# 37

# The computer as a tool for energy analysis

*The engineer is the technician; the computer is the tool. The engineer provides the judgment and skill, and the computer yields the optimum in quantitative data. Together they can lick many of today's complex energy problems.*

Computers have proven very useful for many applications. In the HVAC field, they have greatly increased the capability of the engineer in designing systems. They have also provided him with the means to study systems in existing buildings to effect substantial savings in energy and operating costs.

The intent of this chapter is to discuss relating to the computer as a tool. The engineer is the technician; the computer is a tool. How does the computer fit into the problem solving process?

A computer performs the arithmetic necessary to yield reliable data required for problem solving. An engineer recognizes that many assumptions and approximations are required in solving numerous problems. As a field of engineering matures, it becomes increasingly exacting, requiring a diminishing use of the "approximation" approach.

The computer is the tool that has permitted engineers to reach the *n*th degree of exactness for many types of problems because it can perform many complex calculations in seconds. Without it, comparable computations would require unreasonable lengths of time. Simulating the performance of a HVAC system to determine annual energy usage could take several months, even on the simplest of buildings. Yet, the result would not be as accurate as a properly designed computer program could provide in a few moments. Even changing one or two variables to examine their effect on consumption could necessitate redoing many or all of the calculations. In the past, this situation prompted many assumptions and approximations to be used in determining a building's energy consumption. To conserve valuable time, this was a necessary alternative. A computer provides the quantitative data that otherwise would have to be approximated; *that is all that it does!*

When a computer is applied to the area of energy economics, two considerations are necessary. First, the applied program must contain the proper algorithms relating to the problem and all mathematical relationships that affect energy consumption in a building. Second, the output information should not simply be taken as the answer. This was a common error in some initial efforts, but as computerized engineering problem solving developed, it was realized that *the* answer, or final solution, *could only be obtained by applying skilled engineering judgment.* A computer simply gives good quantitative data that can be used to arrive at better solutions.

The end-to-end computer program, or one in which input data is supplied and a final solution comes out, is generally not a good engineering program. Valuable data generated between these two points, which might indicate that a change in input is desirable, could easily be overlooked. Input should be applied with judgment and experience. Thus, interface programs are more effective in engineering work.

## Determining energy flow rate

Physics is a science of exact definitions, and engineering is a subscience of physics. It may be beneficial to review some of the basic concepts common to both. Energy is defined as work or the capacity to do work. The basic unit of energy is foot-pounds. The unit used in the thermal form is the Btu, which is by definition, the equivalent of 778.26 ft-lb (approximately the amount of heat required to raise the temperature of 1 lb of water 1 F at standard atmospheric pressure).

Power is the time rate of energy. Some commonly used power units are Btu per hour, tons of refrigeration, horsepower, and kilowatts.

In energy economic studies, it is imperative that the difference between energy and power is clearly understood and kept in mind. This is significant because power units are generally input functions to an energy program. Clearly, control (minimization) of the power aspects of any system reduces energy use if other factors, such as operating hours, are kept constant. (To attain this condition, a computer is not needed.) If 1 Btuh is consumed for 8760 hr a year, the energy consumed is 8760 Btu. The significance of this simple statement is that if power is reduced at the front end of the program, the output quantity is also reduced. Explore this relationship by looking at a simple diagram.

Figure 37-1 is a basic diagram of energy flows in a building system. The largest block on the left represents the space (building, zone, room, etc.) being studied. The rate at which energy enters or leaves this space at any given time is the load—a power function. It is a cooling load if it enters and a heating load if it leaves.

Once a building's envelope internal energy systems, and operating schedule are fixed, this energy flow rate becomes the absolute integrated energy requirement. In this analysis, the absolute integrated energy requirement is considered to be the block load, not the sum of the peaks. This function is the starting point in a study of energy economics. Energy requirements at the building ultimately lead to consumption of resource energy—coal, gas, oil, etc.—in a magnified form due to losses and inefficiencies during distribution and conversion processes.

## Load study is first point

The first point of application for a computer when trying to understand and thus minimize

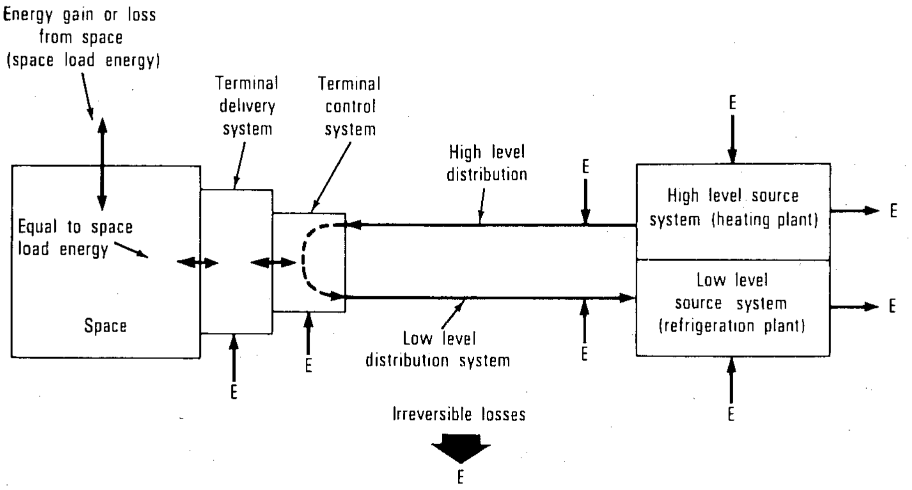

Fig. 37-1. Simplified diagram of energy flows in a building system.

usage is the load study. Load energy is a function of:

- building design, location, and orientation;
- ventilation rates based on contaminants;
- occupancy schedules;
- weather conditions.

Of these four, occupancy schedules and weather are essentially uncontrollable inputs. The controllable variables of the load are:

1) Fenestration systems, including:

- area of the glass;
- type of the glass;
- framing systems;
- interior shading;
- exterior shading.

2) Lighting systems and appliances.
3) Roofing systems and materials.
4) Wall systems and materials.
5) Excess ventilation rates due to:

- infiltration;
- overdesign of mechanical system ventilation rates;
- antiquated building code requirements.

A properly designed computerized load program enables a designer to modify any of the controlled variables to determine the effect on design load. When considering existing buildings, the location, orientation, and occupancy are, obviously, already established. Hence, the engineer must confine himself to the five controllable load variables listed.

The effects of changes in these five variables, either individually or in any combination, on both the block load and the sum of the peaks can be readily determined by a computer during a load study. Without a computer, these detailed load studies would be approximations at best, in addition to being extremely cumbersome and time consuming.

At this point in an energy economic study it is important to note two items. First, the time-integrated block loads—heating and cooling—on a building are the useful product energy requirements. Second, this product energy aspect—input to the mechanical system—is, except for excess ventilation, strictly an architecturally controlled parameter.

## System component definitions

Before proceeding further, it is necessary to define the terms used in the following discussion.

- The *terminal delivery system* conveys air to and from the space. It includes the fans, supply and return ducts, grilles, etc.
- The *terminal control system* solves the space psychrometric problems. It contains everything needed to meet the conditioned space needs: cooling and heating coils with associated controls; control and mixing dampers; air terminal units, such as terminal reheat, mixing boxes, VAV terminals, etc.
- The *high-level distribution system* conveys a thermal fluid from a source to heat transfer surface (such as hot water or steam from a boiler to a coil). This process is self-contained in an electric resistance heating coil. Heat is generated by the current flow, and combustion occurs remotely at the generating station.
- The *low-level distribution system* conveys a fluid from a refrigeration machine (the source) to a chilled water coil or a direct expansion coil (the heat transfer surface).
- *Motivating energy* for the terminal control system includes the air energy required to operate the air terminal units. These require a minimum static pressure to assure proper operation. For example, self-contained variable air volume terminals may require a minimum of 2 in. WG static pressure. This must be added to the static pressure required to operate the duct system before an adequate amount of energy is provided to operate the terminal unit.

## Building versus system energy

Referring again to Fig. 37-1, the second block from the left represents the terminal delivery system. All load energy to and from the space flows through it. A first law analysis* of the space clearly shows that the energy flow between the space and the terminal delivery system is equal to the *block* load energy.

Further analysis reveals that load energy flows into or out of the delivery system, while system motivating energy flows into the system. When a net block heating load exists, the delivery system motivating energy flows to the space. Energy analysis reveals that the motivating energy for the terminal delivery system often represents a major contribution to a building's annual energy consumption.

The terminal control system is represented by the smallest box from the left. Here, the space psychrometric problem is solved. Portions of this subsystem could be integrated with the delivery system in actual practice. In this analysis, however, it is important to identify the terminal control system as a separate subsystem.

First law analysis of the terminal control system reveals one of the more interesting aspects of energy consumption in HVAC systems. The energy flow arrows in Fig. 37-1 represent input from the high-level distribution system, motivating energy, output to the low-level distribution system, and either input or output between the terminal control and terminal delivery systems. The terms high and low level refer to temperatures above and below space ambient conditions, respectively; i.e., heating and cooling distribution systems. The high-level distribution system generates the "runaround" energy in the overall system. When the net building load is in the cooling mode, this system can receive:

- space energy;
- terminal delivery system motivating energy;
- high-level distribution system energy;
- terminal control system motivating energy.

All of these will flow to the low-level distribution system. This runaround energy from the high- to the low-level distribution system is, as the space sees it, wasted energy. This condition often exists at full load as well as part load. As far as the terminal control system is concerned, this runaround energy may be essential to maintain the space conditions.

At full load, many building systems utilize runaround energy to make up the difference between the block load and the sum of the peaks. The high-level system false loads the low-level system to prevent overcooling the space. Figure 37-2 demonstrates this. It shows a single floor of a commercial building and net design cooling load conditions. The block load is 36.75 tons. This is the rate of heat gain into the space at design conditions. The sum of the peak zone loads, however, is 48.75 tons. This is approximately 33 percent higher than the block load.

Many systems are psychrometrically designed to handle the load represented by the sum of the peaks. Many others are designed to provide a cooling plant capacity somewhere between the sum of the peaks and the block loads. The energy difference between the two loads comes from the high-level distribution system. Thus, the high-level system false loads the low-level one. From the standpoint of energy economics, this false loading becomes even more significant. It requires added heat energy and also added refrigeration energy to

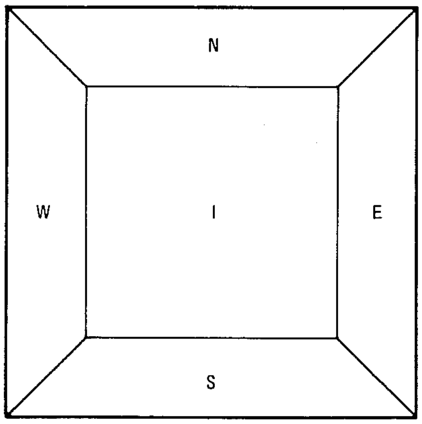

**Fig. 37-2.** Thus: sum of peaks is 33% greater than block 2 A single floor of a commerical building at net design cooling load conditions.

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*The first law of thermodynamics states that (classical definition) work and heat are mutually convertible. This definition can be broadened to include all forms of energy; i.e., one form of energy may be converted to another.

remove the extra heat energy, hence the term runaround energy evolved.

Typical examples of false loading are: hot decks of dual stream systems; reheat coils; perimeter radiation in conjunction with cold deck VAV systems; and single fan, multiple zone economizer systems (those that provide winter cooling with low temperature outdoor air in lieu of refrigeration). As previously mentioned, the external energy for the terminal control system often is a significant contributor to energy consumption when high-pressure delivery air is required to "control" the terminal units.

Energy is transferred between the terminal control system and the high- and low-level source systems through their respective distribution systems. (In an actual system configuration, these systems are often integrated with the terminal delivery systems.) External energy is often required to motivate this energy transfer, and significant savings often can be achieved by careful system analysis. For example with water, or other single-phase heat transfer fluids, doubling the temperature range halves the flow rate, which in turn, reduces the power (pump horsepower and energy) required.

In existing buildings, this halving approach would reduce the distribution system energy to as low as one-eighth of its original value.

## High- versus low-level sources

The first law energy balance also applies to the high-level source system where either fossil fuels or electricity are converted (minus losses) to the heat energy supplied to the high-level distribution system.

The low-level source system follows the second law of thermodynamics: heat will not flow of its own accord from a cold to a warm sink. Thus, it requires external energy to transfer the energy from that system to an available heat sink. This external energy may be in the form of a prime mover or, with absorption refrigeration, heat energy. It is important to remember that the external energy applied to power the refrigeration unit is not the only input. All parasitic loads on the system, such as condenser water pumps, condenser fans, cooling tower fans, control power, ventilation fans, etc., must also be considered.

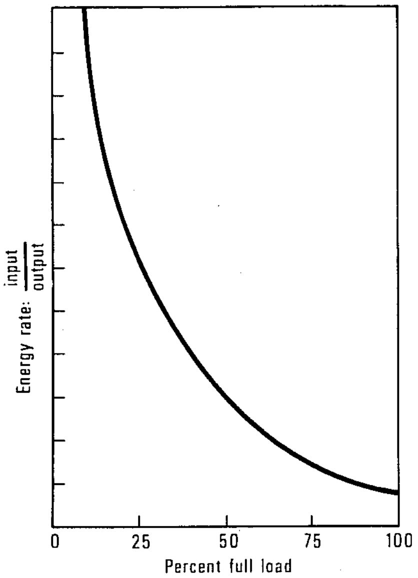

**Fig. 37-3.** An exponential curve depicting the decline in efficiency as the load decreases.

Building environmental control systems operate at less than design load for a major portion of the year. Therefore, any valid energy analysis should recognize part load performance characteristics of the high- and low-level source systems. Virtually all energy conversion systems become less efficient (useful power output/power input) as the load decreases from the design capacity. The exponential curve in Fig. 37-3 depicts this common system characteristic. The fixed parasitic loads establish the rate of increase of input to output as the load decreases, and the curve

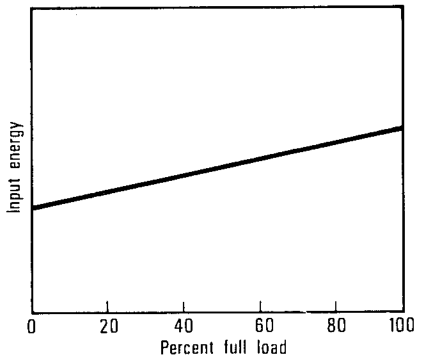

**Fig. 37-4.** A linearized curve as in Fig. 37-3.

approaches infinite input per unit output at zero load. An example of this is a boiler maintained at operating temperature when there is no heating demand. The curve in Fig. 37-3 can be linearized (Fig. 37-4) for computer programming purposes by multiplying the ordinate by the abscissa.

### From load to energy analysis

It is with recognition of the proper algorithms and concepts previously discussed that a computer program to analyze energy consumption in a building is employed. Also, human interface with the output of the load program and the input to the energy program is essential in order to arrive at the best energy reduction solution.

Figure 37-5 illustrates the minimum requirements and output data of an energy analysis. (This discussion is concerned with the application of these programs rather than an in-depth discussion of the programs themselves.) It was stated at the beginning of this chapter that the computer is a tool. As such, the user applies it to determine what system modifications and/or changes in operating techniques are practical to achieve the desired goals.

Existing buildings provide the opportunity for immediate reductions in energy use compared to projects in the design stage. The procedure for applying computer analysis to existing buildings is as follows:

1) Study the building plans (if available).

2) Make a building survey to check the actual building conditions against the plans and/or to gather what pertinent data are required to perform the study.

3) Run a load program calculation.

4) Input the energy program with the output data from the load program and all the necessary data relating to the mechanical/electrical systems and the building use parameters.

5) Compare the output from the energy program with historical energy consumption records of the building, such as monthly and annual fuel and electric consumption from the utility bills.

6) Identify the reasons for any differences between calculated quantities and the historical data. Examples of differences are:

- improper calibration of controls;
- damper leakage;
- operating techniques;

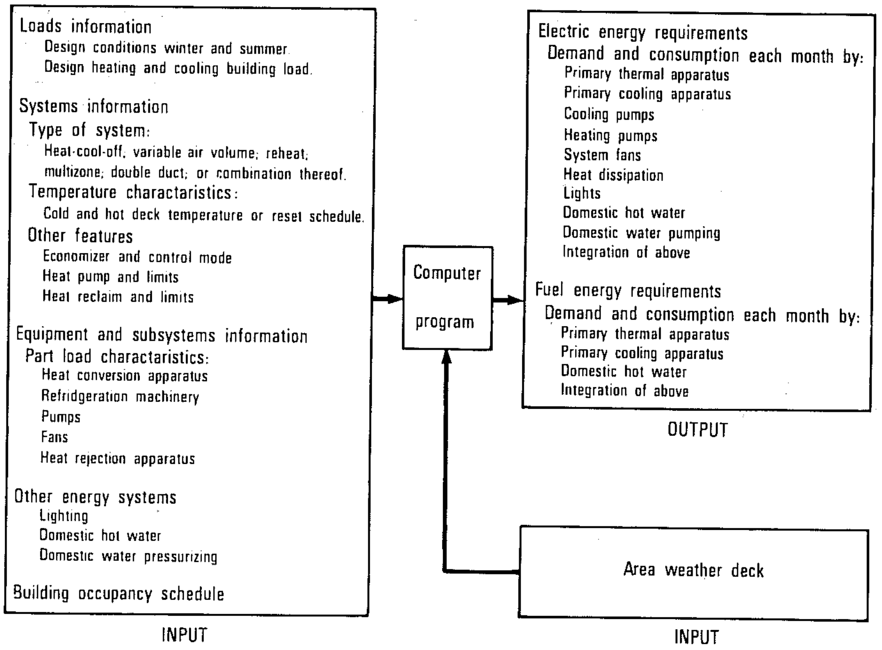

**Fig. 37-5.** The minimum requirements and output data for an energy analysis program.

- installation errors;
- design errors.

7) With the knowledge of the relevant energy-consuming contributors, starting with the building design, explore practical building and system modifications and control and or operating techniques by processing them through the load and energy programs. From the energy savings developed, determine the dollar savings yielded by each modification.

8) Determine the costs of implementing each of the various conservation steps analyzed.

9) Conduct a quantitative comparison between the energy cost savings and the implementation costs.

10) Determine the combined owning and operating costs and the rate of return for each conservation measure.

11) From all of this information, prepare a feasible course of action in implementing the steps that prove economically viable.

It is the quantitative aspect that is provided by the computer. Reductions in energy consumption can be accomplished in virtually all existing building systems. However, when modifications are undertaken, capital investment is often required, and only a thorough quantitative analysis will determine the wisdom of the investment.

With a valid energy program, the calculated results can be assumed correct, adjusting, of course, for statistical versus actual weather conditions. Obviously, this also depends on all input factors being correct. Many times, factors causing high-energy use problems can be readily identified and corrected with little or no capital investment, and engineering costs represent the only expense involved.

Proper understanding of the factors affecting energy usage in buildings and of the relevant algorithms in computing this energy use will permit the user to intelligently apply the computer to solving most, if not all, of the problems he is likely to encounter.