Photo 1: Equinox House near the fall equinox (September 20) with clerestory overhang and lower roof overhang allowing full sun to enter the house.

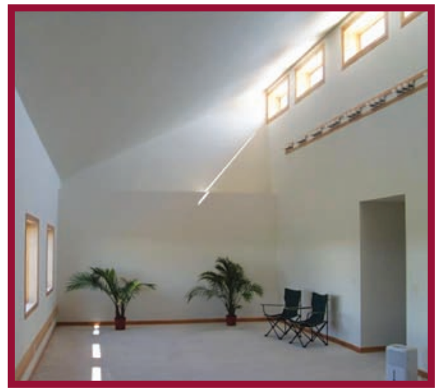

Photo 2: Interior light with full sun entering Equinox House on September 20. The sun's elevation through most of the winter will move the direct beam radiation onto the upper walls and ceiling.

Windows & Overhangs

By Ty Newell, Member ASHRAE; and **Ben Newell,** Associate Member ASHRAE

Windows, after people, are maybe the second most complex component affecting building performance. Windows impact comfort (both visual and thermal), capital cost, and operating cost. Proper integration into a building for achieving good performance and aesthetic appeal requires close cooperation of architects and engineers. A great source for learning about window performance is found in Chapter 31 of *ASHRAE Handbook—Fundamentals.*

Photo 3: North looking view of Equinox showing the main living space picture windows and smaller casement windows in the master bedroom. Note the 1,700 gallon (6435 L) cistern access cover for rainwater harvesting and adjacent rain garden area for storm water retention in the foreground.

Equinox House is defined by its windows and their protective overhangs. The house is named after its "equinox overhang" design protecting the clerestories in the summer from direct solar radiation, and acting as a solar energy reflector in the winter. *Photo 1* shows the outside of Equinox House taken on September 20, close to the fall equinox.

The top edge of the clerestory overhang was placed at a distance and angle from the top of the clerestory windows such that three weeks prior to the equinox, the clerestories were fully covered. From our simulation modeling, the equinox is the optimal time in our area (Central Illinois) to cover (spring equinox) and uncover (fall equinox) the clerestories. The optimal time to cover and uncover windows is dependent on other factors, too, such as the window-to-wall area ratio and internal activities.

Too many buildings have been over windowed under the guise of energy efficiency or daylighting. *Photo 2* shows the interior view of the main open living area in Equinox House on September 20 when the first beam of sunlight has penetrated into the space. The 5.5 m^2 (59.2 ft^2) of clerestory and 5.5 m^2 (59.2 ft^2) of picture windows in the main living area provide 400 to 500 lux (37 to 46 footcandles) during the summer and 800 lux (74 footcandles) in the winter with the admission of beam radiation. The movement of sunlight through the space is quite animated and fun in an unobtrusive manner to room occupants. The north-facing picture windows, shown in *Photo 3*, were chosen to view the backyard garden.

This is the fourth in a series of columns. Find previous columns at www.ashrae.org/ashraejournal.

Figure 1 shows the National Fenestration Rating Council (NFRC) stickers for the three types of windows in Equinox House along with the NFRC sticker for a replacement window recently installed in our laboratory building. Window Type 1 is a hinged casement window used in our bedrooms that is sized to meet emergency egress requirements by the International Residential Code.

Window Type 2 is the picture window used in the main living space. Window Type 3 is the fixed clerestory window, and Window Type 4 is a replacement casement window installed in our laboratory last year.

Two parameters on the NFRC sticker are of the most interest for this discussion. The U-factor, or overall heat transfer coefficient, should be as low as is practical. Converting the U-factors to an insulation R-value indicates that these windows are equivalent to an R-3 to R-4 insulation, or more than 10 times less than the R-44 rating of the structural insulated panels (SIPs) wall and roof.

The other parameter of interest on the NFRC sticker for energy performance is the solar heat gain coefficient (SHGC). This is the fraction of solar energy that is transmitted through the window. As multiple panes of glass or plastic are incorporated into a window, interreflections and absorption within the panes reduces the SHGC. Special coatings (low e) added to the surfaces of the panes also affect solar energy transmittance. For windows intended to transmit winter solar energy into a house for heating, the SHGC should be as high as possible. 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.

Figure 1: NFRC window performance parameters for the three types of windows installed in Equinox House and a replacement window installed in Newell Instruments Laboratory.

The visible transmittance 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. In Equinox, the clerestory windows designed to contribute to winter heating have purposely been chosen for high SHGC. The other windows in which solar heat gain is either not important or not desired, such as in casement windows in the small south bedrooms, have been chosen with low SHGC and low U-factor.

For residences, our economic analyses combined with energy performance effects indicate that minimizing windows increases the economic performance of a house in our region. *Table 1* shows the annual energy performance of Equinox House with a variety of window styles. Six sets of window parameters, with three window areas are shown in *Table 1*. At the top of *Table 1* is the energy requirement prediction for Equinox House without any windows. The next two conditions show Equinox House performance with "good" windows. Good refers to a mass produced, triple-pane, gas-filled, low-e window with performance characteristics of Window Type 3 shown in *Figure 1*, used for the clerestories. The first condition assumes no overhang protection during the spring to fall time period with south facing window areas ranging from 9.3 m^2 to 27.9 m^2 (100 ft^2 to 300 ft^2).

Although all three window areas reduce the house energy below that of an unwindowed house, increasing the window area above 18.6 m^2 (200 ft^2) begins to increase the annual energy load due to increases in summer air conditioning. The second condition representing the same windows but with overhang protection from the spring equinox to the fall equinox decreases the house energy requirements by 10% to 20% compared to the unwindowed house.

The next two sets of windows are described as "super" windows due to very low U-factor while maintaining high SHGC. The parameters used for these windows are based on manufacturers' literature. The first set shows super window performance with no overhang protection from spring to fall equinox while the second set of results shows performance with overhang protection. As with the good windows in the previous results, super windows perform even better due to the low U-factor. Overhangs matched with super windows show the potential to reduce building energy by 35% from that of a house with no windows.

Window	Orientation	Overhang	U-Factor	SGHC	Window Area (ft²)	Energy (kWh)
No window	NA	NA	–	–	0	7,980
Good	South	None	0.3	0.51	100	7,300
Good	South	None	0.3	0.51	200	7,240
Good	South	None	0.3	0.51	300	7,520
Good	South	Yes	0.3	0.51	100	7,250
Good	South	Yes	0.3	0.51	200	6,720
Good	South	Yes	0.3	0.51	300	6,450
Super	South	None	0.12	0.53	100	6,850
Super	South	None	0.12	0.53	200	6,510
Super	South	None	0.12	0.53	300	6,660
Super	South	Yes	0.12	0.53	100	6,740
Super	South	Yes	0.12	0.53	200	5,870
Super	South	Yes	0.12	0.53	300	5,250
Low SHGC	South	None	0.26	0.18	100	8,060
Low SHGC	South	None	0.26	0.18	200	8,240
Low SHGC	South	None	0.26	0.18	300	8,440
Good	North	None	0.23	0.28	100	8,660
Good	North	None	0.23	0.28	200	9,340
Good	North	None	0.23	0.28	300	10,020

Table 1: Annual energy requirements for Equinox House with various windows.

Window	Orientation	Overhang	Window Area (ft²)	Energy (kWh)	Window ($)	Solar PV ($)	House ($)	Total ($)
No window	NA	NA	0	7,980	0	22,500	224,600	247,100
Good	South	None	100	7,300	3,500	20,500	224,600	248,600
Good	South	None	200	7,240	7,000	20,500	224,600	252,100
Good	South	None	300	7,520	10,500	21,400	224,600	256,500
Good	South	Yes	100	7,250	3,500	20,500	224,600	248,600
Good	South	Yes	200	6,720	7,000	19,100	224,600	250,700
Good	South	Yes	300	6,450	10,500	18,240	224,600	253,340
Super	South	None	100	6,850	7,000	19,400	224,600	251,000
Super	South	None	200	6,510	14,000	18,200	224,600	256,800
Super	South	None	300	6,660	21,000	18,800	224,600	264,400
Super	South	Yes	100	6,740	7,000	19,100	224,600	250,700
Super	South	Yes	200	5,870	14,000	16,500	224,600	255,100
Super	South	Yes	300	5,250	21,000	14,800	224,600	260,400
Super Cheap	South	Yes	300	5,250	10,500	14,800	224,600	249,900
Low SHGC	South	None	100	8,060	3,500	22,800	224,600	250,900
Low SHGC	South	None	200	8,240	7,000	23,100	224,600	254,700
Low SHGC	South	None	300	8,440	10,500	23,900	224,600	259,000
Good	North	None	100	8,660	3,500	24,500	224,600	252,600
Good	North	None	200	9,340	7,000	26,200	224,600	257,800
Good	North	None	300	10,020	10,500	28,200	224,600	263,300
Super	North	None	100	8,300	7,000	23,400	224,600	255,000
Super	North	None	200	8,600	14,000	24,200	224,600	262,800
Super	North	None	300	8,900	21,000	25,100	224,600	270,700

Table 2: Overall cost (house + energy + window costs) for different window performance parameters and window areas.

The next set of results is for an ENERGY STAR window with Window 4's U-factor and SHGC shown in *Figure 1* without overhang protection. Because the SHGC is so low, the windows do not provide a reduction in annual energy relative to the no windowed house case. Window 4 is ENERGY STAR rated while Window 3 used for the clerestories is not ENERGY STAR rated. This shows how the ENERGY STAR ratings are set up to, on average, minimize the damage of selecting poor windows because the requirements and capabilities for proper building design and window selection is nearly nonexistent. The last set of results is for the good windows placed on the north side of the house. As one would expect, north-facing windows perform worse than no windows, however this should be tempered by the value one places on the view and daylighting of these windows.

A super window with overhang protection makes most sense from a pure energy basis. How do economic factors affect this conclusion? *Table 2* presents the energy performance data of *Table 1* with estimated costs included. The table includes window cost, energy cost (based on solar photovoltaic [PV] energy) and base house cost. Good windows are assumed to cost $375/m^2 ($35/ft^2) and super windows are assumed to cost $750/m^2 ($70/ft^2). These are window costs without installation cost. Window installation cost is somewhat of a fixed cost independent of window size and window type to a large extent. In our case, the installation cost for a window was $100 to $150 based on $40 per hour of labor and two to three hours for installation and framing. In addition to the parameter conditions listed in *Table 1*, a "cheap" super window that costs the same as a good window is included, as well as the cost and energy of a north facing super window.

The base house is assumed to cost $1,150/m^2 ($107/ft^2) of floor area, resulting in a base house cost of $224,600 for a 195 m^2 (2,100 ft^2) floor area house. This cost is included in *Table 2* for perspective relative to the window cost and associated energy cost. The energy cost included in *Table 2* is determined from our house simulation model in which we have determined the solar PV system size required to reach net zero annual energy performance. As discussed in our previous column, the solar PV energy cost is $0.128 per kWh.

Table 2 indicates that the unwindowed house is the most cost efficient configuration, however not by a significant amount relative to a number of the windowed configurations. The superior energy performance of the super windows is not recouped in cost due to the expense of the super windows. The super window with the same cost as the good window is about $3,000 less in total cost due to improved energy performance; however, the overall cost is still more than that of the unwindowed house. North windows cost more than the unwindowed house due to both window and energy costs as one would expect. Note that the window cost for both the good and super windows is greater than the associated increase in energy cost of having a north facing window in the central Illinois climate.

In summary, for central Illinois and many other locations, the cost of a window outweighs the potential savings due to improved energy performance. Overhang protection for windows improves energy performance. Keeping window-to-wall area ratios less than 10%, as in Equinox House, results in excellent interior daylighting and ample opportunity to provide views without significantly impacting overall cost. Over-windowing adds cost, potentially increases energy, and makes comfort control more difficult. We'll see this last issue in more detail when we look at building mass.

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