Title

CIRAuA MICROCOMPUTER-BASED ENERGY ANALYSIS AND AUDITING TOOL FOR RESIDENTIAL APPLICATICNS

Authors

Sonderegger, R.C.
Dixon, J.D.

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R.C. Sonderegger and J.D. Dixon

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R.C. Sonderegger and J.D. Dixon

Energy Performance of Buildings Group
Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720 USA

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CIRA — A MICROCOMPUTER-BASED ENERGY ANALYSIS AND AUDITING TOOL FOR RESIDENTIAL APPLICATIONS

Robert C. Sonderegger & James D. Dixon

Energy Performance of Buildings Group, Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

ABSTRACT - Computerized, Instrumented, Residential Audit (CIRA) is a collection of programs for energy analysis and energy auditing of residential buildings. CIRA is written for microcomputers with a CP/M operating system and 64K RAM. Its principal features are: user-friendliness, dynamic defaults, file-oriented structure, design energy analysis capability, economic optimization of retrofits, graphic and tabular output to screen and printer. To calculate monthly energy consumptions both for design and retrofit analyses CIRA uses a modified degree-day and degree-night approach, taking into account solar gains, IR losses to the sky, internal gains and ground heat transfer; the concept of solar storage factor addresses the delayed effect of daytime solar gains while the concept of effective thermal mass ensures proper handling of changes in thermostat setting from day to night; air infiltration is modeled using the LBL infiltration model based on effective leakage area; HVAC system performance is modeled using correlations developed for DOE-2.1. For any given budget, CIRA can also develop an optimally sequenced list of retrofits with the highest combined savings. Long run-times necessary for economic optimization of retrofits are greatly reduced by using a method based on partial derivatives of energy consumption with respect to principal building parameters. Energy calculations of CIRA compare well with those of DOE-2.1 and with measured energy consumptions from a sample of monitored houses.

INTRODUCTION

Building energy analysis computer programs often are designed by engineers for engineers. Sophisticated algorithms are embedded in programs developed for batch-computer systems with line-oriented input devices and high-speed printers. Such programs may have a fixed format input language that the user has to learn and may produce book-thick printouts. Relatively inexpensive microcomputers allow considerably more user interaction during input and permit to view output before it is printed, usually on a slow device. The price for this convenience is limited memory size and slow calculation speed.

Computerized, Instrumented, Residential Audit (CIRA) is a user-friendly program developed for 8-bit, 64K microcomputers with the CP/M operating system that attempts to make maximum use of the advantages of microcomputers while maintaining an adequate level of sophistication in the energy calculations.[1] More precisely, CIRA is a collection of programs for building energy analysis and economic optimization of energy-saving retrofits using state-of-the-art interactive features and database management capabilities, designed to be used by relatively non-technical users.

CIRA does more than conventional energy analysis programs: from a large list of energy retrofits, CIRA can select those that will maximize total energy savings and indicate the order in which they should be installed, for any house in hundreds of different climates, using economic parameters specified by the user.

INPUTS

CIRA accepts inputs on a wide variety of house components and related features:

- Walls, windows, doors
- Roof/ceiling and floor/subfloor
- Active and passive solar features
- Heating and cooling system
- House orientation and shielding
- Occupant behavior related to energy use
- Economic assumptions.

In the context of an energy audit, some of these entries may require the use of specialized instrumentation, such as a tape measure, a solar siting meter, a combustion efficiency meter, and a blower door to pressurize the house. Thanks to dynamic defaults, however, these measurements and the attendant instruments are not indispensable -- CIRA can function as a "stand-alone" diagnostic program.

In developing CIRA, much effort was devoted to facilitating the tedious process of entering the appropriate building data. A data base manager was developed to enter, delete and edit building characteristics with a minimum of work for the user. The main features are summarized below.

Data are input by answering questions on wall areas and types, heating system specifications, passive solar features, etc. There are only two types of questions: multiple choice, to enter information such as window types and city designa-

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tion, and numeric, to enter U-values, solar storage factors and similar values.

If the CIRA novice does not understand a question such as

"Terrain Class.....?",

he or she can call for help with a simple keystroke, to which the computer responds with one or two paragraphs of explanation of the question, together with examples when appropriate.

If the user understands the question, such as "Window Glazing.....?", but does not remember the possible answers, another keystroke displays a list of options in multiple choice style, in this case

S=Single Pane
D=Double Pane
T=Triple Pane

The same list is automatically checked by CIRA before accepting an answer. For numeric questions, the answer is checked against minimum and maximum limits. The same keystroke that produced the list above will display the acceptable limits of an answer, for example

"Enter value between 0 and 20 %"

Frequently, the user may not know the answer to technical questions, such as the R-value of a wall or the solar-gain factor of a window. What is, for example, the R-value of a 850 mm x 1350 mm frame wall whose cavity is insulated with vermiculite insulation and 50 mm of exterior insulating sheathing? CIRA provides the answer, in this case 2.9 $^{\circ}Cm^2/W$, at the touch of another special key. We call the values provided by this keystroke dynamic defaults. Defaults, because they provide the most likely answer when the user hasn't a clue, and dynamic, because the program usually calculates them on the basis of the user's answers to one or more previous questions. Beyond the lay user, the professional can use dynamic defaults to avoid leafing through voluminous handbooks in search of material properties.

Often, the user may want to alter previous input, or correct mistakes, or re-use a house entered earlier, changing only details such as floor area, the city where it is located, and the window size. As soon as another simple keystroke is hit, the computer enters an editing mode, and displays the desired questions and the answers previously given on the screen, along with a request for new answers where desired. The computer even keeps track of all those questions whose defaults are affected by the changed answers and that may have been forgotten in the process: if the user changes the city from Denver to San Francisco, for example, a flag will appear next to the question "Altitude...?" as a reminder of the probable change in altitude upon leaving the mile-high city.

ENERGY CALCULATIONS

The energy calculations used in CIRA are part simulation, part correlations of the results of other programs. Although several correlations are based on hour-by-hour data, the basic time step in CIRA is one month with a distinction made between day (8 am to 8 pm) and night (8 pm to 8 am). A detailed discussion of all heating and cooling calculation algorithms can be found in the engineering section of the CIRA reference manual.[2] The main features are summarized below.

Heat Conduction

Heat conduction through walls, floor, ceiling, doors and windows is handled in conventional steady-state manner, using component U-values. For unfinished attics, low-pitch roofs or cathedral ceilings, an equivalent U-value is calculated taking into account roof conduction, ceiling conduction, and ventilation between roof and ceiling. Solar gains or infrared radiation losses through the roof/ceiling, walls and windows are handled separately and discussed later.

For the floor/subfloor combination, the user can select among full basement, crawlspace or slab-on-grade floor. For basement and crawlspaces, an equivalent U-value is determined using a method recommended by ASHRAE.[3] The equivalent U-value of slab-on-grade floors is calculated using an algorithm developed by Muncey and Spencer[4] and adapted for use in numerical calculations by Kusuda.[5]

Air Infiltration and Outside Film Coefficient

Air infiltration is calculated on a monthly basis using a method developed by Sherman and Grimsrud[6]. This method uses information on the leakage area, L_0, of the house, the type of terrain on which it is located, and the type of shielding surrounding the house. Leakage area is generally measured with a so-called "blower door", a fan-like device that creates an over- or under-pressure in the house and measures the amount of air flow through the fan necessary to reach several special levels of pressure. Alternatively, the leakage area can be estimated from information on the air tightness of windows, walls, doors, and all other building components. As usual, dynamic defaults are available to provide what the user may not know.

The air infiltration equations are summarized below.

$$Q = L_0 \sqrt{f_w^2 \, v^2 + f_s^2 \, \Delta T + Q_m^2} \qquad (1)$$

where: Q is the infiltration $[m^3/s]$;
L_0 is the leakage area $[m^2]$;
v is the wind speed $[m/s]$;
ΔT is the indoor-out temperature diff. [°C].
Q_m is the unbalanced mech. ventilation $[m^3/s]$.

The wind and stack coefficients, f_w and f_s, contain the necessary information about the distribution of leakage area in the envelope and about the effect of surrounding terrain and local shielding. These coefficients are calculated as:

$$f_w = C' \, (1 - R_L)^{1/3} \left[\frac{\alpha (H/10)^{\gamma}}{\alpha_w [H_w/10]^{\gamma_w}} \right] \qquad (2.1)$$

$$f_s = \frac{1}{3} \left[1 + \frac{R_L}{2} \right] \left[1 - \frac{X_L^2}{(2-R_L)^2} \right]^{3/2} \qquad (2.2)$$

where: $R_L = (L_C + L_F)/L_O$
$X_L = (L_C - L_F)/L_O$
L_C, L_F are ceiling and floor leakage areas $[m^2]$.

The term C´ describes local wind shielding within two house heights by trees, fences and similar obstacles. The terms α, α_w, γ, γ_w, describe the effect of terrain in a radius of several kilometers on the wind velocity distribution near the ground and, thus, on the wind-induced air infiltration. On request by the user during input, appropriate values for terrain and shielding coefficients are obtained from tables indicating their values in function of easily observable landscape features.[6] Together with wind speed, the information on terrain and shielding is also used to calculate monthly values of the outside convective-radiative heat transfer coefficient, or film coefficient.

Direct Solar Gains and IR Radiation Losses

Solar gains are computed by taking into account weather-averaged solar radiation in the city chosen by the user, the shading effects of trees, nearby buildings and overhangs, and the optical characteristics of windows and walls. The shading effects of overhangs and the angular dependence of the transmission of glazed surfaces are modeled by using correlation methods described in the Passive Solar Handbook.[7] Solar gains through walls and roof/ceiling are calculated using a method similar to the sol-air temperature method.[3]

Some of these direct solar gains are felt during daytime, some of them at night. If the indoor temperature is kept constant day and night, the partition between nighttime and daytime solar gains is not overly important, except for the swing months. If, however, the thermostat is set back at night (8 pm to 8 am) and the indoor temperature is left to float, the partition becomes very important, especially for the spring and fall months. This partition is modeled by using a solar storage factor, β, defined as the fraction of the solar gain received over 24 hours that is released during the night period. Numerical values for β, dependent on the house's thermal storage and the outside temperature, were derived from correlations of computer runs using the BLAST program.[8]

The net infrared heat losses to the sky, ΔR^d and ΔR^n, are calculated using the concept of an equivalent sky emissivity, calculated from the outdoor dew point using a correlation developed by Berdahl and Fromberg.[9]

Internal Gains and Effective Outside Temperature

Internal gains are assembled on a month-by-month basis, separately for night and day, as the sum of solar gains, S, and other gains from appliances and people, referred to as "free heat," F^d by day and F^n by night, minus the radiation loss to the sky, ΔR^d and ΔR^n. The ratio of internal gains and the overall building loss coefficient (encompassing both conduction and infiltration) has dimension of a temperature and describes an outdoor temperature increase equivalent to the internal gains. When added to the outdoor temperature, T_o, this increase leads to the definition of an "effective outdoor temperature," T_{eff}

$$T^d_{eff} = T^d_o + 2 \left[\frac{(1-\beta)S + F^d - \Delta R^d}{K + \rho c Q} \right] \qquad (3)$$

where: K is the heat conduction coefficient $[W/^oC]$;
ρcQ is the infiltration coefficient $[W/^oC]$.

This equation is for the daytime value of outdoor temperature. A similar expression defines the nighttime effective temperature, but the term $(1-\beta)$ becomes β. The effective outdoor temperature is that outdoor dry-bulb temperature that would produce the same heat transfer through the envelope by conduction and convection only, under steady-state conditions, as the superposition of conductive, convective and radiative heat transfer (short and long-wave) and internal "free heat" actually occurring.

Variable-Base Degree-Days and Degree-Nights

The monthly values of effective outdoor temperature and average indoor temperature are used to compute monthly heating and cooling degree-days, DD^d, and "degree-nights," DD^n. Degree-days are defined like conventional degree-days as the sum of hourly differences between indoor temperature and outdoor effective temperature, counting only hours between 8 am and 8 pm and positive differences. Degree-nights are similarly defined for hours between 8 pm and 8 am.

To calculate monthly heating or cooling degree-days and degree-nights without the need for extensive on-line tables, an empirical, three-coefficient correlation was developed with monthly average temperature:

$$DD = \frac{N}{2} \left\{ [T^d_a - T^d_{eff}]_+ + \mu [\lambda - | T^d_a - T^d_{eff} |]^{\nu}_+ \right\} \qquad (4)$$

where: N is the number of days per month;
μ, ν, λ are dimensionless empirical degree-day coefficients (three for each combination of heating/cooling and day/night);
$[X]_+$ is X (-X for cooling) for X>0 and zero otherwise.

If the day and night thermostat settings are equal, then $T_a^{d,n}$, the average day and night indoor temperatures are identical to the thermostat settings; if these are different, then day and night average indoor temperatures are calculated assuming an indoor temperature float with a single time constant governed by the house equivalent thermal mass determined during the input session.[2]

Sensible Heating and Cooling Loads

Monthly heating loads and sensible cooling loads are calculated for day and night periods using

$$L = 24\ (K + UA_s + \rho cQ)\ DD \qquad (5)$$

where: UA_s is the heat conduction coefficient of all passive solar components [W/^{o}C].

Where there is a night thermostat setback, the nighttime load is decreased by the amount of heat released by the equivalent thermal mass of the house and the daytime load increased by the same amount.[2]

Sensible cooling loads are calculated similarly. The calculation of latent cooling loads is described in the section on equipment efficiencies.

Solar Features

Direct gain passive solar systems are treated as windows, as described earlier. Trombe walls, water walls and greenhouses are modeled using the correlation method developed by Balcomb et al[8] that expresses the reduction of heating load by passive solar means by the "solar savings fraction", SSF, a function of the solar load ratio (solar gain through the Trombe or water wall divided by the heating load) and the load to collector ratio (heat conduction and infiltration coefficient in W/^{o}C divided by the Trombe or water wall area in m^2). Heating loads then are decreased by monthly values of (1-SSF).

Active solar systems for space and water heating are treated using the f-chart method.[10] f is the fraction of monthly space and/or water heating loads supplied by active solar systems. Thus, the space and water heating loads are reduced by monthly values of the factor (1-f).

Heating and Cooling Equipment Efficiencies

Monthly heating energy consumptions are figured separately for daytime and nighttime using the equation:

$$E = \frac{L_h}{\eta_h} \qquad (6)$$

where: L_h is the day or night heating load [Wh/month];

η_h is the overall heating efficiency.

For heating equipment the efficiency, η_h, is calculated as a function of rated efficiency, distribution losses, and part-load ratio. The part-load ratio is the fraction of total capacity of the heating equipment that is required to meet the heating load. For oil boilers, a correlation between efficiency and part-load ratio was developed, based on measured data from 16 boilers.[11,2] For heat pumps, manufacturer's data was used to develop a similar correlation, that also takes into account the dependence of the heat pump capacity on indoor-outdoor temperature difference.[12] No decrease in efficiency under part-load conditions is assumed for gas heating equipment.

For cooling equipment, a detailed heat and moisture balance is done monthly for day and night to arrive at an equilibrium indoor wet bulb temperature. Together with indoor and outdoor dry bulb temperature, it is used to determine latent and sensible cooling capacity of the equipment used. Then, the part-load ratio is obtained from the ratio of sensible cooling load and sensible cooling capacity. The rated equipment coefficient of performance, COP_r, is modified according to these part-load conditions and the indoor-outdoor dry bulb temperature difference. Finally, the cooling energy consumption is calculated as

$$E = \frac{L_s + L_m}{\eta_c} \qquad (7)$$

where: L_s is the sensible cooling load [Wh/mo];

L_m is the latent cooling load [Wh/mo];

η_c is an overall cooling efficiency.

The cooling efficiency, η_c, includes the COP and the effect of distribution losses.

Validation

Space heating and cooling predictions using this method have been shown to approximate the results from the DOE-2.1 building simulation program within $\pm$10%,[2], as shown in Fig. 1. Preliminary comparisons with measured energy consumption data from 42 houses have shown a comparable correspondence between measured and predicted yearly heating and appliance energy consumption.

Viewing the results

After the minute or so that it takes to perform the heating and cooling calculations, CIRA displays monthly values and yearly totals and means of several quantities, such as daily and nightly heating and cooling energy loads and consumptions, air infiltration, solar gains, dollar expenditures for heating and cooling, and more.

By pressing the appropriate key from a menu displayed at the top of the screen, the user may also plot any arithmetic combinations of these quantities (e.g., the sum of all space heating expenditures divided by the floor area). All can be displayed either in tabular form or graphically, depending on the user's wishes.

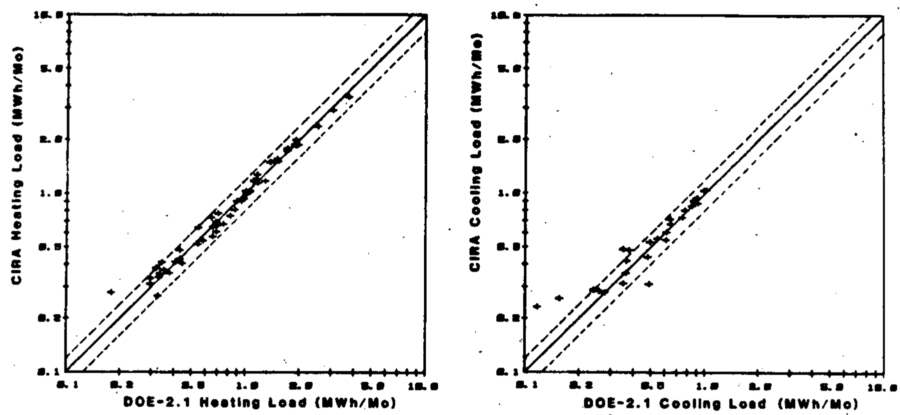

Fig. 1: Comparison of CIRA and DOE-2.1 monthly heating and cooling loads for 7 climates

ECONOMIC OPTIMIZATION

For energy auditors and energy policy makers, calculating yearly energy consumption may be of less interest than determining the most cost-effective strategy to save energy. That is, for a given budget, what is the most energy-saving combination of retrofits or, what is the highest retrofit budget for which the dollar savings still exceed the expenditures (including maintenance costs)?

Optimizing a mix of retrofits on a building may be compared to the textbook case of ranking investments by return on investment. Each retrofit, then, is viewed as an investment in energy savings and the monetary savings realized over the years to come constitute the return. However, the analogy is incomplete at best, as the returns on retrofit investments are a moving target. With each retrofit that the "investor" acquires, the returns on all remaining retrofits change, in general downward. Furthermore, for individual retrofits the parameters affecting energy are rarely monotonic functions of cost. A good example is the multitude of window shades commercially available, some cheap and others expensive, and often with little correlation to R-value or shading coefficient or any reasonable combination thereof.

It is partly because of these difficulties that a numerical approach to retrofit optimization was taken in CIRA. The strategy to find the mix of retrofits with the largest net life-cycle savings is essentially that used by a blind person to find the highest point of a hill: follow the line of steepest ascent. That is, keep re-rating retrofits and implement those with the highest savings-to-cost ratio until the available budget is used up or the remaining retrofits don't pay for themselves any more.

Energy Savings of Applicable Retrofits

After the energy consumption of the original house has been evaluated, CIRA scans a retrofit data base on disk containing close to hundred retrofit options. Costs are indicated per unit area, per unit length, etc. Those retrofits which physically cannot apply to the building are not considered -- e.g. cavity insulation for solid masonry walls, or a replacement oil burner for a gas furnace.

The retrofit database also stores instructions on how each of the building parameters (such as thermal resistance, leakage area, thermal mass, spatial distribution of thermal resistance and leakage area, furnace efficiency, and distribution losses) is altered by a retrofit. More than one parameter may be changed -- e.g. adding a storm window in winter will decrease conduction and infiltration coefficients and will decrease solar gains.

During optimization, the program translates the retrofit instructions into corresponding changes of annual energy consumption. This structure allows the addition of almost any retrofit to the database used for the optimization. It also allows for retrofits to be "removed" if displaced by more cost-effective retrofits at a later stage of the optimization.

Dollar Savings and Costs

For each retrofit, the energy saving calculated by CIRA is converted into a gross lifetime dollar saving, S, by multiplying by the price of energy and reducing to present value, using fuel escalation rates and a discount rate entered by the user.

For each retrofit, the maintenance cost, M, is given in the retrofit database as a percentage replacement after a number of years, e.g. 100% after 3 years for plastic storms. If the lifetime of a retrofit is short, more than one replacement may be needed, such as for a ten year horizon and plastic storms, that may have to be replaced after three, six, and nine years. The present value for such maintenance expenditures is figured using a projected escalation rate in maintenance costs and the discount rate.

The cost, C, of a retrofit is calculated from the unit cost (e.g. dollars per square meter of double pane windows) and the quantity of that unit in the particular application (here, the area of the window to be retrofitted).

The savings-to-cost ratio, SCR, is defined as SCR = (S-M)/C. Retrofits are ranked in decreasing order of SCR and the optimization stops when only retrofits with a SCR of less than one remain.

Economic Optimization Loop

After finding all applicable retrofits, the next step is to rate each retrofit by the SCR calculated as if taken alone. The retrofits are sorted by individual SCR, and the retrofit with the highest SCR is chosen, then removed from the list of retrofits and installed in the house. Finally, the new energy consumption of the house is re-calculated.

Now the process starts anew. Each remaining retrofit is re-rated (for the altered house) by calculating a new SCR. These retrofits are sorted, and the best one chosen and installed. The second installed retrofit naturally has a lower SCR than the first, and this trend continues as more retrofits are chosen. The loop of rating, sorting, installing, and re-calculating energy consumption continues until there are no more cost-effective retrofits. The list of retrofits is then printed out, together with relevant economic parameters. A sample output for a limited library of retrofits is shown in Fig. 2. At the top is some summary information about the house and the economic assumptions. Not indicated is the economic horizon, in this case 20 years. The fuel costs chosen represent the U.S. national averages for residences for April, 1982. The rest of the printout shows the list of retrofits ordered by decreasing SCR. The "Name and Location" column refers to components of the house, such as windows and walls, and to their user-chosen names, such as "West" windows or "North" walls. The "first year savings" include space conditioning and all other uses of energy. The "annualized maintenance" is the annualized present value of maintenance cost. Fig. 3 is a graphic representation of the net life-cycle savings (savings minus maintenance) versus total expenditure for all retrofits.

Partial Derivatives

In principle, the procedure outlined above requires the recalculation of annual energy consumption each time a single retrofit is rated, which could require several thousand calculations of annual energy use for a full optimization. To speed up the process, CIRA rates the retrofits by an estimate of the savings based on partial derivatives of annual energy consumption with respect to building load coefficient (conduction and infiltration), internal gains (solar, IR losses, and free heat), equipment efficiency (heating and cooling) and distribution losses. Actual annual energy consumptions and new values for the partial derivatives are recalculated only each time a "winning" retrofit has been identified and installed.

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'ASHRAE-TEST' house in WASH-DC at 14 feet.

Spent: $4205.50 Limit: $10000.00

Real DISCOUNT rate (%): 3.00 Real MAINT ESC rate (%): 0.00

	Heating	Cooling	Water	Electric
Type of EQUIPMENT	Gas Furnace	Central AC	Gas	-na-
Fuel PRICES ($/MBtu)	5.30	20.50	5.30	20.50
Real ESCALATION rate (%)	3.00	3.00	3.00	3.00

	Retrofit DESCRIPTION	NAME & LOCATION	Initial COST	1st Year SAVINGS	Annualized MAINTENANCE	Net SAVGS to COST R
1	Set water htr. thermostat to 120 F	Smith APPLIANC	$0.50	$34.41	$0.09	999.9
2	AUTO. 5 F Htg. & Clg. NIGHT SETBACK	ASHRAE-TEST GENERAL	$120.00	$174.68	$4.47	28.6
3	Install 6 inches of loose fiberglass	Insulated ROOF/CEI	$695.00	$648.24	$7.50	18.5
4	Install R-6 water htr. blanket	Smith APPLIANC	$30.00	$13.93	$2.62	8.0
5	DOUBLE glaze	North WINDOWS	$168.00	$34.14	$0.00	4.1
6	DOUBLE glaze	East WINDOWS	$168.00	$34.14	$0.00	4.1
7	DOUBLE glaze	West WINDOWS	$168.00	$34.14	$0.00	4.1
8	*TRIPLE glaze	North WINDOWS	$72.00	$15.41	$0.00	3.7
9	*TRIPLE glaze	East WINDOWS	$72.00	$15.41	$0.00	3.7
10	*TRIPLE glaze	West WINDOWS	$72.00	$15.41	$0.00	3.7
11	DOUBLE glaze	South WINDOWS	$168.00	$29.14	$0.00	3.5
12	Buy new EFFICIENT REFRIGERATOR	Smith APPLIANC	$700.00	$106.92	$0.00	3.1
13	*TRIPLE glaze	South WINDOWS	$72.00	$8.85	$0.00	2.4
14	INSULATE with 3.5" blown-in cellulose	North WALLS	$440.00	$45.76	$0.00	2.1
15	INSULATE with 3.5" blown-in cellulose	South WALLS	$440.00	$38.64	$0.00	1.8
16	INSULATE with 3.5" blown-in cellulose	West WALLS	$260.00	$22.02	$0.00	1.7
17	INSULATE with 3.5" blown-in cellulose	East WALLS	$260.00	$22.02	$0.00	1.7
18	*Install 9 inches of loose fiberglass	Insulated ROOF/CEI	$300.00	$21.73	$3.24	1.2

* - This replaces a previous retrofit on this component. Savings and costs are in addition to those of the replaced retrofit.

CIRA---------------------------------------COMPUTERIZED INSTRUMENTED RESIDENTIAL AUDIT---------------------------------------CIRA

Fig. 2: Sample retrofit optimization output. There are more retrofits in the database than selected above.

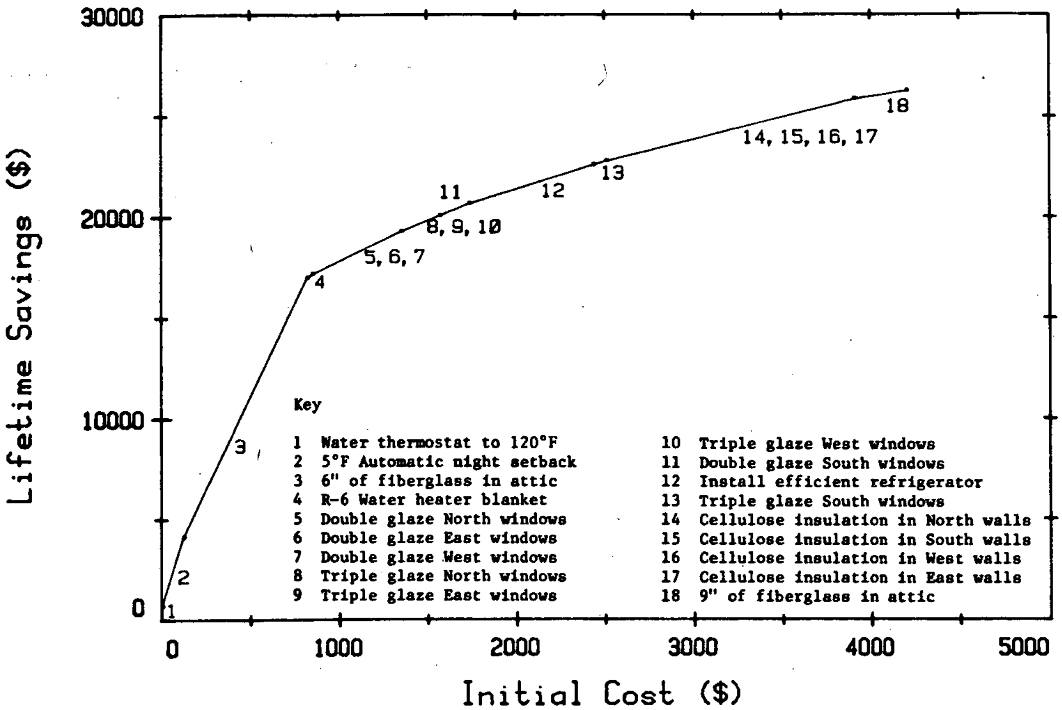

Fig. 3: Cumulative lifetime savings (after maintenance) versus cumulative retrofit installation cost.

CONCLUSION

The first version of CIRA was released in April 1982. Modifications are under way to make the program usable for small commercial and multifamily buildings. In parallel, an extensive validation program of the energy calculations using data from actual buildings is planned.

Currently, CIRA can be run on any microcomputer with a CP/M operating system,[13] 64K of random access memory (of which at least 56K user-accessible), two 8" single density disk drives or equivalent (2x200K or 450K bytes total), an 80 column, cursor-addressable video terminal, a 132 column printer. At the time of this writing (November 1982), a complete system with these specifications can be purchased for around $4,000.

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