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NFRC Efforts to Develop a Residential Fenestration Annual Energy Rating Methodology

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Abstract

This paper documents efforts currently being undertaken by the National Fenestration Rating Council's Annual Energy Rating Subcommittee to develop procedures to quantify the energy impacts of fenestration products in typical residential buildings throughout the United States. Parallel paths focus on (1) the development of simplified heating and cooling indices and (2) the development of a more detailed methodology to calculate the cost and energy impacts of specific products in a variety of housing types. These procedures are currently under discussion by NFRC's Technical Committee; future efforts will also address commercial buildings.

Introduction

The National Fenestration Rating Council (NFRC) with technical support from the Lawrence Berkeley Laboratory is in the process of defining procedures that provide an energy rating for residential windows. NFRC member researchers in both the private and public sectors are working together to create a rating system which is simple and easy to understand, but also yields accurate information about the heating and cooling energy performance and cost of windows. We are currently developing two parallel approaches which are targeted for use by different kinds of decision makers such as homeowners, architects, builders, etc. The methods discussed represent the current direction of NFRC, and have not yet been formally approved by the membership.

The first approach is a simplified rating procedure which makes use of two dimensionless indices: FHR (Fenestration Heating Rating) and FCR (Fenestration Cooling Rating). The indices for a particular window establish how well that window performs relative to other windows in any location in the U.S. Substantiation of FHR/FCR is being accomplished by completion of a sensitivity study of window performance to parameters such as geographic location, wall insulation level, foundation type, floor area, window type, distribution, size, etc. FHR or FCR can be used with other site specific information to establish annual heating and cooling savings for a window.

The second approach, developed in conjunction with the FHR/FCR methodology, is a customized procedure that will more accurately calculate the annual energy performance of windows in a home. Users can input any combination of window orientation, size, U-factor, shading coefficient, air leakage, and exterior or interior shading and obtain annual heating and cooling energy use and cost as well as peak heating and cooling increments due to the windows. This

method will ultimately incorporate an hour-by-hour simulation using a version of the DOE-2 computer program[1] dedicated to window energy performance analysis, although the simulation details will be invisible to the user.

We first describe the residential prototype used to define the rating methodology, and then discuss the simplified annual energy rating methodology and the parametric study that was accomplished to understand the sensitivity of the rating to residential house variations. We then present a brief description of the more detailed, customized annual energy performance analysis tool that can be used by architects, builders, and homeowners to assist in their selection of windows.

Residential Prototype Description

Development of the FHR and FCR methodology started with the definition of a base case prototype residential building model. We selected a single-story, slab-on-grade, one-thermal zone house with a floor area of 143 m^2 (1540 ft^2) as the prototype (see Table 1). It is very similar to one developed at the Lawrence Berkeley Laboratory for studies related to ASHRAE 90.2[2,3], ASHRAE Special Project 53[4], and in the creation of the RESFEN computer program[5]. In the most recent refinement of the prototypical house, some parameters below have been adjusted to be more consistent with recent changes in the Model Energy Code.[6]

Wood-frame construction is used with a wall U-Factor of 0.30 W/m^2K (0.053 Btu/hr-ft^2F, R19) and a roof U-Factor of 0.19 W/m^2K (0.033 Btu/hr-ft^2F, R30). Windows are uniformly distributed at a size of 5.57m^2 (60ft^2) on each side of the house facing the four cardinal directions (north, east, south, west). Total amount of window area is 15.6% of the floor area. A monolithic 3mm clear glazing with aluminum frame was selected as the base case window system. The base case building model does not include any shading devices. House infiltration is assumed using an average level of building leakage area, 0.071m^2 (0.77 ft^2). A direct-expansion air-cooled air-conditioning unit is used for cooling and a forced-air gas furnace for heating. Cooling system COP is 2.3 and furnace efficiency is 0.74. A dual setpoint thermostat is used to control the space conditioning system. Heating is set at 21.1C (70F); cooling is set at 25.6C (78F).

Internal loads for occupants, lights, and appliances are modeled by considering a composite process heat gain input with a maximum value of 10721 kJ/hr (10163 Btu/hr) which is equivalent to a daily heat input of 56932 kJ/day (53963 Btu/day) sensible and 12875 kJ/day (12156 Btu/day) latent. Natural ventilation of 10 air-changes per hour is provided by opening the windows provided the following conditions are met: (1) if the act of opening the windows provided more cooling than would be provided by the mechanical system with the windows closed; and (2) the enthalpy of the outside air was less than the enthalpy of the inside air (this condition eliminates the possibility of introducing a latent load into the house).

In developing the FHR/FCR, we analyzed data in seven geographic locations within the continental United States: Boston MA, Denver CO, Madison WI, Miami FL, Phoenix AZ, Seattle WA, and St. Louis MO. The locations covered a broad range of climate variations as can be seen in Table 2. Heating-degree-days vary from a high of 4246 (7642) for Madison WI to a low of 123 (222) for Miami FL; cooling-degree-days vary from 967 (1740) for Phoenix AZ to 0 (0) for Seattle WA; latent-enthalpy-days varied from 1155 for Miami to 0 for Seattle.

Table 1. Residential Prototype Description and Sensitivity Study Variations
(Base case in bold)

BASIC HOUSE PARAMETERS

Insulation - Wall/Roof U-Factor

0.30 W/m^{2}K (0.053 Btu/hr-ft^{2}F, R19) / 0.19 W/m^{2}K (0.033 Btu/hr-ft^{2}F, R30)
0.22 W/m^{2}K (0.038 Btu/hr-ft^{2}F, R^{2}6) / 0.15 W/m^{2}K (0.026 Btu/hr-ft^{2}F, R38)
0.44 W/m^{2}K (0.077 Btu/hr-ft^{2}F, R13) / 0.30 W/m^{2}K (0.053 Btu/hr-ft^{2}F, R19)
0.52 W/m^{2}K (0.091 Btu/hr-ft^{2}F, R11) / 0.52 W/m^{2}K (0.091 Btu/hr-ft^{2}F, R11)

Foundation

Slab on Grade, Vented Crawl Space, Unvented Crawl Space, Full Basement

Floor Area

Single Family, 1 Level - **143.1m^2 (1540ft^2)**, 114.5m^2 (1200ft^2)
Single Family, 2 Level - 286.1m^2 (3080ft^2), 222.9m^2 (2400ft^2)

Infiltration Effective Leakage Area

0.31m^2 (0.33ft^2), 0.011m^2 (1.16ft^2), **0.072m^2 (0.77ft^2)**, 0.143m^2 (1.54 ft^2)

WINDOW PARAMETERS

Window Type

See Table 3. Monolithic 3mm clear glazing with aluminum frame is the base case window.

Window Area - Percent Floor Area

5%, 10%, 15%, **15.6%**, 20%, 25%)

Window Distribution

Equal (North, East, South, West)
Distribution Set 1 - 40% on one side, 20% each of the other sides
Distribution Set 2 - 60% on one side, 0% opposite side, 20% adjacent sides

Exterior Shading

None, Overhangs, Obstruction, Obstruction (south only)

Interior Shading

None, Optimum, Average, Mismanagement (Solar Control Only)

HVAC PARAMETERS

System TYPE

Furnace (Gas, Oil) w/ Central AC, Gas Heat Pump,
Electric Heat Pump, Electric Resistance Heat

System Efficiency

Eff.=0.64 & COP=1.8, **Eff.=0.74 & COP=2.3**, Eff.=0.82 & COP=3.0
Eff.=0.90 & COP=4.0

Thermostat Settings

Heating - 21.1C (70F), Cooling - 25.6C (78F)
Heating - 22.2C (72F), Cooling - 24.4C (76F)
Heating - 20.0C (68F), Cooling - 25.6C (78F)
Heating - 21.1C (70F) [15.6C (60F) Night Set Back], Cooling - 25.6C (78F)

OCCUPANT USAGE PARAMETERS

Internal Loads - MJ/day (kBtu/day)

37.9 (40), **51.2 (54)**, 64.5 (68), 75.4 (82)

Natural Ventilation

None, Enthalpic - 5 ACH, **Enthalpic - 10 ACH**, Non-enthalpic - 10 ACH

Table 2. Geographic Locations for FHR/FCR Study

City	Lat	Long	Altitude m (ft)	HDD 18.3C (65F)	CDD 23.9C (75F)	LED	CID
Boston MA	42.0	71.0	4.6 (15)	3126 (5627)	54 (97)	48	252 (80)
Denver CO	39.1	104.1	1610 (5283)	3418 (6153)	27 (48)	0	365 (116)
Madison WI	43.0	89.0	262 (858)	4246 (7642)	10 (18)	82	274 (87)
Maimi FL	25.8	80.3	2.1 (7)	123 (222)	604 (1087)	1155	869 (276)
Phoenix,AZ	33.1	112.0	340 (1117)	733 (1320)	967 (1740)	97	769 (244)
Seattle WA	47.1	122.0	4.3 (14)	2853 (5136)	0 (0)	0	110 (35)
St. Louis MO	38.7	90.4	163 (535)	2694 (4850)	178 (320)	266	432 (137)

Notes:
(1) LED is Latent Enthalpy-Days at a base temp of 23.9C (75F) and base humidity ratio of .0116 and gives an indication of the effect of latent cooling. Defines the amount of energy that must be removed from the air each hour to lower it to the a reference humidity ratio without changing the drybulb temp.
(2) CID is Cooling Insolation-Days, kW/m^2 ($kBtu/hr\text{-}ft^2$), at a base temp of 21.1C (70F). Represents the total insolation hitting an average 0.09 m^2 (1 ft^2) vertical surface (avg of N, E, S, W) when temperatures are above a designated value. Correlates with cooling load penalties due to unwanted solar gain.

Simplified Annual Energy Rating Methodology

To be useful to the residential consumer, a window rating system must be simple, easy to understand, and must be translatable to the energy use and cost associated with the window. We have developed such a system, designated Fenestration Heating Rating (FHR) and Fenestration Cooling Rating (FCR), that will enable the consumer to compare the performance ranking for various window products independent of climate[7]. Energy cost factors are then applied based on localized heating and cooling unit costs.

FHR and FCR are essentially dimensionless numbers assigned to a particular window which establish how well the window will perform in relation to other windows. A window with a higher FHR or FCR means more energy savings can be expected. The number represents a percentage of total house energy savings associated with a particular window versus a base line window under the same parametric set of conditions. If the heating energy use of the prototype house with the baseline windows is H_{BASE} and the heating energy for the house with window type A substituted is $H_{ALTERNATE}$, then the FHR is defined as:

$$FHR = 100 * (H_{BASE} - H_{ALTERNATE}) / H_{BASE} \quad (1)$$

The FCR is defined similarly. Although the rating scheme is intrinsically approximate, it is reasonably accurate for most house parameters that have an affect on energy performance.

Ten window types were defined to test the FHR/FCR concept and these are presented on Table 3. They vary from the base case single pane clear glass with an aluminum frame and no thermal break with an overall U-factor of 7.5 W/m^2K (1.32 $Btu/h\text{-}ft^2F$) and solar heat gain coefficient of 0.78 to a triple pane insulating glass unit with krypton gas fill and highly insulated frame with an overall U-factor of 0.85 W/m^2K (0.15 $Btu/h\text{-}ft^2F$) and solar heat gain coefficient of 0.35. These ten windows were also used in the detailed sensitivity study which is discussed in the next section.

Table 3. Window Types for the Cardinal IG Studies

Type	Glazing Description	Glass Center U	Glass Center SC	Frame	Overall U	Overall SC	SHGC
		W/m^2K (Btu/h-ft^2F)			W/m^2K (Btu/h-ft^2F)		
1	Monolithic - 3mm, Clear	6.30 (1.11)	1.00	Alum w/o T.B.	7.50 (1.32)	0.91	0.78
2	Monolithic - 3mm, Bronze Tint	6.30 (1.11)	0.84	Alum w/o T.B.	7.50 (1.32)	0.80	0.69
3	IGU - 3mm, Clear 13mm Air 3mm Clear	2.78 (0.49)	0.89	Alum w/ T.B.	3.69 (0.65)	0.75	0.64
4	IGU - 3mm, Bronze 13mm Air 3mm Clear	2.78 (0.49)	0.72	Alum w/ T.B.	3.69 (0.65)	0.62	0.53
5	IGU - 3mm, Clear 13mm Air 3mm Clear	2.78 (0.49)	0.89	Wood	2.78 (0.49)	0.65	0.55
6	IGU - 3mm, Bronze 13mm Air 3mm Clear	2.78 (0.49)	0.72	Wood	2.78 (0.49)	0.54	0.46
7	IGU - 3mm, Clear 13mm Argon 3mm, Pyr. LE (0.20)	1.70 (0.30)	0.86	Vinyl, S.S. Spcr.	1.87 (0.33)	0.62	0.52
8	IGU - 3mm, Sput. LE (0.08) 13mm Argon 3mm Clear	1.48 (0.26)	0.68	Vinyl, S.S. Spcr.	1.70 (0.30)	0.50	0.42
9	IGU - 3mm, Sel. LE (0.04) 13mm Argon 3mm Clear	1.36 (0.24)	0.47	Vinyl, S.S. Spcr.	1.65 (0.29)	0.36	0.30
10	IGU - 3mm, L.E. 9.5 Kryp. 3mm 9.5 Krup. 3mm L.E.	0.62 (0.11)	0.57	U=.20, Ins.Spcr.	0.85 (0.15)	0.41	0.35

Note: Each window was anlayzed as a casement (NFRC size AA) using the WINDOW 4.0 defaults for the given frame unless otherwise indicated. The edge correlation method in WINDOW 4.0 was utilized to determine glass edge U-factor. Aluminum spacers (Edge Corr=1) were assumed for glass types 3-6. Glass types 7,8, and 9 were assumed to have an Edge Correlation of 2; whereas, glass type 10 has an insulated spacer (Edge Corr=4). The frame width for the aluminum frames (type 1 through 4) is 57.1mm (2.25in). The frame width for the wood and vinyl frames (type 5 through 10) was 69.9mm (2.75in).

The viability of the FHR/FCR methodology is best seen by considering an example. Figures 1 and 2 present required heating and cooling energy generated using the DOE 2.1E program[1] for seven locations for the window types shown in Table 3. Also shown are the respective FHR and FCR values. They are calculated using window number 1 as the base. This window is the monolithic clear glazing with aluminum frame and no thermal break and results in the highest values of U-factor and solar heat gain coefficient. Results in Boston show that the heating energy consumption for window number 1 is 102.7 GJ (97.4 MBtu). To calculate the FHR for window number 6 in Boston we use its heating energy value 74.6 GJ (70.7 MBtu) as follows:

$$FHR = 100 * (102.7 - 74.6) / 102.7 = 27.4 \quad (2)$$

The cooling energy consumption in Boston for window no. 1 is 1811 kWh and for window no. 6 it is 1390 kWh. The FCR would be:

$$FCR = 100 * (1881 - 1390) / 1881 = 26.1 \quad (3)$$

Figures 1 and 2 indicate that the FHR and FCR values (with the exception of heating in Miami) are very consistent as geographic location and glazing type are varied. Such consistency is also true for most of the other residential configuration changes as we will see in the discussion to follow which documents a very detailed parametric sensitivity study.

Since FHR and FCR in this example represent a percentage of total house energy that is saved by replacing the base case monolithic window with aluminum frame (window no. 1) with an IG unit with a wood frame (window no. 6), we can use them as multipliers of the total house heating and cooling energy costs and easily determine an annual dollar savings. For example, assume that from our house energy bills or from the local utility company we have determined that our total house heating for a one year period was \$700 and the total house cooling was \$200. Replacing the windows yields an annual savings of:

$$\begin{array}{rcccl} & \text{Heating} & & \text{Cooling} & \\ \text{Savings} = & (\$700 \times .274) & + & (\$200 \times .261) & \\ = & \$191.80 & & \$52.20 & = \$244.00 \text{ / year} \end{array} \quad (4)$$

The relative performance of any two windows can be easily determined by first calculating the FHR (and FCR) for each, and then using the ΔFHR and ΔFCR in the savings equation above. It is envisioned that the FHR/FCR methodology will be extended to a continuous range of U-factor and solar heat gain coefficient variations by use of a simplified algebraic equation. We derived such an equation by performing a regression analysis of results for each city using the base case model. The equation had the following form:

$$FHR/FCR = A + B\,(\text{U-Factor}) + C\,(SHGC) + D\,(\text{U-Factor})^2 + E\,(SHGC)^2 \quad (5)$$

where A,B,C,D, and E are regression coefficients. Although they are a function of geographic location, the regression coefficient values did not vary significantly indicating that one set of FHR and FCR values for a particular window can be used for all U.S. locations.

The next section of this paper discusses a parametric study aimed at determining the differences in FHR and FCR as changes are made to the residential configuration. The results of the study have

given us the necessary confidence to recommend this methodology to the full membership of the NFRC.

Parametric Sensitivity Study

The simplicity and value of the FHR/FCR approach is based on the assumption that relative window performance is largely independent of house parameters and climate/location. It is thus critical to demonstrate the validity of this observation. A parametric sensitivity study was performed to help define the energy rating scheme defined above[8,9] and determine if the FHR and FCR changed dramatically as the base case prototype characteristics were varied. We also gained additional insight into how the windows interact with the building and how homeowners lifestyle choices affect energy performance. Table 1 shows the parameters that were varied in the study. More than 3500 hour-by-hour simulations were performed using the DOE 2.1E energy analysis simulation program. An attempt was made to address a broad range of the most common variables which influence annual energy performance for both new and existing residential construction.

Initially, the results of the DOE 2.1E runs for the ten window types described in Table 3 were rank ordered from 1 to 10 based on the calculated heating and cooling energy use quantities. This was done to see what changes in rank for the windows occurred as each parameter was varied. Relative ranking among windows is an important element when defining a rating scheme in that one would not want significant movement of a window's rank as residential parameters changed. Generally, rank changes occurred at low values of required heating and/or cooling, thus negating the significance of the rank change. Also, when rank changes did occur, the relative performance of the windows in question was very small. Such rank changes were due primarily to similar solar heat gain coefficients and/or U-factors. The sensitivity study indicated that the rank ordering of windows is not significantly affected by major changes in residential house parameters.

Upon completion of the ranking study, we calculated the FHR and FCR for each parametric subset and obtained averages and standard deviations for each of the window types. There was not much difference in the average value for many of the parameters as the climate was varied. Also, the standard deviation was generally very small, less than 1 or 2, indicating an inconsequential change to FHR or FCR. There were several house configuration parameters, however, which did affect the rating values; i.e., FHR values were affected by the following (in order of decreasing importance): Window Area, House Infiltration, and House Insulation; FCR values were affected by: Window Area, Natural Ventilation, External Shading, Foundation Type, and Internal Shading.

An example of the expected variations is presented in Table 4 which shows average FHR and FCR values and standard deviations for several of these more critical house configuration variations. The data is representative of Boston, MA; however, the other locations in the study have similar standard deviations. Shown in the far right column is the overall average FHR or FCR for the total set of parametrics simulated. By far, the largest standard deviation shown in Table 4 occurs for the FHR due to window area.

Table 4. Average FHR/FCR Values and Standard Deviations for Configuration Changes in Boston, MA

Fenestration Heating Rating (FHR)							
Glazing Type	Window Area Avg. FHR	Window Area Std. Dev.	House Infilt. Avg. FHR	House Infilt. Std. Dev.	House Insul. Avg. FHR	House Insul. Std. Dev.	Overall Avg. FHR
2	-1	0.4	-1	0.2	-1	0.3	-1
3	21	6.9	22	4.8	21	2.7	22
4	19	6.5	20	4.8	20	2.4	21
5	26	8.5	28	6.3	27	3.4	28
6	25	8.2	26	6.3	26	3.2	27
7	34	11.2	35	7.8	35	4.3	36
8	34	11.6	36	8.3	35	4.4	37
9	33	11.5	35	8.6	34	4.2	36
10	39	13.4	41	9.6	40	5.0	42

Fenestration Cooling Rating (FCR)							
Glazing Type	Window Area Avg. FCR	Window Area Std. Dev.	Natural Ventil. Avg. FCR	Natural Ventil. Std. Dev.	Exterior Shading Avg. FCR	Exterior Shading Std. Dev.	Overall Avg. FCR
2	8	1.8	9	1.0	6	1.6	8
3	10	1.5	11	2.8	10	1.5	11
4	18	4.1	21	1.7	17	3.1	20
5	16	3.0	18	3.1	16	2.3	28
6	24	5.5	27	2.1	23	3.8	26
7	17	2.8	19	4.8	18	2.2	19
8	25	5.7	28	3.5	25	3.9	28
9	34	8.6	38	2.4	32	5.0	36
10	30	7.0	33	4.1	29	4.3	33

This is more clearly shown in Figure 3 which shows the required heating and FHR values for all the window size variations. We see that the largest increase in house heating associated with window size increases occur for those windows with high U-factors. As the insulating value of the window improves, these heating increases are substantially reduced until with window no. 10, we have almost constant heating energy use for all window areas. With FHR being proportional to the difference in heating between the window of interest and the base case window, and since these differences increase with window size, the calculated FHR also increases. For glazing no. 10, FHR varies from 19.9 to 53.8. Figure 4 shows the corresponding values of required cooling and

FCR for window area variations. Basing the FHR/FCR on a particular average window area will overpredict savings in the case of smaller window areas and underpredict the savings that are possible with larger areas.

In general, the sensitivity study results indicate that the proposed rating system will tend to overestimate the energy savings of replacement windows. For example, homes with poor insulation and high infiltration levels, relatively small fenestration area, and unheated/uninsulated basements will tend to overestimate the savings associated with a particular FHR. On the other hand, a window replacement strategy is often implemented with other upgrades, such as vinyl siding, insulation, and caulking/weather-stripping. Given this scenario, the FHR can be reasonably accurate. Scaling factors may be used for different climates (possibly based on area code) so that a more accurate rating can be obtained. Another possible alternative for a more accurate rating is to give two separate numbers, one for new construction and one for replacement. We are continuing our research and validation efforts to better understand the value and limitations of FHR and FCR as a rating system for residential windows.

Customized Annual Energy Performance Methodology

Concurrent with the development of FHR and FCR is the creation of a more detailed fenestration performance analysis tool that users can customize to their own particular needs and complements the simplified approach discussed above. This method will actually perform an hour-by-hour simulation using a unique version of the DOE-2 computer program dedicated to window energy performance analysis. It will enable accurate prediction of energy use and cost for any arbitrary window placement, size, type, etc., with the ability to account for all important house design parameters.

The foundation of the tool will be PowerDOE, the most recent version of the DOE-2 hour-by-hour building energy simulation program[1]. We are in the process of creating a user interface to PowerDOE that will focus on those house parameters that have a strong influence on window performance. The interface will be similar to that shown on Figure 5, which is similar to the latest version of RESFEN, Version 2.0[5]. RESFEN has served and continues to serve as a prototype for a detailed window performance analysis tool since 1991. The program was developed by LBL to give users some indication of the energy and peak load performance as well as utility cost of windows in residential buildings.

We envision a tool that facilitates versatile user input of fenestration parameters and subsequently yields output of heating and cooling energy quantities and costs. Eventually, we plan on including data related to thermal and visual comfort, condensation, and ultraviolet transmittance of windows. Figure 6 can be used to better understand the program's versatility and usefulness in helping make residential window design decisions. Pull-Down Menus are along the top part of the screen, House Data parameters are displayed along the left-hand side of the screen, Window Data parameters appearing on the upper right half of the screen, and Output Data displayed on the bottom right half of the screen. The "House Data" entries identify each run, the units to be used for input/output, the geographic location, the cost of gas and electricity, and the particular house configurations. The "Window Data" input can vary the area, U-value, and solar heat gain coefficient or shading coefficient for windows on each orientation of the building. Each window can also have associated with it an adjacent obstruction, overhang, or interior shading device.

The output portion of the screen contains incremental heating, cooling, and total energy use and cost values due to the windows. These values can be referenced to any other residential or window configuration. Currently, the default is a windowless wall. Summed quantities for total window area as well as per unit window area values are given. A simple bar-chart type presentation of these results is also presented on the screen.

Conclusions

We have presented an overview of two new methodologies that predict window energy performance. These techniques are currently being proposed to the general membership of the National Fenestration Rating Council to fulfill energy rating and labeling requirements set by the Energy Policy Act of 1992. Both simplified and customized procedures have been developed.

The simplified procedure focuses on the use of two indices: the Fenestration Heating Rating (FHR) and Fenestration Cooling Rating (FCR). These are dimensionless numbers representative of the percent of total house energy savings associated with a window and defines how well the window performs when compared to other windows. A sensitivity study performed simultaneously with the development of FHR/FCR indicates that the method, although approximate in some cases, does predict performance with acceptable levels of accuracy. In particular, the relative performance of windows as defined by the calculated FHR/FCR is good enough to differentiate among the large variety of windows available today. Eventually, the FHR and FCR values will appear on each window label.

The customized procedure is a more detailed computer-based analysis of window performance and allows arbitrary window placement, sizing, and property definitions, etc. It is based on actual hour-by-hour simulations using the DOE-2 energy simulation program. This method follows in the steps of a computer program called RESFEN and has a very friendly user interface aimed specifically at fenestration performance analysis in residential buildings.

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References

1. Winkelmann, F.C.; Birdall, B. E.; Buhl, W.F.; Ellington, K.L.; and Erdem, A.E. 1993. "DOE-2 supplement: version 2.1E," Lawrence Berkeley Laboratory Report LBL-34947.

2. ASHRAE. "Energy-Efficient Design of New Low-Rise Residential Buildings." ASHRAE Standard 90.2-1993.

3. Energy Analysis Program, Lawrence Berkeley Laboratory. 1983. "Affordable Housing Through Energy Conservation - A Guide to Designing and Constructing Energy Efficient Homes." Department of Energy Report DOE/SF/00098-1.

4. Huang, Y.J.; Ritschard, R.; and Bull, J. 1987. "Technical Documentation for a Residential Energy Use Data Base Developed in Support of ASHRAE Special Project 53." Lawrence Berkeley Laboratory Report LBL-23406.

5. Sullivan, R.; Chin, B.; Arasteh, D.; and Selkowitz, S. 1992. "RESFEN: A Residential Fenestration Performance Design Tool." ASHRAE Transactions 1992, V.98, Pt. 1 and Lawrence Berkeley Laboratory Report LBL-31176.

6. CABO "Model Energy Code." 1993 Edition with 1994 Amendments. Council of American Building Officials, 1994.

7. Crooks, B.P. "Annual Energy Performance for Windows, Summary of Simplified Rating Syatem." Product Development Group, Cardinal IG, June 22, 1994.

8. Crooks, B.P. "Annual Energy Performance for Windows, Summary of Parametric Sensitivity Study." Product Development Group, Cardinal IG, June 22, 1994.

9. Crooks, B.P. "Annual Energy Performance for Windows, Parametric Sensitivity Study." Product Development Group, Cardinal IG, May 27, 1994.

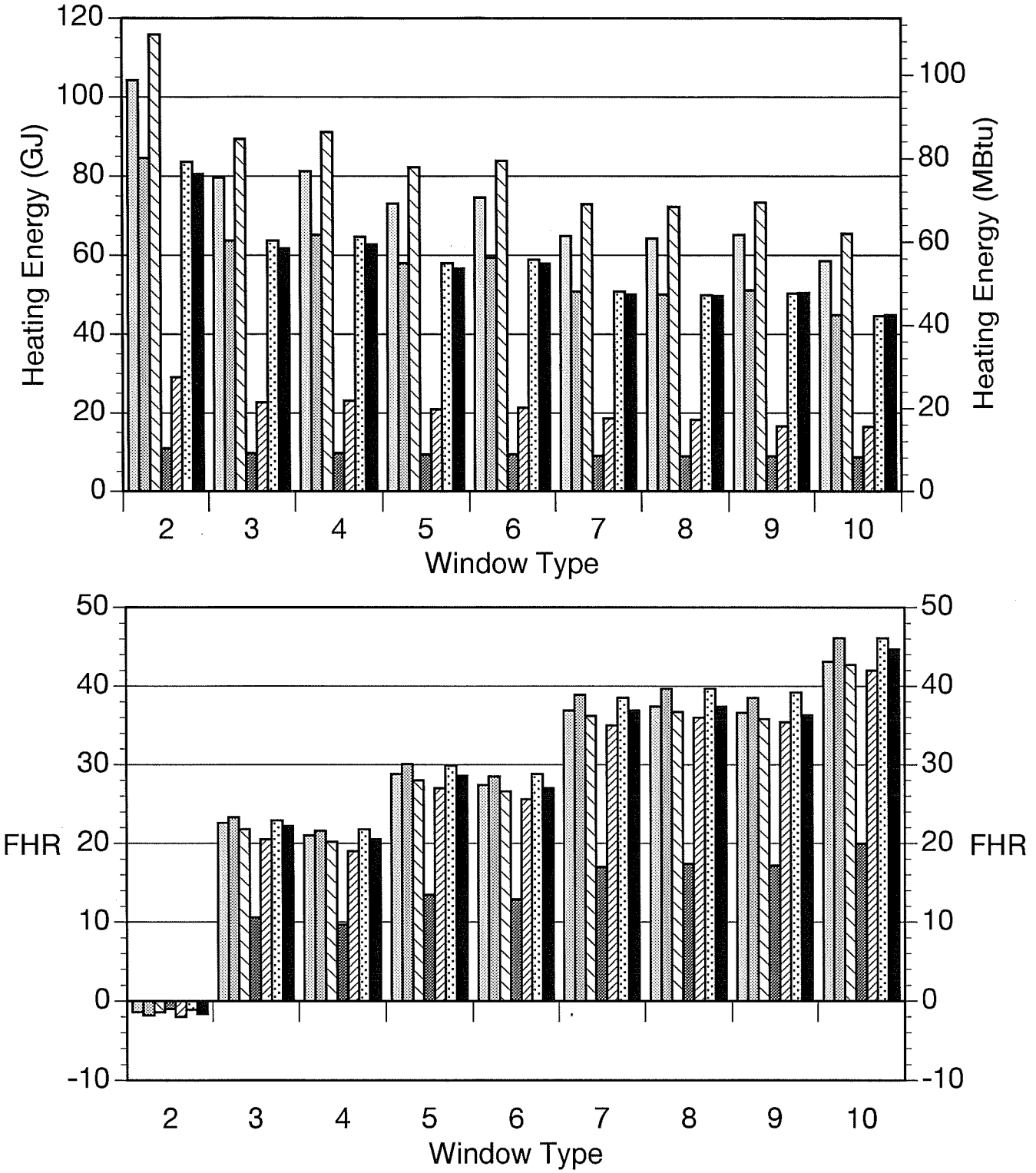

Figure 1: Heating energy and FHR values for seven geographic locations using window number 1 as a base. Base heating energy values are: Boston (102.7 GJ, 97.4 MBtu), Denver (83.1 GJ, 78.8 MBtu), Madison (114.2 GJ, 108.3 MBtu), Miami (10.9 GJ, 10.3 MBtu) , Phoenix (28.6 GJ, 27.1 MBtu), Seattle (82.7 GJ, 78.4 MBtu), and St. Louis (79.3 GJ, 75.2 MBtu).

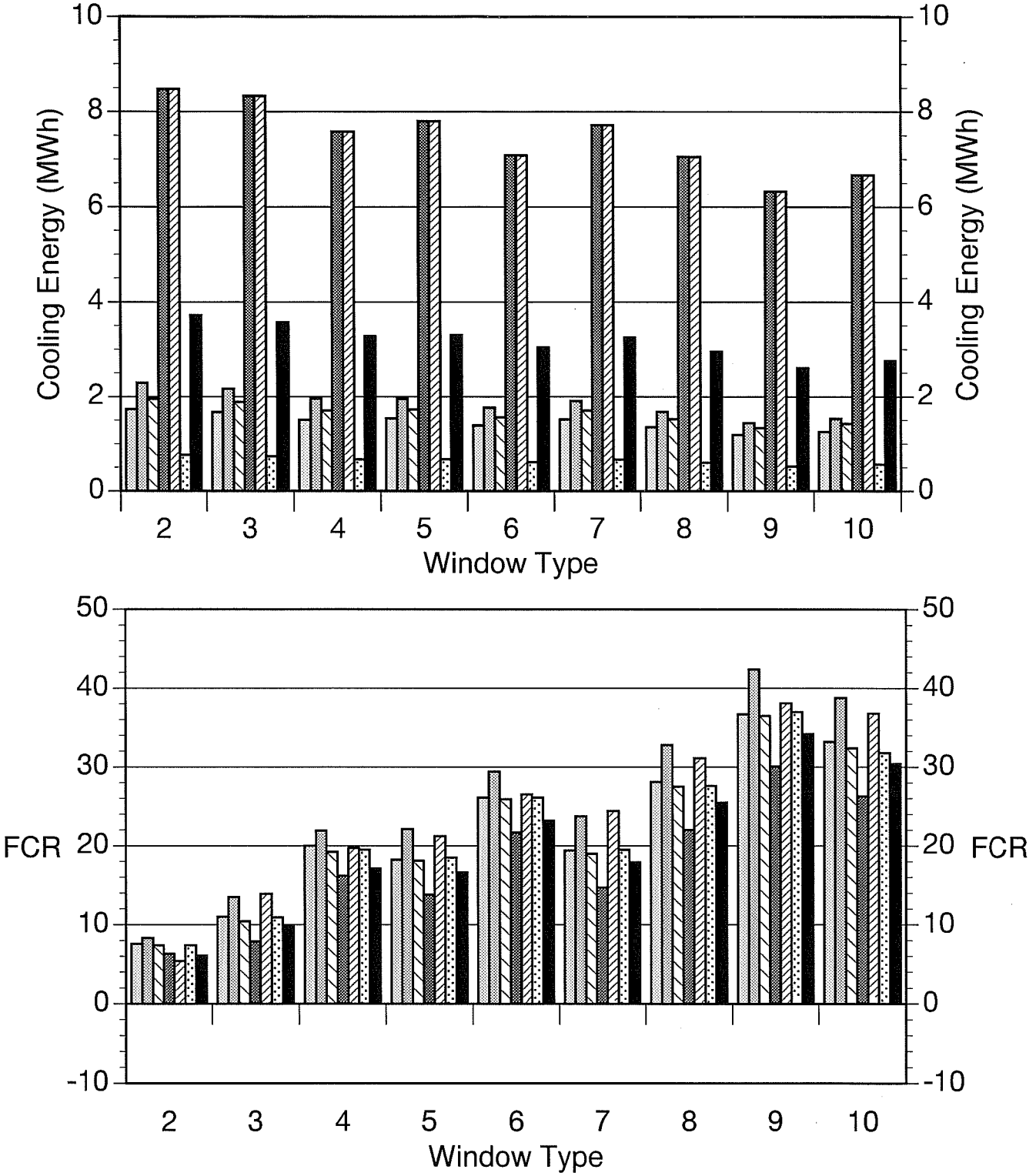

Figure 2: Cooling energy and FCR values for seven geographic locations using window number 1 as a base. Base cooling energy values are: Boston (1881 kWh), Denver (2502 kWh), Madison (2108 kWh), Miami (9048 kWh), Phoenix (9932 kWh), Seattle (827 kWh), and St. Louis (3962 kWh).

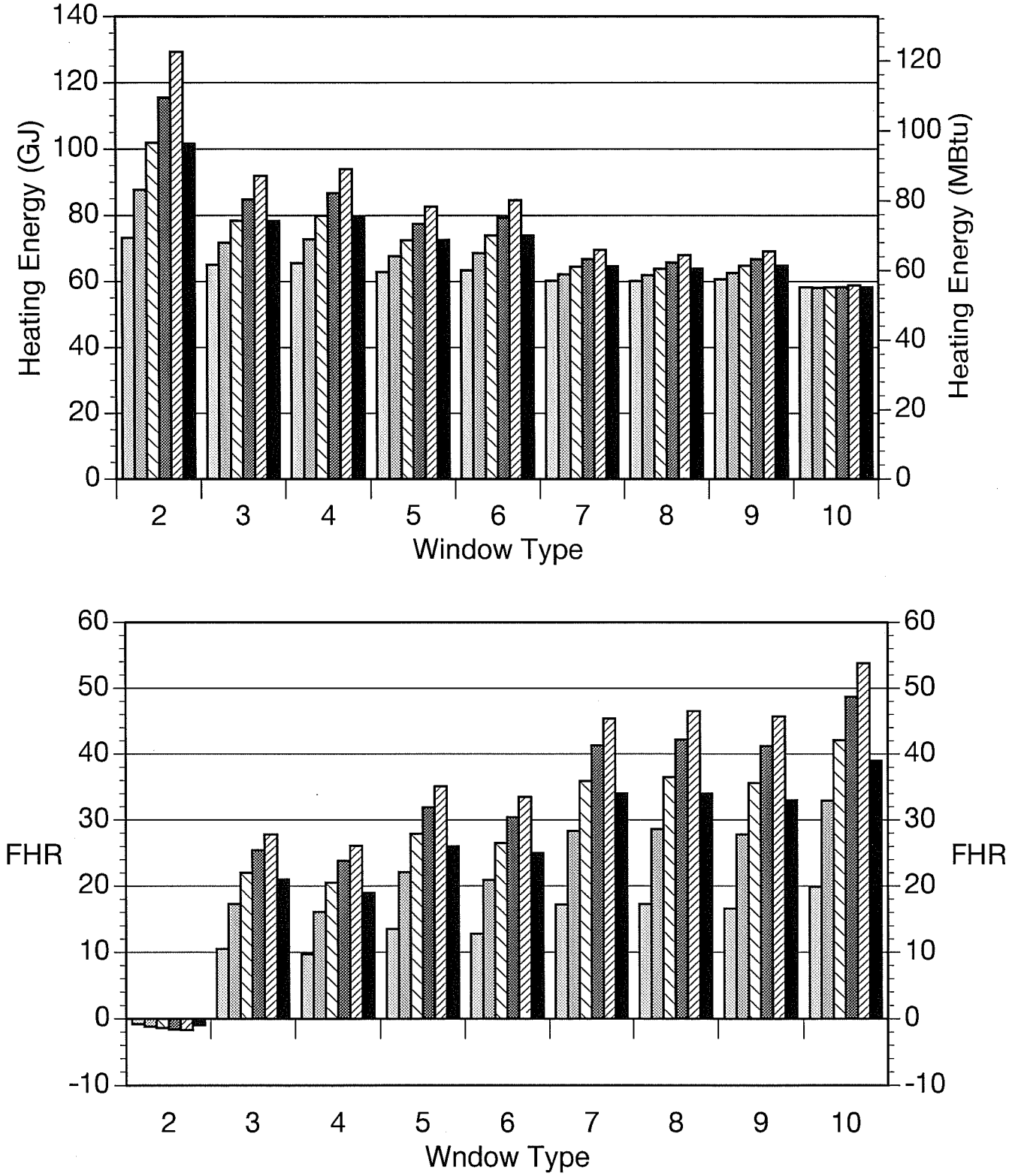

Figure 3: Heating energy and FHR values for window size variations in Boston, MA. Sizes vary left-to-right as follows: 5% floor area, 10%, 15%, 20%, 25%, and average values.

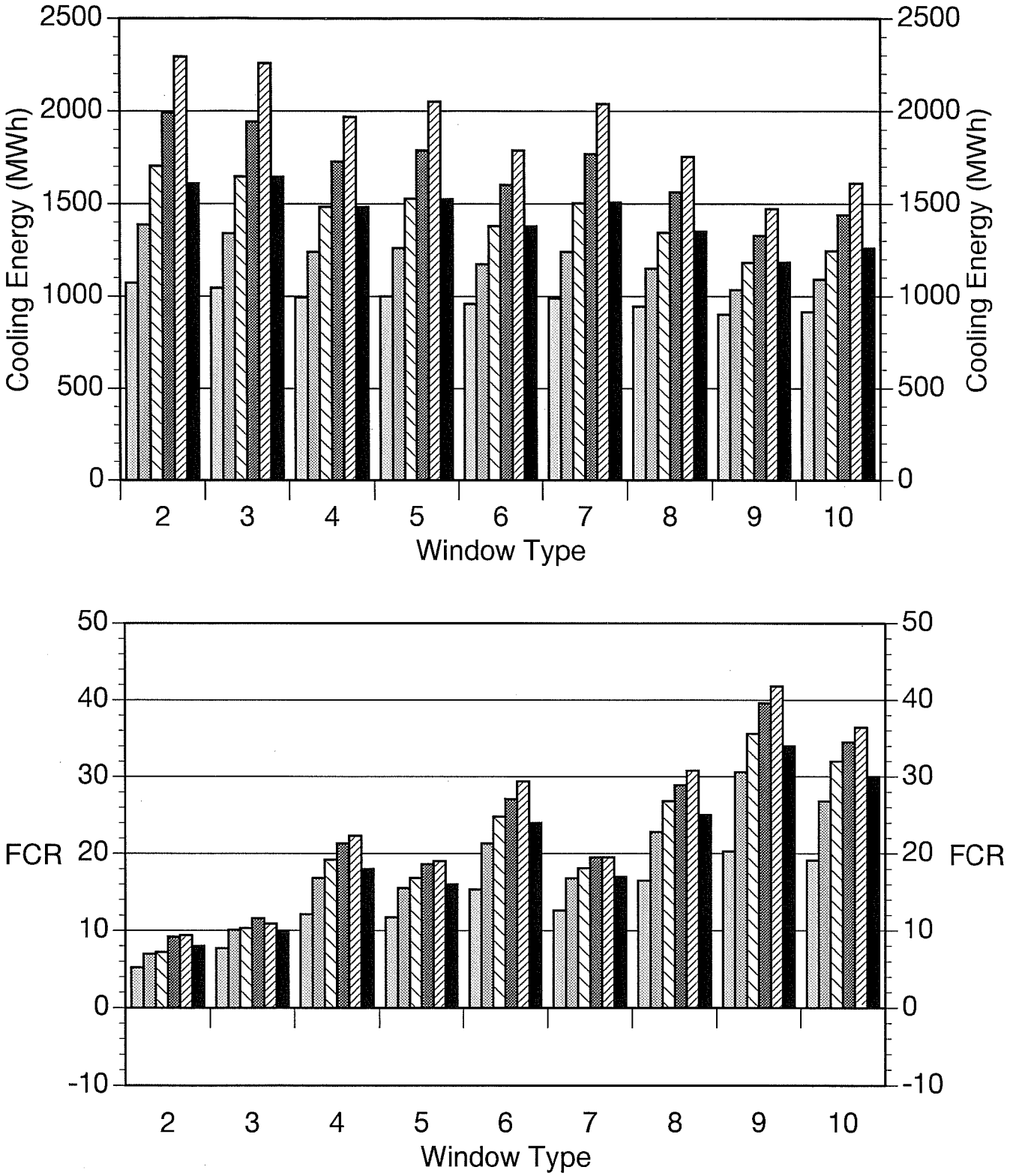

Figure 4: Cooling energy and FCR values for window size variations in Boston, MA. Sizes vary left-to-right as follows: 5% Floor area, 10%, 15%, 20%, 25%, and average values.

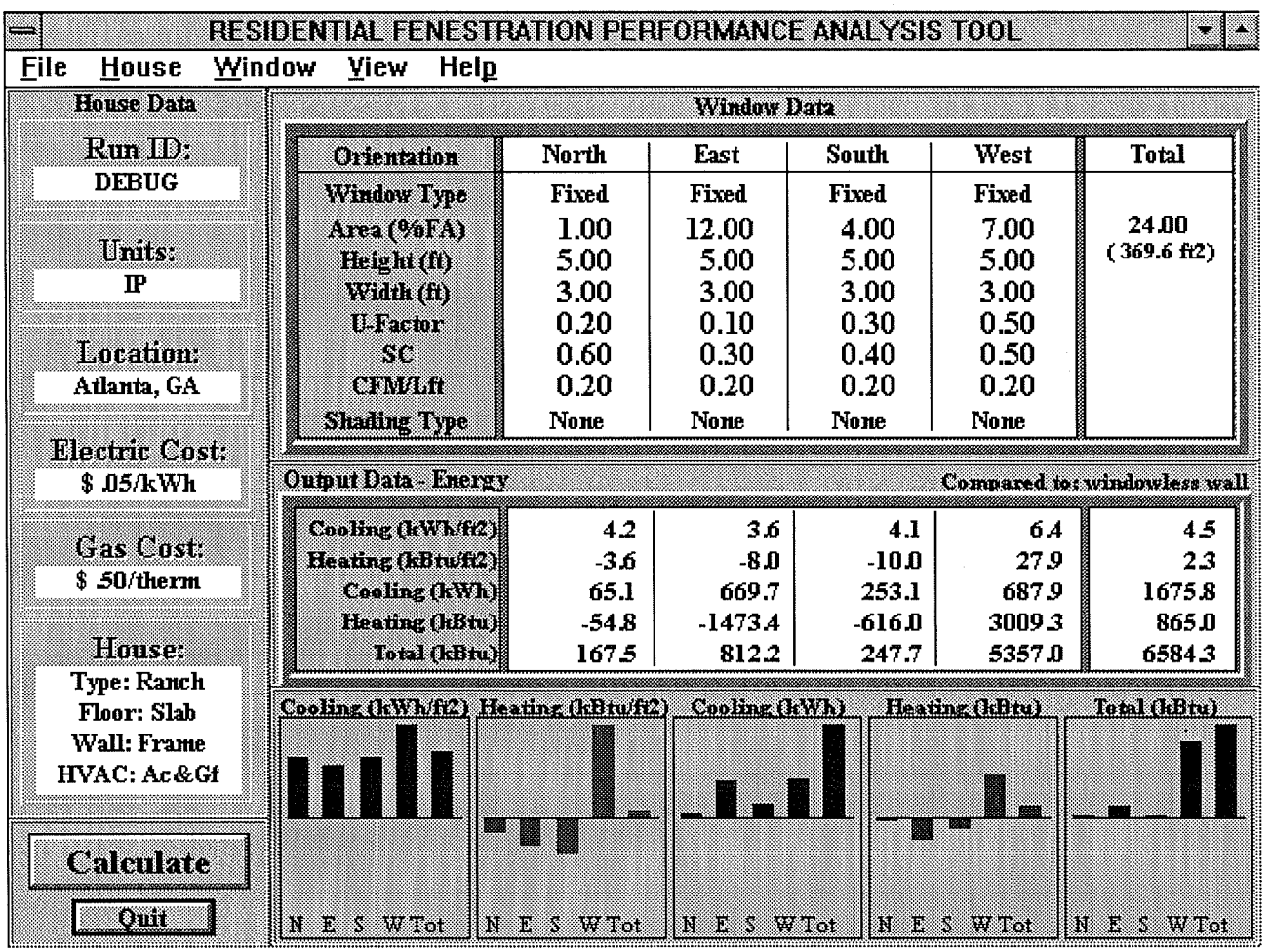

Figure 5: Screen image showing the input/output user interface of a residential fenestration performance analysis tool. Input consist of House Data and Window Data. The output shows numerical and graphical heating and cooling energy usage values.

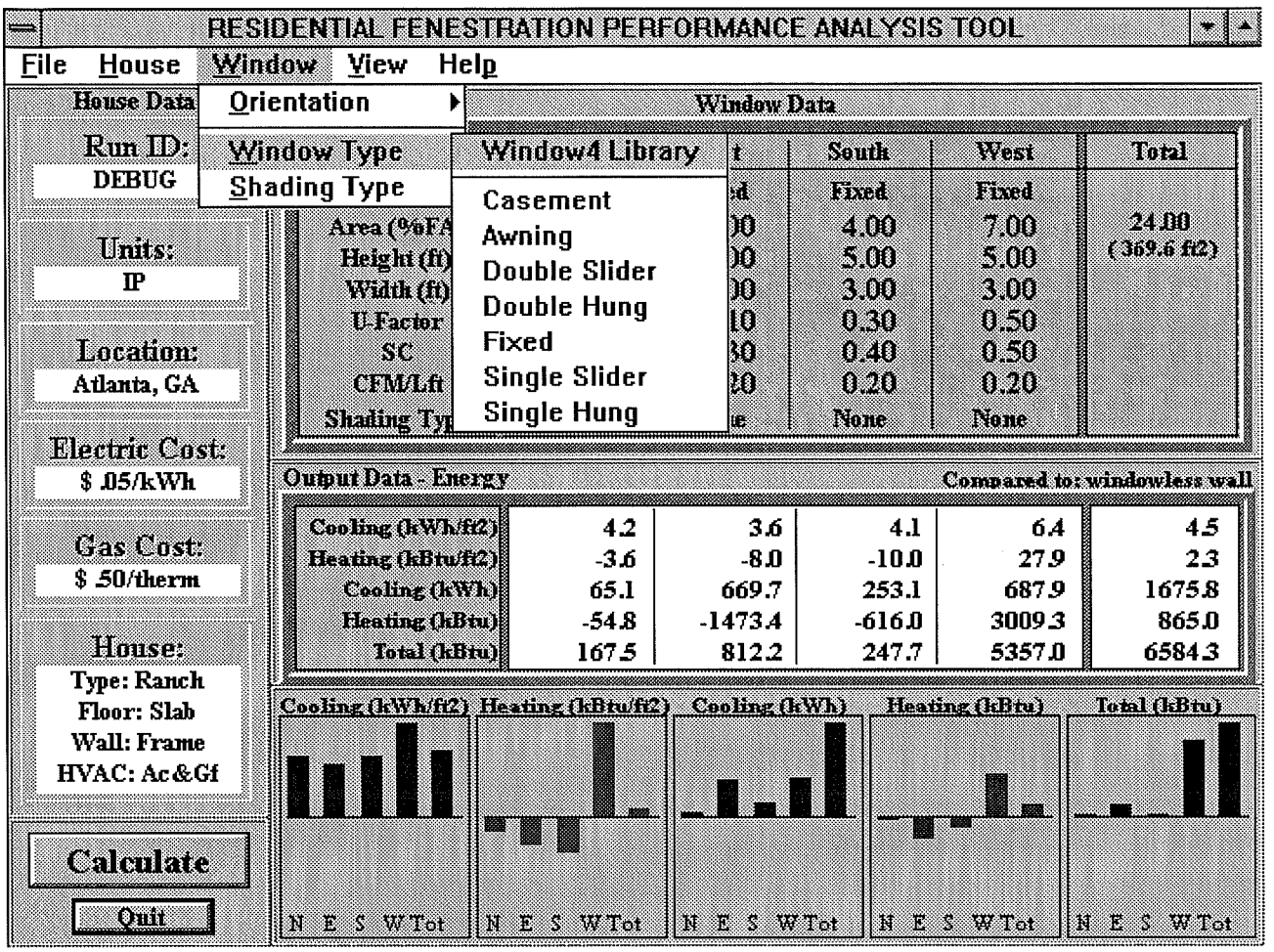

Figure 6: Screen image showing the input/output user interface of a residential fenestration performance analysis tool. The pull-down menu items for the selection of window type are presented.