SUNHOUSE:
A MICROCOMPUTER PROGRAM TO ESTIMATE CONSERVATION AND SOLAR BENEFITS

Danny S. Parker

Precision Environments, P.O. Box 243, Helena, Montana 59624

Abstract

SUNHOUSE is a microcomputer program that estimates space heating, cooling, hot water and appliance energy use for residences on a monthly basis. Improved empirical relationships are incorporated that determine the utilizability of solar and internal heat gains, heat losses to the ground and radiative heat loss to the sky. Data on average temperatures, solar insolation, sky clearness, relative humidity and windspeed are used to make the estimates. The program uses the Barakat-Sander gain load ratio method (1) for determining the utilizability of solar heat from direct gain windows. Unlike the solar load ratio (SLR) method (2), this procedure has the advantage of. being applicable to low mass buildings which dominate the housing market. A series of correlations based on the method outlined by Shipp (3) is used to more accurately estimate losses from the earth contact portion of the structure. Extensive economic options for analysis and optimization of conservation and solar measures are available. SUNHOUSE gives good agreement with other building energy use microcomputer programs, such as HOTCAN (4), SUNDAY (5) and CIRA (6).

Description

SUNHOUSE is written for IBM PC computers with at least 256K memory. The program has been composed in C-language for maximum speed and transportability. A more simple version is available for the Apple II microcomputer written in basic. The execution time for all annual calculations is approximately 4 minutes for the Apple, one minute for the IBM C-version and five seconds for the C-version with an 8087 math chip. Calculation of economic optimums for solar and conservation levels take about twice the time noted above.

The program is designed to make residential energy analysis as easy as possible. The C-language version features a state of the art user interface with bump bar and pop-up utility menus, contact sensitive help screens and dynamic defaults. User friendly features minimize use of the documentation, and error and range checking routines prevent user mistakes.

Design Philosophy

SUNHOUSE is designed with two goals in mind: 1) to be fast, accurate and easy to use and 2) to give users a proper conceptual understanding of how houses use energy. There is a developing trend of reliance on hourly simulation as the only means to estimate residential energy use. Although simulations have a large value for the research scientist, their power is usually poorly matched to the needs of the architect or builder. Furthermore, use of simulation to the exclusion of other methods may obscure fundamental relationships that can be more meaningfully solved through a simplified approach. Correlation methods have an undeserved bad reputation because of their inflexibility. However, better and more useful calculation methods now exist that retain the flexibility necessary to solve most commonly encountered problems. This is more easily done when the correlations embody the theoretical attributes of the problem they model.

By now, most calculation methods can give the proper answer to the energy use question. The most useful answer, however, is one that conveys insight into the nature of how houses respond to their thermal environment. For the design of SUNHOUSE, commonly used techniques such as solar fractions and balance temperatures were discarded as correct but conceptually misleading. Contrary to what the SLR method leads one to believe, the thermal load of the south glazing is extremely important to building performance. Recent findings indicate that the use of balance temperatures for estimating economic benefits of conservation understates the potential available from these measures (7). SUNHOUSE estimates the utilization of internal and solar heat directly and subtracts the useful portion from the building thermal load. Such information is shown in the monthly heat balances so that the analyst can see the magnitude of each effect.

House Heat Balance

In its most basic form, the program estimates monthly space heating loads according to the following heat balance equation:

$$Lh = Lcnd + Linf + Lgrd + Lsky - \eta Qint - \eta Qsol$$

Where:

Lh = Monthly auxiliary space heating (Btus)
Lcnd = heat losses due to conductance (Btu)
Linf = heat losses from infiltration of outside air (Btu)
Lgrd = heat losses from the below grade building (Btu)
Lsky = radiative heat loss to the sky (Btu)
Qint = useable heat gains from lights, appliances and people (Btu)
Qsol = useable heat gains due to solar heat gain through windows and exterior building surfaces (Btu)

Similarly, the cooling loads governing air conditioning consumption are summarized as:

$$Lc = Lcnd + Linf + Qint + Qsol - Qsky - Vent + Llat$$

Where:

Lc = monthly cooling load (Btu)
Lcnd = load due to conductance (Btu)
Linf = load due to air infiltration (Btu)
Llat = load from latent heat in water vapor (Btu)
Qsky = radiative heat loss to the sky (Btu)
Qint = load due to internal heat gains (Btu)
Qsol = load due to solar heat gains (Btu)
Vent = load abated by ventilation (Btu)

Conductance and Infiltration Losses

The daily heat loss or gain through the above grade portion of the house due to heat conductance is calculated based on conventional ASHRAE techniques (8). The thermal resistance of each component includes all portions of the above grade building comprising the roof, walls, windows and doors.

The effective building air change rate depends on many dynamic factors such as the tightness of the construction, the difference between indoor and outdoor temperatures, wind speeds, heating systems, occupant effects and the presence of induced ventilation systems. SUNHOUSE has two modes of estimating the air change rate. One is the traditional constant air change rate estimate. The other available method is the LBL Sherman-Grimsrud infiltration model (9). This requires information on the equivalent leakage area of the building which can be obtained from a blower door test. Where this is not available, default estimates are available. Data on temperature difference and wind create site specific factors that influence the dynamic infiltraton rate. Building height, terrain and shielding classes are entered from tabular data to determine the wind and stack terms.

The wind term is arbitrarily reduced by 50% based on the findings of Hamilton et. al. (10). The LBL method assumes that directional wind effects are unimportant which may be responsible for overpredicted air change rates against tracer gas results. The other possibility is that the shielding parameter for the method underestimates the reduction in wind speed in built-up areas. The effect of this adjustment is to reduce predicted infiltration rates by 20% on the average.

Balanced ventilation air flows simply add to the overall infiltration rate. Where there is induced ventilation such as with an air to air heat exchanger, the effective air change rate is increased to reflect the inefficiency of the heat recovery unit.

Below Grade Heat Loss

Losses below grade are estimated using correlations for 'UA' equivalents based on perimeter length from Shipp (3). These are taken from 'F-factors' from an interpretation of Shipp's work (11). The method allows adjustment of soil conductivity as well as the input of mixed floor types. This arrangement maintains maximum flexibility for determination of design heating loads, estimation of the building time constant and comparison of the program results to other codes. Unheated basements and crawlspaces are modeled as conductances in series. The three basic floor configurations considered are slab on grade, crawlspaces and basements. Shipp's correlations give agreement with the estimates of Mitalas (12) within 9% on an annual basis over a range of climate types.

Internal Heat Gains

Internal heat gain due to lights, appliances and people is a significant part of the heat balance of a typical residential building. Most of appliance electricity use is converted into heat within the structure. Sensible heat from occupants is estimated to average 230 Btus per occupant hour. Internal heat gains from hot water use depend on location of the hot water tank. Only a small fraction of hot water energy is released into the building interior and most of this is in the form of latent heat gains. However, if the tank is located on the interior of the building, then the standby heat losses contribute significantly to internal gains in this zone. SUNHOUSE has a dynamic input procedure that recommends an internal heat gain rate based on previously entered values for electricity use, occupancy and hot water heater location.

The usefulness of internal gains in offsetting auxiliary heating is based on the gain-load ratio method that is also used for determination of solar utilizability. This method is described in detail below. Generally, the utilizability of internal gains are greater than for solar heat since the gains are more constant against the larger building thermal load.

Monthly Heat Load

The heat load is determined by finding the average interior temperature of the building and calculating the effective heating degree days for the month. The average interior temperature depends on the thermostat setback and the building time constant. This effect is estimated according to the procedure described for the CIRA program (6) where the night-time temperatures are modeled as under either partial or full float conditions.

Once average temperature conditions are determined, variable based heating degree days are estimated using an approximation recommended by Erbs, Beckman and Klein (13). The monthly heat load is then the monthly product of heating degree days, the loss coefficient for the above and below grade portion of the structure and radiative heat losses to the sky. The program summary for an example building heat loss coefficient is shown in Figure 1. Heat loss to the sky is estimated based on a correlation of equivalent sky emissivity from Berdahl and Fromberg (14), and the UA value for sky radiation losses. This value is proportional to the loss coefficient of the roof and one-third that of walls.

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SUNHOUSE  Energy  Analysis  Program     : 7 Jul 1985 : Run No. 3
Gerry and Do Foland- Insulate All Walls : Task:  83 Argyle Street
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          Building Characteristic and Heat Loss Summary

Building        Area         R-Value     Heatloss Coeff.  Percent of
Component      (sqft)      (btu/hr-f)      (btu/hr-f)       Total
------------  --------     ----------   --------------   ----------
Roof           1479.0         28.0            52.8            4.3
Walls          3707.0         13.0           285.2           23.0
Floors         1479.0         10.0           148.1           11.9
South Glass     150.0          2.0            75.0            6.0
E/W Glass       207.0          2.0           103.5            8.3
North Glass     135.0          2.0            67.5            5.4
Doors            40.0          4.0            10.0            0.8
Infiltration  39924.0 (cuft)   0.7 ac/hr     498.3           40.2
----------------------------------------------------------------------
Building Total Heat Loss Coefficient is     1240.4  (btu/hr-f)
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Fig. 1. Building Heat Loss Summary

Solar Gains through Windows

Solar gains through windows and sunspaces are determined using McFarland's correlations presented in Volume III of the Passive Solar Design Handbook (15). The solar radiation data for each site is given in Btu per square foot per day on a horizontal axis. The incident and transmitted total solar radiation through vertical glazings facing the cardinal directions is given by a series of polynomial regressions based on declination and the monthly clearness index. The solar energy transmitted monthly is further modified by any shading of the south, east and west exposures and the interior absorptance. Regressions are available for both direct gain and sunspace types. Mass storage walls can be approximated by modifying glazing U-values to account for the conductance of the collector wall and adding the additional thermal storage to the overall building heat capacity.

Solar Energy Transmitted through Opaque Building Surfaces

The solar energy transmitted through building walls and roof is modeled according to a modified sol-air procedure (16). The transmitted heat energy is proportional to the incident amounts on surfaces, their absorptance, the structure thermal resistance and that of the convective-radiative air film coefficient. Although the mass less wall assumed is incorrect in terms of transient effects, it will give good results on a monthly time step since heat storage effects over this period are negligible. Users can set values for wall and roof absorptance which allow estimates for effects of color or approximation of the presence of radiant heat barriers (17). The total solar gains absorbed by the building through both transmittive and opaque surfaces are summed for the total monthly solar input to the building.

Utilizability of Solar Gains

A portion of the total internal and solar gains received by the building are useful for offsetting auxilary heating needs. However, some of these gains cause the building interior temperature to exceed the heating setpoint and are not beneficial. These un-utilizable solar and internal gains contribute instead to the building cooling load. The situation is made more complex because of the large interaction between the thermal load of the building, the absorbed solar gains and the effective heat capacity of the structure as modifed by allowed temperature swings.

SUNHOUSE uses the gain-load ratio (GLR) method of determining the usefulness *of solar heat* (1). The fraction of the total solar gains that are useful can be expressed as a function of two dimensionless parameters, the "gain-load io" and the "mass-gain ratio":

$$GLR = Sol / L$$

Where:

GLR = monthly gain load ratio
Sol = average hourly total solar gains (Btu)
L = average hourly heat load for the building (Btu)

This ratio represents the outside boundary of the possible solar contribution to reduction of auxilary energy use. A building with infinite thermal mass would have a gross solar fraction equal to GLR. Since real buidings will have a finite thermal capacitance, a correction must be introduced to account for this effect. This is included as the ratio of the building effective heat capacity to the hourly average solar input:

$$MGR = C / Sol$$

Where:

MGR = monthly mass to gain ratio
C = building thermal capacitance (ı-F.)
Sol = average hourly solar gains (Btu)

Generally, the higher the ratio, the more useful solar or internal gains will be since the building has adequate heat capacity to store them for later use. The useful fraction of total monthly solar input is a function of both ratios:

$$Usol = \frac{a + b\,GLR}{1 + c\,GLR + d\,GLR^2}$$

Where:

Usol = the useful fraction of monthly solar heat gains
a,b,c,d = regression coefficients for four mass-gain ratio levels.

The 'Usol' values are solved for each of the mass-gain ratios and the actual monthly values are obtained through linear interpolation between the appropriate levels. The parameters for the curve fit equations are based on allowed temperature rises of five or ten degrees. This was deemed appropriate since interior temperature swings greater than this amount will be attributable to cooling loads and such temperature ranges are typical of the average difference between heating and cooling setpoints.

Readers will note a strong similarity of this calculation to the un-utilizability method of Monsen (18). Use of the two procedures on a similar case has shown virtually identical results. Estimation of thermal capacitance is fundamental to both methods. The simple recommendations made with the HOTCAN documentation or in Monsen's paper probably overestimate the effective heat storage of low mass buildings. Frequency domain analysis is a more appropriate means of estimating actual thermal capacity. Default values in SUNHOUSE are based on results of estimating building heat storage using Balcomb's methodology (19) which is based on a frequency domain approach.

Cooling Load Determination

Cooling loads consist of four components, conductive loads, excess internal and solar gains, and loads from the latent heat of water vaporization. Excess internal and solar gains are defined as those that are not useful in offsetting heating loads. This also includes solar loads from conductance through the roof and walls. No heat gain is assessed from floors since they are often adiabatic or in the case of basements, provide cooling during the summer months. The effective cooling degree days are computed using the Erbs, Beckman and Klein approximation (13).

Latent cooling loads are important since they tend to be quite large in the southeastern U.S. and cannot be abated by ventilation. It is estimated based on the allowable interior humidity, latent internal heat gains, the ambient relative humidity and infiltration rates.

Ventilation and Radiative Cooling

Opening windows can significantly reduce sensible cooling requirements provided the exterior temperature is below the setpoint, local winds are sufficient and relative humidity levels are acceptable. The model uses an adaptation of the algorithm proposed by Chandra for design purposes (20). Simplifying assumptions are made with regard to the distribution of inlet and outlet areas and directional wind effects. Site specific windspeed is modified from weather data by the reduced wind parameter from the ventilation model. Ventilation cannot reduce latent heat gains, although it can have a very significant effect in reducing cooling loads during the shoulder months.

Radiative cooling during clear summer nights can help to reduce cooling loads. Since sky emissivity is proportional to vapor pressure,. this effect will be most beneficial in areas with low summertime humidity.

Space Conditioning Energy Use

Once the monthly heating and cooling loads have been established, the total fuel consumption for each use is computed. Values are entered that represent the seasonal fuel utilization efficiency for conventional heating systems or the coefficient of performance for heat pumps at 47 degrees. The EER rating for air conditioners is entered for cooling equipment. The performance of heat pumps and air conditioners vary depending on the partial load and ambient temperature conditions. Their operating characteristics are taken from Parken. Beausoliel and Kelly (21). Space heating and cooling energy use is summarized in terms of thermal loads, fuel consumption and cost.

Hot Water Energy Use

Hot water heating loads are based on the temperature rise of the water, the amount of hot water consumed and the thermal characteristics of the hot water heating system. The average temperature of mains water typically varies around the annual mean temperature. The variation is based on an estimate of the undisturbed ground temperature (22) at at depth of six feet. This function was shown to provide a good fit to collected monthly mains water temperature data. Average consumption of hot water is nearly linear with household size. The default value is 18.4 gallons per person per day. Standby losses are based on the hot water system loss coefficient and the ambient temperature where the system is located. Often the tank will be located in a non-conditioned basement or crawlspace.

Solar Hot Water Heating

The program allows F-Chart analysis of solar domestic hot water heating. For active systems, two dimensionless parameters are calculated -- 'X' and 'Y' that when correlated yield 'F', the monthly solar hot water heating fraction (23). The incident solar radiation is computed through use of McFarland's incident to horizontal radiation approximations for 30, 60 and 90 degree tilts and performing linear interpolation between these amounts. A correction factor is estimated for 'X' because the original method was designed to estimate space heating contributions.

For passive solar hot water systems, the program uses an algorithm proposed by Robison (24). Values are entered from results of the ASHRAE 95-81 system testing standard. These include 'Qnet', the daily solar energy produced by the system, 'L' the exponential heat loss coefficient and the ratio of the number of installed units to the number used in the test.

Both performance and economic analysis are provided for any of the installed systems. This includes solar fraction, and annual and lifecycle savings.

Appliance Energy Use

The energy use from appliances can be based on the average monthly summertime electricity consumption if no electric water heating or air conditioning is used. Otherwise, the average can be estimated based on a help screen listing of typical electricity consumption by appliance.

Once the summer base load is established, the use in other months is varied based on results from Burwell et.al. (25). This study found that electricity use for appliances and lights varied seasonally so that wintertime use was about 10% greater than that in summer. This is due to the increased use of interior lighting from shorter daylight hours and greater occupancy rates.

Predicted Energy Budget

Predicted space heating, cooling, hot water and appliance loads are used to estimate monthly total energy consumption and costs. This data is summarized for each end use in tablular form. An example of the program output for this data is shown in Figure 2. It is important to note that the annual costs are apt to be considerably more accurate than the intermediate monthly calculations.

Economic Parameters

Ultimately, the significance of conservation and solar improvements in design must be weighed against their cost. There are numerious factors that must be taken into account in a thorough economic analysis. SUNHOUSE uses Brandemuehl and Beckman's P1, P2 method (26). P1 is a differential present worth factor that takes into account the time related cost of money and the future changes in conventional fuel prices. It converts life-cycle fuel savings into an equivilant amount in present worth dollars. The factor, P2, relates all costs that are proportional to the intial investment. It is the ratio of life cycle costs incurred from the investment compared to the initial project cost.

Together these two parameters allow a comprehensive economic analysis of any

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SUNHOUSE  Energy  Analysis  Program      : 7 Jul 1985 : Run No. 2
Gerry and Do Foland- Current House       : Task:  83 Argyle Street
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                    Annual Energy Use and Budget Summary
                    ------------------------------------
             Heating    Cooling  Hot Water   Appliances    Total Cost
Month        Gal. Oil   KWH Elec  Gal. Oil    KWH Elec      Dollars
------       --------   -------  ---------   ----------    ---------
 Jan          438.5      0.0       40.2        616.0        580.70
 Feb          362.3      0.0       37.3        599.2        491.42
   r          286.2      0.0       41.5        593.6        411.21
   r          135.1      0.0       39.1        582.4        239.96
  .y           39.8      0.0       38.5        576.8        133.05
 Jun           14.5      0.0       35.0        565.6        100.15
 Jul            0.8      0.0       34.1        560.0         83.57
 Aug            3.0      0.0       32.9        560.0         84.60
 Sep           14.4      0.0       31.8        571.2         96.93
 Oct           99.8      0.0       33.9        582.4        195.00
 Nov          234.3      0.0       34.7        593.6        346.05
 Dec          400.7      0.0       38.2        604.8        535.54
------       --------   -------  ---------   ----------    ---------
Total Use     2029.4     0.0      437.1       7005.6
Ann. Cost ($)2252.58     0.00     485.16       560.45       3298.19

Annual Cooling Load  :    5.9 Million btus  (experienced as overheating)

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Fig. 2. Annual Energy Cost Summary

energy saving option. The life cycle cost of a project is product of P2 times the intial project costs; the life cycle savings is the product of P1 times the first year fuel savings.

Optimization of Conservation

The economic optimum levels of insulation for houses can be estimated based on the fact that optimal R-values increase at the square root of cumulative temperature differentials. Given a cost of heat delivered to load, the cost of a Btu/hr F. over the investment life can be estimated as:

$$CE = HDD * 24hrs * HC * FC *PV$$

Where:

HDD = heating degree days at the temperature setpoint
HC = heat content of fuel (Btu)
FC = fuel cost ($/unit)
P1= present value of future fuel costs.

The optimal R-value for a component can be estimated as:

$$Ro = \sqrt{CE/ [(C1 - C2) * P2]}$$

Where:

Ro = optimal R-value
P2 = present value factor for the investment
C1 = cost per square foot of a higher R-level
C2 = cost per square foot of a lower R-level

Unfortunately, complex interactions are involved for solar effects on exterior surfaces, sky radiation heat loss, utilizability of solar and internal gains thermostat effects. Given the difficulty of an analytic solution, a surrogate heating degree hour estimate is obtained by taking the partial derivatives of total heating energy consumption with respect to a 10% decrease in the building heat loss coefficient and associated U-values. This can also be done with respect to the cooling calculations so that optimal conservation levels can be accurately determined for heating, cooling or a combination of both.

Solar Area Optimization

The solar optimization routine allows the south facing glazing area to be optimized either in the specified building or the optimally insulated one as determined above. In the calculation, any existing south facing glass is first eliminated, with the former glass area being replaced with a wall at the specified R-value. The amount of energy used in this configuration (opaque wall facing south) is estimated and set as a reference value.

The area of glass is then increased by 20 square feet for each iteration. With each pass, the heat loss coefficient of the building increases as more low R-glass is added and the cost of the project increases at the difference between the cost of the glass and that of the replaced wall. The reduction in energy use from the reference amount is used to estimate fuel savings.

Figure 3 shows the reduction in energy use for two 1,350 square foot houses in Topeka, Kansas as the double glazed south glass area is increased. The "low mass" house is a typical frame construction type with R-38 roof, R-19 walls and R-11 under a crawlspace floor. The "high mass" house is identical except that its floor is a 4" insulated slab on grade. Note that the "energy optimum" for the houses is quite different in terms of south glass. No more than 80 square feet is warranted for the low mass house while nearly three times this amount results in the lowest energy budget for the high mass version.

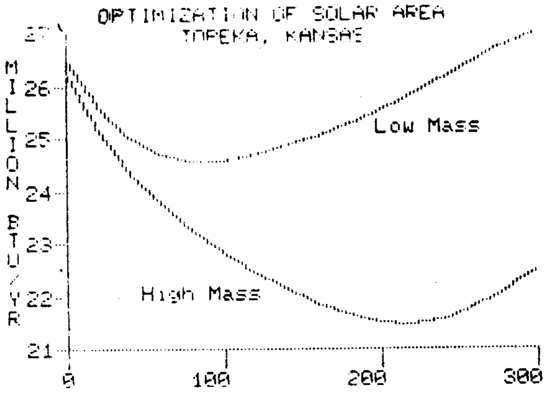


Fig. 3. Solar Area Optimization

When south glazing is optimized based on economic criteria, the aperature area is increased until the lifecycle solar savings are maximized. Assuming a $10 differential cost per square foot over the replaced wall, the curve in Figure 4 depicts the economic analysis for the case shown in Figure 3. In both cases, the optimum levels are less than the minimum energy budget since the performance curves are quite flat around the optimum. Only fifty square feet of glass is warranted in the low mass house while 120 square feet is justified for the high mass structure.

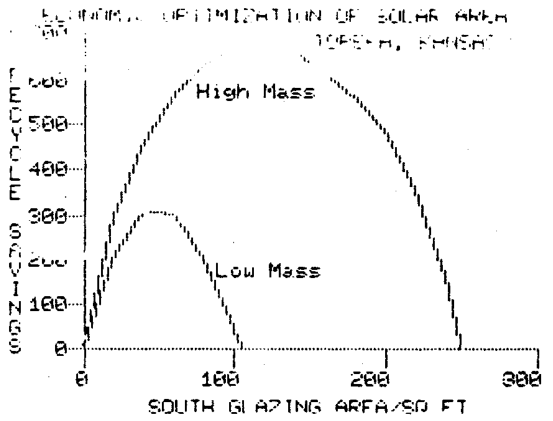


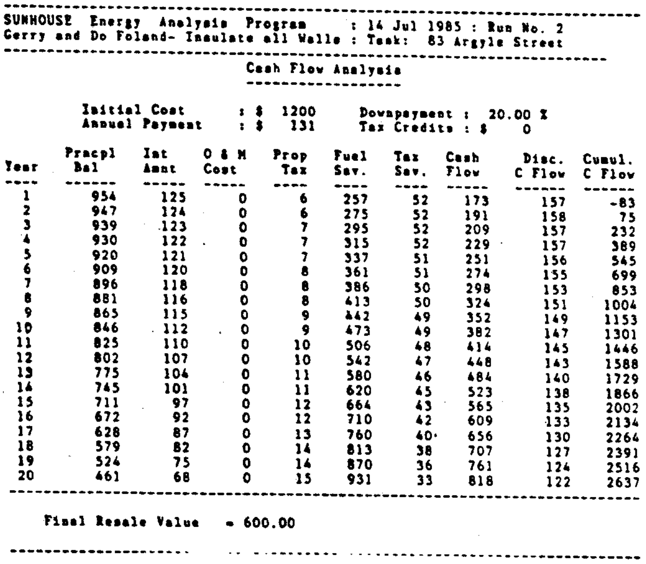
Fig. 4. Solar Area Economic Optimization

Cash Flow Analysis

Most economic analysis is rendered in net present value terms. While this method is analytically correct, it is also quite difficult for many people to understand. Experience has shown that lay persons have an intuitive grasp of a cash flow presentation. SUNHOUSE has a powerful cash flow routine which allows incorporation of all relevant economic parameters in it's year by year summary. An example of this analysis for is shown in Figure 5 for a building being retrofitted with wall insulation at a cost of $1,200. Cumulative cash flows are discounted in the last column so that lifecycle savings are estimated as well. Parametric comparison of one analysis to another can be used as a direct output to the cash flow routine. Thus, it is possible to analyze any parameter change in the model in terms of its cost effectiveness.

Validation

The program has been compared against results of the SUNDAY program (4) and has shown good agreement with that model for heating estimates. A systematic bias of +6% was observed across seven sites in the western United States. SUNDAY is a daily analysis model that is being used as the basis for development of Model Conservation Standards for the Pacific Northwest. Generally, SUNHOUSE predicts higher energy consumption than does SUNDAY. Most of this is due to inclusion of the sky radiation heat loss algorithm. Agreement with the HOTCAN program is excellent. A systematic error of only 3% was found against several Canadian sites. A comparison of the GLR method used in the program against the more widely known un-utilizability method (18) gave nearly identical results. Current validation efforts are focusing on validaton of the cooling model and comparison with CIRA (6). Initial results have been encouraging. As with most microcomputer energy analysis programs, the estimates of energy use can be generally bounded by a 10% variation against more detailed simulation.



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---------------------------------------------------------------------------
SUNHOUSE  Energy  Analysis  Program    : 14 Jul 1985 : Run No. 2
Gerry and Do Foland- Insulate all Walls : Task:  83 Argyle Street
-----------------------------------------------------------------------
                   Cash Flow Analysis
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        Initial Cost       : $  1200     Downpayment :  20.00 %
        Annual Payment     : $   131     Tax Credits : $    0

      Pracpl    Int     O & M    Prop    Fuel    Tax    Cash       Disc.   Cumul.
Year   Bal      Amnt    Cost      Tax    Sav.    Sav.   Flow      C Flow   C Flow
----  ------   -----   -----     ----    ----    ----   -----     ------   ------
  1      954     125      0        6     257      52     173        157      -83
  2      947     124      0        6     275      52     191        158       75
  3      939     123      0        7     295      52     209        157      232
  4      930     122      0        7     315      52     229        157      389
  5      920     121      0        7     337      51     251        156      545
  6      909     120      0        8     361      51     274        155      699
  7      896     118      0        8     386      50     298        153      853
  8      881     116      0        8     413      50     324        151     1004
  9      865     115      0        9     442      49     352        149     1153
 10      846     112      0        9     473      49     382        147     1301
 11      825     110      0       10     506      48     414        145     1446
 12      802     107      0       10     542      47     448        143     1588
 13      775     104      0       11     580      46     484        140     1729
 14      745     101      0       11     620      45     523        138     1866
 15      711      97      0       12     664      43     565        135     2002
 16      672      92      0       12     710      42     609        133     2134
 17      628      87      0       13     760      40     656        130     2264
 18      579      82      0       14     813      38     707        127     2391
 19      524      75      0       14     870      36     761        124     2516
 20      461      68      0       15     931      33     818        122     2637
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   Final Resale Value    = 600.00

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Fig. 5. Cash Flow Analysis

Conclusions

SUNHOUSE is an easy to use and accurate residential energy use program. Estimates are made of space heating, cooling, hot water and appliance energy use. A variety of economic measures are available including optimization of conservation and solar levels.

The program is written in C-language and is formatted to run on IBM PC computers. Runtime for an annual calculation is approximately one minute and only five seconds with an 8087 math chip. A more simple basic version is available for the Apple II.

The advanced user interface and powerful technical capabilities should make SUNHOUSE a very useful tool for a diverse group of users such as engineers, consultants, designers, architects and builders.

Future Work

SUNHOUSE is an evolutionary program. Residential energy analysis methods have been steadily improving over the three years since development began. Period updates are planned for future provements. Version 2.0 will feature an vanced below grade heat loss algorithm based on the work of Akridge and Poulos (27) and Labs (28). An option-by-option economic optimization algorithm similar to that of CIRA will be included. Other work is focusing on multi-zone capabilities including an explicit sunspace model. Release of version 2.0 is expected in the late fall of 1985.

Acknowledgements

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References

1. Barakat, S.A. and Sander, D.M., 1982. Utilization of Solar Gain Through Windows r Heating Houses, Building Research Note #184, National Research Council of Canada, Ottawa, Ontario.

2. Balcomb et. al., 1980. Passive Solar Design Handbook , Vol II, DOE/CS-0127, Los Alamos, NM.

3. Shipp, P.H., 1983. "Basement, Crawlspace and Slab on Grade Thermal Performance," ASHRAE Special Pub. #38, ASHRAE/DOE Conference - Thermal Performance of Exterior Envelopes of Buildings, Las Vegas, NV.

4. Lux, M.E.. and Dumont, R.S., 1984. "HOTCAN 3: Housing Energy Program," Proceedings of the the 9th Passive Solar Energy Conference, Columbus, OH.

5. Palmiter, L. and Straub, D., 1982. SUNDAY, Ecotope, Seattle, WA.

6. Sonderegger, R.C. and Dixon, J.D., 1983. CIRA - A Microcomputer BAsed Energy Analysis and Auditing Tool for Residential Applications, Lawrence Berkeley Laboratory, LBL-15270, Berkeley, CA.

7. Lunde, P.J., 1984. "A New Look at Optimization," Solar Age , December, 34.

8. ASHRAE, 1981. Handbook of Fundamentals, Atlanta, GA.

9. Sherman, M.H. and Grimsrud, D.T., 1981. Measurement of Infiltration Using Fan Depressurization and Weather Data, Lawrence Berkeley Laboratory, LBL-10852, Berkeley, CA.

10. Hamilton, B. et al., 1983." Measurement-Based Calculation of Infiltration in Passive Solar Performance Evaluation," Proceedings of the 8th National Passive Solar Conference, Santa Fe, NM.

11. Parker, D.S., 1985. "A Simplified Method for the Determination of Below Grade Heat Loss," Proceedings of the 1985 Intersol Conference, Montreal, QBC.

12. Mitalas, G.P., 1982. Basement Heat Loss Studies at DBR/NRC, Paper #1045, National Research Council of Canada, Ottawa, ONT.

13. Erbs, Beckman and Klein, 1983. "Estimation of Degree Days and Ambient Temperature Bin Data from Monthly Average Temperatures," ASHRAE Journal, June, 1983.

14. Berdahl, P. and Fromberg, R., 1982. "The Thermal Radiance of Clear Skies," Solar Energy, Vol.29, No.4.

15. McFarland, R., 1982. "Solar Radiation Approximations," in Passive Solar Handbook, Volume III, Los Alamos National Laboratory, Los Alamos, NM.

16. Costello, F.A., Kusuda, T. and Aso, S., 1982. T-59 Program for Calculating the Annual Energy Requirements for Residential Heating and Cooling, DOE/NBB-0011, Washington D.C.

17. Viera, R., Chandra, S. and Fairey, P., 1984. "Residential Cooling Loads in Hot, Humid Climates," Proceedings of the 9th Passive Solar Energy Conference, Columbus, OH.

18. Monsen et. al., 1981. "Prediction of Direct Gain Solar Heating System Performance," Solar Energy, Vol.27, No.2.

19. Balcomb, J.D., 1983. Heat Storage and Distribution Inside Passive Solar Buildings, LA-9694-MS, Los Alamos, NM.

20. Chandra, 1983. "A Design Procedure to Size Windows for Naturally Ventilated Rooms," in Proceedings of the 9th National Passive Solar Energy Conference,

Florida Solar Energy Center, Columbus, OH.

21. Parken, W.H., Beausoleil, R.W. and Kelly, G.E., 1977. "Factors Affecting the Performance of a Residential Air to Air Heat Pump," ASHRAE Transactions, 1977.

22. Kusuda, T. and Achenbach, P.R., 1965. "Earth Temperatures and Thermal Diffusivity at Selected Stations in the United States," Report 9493, National Bureau of Standards, Washington D.C.

23. Beckman, W.A., et. al., 1977. Solar Heating Design by the F-Chart Method, John Wiley and Sons, NY.

24. Robinson, D., 1984. "Comparing Passive Water Heaters," Solar Age, February, 1984.

25. Burwell, et. al, 1982. Electric Home Heating: Substitution for Oil and Gas, Institute for Energy Analysis, Oak Ridge National Laboratory, Oak Ridge, TN.

26. Brandemuehl, M.J. and Beckman, W.A., 1979. "Economic Evaluation and Optimization of Solar Heating Systems," Solar Energy, Vol 23, No.1.

27. Akridge, J.M. and Poulos, J.J., 1982. A Simple Method for Calculating Thermal Losses from Underground Walls, Georgia Institute of Technology, Atlanta, GA.

28. Labs, K., 1984. "Experiences and Expectations of Earth Coupled Buildings Research," Proceedings of the Passive and Low Energy International Conference, Mexico City.