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## Abstract

This paper describes the development of a prototype PC-based computer program called RESFEN. The program calculates the heating and cooling energy performance and costs of residential fenestration systems. Regression analysis of a data base of DOE-2 building energy simulations of single- and two-story residential buildings was used to develop algrbraic expressions that form the basis of the calculation procedure. The user can vary geographic location, electricity and gas cost, infiltration and internal load levels, HVAC and wall type as well as window size, U-value, and shading coefficient for the four cardinal orientations of north, east, south, and west. Incremental changes in energy use due to obstructions, overhangs, and interior shades can also be calculated.

## Introduction

Window placement, size, and type are important topics to be addressed during the residential building design process. Windows influence many aspects of a building, such as the exterior and interior appearance of the building, the visual and thermal comfort of the occupants, and the structure's overall heating and cooling energy requirements. Analytical tools that aid building designers in their selection of windows must deal with specific issues such as the large variety of glazings with unique solar-optical properties that are currently available and the number of different solar shading devices, such as overhangs, fins, obstructions, interior shades, etc. that can be utilized in a design. Each new issue generally results in more complicated analysis procedures and individuals in the design community currently have no simple and uniform methodology with which to evaluate the performance of fenestration systems in a systematic and reproducible way.

The Windows and Daylighting Group at Lawrence Berkeley Laboratory (LBL) has been involved in research related to analyzing and improving the energy and comfort performance of window systems for many years. As part of these efforts, we have been exploring new methods of transferring technology to window manufacturers and others in the building industry, particularly developers, architects, engineers, and building owners. This paper describes one such effort: the development and implementation of an microcomputer-based fenestration performance design tool for residential buildings, designated RESFEN. The tool is based on algorithms derived from a large data base of hour-by-hour building energy simulations of a prototype residence using the DOE-2 (Building Energy Simulation Group 1984) simulation program. The algorithms enable arbitrary user input of fenestration parameters and subsequently yield output of heating and cooling energy quantities and costs. Such a computer program also has relevance to the definition of a performance rating procedure for windows, a task that is currently being discussed by the National Fenestration Rating Council (NFRC).

## Residence Description

We selected a prototype residential building configuration similar to the residence modeled in past LBL studies (Energy Analysis Program 1985, Huang 1987, Sullivan & Selkowitz 1987, 1985) which were accomplished in support of ASHRAE and DOE efforts in establishing residential energy conservation standards. Rather than using a rectangular floor plan, however, we modeled a square plan which facilitated a convenient simultaneous variation of fenestration properties on each cardinal direction. The building was a 39.2ft x 39.2ft (11.9m x11.9m), one-zone structure of wood-frame construction (R19 walls and R34 roof). Window sizes were varied on each orientation from 0% to 12% of the floor area as shown in Table 1. Total window size varied from 0% to 25% floor area. Five combinations of U-value and shading coefficient defined the primary parametric on glazing type. The values were chosen to bracket the complete range of expected properties. They varied from single-pane clear glass with a U-value of 1.3 Btu/hr-ft$^2$F (7.38 W/m$^2$C) and shading coefficient of 1.0 to a postulated super-insulated, low-E, gas-filled unit with values of 0.10 Btu/hr-ft$^2$F (0.57 W/m$^2$C) and 0.30 respectively (see Table 2). The values are representative of total window values and thus include the frame, sash, and divider effects.

Shading influence on fenestration performance was simulated by consideration of exterior obstructions, overhangs, and interior shade management. The exterior obstructions consisted of four residences similar to the base-case building which were positioned 20ft (6.1m) away from each facade. Overhangs were modeled using a fixed width of 2ft (.61m) above each window. Our shade management strategy reduced solar heat gain by 40% when the direct solar gain on a particular window exceed 30 Btu/ft$^2$ (94.5 W/m$^2$).

In addition to our concern with specific window related variables and their effect on energy performance, we were also interested in defining what the influence of infiltration, internal loads, HVAC systems, exterior wall mass, and building type would be on this performance. Table 3 shows the changes that were made to the base-case building. Infiltration was calculated using different values of building leakage area. DOE-2 defines an average residential leakage area of 0.77 ft$^2$ (.24m$^2$). We varied this value to account for an especially tight house (0.46 ft$^2$, 0.14 m$^2$) and a loose one (1.54 ft$^2$, 0.46 m$^2$). Internal loads were changed from the base-case level of 53963 Btu/day (56930 KJ/day) to 40472 Btu/day (42698 KJ/day) to 80944 Btu/day (85395 KJ/day).

Our base case HVAC system consisted of an air conditioner with a peak condition COP of 2.2 and a gas furnace with a peak efficiency of 0.74. As an alternative, we also simulated use of an air-to-air heat pump. In addition, the wood frame exterior wall construction was changed to reflect use of a masonry wall of equivalent U-value and we also obtained results for a 2-story prototype building whose floor area was twice the size of the base case residence.

Each of the above configuration prototypes was simulated in two very different geographic locations: Madison, WI and Lake Charles, LA. This was done to account for the expectedly large variations in heating and cooling associated with each climate. The intent in future versions of the program is to expand the data base to many cities throughout the U.S. and have a tool that will yield representative numbers for a variety of climates.

## Methodology

We used regression analysis techniques to simplify the process of analyzing a large data base of building energy simulations. Regression analysis uses the method of least squares to characterize the form of a relationahip between variables. Sets of independent variables (configuration parameters) are defined from which dependent variables (heating and cooling energy) are predicted.

In past studies, our residential modeling was done so that we could examine energy performance due to size changes of one primary window that was facing a particular direction. By varying the orientation, we were thus able to determine performance across a complete 360° profile. This procedure was limiting in the sense that the windows on the three other facades were fixed in size. Our strategy in this study has eliminated this limitation, since we varied window sizes and properties on all four facades. The regression analysis resulted in algebraic expressions of the form shown on Table 4, a portion of which is shown below.

Heating or Cooling (SOUTH) =

$$\beta 1S \times UAS + \beta 2S \times (UAS)^2 + \beta 3S \times SAS + \beta 4S \times (SAS)^2 +$$

$$\beta 6 \times UAS \times UAN / 2 + \beta 8 \times UAS \times UAE / 2 + \beta 10 \times UAS \times UAW / 2 +$$

$$\beta 12 \times SAS \times SAN / 2 + \beta 14 \times SAS \times SAE / 2 + \beta 16 \times SAS \times SAW / 2$$

where $\beta$'s = Regression Coefficients
UAS = U-value x Window Area where S is for SOUTH
$UAS^2$ = UAS x UAS
SAS = SC x Window Area
$SAS^2$ = SAS x SAS

These equations yield the energy use due only to the fenestration of the north, east, south, and west facades and represent incremental values relative to an insulated wall. There are a total of 28 regression coefficients. Table 5 shows the coefficients for Madison, WI. The components for one particular orientation can be separated into distinct conduction and solar gain effects as well as component influences due to windows facing other orientations. Figure 1 shows a comparison between several individual DOE-2 simulation results and the corresponding energy values calculated by the regression expression. The correlation coefficients for heating energy use in Madison and cooling energy use in Lake Charles are both 0.998 (a value of 1.0 would mean perfect correlation).

## RESFEN Program Description

Figures 2 through 4 show several pairs of energy and cost screens from RESFEN. They give an indication of the program's versatility and usefulness in helping make residential window design decisions. The upper part of each screen contains input information and the lower portion represents the calculated energy usage or cost figures. Data is input by highlighting a particular parameter by moving the cursor with left/right and up/down keyboard entries. Beginning at the first line, users can enter information related to run identification, geographic location, cost of gas and electricity, and units used for input and output; the second line is used to input non-window related parameters and the library of possible configurations is accessed by the F2 key; the remaining input entries are concerned with window variables. Users can vary the area, U-value, and 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. In the current version of the program, these latter three items can only be implemented one at a time on any one window. Future version will enable a simultaneous capability.

The output portion of the screen contains heating, cooling, and total energy use and cost values. As mentioned above, these are incremental values due to the fenestration system on each orientation relative to an insulated wall. Summed quantities for total window area as well as per unit window area values are given. A positive sign indicates increased energy use and a negative sign indicates a potential saving.

Figure 2 presents sample energy and cost results for Madison, WI. Gas cost has been set to $.60/therm and electric cost to $.07/kwh. The residence is a ranch style house with a slab-on-grade floor of frame construction with average levels of internal load and infiltration. Window areas on each facade have been set to 4% of the floor area and the selected U-value and shading coefficient represent use of a double-pane clear glass. No obstruction, overhang, or shading device has been used. The results provide some interesting insights into the subtleties of window performance. For example, we expect north facing windows to be a significant contributor to winter heating requirements in a location such as Madison; the numbers indicate that over 60% of the window related net heating energy requirement is coming from the north. South-facing windows yield a net heating energy savings; east and west-facing windows contribute 23% and 32% of the heating respectively. Cooling energy increments due to south, east, and west windows are about the same at 30% each, while the north is 10%.

Total energy cost figures reflect the relative difference between the use of electricity (cooling) and gas (heating). North, east, and west windows each account for the same percent of total cost at 28-30% of the whole building. South-facing windows account for only 14% of the total cost due to the benefits of winter solar gain.

We show results on Figure 3 for the same residential configuration when using double-pane low-E glazing on all facades. As expected, because of lower shading coefficient and conductance values, cooling and heating energy use was lower than the double-pane windows. Overall total energy was decreased by 72% and total cost by 47%. The 18% decrease in shading coefficient and 37% decrease in U-value resulted in cooling energy reductions varying from 13% for north to 18% for west windows. Heating energy decreases were dramatic: 49% for north, 53% for south, and 79% for west. The east-facing windows changed to being a net energy user to a net energy provider.

Figure 4 shows output (energy only,no cost data) for both double-pane clear and double-pane low-E units for a south-facing window size at 8% of the floor area. All other orientations were fixed at the 4% level used above. In this example, we see that by changing only the south-facing window to a low-E unit, there is a 33% reduction in total energy requirements (10% cooling reduction, 45% heating reduction). The east- and west-facing heating and cooling values do not change significantly; however, the north-facing heating component increases 10% as the south-facing window component decreases.

Comparing the double-pane clear results for Figure 4 to those in Figure 2 also yields interesting results. Total cooling and heating energy are increased, and the increase is only apparent for the south facade; the other window systems all decrease in varying amounts. Such comparisons are facilitated by RESFEN's algorithm which calculates both the independent and dependent components of each fenestration system. Users are able to quickly analyze the effects of one window system on the other systems.

## Conclusions

This paper has described the development of a prototype software program that gives insight into the energy and cost implications of fenestration systems on residential buildings. The program has been structured to enable building designers, homebuilders, etc. to isolate effects due to window orientation, size, conductance, and solar gain. Such a component breakdown facilitates selection of design strategies that can lead to optimum fenestration performance. Since the program is a prototype, we expect several of the following revisions to occur prior to formal release to the general public:

(1) Increase the size of the data base to include additional geographic locations; off-cardinal orientations; varying obstructions, overhangs, and interior shades. This will increase the program's usefullness and perhaps lead to a successful rating or labeling system for window performance.

(2) Define more accurate infiltration effects on fenestration performance. The current version of the program does not directly deal with infiltration. However, we do feel that infiltration is important enough to warrant development of algorithms that can adequately predict these effects. Future versions will enable the user to specify CFM/Lft and crack length of windows.

(3) Create the capability to simultaneously analyze obstruction, overhang, and interior shades on any one window. Each item has an important individual effect on solar gain; however, the relative importance of any one element will vary depending upon the presence another.

(4) Design a graphic output so that users can more easily interpret results. Also create a parametric run capability to enable simultaneous comparisons of several alternative fenestration systems.

(5) Integrate RESFEN with LBL's WINDOW 3.1 program. WINDOW 3.1 has become a useful tool in the window industry to help determine the thermal and solar/optical characteristics of windows. By making RESFEN part of WINDOW 3.1, users will have the ability to immediately determine energy use and cost values for any arbitrarily defined fenestration system.

(6) Define program procedures that will facilitate its use as a window rating device for the NFRC. RESFEN was developed to give residential building designers information about expected energy use and cost for fenestration systems. The same methodology could also be used to classify such systems and simplify the decision-making process homeowners and other must make in selection.

(7) ASHRAE and NFRC are supporting efforts to switch from the use of shading coefficients to solar heat gain coefficients as a means of defining solar gain performance of windows. Future versions of the RESFEN program should incorporate appropriate revisions to address these issues.

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## Table 1: Window Size Parametrics (% Floor Area)

| N | E | S | W | Total |
|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4.00 | 0.00 | 0.00 | 0.00 | 4.00 |
| 0.00 | 2.67 | 2.67 | 2.67 | 8.00 |
| 4.00 | 1.33 | 1.33 | 1.33 | 8.00 |
| 0.00 | 4.00 | 4.00 | 4.00 | 12.00 |
| 6.00 | 2.00 | 2.00 | 2.00 | 12.00 |
| 6.00 | 1.00 | 4.00 | 1.00 | 12.00 |
| 1.00 | 6.33 | 6.33 | 6.33 | 20.00 |
| 9.00 | 2.00 | 7.00 | 2.00 | 20.00 |
| 9.00 | 9.00 | 4.00 | 3.00 | 25.00 |
| 12.00 | 4.00 | 5.00 | 4.00 | 25.00 |
| 0.00 | 4.00 | 0.00 | 0.00 | 4.00 |
| 2.67 | 0.00 | 2.67 | 2.67 | 8.00 |
| 1.33 | 4.00 | 1.33 | 1.33 | 8.00 |
| 4.00 | 0.00 | 4.00 | 4.00 | 12.00 |
| 2.00 | 6.00 | 2.00 | 2.00 | 12.00 |
| 1.00 | 6.00 | 1.00 | 4.00 | 12.00 |
| 6.33 | 1.00 | 6.33 | 6.33 | 20.00 |
| 2.0 | 9.00 | 2.00 | 7.00 | 20.00 |
| 3.00 | 9.00 | 9.00 | 3.00 | 25.00 |
| 4.00 | 12.00 | 4.00 | 4.00 | 25.00 |
| 0.00 | 0.00 | 4.00 | 0.00 | 4.00 |
| 2.67 | 2.67 | 0.00 | 2.67 | 8.00 |
| 1.33 | 1.33 | 4.00 | 1.33 | 8.00 |
| 4.00 | 4.00 | 0.00 | 4.00 | 12.00 |
| 2.00 | 2.00 | 6.00 | 2.00 | 12.00 |
| 4.00 | 1.00 | 6.00 | 1.00 | 12.00 |
| 6.33 | 6.33 | 1.00 | 6.33 | 20.00 |
| 7.00 | 2.00 | 9.00 | 2.00 | 20.00 |
| 4.00 | 3.00 | 9.00 | 9.00 | 25.00 |
| 5.00 | 4.00 | 12.00 | 4.00 | 25.00 |
| 0.00 | 0.00 | 0.00 | 4.00 | 4.00 |
| 2.67 | 2.67 | 2.67 | 0.00 | 8.00 |
| 1.33 | 1.33 | 1.33 | 4.00 | 8.00 |
| 4.00 | 4.00 | 4.00 | 0.00 | 12.00 |
| 2.00 | 2.00 | 2.00 | 6.00 | 12.00 |
| 1.00 | 4.00 | 1.00 | 6.00 | 12.00 |
| 6.33 | 6.33 | 6.33 | 1.00 | 20.00 |
| 2.00 | 2.00 | 2.00 | 9.00 | 20.00 |
| 9.00 | 4.00 | 3.00 | 9.00 | 25.00 |
| 4.00 | 5.00 | 4.00 | 12.00 | 25.00 |

## Table 2: U-Value and Shading Coefficient Parametrics

| U-Value | | SC |
|---|---|---|
| Btu/hr-ft$^2$F | (W/m$^2$C) | |
| 1.30 | (7.38) | 1.0 |
| 0.55 | (3.12) | 0.90 |
| 0.35 | (1.99) | 0.85 |
| 0.50 | (2.84) | 0.30 |
| 0.10 | (0.57) | 0.30 |

## Table 3: Configurations Simulated

**Base:**
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: Avg INFILT: Avg
53,963 Btu/day sensible Leakage area = .77 ft$^2$

**Infiltration:**
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: Avg INFILT: Tight
Leakage area = .46 ft$^2$
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: Avg INFILT: Loose
Leakage area = 1.54 ft$^2$

**Internal Loads:**
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: Low INFILT: Avg
40,472 Btu/day sensible
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: High INFILT: Avg
80,944 Btu/day sensible

**HVAC System:**
HOUSE: Ranch FLOOR: Slab WALL: Frame HVAC: Heat Pmp INT LOAD: Avg INFILT: Avg

**Exterior Wall Mass**
HOUSE: Ranch FLOOR: Slab WALL: Masonry HVAC: Ac & Gf INT LOAD: Avg INFILT: Avg

**Building Type:**
HOUSE: 2-Story FLOOR: Slab WALL: Frame HVAC: Ac & Gf INT LOAD: Avg INFILT: Avg
Floor Area = 3080 ft$^2$

## Table 4: Regression Expressions

**Heating or Cooling (NORTH) =**

$$\beta1N \times UAN + \beta2N \times (UAN)^2 + \beta3N \times SAN + \beta4N \times (SAN)^2 +$$

$$\beta5 \times UAN \times UAE / 2 + \beta6 \times UAN \times UAS / 2 + \beta7 \times UAN \times UAW / 2 +$$

$$\beta11 \times SAN \times SAE / 2 + \beta12 \times SAN \times SAS / 2 + \beta13 \times SAN \times SAW / 2$$

**Heating or Cooling (EAST) =**

$$\beta1E \times UAE + \beta2E \times (UAE)^2 + \beta3E \times SAE + \beta4E \times (SAE)^2 +$$

$$\beta5 \times UAE \times UAN / 2 + \beta8 \times UAE \times UAS / 2 + \beta9 \times UAE \times UAW / 2 +$$

$$\beta11 \times SAE \times SAN / 2 + \beta14 \times SAE \times SAS / 2 + \beta15 \times SAE \times SAW / 2$$

**Heating or Cooling (SOUTH) =**

$$\beta1S \times UAS + \beta2S \times (UAS)^2 + \beta3S \times SAS + \beta4S \times (SAS)^2 +$$

$$\beta6 \times UAS \times UAN / 2 + \beta8 \times UAS \times UAE / 2 + \beta10 \times UAS \times UAW / 2 +$$

$$\beta12 \times SAS \times SAN / 2 + \beta14 \times SAS \times SAE / 2 + \beta16 \times SAS \times SAW / 2$$

**Heating or Cooling (WEST) =**

$$\beta1W \times UAW + \beta2W \times (UAW)^2 + \beta3W \times SAW + \beta4W \times (SAW)^2 +$$

$$B7 \times UAW \times UAN / 2 + \beta9 \times UAW \times UAE / 2 + \beta10 \times UAW \times UAS / 2 +$$

$$\beta13 \times SAW \times SAN / 2 + \beta15 \times SAW \times SAE / 2 + \beta16 \times SAW \times SAS / 2$$

where $\beta$'s = Regression Coefficients
UAN = U-value x Window Area where N is for NORTH
$UAN^2$ = UAN x UAN
SAN = SC x Window Area
$SAN^2$ = SAN x SAN

same for EAST, SOUTH, WEST

## Table 5: Example Regression Coefficients

| | Madison Cooling | Madison Heating |
|---|---|---|
| β1N | -1.5327 | 237.1023 |
| β2N | -.0008359 | .2629 |
| β3N | 12.4147 | -66.6071 |
| β4N | .05566 | .3251 |
| β1E | -3.4918 | 240.3053 |
| β2E | .008608 | .1557 |
| β3E | 27.7179 | -142.4901 |
| β4E | .02686 | .4969 |
| β1S | -.3945 | 268.4548 |
| β2S | -.02387 | .2975 |
| β3S | 25.7155 | -238.0366 |
| β4S | .1111 | .7074 |
| β1W | .6415 | 240.4198 |
| β2W | .005103 | .1680 |
| β3W | 19.9773 | -128.3081 |
| β4W | .05208 | .5545 |
| β5 | -.006432 | -.1363 |
| β6 | .01319 | -.8054 |
| β7 | -.01599 | -.2355 |
| β8 | .003293 | -.4395 |
| β9 | -.01072 | -.5229 |
| β10 | -.01863 | -.3696 |
| β11 | -.01258 | -.1117 |
| β12 | -.1436 | -.09254 |
| β13 | -.01599 | -.07911 |
| β14 | -.06230 | .1789 |
| β15 | -.06091 | -.1297 |
| β16 | -.008272 | .0547 |

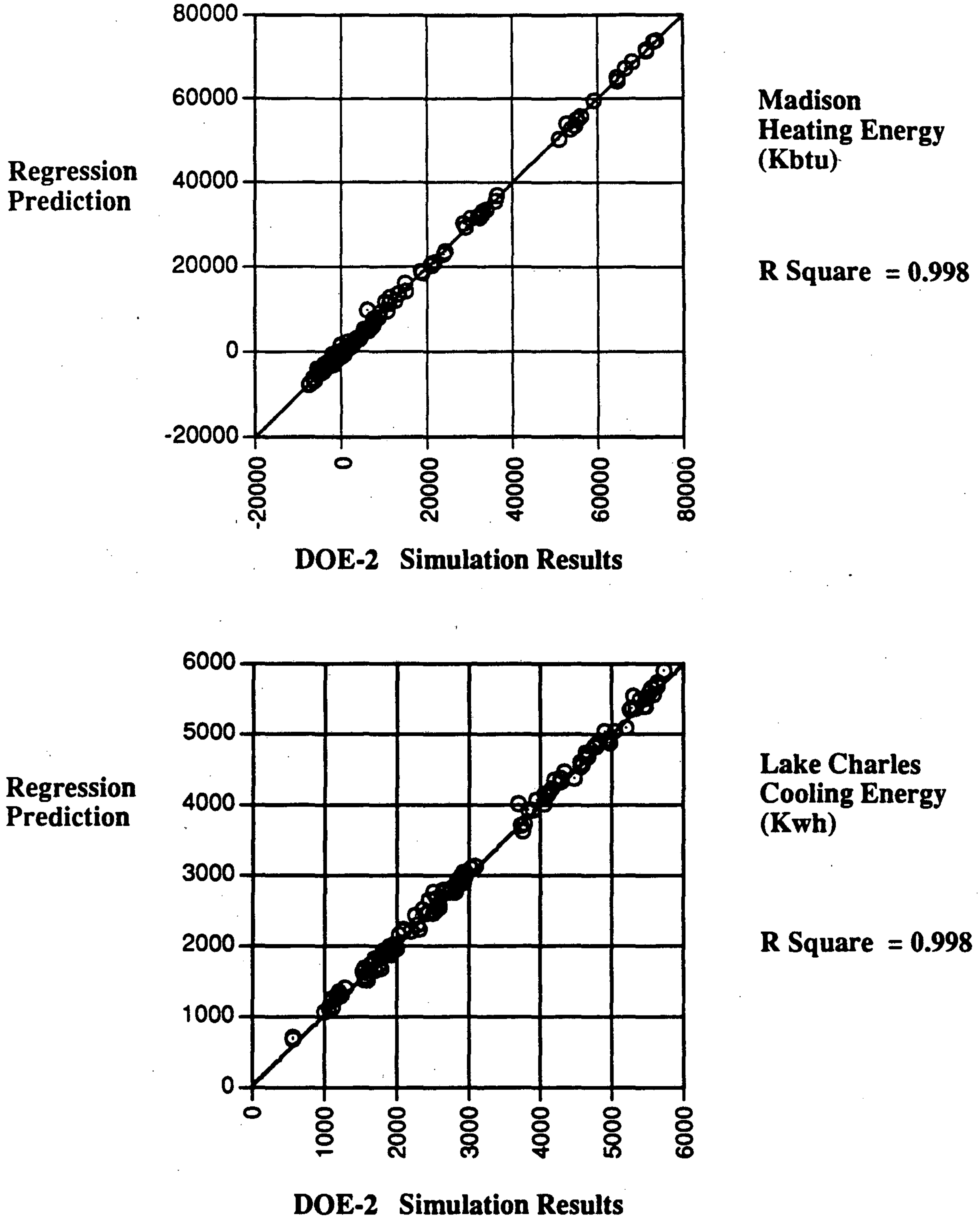
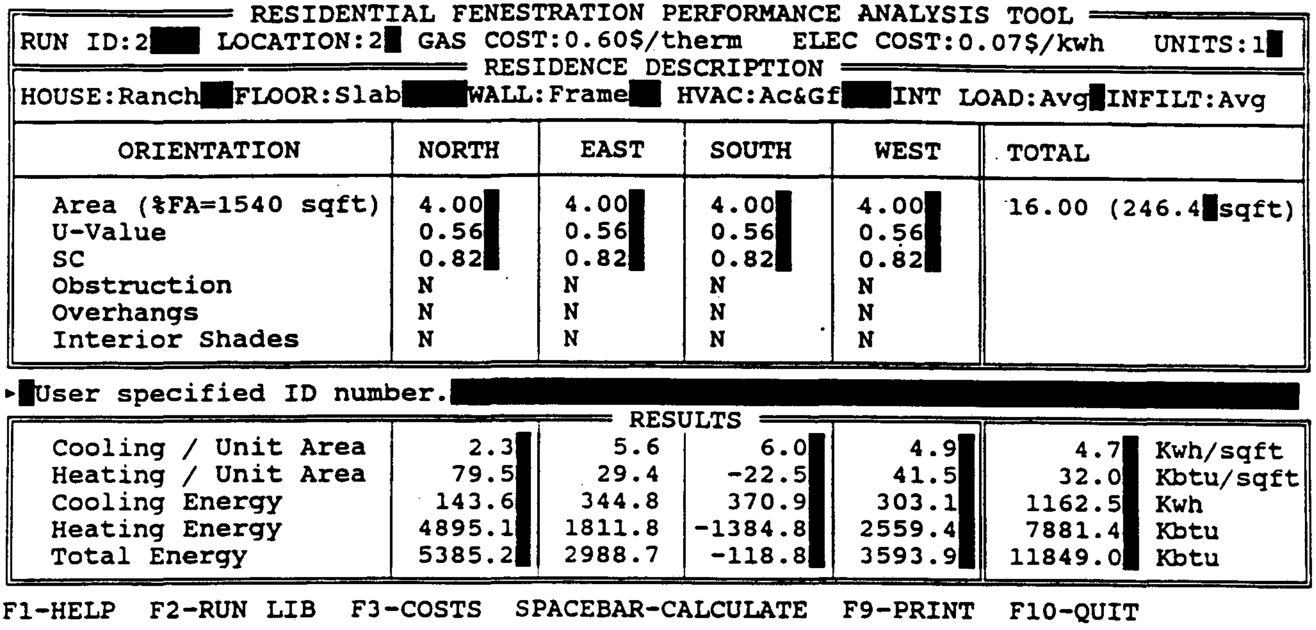
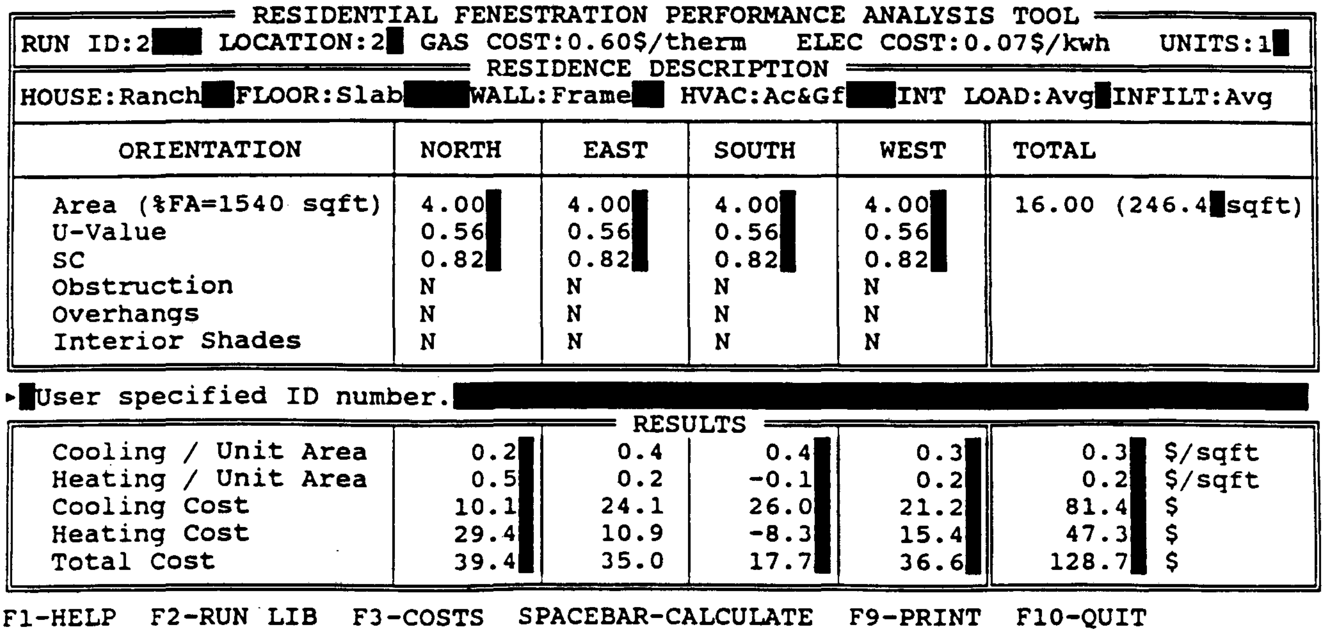


Figure 1. Comparison of DOE-2 simulation results and regression prediction for heating energy use in Madison, WI and cooling energy use in Lake Charles, LA, for a prototype single-story residential building of 1540ft$^2$ (143m$^2$).

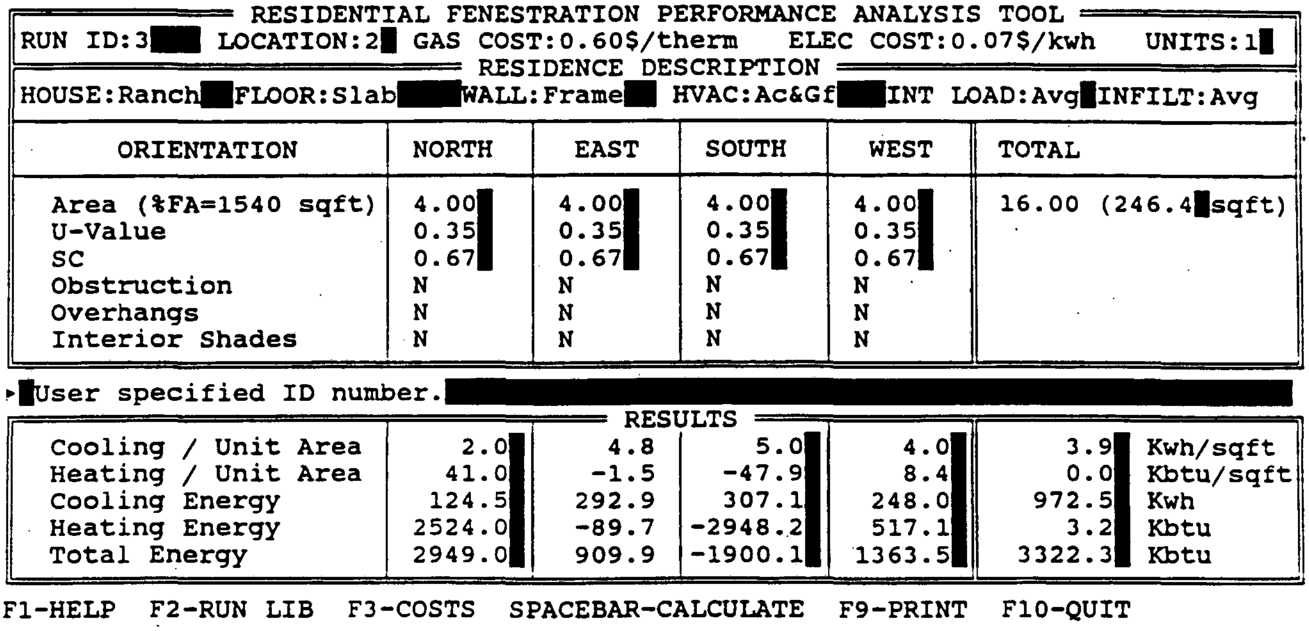


```
RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL
RUN ID:2███ LOCATION:2█ GAS COST:0.60$/therm   ELEC COST:0.07$/kwh   UNITS:1█
RESIDENCE DESCRIPTION
HOUSE:Ranch█FLOOR:Slab███WALL:Frame█ HVAC:Ac&Gf██INT LOAD:Avg█INFILT:Avg

ORIENTATION            NORTH    EAST     SOUTH    WEST     TOTAL

Area (%FA=1540 sqft)   4.00█    4.00█    4.00█    4.00█    16.00 (246.4█sqft)
U-Value                0.56█    0.56█    0.56█    0.56█
SC                     0.82█    0.82█    0.82█    0.82█
Obstruction            N        N        N        N
Overhangs              N        N        N        N
Interior Shades        N        N        N        N

▸█User specified ID number.████████████████████████████████
RESULTS
Cooling / Unit Area       2.3█     5.6      6.0█     4.9█      4.7█ Kwh/sqft
Heating / Unit Area      79.5█    29.4    -22.5█    41.5█     32.0█ Kbtu/sqft
Cooling Energy          143.6█   344.8    370.9█   303.1█   1162.5█ Kwh
Heating Energy         4895.1█  1811.8  -1384.8█  2559.4█   7881.4█ Kbtu
Total Energy           5385.2█  2988.7   -118.8█  3593.9█  11849.0█ Kbtu

F1-HELP  F2-RUN LIB  F3-COSTS  SPACEBAR-CALCULATE  F9-PRINT  F10-QUIT
```

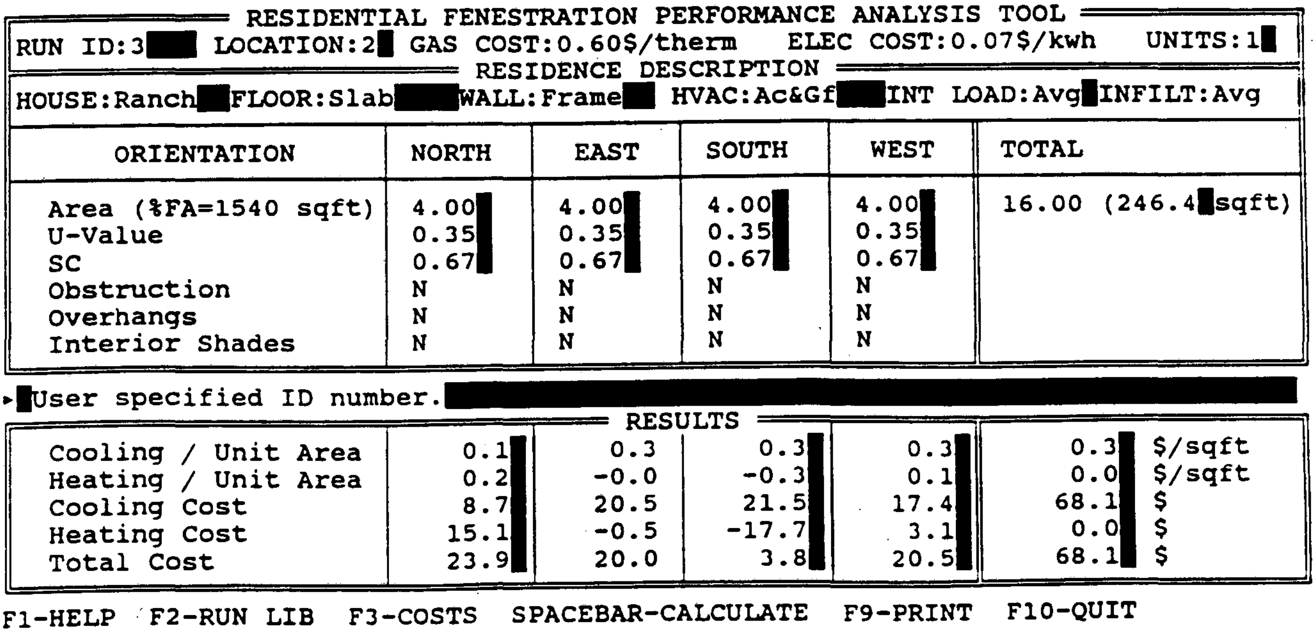


```
RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL
RUN ID:2███ LOCATION:2█ GAS COST:0.60$/therm   ELEC COST:0.07$/kwh   UNITS:1█
RESIDENCE DESCRIPTION
HOUSE:Ranch█FLOOR:Slab███WALL:Frame█ HVAC:Ac&Gf██INT LOAD:Avg█INFILT:Avg

ORIENTATION            NORTH    EAST     SOUTH    WEST     TOTAL

Area (%FA=1540 sqft)   4.00█    4.00█    4.00█    4.00█    16.00 (246.4█sqft)
U-Value                0.56█    0.56█    0.56█    0.56█
SC                     0.82█    0.82█    0.82█    0.82█
Obstruction            N        N        N        N
Overhangs              N        N        N        N
Interior Shades        N        N        N        N

▸█User specified ID number.████████████████████████████████
RESULTS
Cooling / Unit Area       0.2█     0.4      0.4█     0.3█      0.3█ $/sqft
Heating / Unit Area       0.5█     0.2     -0.1█     0.2█      0.2█ $/sqft
Cooling Cost             10.1█    24.1     26.0█    21.2█     81.4█ $
Heating Cost             29.4█    10.9     -8.3█    15.4█     47.3█ $
Total Cost               39.4█    35.0     17.7█    36.6█    128.7█ $

F1-HELP  F2-RUN LIB  F3-COSTS  SPACEBAR-CALCULATE  F9-PRINT  F10-QUIT
```

Figure 2. Energy use and cost output screens from the program RESFEN. Results are shown for a prototype single-story residential building of 1540 $ft^2$ ($143m^2$) using windows that are double-pane clear glass equal to 4% of the floor area on all facades.

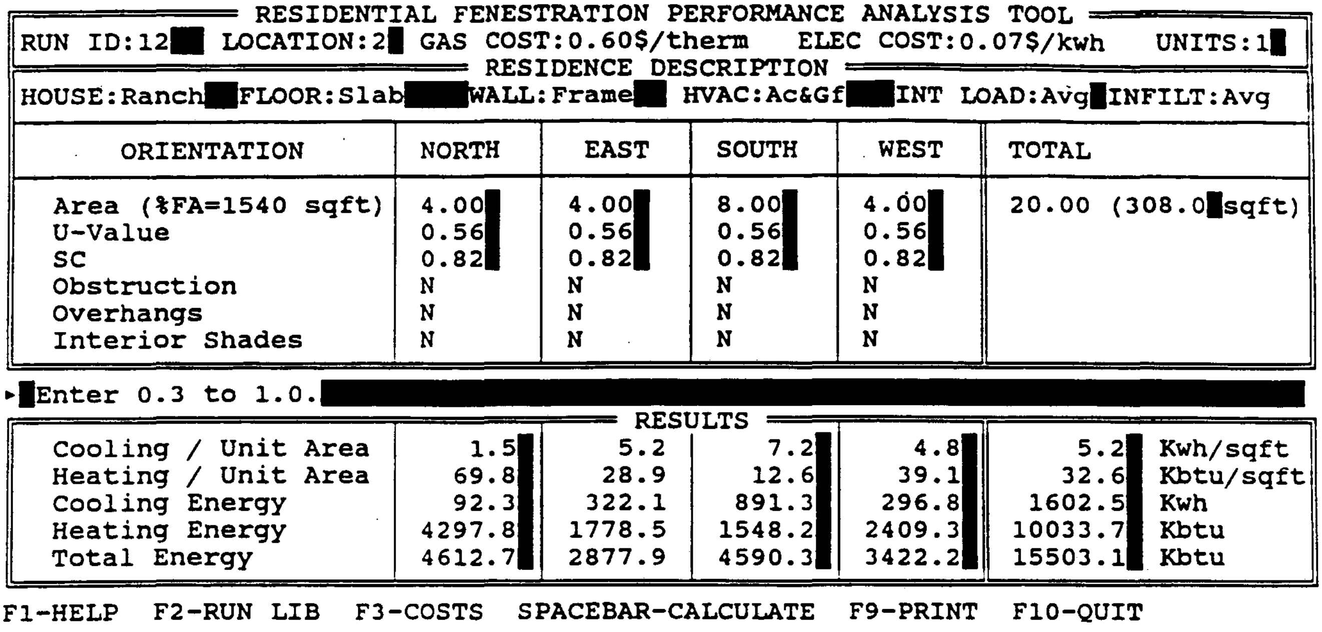


```
================ RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL ================
RUN ID:3     LOCATION:2  GAS COST:0.60$/therm    ELEC COST:0.07$/kwh    UNITS:1
============================= RESIDENCE DESCRIPTION ================================
HOUSE:Ranch FLOOR:Slab   WALL:Frame  HVAC:Ac&Gf   INT LOAD:Avg INFILT:Avg

    ORIENTATION           NORTH      EAST       SOUTH      WEST       TOTAL

  Area (%FA=1540 sqft)   4.00       4.00       4.00       4.00       16.00 (246.4 sqft)
  U-Value                0.35       0.35       0.35       0.35
  SC                     0.67       0.67       0.67       0.67
  Obstruction            N          N          N          N
  Overhangs              N          N          N          N
  Interior Shades        N          N          N          N

▸ User specified ID number.
===================================== RESULTS ======================================
  Cooling / Unit Area       2.0        4.8        5.0        4.0         3.9  Kwh/sqft
  Heating / Unit Area      41.0       -1.5      -47.9        8.4         0.0  Kbtu/sqft
  Cooling Energy          124.5      292.9      307.1      248.0       972.5  Kwh
  Heating Energy         2524.0      -89.7    -2948.2      517.1         3.2  Kbtu
  Total Energy           2949.0      909.9    -1900.1     1363.5      3322.3  Kbtu

F1-HELP   F2-RUN LIB   F3-COSTS   SPACEBAR-CALCULATE   F9-PRINT   F10-QUIT
```

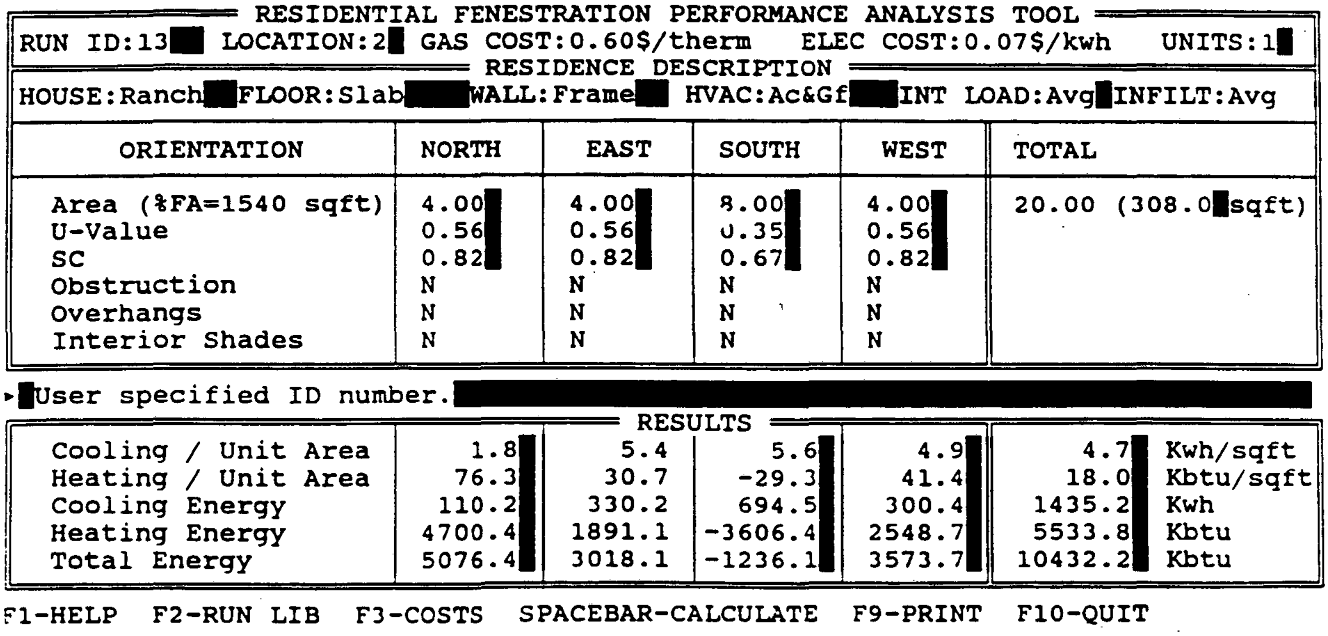


```
================ RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL ================
RUN ID:3     LOCATION:2  GAS COST:0.60$/therm    ELEC COST:0.07$/kwh    UNITS:1
============================= RESIDENCE DESCRIPTION ================================
HOUSE:Ranch FLOOR:Slab   WALL:Frame  HVAC:Ac&Gf   INT LOAD:Avg INFILT:Avg

    ORIENTATION           NORTH      EAST       SOUTH      WEST       TOTAL

  Area (%FA=1540 sqft)   4.00       4.00       4.00       4.00       16.00 (246.4 sqft)
  U-Value                0.35       0.35       0.35       0.35
  SC                     0.67       0.67       0.67       0.67
  Obstruction            N          N          N          N
  Overhangs              N          N          N          N
  Interior Shades        N          N          N          N

▸ User specified ID number.
===================================== RESULTS ======================================
  Cooling / Unit Area       0.1        0.3        0.3        0.3         0.3  $/sqft
  Heating / Unit Area       0.2       -0.0       -0.3        0.1         0.0  $/sqft
  Cooling Cost              8.7       20.5       21.5       17.4        68.1  $
  Heating Cost             15.1       -0.5      -17.7        3.1         0.0  $
  Total Cost               23.9       20.0        3.8       20.5        68.1  $

F1-HELP   F2-RUN LIB   F3-COSTS   SPACEBAR-CALCULATE   F9-PRINT   F10-QUIT
```

Figure 3. Energy use and cost output screens from the program RESFEN. Results are shown for a prototype single-story residential building of 1540 $ft^2$ (143$m^2$) using windows that are double-pane low-E glass equal to 4% of the floor area on all facades.



```
══════════ RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL ══════════
RUN ID:12█ LOCATION:2█ GAS COST:0.60$/therm   ELEC COST:0.07$/kwh   UNITS:1█
══════════════════════ RESIDENCE DESCRIPTION ══════════════════════
HOUSE:Ranch█FLOOR:Slab█WALL:Frame█ HVAC:Ac&Gf█INT LOAD:Avg█INFILT:Avg

   ORIENTATION           NORTH    EAST     SOUTH    WEST     TOTAL

 Area (%FA=1540 sqft)    4.00█    4.00█    8.00█    4.00█    20.00 (308.0█sqft)
 U-Value                 0.56█    0.56█    0.56█    0.56█
 SC                      0.82█    0.82█    0.82█    0.82█
 Obstruction             N        N        N        N
 Overhangs               N        N        N        N
 Interior Shades         N        N        N        N

►█Enter 0.3 to 1.0.█████████████████████████████████████████████████
══════════════════════════ RESULTS ══════════════════════════
 Cooling / Unit Area        1.5█     5.2      7.2█     4.8█       5.2█ Kwh/sqft
 Heating / Unit Area       69.8█    28.9     12.6█    39.1█      32.6█ Kbtu/sqft
 Cooling Energy            92.3█   322.1    891.3█   296.8█    1602.5█ Kwh
 Heating Energy          4297.8█  1778.5   1548.2█  2409.3█   10033.7█ Kbtu
 Total Energy            4612.7█  2877.9   4590.3█  3422.2█   15503.1█ Kbtu

F1-HELP  F2-RUN LIB  F3-COSTS  SPACEBAR-CALCULATE  F9-PRINT  F10-QUIT
```



```
══════════ RESIDENTIAL FENESTRATION PERFORMANCE ANALYSIS TOOL ══════════
RUN ID:13█ LOCATION:2█ GAS COST:0.60$/therm   ELEC COST:0.07$/kwh   UNITS:1█
══════════════════════ RESIDENCE DESCRIPTION ══════════════════════
HOUSE:Ranch█FLOOR:Slab█WALL:Frame█ HVAC:Ac&Gf█INT LOAD:Avg█INFILT:Avg

   ORIENTATION           NORTH    EAST     SOUTH    WEST     TOTAL

 Area (%FA=1540 sqft)    4.00█    4.00█    8.00█    4.00█    20.00 (308.0█sqft)
 U-Value                 0.56█    0.56█    0.35█    0.56█
 SC                      0.82█    0.82█    0.67█    0.82█
 Obstruction             N        N        N        N
 Overhangs               N        N        N        N
 Interior Shades         N        N        N        N

►█User specified ID number.█████████████████████████████████████████
══════════════════════════ RESULTS ══════════════════════════
 Cooling / Unit Area        1.8█     5.4      5.6█     4.9█       4.7█ Kwh/sqft
 Heating / Unit Area       76.3█    30.7    -29.3█    41.4█      18.0█ Kbtu/sqft
 Cooling Energy           110.2█   330.2    694.5█   300.4█    1435.2█ Kwh
 Heating Energy          4700.4█  1891.1  -3606.4█  2548.7█    5533.8█ Kbtu
 Total Energy            5076.4█  3018.1  -1236.1█  3573.7█   10432.2█ Kbtu

F1-HELP  F2-RUN LIB  F3-COSTS  SPACEBAR-CALCULATE  F9-PRINT  F10-QUIT
```

Figure 4. Energy use output screens from the program RESFEN. Results are shown for a prototype single-story residential building of 1540 ft$^2$ (143m ) using windows that are double-pane clear glass equal to 4% of the floor area on north, east, and west facades and 8% on the south facade and windows that are double-pane clear glass equal to 4% of the floor area on north, east, and west facades and double-pane low-E glass equal to 8% of the floor area on the south facade.

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BERKELEY, CALIFORNIA 94720