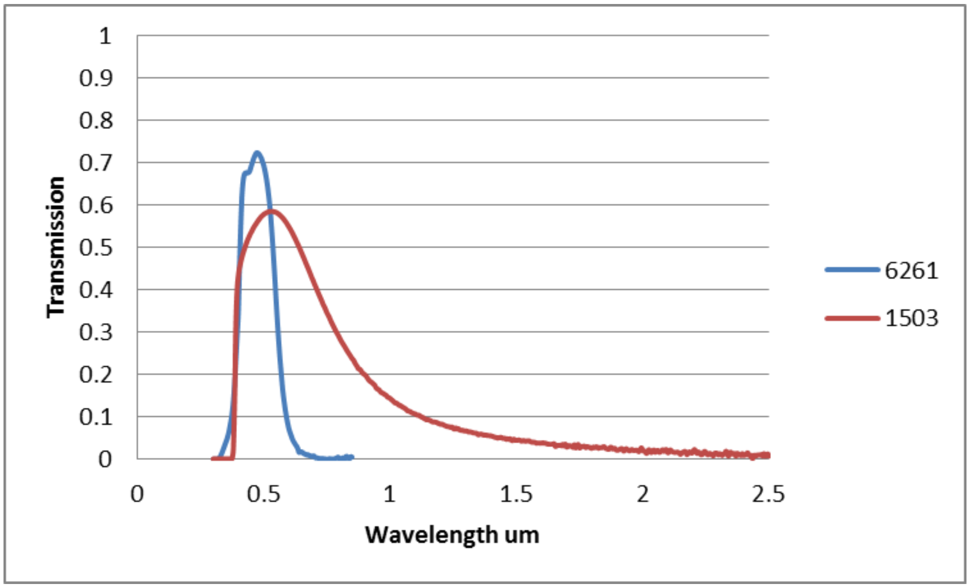


Figure 15Transmission spectra of optimal (6261) and candidate coatings.

The U value was further improved by making a triple pane window with a clear glass midpane, and by using Kr gas in the gap, shown in Figure 14.

The optimal cold climate window requires a different optimization strategy, because of the need for the lowest thermal conduction to offset the cold night time temperatures produce. Using the glasses with the highest Tsolar, the windows had high solar gain , but also high U because the glasses had emissivity's around 0.2-0.3, consistent with a SnO_2:F coating, and are plotted blue points in Figure15.

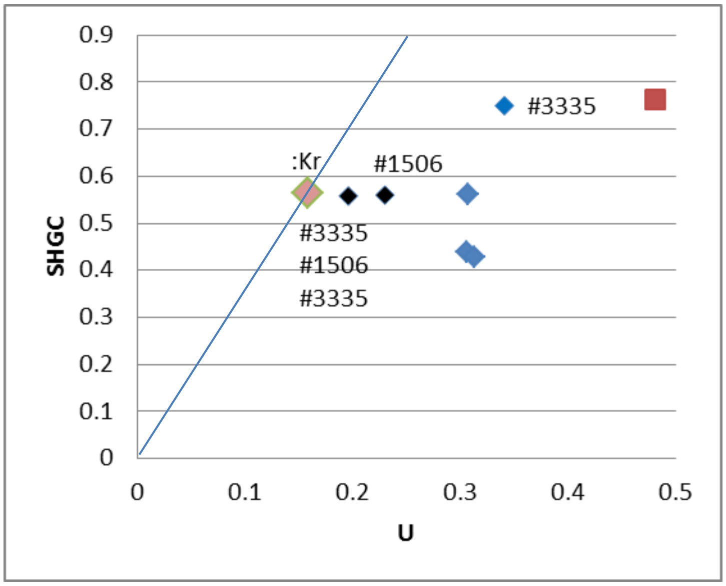


Figure 16 Optimization of cold climate window with high solar gain (SHGC). Blue points for double pane windows built with glasses with the highest T solar. A triple pane using a silver coated plastic film (IDGB #1506) had improved U. The optimal point, :Kr, is a triple pane with IDGB #1506 as the mid pane, IDGB#3335 as the two outer panes, and Krypton gas fill. The red square is a standard double pane window.

Lower emissivity coatings are needed to obtain a lower "U", even at the expensive of lower SHGC. A search of the IGDB for coatings with lower emissivity and the high solar transmission identified a plastic film IGDB #1503. A triple pane window with plastic film (IDGB#1503) as a mid-pane, is shown in Fig 15 The window had a lower U resulting from both low e and the dual air gap in the triple pane window. When the coated mid-pane is combined with 2 coated outer panes (3335/1506/3335), the U value is further reduced to 0.2, with a SHGC of 0.55. Adding Krypton (:Kr) as a gas fill reduces U as well, as shown in Figure 13. The transmission spectra of the two components are shown in Figure 17.

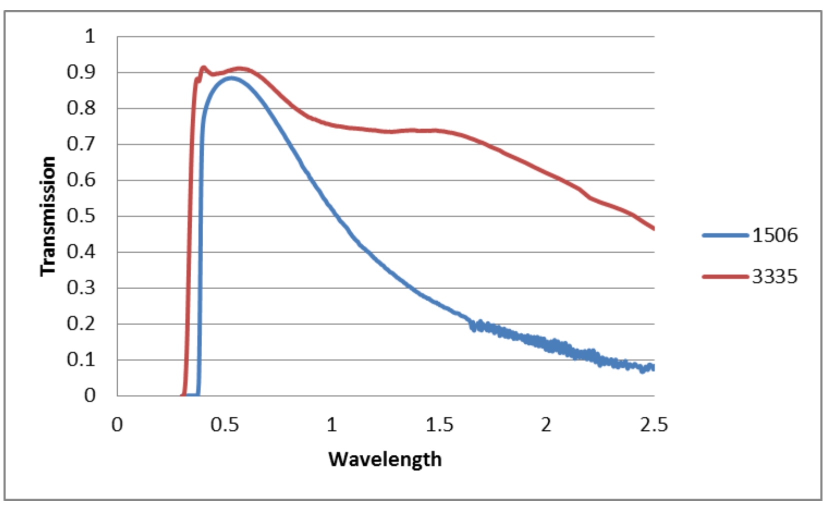


Figure 17 Transmission spectra of the glass and film in the optimal cold climate window

The # 1503 Ag coated film has high visible transmission, and better than 50% transmission at 1 um. This is much higher transmission than a silver coated film designed to reflect near IR shown in Figure 15.

Engineering the optimal solution

The engineering of the optimal solutions can now be understood based on a "tops down approach" by referring back to Figure1. Each of the 4 energy bands requires it's own mitigation strategy, dictated by the available materials. The optimization of the various materials properties are illustrated In Figure 18; the different energy bands are shown vertically similar to Figure 1, with the black body spectrum on the left and the thermal properties across the bottom.

The majority of energy transfer in and out of a structure occurs by convection from air to the window at 7 Watts/m^2 C, and by re-radiation in the mid IR at 5.5 Watts/m^2 C. The thermal conductance "U", measures the combined convection and re-radiation loss, with units in the US of Btu/h ft^2 F. Convection and re-radiation are similar in magnitude, so both losses must be mitigated to produce a low "U" window.

Convective heat transport through a multiple pane window include a series of steps; transfer between air and glass, conduction through glass, transfer between glass and fill, conduction through fill, etc. Each step acts as a series resistance ("R"= 1/U) to heat transport. The results of an analytical model of heat transport are shown in Figure 19 for an optimal triple pane window with a low conductivity gas (Krypton) as the fill between the panes. The high atomic weight and low conductivity noble gases are preferable as a gas fill as shown at the bottom of Figure 18.

At wavelengths greater than 3 um (mid infra-red), soda lime window glass is no longer transparent as shown in the optical properties of glass in the Figure 18. As a result, the emissivity of the glass in the mid IR controls radiant energy transfer. The re-radiation energy transfer for a multiple pane window is determined by the resistance of a series of paired transfers from an emitting surface to an absorbing surface through a transparent air gap. Emissivity is primarily a function of coating conductivity. A window requires the coating to be visibly transparent, which limits the choices. Materials based on tin oxide such fluorine doped tin oxide (SnO_2:F) are used an transparent conductors for displays and have an emissivity of 0.25. Very thin (15 nm) silver (Ag) is partially transparent and used in "partially silvered mirrors" with a very low emissivity of 0.02, as shown in optical properties of silver in the Figure18. The results of an analytical model of re-radiation transfer are shown in Figure 19. The series resistances the each emission – absorption pair in an optimal triple pane window shows that 2 silver coatings can minimize re-radiation losses.

The thermal conductance "U" for the window is the sum of the heat transferred by thermal convection and heat re-radiated mid IR.

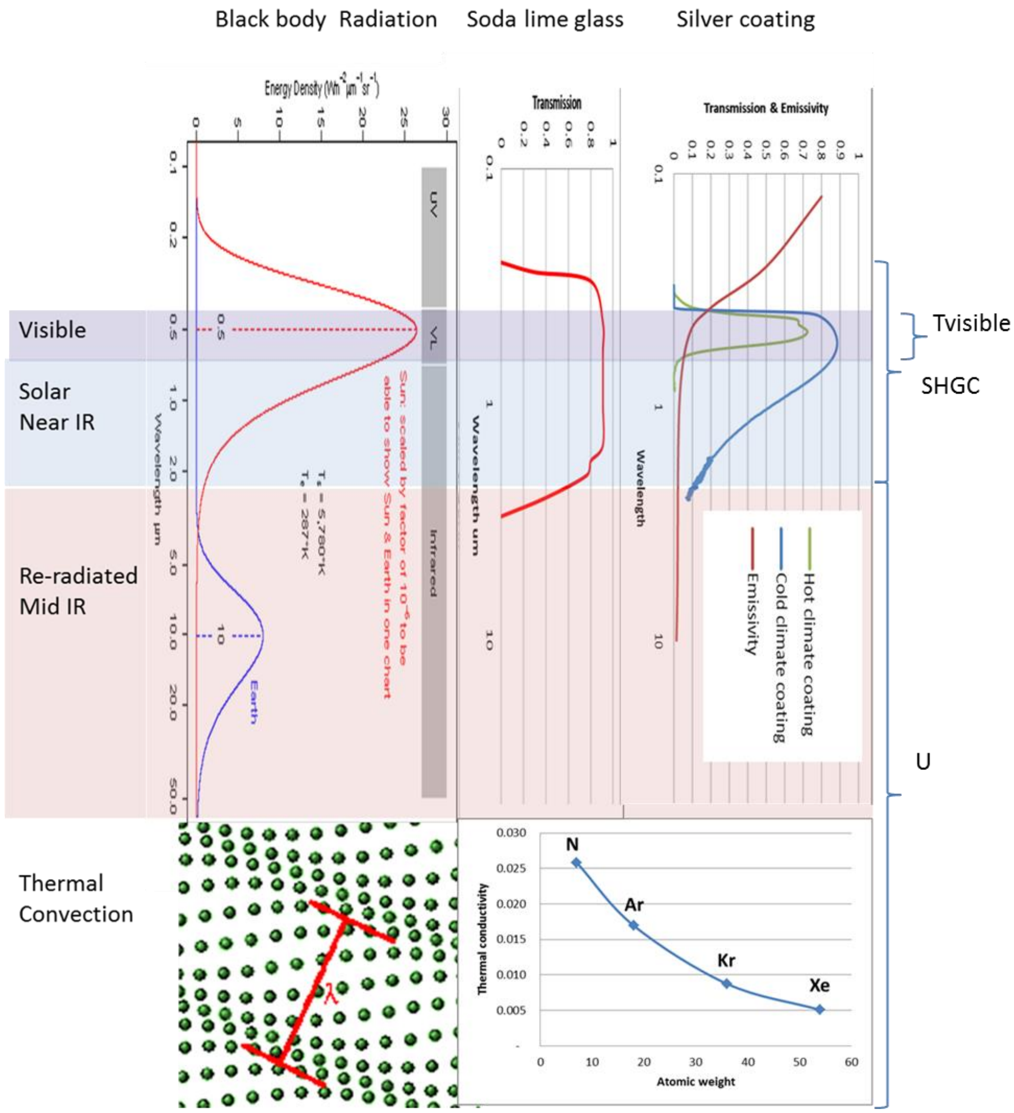


Figure 18 Materials engineering the optimal solutions. At top left, the black body emissions of sun and re-radiation from earth[16], In middle, the transmission of soda lime glass[17]. At top right, the transmission spectrum of the optimal coatings for cold climates (IGDB#6261), hot climates (IGDB#1506), and emission spectrum of Ag films[18]. At the bottom, thermal convection illustrated by phonon vibrations and the reduction of thermal conductivity with atomic weight for the noble gases.

The transmission spectra of the two optimal coatings shown in Figure 18 are engineered to either block or transmit the solar near IR, where the glass is transparent.

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16 D.Kelly O'Day http://chartgraphs.wordpress.com

17 Replotted from Figure 4.
18 Replotted from Figure 7.

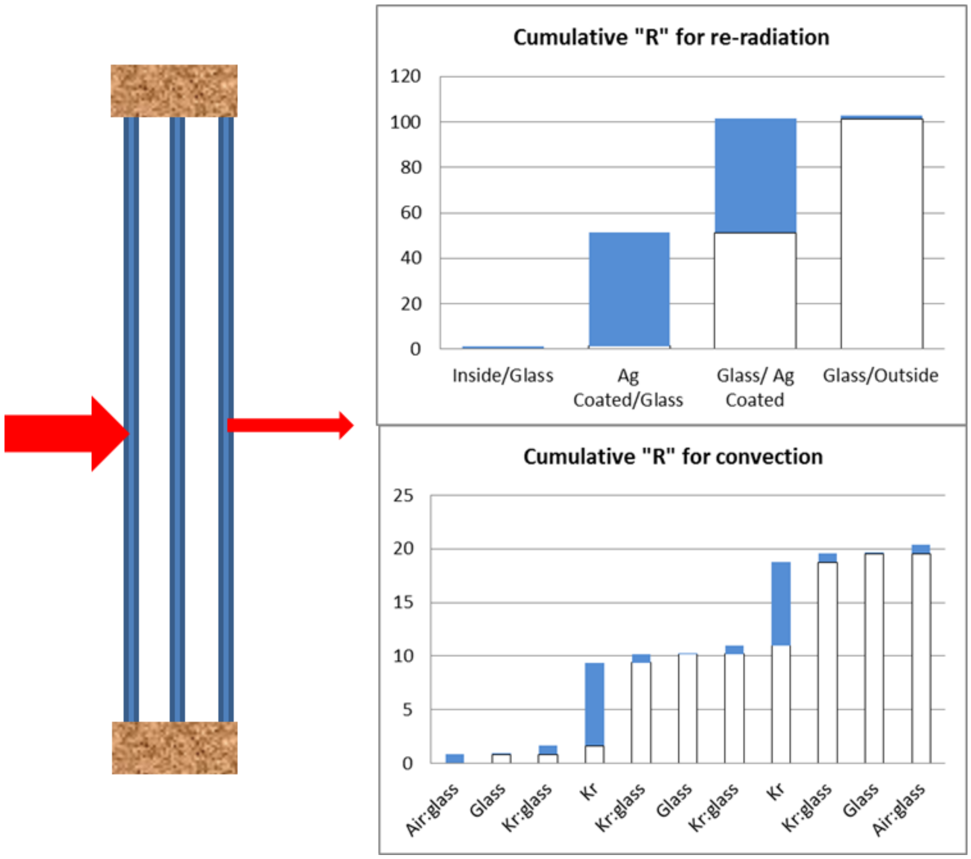

Figure 19 Window engineering for convection and re-radiation of an optimal triple pane window, showing silver coatings and Kr fill as the biggest contributors to window insulation.

The performance of the optimal hot and cold windows are shown in Figure 1. There is a 2x difference in SHGC for optimal hot and cold climate windows. The insulation is usually ranked by "R" values (= 1/U), and are 7-10 for the optimal windows. This is a big improvement over conventional double pane windows with R=2, it is still less than good quality walls at R=20.

Financial impact

The financial impact of the improved window depends on the extremes of the local climate. In Texas, the annual average is 68F and the quarterly seasonal swing relative to comfort at 70F is +_ 15F. The typical energy loss for a modern, well insulated, double glazed house is 1KW, and the monthly AC or heating bill is around $100 a month. In Fargo ND, the annual average temperature is 40F and the quarterly seasonal swing relative to comfort at 70F is +0, -60. For the winter quarter, the heating bill in North Dakota will be roughly 4x the bill in Texas, averaged over the year, the ND bill will be 2x .

Windows cost around $250, low e windows cost 10-15% more. With energy savings of 50% , the payback in Texas on a new house installation with 20 windows is around 1 year and on replacing an existing set of windows around 10 years, half the time in North Dakota. Improved windows are best made as a new house construction decision.