Equinox House Project

Topic 4 Windows

Ty Newell – February 11, 2010

Remember I said I could be more boring? Well, this is where I prove that to be true.

Windows are among the most complicated components affecting building comfort. And, as such, they are the most inappropriately designed feature of any building. The only thing more complex in maintaining building comfort are people. If we could get rid of people and windows, building design would be easy.

As discussed in the earlier topic on sun angles, engineers and architects have unwittingly conspired to promulgate horrible building designs. Current building practice is reminiscent of the auto industry of the 1950's where fanciful designers added a gaudy array of appendages to vehicles to emulate jets and rocket ships that increased cost and weight while reducing gas mileage. We need policy and sensible regulation that results in performance based building design. Any building certification system should be based on measured performance rather than a checkbox list of items. Possibly a portion of real estate taxes could be based on actual energy performance to incentivize good design? Borrowing from Amory Lovins' "feebate" idea, this can be a revenue neutral system in which efficient buildings receive a credit paid from a tax on inefficient buildings. Enough of that. Let's see how to design windows.

The photo below shows four stickers from four types of windows we recently purchased. Three are installed in Equinox House and the fourth is from windows we installed last fall at Newell Instruments' Lab. Three photos following the sticker picture show the location of the windows. What is the meaning of the numbers on the stickers? These stickers are ratings from the National Fenestration Rating Council (http://www.nfrc.org/). Note that all four window types are Pella. The three types for Equinox are from a local Pella distributor and the fourth, called ThermaStar, is a vinyl clad Pella window sold by Lowes. Vinyl tends to be a "low end" window, which for something like our lab, a metal clad building, we aren't so interested in aesthetics. Interestingly, Pella's top line (Architect Series) has a more restricted energy performance selection range than the less expensive models.

There are lots of windows with comparable performance to Pella (Andersen, Marvin, etc) in the high volume window manufacturing market. Also, there are a number of "super window" manufacturers (e.g., Serious Materials, http://www.seriousmaterials.com and Optiwin; http://www.optiwin-usa.com/performance.html). Below is a table with performance values that are representative of these manufacturers. Of course, this level of performance comes at a cost that must be justified. These windows may have up to four sheets of glass or plastic films with "low e" coatings and krypton or xenon gas filled spaces (krypton gas, named for the home planet of one of my favorite superheroes, Superman, has a very low thermal conductivity….some of our windows are "argon" gas filled, which is also a low conductivity gas, but not quite as low as krypton gas….for my fellow superhero fans, if you buy windows filled with krypton, you don't have to worry about harming Superman…..this gas is not related to green, red or gold kryptonite that formed when the planet Krypton exploded).

Table listing "U", "R", "SHGC" and "VT" values for some super windows.

Manufacturer	U	R	SHGC	VT	Comments
Serious725	.14	7.1	0.27	0.49	"9" package
Serious725	.2	5.0	0.50	0.65	"5" package
Serious925	.11	9.1	0.22	0.38	"14" package
Serious925	.14	7.1	0.42	0.57	"9" package
Optiwin	.12	8.4	0.53	NA	

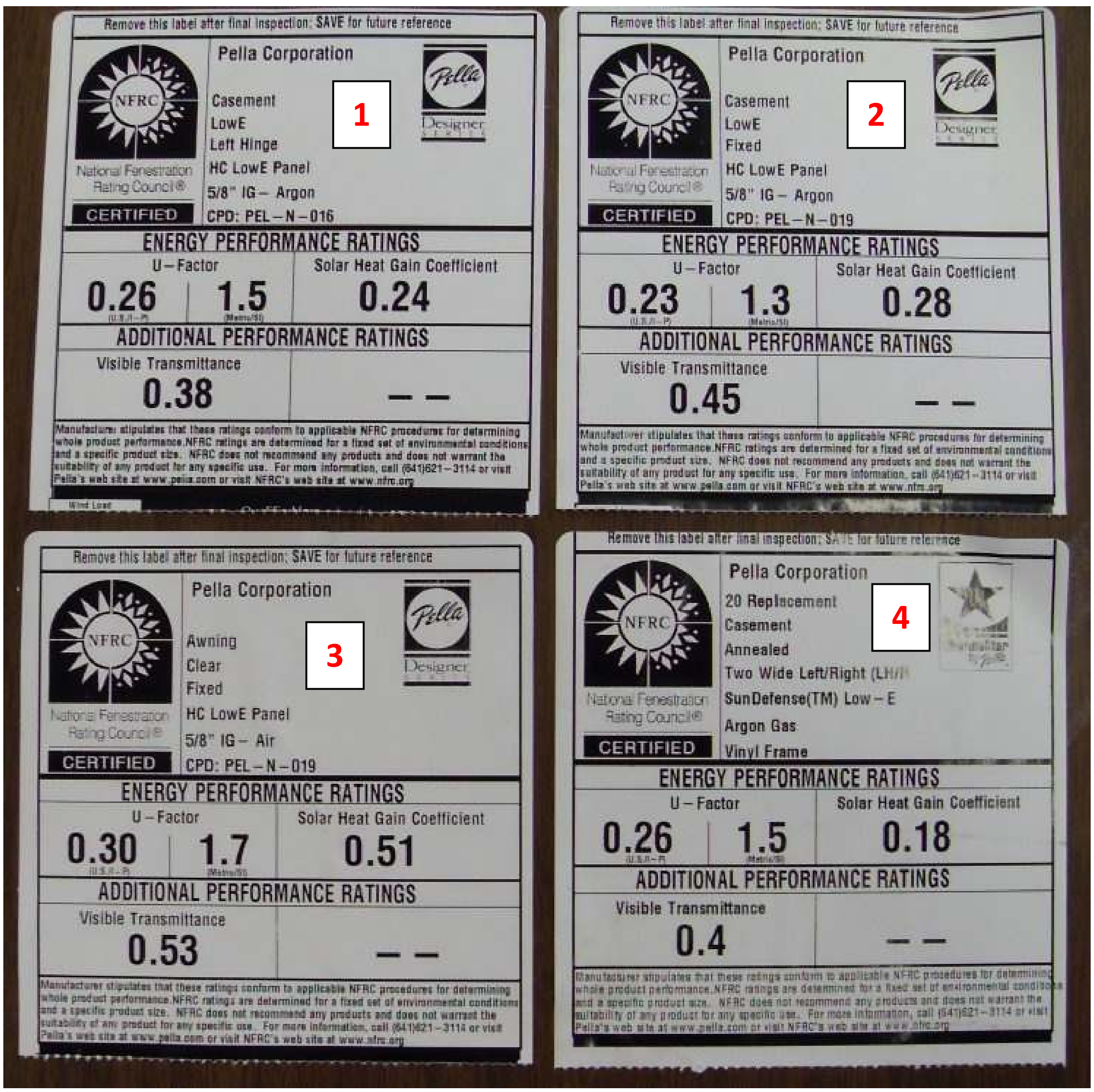

Photo of stickers removed windows we recently installed. Windows 1, 2 and 3 are used in Equinox House and window 4 was installed in Newell Instrument's Lab.

Windows installed in Equinox and the laboratory. Note Ben harvesting hops for our brewing activities from vines we are training to grow over the south windows on the Laboratory.

So why did we choose fairly run-of-the mill windows rather than some of the super windows? Well, that's the point of this discussion topic, examining the performance of windows relative to their cost. We'll start with a brief discussion of the NFRC sticker values to give an idea of the performance ratings. Then, we will examine the effect of windows on the annual energy performance of a house. The cost effects of windows on a house will be presented after discussing energy effects. Finally, some comments regarding daylight and ventilation will be made, but detail on these topics will be left for later.

NFRC Sticker Parameters

Two parameters on the NFRC sticker are of most interest for this discussion. The "U" value, related to the heat transfer due to the difference between the inside and outside temperatures, should be as low as is practical. Sometimes, the "R" value, or thermal resistance value is included in the NFRC sticker information as listed in the table for the Serious and Optiwin windows. The R value is just the reciprocal of the U value. For the Pella windows, there are two "U" values: one in English units and one in SI units. The lower value is the English units value. Notice that the R value (reciprocal U value) of the Pella windows ranges from approximately 3 to 4, or less than half of some of the high performance windows in the table. From our discussion of optimal wall insulation, we found an R value of nearly 50 to be optimum. Even the very best windows are only a small fraction of the wall and roof thermal resistance per area.

The other parameter of interest on the NFRC sticker for energy performance is the SHGC (solar heat gain coefficient). This is the fraction of solar energy that is transmitted through the window. A single sheet of clear glass without any special coatings will transfer more than 90% of solar energy. As multiple panes of glass or plastic are incorporated into a window, inter-reflections and absorption within the panes reduces the SHGC coefficient. Special coatings ("low e") added to the surfaces of the panes also effect solar energy transmittance. For windows intended to transmit winter solar energy into a house for heating, the SHGC should be as high as possible. For windows in which solar energy transmission is not important, such as in north facing windows (although, note that during summer, the sun can "see" a north window for a bit in the early morning and late afternoon), the SHGC is not so important. And, for windows without overhangs that see the sun for significant periods of time when solar heat is undesired, the SHGC should be as low as possible (think east and west windows).

The "low e" coatings that you hear about is a special coating, often a very thin metallic or metallic oxide coating, that reduces the transmission of radiant energy in the long wave length (infrared) and ultraviolet regions through the panes. This is important for reducing the U value. The coatings also affect visible light transmission to some degree. Maintaining a high level of visible light transmission for day lighting, while minimizing the transfer of radiant energy in the invisible light wavelength ranges is desirable. The "VT" value on the NFRC sticker is the fraction of the sun's visible light transmitted through a window. As can be seen on the stickers and in the table, current window technology allows different levels of visible light and full solar spectrum energy to be transferred through a window.

Window Energy Impact

There is a lot of coming and going with these parameters. A window with a single piece of clear glass could let in 90% of solar energy, but its U-value would be 5 times higher than the Pella window U values. At the same time, adding extra panes of glass and plastic to suppress heat transfer and lower the U value causes a drop in the solar transmission.

The table below shows the significant energy impact that windows can have on a house in the central Illinois climate. These results are whole house electric energy requirements that are obtained from our house simulation model. Included in these results are the effects of house ventilation, human activities, refrigerator operation, and about a dozen other effects. One cannot take a window by itself to assess its performance.

The "Good" windows in the table below are representative of window #3 used for the clerestory windows in Equinox House. These are "triple pane" windows with 3 sheets of glass. One sheet has a low e coating. No low conductivity gas is incorporated into the window as it was not available for this line of windows with Pella's higher SHGC (argon gas would have lowered the U value to ~0.25 without affecting the SHGC). The "Super" windows represent values similar to the Optiwin window. Note that when there is no overhang protection or other exterior shading for summer months, the winter benefit turns into a summer detriment as excessive solar energy increases the summer cooling load. Overhangs or other shading devices are important!

A set of energy requirements for a house with south facing windows with low SHGC, such as window #4 used for our lab are listed in the table. Placing windows on the south side of a building with a low SHGC requires more energy than having no windows because the balance of the solar energy transmitted into the building does not make up for the heat lost to the outside through the windows during the winter. It's interesting that the current government tax credit for windows includes window #4, but it doesn't include the "Good" window even though the "Good" window outperforms window #4 in our climate. The government's attempt to oversimplify the process is working against us.

Table showing annual energy requirements for Equinox House with various windows

Window	Orientation	Overhang	U	SGHC	Win Area (ft2)	Energy(kW-hr)
No window	NA	NA	-	-	0	7980
"Good"	south	none	0.3	0.51	100	7300
"Good"	south	none	0.3	0.51	200	7240
"Good"	south	none	0.3	0.51	300	7520
"Good"	south	yes	0.3	0.51	100	7250
"Good"	south	yes	0.3	0.51	200	6720
"Good"	south	yes	0.3	0.51	300	6450
"Super"	south	none	0.12	0.53	100	6850
"Super"	south	none	0.12	0.53	200	6510
"Super"	south	none	0.12	0.53	300	6660
"Super"	south	yes	0.12	0.53	100	6740
"Super"	south	yes	0.12	0.53	200	5870
"Super"	south	yes	0.12	0.53	300	5250
"Low SHGC"	south	none	0.26	0.18	100	8060
"Low SHGC"	south	none	0.26	0.18	200	8240
"Low SHGC"	south	none	0.26	0.18	300	8440
"Good"	north	none	0.23	0.28	100	8660
"Good"	north	none	0.23	0.28	200	9340
"Good"	north	none	0.23	0.28	300	10,020

The last set of energy performance values in the table is for north facing windows that do not contribute winter solar energy contributions. The windows displace higher insulation value walls, and the more windows added, the more energy required. Although north facing windows increase the energy requirement, north windows are a wonderful direction to view the outside as outdoor features are illuminated by sunlight rather than being washed out when one tries to view objects to the south. In the case of the Equinox House, we have as many windows on the north as on the south because we want to see the gardens in the backyard. We'll take a look at the cost impact in the next section.

Window Economic Impact

So, here is the big question, are windows worth it? And here's the answer before giving the details. On an economic basis, for many locations, the reason for having a window is because you want a window. The primary cost of a window over its expected lifetime is …. the cost of the window. But, who wants to live in a Styrofoam igloo with no outside view or natural sunlight? So, pick windows wisely and place them wisely so that they perform in as efficient of a manner as possible relative to a house's overall energy interactions. Place windows where you have a view you would like to see. And where you don't need a view or some light, be conservative in your window placement and save some money.

In the previous table with whole house annual electric needs, we saw that the Styrofoam igloo without any windows would require nearly 8000kW-hr of energy compared to only 5250kW-hr for the same size house with 300square feet of south facing super windows that have good spring/summer/fall overhang protection. This sounds great! A 35% energy reduction by adding windows. Surveying the web for cost information on various windows (a lot people have shared information on their cost for windows), super window cost will range from $50 per square foot to $100 per square foot (not installed).

Solar PV panels, our source of energy for Equinox House, currently cost less than $55 per square foot and the price is dropping rapidly. This should prompt you to think about whether it is more economical to have solar energy enter your house remotely through solar PV panels versus directly through a window. While many debates abound regarding the more "natural, organic" nature of sunlight directly entering your house, solar energy that enters your house via solar PV panels is every bit as natural as the energy entering through windows. It abides by the same laws of physics. Sure, sunlight directly entering your house provides a pleasant source of light that we enjoy, and produces some essential vitamins within us, however, it is also the cause of some cancers and deterioration of furnishings. We'll leave these topics of debate alone and concentrate on the economics of windows.

The table below provides cost information for a house similar to Equinox House with 2100sqft of living space. The same conditions used for the previous table's energy are used. The cost of windows are assumed to range from $35/sqft ("good" window performance; costs range from $20 to $45/sqft for these windows depending on size and trim styles) to $70/sqft ("super" window). The total house cost is based on a general construction cost of the house of ~$100/sqft (includes insulation cost fixed at R50 for 4600sqft of roof and wall), and the installed cost of the solar PV system (installed cost of $55/sqft without any tax credits assumed).

The table shows window systems that reduce house energy requirements will reduce the energy cost by reducing the size of the solar PV system for net zero energy operation. The overall cost, however, does not decrease because the cost of a window is greater than the window's relative impact on house energy for central Illinois. For example, 300 sqft of super windows with proper summer overhang protection has a window cost of $21,000 and an overall house cost of $260,400. The solar PV system has dropped almost $8000 in cost, but this is outweighed by the window cost. One row in the table labeled "super cheap" is a super window purchased at $35/sqft. If super window prices were to drop to below this level, a window cost range is reached where windows may economically compete with walls. We are not there yet, however. The costs in this table are conservative as far as the windows because no installation costs are included (about $5 to 10 per square foot). And, remember that the current 30% federal tax credit is not included which further reduces the cost of solar PV from the values shown.

Table of overall house cost (house plus energy plus window cost) and window cost.

Window	Orien tation	Over hang	Win Area (ft2)	Energy (kW-hr)	Window $	Solar PV $	House $	Total $
No window	NA	NA	0	7980	0	22,500	224,600	247,100
"Good"	south	none	100	7300	3500	20,500	224,600	248,600
"Good"	south	none	200	7240	7000	20,500	224,600	252,100
"Good"	south	none	300	7520	10,500	21,400	224,600	256,500
"Good"	south	yes	100	7250	3500	20,520	224,600	248,620
"Good"	south	yes	200	6720	7000	19,100	224,600	250,700
"Good"	south	yes	300	6450	10,500	18,240	224,600	253,340
"Super"	south	none	100	6850	7000	19,400	224,600	251,000
"Super"	south	none	200	6510	14,000	18,200	224,600	256,800
"Super"	south	none	300	6660	21,000	18,800	224,600	264,400
"Super"	south	yes	100	6740	7000	19,100	224,600	250,700
"Super"	south	yes	200	5870	14,000	16,500	224,600	255,100
"Super"	south	yes	300	5250	21,000	14,800	224,600	260,400
"Super"cheap	south	yes	300	5250	10,500	14,800	224,600	249,900
"Low SHGC"	south	none	100	8060	3500	22,800	224,600	250,900
"Low SHGC"	south	none	200	8240	7000	23,100	224,600	254,700
"Low SHGC"	south	none	300	8440	10,500	23,900	224,600	259,000
"Good"	north	none	100	8660	3500	24,500	224,600	252,600
"Good"	north	none	200	9340	7000	26,200	224,600	257,800
"Good"	north	none	300	10,020	10,500	28,200	224,600	263,300
"Super"	north	none	100	8300	7000	23,400	224,600	255,000
"Super"	north	none	200	8600	14,000	24,200	224,600	262,800
"Super"	north	none	300	8900	21,000	25,100	224,600	270,700

The above table shows how cost can quickly cost run away if windows are improperly designed. The most expensive south window case would be 300 sqft of super windows with no overhang. North windows, of course, will not be more economical than a well insulated wall. Maybe at some point in the future an affordable, vacuum window will be developed that will have better energy and economic performance, but that time is not now. As far as north viewing windows (or other non-solar gain windows, eg, a house in the woods), one way to get a feel for the cost impact is the following. If you add 100 sqft of north viewing windows, your additional cost will be approximately $5500 to $8000 more than an insulated wall for central Illinois climate, for "good" to "super" window cost range. "Good" windows have 65% of their increase cost due to the window ($3500) and 35% of the cost for increased solar PV system. For a north facing "super" window, nearly 90% of the increased cost is due to the cost of the window and 10% for the additional energy requirement. Assuming a window lifetime and a solar PV system lifetime of 20 years with an additional cost of $5500 for 100 sqft of north facing windows spread over 20 years is $25 per month, or less than your cable, internet or cell phone bills. Nobody knows the longevity of these windows with sealed gas and coatings but we are approaching a couple decades of experience and a number of them seem to be doing fine. Solar PV panel warrantees of 20 to 25 years are now common and based on experience.

Hopefully these comparisons help put things in perspective and give you some idea of window cost. Equinox House tends toward the small but reasonable side of things. We have approximately 100 sqft of south facing windows with a reasonably high SHGC and an ok U value with minimal negative impact on system cost. In our next topic on thermal mass, we'll also see the difficulty of keeping a heavily windowed building (window area greater than 10% of floor area) comfortable. We also have nearly 100 sqft of north facing windows at a cost that we feel is worth it. Our gardens are going to be wonderful to look at year around with a very pleasant light illuminating the yard. I would choose the cost for this view over the cost of cable TV without a second thought.

This confusing array of results can be summarized as follows:

1) Don't overemphasize south facing windows. South facing window areas in the 5 to 10% of floor area range are reasonable (100 to 200sq ft) and provide substantial daylight to the interior is properly placed. Be sure the SHGC is 0.5 or higher and the U value is 0.3 or less.
2) Add non-solar gain windows for viewing pleasure and daylighting while recognizing the cost implication. A cost of $25 per month for 100 square feet of window is the cost impact in central Illinois. The SHGC is not so important, so emphasize a low U value along with as high of a VT (visible light) transmittance as possible (something greater than 0.4).

Daylighting and ventilation are important aspects of a comfortable home that will be covered in later topics. At this point, we'll mention two things. First, the modest amount of windows described above (100sqft for a 2000sq ft home) is more than enough daylight for great illumination within a home, assuming good placement of windows. Second, windows do not need to be used for ventilation if a home's fresh air exchange system is properly designed. Choose fixed windows and save yourself the headaches of broken window mechanisms, cracked window seals, and insect invasions. Building codes require that some windows (eg, bedroom) are operable, but beyond these, fixed windows are a good choice is the ventilation system is properly designed. Most humans do not do a good job of opening and closing windows in an energy efficient manner, even though they think they do. It is similar to a room full of people who are asked if they are above average drivers. More than half will raise their hands.