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ENERGY CONTROL SYSTEM APPLICATIONS

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Peter E. Baum
US Army Facilities Engineering Support Agency
Research and Technology Division
Fort Belvoir, VA 22060

24 June 1977

Final Report

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The recent escalation in the price of energy has been forcing the Army to investigate better ways to achieve effective use of our natural resources. Although considerable attention has been directed towards improved methods of construction of new buildings and of reducing energy consumption in existing buildings, the means of controlling the HVAC equipment in buildings to achieve energy savings has been only lightly addressed. → next page

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The typical Army installation is spread out over a large area and contains a heterogeneous mixture of buildings with regard to size, age, use, and mechanical systems. Accordingly, their growth and expansion has occurred primarily during a time when neither the technology was available nor did the justification exist for incorporating sophisticated control equipment to achieve more effective energy utilization. That situation has now changed and facilities engineers must examine the energy saving benefits through more effective energy management with automated controls. Automatic control can simply be defined as a closed loop where control of a piece of equipment is based on feedback, often in the form of an electrical signal, from the equipment being controlled.

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SUMMARY

The recent escalation in the price of energy has been forcing the Army to investigate better ways to effectively use our natural resources. Although considerable attention has been directed towards improved methods of construction of new buildings and of reducing energy consumption in existing buildings, the methods of controlling the HVAC equipment in buildings to achieve energy savings have been only lightly addressed.

The typical Army installation is spread out over a large area and contains a heterogeneous mixture of buildings with regard to size, age, use, and mechanical systems. Accordingly, their growth and expansion have occurred primarily during a time when neither the technology was available nor did the justification exist for incorporating sophisticated control equipment to achieve more effective energy utilization. That situation has now changed and facilities engineers must examine the energy saving benefits through more effective energy management with automated controls. Automatic control can simply be defined as a closed loop where control of a piece of equipment is based on feedback, often in the form of an electrical signal, from the equipment being controlled.

1. Introduction. Heating, ventilating, and air conditioning (HVAC) systems normally have simple local controls which typically maintain the temperature of the boiler, chilled and hot water distribution systems, and building rooms. An initial operation point is usually specified by the design engineer based on achieving desired conditions at system peak load. Many systems run at the original specified points for the life of the system, even though they could easily be reset to a better operating condition. This is due primarily to logistics. More simply stated, a reset control without an operator to reset it is a poor investment. Reducing logistic problems is a major factor that has prompted the initial development of centralized controls.

1.1 Until recently, cost-effective centralization was limited by technology. In early model systems, signals from sensing devices to the data panels and from the panels to the control valves were transmitted by pneumatic tubes or electrical signals in which one set of tubes or one wire was required for each signal. Cost and space requirements generally resulted in designers minimizing functions to be monitored and reset.

1.2 Advancements in electronic data transmission and minaturization techniques have greatly increased the feasibility of centralization. These advancements include new techniques of digital communications which allow the transmission of several different signals over a single pair of coaxial wires, or telephone lines. This, along with new and inexpensive microprocessors and minicomputers to organize the data, has resulted in sophisticated management and control systems that can cost effectively perform a variety of tasks. The central controller may now be located, economically, at a remote point from the equipment to be controlled and may further control many more buildings than was previously possible.

1.3 An Energy Control System (ECS) can provide constant monitoring and control of building mechanical systems, permitting efficient and effective use of energy and manpower, while it also serves to connect virtually all other energized systems of a building or complex of buildings into one central location.

1.4 Energy control systems can vary from the relatively simple types designed to perform a few functions to the progressively more complex types performing more and more complicated functions. An energy control system should be tailored to the present requirements of the building and the equipment to be controlled. An overview of the total system capacity should be made with provisions included for expanding the system hardware and software capacity as funds become available.

2. Levels of Automatic Controls. There are basically two levels of automated controls for HVAC equipment. The first level is localized control and the second level is centralized control.

2.1 Local control systems provide independent, relatively low cost control for specified systems and equipment in separate buildings. Each local controller independently controls its specified operating system or equipment and does not act in conjunction with any other controlling device. Since local controllers provide limited control capacity, costs for such devices are relatively low. Wiring and communications costs are also minimized since local controllers do not require trunk line wiring as with central control systems. A local control system usually results in a relatively higher HVAC equipment maintenance cost as opposed to a central control system due to lack of equipment monitoring and documentation.

2.2 Some of the major types of localized automated functions and controls available are: electric time clocks, automatic temperature setback/setup controls, economizer controls, and what is generally known as enthalpy control and optimization. Electric time clocks can handle start/stop operations on a local level. The clocks are preset to turn equipment on and off at different times for each day of the week. For example, Monday through Friday a chiller motor can be turned on at 0600 hrs. and taken off line at 1700 hrs. while on weekends the chillers can be left off.

2.2.1 Automatic temperature setback/setup controls consist basically of two thermostats and a time clock. One thermostat can be set for a desired temperature such as 68°F during the day while the other one can be set for another temperature such as 58°F (a 10°F setback) during the night. The time clock switches the control from one thermostat to the other at a preset schedule such as 1700 hrs.

2.2.2 An economizer control senses and compares outdoor air and return air dry bulb temperature. When outdoor air is capable of cooling and the system is calling for cooling, the economizer opens the outdoor air damper to the maximum position, otherwise the dampers are closed to the minimum position that will allow adequate ventilation for odor control.

2.2.3 Enthalpy control works on about the same principal as economizer control except that the controller continuously monitors and compares the outside air and return air heat content which includes the relative humidity. When the controller has determined which air stream has the highest enthalpy, that damper is closed to its minimum position while the other is opened to the maximum position. In this way, natural outdoor air is used as much as possible to minimize the cooling equipment operation.

2.3 These local controllers can be used in single buildings or closely grouped buildings with a variety of single or multizone systems and radiator heating. Energy and dollar savings from the use of outdoor air damper shutdown can also aid in energy conservation. Better system supervision and control can result in additional savings through increased equipment life due to reduced operation time.

3. Central control systems may be either manual or computerized. These systems are capable of all local control system functions, mentioned before, except that the controls can be extended to many more buildings over a wide area and operated from a single command console, usually with the aid of a microprocessor, without the need for a local control panel in each building. A central manual control system usually requires a trained operator who is responsible for the efficient operation of the total system based on his own decision making capability and knowledge of the building equipment. This type of system is totally dependent upon the operator for optimum equipment operation, while the microprocessor can take care of the day-to-day operation of the building equipment. This system can be adequate, depending on the size and sophistication of the equipment being controlled.

3.1 Central computerized control differs from central manual control in that optimum equipment operation is often accomplished by software programs.

Software or minicomputer based systems provide versatility in equipment operation since reprogramming can usually be accomplished without physical hardware changes to the microprocessors as are required with the local and central manual control systems.

4. Central Control Functions. Manual central control systems are capable of the same operations as the local control systems, only they are done from a single point. Computerized central control is also capable of the same operation except that optimization of the control functions is achieved automatically with the use of software programs and usually requires no operator intervention.

4.1 Some of the typical operations that can be handled by a central control system, with the aid of a computer in some cases, include functions which will:

- monitor all fire alarm and security devices;
- monitor operating conditions of all systems and reschedule set points to optimize energy use;
- monitor all systems for off-normal conditions;
- limit peak electrical demand values by predicting trends of loads and shedding nonessential services according to programmed priorities;
- continuously monitor selected portions of any system and store information in bulk memory for later retrieval and use in updating software;
- optimize maintenance tasks to effect maximum equipment life for minimum manpower labor and costs;
- optimize operation of all systems to obtain the maximum effect for the minimum expenditure of energy, and;
- provide inventory control of spare parts, materials, and tools used for maintenance.

4.2 By judicious use of these functions, the facilities engineering staff will be able to operate all systems from the central console and have a minute-by-minute control of operations. Any physical plant critical alarm will be reported automatically at the console. The operator will then be able to scan the system in alarm, analyze the fault, and dispatch the correct maintenance man to effect repairs. Maintenance alarm summaries will be available on demand as well as being printed out once per day. These maintenance alarms will allow work scheduling and maximum use to be made of maintenance personnel.

5. Central System Configurations. Proprietary local and central automated control systems are marketed by several major temperature control manufacturers. These systems all have some common features and can accomplish a similar range of tasks. Each manufacturer, however, uses hardwire coding and computer languages which are unique to his system and usually cannot be decoded by any other system. Once a basic system has been selected and installed, all subsequent additions must be obtained from the original manufacturer. For this reason, it is important to thoroughly investigate the expansion potential of a system in relation to future predicted requirements.

5.1 Central systems are usually modular in design and additional hardware and software can be added later if the necessary provisions have been made in the basic system. Each manufacturer's system comprises standard "off the shelf" hardware, but the application is always tailored to the specific project. Basically, any system is composed of four major parts (Figure 1).

5.1.1 A central control console and associated hardware are usually located in a control room close to the boiler room or chief engineer's office. The

TYPICAL CENTRAL CONTROL SYSTEM

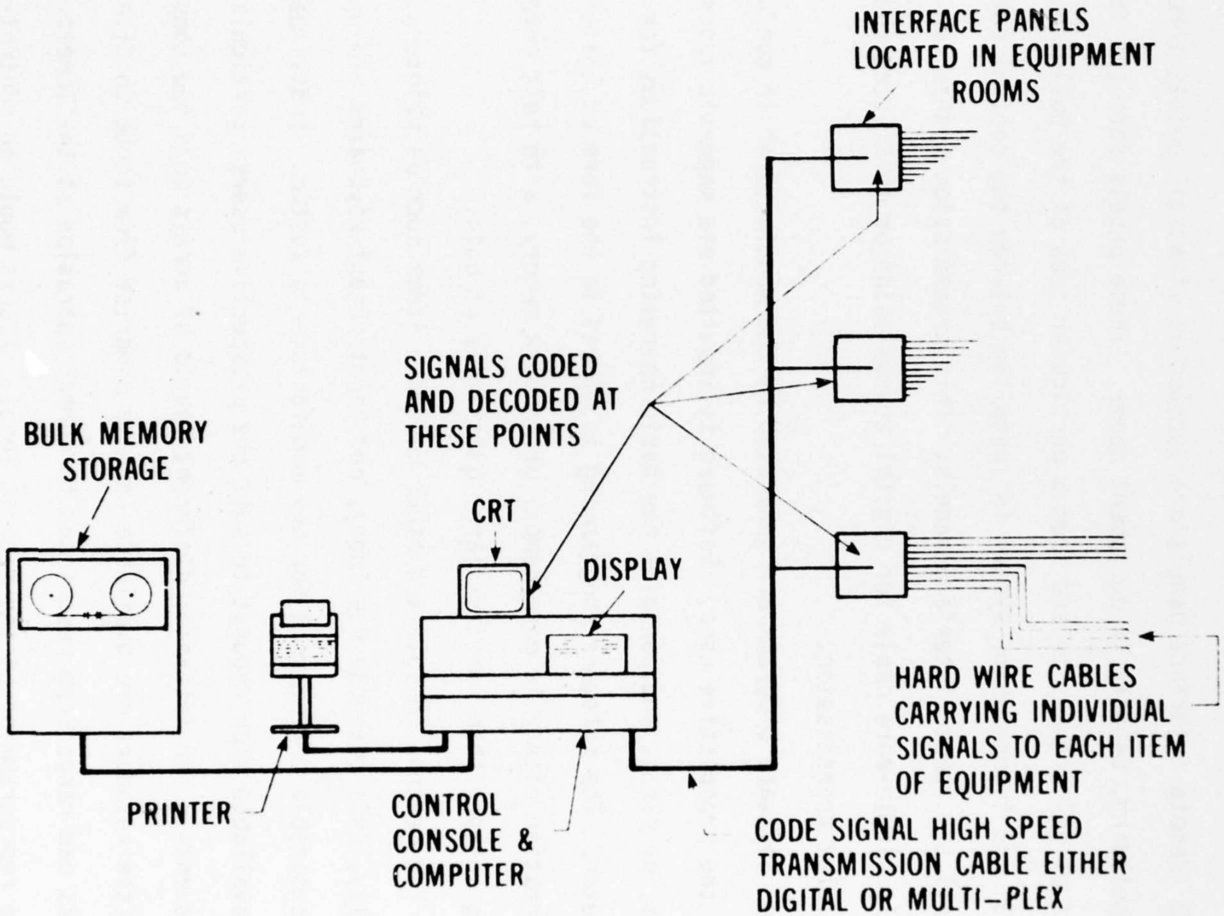

FIGURE 1

console, computer, and associated hardware are the point at which the operator enters all command instructions and retrieves all data. In addition, the computer can generate routine operating instructions according to preprogrammed contents.

5.1.2 Remote interface panels are located at strategic points throughout the building, usually in equipment rooms. These panels form the focal point of all signals to and from a particular area of the building.

5.1.3 The transmission system is installed between the control console and all the remote interface panels. This transmission system can be a simple single-core cable for digital transmission or multi-core cable for multiplex transmission.

5.1.4 Software programs are generated by the manufacturer in conjunction with the prospective user. Software is inputted via magnetic tapes, paper tapes, or cards, and contains the basic operating instructions for the computer. The software programming is stored in the form of "bits" of information either in core memory or in bulk memory, with bulk memory being cheaper than core for large quantities of data.

5.2 The central console and other hardware items such as printers, graphic display, CRTs (Cathode Ray Tube), and input/output keyboards are usually of comparable performance for any manufacturer's system. Individual options are available upon request to suit the prospective users' particular requirements. For instance, different levels of access into the computer from the keyboard are available and may comprise from three to five levels. Access can range from restricted to normal operation at the lowest level up to reprogramming at the highest level. Access would be controlled by key-switch since it is vital to protect the computer memory from accidental erasure.

5.3 The central processor or computer is usually supplied with integral core memory. Capacities typically vary from 16,000 to 64,000 words, each word containing 16 bits of information. Core memory is expensive compared with bulk memory and if it is felt that if the core capacity will be exceeded, then the addition of a bulk memory unit should be considered but the computer selected should be capable of interface with an external memory source.

5.3.1 Bulk memory can be either disc or tape, both having random access, with disc memory being preferred for control applications and they both typically have a capacity of 192,000 words.

6. Interface Requirements Between Computer and Equipment. To obtain maximum benefit from a central console system it is necessary to measure, monitor, and control many different items of equipment. The automated system must be interfaced with the existing equipment to obtain this information in rational form and to exert its control function, therefore the interface of two types of signal is usually required; binary signals which comprise only two alternatives (on/off, open/close, etc.) and analog signals which measure a value against a particular scale (temperature, pressure, etc.).

6.1 Binary singals are often used as instructions to start and stop equipment, open and close valves and dampers, etc. They are also used for retrieving data such as is the equipment on/off, open/closed, etc.

6.2 Analog signals are used as instructions to raise or lower temperature set points, adjust damper positions, raise or lower pressure set points, etc. They are also used for retrieving data from the sensors such as temperature, pressure, humidity, etc.

6.3 To aid in selecting a central control system, it is first necessary to assemble a complete list of all desired control and monitoring points under the two categories of binary and analog signals and to arrange them in groups to be served by each interface panel.

Table 1 shows some of the typical variables that can be handled by an Energy Control System and we can see the broad range of variables that can be monitored and controlled.

6.4 Depending on the type of existing controls, motor starters, contractors, etc., modifications, and additions may be required to allow satisfactory interface. For instance, if a motor starter does not have spare auxiliary contact, a relay must be added to the control circuit.

7. Signal Transmission. To make effective use of the computer's capabilities, information between the computer console and the interface panels must be transmitted at high speed in a format easily handled by the computer. The most convenient method of transmission is digital, where information is represented by pulses arranged serially and transmitted through a single core conductor. Digital cable is commonly coaxial although some systems use a twisted pair of insulated wires. Voice intercom may be carried over a separate screened cable.

7.1 Telephone cable is usually multi-core with the signals being multiplexed and transmitted in parallel. Typically the cable will comprise

VARIABLE	EXAMPLE	TYPICAL APPLICATION
Air Temperature	Outdoor, return, and mixed air.	Monitor system performance, detect out of limit conditions, enthalpy control, reset control points to meet changing loads, fire detection.
Humidity	Outdoor, return, and mixed air.	Monitor system performance, detect out of limit conditions, enthalpy control.
Fluid Temperature	Chilled water, heated water, domestic hot water, process fluids.	Monitor system performance, detect out of limit conditions, reset control points to meet changing load conditions, chiller optimization.
Machine component Temperatures	Bearings in chillers, fans, and pumps.	Maintenance scheduling, detect problems before failure occurs.
Pressure	Air, water, steam, etc.	Monitoring system performance, detect out of limit conditions.
Pressure Drop	ΔP across filters, through heating and cooling apparatus, etc.	Monitor system performance, maintenance scheduling.
Flow	Steam, air gas, liquid	Totalizing (determining consumption), determine whether air handling unit is on or off, etc.
Power Input	Power to lights, elevators, machinery, furnaces, etc.	Demand limiting, chiller optimization.
Equipment Status	Boilers, pumps, fans, etc.	Monitoring status (on or off), starting, stopping, etc.
Product of Combustion		Fire & smoke detection.
PH	Water	Water treatment--cooling towers, boilers, etc.
Contact Closure		Starting-stopping equipment; security; doors locked, unlocked, etc.

TYPICAL VARIABLES HANDLED BY ECS

TABLE 1

between 50 and 100 separate wires and have an overall diameter of one inch. Multiplex cable is more difficult to install than the coaxial, particularly in existing buildings, where empty conduits and throughways are not available.

7.2 Some systems still use multiplex cable on the grounds that analog signals should be transmitted in unmodified form to the interface panels where they are converted from analog to digital form with a small loss of accuracy. Conversely, analog signals are sensitive to interference from "spikes" and other spurious signals induced by adjacent building wiring, whereas digital signals are not subject to interference.

7.3 In order to reduce the high installation cost of coaxial cable, existing telephone wires can be used, however, modems must be installed Phone lines are designed to send audio signals while digital signals are used by the control equipment. Modems bridge the interface between these two types of signals. The system works as follows: a modem converts pulses (digital signals) to continuous waves (modulated audio signal) that will not be degraded when transmitted over a telephone line; a modem can then reconvert the incoming signals back into digital pulses. One modem is connected to the central console and another modem is connected to each remote panel. Then, existing telephone lines are tied into the modems, thereby completing the circuit. A remote panel sends a digital signal to its modem which changes the signal to audio. This signal is transmitted to the central console's modem which transforms it back to the original digital pulse.

7.4 Whether or not existing telephone lines can be utilized for data transmission depends on the availability of enough spare pairs in the telephone cables that run to each of the buildings in which the remote panels are located. Since many military bases own their own telephone lines, it is assumed that no leasing charge will be incurred for the use of the telephone line network. The only costs are the initial capital cost of the modems and the connection cost between the phone lines and the modems.

7.5 When selecting a central control system, the different characteristics of the transmission methods must be analyzed and a choice made based on the particular circumstances. Generally, digital transmission systems provide more options for later additions because multiplex systems have a finite limit of the number of points that can be connected.

8. Computer Software. Standard software or programs for computerized building control applications are usually available from the manufacturer. These programs can take over many of the functions of a trained operator. Each of the major controls manufacturers has a library of application programs which have been developed over a number of years. The cost of these programs is low compared to custom written software. When selecting a central control system, investigating the library of programs available according to their extent and range is a good indication of a particular manufacturer's commitment and ability in the computer control field.

8.1 Programmed Functions. In addition to all the control capabilities of a local control system, some of the typical functions which can be provided by the computerized control system, through programming, include equipment optimization, maintenance scheduling, management information and security.

8.2 Start/Stop Optimization. For purposes of management control, building comfort conditioning equipment start and stop times usually are fixed. That is, systems usually are activated at that time which generally will ensure achievement of desired comfort levels when the first building occupants arrive. Likewise, systems are deactivated when most occupants have left. If a variety of indoor and outdoor factors could be considered each day however, start/stop times could be set on the basis of variable rather than fixed schedules, thus achieving start/stop optimization. Computerized monitoring and control can achieve precisely such optimization by monitoring outdoor air temperature, solar effects (including presence of cloud cover, etc.), indooor temperature and humidity, and thermal mass of the building. Calculation and analysis of such data can then determine when systems should be started and stopped.

8.2.1 For example, Figure 2 is a plot of the load and temperature drift for an office building during a weekday of relatively cold weather. Note that equipment shutdown occurred at 1600 hrs., with start up seven hours later. However, full recovery was not complete until 1100 hrs., the following morning, twelve hours after start up of equipment. If the outside air temperature had been higher, start up could have been delayed longer than seven hours with full recovery occurring sooner than 1100 hrs. This particular function can result in significant energy savings when one considers the many different energy-consuming elements (fans, pumps, chillers, etc.) of the systems involved.

EXTREME HEATING LOAD AND ROOM TEMPERATURE DRIFT FOR OFFICE BUILDING DURING WEEKDAY

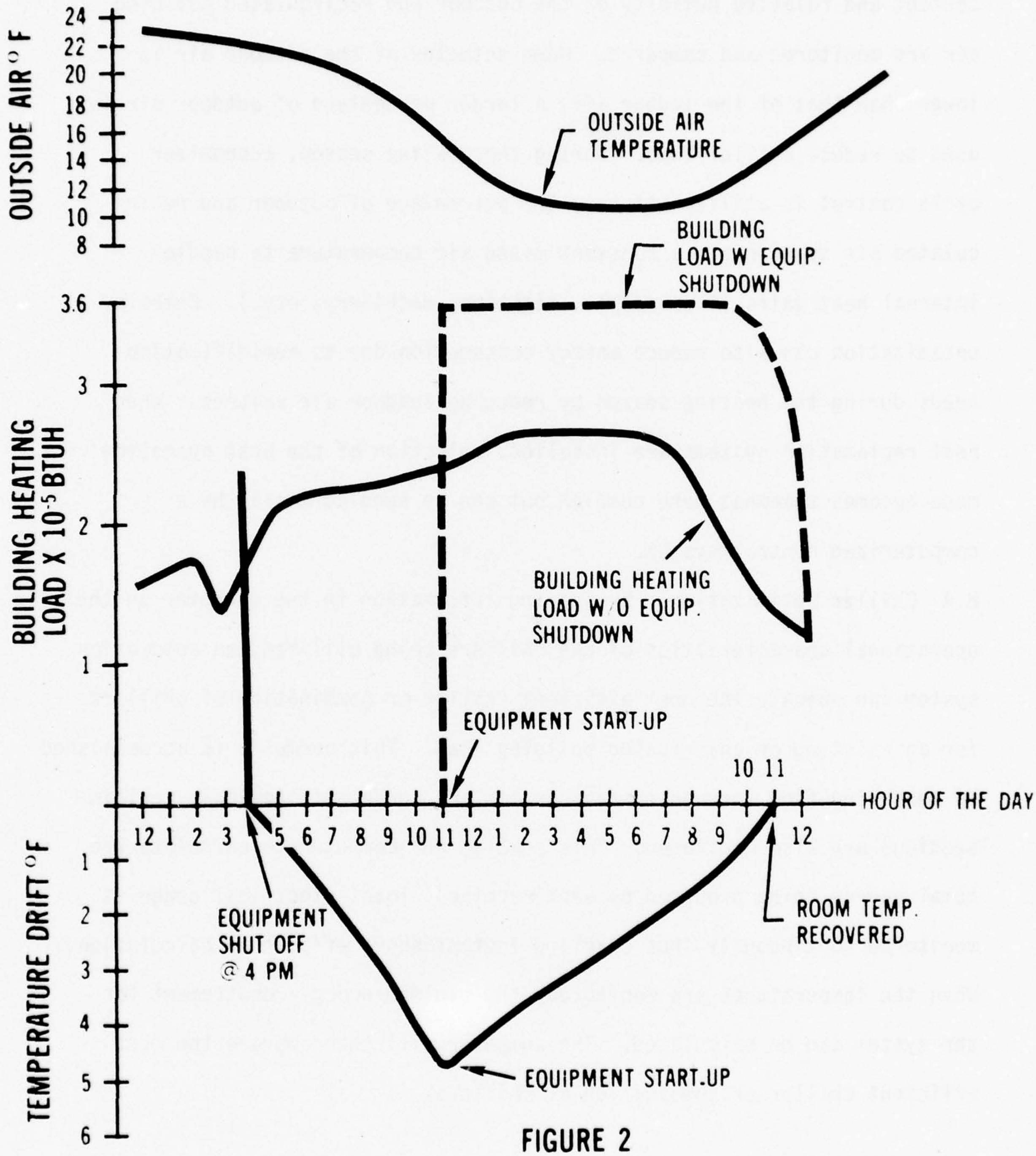

FIGURE 2

8.3 Enthalpy Optimization. Enthalpy optimization is also known as outdoor air optimization. During the cooling season, the total heat content and relative humidity of the outdoor and recirculated building air are monitored and compared. When enthalpy of the outdoor air is lower than that of the indoor air, a larger percentage of outdoor air is used to reduce chiller load. During the heating season, economizer cycle control is utilized to vary the percentage of outdoor and recirculated air to maintain a constant mixed air temperature to handle internal heat gains (from people, lighting, machinery, etc.). Enthalpy optimization can also reduce energy consumption due to humidification needs during the heating season by reducing outdoor air volumes. When heat reclamation systems are installed, selection of the best operating mode becomes somewhat more complex but can be handled easily by a computerized control system.

8.4 Chiller Optimization. *By storing information in the computer on the* operational characteristics of the chillers being utilized, an automation system can operate the most efficient chiller or combination of chillers for an existing or anticipated building load. This normally is accomplished by measuring flow through the evaporator and condenser sections; reclaim sections are also monitored. This enables the computer to calculate the total energy being produced by each machine. Total electrical usage is monitored continuously thus enabling instantaneous efficiency calculations. When the temperatures are monitored, the minimum energy requirement for the system can be calculated. The computer will then operate the most efficient chiller or combination of chillers.

8.4.1 Chiller efficiency as monitored by the computer is continuously entered into memory and updated so that the system is always working with the latest information. If the need for heating or cooling energy is determined late in the day, chillers will not be started if the building will soon be unoccupied. Accordingly, chiller optimization normally is an integral part of the start/stop time optimization.

8.4.2 One of the simplest methods of providing chiller optimization is through control of chilled water supply temperature by monitoring the chilled water return temperature and reducing condenser water temperature. By reducing condenser water temperature, the cooling tower fans run more. The computer can calculate which will use less energy - chillers on with reduced condenser water temperature or cooling tower fans - and select the arrangement that uses the least energy.

8.5 The computer can also be used to calculate BTU and flow data for water and steam on boilers and chillers thus eliminating a need for individual metering devices. Since characteristics of air can be determined by any two variables - dry-bulb temperature and relative humidity are used most frequently - simple programs can be developed to obtain data on other variables as needed.

8.6 Many comfort conditioning systems have individual system controls for switching from cooling season mode to heating season mode or vice versa. During intermediate fall and spring seasons, conditions requiring changeover can occur at any time of day. Depending on its degree of sophistication, the system can either tell the operator when the switch-over should take place or can make the switchover automatically.

8.7 Lighting Optimization. An effective program of lighting control requires circuiting that enables selected or staggered portions of lighting to be extinguished while leaving enough light for activities such as after-hours cleaning, maintenance, and multishift operations. Lobby and ornamental lighting are areas where savings can be realized, especially to hold down peak electrical demand.

8.8 Electrical Demand Limiting. Electric utilities charge for the amount of electrical energy used and for the maximum amount of energy which the customer demands in any given 15- or 30-minute period. In some cases the maximum amount required during a 15-minute period establishes the demand rate for the entire year.

8.8.1 Figure 3 shows the demand level of a certain military installation for the peak day of the year which is shown in Figure 4. The peak demand, during the month of August, was recorded to be 21,158kW, which resulted in a monthly demand charge of $65,590 at $3.10 per kW demand. Further, it can be seen from Figure 4 that this peak affected the billing policy which states that the peak kW that will be used for billing in a particular month is the greater of the following two numbers: (1) the highest peak for the current month or (2) 85% of the peak value during the previous six months. This results in the artificially high value of 17,984 kW (85% of 21,158 kW) shown for October through February at a cost of $55,751 per month. Thus, if the customer can lower peak demand, energy cost savings of 15% or more may be achieved.

8.8.2 Lowering of the peak demand usually begins with the identification of loads which can be shed during peak demand periods. These secondary

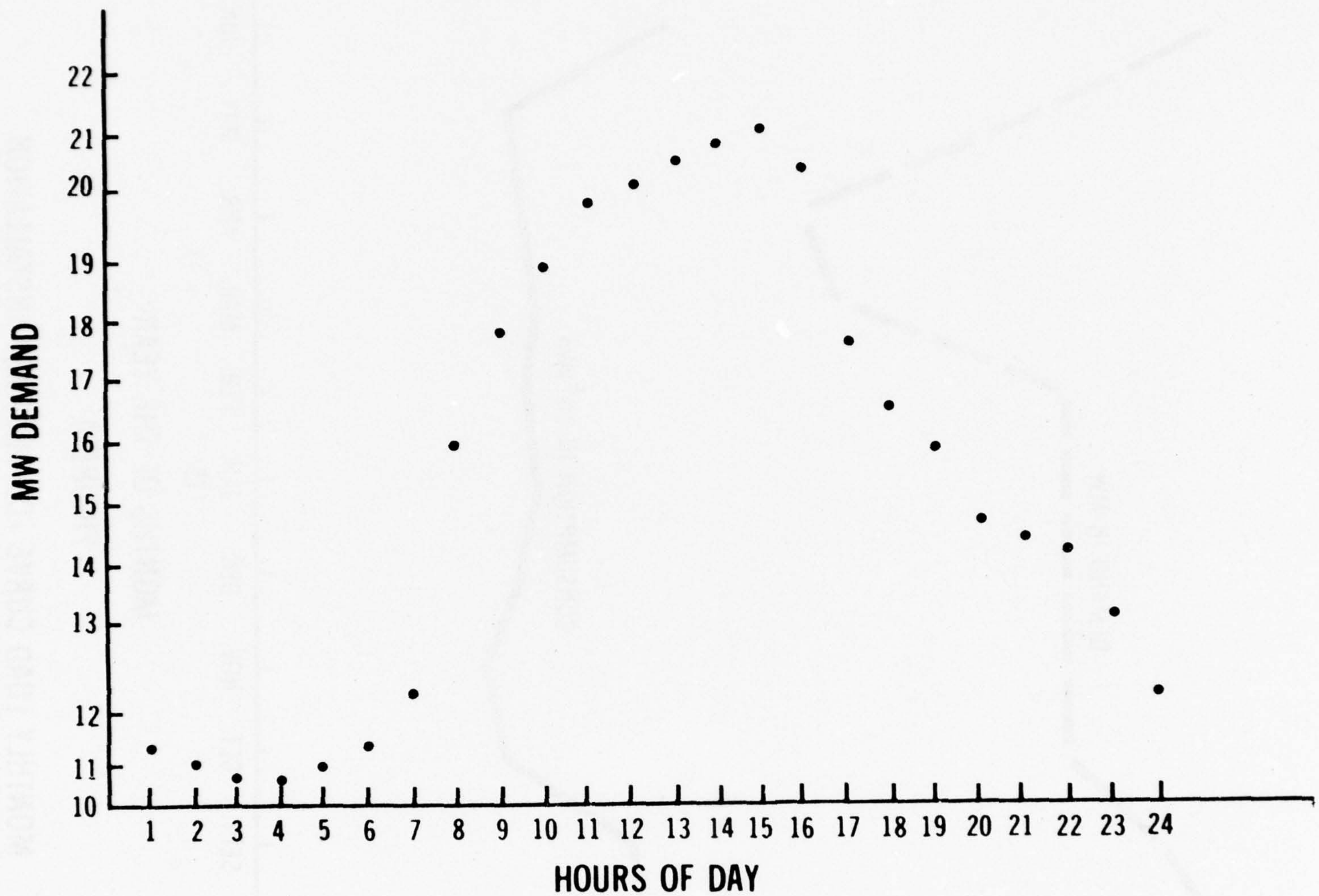

FIGURE 3

HOURLY LOAD CURVE FOR PEAK DAY

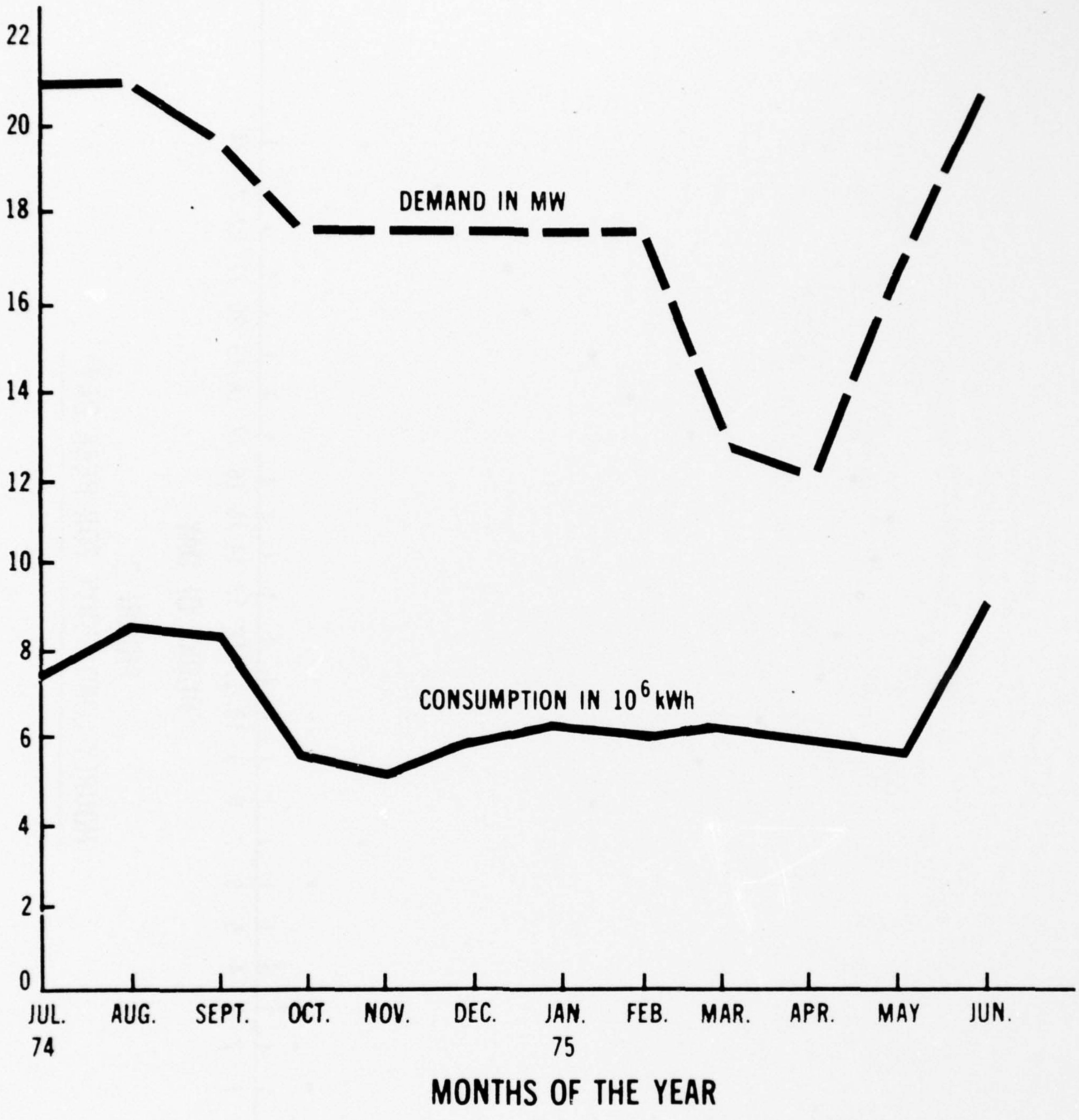

FIGURE 4

MONTHLY LOAD CURVE FOR MILITARY INSTALLATION (or "sheddable") loads are then connected into the demand limiting element of the automation system which can automatically shed them as the maximum demand limit is approached.

8.8.3 Most computer systems which can handle automatic power demand measurement and load shedding can accommodate up to 20 load groups (where a large number of motors in the one half to 20-horsepower range can be connected in series or groups to be shed at the same time). In most cases much of the lighting in a large commercial building can be shed for a few minutes out of each interval without the occupants even being aware of the reduced lighting. The same applies to ventilation fans, sewage ejection pumps, deep freeze motors, and other miscellaneous power users. Most chillers can be throttled back for a short term during each interval without any appreciable effort on the cooling capacity.

8.9 A word of caution is needed here and that is that not all of these programs can be applied to all types of buildings without some rework to the HVAC equipment or if the equipment does not lend itself to a particular mode of control. For example, to take advantage of an electric demand limiting program through reduced lighting requires that the circuiting be such that it can accomplish this feature. If all of the lighting for a particular room or group of rooms is on one circuit, the lighting load obviously cannot be reduced without turning off all the lights which is unacceptable. Automatic adjustment of thermostat settings for night setback cannot be accomplished unless existing thermostats are capable of remote adjustment. Automatic centrifugal chiller optimization cannot be achieved unless the inlet vanes are capable of automatic adjustment.

Enthalpy optimization is not possible on buildings with radiator or fan-coil heating. In most cases, just plain common sense can determine the features and benefits that can be applied with little or no retrofit to existing equipment.

8.10 Equipment Maintenance Scheduling. Although a computerized building automation system cannot perform maintenance, it can be programmed (depending on the specific type system involved) to provide printouts of regular maintenance procedures which must be undertaken, as well as notification of unscheduled maintenance procedures which may be required. There are at least four ways in which maintenance scheduling can be handled.

8.10.1 The calendar time method obviously is the easiest and most direct way to schedule maintenance. For example, every 20 days maintenance men could be instructed to change all air handling unit filters or once-a-month instructions can be given to grease and lubricate certain equipment, clean luminaries, etc.

Since all machinery does not run on a regular schedule, calendar time scheduling for many items is not sufficient. Accordingly, the computer can be set to accumulate running time of certain equipment and, after a predetermined number of running hours for each item, print out maintenance instructions at the appropriate time.

8.10.2 In certain cases the amount of time a piece of equipment runs will not be an accurate indicator of its operating efficiency or need for maintenance. Since the computer can calculate equipment operating efficiency on the basis of raw data inputs, it can be programmed to provide maintenance instruction when efficiency deteriorates to a certain predetermined level.

8.10.3 The system can also be designed to provide early warning of impending equipment failure. As one example, bearings of certain pieces of equipment can be monitored for vibration and/or temperature. When the vibration or temperature level increases to a certain predetermined level, an immediate, unscheduled maintenance problem is indicated. It also would be feasible for the computer to stop the particular piece of equipment involved - or the entire system of which it is a component, if necessary - until the needed maintenance is performed.

8.11 Management Information. Computerized systems are also able to provide valuable management functions that can produce a signficant return on investment and enable additional control of energy consumption and cost. The computer's ability to store data, compute "indirect" analog quantities directly related to energy consumption (such as BTU's, kilowatt hours, or tons of steam), and to provide hard copy record of these values is essential to effective planning for long term energy conservation practices. For example, an energy usage profile, printed by the computer, is a convenient graphic representation of consumption patterns by hour, day, month, or year. With a computer, virtually any desired combination of actual performance parameters can be stored and subsequently extracted in hard copy in whatever form may be most convenient for analysis. While it is difficult to place definite dollar values on these management features, they nevertheless are useful and valuable tools for planning and implementing effective energy conservation.

8.12 Security. There are several typical applications for the security component of a computerized control system if needed or desired. Door security and control are achieved by a signaling device for use by those wishing to gain entrance. An intercom can be used for the operator to ascertain the identity of the person. If he is to be allowed in, the operator can activate an electro-mechanical device which releases the door. Closed-circuit television (CCTV) and magnetically coded identification cards can be used to supplement or replace certain elements of this system.

8.12.1 Closed-circuit television cameras can be placed to monitor selected doors, isolated pedestrain tunnels, certain stairwells, large open areas (such as malls or parking lots), etc. The security or central console can have one viewer for each camera.

8.12.2 Intrusion protection usually consists of monitoring devices attached to possible ingresses and connected to the central console. Typical devices are the familar strips of metallic foil placed on a window which activates an electric beam; infrared beams; vibration detection devices; ultrasonic motion detectors; video motion detectors; microwave detectors (which sense disturbances in the electromagnetic field); electrical capacitance detectors (for small areas), and so on. Selected objects, such as file cabinets and vaults, can be fitted with devices which sense changes in electrical capacitance or vibration.

8.12.3 A transmitter-receiver can be built into the console for communication with guards who would carry walkie-talkies; or the operator can signal guards to communicate by activating a light at the guard tour station. Also, a guard can notify the operator of his position on his tour of duty by activating signals at each of his tour stations.

8.13 Fire Security. Automated building control is an invaluable asset for purposes of fire detection and alarm. The computer can be designed to continuously monitor the entire building's fire detection and alarm network, including flame and smoke detectors, thermal fire detectors, firestats, sprinkler alarms, etc. Any off-normal condition can be reported immediately, along with the type and location of the device triggered. Depending on the sophistication of the system, certain control functions can be implemented automatically with or without the presence of an operator. Such functions could include notifying the nearest fire station of a problem activation of sprinkler systems, activation of audible alarms, and even activation of selected prerecorded tapes for building-wide transmission providing clear, distinct instructions - programmable so that selected instructions are broadcast to the respective areas of the building to which they apply.

9. Building Selection. Although most buildings and their HVAC equipment can be controlled, either manually or automatically, not all buildings will be good candidates for installation of automated control systems. Four major factors may be identified which affect the energy savings and control system cost potential of most buildings, and they are: a) building size; b) usage pattern; c) heating and cooling system, and d) relative building location. These factors should be examined before deciding which buildings are most suitable for control purposes.

9.1 Building size is usually the most significant factor in the selection process. The greater the total floor area, the greater the energy consumption. One notable exception is in warehouses and repair shop buildings. By nature these buildings encompass large floor areas which are usually not centrally heated or cooled. The supervisor offices, a small percent of the floor area, are usually cooled by window units or small package direct expansion systems. Work areas are usually ventilated during the summer and heated in winter by unit heaters since air temperatures do not need to be as closely maintained as in an office complex. Therefore, energy consumption by the heating and cooling system will be relatively small compared to the total floor area. Heavy energy consumption in a machine shop will probably be due to process equipment rather than the heating and cooling system. In general, the larger office and administrative buildings with large HVAC systems are the most attractive for connection to a central system. Smaller buildings having a variety of HVAC systems may be better suited for connection to localized control systems. In a study of Fort Belvoir, Virginia, buildings with more than 10,000 square feet were the most attractive for connection to a central system while smaller building having a variety of HVAC systems throughout the structure were more attractive for local control.

9.2 Patterns of building usage can affect energy consumption to a large extent. Recreational centers with heavy occupancy tend to be the greatest consumers of energy followed by office and residential buildings. Most buildings can be loosely categorized by one of these three types of occupancy.

a. Evening occupancy which generally involves recreational buildings such as bowling alleys and theaters. The time range is approximately 1700 - 2400 hrs.

b. Office occupancy which is confined to buildings used during the typical work day. The time range is approximately 0730 - 1630 hrs.

c. Residential occupancy which is essentially late evening and early morning. The time range is approximately 1800 - 0600 hrs.

9.3 The type of heating and cooling system serving the building can influence the energy savings potential as well as the expense of conversion to a central control system. Generally, the central heating and cooling systems found in larger, more complex buildings usually produce the greatest savings potential. System components such as air handling units, chillers, and boilers are usually located in the same area of the building, thus simplifying control system modifications.

9.3.1 Smaller buildings tend to have a conglomeration of widely distributed window units and unit heaters which are difficult and expensive to adapt to a central energy control system; and since smaller buildings tend to have small savings potential, the expense of tying into an ECS may not be justified. In some cases, a system of local control may be more cost effective.

9.4 Another major cost factor in central systems costs is wiring and transmission expenses. This interconnection cost is usually a function of building location relative to its remote panel and to the central console. The use of telephone lines between the remote panel and the central console will usually not incur any expense, but where spare telephone lines do not exist, installing additional telephone link capacity or coaxial cable must be included in the system cost estimate.

9.4.1 The connection between the equipment control points and the remote panel in each building also represents an expense. In some cases, the larger energy using facilities require many points and are a considerable distance from other facilities. For this reason, many office and recreational buildings will offer the best possibilities for controlling several facilities through one remote panel. Where possible, multiple building connection to one remote panel is usually cheaper than installing a remote panel in each structure in spite of increasing wiring costs.

9.4.2 An exception to this is the local control system, where wiring from equipment control point to controller is always within one building and where there is no need for telephone lines interfacing, building location is not a significant cost consideration. Again, isolated buildings or small energy using facilities without spare telephone lines lend themselves very well to local automatic control.

10. Economic Feasibility. Obviously, we are talking about an expensive and sometimes complex system that may not always prove feasible to install. Progressive engineering technology has resulted in the production of a hierarchy of increasingly sophisticated Energy Control Systems, each designed to satisfy a particular energy conservation goal and each having unique investment and operating cost requirements. Due to the variety of ECS designs and installations for which they are designed to serve, there is not necessarily a straight-line relationship between costs and benefits as ECSs become more sophisticated. In other words, the point at which increasing costs fail to yield increasing benefits will vary from installation to installation and even among individual facilities within a single installation. For this reason, it is necessary to measure the investment merits of ECSs on a case-by-case basis. However, in order to evaluate alternate systems, the methodology of analysis must be uniform and unprejudiced towards either the high capital investment/low expense or low capital investment/high expense systems. Life-cycle costing is one analysis technique which can accomplish this.

10.1 Life-cycle costing is a method of financial evaluation which recognizes all the finanical requirements and benefits of a system in terms of cash outlays and benefits. In brief, this technique measures the discounted present value of an investment against the discounted present value of its corresponding benefits and energy savings based upon the timing of cash flows.

10.1.1 In order to perform life-cycle analysis, a baseline case must first be established for the present situation, and then for each ECS alternative, the savings/investment ratio should be calculated. The purpose of quantifying a baseline case is to firmly establish a standard against which all alternatives will be measured and from which benefits will be computed. The analyst must project on an annual basis all the energy-related recurring and capital replacement costs associated with the status quo, i.e., what the costs are expected to be without implementing an ECS or other expense-borne conservation measures. Then the projected savings/investment for each ECS alternative can be calculated and should include a cost and benefit analysis.

10.2 The cost of the ECS can usually be broken down into two categories - recurring and nonrecurring. Recurring costs include operating and maintenance expenses plus continuing training costs for maintaining a high level of operator competence. Principal nonrecurring costs are the initial capital investments in obtaining the system itself plus equipment replacement cost so that the entire system can be controlled. In addition, housing for the ECS control center may be needed. This is because from a communications standpoint, the central console should be located near a telephone junction in a phone line system.

10.3 The benefit analysis or economic justification can be found through projected energy savings for heating, cooling, and demand charge reductions calculated in dollars per year for the given combination of control schemes. Additional savings may also be realized through manpower cutbacks, although certain trade unions may object to men being replaced by computers.

10.4 We now can determine the discounted present value of the ECS cost and benefits, which will consider the time value of money. That is, a future cost of an ECS which is discounted since a delayed investment means an extended period of return on the uninvested capital. Similarly, future benefits are discounted because they would represent greater value if they were available for investment at the present time. Therefore, each annual cost and benefit must be multiplied by the discount factor for the year in which the cost or benefit occurs.

10.5 The savings/investment (S/I) ratio can now be calculated for the analysis result. In theory, the higher the S/I ratio, the shorter the payback period on the ECS project. The payback period may also be calculated by summing the net annual savings (benefits less annual cost) until the initial capital investment is amortized.

10.6 The most obvious indicator of control system value would be the difference between associated system benefits and costs over a selected payback period. In the case where a specified energy saving figure is the goal, a benefit/cost ratio would be more appropriate means of measuring system economic feasibility. However, the comparison of resource efficiencies among the different levels of control should be tempered by the consideration of certain intangible differences between local and central control systems.

11. Secondary Benefits of Energy Control Systems. The value of maintenance and equipment performance documentation, increased speed of response to alarm conditions, and improved utilization of manpower can be credited to central systems, although these benefits are difficult to quantify in general applications. Most buildings and facilities can achieve maximum resource efficiency by a combination of local and central automatic controls, with the ECS controlling the larger capacity energy-using systems or systems where frequent supervision is desirable, and local controls installed in smaller capacity, noncritical HVAC systems. In general, the basic benefits of building automation are improved effectiveness of operating personnel and equipment, reduced operating costs, increased comfort and safety for building occupants, and greater security and asset protection.

11.1 So before any type of control system is purchased, its use should be thoroughly analyzed in order to select the most reasonable and most effective system for a particular application. Along with cost, which is the primary consideration, we also have to consider versatility, simplicity, and reliability. The system should be versatile enough to accommodate any future changes or additions; it must be simple enough in its operation so that it can be operated by average maintenance personnel; and it must be reliable enough to perform its functions without constant monitoring and repair to keep it running properly.

11.2 In conclusion, facilities automation systems have a definite role to play in positively attacking the problems of increasing cost and energy shortages. Properly applied, they can permit substantial reductions in the life-cycle cost of new buildings, as well as the operating cost of existing buildings.

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