Selecting Windows Based on Annual Energy Performance

John Carmody, Minnesota Building Research Center, University of Minnesota
Brian Crooks, Cardinal IG

There is a need to understand the impact of window choices on the annual energy performance of a house. Knowing the U-factor, solar heat gain coefficient (SHGC), and air leakage rating do not directly lead consumers to this information. In order to understand the impact of window selection on annual energy use, researchers performed thousands of computer simulations (using DOE-2.1E) of houses with a wide range of characteristics in several U.S. climates. The results of these simulations suggested the impact of higher performance windows on housing design. Results show that using highly-efficient windows can significantly change traditional design assumptions related to window orientation, shading devices, and optimal amounts of glazing. Based on these computer simulations, it was discovered that a rating number can be developed that reflects the relative annual performance and it can simply be applied to any house in any U.S. climate. These numbers are referred to as FHR (Fenestration Heating Rating) and FCR (Fenestration Cooling Rating).

INTRODUCTION

Windows have undergone a technological revolution in the last fifteen years. They are no longer the weak link in energy-efficient home design. It is now possible to have expansive views and daylight without sacrificing comfort or energy efficiency. This remarkable change has two important effects. First, any house can be made considerably more energy efficient by using high-performance windows. Second, and possibly more important, technologically advanced windows perform so much better and differently than their predecessors of just ten years ago, that many of the assumptions of both traditional and more recent energy efficient design must be reexamined (Carmody et al. 1996).

The major technological innovations that are appearing in today's fenestration products include: (1) multiple layers of glass or plastic films, (2) low-emissivity or solar control coatings, (3) low conductance gas fills, and (4) warm-edge spacers and insulating frame materials.

The National Fenestration Rating Council (NFRC) has developed a fenestration energy rating system based on whole product performance. This accurately accounts for the energy related effects of all the product's component parts, and prevents information about a single component from being compared in a misleading way to other whole product properties. With energy ratings based on whole product performance, NFRC helps builders, designers, and consumers directly compare products with different construction details and attributes. At this time NFRC labels on window units give ratings for U-value, solar heat gain coefficient (SHGC), and visible transmittance (VT). Soon labels will include air infiltration rates and annual energy performance (FHR and FCR). In the future, ratings may be developed to indicate condensation resistance and long term energy performance.

IMPACT OF WINDOWS ON ANNUAL ENERGY USE

In order to understand the impact of window selection on annual energy use, researchers performed thousands of computer simulations of houses with a wide range of characteristics in several U.S. climates (Crooks 1994). The simulation program was DOE-2.1E, which is considered one of the standards for building simulation in the United States. The characteristics of the prototypical house used in the simulations are shown in Table 1. Three notable design implications from these studies are discussed below.

Orienting windows to reduce heat gain

Until recently windows had little inherent capability of reducing solar heat gain, so the layout of energy-efficient houses evolved to protect windows from the most significant gains. In hot climates, the goal with this approach is to face most windows north where there is little direct exposure or to the south where they can easily be designed with overhangs that will keep out most of the hot summer sun. Overhangs are much less effective against the lower angles of the east and west sun. Therefore, simply reducing the size and number of east and west windows can be the most direct strategy. West windows are subject to the full force of the strong afternoon sun, at a time of day when temperatures generally climb to their peak. East windows have the same problem in the morning hours, but air temperatures tend to be cooler at that time.

Table 1. *Characteristics of the Prototypical House Used in Simulations*

Building	
Floor area	1540 square feet
Insulation levels	R-19 walls, R-19 floor, R-30 ceilings
Foundation type	Vented crawl space
House infiltration	Effective leakage area (ELA) = 0.77 sf (approx. 0.5 ACH)
Natural ventilation	10 20 air changes per hour (variable) (Sherman-Grimsrud method)
Thermal mass in building	3.5 lbs. per sq. ft. for structure 8.0 lbs. per sq. ft. for furnishings
Windows	
Fenestration area	231 square feet (15% of floor area)
Window orientation	Equal (57.75 sq. ft. on each side)
External shading	None
Internal shades/blinds	None
Mechanical System	
Mechanical system type	Gas furnace with central air conditioning
HVAC efficiency	Heating system efficiency = 78% Air conditioning COP = 2.3 (10 SEER)
Thermal zones	None
Internal loads	54 kBtu per day
Thermostat settings	Heating = 70 F, Cooling = 78 F
Seasonal plant cutout	None

These traditional patterns are not necessarily valid, however, when better performing windows with low solar heat gain coefficients are used. Figure 1 illustrates the impact of different window orientations on cooling energy use for a house in Phoenix, Arizona. As expected, facing windows in different directions has a significant impact when typical single- or double-glazed windows are used. When higher performance windows with spectrally selective low-E coatings are used, however, the window orientation has a greatly diminished impact on energy use. In effect, with these more advanced windows, nearly all of the glazing can face west or south without a significant energy penalty. Moreover, these computer simulations are done for a house with no overhangs, external or internal shading devices.

Using overhangs and landscaping to reduce solar heat gain

Exterior shading devices have long been considered the most effective way to reduce solar heat gain into a home. The most common is the fixed overhang. For south-facing windows, overhangs can be sized to block out much of the summer sun but still permit lower-angled winter sun to enter. Similarly, shade trees are an effective way to reduce solar gain.

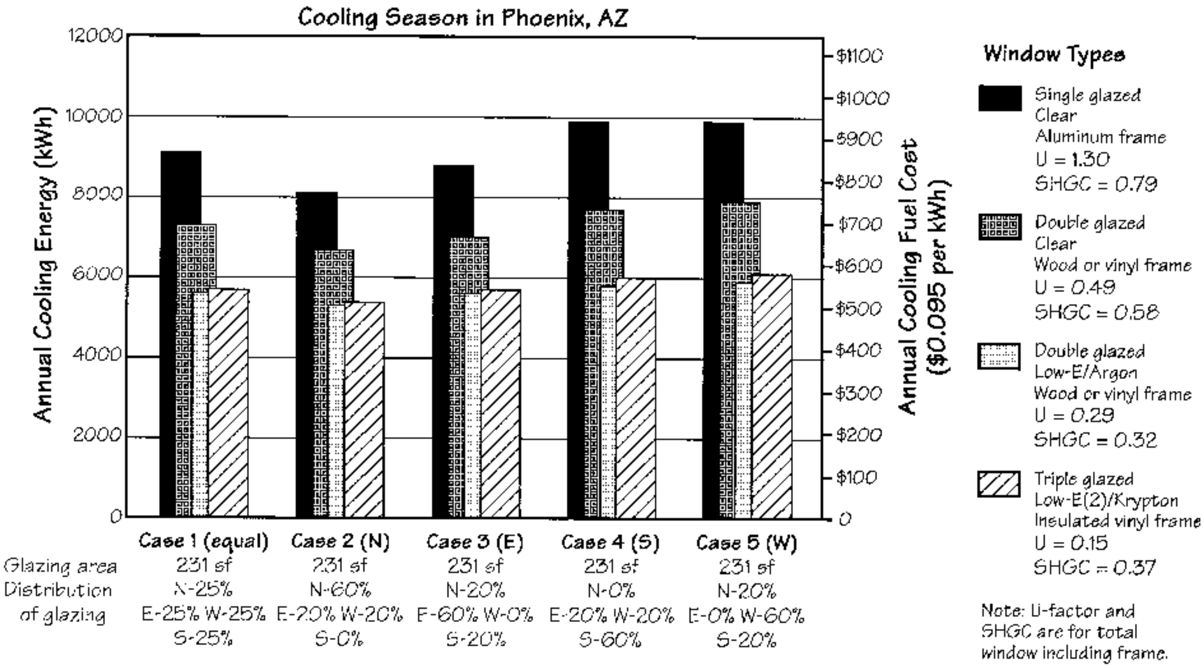
Reliance on external shading devices and landscape elements is not nearly as important, however, when better performing windows are used (low solar heat gain coefficients). Figure 2 illustrates the impact of overhangs and a densely wooded lot on cooling energy use for a house in Phoenix, Arizona. As expected, the external shading devices reduce total cooling energy use by 20 to 25 percent when single glazing is used and a significant amount for clear double glazing as well. Using spectrally selective low-E coatings, however, results in less impact from the use of overhangs or shade trees. This is because the glazing itself provides the necessary control of solar radiation so these additional measures become less important in terms of energy use.

Determining the optimal amount of glazing to reduce winter heat loss

In the 1970s, when energy use was an emerging concern, the high-performance windows of today were not available. One of the clear architectural design approaches was simple: to reduce heat loss, reduce window area. As windows have improved considerably in the last 20 years, the truly high-performance windows are almost equivalent to insulated walls. Consequently, the strategy of reducing window area to reduce energy use is no longer valid if highly efficient windows are used.

As Figure 3 illustrates, total glazing area has a profound impact on heating energy use when single- and even double-glazed windows are used. With high-performance windows, however, the glazing area is not an important factor. In fact, with the superwindow (U = 0.15), the total heating energy use for a house in Madison, Wisconsin decreases slightly as the glazing area increases. This indicates that the benefit of more passive gain exceeds any losses from more glazing area. It should be noted, however, that cooling energy for the house with high-performance windows increases slightly with greater glazing area. Depending on the exact U-factor,

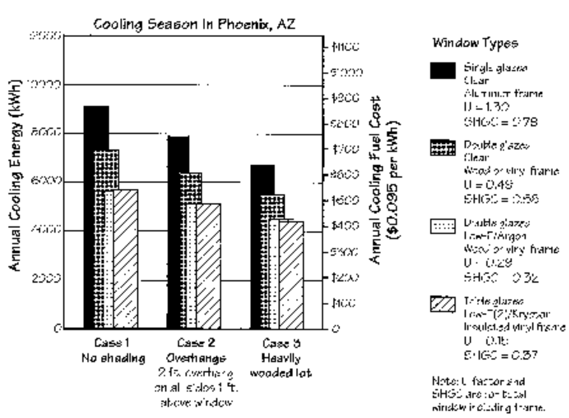
Figure 1. Impact of window orientation on annual cooling season energy use in Phoenix, Arizona.



Source: Carmody et. al. 1996.

Note: The annual energy performance figures shown here for a typical house are the result of computer simulations using DOE2.1e. The house characteristics are shown in Table 1.

Figure 2. Impact of overhangs and shading on annual cooling season energy use in Phoenix, Arizona.



Source: Carmody et. al. 1996.

Note: The annual energy performance figures shown here for a typical house are the result of computer simulations using DOE2.1e. The house characteristics are shown in Table 1.

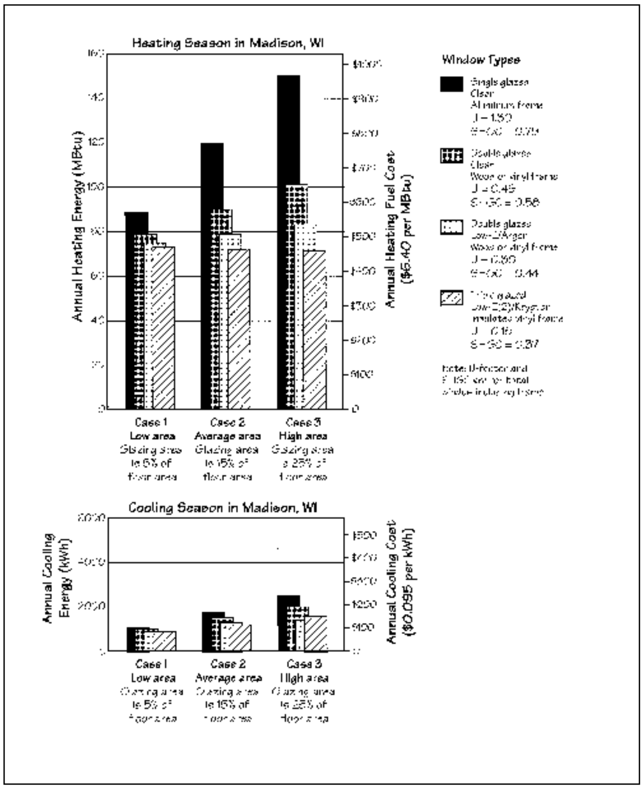
SHGC, and climate, energy gains in the heating season may be offset by losses in the cooling season.

DETERMINING ANNUAL ENERGY PERFORMANCE

One reason to select a higher quality window unit is the expectation of improved energy performance. A better U-factor, solar heat gain coefficient, or air leakage rating translates into less money spent on heating and cooling bills. The question is how much savings will actually result from selecting a particular window. The previous examples are for a specific set of conditions that do not necessarily translate to another situation. The actual impact of window selection on energy costs will vary depending on a number of factors:

- The characteristics of the window units being compared (U-factor, solar heat gain coefficient, air leakage).
- The climate where the building is located.
- The amount and orientation of glazing on the building.

Figure 3. *Impact of window glazing area on annual heating and cooling season energy use in Madison, Wisconsin.*



Source: Carmody et. al. 1996.

Note: The annual energy performance figures shown here for a typical house are the result of computer simulations using DOE2.1e. The house characteristics are shown in Table 1.

- Various building elements that directly affect the window performance (overhangs, trees or buildings that block the sun, internal shading devices).
- Building characteristics that affect energy performance and thus influence the impact of the windows (floor area, insulation levels, foundation type, internal loads, house infiltration, natural ventilation, type of mechanical system, and the heating and cooling system efficiency).
- How the occupants operate the house (thermostat settings and the use of internal shading devices).
- The cost of energy for heating and cooling.

The most accurate method of determining annual energy performance is by using computer simulations that incorporate all of the characteristics of a particular building in a particular climate. These tools are not always practical for designers, builders, and homeowners to use in making a window purchasing decision, though this may change in the coming years as computer tools become easier to use, more widely available, and more familiar to the building community.

Development of the annual energy performance rating system

To overcome the limitations of requiring detailed computer simulations for each situation, a rating system has been developed for windows that reflects annual performance (Crooks et al. 1995). This rating system, currently being refined by U.S. Department of Energy and window industry researchers in cooperation with the National Fenestration Rating Council, has been adopted as the official annual performance rating system of the NFRC.

Using the prototypical house described in Table 1 and the eleven window types shown in Table 2, a series of computer simulations were run that predicted annual heating and cooling energy use in 30 U.S. cities. The set of results clearly indicates the energy impacts of window selection for the prototypical house, but, of course, gives no information on the impact for a house of different design or operating conditions.

Each basic characteristic of the house shown in Table 1 was changed and new simulations run to determine how these parameters affected the annual energy use. In each case, a range of conditions was simulated that reflected most housing conditions. For example, floor areas of 1200, 1540, 2400, and 3080 square feet were simulated.

These simulations revealed that while the actual energy use varied as house characteristics were changed, the relative impact of changing window types was often unchanged. For example, if changing from Window A to Window B resulted in a 20 percent annual energy savings, the savings remained at 20 percent even if many of the house characteristics were changed. Remarkably, as shown in Figure 4, similar percent savings numbers resulted in a wide range of climates (with a few exceptions that do not have great significance).

This means that a rating number can be developed that reflects this relative performance and it can simply be applied to any house in any U.S. climate. The heating rating number can be converted to a percentage and multiplied by heating energy use and then by heating energy cost to determine an approximate savings when comparing two window units. A similar procedure can then be done for cooling. These numbers are referred to as FHR (Fenestration Heating Rating) and FCR (Fenestration Cooling Rating). The FHR and FCR are shown in Table 2 for eleven window types.

Table 2. Window Types Used in Computer Simulations of Annual Energy Performance

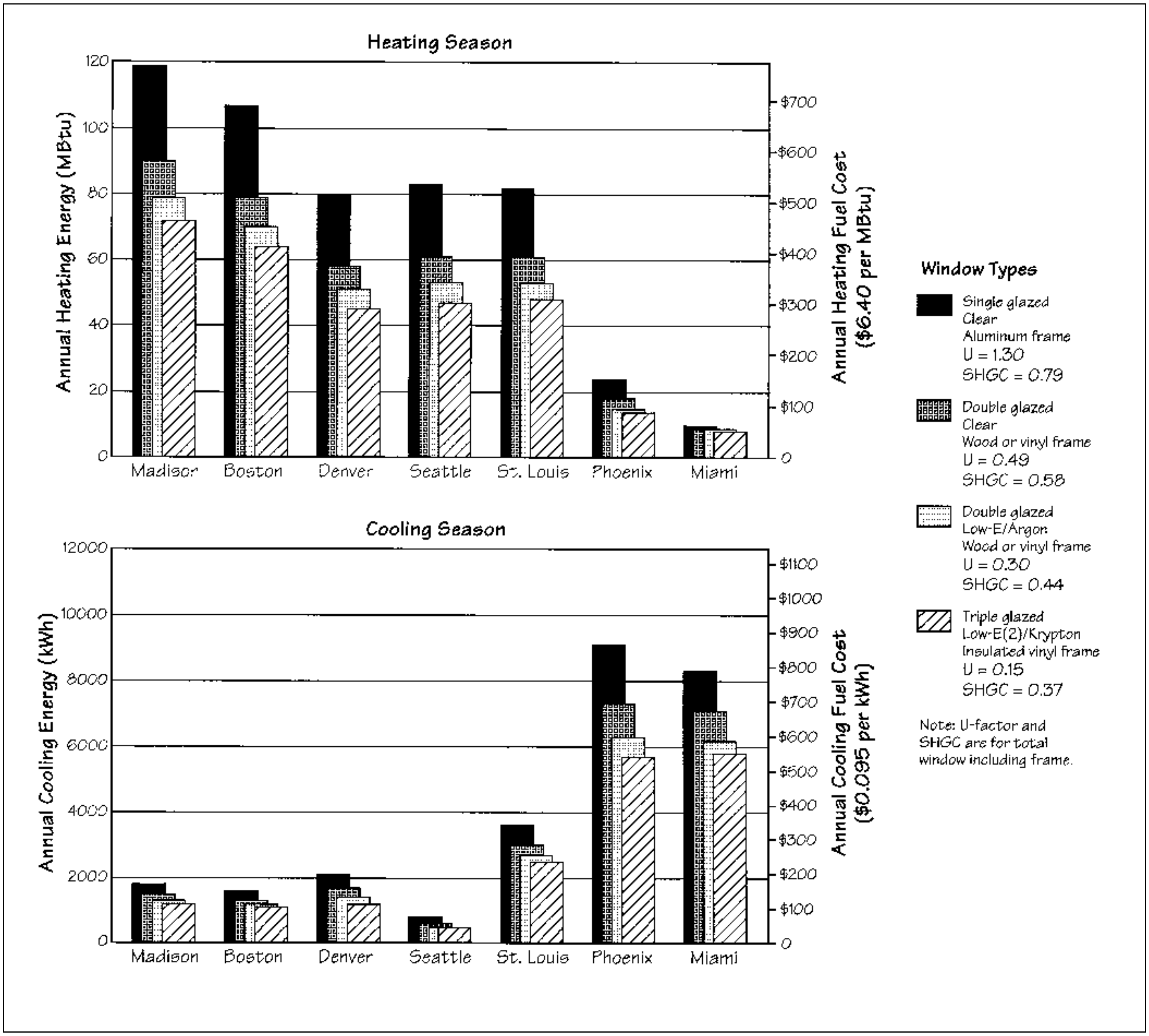
	Window description	U-factor (overall)	Solar Heat Gain Coefficient (overall)	Visible Transmittance (overall)	Air Leakage (cfm/ft^2)	FHR (30 climate average)	FCR (30 climate average)
1	Single glass Aluminum frame with no thermal break	1.30	0.79	0.90	0.98	0	0
2	Single glass bronze Aluminum frame with no thermal break	1.30	0.69	0.68	0.98	−2	8
3	Double glass Aluminum frame with thermal break	0.64	0.65	0.81	0.56	19	12
4	Double glass bronze Aluminum frame with thermal break	0.64	0.55	0.61	0.56	17	20
5	Double glass Wood or vinyl frame	0.49	0.58	0.81	0.56	24	18
6	Double glass bronze Wood or vinyl frame	0.49	0.48	0.61	0.56	22	25
7	Double glass Low-E (.20) argon Wood or vinyl frame	0.33	0.55	0.74	0.15	32	19
8	Double glass Low-E (.08) argon Wood or vinyl frame	0.30	0.44	0.78	0.15	32	27
9	Double glass Selective low-E (.04) argon Wood or vinyl frame	0.29	0.32	0.72	0.15	30	36
10	Double glass Selective low-E (.10) argon Wood or vinyl frame	0.31	0.26	0.44	0.15	27	40
11	Triple glass Low-E (2 surfaces) krypton Insulated vinyl frame	0.15	0.37	0.68	0.08	38	33

Using the FHR/FCR ratings to determine energy performance

The concept of a single number representing heating energy use and another representing cooling energy use is a powerful and useful tool. It also opens the possibility of misinterpretation or misuse of the numbers. It is important that the rating system (with its strength and limitations) be clearly understood by users. For this reason, NFRC is developing a User's Guide for the FHR/FCR rating system. The guide will address the following concepts:

(1) The FHR and FCR numbers reflect the percent savings in annual energy use when using one window type

Figure 4. *Annual energy performance of four window types in seven U.S. cities.*



Source: Carmody et. al. 1996.

Note: The annual energy performance figures shown here for a typical house are the result of computer simulations using DOE2.1e. The house characteristics are shown in Table 1.

when compared to a base case window. The higher the rating, the more energy efficient the window. For example, if the FHR = 30 for a particular window, then the total annual heating energy cost for a house will be reduced by 30 percent compared to a house with clear, single-glazed windows.

(2) If two window types are being compared, the net difference between the two FHR (or FCR) ratings represent the percent savings in annual heating (or cooling) energy use. If FHR = 30 for window A and FHR = 20 for window B, using window A will result in 10 percent savings in annual heating energy compared to window B.

(3) The percent savings derived from designing a more efficient window can be applied to the annual heating costs of the house. For new construction, the annual energy costs can be predicted by computer simulation or from estimates based on utility costs for similar

houses in the area. For remodeling of an existing house, actual energy costs can be determined from utility bills. The NFRC User's Guide will provide FHR and FCR ratings for typical older window types.

(4) By doing a separate cost savings calculation for heating and cooling, the relative importance of FHR and FCR is obvious in a particular climate. For example, if annual heating costs are $1200 and cooling costs are $200, then the FHR is far more important than FCR in that location. If consumers are simply looking at the rating numbers, they must be made aware that FHR and FCR may be equally important in St. Louis, but FHR is far more important in Minneapolis while FCR is the critical number in Phoenix.

The FHR/FCR estimate of savings is a simplified technique that is based on specific conditions. Better estimations of savings can be obtained by using the RESFEN computer program (Sullivan et al. 1992). The simplified FHR/FCR estimate of savings is likely to be less accurate in houses with the following conditions:

- Large glazing areas (glazing-to-floor-area ratio over 0.20).
- Substantial shading of windows.
- Older, poorly insulated homes with high air infiltration.
- Passive solar homes.
- Homes where only some windows are being replaced.

CONCLUSIONS

Advanced window technologies can clearly improve annual energy performance in housing. In addition, the high-performance glazings can provide insulating value and solar control that have fundamental implications for house design. Based on computer simulations for a typical houses in a cooling-dominated climate, facing windows in different directions has a significant impact when typical single- or double-glazed windows are used. When higher performance windows with spectrally selective low-E coatings are used, however, the window orientation has a greatly diminished impact on energy use. Similarly, the external shading devices reduce total cooling energy use by 20 to 25 percent when single glazing is used and a significant amount for clear double glazing as well. Using spectrally selective low-E coatings, however, results in less impact from the use of overhangs or shade trees. In a heating-dominated climate, total glazing area has a profound impact on heating energy use when single- and even double-glazed windows are used With high-performance windows, however, the glazing area is not an important factor.

Basically, the NFRC Annual Energy Performance Rating is similar to a miles per gallon rating for automobiles. It gives a good relative comparison for most situations, but actual performance may vary. The use of computer tools like RESFEN is required for more accurate calculations (Sullivan et al. 1992). To determine which calculation method or rating system is useful, it is first necessary to understand the needs and approach of the designer, builder, or homeowner who is seeking the information. There are some situations like houses with large glazing areas where using the simplified FHR/FCR method to determine annual energy savings will not be accurate.

The introduction of an annual energy performance rating system for windows has obvious marketing implications. Products can be compared on this basis and approximate cost savings calculated. The design implications of higher performance windows also present some marketing opportunities. For example, if windows are efficient enough, there is minimal energy penalty with increased glazing area. Also, if windows with effective solar control are chosen, the impact of external and internal shading devices becomes redundant. With better windows, there is more design freedom, money can be saved by not investing in attachments, and heat gain is reduced without diminishing daylight significantly.

REFERENCES

Carmody, J., S. Selkowitz, and L. Heschong. 1996. Residential Windows: New Technologies and Energy Performance. W.W. Norton & Co.

Crooks, B. 1994. Annual Energy Performance for Windows: Parametric Sensitivity Study. Product Development Group, Cardinal IG, Minneapolis.

Crooks, B., J. Larsen, R. Sullivan, D. Arasteh, and S. Selkowitz. 1995. ''NFRC Efforts to Develop a Residential Fenestration Annual Energy Rating Methodology,'' Proceedings, Windows Innovations Conference 95. Toronto. Natural Resources Canada and LBL Report 36896.

Sullivan, R., B. Chin, D. Arasteh, and S. Selkowitz. 1992. ''RESFEN: A Residential Fenestration Performance Design Tool.'' ASHRAE Transactions 1992, v. 98, pt. 1 and LBL Report 31176.