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PEAR: A MICROCOMPUTER PROGRAM FOR RESIDENTIAL ENERGY ANALYSIS

R. Ritschard, Y.J. Huang, S. Byrne, I. Turiel, and J. Bull

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ABSTRACT

We have designed a software package called PEAR (Program for Energy Analysis of Residences), which is written with user-friendly input and output and runs on the IBM PC. PEAR provides an easy-to-use and very fast compilation and extrapolation of a comprehensive DOE-2.1 database for residential buildings. The current version, which covers five residential building prototypes in over 800 locations, estimates energy and cost savings resulting from typical conservation measures such as ceiling, wall and floor insulation, window type and glazing layers, infiltration levels, and equipment efficiency. It also allows the user to adjust for optional measures including roof or wall color, movable insulation, whole-house fans, night temperature setback, reflective or heat absorbing glass, thermal mass in exterior walls, and two attached sunspace options. The program is designed to be used both as a research tool by energy and policy analysts, and as a non-technical energy calculation method by architects, home builders, home owners, and others in the building industry.

INTRODUCTION

Over the past several years, the Building Energy Analysis Group of Lawrence Berkeley Laboratory has created a comprehensive database on the effects of different conservation measures on residential energy consumption. The single-family portion of the database, which consists of over 12,000 computer simulations using the DOE-2.1 simulation code, served as the technical foundation for developing a set of energy calculating slide rules for five prototypical building types in 45 climate regions. The slide rules and an accompanying home builders' guidebook are part of a Department of Energy program to develop voluntary performance guidelines for new single-family residences. These simplified tools are capable of estimating the energy savings associated with various energy conservation measures used in site-built homes. The slide rule was designed to be used by a non-technical audience such as home builders and home buyers.

Last year, we expanded the LBL residential database to cover multi-family units and automated it into a computerized format that can be accessed easily by researchers and by the interested public. This computerized version can be used as a research tool, as well as a simplified calculation procedure that goes beyond the slide rule format. We also developed more sophisticated interpolation procedures that extend the accuracy and flexibility of the database. We used the database and simplified mathematical relationships to design a software package called PEAR (Program for Energy Analysis of Residences).

In this paper, we provide a general overview of a simplified energy analysis method (i.e., PEAR) that was designed to be used both as a research tool by energy and policy analysts, and as a non-technical energy calculation method by architects, home builders, home owners, and others in the building industry. First, we describe the LBL residential database that forms the cornerstone for both the slide rules and the microcomputer version. We also describe examples of the interpolative procedures used to extrapolate the database to account for the effects on building energy use of variations in building design, climate, and operating conditions. Second, we present a description of the input and output to PEAR and a brief summary of the user interface. Finally, we discuss potential applications for this simplified analysis tool and list additional data being developed for future versions of the program.

METHODOLOGY

We compiled the residential database on the predicted energy consumption of typical buildings from a series of simulations using the DOE-2.1 computer program. The current database includes results for seven prototypical buildings in 45 base locations. We simulated more than 20 levels of thermal integrity (i.e., wall, roof, and floor insulation, infiltration levels, and window glazing layers) for each prototype building in all base locations. In addition, we performed sensitivity analyses for different floor areas, window areas and control strategies, night temperature setback, whole-house fans, attached sunspaces, thermal mass in exterior walls, and building color for a smaller number of locations. The residential database is summarized in Table 1. These data provide sufficient information for estimating heating and cooling energy use for typical residential houses of various configurations throughout the nation. We present here only an example of the overall approach used to transform the data base into the microcomputer format. Detailed descriptions of the modeling assumptions, simulation methodology, and interpolative procedures are found in several technical support documents (1,2,3).

Table 1. LBL Residential Database

Computer Program Used:	DOE-2.1
Prototype Buildings:	7 (1-Story, 2-Story, Split-level, Middle and End Townhouse, Middle and End Apartment)
Locations:	45-50
Conservation Options:	20
Foundation Types:	3 (Slab, Basement, Crawl Space)
Equipment:	2 (Furnace/Air Conditioner, Heat Pump)
Sensitivity Studies:	Attached Sunspaces Building Area and Orientation Night Temperature Setback Thermal Mass Wall and Roof Color Window Area and Orientation Window Control Strategies

From our extensive database, we calculated reductions in building loads for key conservation measures such as added insulation, glazing layers, and reduced infiltration. We based these reductions on the load differences between successive DOE-2.1 simulations with that conservation measure added, while holding other parameters constant. For example, we calculated the Δload from double to triple glazing assuming R-38 ceiling insulation and R-19 wall insulation. This procedure insures maximum accuracy for most reasonable construction situations and avoids bias towards a fixed base case building. We interpolated loads for intermediate conservation measures from the closest data points based on steady-state conductances. This analytical effort transformed the data base into a set of estimated savings for typical conservation measures for each building prototype in 45 climate regions. These results, in the form of a data matrix, were transposed graphically into the slide rule format.

For the microcomputer program, we regressed the Δloads against Δsteady-state conductances to calculate the component loads per unit amount of ceiling, wall, and window area, perimeter length, or house volume. This increases the flexibility of the database and makes it possible to scale from the five building prototypes to houses with differing geometries, ceiling heights, and window areas. This topic is covered in more detail elsewhere (4).

We also performed sensitivity analyses to extend the base case results to account for differences between individual buildings and to develop a basic scientific understanding of the parameters that determine energy use. Using a variety of interpolative procedures such as linear and nonlinear regression, as

well as multivariate analysis of variance, and other methods, we correlated simulated data to important building design and climate variables. For example, in studying the energy impact of nighttime temperature setback, we found a strong correlation between night setback and percent nighttime degree-day reductions (see Fig. 1). Test runs done for Jacksonville, Great Falls, and Boston deviated less than 1% from this regression line. From this type of interpolative analysis, we developed a set of regression equations, algorithms, or other simplified mathematical relationships for each of the building variables analyzed. We used these relationships to extrapolate from the extensive DOE-2.1 database to building variations or climates that are not part of the base case data. The complete set of equations and algorithms used in developing PEAR are presented and discussed in more detail elsewhere (3). We will briefly describe two examples that typify the overall approach.

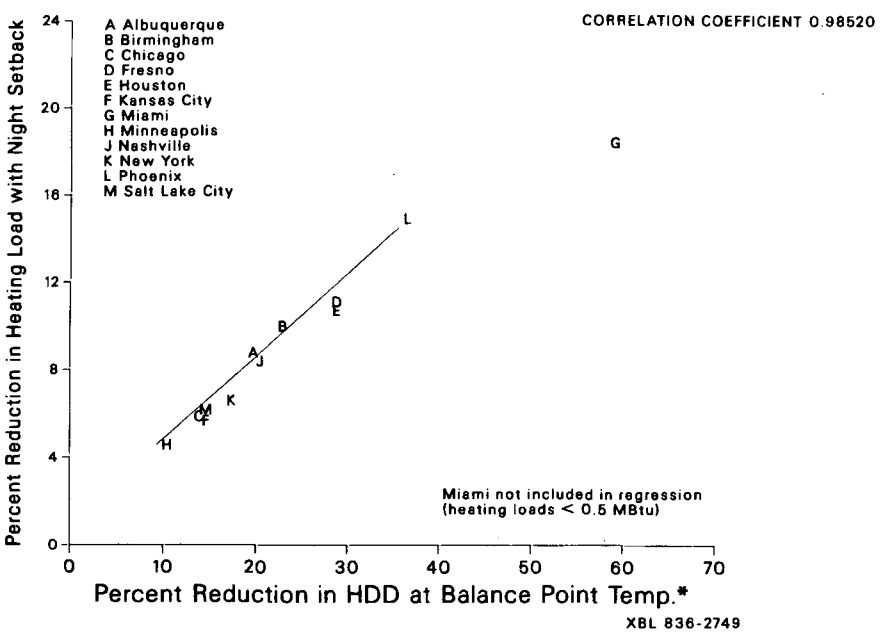

Fig. 1. Night Setback Heating Load Reduction

Thermal Mass in Exterior Walls

We performed a sensitivity analysis in three climate zones for a wide variety of mass wall configurations to determine how several complex interactions could be reduced to a set of simple equations. We varied parameters such as the density, thickness, conductivity, and specific heat of the mass layer as well as the location and U-value of the insulation layer within the full range found in common residential construction. We found that this large set of parametric simulations (representing concrete

masonry, brick, and log walls) could be substantially reduced by combining certain parameters and using nonlinear multiple regression to interpolate between the others.

We used the following model to predict the difference in heating or cooling load between a wood-frame wall and a massive wall with the same total wall U-value:

$$\phi = e^{(\beta_o * HC)}$$

$$\Delta LOAD = \beta_1 + \beta_2 = \beta_3 U_T + \beta_4 \phi U_T,$$

where:

β_0–β_4 = regression coefficients,

HC = mass heat capacity (Btu/ft^2*F),

U_T = total wall U-value (Btu/hr*ft^2*F).

This model accounts for the exponential decay effect of mass heat capacity (thickness * density * specific heat), the linear effect of wall U-value and the interaction between these two effects. We generated separate regression coefficients to account for the location of insulation in the wall (inside or outside of the mass, or insulation and mass well mixed). As shown in Figure 2, this model equation accurately interpolates between the results of the DOE-2 simulations.

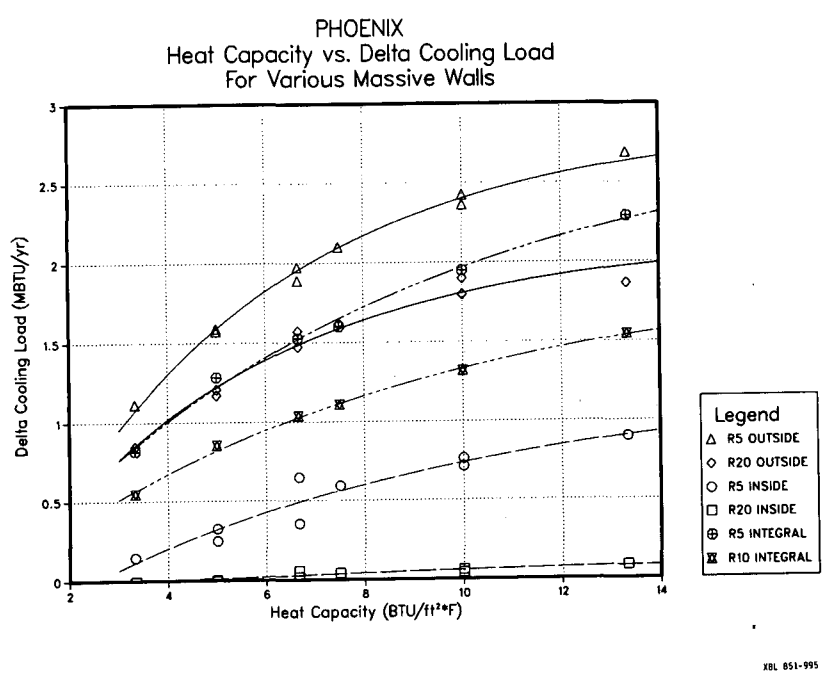

Fig. 2. Heat Capacity -vs- Delta Cooling Load (Phoenix)

By analyzing the thermal mass effect in all 45 base locations, we were able to reduce to 12 the number of locations for the mass wall parametric simulations. A set of regression coefficients for each of these 12 locations are incorporated into PEAR to allow a fast and accurate assessment of the effects of thermal mass on reducing heating and cooling loads.

Movable Night Insulation

We modeled movable insulation as a standard, off-the-shelf product with a material R-value of 3 ($hr*ft^2*F/Btu$). We assumed the movable insulation to be in place between the hours of of 10 p.m. and 8 a.m. during the heating season. We varied the actual length of the heating season, however, depending on local climate. We simulated the impact of movable night insulation on annual heating loads in 11 representative cities for three glazing types (single, double, and triple-pane clear windows), one window area (15% of floor area), and one orientation (equally-distributed).

Analyzing these results, we found a good correlation between heating load reduction and nighttime heating degree-days (i.e., degree-days during the hours 10 p.m. to 8 a.m.). Figure 3 shows heating load reductions plotted as a function of nighttime heating degree-days (base 63 °F) for the ranch prototype single-glazed windows in 11 cities. We used 63 °F to calculate nighttime heating degree-days because it corresponds to the average nighttime balance point temperature for the house.

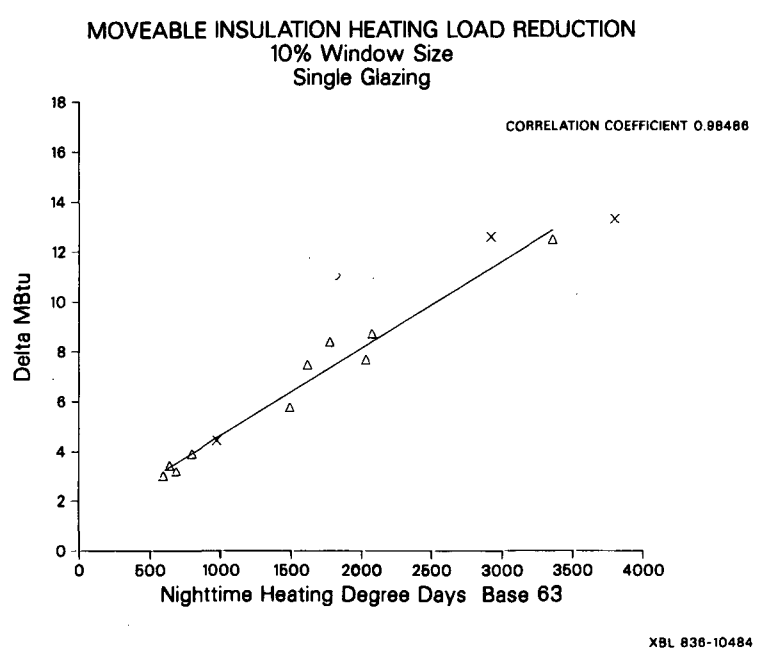

Fig. 3. Movable Insulation Heating Load Reduction

We used 15% window area simulation data in 11 cities to compute regression lines for predicting heating load reductions in the other 34 base case locations. We extrapolated from the simulated data to other levels of night insulation (i.e., R-1 and R-5) and to other window areas. The regression equations incorporated into PEAR to accomodate for the movable insulation option are:

$$\textit{Single pane}: \; Load/Area \; (MBtu/ft^2) = 0.00202 + 1.706 \; x \; 10^{-5} NHDD,$$

$$\textit{Double pane}: \; Load/Area \; (MBtu/ft^2) = 0.00133 + 0.794 \; x \; 10^{-5} \; NHDD,$$

$$\textit{Triple pane}: \; Load/Area \; (MBtu/ft^2) = 0.00336 + 0.422 \; x \; 10^{-5} \; NHDD,$$

where: NHDD = nighttime heating degree-day (base 63 °F).

DESCRIPTION OF PEAR

PEAR is written with user-friendly input and output, and runs on the IBM PC with either color or monochromatic monitors. PEAR provides an easy-to-use and very fast compilation of the extensive DOE-2.1 database for residential buildings. The current version covers five residential building prototypes (one-story, two-story, split-level, middle-unit townhouse, and end-unit townhouse) in 45 base locations, but will be extended in the future to include multi-family buildings as well as manufactured homes. The program allows adjustments to the building prototypes for differing window area and location, as well as floor area, gross wall area, and perimeter length. It also allows for extending the data to 800 other locations by using heating and cooling degree-day modifications. In addition to the typical conservation measures such as ceiling, wall and floor insulation, window type and glazing layers, infiltration levels, and equipment efficiency changes, the user can adjust for optional measures, such as roof or wall color, movable insulation, whole-house fans, night temperature setback, reflective or heat absorbing glass, and two attached sunspace options (glass or opaque roof). PEAR also contains an algorithm that accounts for heavy mass construction (e.g., concrete block, brick, and log) in the exterior walls.

The user interface of the microcomputer program includes six modes. INPUT consists of three screens that allow users to calculate the energy use of a typical residential building. The BAR CHART option gives more detailed analysis of any building configuration by separating total building energy use into the contribution due to ceiling, walls, floor, infiltration, and windows. ECONOMICS does economic calculations based on the data used in the INPUT mode. SAVE, READ and CHANGE FILE are bookkeeping options that show the status of the calculated files, and create new files as needed.

The INPUT mode is organized on three screens. The left side of *Input Screen 1* contains the location (by state and city for about 800 locations) and the general house description: building prototype, foundation type, floor area, gross wall area, wall height or perimeter length, window orientation, and

window area (see Fig. 4). In the current version, this general input appears on the left side of all input screens for reference purposes. The right side of *Input Screen 1* contains the following basic conservation measures: ceiling insulation, roof color, wall insulation, wall color, wall heat capacity, foundation insulation (basement or slab-on-grade), floor insulation (basement or ventilated crawl space), window layers, sash type (plain, wood, aluminum, or aluminum with thermal breaks), glass type (regular, reflective or absorptive), movable insulation, and level of infiltration (0.4 ach to 1.0 ach). As the various inputs are changed, the heating energy (in therms or kWh) and cooling energy (kWh) are calculated immediately at the bottom of the screen, allowing users to assess quickly the effectiveness of different basic measures.

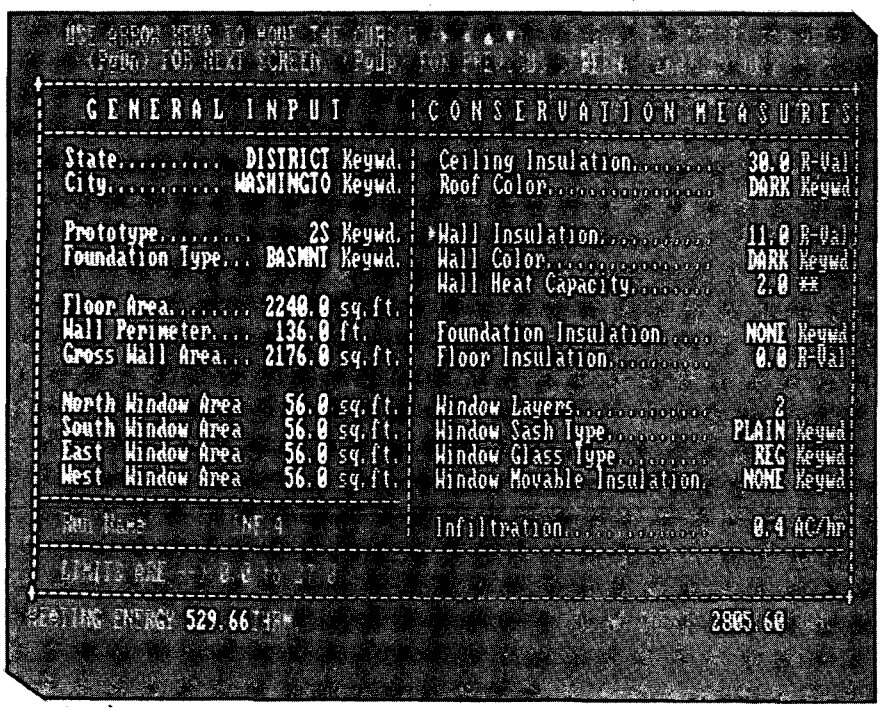

Fig. 4. Conservation Measures Input

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On-line help is available for any option on any input screen by typing "?" instead of the usual numeric or code word input. Figure 4, as an example, shows the limits for wall insulation at a particular location that are provided to a user who seeks help by typing "?".

The right side of *Input Screen 2* provides a selection of optional conservation measures (see Fig. 5). These measures include attached sunspaces and whole-house fans as well as several equipment options: heating equipment (oil and gas furnaces, electric resistance heaters, or heat pumps) and efficiency as AFUE (Annual Fuel Utilization Efficiency) or HSPF (Heating Seasonal Performance Factor), night temperature setback, and cooling equipment (central air conditioners or heat pumps) and efficiency as SEER (Seasonal Energy Efficiency Ratio).

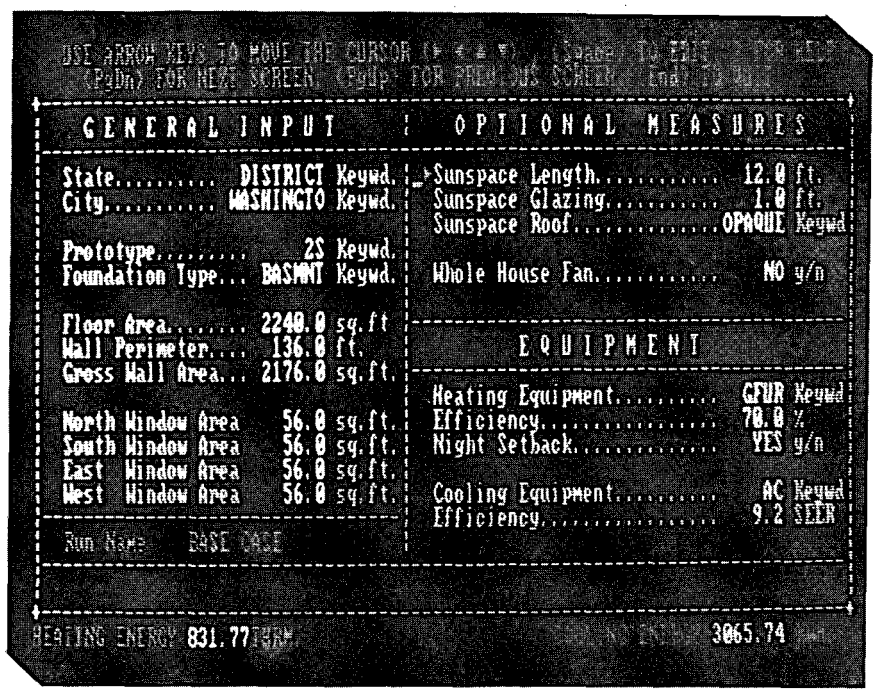

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Fig. 5. Optional Measures Input

The right side of *Input Screen 3* contains the economic parameters (see Fig. 6). In the current version, the economic input is used to calculate simple payback (in years) and the benefit-to-cost ratio.

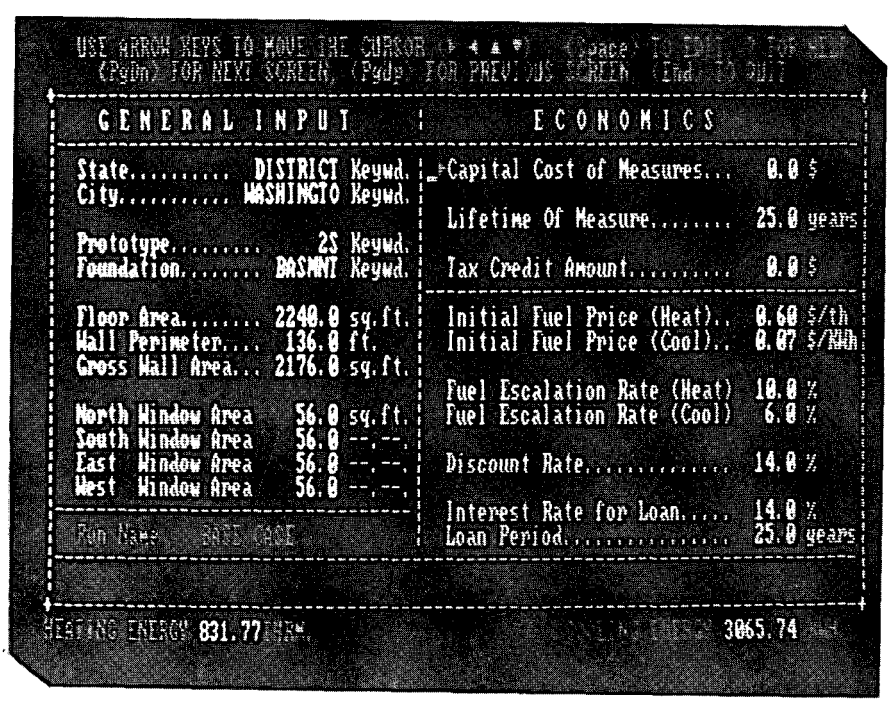

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Fig. 6. Economics Input

We are considering other economic indicators such as net present value, etc. and may add them in future versions. On this screen, the user can input information on the capital cost of the measures selected, lifetime of the measure, tax credit (if available), initial fuel prices for heating and cooling, real fuel price escalation rates, real discount rate, and information relevant to loans (e.g., interest rate and loan period).

For users wishing more detailed diagnosis of any particular building configuration, the BAR CHART option plots the estimated contribution to heating and cooling loads due to the following major components: ceiling, walls, floor, infiltration, and windows (see Fig. 7). These graphs allow users to determine quickly which envelope components contribute most to the building load and should be improved. Heating and cooling are plotted in dollars to give the proper weighting of heating to cooling energies.

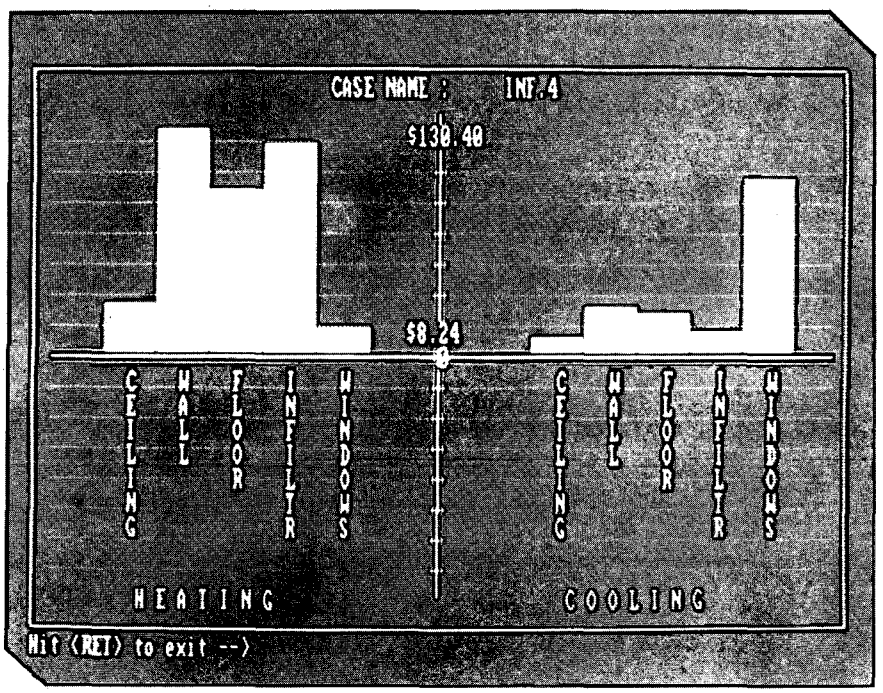

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Fig. 7. Bar Chart Option

Once two or more runs have been completed (base case and any other combination of conservation measures), the user can enter the ECONOMICS mode and the program will do an economic analysis. Figure 8 shows a comparison of five runs (combination of conservation options) against a base case. A brief description of the base case characteristics is given along the bottom of the screen as R-values of the ceiling, wall and foundation, infiltration rate, window area (ft^2), number of window layers, and total yearly energy cost ($). Below the specific run names (at the top of the screen) are listed the characteristics of the individual cases chosen. Additional runs may be viewed by scrolling horizontally (left or right) with the arrow keys run in any column. The output on the ECONOMICS screen includes the following: yearly savings for heating and cooling energy ($), yearly energy cost ($), a summary of economic input

parameters (cost of measure, lifetime of measure, and tax credit), and two economic indicators: simple payback (yrs.) and benefit-to-cost ratio. The user can change the economic input on this screen, such as cost and lifetime of measure and tax credit to see their effects on simple payback periods and benefit-to-cost ratios.

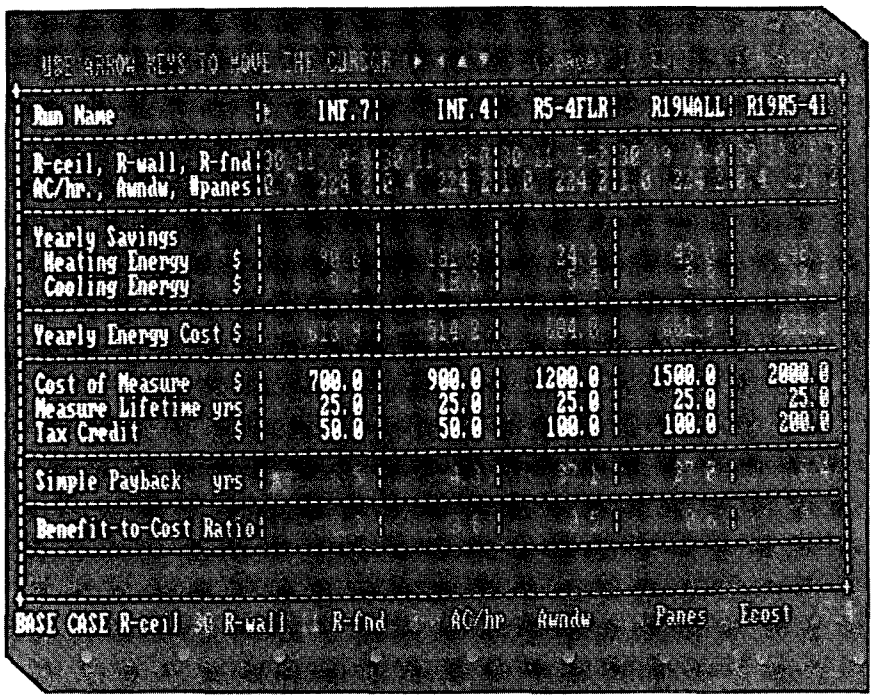

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Fig. 8. Economics Output

APPLICATIONS

Our research, which supports the Department of Energy's mission to improve the energy efficiency of the nation's stock of conventionally-built homes, has developed two simplified energy analysis tools: slide rules and microcomputer program. These tools provide simplified calculation techniques capable of estimating the energy and cost savings associated with various conservation measures used in single-family houses throughout the United States. The slide rule, which is a simple graphic representation of the DOE-2.1 database, received public review in early 1984. An updated version that includes thermal mass in the exterior walls is currently being reviewed. The full set of slide rules for 45 climates and five site-built prototypes should be available by the end of 1985.

The software program (PEAR) extends the accuracy and flexibility of the database well beyond the slide rule format. For example, using PEAR one can adjust for different building types and window geometries as well as expand the number of locations from the 45 base cities to about 800 locations across the country. The user can also quickly calculate the energy savings for several optional measures (e.g.,

night temperature setback) that were included with the slide rule as a set of modifier tables. In addition, PEAR offers several economic analyses and the ability to compare the energy and cost savings of different sets of conservation measures at one time. A demonstration version of PEAR will be made available to a selective group of architects, builders, designers, policy makers, and utility planners for their review. An early version of the program was presented to the ASHRAE Standard Project Committee 90.2P that is revising Standard 90 for the energy efficient design of new residential buildings.

We are developing additional data that will become part of the data base and interpolative procedures supporting the microcomputer program. The following areas are currently under investigation:

1. We are adding two apartment prototypes (middle and end unit), which we analyzed as part of our low-rise multi-family buildings research project. We are selecting and modeling other multi-family prototypes including apartments in a three-story building.

2. We are extending our analysis of the effects of heavy mass construction on building energy use. From this research effort, we will develop a better understanding of the interaction between solar gain and thermal mass including such variables as shading, window area and orientation, ventilation rate, and amount of interior mass.

3. We are performing further analyses of the database that will allow the user to make modifications for different window shading options, conductance schedules, internal loads, and thermostat settings.

We believe that PEAR offers a simple and reliable way to determine the energy and cost effectiveness of different energy conservation options. It allows the user to consider regional differences in climate, building design and materials, energy prices, interest rates, and fuel types. Using PEAR, one can recreate the results of a complex state-of-the-art simulation program (DOE-2.1) without substantially sacrificing accuracy or requiring detailed input parameters that most people do not understand. The main goal of this research effort is to develop simplified energy analysis tools that provide technical assistance for the design and construction of energy efficient homes. If we can meet this goal, we may also enhance the public's ability to obtain affordable housing through energy conservation.

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ACKNOWLEDGEMENT

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