Chapter 9

Control Systems and Computers

9.0 INTRODUCTION

Energy use can be controlled in order to reduce costs and maximize profits. The controls can be as simple as manually turning off a switch, but often automated controls ranging from simple clocks to sophisticated computers are required. Our view is that the control should be as simple and reliable as possible. Consequently, this chapter starts with manual controls and proceeds through timers, programmable controllers, and digital computers.

As one moves through this hierarchy of controls, each level of automation and complexity requires additional expenditure of capital. That is, the automated controls are more expensive, but they do more. Because choosing the proper type of control is often a difficult task, we will explore this decision process.

Computers can also help the energy manager in the analysis of proposed and present energy systems. Some excellent large-scale computer simulation programs have been written that enable the energy analyst to try alternative scenarios of energy equipment and controls, so in the last part of this chapter we discuss these computer programs and their use. BLAST 3.0 and DOE-2.1D are the two described in depth, but several others are mentioned.

9.1 WHY CONTROLS ARE NEEDED

Every piece of energy-consuming equipment has some form of control system associated with it. Lights have on-off wall switches or panel switches, and some have timers and dimmer controls. Motors have on-off switches, and some have variable speed controls. Air conditioners have thermostats and fan switches; they sometimes have night setback controls or timers. Large air conditioning systems have extensive controls consisting of several thermostats, valve and pump controls, motor speed controls, and possibly scheduling controls to optimize the operation of all of the components. Water and space heaters have thermostats and pump controls or fan motor controls. Large heating systems have modulating controls on the boilers and adjustable speed drives on pumps and variable air volume fans.

These controls are necessary for the basic safety of the equipment and the operators, as well as for the proper operation of the equipment and systems. Our interest is in the energy consumption and energy efficiency of this equipment and these systems, and the controls have a significant impact on both these areas. Controls allow unneeded equipment to be turned off, and allow equipment and systems to be operated in a manner that reduces energy costs. This may include reductions in the electric power and energy requirements of equipment, as well as the power and energy requirements associated with other forms of energy such as oil, gas and purchased steam.

9.2 TYPES OF CONTROLS

In this section, we present the different types of controls in order of increasing complexity and cost. In each subsection, the control discussed can perform the functions covered in that subsection as well as all those functions covered in the preceding subsections. For example, the functions discussed in the second subsection on timers can be performed very well by a timer or any of the succeeding types of controls (programmable controllers, microprocessors, and large computers) but not by a manual system.

9.2.1 Manual Systems

Manual control systems can be used to turn equipment off when it is not needed. Turning equipment off when not in use can lead to dramatic savings. For example, lights are often left on at night, but they should normally be turned off whenever possible. (Often a small series of lights is left on for security purposes.)

One of the best opportunities for manual control exists in the area of exhaust and makeup air fans. These fans are often located at the top of a high ceiling, and they are frequently left on unnecessarily because their running is undetectable without close scrutiny. The savings for turning off exhaust fans is twofold. First, electricity is no longer required to run the fan motor, and, second, conditioned air is no longer being exhausted. Consider the following example.

Example 9-1: Suppose that a fan is exhausting air at a rate of 10,000 ft^3/min from a welding area. The fan is run by a 5-hp motor and is needed for two shifts (8:00 a.m. to 12:00 midnight) 5 days/ week. Previously, the fan has been left running all night and on weekends. If the space is not air-conditioned and is heated to 65°F by a gas furnace that is 80% efficient, and the efficiency of the motor is 84%, what is the savings for turning the fan off at night and on the weekends? Gas costs $5.00/million Btu and electricity, $.08/kWh. (There will be no demand savings since peaking does not occur at night). Assume the outside temperature averages 30°F for the hours the fan can be shut off. (This would have been determined through weather data analyses, as discussed in Chapter 2.)

Solution:

1. Electricity savings:

The electric energy savings from turning the motor off during nights and weekends is found by multiplying the motor load in kW times the number of hours saved (number of hours the motor is not running). This energy savings in kWh is then multiplied by the energy cost to get the dollar cost savings.

Electric energy savings =

$$5\text{ hp} \times \frac{.746\text{ kW}}{\text{hp}} \times \frac{1}{.84} \times \left[\frac{5\text{ days}}{\text{week}} \times \frac{8\text{ h}}{\text{day}} + \frac{2\text{ days}}{\text{week}} \times \frac{24\text{ h}}{\text{day}}\right] \times \frac{52\text{ weeks}}{\text{year}} \times \frac{\$.08}{\text{kWh}}$$

$$= \$1,625.57$$

2. Heating savings: (see equation 6-13 in Chapter Six)

Heating cost savings =

$$\frac{10,000\text{ ft}^3}{\text{min}} \times \frac{60\text{ min}}{\text{h}} \times \left[\frac{5\text{ days}}{\text{week}} \times \frac{8\text{ h}}{\text{day}} + \frac{2\text{ days}}{\text{week}} \times \frac{24\text{ h}}{\text{day}}\right] \times \frac{52\text{ weeks}}{\text{year}}$$

$$\times \frac{.075\text{ lbs}}{\text{ft}^3} \times \frac{.24\text{ Btu}}{\text{lb °F}} \times (65°\text{F} \pm 30°\text{F}) \times \frac{\$5.00}{10^6\text{ Btu}} \times \frac{1}{.8}$$

$$= \$10,810.80$$

where the density of air =.075 lb/ft^3 and the specific heat of air =.24 Btu/lb°F.

3. Total annual savings = $12,436.37

In another example, a large office complex made a detailed study of building utilization and found that only a few tenants worked at nights or on the weekends. By making provisions for these few, the office complex was able to reduce lighting and space conditioning, saving about a third of its annual energy bill. For most industrial plants and many office buildings, the use of night setback to lower heating temperatures offers significant savings with little or no capital expenditure.

The calculation procedure for determining this savings is relatively simple and involves heat loss calculations during the hours of setback. Bin weather data on outside temperatures and inside thermostat settings are required. The heat losses are calculated for the old thermostat setting and again for the revised setting. The difference is the heating savings in Btu. To simplify this procedure, or at least to give an approximation, a nomograph is given in Figure 9-1. The following example shows how to perform the calculation.

Example 9-2: A manufacturing company of 100,000 ft^2 is located in an area where heating demands are 4000 degree days. The company keeps its thermostats set at 70°F all the time even though it works only one shift. Presently, the company figures it consumes 240×10^3 Btu/ft^2 of gas for heating. (Normally, this can be estimated from gas bills.) If the company pays \$4.50/10^6 Btu for its natural gas and the heaters are 75% efficient, what would the savings be for turning the thermostats back to 55°F at night when the building is not occupied?

Solution: To use the nomograph, follow the heavy black lines in Figure 9-1. The savings are approximately 125×10^3 Btu/ft^2. Total savings then are found by first determining the actual fuel savings and then finding the dollar savings.

Fuel savings in Btu = $(125 \times 10^3 \text{ Btu/ft}^2)(100{,}000 \text{ ft}^2) \times 1/.75$
= $16{,}700 \times 10^6$ Btu

Savings in dollars = $(16{,}700 \times 10^6 \text{ Btu})(\$4.50/10^6 \text{ Btu})$
= \$75,150/year

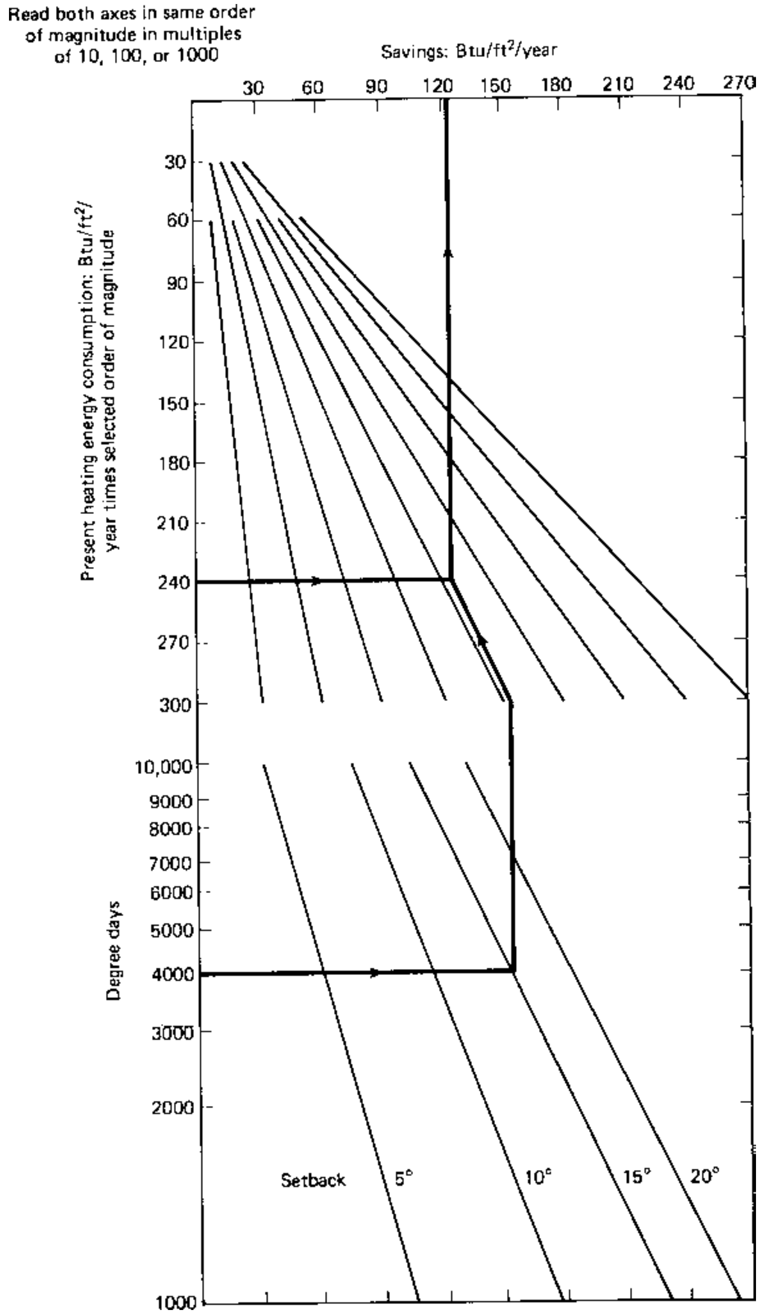

Figure 9-1 Estimation of savings via thermostat night setback. (*Identifying Retrofit Projects for Buildings*, FEA/D-76-467, Sept. 1976.)

The savings for thermostat setback can be substantial, as shown in the example. In warm climates similar savings can result from turning off the air conditioners at night and on weekends, but the dollar amount is usually less since heating demands peak at night, while cooling demands peak during the day. Of course, the energy manager needs to be careful to ensure that the night setback does not cause heating plant problems or cause process problems, e.g., changing the tolerances on large metal parts or affecting the hardening rate of thermocure resins. This depends on the particular equipment and controls used as well as the thermal load of the building itself.

Night setback can also be applied to process areas. For example, large furnaces such as brick kilns should be turned off when possible, but often the preheat time required and/or the thermal wear on the furnace walls makes this impossible. Many times, however, the thermostat can be adjusted downward significantly without causing these problems. Trial and error may be required to determine the optimum setting.

9.2.2 Basic Automatic Controls—Timers and Dimmers

The next step in level of control complexity is the use of automatic controls such as timers and dimmers. Timers can range from very simple clocks to fairly complicated central time clocks with multiple channels for controlling numerous pieces of equipment on different time schedules. Automatic timer controls can range from simple thermostats each with a built-in time clock (costing somewhere around $100 each) to a central time clock that overrides all the thermostats. An installed single-channel central time clock will cost around $1000, but it can control numerous thermostats if all are on the same schedule. Different setback schedules require multiple channels, increasing the cost somewhat.

Some companies have utilized time clocks to duty cycle equipment such as exhaust fans. For example, a large open manufacturing area will likely have several exhaust fans. If there are six fans, then a central time clock could turn one fan off each 10 minutes and rotate so that each fan is off 10 minutes of each hour, but no more than one fan is ever off at the same time. This saves on electrical consumption (kWh) to run the fan, electrical demand (kW, since one fan is off at any time), and heating (since less conditioned air is exhausted). General ventilation over a wide area is maintained. Of course, care must be taken to ensure that no ventilation problems develop.

The use of timers allows a company to start-stop equipment at exactly the correct time. It is not necessary to wait for maintenance people to make their rounds, turning off equipment and adjusting thermostats.

However, although timers don't forget to do their job, they do suffer from other problems. For example, power outages may require timers to be reset unless a battery backup is used. Also, arrival or termination of daylight savings time requires all timers to be set up an hour in the spring and back an hour in the fall. Finally, the clocks must be maintained and replaced as they wear out.

The authors had an opportunity to audit a plant that had sophisticated time clock controls on its equipment, but management was not maintaining the clocks. The 7-day time clocks allowed for night and weekend setbacks. The audit was done on a Thursday, but the time clocks read Saturday. Consequently, the thermostats were on night setback, and the employees were cold. To remedy this, maintenance had purchased several additional portable heaters. If they had come in on a Saturday, when the clock read Monday, the plant would have been nice and warm. In this case, the poorly maintained clocks were costing the company a great deal of money. Timers and any other type of control system must be maintained.

Another type of control that has some attractive savings potential is a light dimmer. Dimmers can be automatically controlled depending on time, and on natural lighting levels if photocell sensors are used. It is important to be sure the dimming system chosen actually reduces electrical consumption and is not simply a rheostat (variable resistor) that consumes the same amount of energy regardless of the amount of light delivered. Supermarkets can often use relatively sophisticated dimming systems. For example, supermarkets might:

1. Use photocells to detect natural light and dim the window lights as appropriate.

2. Use photocells that turn parking and security lights off at dawn and on at dusk.

3. Use photocells to determine dusk so that interior lighting can be reduced. (Studies have shown that people coming from a dark street to a brightly lit room are actually uncomfortable. Lower lighting levels are preferred.)

As with timers, photocells and dimmers must be maintained. They sometimes fail, and if undetected, the failure can cause other more severe problems. A regular maintenance schedule of checking photocells and dimmers should be used. Photosensors were also discussed in Chapter 5.

9.2.3. Programmable Controllers

A programmable controller is a control device that has logic potential but is not powerful enough to be called a computer. As might be expected, it fills a need for systems requiring more than a timer but less than a computer. It can do all that timers can do and considerably more but at a cost significantly less than that of a computer. Fixed logic devices —such as timers—are primarily useful in buildings under 50,000 ft^2 with maybe a dozen control points. (A control point is a switch, a thermostat, or a control actuator.) Computerized systems would be applicable in buildings of 100,000 ft^2 with more with 100 control points. The middle group would be suitable for programmable controllers. Some control system selection guidelines are given in reference 1.

A programmable controller adds logic capability to control systems. Demand shedding is a prime example. When the controller senses that the electrical demand is approaching a critical programmed level, the unit then shuts off equipment and/or lights to keep the demand from passing that critical level. As shown in Chapter 3, demand can be a large part of an electrical bill, so the savings can be significant.

Another example is excess air control for a boiler or any larger combustion unit. By sensing CO_2 or O_2 and perhaps CO levels in exhaust, the controller can adjust the combustion air intake to yield optimum combustion efficiency. As shown in Chapter 7, this can be a real money saver. Continuous control through the use of a programmable controller allows the air intake to be adjustable according to the heating demand on the unit.

Programmable controllers can also be used to control outside air for heating, ventilating and air conditioning systems. In air conditioning, if the outside air is more comfortable than the inside air, the outside air should be used rather than returning the inside air. In fact, sometimes the air conditioning units can be turned off completely and outside air used for cooling. Programmable controllers can sense the difference between outside and inside enthalpy and determine the optimum damper setting. The same controller can shut off outside air completely for early morning start-up and nighttime operation during heating seasons. Outside air control is discussed further in the next section.

9.2.4 Computerized Systems

Most computerized energy management control systems (EMCSs) sold today are microprocessor-based. These capabilities run from a few control points up to several thousand, with the larger ones often performing fire-safety functions, equipment maintenance status monitoring and report generation as well as energy management [2]. The technology is changing very rapidly and there are many vendors in the field, each introducing new equipment. A potential user should consult several vendors and be well prepared to discuss the facility's needs. Some general approaches to the selection and specification of computer control systems for energy management are given in references 3 and 4.

EMCS users must recognize the need for feedback. The computer may have sent a signal to turn off a load, but was the load actually turned off? A sensor is required to feed the control status back to the computer. Also, it is helpful if the computer maintains a record of when control was exercised. With these records, histograms can be developed periodically to show how frequently any given load is being shed.

Additional control options are available to the EMCS user, but mostly they are some combination of the techniques discussed in the previous sections. Figure 9-2 is useful in summarizing these techniques. In Figure 9-2(a), the original electrical demand profile is shown before control is applied. Note that the area under these curves is the integration of demand over time and thus is the kWh consumption. In Figure 9-2(b), demand control is applied. Here, a peak demand is determined, and loads are shed once that peak is approached. Shedding requires predetermining what loads can be shed and in what priority. For example, display lighting would likely be shed before office lighting.

Many systems also "remember" loads previously shed. They will rotate among shedable loads, and will obey preset maximum shed times. As Figure 9-2(b) shows, shed loads must sometimes be recovered and sometimes not. For example, shedding refrigeration saves demand, but sooner or later the unit must catch up. Shedding lights, on the other hand, saves energy because lighting cannot be recovered. As shown, then, some consumption is shifted but usually not as much as was shed. Demand savings remain the predominant goal.

In Figure 9-2(c), a fixed start-stop schedule is utilized. Now units are turned on and off at exactly the same time each day. No longer are personnel required to make rounds, turning equipment on and off. In Figure 9-2(d), an optimized start-stop schedule is employed. The precise time of need is determined each day, and the equipment is turned on at that time. For example, if the outside and inside temperatures are both warm, the heating units do not have to be turned on as early as they would be if the respective temperatures were quite cold.

Figure 9-2(e) shows what happens when the use of outside air is optimally controlled. In this case, the plant requires air conditioning. The fans—but maybe not the compressors—are turned on early in the morn-

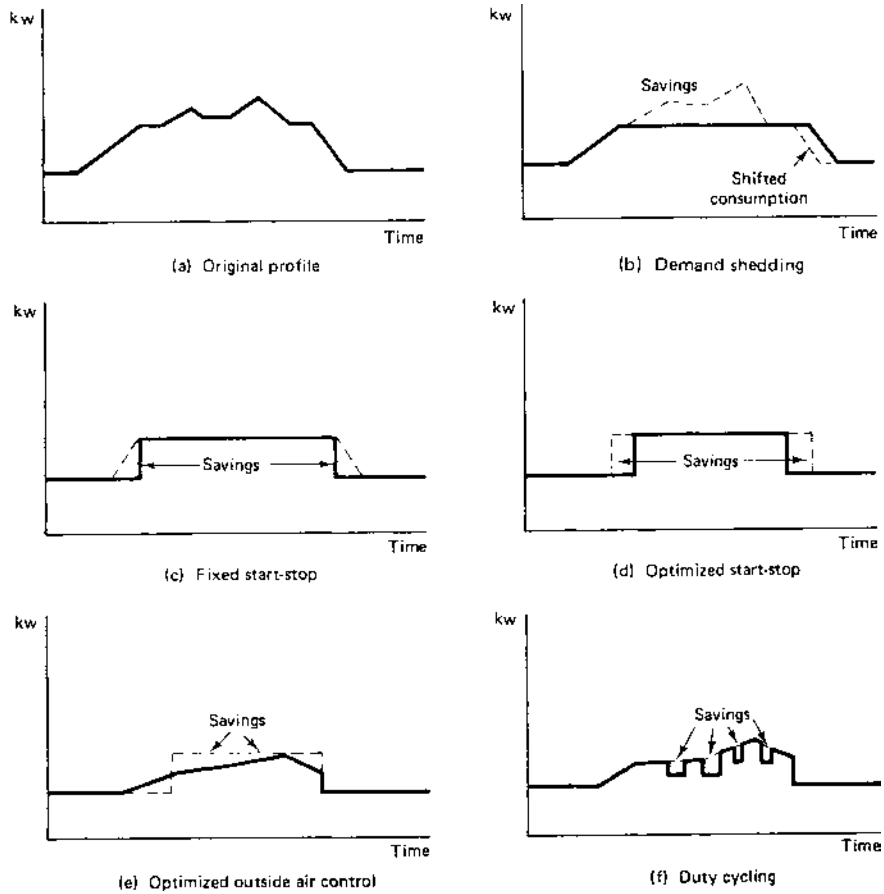

Figure 9-2. EMCS control techniques. (From Dick Foley, "Reducing Waste Energy with Load Controls," *Industrial Engineering*, July 1979, p. 24. Extracted with permission from Institute of Industrial Engineers, Inc., 25 Technology Park/Atlanta, Norcross, Ga., 30092, ©1979.)

ing to draw in cool outside air for precooling. As the daytime temperatures warm, less outside air is used, and the compressors have to run longer; at the peak air conditioning time a minimum of outside air is used. Toward the end of the operating time, it may again become profitable to utilize outside air.

Duty cycling is depicted in Figure 9-2(f). Here loads are selected to be turned off on a predetermined schedule. For example, in our earlier discussion exhaust fans were turned off 10 minutes out of each hour. Duty cycling will produce a savings in kWh since the units are operating less. If these schedules are determined so that some piece of equipment is being cycled off at any time that peaks are likely to occur, a demand savings will also result.

All the techniques shown in Figure 9-2 deal with electrical consumption. Other techniques cannot be easily demonstrated in such a figure because of their nature and/or because they affect fuel consumption rather than electricity. Examples include the following:

1. Light dimming, as discussed in Section 9.1.2.

2. Combustion air control for furnaces. This affects fuel consumption.

3. Night setback for heating. This normally affects fuel consumption instead of electricity.

4. Surge protection. If power outages occur, EMCSs can be programmed to start turning loads off to prevent an extremely large surge of power once the service is reconnected.

5. Temperature reset. Here the temperature of supply air or water is modified to meet actual demand. For a heating system, the supply air temperature may be reduced by 10 to 20°F when heating demands are small. This could save substantial fuel.

There are several different generic forms of computer EMCS configurations available. In a centrally controlled system, control is vested in one central unit—a microprocessor or microcomputer. The control points are accessed directly (a *star network*) or through common wiring (a *common data bus network*). These two configurations are shown in Figure 9-3. In the star network, control is more direct but installation is considerably more expensive. So, its use is limited to facilities with few control points. The common bus design allows for common use of wiring, so its installation cost is less for facilities with a large number of control points. Some of the current activities in the design of EMCSs involve the movement to standardized communication methods called protocols [5]. Standardized systems should be cheaper and easier to maintain and expand.

Instead of using a centrally controlled EMCS, many newer EMCS systems use a distributed configuration where remote processing units using microprocessors or microcomputers perform the actual control functions. A central unit is still used, but primarily for coordination and report generation. This is illustrated in Figure 9-4 using a star network.

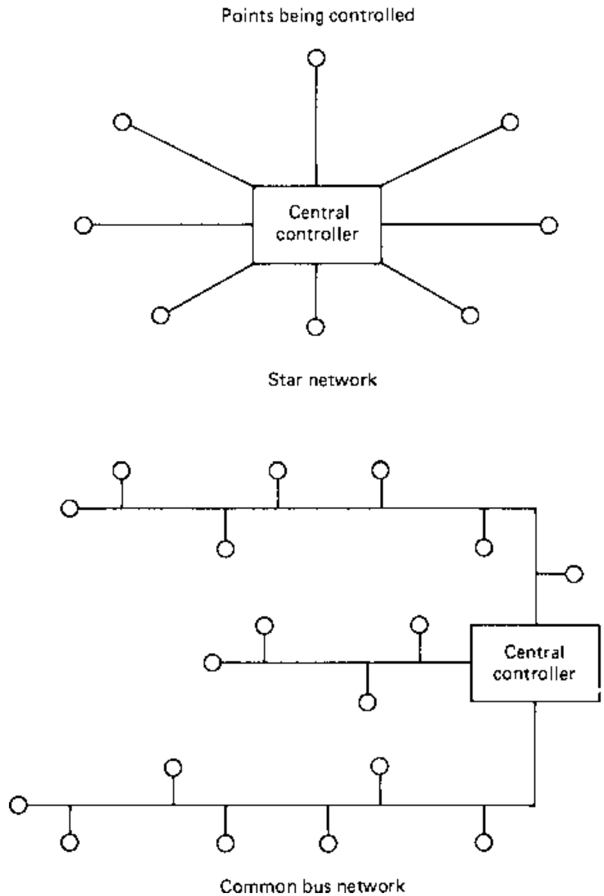

Figure 9-3. Centrally controlled EMCS star network and common bus network.

The remote control units vary in capability from a simple transfer function to complete control. In a true distributed control system, the remote controllers can function with or without the central unit—at least for a period of time. Intelligent remote controllers are only slightly more expensive than unintelligent ones. Most designers predict that future EMCSs will have more distributed control as the cost of remote controllers is reduced. Of course, systems can be hybrids so that some star networking is used along with common bus designs. Also, some remote controllers may be intelligent and others not, and some points may be directly controlled by the central controller even in a distributed control basic design.

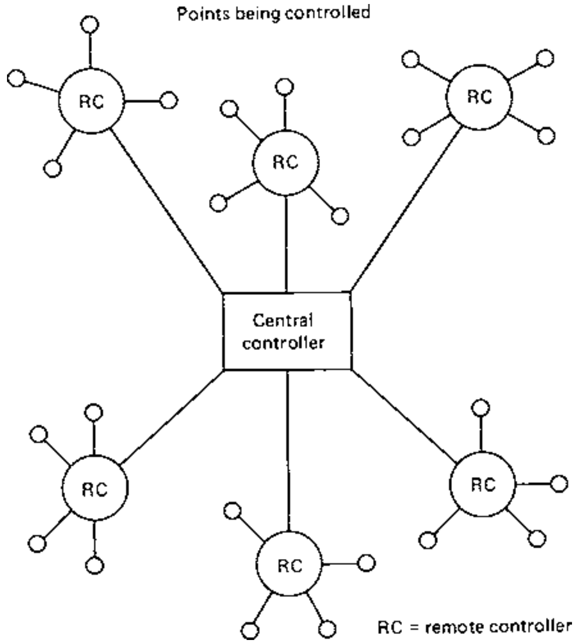

Figure 9-4. Distributed control EMCS star network.

An important factor to consider in the selection and cost of EMCSs is the type of control needed at the points being controlled. The simplest and cheapest is a digital point which is a simple on-off control. Examples include switches for fans, lights, and motors. Analog controls, on the other hand, are more complex and therefore more expensive. Analog controls are needed when signals of varying intensity are required. For example, control of outside air for air conditioning systems requires an analog signal to adjust the position of a supply vent damper. As the outside air cools, the EMCS will continue to open the damper, allowing more outside air to enter. A significant number of analog points will run up the cost of an EMCS rather rapidly, but the savings should also increase. Careful studies should be conducted in order to determine the optimum number of control points.

EMCSs sometimes fail to provide the energy cost savings that have been predicted. These reasons usually fall into one of the categories shown in Table 9-1. The prudent energy manager will consider these potential pitfalls and plan accordingly.

Table 9-1. Why EMCS units fail to produce the desired results.

1. *Simple things not done first.* The EMCS can do many things, but it should not be asked to do the things that should have already been done. For example, the EMCS cannot turn a standard lighting system into an energy-efficient one.

2. *Simple alternatives overlooked.* An EMCS may not be necessary. Manual or time control may suffice.

3. *Requirements not carefully defined.* This is the most important reason. The buyer must define the requirements before choosing the system. Considerable planning is necessary.

4. *Inadequate buyer commitment/inadequate seller backing.* All too often, buyers seem to expect the EMCS units to install, program, and maintain themselves. Sometimes the seller misrepresents the amount of work necessary to get the EMCS operational. The energy manager should insure that the seller will back the product and provide the necessary technical aid.

5. *Poor vendor assessment.* The energy manager should screen the vendors carefully. Ask for reference letters and check with other energy managers. Be wary.

In summary, EMCSs can do many things, but they are only machines. The energy manager must be aware of their limitations as well as their strengths and design their applications accordingly. The major part of the design should occur before selection of the equipment—not afterwards.

9.3 COMPUTER UTILIZATION

Computers have become so inexpensive and so powerful that they are used everywhere today, including use in a wide variety of tasks in energy management and energy analysis. The energy manager must be aware of computing capabilities and applications, and must carefully integrate computers into his or her environment. In addition to the direct EMCS applications, there are many other energy management uses for computers. Personal computers can be programmed to perform cash flow analyses, waste heat recovery studies, excess air control studies, and a myriad of other aids. Some desktop computers are capable of running large building simulations or equipment design programs requiring significant data storage and lengthy computing times.

Energy Engineering, the journal of the Association of Energy Engineers, has started publishing an annual Directory of Software for Energy Managers and Engineers. In the 1991 directory there were one hundred and thirty-three different software products for energy applications that were produced by forty-four companies [6]. The editor of this journal commented that there was more interest in the Directory Issue than any other issue produced [7]. The Directory is compiled by companies voluntarily sending in information, so it is not a complete listing of all energy-related computer programs. However, the listings in the 1991 Directory are more than twice as long as the listings in the 1990 Directory, which indicates a growing interest among both the users and the suppliers of these programs.

It is impossible to summarize or list all of the possible energy-related uses for computers, but one does stand out from the rest. That is the use of computers to perform building energy use analysis and simulation studies. In the rest of this chapter we will examine some of the programs that are most commonly available for this task. Building energy use analysis and simulation studies require the input of weather data, operating times, and other energy-consuming parameters such as number and type of lights and equipment, efficiency of various devices, etc. as well as the parameters of the building shell such as wall construction, insulation levels, amount of window area, etc. The computer will then simulate a year of building operation (or whatever cycle is chosen), and develop energy consumption and energy bills. Thus various scenarios involving energy efficiency improvements to the building shell or to building equipment can be fed into the computer and the likely savings identified and estimated. Most of the programs available also contain a financial analysis subroutine that provides the economic decision measures needed to help select the most cost-effective EMOs. Thus, the complete energy management study can be done by the computer.

Some of the better known programs include BLAST 3.0, DOE-2.1D, AXCESS, ASEAM, TRACE, and ECUBE, although there are many others. A call to your local utility, university, and/or energy management consultant can identify which are available in your area. We will discuss the capabilities of BLAST 3.0 and DOE-2.1D. Brief discussions of AXCESS, ASEAM, TRACE, and ECUBE, as well as where to get additional information on those programs, can be found in the Software Directory from reference [6].

9.3.1 BLAST 3.0

BLAST can be used to investigate the energy performance of new and retrofit building design options of almost any type and size [8]. BLAST is the acronym for the Building Loads Analysis and Systems Thermodynamics family of programs. Not only can BLAST calculate the building peak loads using design day criteria, which is necessary for mechanical equipment design, it can also estimate the annual energy performance of a facility. This is essential for the design of solar and cogeneration systems and for determining the building's compliance with a design energy budget.

Apart from its comprehensiveness, the BLAST system differs in three key aspects from other similar programs. First, BLAST uses extremely rigorous and detailed algorithms to compute loads, to simulate fan systems, and to simulate boiler and chiller plants. Second, the program has its own user-oriented input language and is accompanied by a library which contains the properties of all materials, wall, roof, and floor sections. Third, BLAST's execution time is short enough to allow many alternatives to be studied economically. In this way, efficient designs can be separated from the inefficient, and proper equipment type, size and control can be determined.

The BLAST Energy Analysis Program contains three major subprograms. First, the Space Load Predicting subprogram computes hourly space loads in a building based on weather data and user inputs detailing the building construction and operation. Next, the Air Distribution System Simulation subprogram uses the computer space loads, weather data, and user inputs describing the building air-handling system to calculate hot water, steam, gas, chilled water, and electric demands of the building and air-handling system. Finally, the Central Plant Simulation subprogram uses the weather data, the results of the air distribution system simulation, and user input describing the central plant to simulate boilers, chillers, on-site power-generating equipment, and solar energy systems; and then computes monthly and annual fuel and electrical power consumption.

Early versions of BLAST were considered difficult to use, but several new methods have been developed to communicate with BLAST. Available methods include BTEXT and Drawing Navigator for Autocad. BTEXT is a text-based scrolling menu program to solicit information about the building model. It builds a special file of building information and can generate BLAST input files. Drawing Navigator for Autocad uses the graphic information accessible in drawings to generate the necessary building geometric data; it passes information into BTEXT for eventual BLAST input file creation. Both preprocessors simplify input file creation [8].

MICRO BLAST 3.0 is available to run on any PC compatible 386 or 486 computer with 20-100 MB of hard drive memory and 4 MB of RAM. Users may obtain access to the BLAST program, and additional information about it from the BLAST Support Office, University of Illinois, 1206 West Green Street, Urbana, IL 61801.

9.3.2 DOE-2.1D

The DOE-2.1D Computer Simulation Program was developed for the Department of Energy (DOE) to perform energy analysis and simulation of plants and buildings [9]. It calculates the hour-by-hour energy use of a building and its life-cycle cost of operation using information on the building's location, construction, operation, and heating, ventilating, and air conditioning system. This program is used to design energy efficient new buildings, analyze energy conservation measures in existing buildings and calculate building design energy budgets. The program is divided into five major subprograms: (1) Building Description Language (BDL), (2) LOADS, (3) SYSTEMS, (4) PLANT, and (5) ECONOMICS.

The Building Description Language (BDL) subprogram allows the user to enter key building design information. The program uses a library of properties of all materials, walls, roof, and floor sections. The user also inputs a description of the HVAC systems, occupancy, equipment, lighting schedules, and other parameters.

The LOADS subprogram computes hourly space loads resulting from transmission gains and losses through walls, roofs, floors, doors, and windows; internal gains from occupants, lighting, and equipment; and infiltration gains and losses caused by pressure differences across openings. The LOADS calculations are based on ASHRAE algorithms, including the response factor technique for calculating transient heat flow through walls and roofs and the weighting factor techniques for calculating heating and cooling loads.

After the building loads are calculated, the program begins the SYSTEMS analysis. The SYSTEMS subprogram takes the hourly space loads, along with characteristics of secondary HVAC equipment, the component and control features, and the thermal characteristics of the zone, and determines the actual room temperature and heat extraction or addition rates using ASHRAE algorithms.

The PLANT subprogram uses the building thermal energy load data determined by SYSTEMS and various other user-input operating parameters of the plant equipment to allocate available equipment and simulate their operation. The PLANT program simulates conventional central plants, solar heating and cooling systems, and plants with on-site generation and waste heat recovery. It also permits load management of plant equipment and energy storage. It calculates the monthly and annual cost and consumption of each type of fuel used, the daily electrical load profile, and the energy consumption at the site and at the source.

The ECONOMICS subprogram uses the life-cycle costing methodology derived from DOE guidelines. Life-cycle costing method investment statistics such as cost savings, savings-to-investment ratio, energy savings, energy savings-to-investment ratio, and discounted payback period are calculated to provide a measure for comparing the cost effectiveness of each case against a reference case.

The MICRO DOE-2.1D program is available for a PC compatible 386 or 486 computer with 2 MB of RAM and at least 20 MB of hard disk space. A newer version, DOE-2.1E, has recently been made available, and a greatly expanded version named DOE-3 is currently under development. The DOE-2 program is used extensively by electric utilities, government agencies, national laboratories, architect/engineering firms, universities, and many private organizations. A version of DOE-2 is used by the State of California to determine building code compliance.

Users may obtain access to the DOE-2.1D program or the MICRO DOE-2.1D program from various commercial vendors. Some of these vendors also offer user support and training for the system. Additional information on DOE-2.1D is available through the Building Energy Analysis Group, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720. Information is also available through the Department of Energy, Office of Building Systems Technology, Architectural and Energy Systems Branch, 1000 Independence Avenue, SW, Washington, DC, 20008.

9.4 SUMMARY

In this chapter we have examined control systems and computer applications for energy management. We began with a discussion of the types of controls, including manual, timer, programmable controllers, and computers. Then we discussed each level of control, giving advantages and limitations. Basically, the simpler controls are the least expensive and least robust. The more expensive controls (such as EMCSs) are more robust in that more control activities can be utilized. Computers can be used in other areas of energy management also. Data manipulation, data summary, and large-scale modeling or simulation are among some of the examples of other areas where computers can be utilized. Large-scale computer simulation models of energy systems are available and are quite useful in simulation of system operation, various scenarios of new equipment selection, or use of revised control schemes. BLAST 3.0 and DOE-2.1D are two programs discussed in some depth in the chapter.

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