THE EN4M MICROCOMPUTER PROGRAM FOR ESTIMATION OF BUILDING ENERGY CONSUMPTION AND ECONOMIC COMPARISON OF ENERGY SAVING OPTIONS

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ABSTRACT - Criteria for a practical microcomputer energy program are enumerated. A detailed description of the EN4M program as compared to these criteria is given. Inputs, output and operating procedures for the program are summarized. Enhancements to the program versus the ASHRAE TC 4.7 Modified Bin Method on which it is based, are detailed. Methods used in the principal calculations are described. A summary is given of the EN4M program compared to the practical microcomputer energy program criteria.

INTRODUCTION

The engineer often needs to find a practical solution to engineering problems among the factors of 1) engineering effort, 2) cost, 3) ease of use, 4) speed, and 5) accuracy. These key criteria must be met in developing practical software for energy analysis, plus one more very important item - 6) good economic analysis of the options that exist for energy saving. In the case of energy analysis, these criteria are particularly hard to meet because of the mathematical complexity of the calculations. ASHRAE has pointed the way with its TC 4.7 Modified Bin Method of Energy Analysis(1)(2) Life Cycle Cost Analysis(3).

The EN4M microcomputer program is the result of an intensive private sector effort to develop a microcomputer program with the above qualifications. In several respects, it has been possible to significantly enhance the accuracy of the calculations, while remaining within the original criteria for engineering effort, cost, ease of use and speed.

In this paper we shall often make reference to the ASHRAE Modified Bin Method of energy analysis as simply "the ASHRAE method." Temperatures will be given in degrees Farenheit, and English units will be used in general.

GENERAL ENERGY ANALYSIS METHODOLOGY

In estimating the energy consumption of a building, one must first calculate the cooling and heating requirements of the building during a typical month or year. This, in turn, requires weather data for the period, a physical description of the building and a knowledge of the internal building loads and their variation over time.

Once the heating and cooling requirements have been estimated, they must be calculated back to the primary energy needed to operate the building. This implies the modeling of the heating and cooling systems of the building, and the operating procedures and schedules under which they are to be operated.

It is evident that these complex calculations require the approximation of many, many variables. Although acceptable computer methods for carrying out these calculations for new buildings have been developed, it remains significantly more accurate to work with an existing building, calibrating the outputs from a program such as EN4M so as to accurately reproduce historic data. Options can then be tried by varying any of the details of the base case, from orientation of the building and construction details, to interior loads, operating practices and equipment systems.

Reasonable estimates can be made with EN4M for new construction, however, by experienced engineers. Estimates on new buildings will usually be more accurate for comparison among energy options than they will be for estimating the absolute energy consumption of the building.

WEATHER DATA

The EN4M program and the ASRAE analysis method both make use of bin weather data obtained from Air Force Manual 88-29, Engineering Weather Data[4]. These data are furnished for some 212 U.S. locations and 36 sites outside the U.S. Some states and countries make available data on additional sites in similar format. The data give outdoor temperature occurrences divided into five degree temperature bins, and further divided into three eight hour bins for a typical day for each month of the year and for annual totals. The ASHRAE method uses the annual total data, and suggests use of monthly calculations where variations exist in loads or system operation.

The EN4M program makes monthly calculations and sums these to get its annual consumption estimate. This allows the energy calculation to reflect monthly variations in weather, internal loads and operating procedures.

EN4M further enhances the basic ASHRAE method by mathematically smoothing the three eight-hour bins into 24 one-hour temperature bins. This permits internal load profiles to be specified on an hour-by-hour 24-hour basis. The program can then calculate Cooling Load Factors (CLFs) for internal loads as prescribed by ASHRAE using time of connection and hours in space as the governing variables. Occupancy hours and machine room and fan operating schedules can be specified on an hourly basis. All of these factors can then be varied on a monthly basis if desired.

The EN4M program contains a weather module, accessible from its main menu illustrated in Figure 1. The weather module takes as inputs the weather data from Air Force Manual 88-29 and performs the mathematical manipulation necessary to smooth the data into 24 one-hour bins and calculate maximum solor heat gain factors (SHGFs) for every month and every exposure. A weather file is created once for each location and may be utilized whenever necessary thereafter.

Although the Manual 88-29 offers data for some 248 U.S. and foreign locations, there are many areas which have local weather variations and sub-climates. Data to be input into the EN4M weather module can be interpolated by the engineer between

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/-----------------------------------------------------------------\
|                                                                 |
|  E N 4 M   M A S T E R   M E N U           File: SAMPLE.DAT     |
|  ///////////////////////////////////////////////////////////    |
|  1. Input New Building Data      2. Review/Modify Building Data |
|                                                                 |
|  3. Print ALL Input Data         4. Print worksheets            |
|                                                                 |
|  5. Perform energy analysis      6. Print energy analysis results|
|                                                                 |
|  7. Run Weather Generator        8. Perform Economic Analysis   |
|                                                                 |
|  9. Change Building File                                        |
|  ============================================================   |
|                                                                 |
|                                                                 |
|  INPUT SELECTION OR <ESC> TO EXIT > _                           |
|                                                                 |
\-----------------------------------------------------------------/
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Fig. 1. Main EN4M Program Menu

data sites for which data is available, using good judgement. An alternate procedure is also offered by the EN4M weather module, which will develop simulated bin data based on user inputs of average temperature and daily temperature range for each month of the year. Historic bin data are always to be preferred, if available.

In addition to the bin data discussed above, the weather module requires inputs of the monthly values for cloud cover and percent sun for the site. These values are obtained from National Oceanic and Atmospheric Administration (N.O.A.A.) reports[5] or other sources. A summary of N.O.A.A. data for many U.S. locations is furnished with the EN4M program.

A useful application of the EN4M weather module is to model a succession of 12 typical summer or winter months, say with a difference of two degrees in average temperature from month to month. Energy consumption estimates can then be run using this file together with a series of different operating options, such as different percentages of occupancy for a hotel, to arrive at energy consumption forecasts for budget purposes.

ENTERING THE BUILDING DESCRIPTION

The EN4M program requires general inputs such as Gross Building Area, Altitude, Outside Summer Dry Bulb and Wet Bulb Temperatures and Exposed Perimeter Length. The building itself is described by inputting the construction type letter for up to eight walls and roofs, using the wall and roof types set up in ASHRAE Fundamentals Chapter 26[6]. Roofs with and without suspended ceilings can be differentiated. Basement and party walls whose load depends on an "other side temperature" can be handled. The Coefficient of Heat Transfer ("U" Value) and area must be input for each wall or roof, of course. Wall direction is specified as North, North-East, East etc., for the eight principal compass directions. Wall and roof color is input as light, medium or dark. The entry of a "special" elevation is allowed on each exposure to account for more than one type of wall construction.

Glass in each exposure is detailed by entering its area and shading coefficient. A letter code allows the user to specify whether the window has interior shading or not. The weight of interior construction in input as light, medium or heavy, to allow the program to account for the heat stored in the mass of the building and furnishings. Exterior shading is handled by defining shaded glass as north-facing. Doors are entered in terms of "U"-value, area and construction type.

With eight walls available, each able to take four types of elevation, it is almost always possible to adequately describe buildings which have multiple wall constructions, glass types, shading conditions, curved walls, angled exposures and similar complex situations.

HEATING AND COOLING SYSTEM SIMULATION

The EN4M program allows the direct entry of the following system types:

- Double duct
- Multizone
- Reheat
- Variable volume
- Two pipe fan coil
- Four pipe fan coil

From the energy consumption standpoint many other systems may, however, be handled as variants of one of the above. The only difference between a two-pipe and a four-pipe system, for example, is that heating and cooling can be on simultaneously. Thus, a four-pipe system that is operated with only one utility at a time can be simulated as two-pipe.

If either the two-pipe or the four-pipe fan coil unit motors are cycled on-off with their thermostats, they are, in essence, a variable volume system. This, to determine how much energy could be saved by cycling fan coil motors, simply define the system as variable volume with fan horsepower equivalent to the total fan coil unit motors and a shutoff percent equivalent to the system diversity.

Many systems become equivalent to variable volume when they are duty-cycled from space temperature since they then respond to the load directly. If they are duty-cycled on a time schedule rather than from space temperature, they are not equivalent to variable volume since they are not responding to the load. These may be handled by reducing the operating hours by the duty-cycle "percent off" time. Dual duct variable systems cannot as yet be simulated.

Simple gas furnace systems without cooling are equivalent to reheat systems. Gas furnaces with cooling can be represented as two-pipe or four-pipe depending on the scheduling of cooling and heating.

Radiator or convector systems may be described as reheat systems with no cooling. Supply air CFM would be input as infiltration, and if the system has ventilation these CFM would be added to the supply air, forcing the energy that would be consumed at the convectors for heating the air, to be calculated at a non-existent heat coil.

The EN4M program offers an option to set up a heat pump configuration. The program allows any of the systems to be run with an evaporative cooling option, automatically turning off the chiller during any period when weather conditions permit the building to be cooled using evaporative cooling. The evaporative efficiency may be specified by the engineer. The program allows a heat recovery option as well, at an recovery efficiency input by the user.

The program determines energy consumption for the building as a whole and can handle only one type of HVAC system at a time. If all the HVAC systems in a multi-system building are the same, it may be simulated as one system, adding the motor horsepowers and supply CFM together. Since the EN4M program is non-dynamic, it does not add to accuracy to zone a building having the same system throughout.

If a building has different HVAC systems such as a double duct system around the exterior and a variable volume system on the interior, the area served by each system can be easily run separately. The program facilitates such an analysis, as the area, building and system descriptions can be changed to suit the two cases by making partial changes on three screens. Other input information would remain the same. The runs would be summed to get the total energy consumption of the building.

Inputs to characterize the HVAC system are chiller percent shutoff, presence or absence of a preheat coil, preheat coil discharge temperature, mechanical equipment horsepower, boiler efficiency, fan, pump and other auxiliary horsepower, and chiller/condenser kilowatts. Exterior lighting kilowatts may also be input as an auxiliary load.

INTERIOR LOADS

The EN4M program takes interior loads in reasonably detailed form. People, lights and equipment are input separately. Thermal loads due to HVAC equipment may be specified. Up to 10 hour-by-hour load files may be entered, and subsequently applied to the people, lights and equipment loads. Hours in space are specified for each interior load. Equipment may be specified as hooded or unhooded, and the ASHRAE "A" and "B" factors for lights are called for.

Different maximum people, lights and equipment loads may be input for each month, or a short-cut input system permits the same load to be quickly duplicated for as many months as wanted. To add to this flexibility, a different load profile may be applied to each of the interior loads for each month, as well as the number of hours of load for each month. System operating hours for each month are a separate input. Thus such diverse loads as a department store or school can be accurately described in the EN4M program. In such a load, the maximum value changes widely from month to month, the profile varies during the day, and the hours operated each week change through the year.

HVAC SYSTEM OPERATING PROCEDURE

The operating conditions and manner of operating the system can be specified in various ways. Outside summer design dry bulb and wet bulb are required for the CLTD and psychrometric calculations. The inside dry bulb and wet bulb control points may be input for each month of the year. Cold deck dry and wet bulb temperatures are required for each month. The hot deck reset schedule at low and high outside temperature levels is input, and the preheat coil temperature. The economizer shutdown temperature is an input.

Supply air CFM and ventilation/infiltration air CFM are inputs to the program. Night setback/setup temperatures may be input for each month of the year. A number of miscellaneous inputs are provided for other operating factors, for example boiler efficiency and domestic water temperature rise.

Key inputs are the months cooling and heating are turned off and on. For systems which will allow simultaneous operation of the cooling and heating systems, the EN4M program allows these periods to overlap up to the full 12 months per year.

PROGRAM INPUT SCREENS

Inputs to the EN4M program are organized by "screens", and worksheets in the same format are provided so that inputs can be worked up before the engineer sits down for his computer session. When the choice is made from the main menu to input new data, the program automatically goes through the 14 screen pages that make up a normal set of inputs. Some of the inputs on some of the screens need not be made if not important to the job being analysed, and some entire screens may be skipped, in the same manner. These short cut possibilities are spelled out in the operating manual.

A series of numbered input quantities are prompted on each screen as shown on the example screen for System Information reproduced below, and the cursor automatically stops after each prompt, waiting for a user input. Almost all inputs are verified by the program as they are made, to insure they are numerals or words as the case may be, and that they are within an acceptable range or among the acceptable choices. Because of these checks it is difficult, although not impossible, to input unacceptable data for running the program.

When inputs are complete for each screen, an "Accept or Change" line appears at the bottom of the screen, as shown in Figure 2. If the user discovers he needs to change one or more of the inputs, he may enter the item number or range of numbers, and the cursor will automatically return to those items for new inputs. Since the program is compiled, screen and cursor action is quick. Inputs can be made with a minimum of effort on the part of the user. A satisfactory level of user friendliness has be achieved in the input screens.

When, later, the user wishes to make input changes to calibrate his job to historical results or to run options, he selects "2. Review/Modify Building Data" on the main menu, then chooses one of the 14 data input pages to change from the Data Menu, illustrated in Figure 3. Each data

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/------------------------------------------------------------------\
|                                                                  |
| Page  4      SYSTEM INFORMATION                    EN4M/DAT      |
| //////////////////////////////////////////////////////////////// |
| 1. System Type (DD-MZ-RH-VV-2P-4P) 4P                            |
| 2.    Percent Shutoff (Tenths) ----  .2                          |
| 3. Preheat Coil ( Y / N ) --------   Y                           |
| 4.    Discharge Temperature -------  55                          |
| 5. Supply Air Volume (CFM) -------   56101                       |
| 6. Ventilation/Infiltration (CFM)    11000     OSA  HOT DECK     |
|    Hot Deck Reset Schedule ===============>> 7.  0   8.  120     |
|                                           9.  70 10.  120       |
|                                                                  |
| 11. Economizer Shutdown Temp.----    80                          |
| 12. Mechanical Equip. Motor HP ---   8.6                         |
| //////////////////////////////////////////////////////////////// |
|                                                                  |
|  RANGE OF ENTRIES TO CHANGE (OR <ESC> TO  EXIT)  FROM  2   TO >4 |
|                                                                  |
\------------------------------------------------------------------/
```

Fig. 2. Typical Input Screen

In order to gain the job description flexibility featured by the EN4M program, a large amount of input data is needed. Just the capability of month to month calculations multiplies by twelve the amount of data that has to be input and stored for many factors. We were fortunate in being able to develop input screen procedures which permit the rapid duplication of data when the data is constant from month to month, yet allow new figures to be input at any month. The final result has been a program that is characterized by easy inputs yet great flexibility. Total input time for a base case on a new job is 20 to 30 minutes, assuming data sheets have been prepared in advance.

input page is presented to him exactly as it was during original inputs, but with the existing data filled in and the "Accept or Change" prompt on the screen. Only the necessary changes need be made; no existing data needs to be reinput.

The user may back out of the screen at any time without making any changes simply by pressing the "Esc" key. Thus, it is possible to quickly scan screen pages to verify existing data, returning to the main menu or making changes as desired. Data is only saved to disk when it "Accepted" by the user. Conversely, since data is saved to disk at the completion of each screen both in original inputs and during Review/-Change, very little will be lost if there s a power interruption or other natural disaster unless the program happens to be in the midst of saving to disk at the moment of the problem.

data as closely as possible. Outputs of the program present energy consumption broken into considerable detail so that useful comparisons to historical data can

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/-----------------------------------------------------------------------\
|                                                                       |
|  /////////////// S C R E E N   D A T A   M E N U /SAMPLE.DAT /////    |
|  1. General Information               8. Operation Period/Hours       |
|                                                                       |
|  2. Hourly Load Profiles              9. Occupancy Period/Hours       |
|                                                                       |
|  3. Inside DB / WB Temp.             10. Lighting Period/Hours        |
|                                                                       |
|  4. System Information               11. Equip. Period/Hours          |
|                                                                       |
|  5. Cold Deck DB / WB Temp.          12. Auxiliary Loads              |
|                                                                       |
|  6. People / Lighting Loads          13. Lights/Equip/people CLFs     |
|                                                                       |
|  7. Equip. Loads / Night Setback     14. Walls/Roofs                  |
|  //////////////////////////////////////////////////////////////////   |
|                                                                       |
|  INPUT SELECTION OR <ESC> TO  EXIT)..4                                |
|                                                                       |
\-----------------------------------------------------------------------/
```

Fig. 3. Review/Modify Building Data Menu

JOB CALCULATION PROCEDURE

Once the building, the system, interior loads and operating parameters have been specified for the base case, it is time to start calculating energy requirements. The energy calculation is run from the main menu, and is fully automatic. On the IBM PC computer, a typical calculation takes less than five minutes. The progress of the calculation is traced on the screen through each major step - wall and glass loads, internal loads etc.

The program stores the outputs of the energy calculation on disk, in the same file with the job information. Thus, the user has two types of data files on disk; a job file for each job, and the weather file for each location. The program is set up so that the job and weather files may be kept on the same disk with the program files, as would likely be the case when a hard disk is in use, or the data files may be kept on separate disks. One MSDOS floppy disk can marginally hold the program files as well as a few sets of data files so that the program can be run on a single disk machine. More convenient configurations are, however, a two-drive or a hard drive computer.

In the case of an energy audit of an existing building, when the base case run is complete the next step is to calibrate the output so as to conform to historical

be made. Outputs are broken down by month and by occupied and unoccupied periods, and cooling, heating and electrical energy use are separately printed out. Annual sub-totals are given in each category, as well as overall numbers. Cooling energy is given in million BTU and in KWH, heating energy is given in million BTU and therms, and electrical energy is given in million BTU and KWH. These data may be reviewed on the screen of the computer, or may be printed out.

The engineer makes his comparisons with historical data, and may change any of his input quantities through convenient review-/change screens, so as to bring the calculated output more nearly into alignment with historical data. If desired, a weather file can be run with weather data for a particular year so as to permit the closest possible comparison of calculated results with historical.

When the engineer is satisfied with the coincidence of the program energy estimates with his historic data, he returns to the review/change screens to run a series of options varying whatever input factors he wishes. Factors to be varied may be the weather file used, building orientation on site, construction materials, amount or type of glass, amount of insulation, lighting or other interior loads, system type, operating parameters or any of the other inputs enumerated earlier, singly or together.

Normal practice will be to run a logical progression of reasonable possibilities. As each change is run, the user may input an option number and a title, briefly indicating the nature of the change. Energy consumption for the option is then automatically calculated by the program and the results are added to the end of the job file, along with the base case. Job file input data is changed each time a new option is input, however the results of the base case and each previous option remain stored at the end of the job file. When results are printed out, the user may choose the option numbers to be printed. The program will print out the base case and the indicated options, the energy savings for each option compared to the base case, and the energy used per square foot for each. Job input data and weather file inputs may also be printed out so as to provide a complete record of the study.

The number of options that can be compared at one time is limited to seven plus the base case. However after these have been run, together with their economic studies, further groups of seven can be entered and run overwriting the first seven each time. It is not necessary to reenter data or rerun the base case in order to study succeeding groups of seven options. By copying the original job file under another name (while in DOS rather than from within the EN4M program), the results of all the option groups can be preserved, if desired.

Studies of large numbers of options can be conveniently carried out without the investment of a large amount of time, since to make the necessary changes in job data and carry out each run might take from five to ten minutes for an experienced engineer who has his data at hand and knows what options he wishes to study. The economic analysis (to be discussed later) would take an additional 15 minutes for each group of seven.

METHODOLOGY

The utilization of bin weather data has already been discussed under Weather Data. Suffice to say here that the EN4M program and the ASHRAE Method use the same AFM 88-29 Engineering Weather Data as a source, except that the eight-hour bins of the AFM 88-29 are mathematically smoothed and converted to 24 one-hour bins by EN4M, and EN4M uses the monthly data rather than the year totals. It should be noted that the EN4M program weather module uses ASHRAE algorithms to calculate the maximum SHGFs for the precise latitude of the project and each of the twelve months, rather than doing interpolations from table values. This procedure results in a significant improvement in accuracy since linear interpolations do not always accurately approximate these non-linear functions.

In running an energy calculation, EN4M first reads in the cloud cover, percent sun and maximum sensible heat gain factors (SHGFs) from the weather file. The "load factors" and various weighted average weather conditions are then derived from the weather file. The C.O.P. of the refrigeration machine is calculated, and of the heat pump if one is defined.

If the system has a preheat coil, the number of degree-hours below the preheat discharge setpoint is determined. If a heat recovery option has been selected, the entering outside air temperature is adjusted to account for heat exchanged between it and the exhaust air. Average outside air temperature; mixed air temperature above and below the mixed air setpoint (which is assumed to be the same as the cold deck setpoint); the hours between the mixed air setpoint and economizer shutdown temperature; and the hours above the economizer shutdown temperature are calculated for each month. Degree-hours below the room temperature setpoint are also determined.

The wall and roof input data is read in from the job file. The applicable CLTDs and CLFs are recovered from disk data files, corrected according to the "footnote" corrections of ASHRAE, and used together with the maximum SHGFs from the weather file to calculate the radiant and conductive loads due to walls, roof, glass, and doors according to standard ASHRAE practices. The reradiation factor is calculated and applied, and the total building shell cooling load is summed.

The heating load is determined by calculating an overall heat transmission coefficient for the building, which is multiplied by the degree-hours below the room temperature setpoint. A small additional heat load is added based on the length of exposed perimeter.

Internal loads are now calculated. The maximum internal loads which have been input by the user are multiplied by the load profile factor at the particular hour and by the appropriate CLF, determined from the elapsed time since each load was connected and the total number of hours each load will be in the space.

The program then performs the system simulation, based upon the definitions input by the user. Loads on the heating or cooling coils are determined and divided by the C.O.P.s previously calculated. If evaporative cooling is specified, the amount of time the building can be cooled by the evaporative process is determined and subtracted from the operating time. If the cooling coil load is less than 40% of total chiller kilowatts, input power is set at 40%. Electrical energy is determined by multiplying each electrical load by a load factor from the scheduling profiles.

This procedure is carried out twice, once for the occupied period and once for the unoccupied period. The occupied period and the operating period are user inputs to the program. Normally, the occupied period starts when people enter the space and ends when they leave; the balance of the 24-hour day is considered "unoccupied". The program assumes that no energy is consumed during the part of the day when the operating period indicates that the cooling system is turned off.

These features can be used to provide information about the amounts of energy used during particular periods of the day by simply defining the operating and occupied periods to fit the problem. For example, to determine the amount of energy used between 7:00 and 10:00 in the morning the operating period can be input as from 7:00 a.m. to normal shut-off time at night, say 8:00 in the evening, and input the occupied period as from 10:00 in the morning to 8:00 in the evening. The energy reported as "unoccupied use" would be only the energy used from 7:00 a.m. to 10:00 a.m.

Alternatively, the occupied period could be defined as from 7:00 to 10:00 a.m. and the energy for this period would be reported as "occupied use". The actual loads from lights, people and equipment during the period are determined by the maximum values the user has input, multiplied by the load profile factors specified for the period and the cooling load factors (CLFs).

Variations in occupancy can be handled in two ways, each giving different results. A client may wish to know the effect of performing janitorial services earlier in the evening. If the intent is to shut down the system earlier, it would be handled by adjusting the operating and the occupancy periods. If, however, the intent is simply to reduce the cooling load during the period, the operating period would be left unchanged, and the occupancy period, people load profile and possibly the night setback temperature would be adjusted.

The ability to define the operating, occupancy, lighting and equipment hours is a powerful tool. If good profiles can be developed for internal load components on normal days, then abnormal days such as Saturdays can be compensated by changing the monthly hours operated. If, in another example, the building is operated 30 days a month; people are in the space from 8:00 to 5:00 for 25 days; the lights are on from 7:00 to 6:00 for 27 days; and the office equipment is used from 9:00 to 4:00 for 25 days, it is easy to describe these variations by defining separate profiles for each type of load and inputting the applicable hours for each component.

An economizer cycle capability is built into the program. The economizer shutdown temperature is defined as the outside air temperature at which the mixing dampers go to a minimum position, giving maximum return air and minimum outside air. The economizer cycle (mixed air) setpoint is always the same as the cold deck setpoint. Thus, the mixed air setpoint can be raised during the winter, while still keeping the cooling turned off during that period.

If the system is a multizone or double-duct system, it will have a hot deck. Most systems provide a reset schedule that insures that the air is warmest when the outside air temperature is low, and drops as outside temperatures increase. The program allows the user to specify this type of control; for example, to hold a 90 degree discharge temperature when outside air is above 70 degrees and a 110 degree discharge temperature when outside air is below 60 degrees, the reset schedule would be defined as follows:

OSA	Hot Deck
60	110
70	90

The mechanical room motor horsepower is actually a measure of the thermal load on the cooling system from HVAC motors. The effect of moving a motor (or chiller, etc.) in or out of the air stream can be simulated by simply adding or subtracting it from the mechanical room motor horsepower. The auxiliaries define total electrical motor load and are multiplied by the operating hours rather than the equipment hours. The equipment loads are always both a thermal and electric load and are multiplied by the operating hours for the thermal component and the equipment hours for the electrical component.

```
/-------------------------------------------------------------------------\
|                                                                         |
|  LIFECYCLE COST PARAMETERS                          SAMPLE.DAT          |
|  ///////////////////////////////////////////////////////////////////   |
|  1.   Cost of electrical energy per MBTU -----  23.42                  |
|  2.   Cost of fossil fuel energy per MBTU ----   4.12                  |
|  3.   Discount rate, in percent -------------  12                      |
|       Annual Escalation rates:                                          |
|  4.   Electrical energy rate --------  20                              |
|  5.   Fossil fuel energy rate -------   5                              |
|  6.   Operation and maintenance rate   10                              |
|  -------------------------------------------------------------------   |
|  OPTION 1 DATA:                                                         |
|  1.   Option first cost, dollars ------------  $ 123456                |
|  2.   Annual operation and maintenance cost --  $ 1234                 |
|  3.   Economic life , years -----------------    20                    |
|  ///////////////////////////////////////////////////////////////////   |
|  RANGE OF ENTRIES TO CHANGE (OR <ESC> TO EXIT)   FROM >..   TO ..      |
|                                                                         |
\-------------------------------------------------------------------------/
```

Fig. 4. Economic Analysis Input Screen

The cold deck is actually the cooling coil discharge temperature. For two deck systems, it will be the cold deck; for single duct systems, it will be the coil discharge temperature. Variations in cooling coil discharge temperature can be simulated by varying the dry bulb input. Variations in cooling coil performance can be simulated by varying the discharge wet bulb temperature. The program assumes a valve-controlled cooling coil; wild coils cannot be simulated accurately without dynamic hour-by-hour analysis.

ECONOMIC ANALYSIS OF OPTIONS

The bottom line of energy analysis is dollars and cents. Therefore the EN4M program provides an Economic Analysis function to carry out a life cycle cost analysis of seven options at one time, compared to the base case. The principles of discounted cash flow as described in ASHRAE Systems(3) are followed. It will be recalled that in this type of analysis, costs and savings incurred in the early years are given more value than when incurred in the later years of a project. The difference in value is measured by the interest the money might have earned in the intervening years. The amount of this interest is calculated using an "discount rate" input by the user, thus the name "discounted cash flow" method.

When "8. Perform Economic Analysis" is selected from the main menu, the program allows the user to specify economic parameters such as cost of electrical and fossil fuel energy, discount rate, and the inflation rates (annual escalation rates) to be applied to electrical energy, fossil fuel and operating and maintenance costs. The input screen for these entries is illustrated in Figure 4.

From Figure 4, it will be seen that the program asks for input data on the first cost, annual operation and maintenance cost and economic life of each option. Based on these inputs, a detailed economic analysis is run by the program, printing out for the base case and each option, the first year energy cost, total annualized cost and total present worth. These numbers are further evaluated by the program, which prints out the discounted payback period for the added investment of each option, the savings/investment ratio (S.I.R.) of each option, and the energy savings in BTU per annual discounted investment dollar. An abridged example economic analysis printout for a base case and one option is given in Figure 5.

While the evaluation of options carried out automatically by the program is no substitute for thoughtful engineering judgement, it is at least a first pass toward selection of desirable options. Options can be subjected to economic analysis in groups of seven, and ample data is printed out by the program to allow the engineer to construct tables for comparison and presentation purposes, when more than seven options are to be evaluated.

```
E C O N O M I C   A N A L Y S I S   R E P O R T
-----------------------------------------------

ALTERNATE NO. O DATA (REFERENCE BASE CASE)
     INSTALLATION FIRST COST ...........$          0.00
     ANNUAL O&M COST (LESS ENERGY)......$          0.00
     ELECTRICAL ENERGY USED ............     2,099.4900 MILLION BTU
     FOSSIL FUEL ENERGY USED ...........     3,486.3300 MILLION BTU
     ECONOMIC LIFE ............................. 20 YEARS

     RESULTS:
           TOTAL FIRST YEAR ENERGY COST IS      $ 63.631.90
           TOTAL ANNUALIZED COST IS .........  $323,450.00
           TOTAL PRESENT WORTH IS       $     2,415,990.00


ALTERNATE NO. 1 DATA (OPTION RUN:         )
     INSTALLATION FIRST COST ...........$     123,456.00
     ANNUAL O&M COST (LESS ENERGY)......$       1,234.00
     ELECTRICAL ENERGY USED ............     1,000.4000 MILLION BTU
     FOLLIL FUEL ENERGY USED ...........       958.0090 MILLION BTU
     ECONOMIC LIFE ............................. 20 YEARS

RESULTS:
     TOTAL FIRST YEAR ENERGY COST IS             $ 27,437.20
     TOTAL ANNUALIZED COST IS ...............  $142,224.00
     TOTAL PRESENT WORTH IS        $           1,062,330.00
                                .
                                .
                                .
                ***DISCOUNTED PAYBACK PERIODS***

TO GO FROM ALTERNATE O* TO ALTERNATE 1 PAYBACK PERIOD IS  3.12 YEARS
FINAL YEAR'S (YEAR  4) ENERGY SAVINGS/COST IS $     70,482.20
WITH   3,627 MILLIONS OF BTU'S SAVED PER YEAR.
SAVINGS/INVESTMENT RATIO (S.I.R.) IS 11.965
ENERGY SAVINGS ARE     587,644 BTU PER ANNUAL DISCOUNTED INVEST. DOLLAR
                                .
                                .
                                .
  * - LOWEST INCREMENTAL INSTALLATION FIRST COST ALTERNATE
 ** - PRESENT WORTH NOT COMPARABLE DUE TO DIFFERENT ECONOMIC LIVES
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Fig. 5. Abridged Example of Economic Analysis Printout

CONCLUSIONS

The successful development of the EN4M program has demonstrated that a practical program for energy estimation and economic analysis of options can be run on microcomputers commonly available in the market today. The program meets the criteria described in the introduction as follows:

1. Engineering effort

   - Data collection is facilitated by the use of worksheets which duplicate the actual input screens.

   - The program carries permanent files of weather data and other engineering data required in its calculations.

   - The program gives the engineer a maximum of flexibility in describing building construction, HVAC systems, internal loads and system operating parameters, with a minimum of engineering effort.

   - Energy and economic analysis calculations are almost entirely automatic.

2. Cost

   - The program runs on economical equipment, being available for most microcomputers in the market today without requiring hard disk or additional memory.

   - It adequately replaces main-license or lease charges, time charges and long distance telephone line charges.

   - It is offered on a long term license basis for a relatively reasonable one-time payment. A secrecy agreement is required.

   - Updates are made available at a nominal charge as they are released. Working copies may be made by the licensee. Damaged disks may be replaced at a nominal charge.

   - Since microcomputer technology is developing with great rapidity, users frequently upgrade their machines. Program upgrades to new machines are made at nominal cost.

3. Ease of use

   - The program prompts its inputs with quick, self-explanatory screens, which check most entries for reasonableness and permit easy correction of individual entries, both at time of entry and later.

   - A clear, detailed manual is provided with the program.

   - The program fits the definition "user friendly" in use.

   - Short cut entry procedures, exit from input screens, elimination of certain inputs are all possible.

4. Speed

   - Well designed input screens permit quick inputs and changes.

   - Since the program is compiled, it calculates rapidly. IBM PC run time for a typical building is less than five minutes for each option. Total time including input changes is 5 to 10 minutes per option.

   - Economic analysis of up to seven options against a base case takes about another 15 minutes. This speed is almost entirely printer-dependent.

5. Accuracy

   - It has been possible to incorporate several important accuracy enhancements into the EN4M program, as compared to the ASHRAE Modified Bin Method. These are monthly calculations, 24 one-hour weather bins and load profiles, and calculation of SHGFs by detailed algorithms permitting accurate results at any latitude, time of day and time of year.

   - Energy calculations can be calibrated to approximate historic results with a minimum of effort, since ample means are provided to describe buildings, systems, and hourly, weekly and seasonal variations in interior loads and operating parameters.

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