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This report provides guidance for the selection and evaluation of both applications and equipment for energy monitoring and control systems (EMCS) at U. S. Army installations. The guidance is in the form of information relative to the potential application and their associated savings, the various types of EMCS available and their costs, and a method of comparing the costs to the potential savings in order to determine economic feasibility.

CONTENTS

SUMMARY

This report provides guidance for the selection and evaluation of both applications and equipment for energy monitoring and control systems (EMCS) at U.S. Army installations. The guidance is in the form of information relative to the potential application and their associated savings, the various types of EMCS available and their costs, and a method of comparing the costs to the potential savings in order to determine economic feasibility.

PREFACE

The recent escalation in the price of energy has provided impetus to the Army to investigate better ways to achieve effective use of the nation's 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 heating, ventilating and air conditioning systems and similar equipment to achieve energy savings has been only lightly addressed.

A 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. Growth and expansion occurred primarily during a time when neither the technology nor justification existed 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.

This manual has been written to provide information by which facilities engineers and Corps of Engineers Division/District personnel can evaluate designs, estimate costs, and establish benefits of energy monitoring and control systems to be considered for application in existing facilities and new construction. This manual was completed before the tri-service specification was available. Some of the materials listed in this manual may not conform with the tri-service specification, however the manual may be used for the above purposes.

CHAPTER 1 - INTRODUCTION

Primary emphasis in this study is placed in obtaining savings through automatic control of existing heating, ventilating, and air conditioning (HVAC) systems by an appropriate energy monitoring & control system (EMCS).* HVAC systems are major energy consumers at almost every Army facility. They can generally be adapted to automatic control with only minor alterations of existing control devices. Through judicious operation of these HVAC systems, it is possible to reduce both total energy consumption and peak demand. EMCS can also serve to improve the maintenance activity and provide lighting control. Performance of these auxiliary functions contribute to the total savings and should be included when comparing systems of differing capabilities.

In this manual the term "EMCS" is used to denote the application of an automatic control system to the monitoring and control of energy consuming equipment. The term "automatic control system: is used to refer to the physical devices, particularly the computer unit, used in an EMCS application.

1.1 Reduction in Energy Consumption

Considerable energy and dollar savings can be achieved through use of various conservation schemes. These include programmed equipment shutoff, outside air shutoff and system performance optimization. In many cases, the savings in energy cost from these schemes alone will justify the required financial outlay for the control system. In addition, reduction in direct energy consumption will also reduce energy losses associated with distribution of the electrical power and reduce the fuel requirements of the generation plants.

1.2 Reduction in Peak Demand

Further dollar and energy savings may be realized through peak shaving. This technique involves the shutdown of equipment during the peak electrical consumption hours, thus reducing peak demand. Reducing peak demand will have significant effect on the total billing from the utility supplier when rate schedules incorporate a demand charge that extends for several months after the occurrence of the peak. A net reduction in energy consumption is realized in situations where equipment shutdown eliminates, rather than delays, equipment operations. Classic examples of energy saving from equipment shutdown would be in ventilating and lighting applications.

1.3 Improved Maintenance Activity

The application of energy monitoring and control systems to maintenance functions can result in energy, dollars, equipment support and maintenance savings. These savings result from optimized equipment operation due to:

a) reduced equipment runtime,
b) monitoring of equipment condition,
c) preventive maintenance scheduling, and
d) maintenance documentation.

* Definitions of this and other specialized terms are tabulated in the glossary section of this manual.

1.4 Lighting Control

Lighting control is frequently mentioned as an area suitable for control. Like HVAC equipment, lighting is a function that can be eliminated or greatly reduced during periods when the area is unoccupied. Worth-while savings may be achieved in new buildings designed for interior lighting control. Effecting a meaningful reduction of energy consumption by control of existing lighting is more difficult. First, as it is normal for lights to be turned off when an area is unoccupied, the additional savings available from optimum operation is limited. Second, usage of existing electric circuits tends to be mixed. Lighting equipment is frequently on the same circuit as items requiring continuous power such as instrumentation, time clocks, and battery chargers. These difficulties are offset by the ease of physically effecting control of lighting circuits, the lack of impact upon other functions, and the exactness with which estimates of possible energy savings can be made.

CHAPTER 2 - USE OF MANUAL

This manual is designed to aid in the estimation of cost and benefits of an energy monitoring and control system. Subsequent chapters in this manual are organized to provide step-by-step guidance to the facilities engineer. Figure 2-1 illustrates the evaluation procedure used to determine the costs and benefits from various control schemes and building combinations.

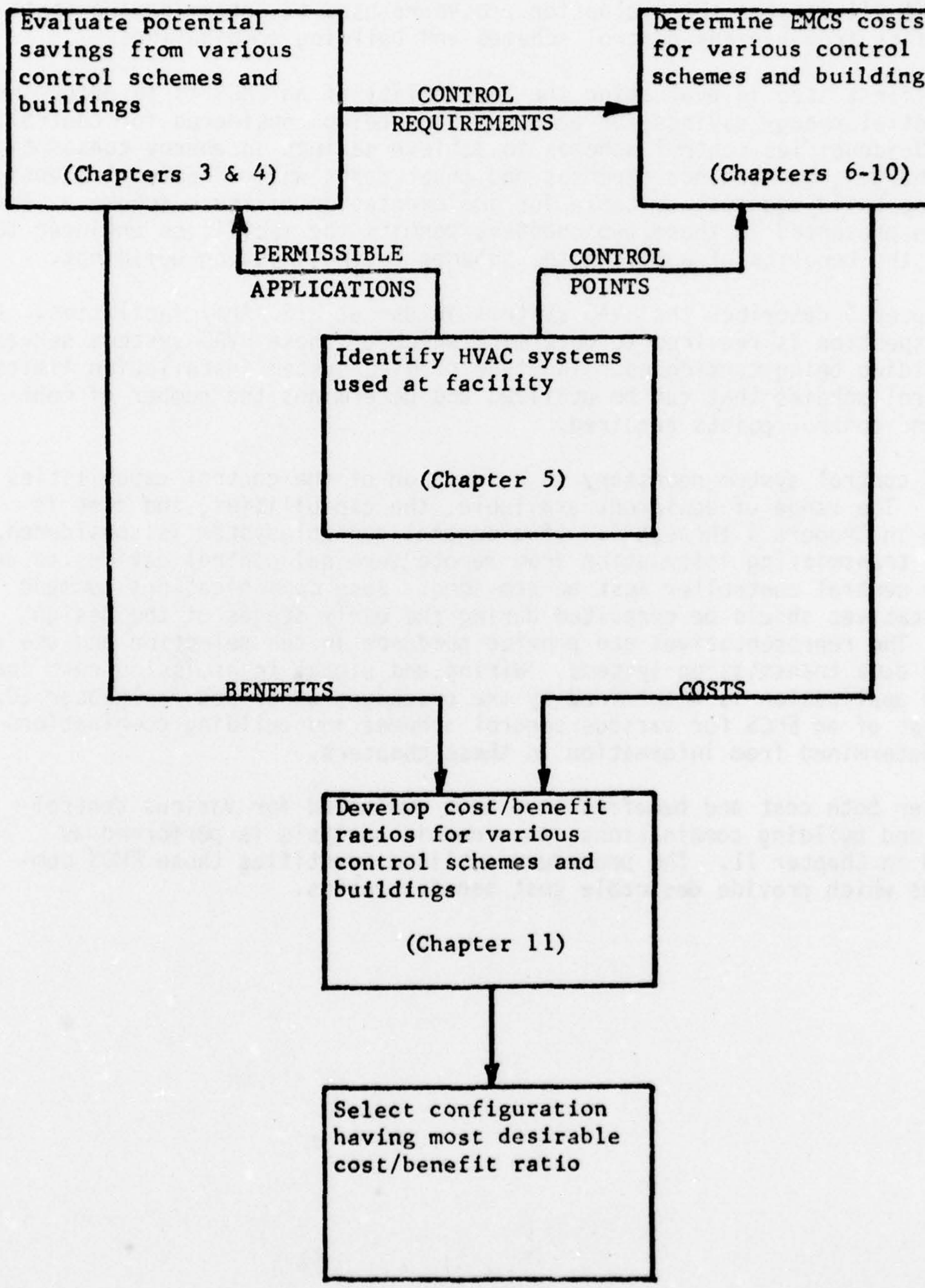
The first step in evaluating the feasibility of an EMCS is to determine the potential energy savings for each building being considered for control. Chapter 3 identifies control schemes to achieve savings in energy consumption, demand charges, maintenance expenses and other costs while Chapter 4 identifies those buildings most suitable for implementation of these schemes. Information presented in these two chapters permits the facilities engineer to estimate the benefits of applying the schemes to the existing buildings.

Chapter 5 describes the HVAC systems in use at U.S. Army facilities. A local inspection is required to determine which of these HVAC systems serves each building being considered. The type of HVAC system installation limits the control schemes that can be utilized and determines the number of monitoring and control points required.

The control system necessary is a function of the control capabilities desired. The range of equipment available, the capabilities, and cost is explored in Chapers 6 through 9. If a central control system is considered, a means of transmitting information from remote terminal control devices to and from the central controller must be provided. Base Communications Command representatives should be consulted during the early stages of the design effort. The representatives can provide guidance in the selection and use of proposed data transmission systems. Wiring and signal transmission cost for a specific application is determined by the procedure described in Chapter 10. Total cost of an EMCS for various control schemes and building combinations can be determined from information in these chapters.

After both cost and benefits have been evaluated for various control schemes and building combinations, an economic analysis is performed as outlined in Chapter 11. The procedure outlined identifies those EMCS combinations which provide desirable cost benefit ratios.

PROCEDURE FOR DEVELOPING COST BENEFIT RATIOS FOR EMCS APPLICATIONS



CHAPTER 3 - APPLICATIONS FOR EMCS

Control devices suitable for HVAC equipment control present a range of capabilities extending from simple time clock control of start/stop switches to implementing complex forecasting and optimization functions. As will be shown in later chapters of this manual, a trade-off exists between the ultimate capability and its cost and complexity of use. To logically determine what capability is needed, each possible application for an EMCS must be considered and an estimate of the annual savings generated. The annual savings can thus form the basis for judging the worthiness of purchasing the more expensive and more complex automatic control system. In this section, a description of possible applications, together with possible benefits and special equipment requirements, will be presented. Potential applications for an EMCS are summarized in Table 3-1.

Savings resulting from implementation of either a single application or a combination of applications is site dependent. Four major factors that affect total energy savings are:

a) building size and construction,
b) building function (from people and process),
c) building usage pattern, and
d) type and capacity of installed HVAC equipment. Previous studies* of buildings at a specific U. S. Army facility (Ft. Belvoir, Va.) have investigated energy consumption and possible energy savings through use of an EMCS. For certain buildings at that site, applications 1, 2 and 6 were found to yield the largest reductions in energy consumption.

3.1 Scheduling of Loads

Programmed shutoff of building heating and cooling equipment during unoccupied periods results in significant energy savings, the magnitude depends on the heat transfer characteristics of the building, equipment capacity and type, operating efficiency, and many other factors. The basic approach is to shut down the heating and cooling system when a building is unused and allow room temperature to drift. The system is reactivated to recover room temperatures before occupancy is resumed. Scheduling may be changed periodically to account for seasonal weather variations. This application needs a binary input and a start/stop output point for each unit of equipment. Control is initiated by a time clock function.

3.2 Shutoff of Outside Air

During periods when the building is unoccupied, it is frequently possible to shut off the outside air intakes even if the heating or cooling equipment were required to remain on. Outside air shutoff would reduce the heating or

* "Feasibility Study of Automatic Load Control for Fort Belvoir, Virginia", ED 76-6, U. S. Army Facilities Engineering Support Agency, Fort Belvoir, Virginia, 22060.

"Building Heating and Energy Consumption at Fixed Facilities, FESA-RT-2034, U. S. Army Facilities Engineering Support Agency, Fort Belvoir, Virginia, 22060.

TABLE 3-1

POTENTIAL APPLICATIONS FOR THE EMCS

1. <u>Scheduling of Loads</u>

   Individual loads are turned on and off at specified times to reflect building occupancy patterns.

2. <u>Shutoff of Outside Air Intake</u>

   Individual air intakes are closed and reopened at specified times to reflect building occupancy patterns.

3. <u>Temperature Setback</u>

   The setpoints for thermostat control are changed during certain time periods to reflect building occupancy patterns.

4. <u>Outside Air Reduction</u>

   Outside air intakes are set at minimum acceptable positions during certain time periods to reflect building occupancy patterns.

5. <u>Lighting Control</u>

   Lighting levels are reduced during specified time periods.

6. <u>Enthalpy Control</u>

   Outside air is used as a source of heating and cooling air when conditions are suitable.

7. <u>Enthalpy Optimization</u>

   Outside air is mixed with return air in proportions necessary to minimize heating/cooling load.

8. <u>Chiller Optimization</u>

   Load split between multiple chillers operating in parallel is adjusted to achieve the greatest system efficiency.

9. <u>Optimal Start/Stop</u>

   Based upon weather data and other information, individual loads are started and stopped to meet design conditions during specified time periods with minimum energy consumption.

10. <u>Load Cycling</u>

    Designated loads are periodically cycled on and off during operational period to reduce system demand and energy consumption.

POTENTIAL APPLICATIONS FOR THE EMCS (Cont.)

11. Predictive Demand Limit Control

Designated loads are cycled on and off as necessary to meet specified maximum demand limitations.

12. Run-time Totalization

Total run time for various equipment is tabulated for use in maintenance planning.

13. Equipment Malfunction Detection

Abnormal operation of equipment is detected and suitable alarms issued.

14. Boiler Plant Optimization

Weather predictions and other information is used to predict demand peaks. Load split between multiple boilers operating in parallel is adjusted to achieve the greatest system efficiency.

15. Energy Cost Allocation

Energy consumption by each load is monitored. The results are tabulated and used to allocate both direct and indirect costs.

cooling load at steady state operation and permit a faster transient if the building was in the process of being returned to occupancy level temperatures. The outside air shutoff feature needs binary input and reset control output for dampers and fans. Control is initiated by a time clock function.

3.3 Temperature Setback

If the building heating or cooling equipment is turned off, the building temperature will drift toward the outside temperature. It may be desirable to limit this drift for the protection of equipment in facilities. This is accomplished by installation of an additional thermostat and a reset (selection) switch. For each unit of equipment, a binary input and a reset control point will be required. Control is initiated by a time clock function.

3.4 Outside Air Reduction

If outside air intakes cannot be turned off entirely during periods of low building occupancy, it is frequently possible to reset the dampers at a minimum acceptable position during these periods. The dampers would thus have two positions, fully open and minimally open. The control system would need binary input and reset control output for dampers. Control is initiated by a time clock function.

3.5 Lighting Control

To facilitate control of a lighting circuit, the control system would need only a reset control attached to the lighting circuit. In certain applications it may be desirable to utilize a photoelectric cell for control. This would require a binary input signal from the cell to the control system.

3.6 Enthalpy Control

Outside air can be used as a source of "free" cooling whenever its temperature and humidity are within an appropriate range. Measuring the total heat content or enthalpy of the outside air allows the economizer to improve efficiency. The simplest form of control is one that activates the economizer when the dry bulb temperature of the outside air is equal to the supply air temperature (less fan heat). The mechanical cooling system is unloaded and outside air becomes the source of cooling.

Additional savings are available when the total heat content or enthalpy of the outside air is used for control. The enthalpy control accounts for not only dry bulb temperature but also moisture content. Such capability allows the system to use outside air whenever its enthalpy is less than room design conditions. This generally increases the number of hours the economizer can be used with a corresponding increase in energy savings.

To implement enthalpy control, the control system will need two analog input signals for measuring wet and dry bulb temperatures of the outside air. Reset signals are required to activate the opening and closing of the air dampers. The chiller will require a start/stop control and a binary input. Comparison logic is required for comparing enthalpy values with acceptable ranges stored in the memory of the control system.

3.7 Enthalpy Optimization

An extension of the concept described as enthalpy control is that of enthalpy optimization. The control system proportions the air mix (outside air and return air) so as to impose the lowest cooling load on the mechanical equipment.

The control system will need four analog input signals for measuring the wet and dry bulb temperatures of both the return and outside air. One or two analog or discrete output signals will be required to position the two air dampers. The chiller will require a start/stop control and a binary input. The control system must provide arithmetic ability to calculate enthalpy and determine the desired air mix proportions.

3.8 Chiller Optimization

The concept of optimal loading of chillers derives from the fact that the efficiency of this equipment is a function of load. If two or more chillers serve a single system, the load of each should be proportioned so that the incremental operating cost of each is equal. If the load was not so proportioned, total operating cost could be reduced by shifting some of the load from the higher cost unit to the lower cost unit. Naturally, operating limitations such as maximum and minimum power levels form physical bounds which occasionally prevent the system from operating at a uniform incremental operating cost.

Chiller loading can be controlled by setting the supply water temperature. The automatic control system will need two analog inputs to measure supply and return water temperture for each unit. Water flow rate for each unit is considered to be constant. Depending upon the mechanism utilized to control capacity of the chiller, either one analog output or numerous discrete binary output signals will be required. The control system must also have sufficient memory to store a table or incremental cost versus power level for each chiller unit and sufficient logic capabilities to utilize this data to achieve the desired operating conditions.

3.9 Optimal Scheduling

Time scheduling of HVAC equipment cutoff during unoccupied periods was discussed in Section 3.1. A time clock function was used to reactivate equipment to restore normal temperatures before the next occupancy period. For a given building, recovery time will vary depending upon its HVAC system, its heat loss or gain characteristics, and outside weather conditions. Time schedules were set to allow for the expected weather extremes. Thus, equipment was normally turned on before necessary, but occasionally, during extreme weather, equipment would not be started as early as required for comfort. An optimal scheduling mode, accounting for existing weather would both save money by delaying normal restart, and would also improve comfort during extreme weather periods.

Optimal start/stop would require the normal binary and start/stop control points as described in Section 3.1. Three additional analog input signals are also required; one to measure wind speed. Other sensors may be desirable in special circumstances. The control system must provide arithmetic ability to perform the required calculation.

3.10 Load Cycling

Total demand and energy consumption can be reduced by load cycling. Designated loads are periodically cycled on and off during normal operating periods. The time on and the time off for each cycle are stored in the memory of the automatic control system. No special I/O connections are required for this application other than those discussed in Section 3.1.

3.11 Predictive Demand Limit Control

Peak reduction under this scheme is accomplished by shutting down selected equipment (shedding) when desirable to reduce a peak during any demand interval. In order to determine when to shut off equipment, the demand meter used for billing is monitored by the control system. The equipment to be shut down is determined by the control system according to a priority list established by the user.

The desirability of shedding is determined by forecasting the demand at the end of the demand interval and comparing the predicted value to an established target demand. Should the forecasted demand be over the target value, equipment is shut down in the order specified by the user to lower the forecast of the demand. A subsequent forecast under the target demand causes the resumption of equipment to operating status or no action if there are no units on disabled status.

In order to prevent excessive cycling, especially of large equipment, a minimum time feature is generally available with power demand controllers. This feature allows the establishment of a minimum off time and a minimum cycle time for each piece of equipment under control. The minimum off time disallows the restart of the equipment for a fixed period following shutdown. The minimum cycle time requires the equipment to run for a fixed period before it may be shut down again. Discrete binary input signals from the power demand meter will be required in addition to the connections described in Section 3.1. The automatic control system must provide adequate memory and arithmetic capability.

3.12 Run Time Totalization

Operating times for each unit of equipment could be automatically updated and stored. Then periodically this information could be compared to the appropriate maintenance schedules. Units nearing the end of their required maintenance interval could then be listed along with their respective locations, nature of the maintenance and parts required. A preventive maintenance program would greatly improve equipment efficiency and lifetime, and enhance the effectiveness of currently employed maintenance personnel. A reduction in manpower requirements may be possible by a consolidation of maintenance functions.

The only equipment necessary to implement run time totalization would be a single discrete binary input signal from each unit of equipment to detect when the equipment is operating. If the unit is to run solely in response to an output signal from the control system, no input signal would be necessary. The control system must provide adequate memory storage and output devices for the specific application.

3.13 Equipment Malfunction Detection

Equipment malfunction can be recognized by the automatic control system by operation at an out-of-range condition, by a failure to respond to a control signal or by a complete loss of communication to a unit. Suitable detectors would reduce the need for roving patrols to check for equipment malfunction.

Additional instrumentation required for malfunction detection range from using separate analog input signals for each unit to using existing discrete binary signals. One simple method is to activate a malfunction alarm if no input signal has been received from a device during a predefined time period. Modest memory and logical capability plus time clock function must be available in the control system to permit implementation of this feature.

3.14 Boiler Plant Optimization

Since the boiler plant is a significant consumer of fossil energy on most army bases, several methods were investigated to improve service and reduce full consumption. One method is to use weather conditions to predict heating demand. Then adjust output water and steam conditions to achieve optimal efficiency for this expected demand. I/O requirements and demands on the automatic control system for this use are the same as that described in Section 3.9, Optimal Start/Stop.

If two boilers are required to furnish the heating demand, the heating load split between the two boilers will affect fuel consumption. This results in a problem similar to that described in Section 3.8, Chiller Optimization.

The boiler plant could be adapted to an automatic monitoring and control system. Electronic probes could constantly monitor the amount of excess oxygen passing through the boiler plant stack which, in turn, allows the control system to determine the heat losses associated with that stack. If the oxygen level is outside optimum limits, the control system can initiate control to regulate the air flow through the boiler and stack to bring the oxygen level within proper operating limits and increase plant efficiency.

Another method of boiler plant optimization consists of decreasing the fuel flow to the boiler as the load on the boiler decreases. During the winter, increasing outside air temperature results in less building heat requirements. Therefore, the amount of heat the boiler has to produce decreases. Fuel consumption, air flow, water flow, and water temperature can all be adjusted to obtain the most efficient operating point for the actual conditions. At low load levels, the temperature of the flue gas is decreased. Generally, the temperture will remain high enough so as to not precipitate corrosive substances inside the boiler stack. But, it is recommended that temperature sensors be located at the top of the stack to warn if flue gas temperatures become too low. Depending upon the sulfur content of the fuel being burned, the flue gas temperature should be maintained above 250 F to 300 F.

The last two applications would each require one analog input signal to the control system for each parameter being measured and one analog output signal to activate the necessary control devices or drive output signals to provide information to a qualified boiler plant operator.

3.15 Energy Cost Allocation

Cost of operating each major unit of equipment for a specified time period can be determined by two techniques. If equipment operates only at one power level, all that is needed to determine power consumption is the number of hours the equipment is operated. This uses the method discussed in Section 3.12, Run Time Totalization.

If the equipment runs at a variable power consumption, it will be necessary to integrate the discrete instantaneous power consumption values over the specified time period. Simpson's rule or a similar technique can be used to approximate the integration process. The automatic control system would need one analog input to measure the instantaneous power consumption. Output would be through the printer. The demand on the memory and logic elements of the automatic control system would be minimal, however, a resident high level language such as Fortran would make the programming task easier.

CHAPTER 4 - BUILDING SELECTION CRITERIA

Four major factors may be identified which affect the energy savings and energy control system cost potential of most buildings. These factors should be examined before deciding which buildings are suitable for control purposes; they are:

a) building size,
b) function and usage pattern,
c) heating and cooling system, and
d) relative building location.

4.1 Building Size

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 shop buildings. By nature these buildings encompass large floor areas which are usually not centrally heated or cooled. Supervisor offices, a small percent of the floor area, may be cooled by window units or small packaged direct expansion systems. Work areas may be ventilated during summer and heated in winter by unit heaters. Air temperatures are not 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 operation of process equipment and air infiltration around the large doors. In general, the larger buildings with large HVAC systems are the most attractive for connection to centralized control systems. Smaller buildings having a variety of HVAC systems throughout the structure may be more attractive for local control.

4.2 Function and Usage Pattern

Patterns of building usage affect energy consumption to a large extent. Most buildings can be loosely categorized by one of these three types of occupancy. A description of each category follows.

a) Evening occupancy generally involves recreational buildings such as bowling alleys and theaters. Time range is approximately 5:00 p.m. to 12:00 midnight.
b) Office occupancy is confined to buildings used during the typical work day. Time range is approximately 7:30 a.m. to 4:30 p.m.
c) Residential occupancy is essentially late evenings and early morning. Time range is approximately 4:00 p.m. to 8:00 a.m.

4.3 Heating and Cooling System

The type of heating and cooling system can influence the energy savings potential as well as the expense of conversion to an energy monitoring and control system. 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 typically located in the same area of the building, thus simplifying control system modifications.

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. Since smaller buildings tend to have small savings potential, the expense may not be justified. In such cases, a system of local control may be cost effective.

4.4 Relative Building Location

A major cost factor in central control system costs is wiring and communication expense. This interconnection cost is a function of a building's location relative to the central console. It has been assumed that each military base owns its own telephone network, so that the use of telephone lines between the remote panel and the central console will not incur any expense. Where spare lines do not exist, installing additional telephone link capacity must be included in the system cost estimate.

The connection between the control points and the remote terminal represents another expense. Closely grouped buildings with similar function and usage patterns offer the best possibilities for controlling several facilities through one remote panel. Where possible, multiple building connections to one remote panel is usually cheaper than installing a remote panel in each structure, in spite of increased wiring costs.

When using local control systems, where control point-to-controller wiring is always within one building and where there is no need for telephone line interfacing, building location is not a significant cost consideration. Therefore, isolated buildings or small energy using facilities without spare telephone lines lend themselves very well to local automatic control.

4.5 Energy Savings

Generalized quantification of predicted energy savings becomes a difficult task due to the wide variations in building systems, orientation, construction, age and geographic location. Accurate estimation is generally beyond the capability of simple calculations. For purposes of determining feasibility, however, simple calculation procedures can be sufficient. The methods presented in this manual were developed with this thought in mind and are at best a rough estimate.

It is important to note that these calculations account for equipment efficiency and assume that the heating and cooling system operates continuously with minimum outside air. For example, a system which operates only twelve hours a day instead of twenty-four will have less potential savings.

A tabulation of HVAC equipment found in existing buildings on a military base near Washington, D.C. is presented in Table 4-1. Base line energy consumption for these buildings is reported in Table 4-2. Energy consumption is assumed to be proportioned to floor area in this table and the ones that follow. Although this assumption is not completely valid, it is sufficient for the purposes intended.

The four energy savings schemes described in Chapter 3 that will likely result in the largest energy savings are:

(a) scheduling of loads,
(b) shutoff of outside air,
(c) outside air reduction, and
(d) enthalpy control.

Energy savings per square foot per year resulting from implementation of each scheme are reported in Tables 4-3 through 4-6.

To determine the energy savings from the implementation of any one scheme, find a building on the list which is similar to the one under consideration. Multiply the corresponding energy savings factor by the conditioned floor area. This gives the unadjusted energy savings per year for the building. An adjustment in the savings should be made to account for differences in climatic regions. Degree heating and cooling days for numerous locations are listed in Tables 4-7 and 4-8. For the location being considered, divide the heating degree days by 4,167 and the cooling degree days by 1,550 (average number of degree days in Washington D.C.). The results are the geographic adjustment factors. Multiply the unadjusted energy savings by the climatic adjustments to determine the annual energy savings.

Savings are calculated in Btu per year. If necessary, these yearly savings can be translated into equivalent fuel quantities from information presented in Table 4-9. A savings of one million Btu would be equivalent to 293 kWh of electricity or 6.67 gallons of No. 2 oil. Present DOD directives require the determination of the expected reduction in source energy. Approximately 11,600 Btu of source energy are required to supply 1 KWh of electrical energy as a result of the thermodynamic process used in generation and various transmission losses.

Energy savings for certain conservation schemes will be independent of one another. For these, the total energy savings is determined by simple addition of the savings of each scheme being used. If schemes to be used together impact on one another, savings from the secondary schemes should be reduced accordingly. It is noted that these energy savings calculation criteria are based on the operations of a typical Army base and should be considered as approximations.

TABLE 4-1

BUILDING EQUIPMENT

1.	E.M. Recreation Center	Local oil fired boiler; electric chiller; six air handling units.
2.	Theatre	Local oil fired boiler; direct expansion cooling; one air handling unit.
3.	Bowling Alley	Local oil fired boiler; direct expansion cooling; one air handling unit.
4.	N.C.O. Club	Local oil fired boiler; two electric water chillers; six air handling units.
5.	Post Exchange	Central plant heating; direct expansion cooling; two air handling units.
6.	Commissary	Local oil fired boiler; electric water chiller; two air handling units.
7.	E.M. Mess	Local gas fired boiler; direct expansion cooling; one air handling unit.
8.	Laundry	Central plant heating (unit heaters); no cooling.
9.	Field House	Central plant heating (unit heaters); no cooling.
10.	Chapel	Central plant heating; electric water chiller; three air handling units.
11.	Library	Central plant heating; direct expansion cooling; two air handling units.
12.	Office Building	Two local boilers; electric water chiller; five air handling units; fan coil units.
13.	Laboratory	Central plant heating; direct expansion cooling; three air handling units.
14.	Laboratory	Local gas fired boiler, local electric boiler; direct expansion cooling; two air handling units.
15.	Barracks	Local gas fired boiler; direct expansion cooling; one air handling unit.
16.	B.O.Q.	Local oil fired boiler; electric water chiller; one air handling unit.

BUILDING EQUIPMENT (Cont.)

17.	Machine Shop	Central plant heating (unit heaters); direct expansion cooling; two air handling units.
18.	Warehouse	Central plant heating (unit heaters); direct expansion cooling; one air handling unit.
19.	Dental Clinic	Central plant heating; direct expansion cooling; one air handling unit.

TABLE 4-2

BASELINE ENERGY CONSUMPTION

Military Building Type	Heating Baseline Energy Consumption In Thousands Of Btu Per Ft^2 - Year	Cooling Baseline Energy Consumption In Thousands of Btu Per Ft^2 - Year
E.M. Recreation Center	92	58
Theatre	193	39
Bowling Alley	36	107
N.C.O.	92	123
Post Exchange	171	120
Commissary	19	24
E.M. Mess	88	139
Laundry (See Note 1)	117	0
Field House (See Note 1)	40	0
Chapel	122	36
Library	11	27
Office Building (See Note 2)	78	36
Laboratory (See Note 3)	83	66
Laboratory (See Note 4)	42	19
Barracks	28	22
B.O.Q. (See Note 4)	77	35
Machine Shop (See Note 1)	43	54
Warehouse (See Note 1)	56	41
Dental Clinic	76	43

BASELINE ENERGY CONSUMPTION (Cont.)

Note 1: Energy savings must be treated for specific cases. Generalized figures unavailable.

Note 2: Energy savings based on a 132,217 square foot three-story office building with five air handling units and numerous fan coil units. Two local boilers and a chiller provide heating and cooling. Brick on block wall construction completed 1952.

Note 3: Energy savings based on a 8,235 square foot single story lab building with three air handling units. Central plant heating and direct expansion cooling. Brick on block construction completed 1942.

Note 4: Energy savings based on a 38,566 square foot three-story lab building with air handling units. Local gas and electric boilers provide heating. Direct expansion refrigeration provides cooling.

Note 5: Energy savings based on a 18,360 square foot two-story B.O.Q. building with one air handling unit. Local oil fired boiler and chiller provide heating and cooling.

TABLE 4-3

ENERGY SAVINGS - EQUIPMENT SHUTDOWN SAVINGS

	Building Type+	Energy Savings in Thousand of Btu's Per Ft^2 Per Year: Heating	Cooling
1.	Enlisted Men's Recreational Center	21.1	5.3
2.	Theater	41.2	5.3
3.	Bowling Alley	4.9	1.8
4.	N.C.O. Club	9.9	3.4
5.	Post Exchange	11.2	6.4
6.	Commissary	0.4	0.5
7.	Enlisted Men's Mess	22.2	8.9
8.	Laundry	3.6	*
9.	Field House	1.2	*
10.	Chapel	6.3	2.3
11.	Library	1.2	0.5
12.	Office Building	14.1	3.5
13.	Laboratory	13.6	5.2
14.	Laboratory	3.5	1.0
15.	Barracks	0.8	0.7
16.	B.O.Q.	0.8	0.5
17.	Machine Shop	3.9	7.4
18.	Warehouse	1.9	1.5
19.	Dental Clinic	16.5	4.6

* Energy savings must be treated for specific cases, generalized figures unavailable.
+ Typical building equipment schedule is given in Table 4-1.

TABLE 4-4

ENERGY SAVINGS - OUTSIDE AIR SHUTOFF SAVINGS

Building Type+	Energy Savings in Thousand of Btu's Per Ft² Per Year Heating	Cooling
1. Enlisted Men's Recreational Center	34.4	8.7
2. Theater	67.2	8.8
3. Bowling Alley	6.9	2.9
4. N.C.O. Club	16.1	5.6
5. Post Exchange	18.5	10.1
6. Commissary	0.6	0.9
7. Enlisted Men's Mess	36.2	11.4
8. Laundry	5.9	*
9. Field House	1.9	*
10. Chapel	10.3	3.8
11. Library	1.9	0.8
12. Office Building	23.0	5.7
13. Laboratory	22.2	8.5
14. Laboratory	5.7	1.7
15. Barracks	1.3	1.1
16. B.O.Q.	1.3	0.8
17. Machine Shop	6.4	12.2
18. Warehouse	3.1	2.5
19. Dental Clinic	26.9	7.6

* Energy savings must be treated for specific cases, generalized figures unavailable.
+ Typical building equipment schedule is given in Table 4-1.

TABLE 4-5

ENERGY SAVINGS - OUTSIDE AIR REDUCTION SAVINGS

	Building Type+	Energy Savings in Thousand of Btu's Per Ft^2 Per Year	
		Heating	Cooling
1.	Enlisted Men's Recreational Center	20.2	12.5
2.	Theater	13.5	2.7
3.	Bowling Alley	3.2	9.3
4.	N.C.O. Club	22.0	28.8
5.	Post Exchange	3.2	2.3
6.	Commissary	1.7	2.0
7.	Enlisted Men's Mess	16.6	26.7
8.	Laundry	*	*
9.	Field House	*	*
10.	Chapel	1.5	0.5
11.	Library	0.2	0.4
12.	Office Building	9.1	3.9
13.	Laboratory	2.7	2.1
14.	Laboratory	2.8	1.4
15.	Barracks	0.2	0.2
16.	B.O.Q.	0.3	0.1
17.	Machine Shop	*	*
18.	Warehouse	*	*
19.	Dental Clinic	2.3	1.4

* Energy savings must be treated for specific cases, generalized figures unavailable.

+ Typical building equipment schedule is given in Table 4-1.

TABLE 4-6

ENERGY SAVINGS - ENTHALPY CONTROL SAVINGS

Building Type+	Energy Savings in Thousand of Btu's Per Ft^2 Per Year Cooling
1. Enlisted Men's Recreational Center	13.7
2. Theater	8.3
3. Bowling Alley	10.6
4. N.C.O. Club	18.6
5. Post Exchange	5.6
6. Commissary	0.4
7. Enlisted Men's Mess	6.6
8. Laundry	*
9. Field House	*
10. Chapel	6.5
11. Library	5.9
12. Office Building	4.6
13. Laboratory	7.1
14. Laboratory	1.7
15. Barracks	1.8
16. B.O.Q.	3.8
17. Machine Shop	*
18. Warehouse	*
19. Dental Clinic	5.6

* Energy savings must be treated for specific cases, generalized figures unavailable.
+ Typical building equipment schedule is given in Table 4-1.

TABLE 4-7

AVERAGE ANNUAL DEGREE DAYS FOR MAJOR CITIES

Local climatological data obtained from National Oceanic and Atmospheric Administration. Reported values based upon years 1956 through 1976 for heating and 1969 through 1976 for cooling.

City	Heating Degree Days	Cooling Degree Days
Abilene, Texas	2,633	2,228
Albuquerque, New Mexico	4,439	1,255
Amarillo, Texas	4,202	1,376
Atlanta, Georgia	3,023	1,582
Bakersfield, California	2,120	2,612
Billings, Montana	7,137	568
Boston, Massachusetts	5,708	798
Brownsville, Texas	625	3,847
Casper, Wyoming	7,606	420
Charleston, South Carolina	2,157	2,198
Chicago, Illinois	6,121	1,019
Colorado Springs, Colorado	6,550	467
Columbus, Georgia	2,326	2,158
Columbus, Ohio	5,628	852
Corpus Christi, Texas	988	3,546
Denver, Colorado	6,038	645
El Paso, Texas	2,617	2,049
Fargo, North Dakota	9,235	538
Ft. Smith, Arkansas	3,409	1,788
Ft. Worth, Texas	2,407	2,548
Fresno, California	2,631	1,782
Hatteras, North Carolina	2,528	1,682

AVERAGE ANNUAL DEGREE DAYS FOR MAJOR CITIES (Cont.)

City	Heating Degree Days	Cooling Degree Days
Honolulu, Hawaii	0	4,450
Houston, Texas	1,418	2,676
Indianapolis, Indiana	5,588	994
Jackson, Mississippi	2,342	2,311
Jacksonville, Florida	1,276	2,650
Kansas City, Missouri	4,865	1,500
Knoxville, Tennessee	3,668	1,382
Little Rock, Arkansas	3,134	1,957
Los Angeles, California	1,087	1,312
Lake Charles, Louisiana	1,538	2,653
Las Vegas, Nevada	2,519	3,053
Louisville, Kentucky	4,493	1,316
Memphis, Tennessee	3,215	2,050
Miami, Florida	184	4,326
Minneapolis, Minnesota	8,057	764
Montgomery, Alabama	2,250	2,178
Nashville, Tennessee	3,706	1,598
New Orleans, Louisiana	1,494	2,668
New York, New York	4,880	1,177
Norfolk, Virginia	3,490	1,569
North Platte, Nebraska	6,880	702
Oklahoma City, Ohlahoma	3,720	1,807
Philadelphia, Pennsylvania	4,993	1,234
Phoenix, Arizona	1,415	3,912
Raleigh, North Carolina	3,576	1,365

AVERAGE ANNUAL DEGREE DAYS FOR MAJOR CITIES (Cont.)

City	Heating Degree Days	Cooling Degree Days
Red Bluff, California	2,688	1,972
Reno, Nevada	5,938	376
Rochester, New York	6,741	652
Sacramento, California	2,763	1,337
St. Louis, Missouri	4,902	1,392
Salt Lake City, Utah	5,874	1,013
San Antonio, Texas	1,606	2,859
San Francisco, California	3,030	128
Sault Sainte Marie, Michigan	9,264	157
Seattle, Washington	4,954	178
Shreveport, Louisiana	2,233	2,348
Tacoma, Washington	4,954	178
Tallahassee, Florida	1,617	2,516
Tampa, Florida	662	3,428
Topeka, Kansas	5,247	1,325
Tucson, Arizona	1,739	2,700
Trenton, New Jersey	4,974	1,086
Waco, Texas	2,097	2,818
Washington, D.C.	4,167	1,550
Wichita, Kansas	4,758	1,561
Winslow, Arizona	4,806	1,197
Yuma, Arizona	920	3,972

TABLE 4-8
INSTALLATION - CLIMATIC REGION -
DEGREE DAY AND LOCATION CHART

INSTALLATION NAME	STATE	CLIMATIC REGION	DEGREE DAYS HEATING	DEGREE DAYS COOLING	LAT NORTH	LONG WEST	ELEVATION FEET
Aberdeen, P.G.	MD	3	5,184	1,076	39°-28'	76°-10'	57
Alabama AAP	AL	4	2,806	1,886	33°-20'	86°-21'	430
Anniston A.D.	AL	4	2,806	1,886	33°-37'	85°-58'	765
Arlington Hall Station	VA	3	4,211	1,415	38°-52'	77°-06'	200
Army Material & Mech R.S.	MA	2	5,621	661	42°-21'	71°-10'	40
Army Topographic Station	DC	3	4,290	1,291	38°-57'	77°-07'	250
Badger AAP	WI	1	7,382	631	43°-22'	89°-45'	830
Fort Baker (East)	CA	4	3,080	0	37°-50'	122°-28'	15
Bayonne Mil. Ocean Term.	NJ	3	5,034	1,024	40°-40'	74°-05'	10
Fort Belvoir	VA	3	4,819	1,120	38°-43'	77°-11'	69
Fort Benning	GA	7	2,406	2,203	32°-21'	85°-00'	232
Fort Bliss	TX	7	2,432	2,253	31°-51'	106°-23'	3,947
Blue Grass Depot Activity	KY	3	4,729	1,197	37°-41'	84°-41'	1,035
Fort Bragg	NC	4	3,105	1,760	35°-08'	78°-56'	242
Brooke AMC	TX	6	1,570	2,994	29°-28'	98°-27'	785
Brooklyn Mil Ocean Term.	NY	3	4,909	1,048	40°-42'	73°-58'	151
Camp Bullis	TX	6	1,952	2,270	29°-41'	98°-45'	1,400
Cameron Station	VA	4	4,211	1,415	38°-48'	77°-07'	60
Fort Campbell	KY	3	4,290	1,472	36°-40'	87°-29'	571
Cape Canaveral Outport	FL	6	711	2,813	28°-29'	80°-34'	16
Carlisle Barracks	PA	3	5,269	995	40°-12'	77°-11'	475
Fort Carson	CO	2	6,373	692	38°-41'	104°-46'	5,840
Fort Chaffee	AR	7	3,336	2,022	35°-18'	94°-17'	440
Charleston AD	SC	7	2,145	2,078	32°-54'	79°-58'	3
Cornhusker AAP	NE	2	6,420	1,036	40°-55'	98°-29'	1,915
Corpus Christi AD	TX	6	930	3,474	27°-46'	97°-30'	41
CRREL	NH	1	7,680	327	43°-40'	72°-16'	800
Fort Detrick	MD	3	5,059	948	39°-26'	77°-26'	335
Detroit Arsenal	MI	2	6,228	743	42°-30'	83°-02'	618
Fort Devens	MA	2	6,475	560	42°-34'	71°-36'	268
Harry Diamond Lab	MD	3	4,483	1,161	39°-02'	76°-59'	200
Fort Dix	NJ	3	5,139	983	40°-01'	74°-38'	172
Fort Drum	NY	1	7,601	452	44°-02'	75°-46'	655
Dugway P.G.	UT	2	5,877	1,088	40°-42'	112°-56'	4,340
D. D. Eisenhower AMC	GA	4	2,547	1,995	33°-26'	82°-11'	465
Fort Eustis	VA	4	3,752	1,585	37°-08'	76°-37'	12

* Courtesy of DAEN-MPE-E

TABLE 4-8
INSTALLATION - CLIMATIC REGION -
DEGREE DAY AND LOCATION CHART

INSTALLATION NAME	STATE	CLIMATIC REGION	DEGREE DAYS HEATING	DEGREE DAYS COOLING	LAT NORTH	LONG WEST	ELEVATION FEET
Fitzsimmons AMC	CO	2	6,016	625	39°-45'	104°-50'	5,375
Frankford Arsenal	PA	3	4,865	1,104	40°-00'	75°-04'	10
Gateway AAP	MO	3	4,557	1,605	38°-42'	90°-16'	500
Fort Gordon	GA	4	2,547	1,995	33°-26'	82°-11'	465
Fort Greely	AK	1	13,698	34	63°-58'	145°-44'	1,314
Fort Hamilton	NY	3	5,184	861	40°-36'	74°-02'	21
Fort Benjamin Harrison	IN	2	5,577	974	39°-51'	86°-00'	864
Fort AP Hill	VA	3	4,398	1,188	38°-08'	77°-21'	230
Fort Holabird	MD	3	4,101	1,491	39°-16'	76°-32'	32
Holston AAP	TN	4	3,695	1,235	36°-31'	82°-40'	1,200
Fort Hood	TX	6	1,959	2,792	31°-09'	97°-43'	923
Fort Sam Houston	TX	6	1,570	2,994	29°-27'	98°-26'	760
Fort Huachuca	AZ	4	2,551	1,573	31°-35'	110°-20'	4,664
Hunter Army Airfield	GA	7	2,029	2,372	32°-01'	81°-08'	42
Indiana AAP	IN	3	4,640	1,268	38°-25'	85°-39'	600
Fort Indiantown Gap	PA	2	5,609	945	40°-26'	76°-34'	475
Iowa AAP	IA	2	6,149	994	40°-49'	91°-15'	730
Fort Irwin	CA	4	2,547	37	35°-16'	116°-41'	2,500
Fort Jackson	SC	7	2,598	2,087	34°-01'	80°-56'	250
Jefferson P.G.	IN	3	5,132	1,191	38°-50'	85°-25'	860
Joliet AAP	IL	2	6,180	993	41°-31'	88°-10'	582
Kansas AAP	KS	3	4,005	1,808	37°-20'	95°-13'	925
Fort Knox	KY	3	4,616	1,360	37°-54'	85°-58'	753
Lake City AAP	MO	3	5,218	1,261	39°-06'	94°-15'	810
Fort Lawton	WA	2	5,678	60	47°-39'	122°-25'	225
Fort Leavenworth	KS	3	4,822	1,292	39°-22'	94°-55'	770
Fort Lee	VA	4	3,939	1,353	37°-14'	77°-21'	145
Letterkenny AD	PA	2	5,519	793	40°-00'	77°-39'	670
Letterman AMC	CA	7	3,080	0	37°-48'	122°-27'	20
Fort Lewis	WA	3	5,339	110	47°-05'	122°-35'	122
Lexington-Blue Grass AD	KY	3	4,729	1,197	38°-02'	84°-36'	966
Fort Hunter Liggett	CA	4	3,332	37	36°-01'	121°-14'	1,090
Lima, USA Mod Ctr.	OH	2	5,838	828	40°-41'	84°-05"	915
Lone Star AAP	TX	7	2,531	2,245	33°-27'	94°-14'	360
Longhorn AAP	TX	7	2,370	2,459	32°-40'	94°-00'	295
Louisiana AAP	LA	7	2,337	2,451	32°-34'	93°-34'	195

TABLE 4-8
INSTALLATION - CLIMATIC REGION - DEGREE DAY AND LOCATION CHART

INSTALLATION NAME	STATE	CLIMATIC REGION	DEGREE DAYS HEATING	DEGREE DAYS COOLING	LAT NORTH	LONG WEST	ELEVATION FEET
Fort MacArthur	CA	5	1,819	615	33°-43'	118°-18'	200
Madigan AMC	WA	3	5,339	110	47°-05'	122°-35'	122
Fort McClellan	AL	4	2,806	1,886	33°-43'	85°-47'	790
Fort McCoy	WI	1	7,558	573	44°-01'	90°-41'	870
Fort Lesley T. McNair	DC	3	4,153	1,517	38°-52'	77°-01'	15
Fort McPherson	GA	4	3,095	1,589	33°-42'	84°-26'	1,053
Fort George G. Meade	MD	3	4,753	1,039	39°-05'	76°-46"	150
Memphis Defense Depot	TN	7	3,227	2,029	35°-05'	89°-59'	295
Michigan AMP	MI	2	6,228	743	42°-34'	83°-01'	615
Milan AAP	TN	4	3,685	1,637	35°-54'	88°-42'	490
Fort Monmouth	NJ	3	5,128	770	40°-19'	74°-02'	15
Fort Monroe	VA	4	3,623	1,539	37°-00'	76°-19'	15
Presidio of Monterey	CA	4	3,556	32	36°-36'	121°-54'	100
Fort Myer	VA	3	4,211	1,415	38°-53'	77°-05'	220
Natick Res & Dev Ctr	MA	2	6,144	636	42°-17'	71°-22'	160
Navajo Depot Activity	AZ	1	7,322	140	35°-14'	111°-50'	7,125
New Cumberland AD	PA	3	5,224	1,025	40°-13'	76°-50'	385
Newport AAP	IN	3	5,346	1,094	39°-52'	87°-26'	640
Oakdale Support Det.	PA	2	5,930	647	40°-30'	80°-13'	1,137
Oakland Army Base	CA	4	2,909	128	37°-49'	122°-19'	5
Ogden Defense Depot	UT	2	6,012	814	41°-12'	112°-01'	4,455
Fort Ord	CA	4	3,812	37	36°-41'	121°-46'	46
Camp Parks	CA	4	3,035	713	37°-44'	121°-53'	684
Picatinny Ars.	NJ	2	6,304	430	40°-56'	74°-34'	706
Fort Pickett	VA	4	3,841	1,319	37°-05'	77°-57'	390
Pine Bluff Ars.	AR	7	2,588	2,314	34°-18'	92°-05'	241
Fort Polk	LA	6	1,889	2,666	31°-03'	93°-11'	330
Pueblo AD Activity	CO	3	5,394	981	38°-17'	104°-21'	4,700
Radford AAP	VA	3	4,680	775	37°-11'	80°-33'	1,750
Ravenna AAP	OH	2	6,262	577	41°-11'	81°-06'	1,130
Red River AD	TX	7	2,531	2,245	33°-27'	94°-20'	385
Redstone Ars.	AL	4	3,302	1,818	34°-39'	86°-41'	602
Fort Riley	KS	3	5,306	1,503	39°-03'	96°-46'	1,065
Fort Richardson	AK	1	10,722	0	61°-16'	149°-39'	342
Fort Ritchie	MD	2	5,897	688	39°-40'	77°-28'	1,320
Riverbank AAP	CA	4	2,767	1,566	37°-43'	120°-55'	135
Camp Roberts	CA	4	2,890	699	35°-48'	120°-45'	765
Rock Island Ars.	IL	2	5,961	1,097	41°-31'	90°-33'	575
Rocky Mountain Ars.	CO	2	6,016	625	39°-50'	104°-53'	5,184
Fort Rucker	AL	6	1,968	2,386	31°-16'	85°-43'	305

TABLE 4-8
INSTALLATION - CLIMATIC REGION -
DEGREE DAY AND LOCATION CHART

INSTALLATION NAME	STATE	CLIMATIC REGION	DEGREE DAYS HEATING	COOLING	LAT NORTH	LONG WEST	ELEVATION FEET
Sacramento Army Depot	CA	4	2,843	1,159	38°-31'	121°-24'	42
St. Louis AAP	MO	3	4,486	1,640	38°-41'	90°-16'	580
St. Louis Area Sup. Ctr.	IL	3	4,486	1,640	38°-41'	90°-11	415
Presidio of San Francisco	CA	4	3,080	39	37°-48'	122°-38'	20
Savanna AD Activity	IL	2	6,694	741	42°-11'	90°-15'	640
Schofield Barracks	HI	6	8	2,821	21°-30'	158°-02'	850
Scranton APP	PA	2	6,114	630	41°-24'	75°-40'	730
Selfridge ANG	MI	2	6,665	661	42°-36'	82°-50'	583
Seneca AD	NY	2	6,359	655	42°-45'	76°-50'	750
Fort Shafter	HI	6	0	4,221	21°-21'	157°-53'	80
Sharpe AD	CA	4	2,806	1,259	37°-51'	121°-17'	16
Fort Sheridan	IL	2	6,068	826	42°-13'	87°-49'	690
Sierra AD	CA	2	5,822	302	40°-09'	120°-07'	4,110
Fort Sill	OK	7	3,367	2,217	34°-39'	98°-24'	1,187
Fort Stewart	GA	6	1,713	2,414	31°-52'	81°-37'	88
Fort Story	VA	4	3,639	1,485	36°-56'	76°-00'	13
Sunflower AAP	KS	3	5,030	1,370	38°-56'	95°-00'	925
Sunny Point MOT	NC	4	2,353	1,901	34°-00'	78°-00'	25
Tobyhanna AD	PA	2	6,816	434	41°-11'	75°-25'	1,990
Tooele AD	UT	2	5,941	859	40°-31'	112°-25'	4,700
Fort Totten	NY	3	4,812	1,084	40°-48'	73°-47'	35
Tripler AMC	HI	6	0	4,221	21°-22'	157°-54'	220
Twin Cities AAP	MN	1	8,310	527	45°-05'	93°-10'	970
Umatilla Depot Act.	OR	3	5,123	738	45°-48'	119°-25'	590
US Military Academy	NY	2	5,753	830	41°-23'	73°-57'	160
Underhill Firing Range	VT	1	7,876	332	44°-28'	73°-09	332
Valley Forge Gen. Hos.	PA	3	5,114	950	40°-07'	75°-33'	245
Vancouver Bks	WA	3	4,792	300	45°-36'	122°-36'	21
Vint Hill Farms Station	VA	3	5,010	940	38°-45'	77°-41'	425
Volunteer AAP	TN	4	3,505	1,636	35°-05'	85°-08'	750
Fort Wadsworth	NY	3	5,184	861	40°-36'	74°-03'	135
Fort Wainwright	AK	1	14,345	52	64°-50'	147°-37	80
Walter Reed AMC	DC	3	4,483	1,217	38°-58'	77°-02	285
Watervliet Ars.	NY	2	6,393	654	42°-43'	73°-42	35
West Point Mil. Res.	NY	2	5,753	830	41°-23'	73°-57	160
White Sands MR, NM	NM	7	2,526	2,243	32°-23'	106°-29	4,330
William Beaumont AMC	TX	7	2,678	2,098	31°-49'	106°-28	4,185
Fort Wingate Depot Act.	NM	2	5,915	593	35°-31'	108°-33	6,600
Fort Leonard Wood	MO	3	4,707	1,314	37°-45'	92°-09	1,15[illegible]

TABLE 4-8
INSTALLATION - CLIMATIC REGION -
DEGREE DAY AND LOCATION CHART

INSTALLATION		CLIMATIC	DEGREE DAYS		LAT	LONG	ELEVATION
NAME	STATE	REGION	HEATING	COOLING	NORTH	WEST	FEET
Yakima Firing Center	WA	2	6,109	479	46°-41'	120°-28'	1,262
Yuma P.G.	AZ	6	968	4,261	32°-52'	114°-26'	225

NOTE: All Army installations listed in DA Pamphlet 210-1 (April 1977) whose degree day and location data were given in TM 5-785 (1 Jul 78) are included in the above chart.

 (next page is page 35)

TABLE 4-9

ENERGY SAVINGS - CONVERSION TABLE

1kWh* = 3,413 Btu (for direct cost of energy consumed)
= 11,600 Btu (for source energy consumed in production)

1 Cubic Foot Natural Gas = 1,000 Btu

1 Ton Coal = 24,000,000 Btu

1 Cubic Foot LPG = 2,840 Btu

1 Gallon LPG = 95,500 Btu

1 Gallon No. 2 Oil = 138,700 Btu

1 Gallon No. 6 Oil = 150,000 Btu

The values given above for gas, coal and oil are approximate and will vary somewhat with supplier. The heating value of the actual fuel should be used in calculation if available.

* Choice of conversion factor depends upon use.

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CHAPTER 5 - DESCRIPTION OF HVAC SYSTEMS

This chapter provides the facilities engineer with information needed to identify the appropriate control devices for existing HVAC equipment and to generate the performance requirements for an appropriate automatic control system. Ten HVAC systems that were identified as being currently used at various facilities of the U. S. Army are listed below.

1. Hydronic heating system.
2. Self-contained HVAC system.
3. Single zone system.
4. Fan coil system.
5. Terminal reheat system.
6. Dual duct system.
7. Multizone system.
8. Constant air volume system.
9. Variable air volume system.
10. Induction HVAC system.

Each of these systems will be described in detail in this chapter. Typical applications and limitations will be noted. To assist the reader in understanding these HVAC systems, a schematic of each has been included. Locations of the required monitoring and control points are shown on the schematics in Figures 5-1 through 5-10. Tables 5-1 through 5-10 list monitoring and control points required for each system.

Specific monitoring and control points needed for control of an HVAC system depend both upon the characteristics of the HVAC system design and the nature of the control schemes being implemented. Table 5-11 summarizes the applicable control schemes for each of the 10 HVAC systems listed above.

5.1 Hydronic Heating System

Hydronic heating systems consist of a boiler, hot water supply loop, and a series of room heating elements connected in parallel to the hot water supply loop. The room heating elements transfer heat to the room air by natural convection. A circulation pump provides forced flow of water through the supply loop.

A typical application of a hydronic heating system would be in a residence or barracks building. Occassionally, several buildings in a cluster will be served by steam from a central boiler plant to take advantage of a more efficient boiler design or size. In such a case, each building would be connected to the steam supply main and to the condensate return main. The individual building boiler would be replaced by a steam to water heat exchanger.

Control points for a hydronic heating system consist of individual room controls and system controls. Individual room controls consist of thermostats which activate off/on flow control valves on the individual radiators. System controls consist of a heating water supply temperature thermostat and a start/stop control device for the heating water flow pump. Monitoring and control points from this system are listed in Table 5-1.

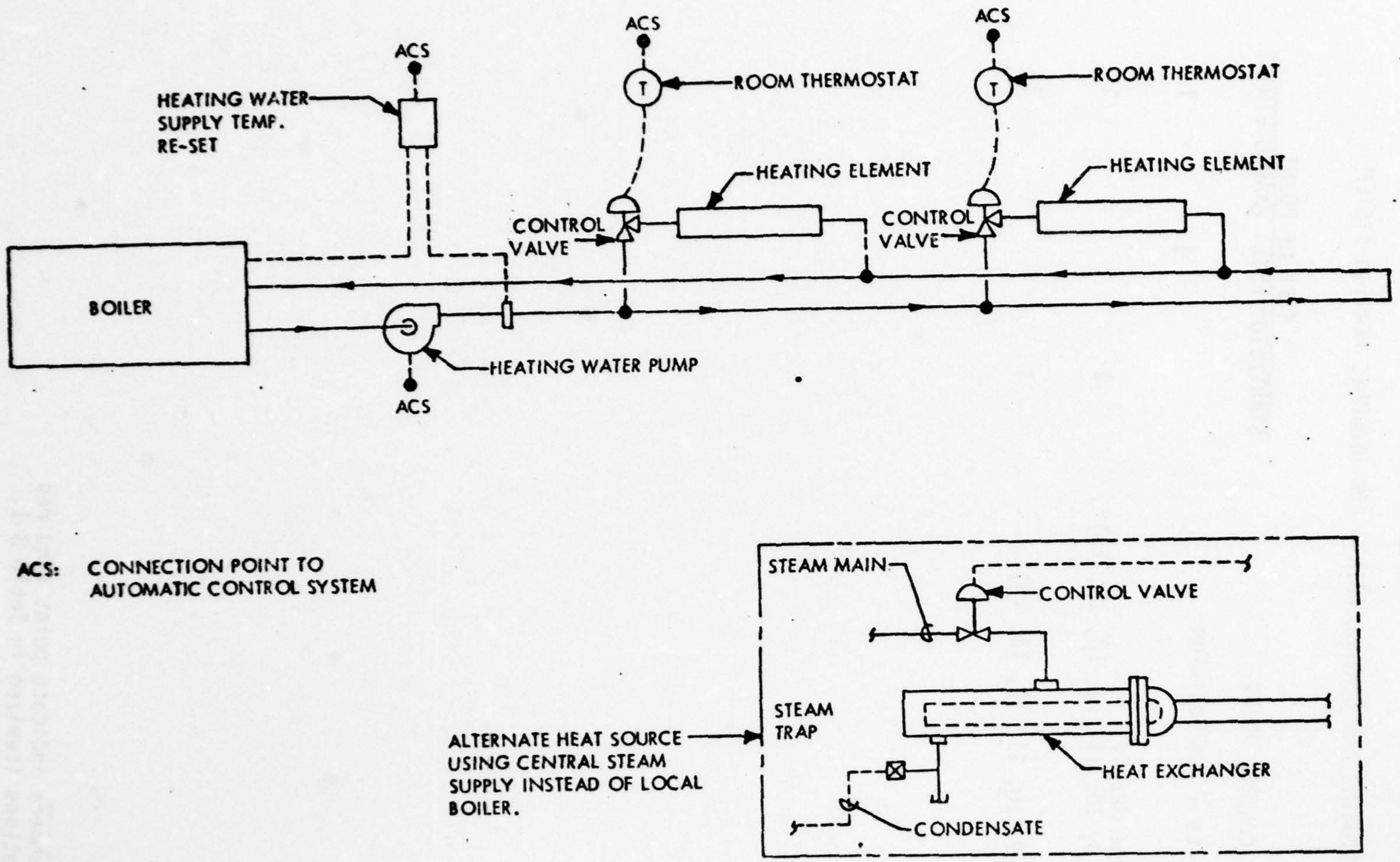


FIGURE 5-1. HYDRONIC HEATING SYSTEM

TABLE 5-1

MONITORING AND CONTROL POINTS FOR HYDRONIC HEATING SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT			
	START/STOP	RESET	ANALOG	BINARY
Room Thermostats - Two Position (Scheme 3)		1		1
Boiler or Steam Supply (Schemes 1, 9, 10, 11, 12, 13, 14, 15)*	1			1
Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.2 Self-Contained HVAC System

Self-contained system consists of an air cooled refrigeration section with a direct expansion cooling coil. The heating section is an electric heat strip or it could be a gas fired furnace or just a steam or hot water heating coil. The blower section includes a fan and air filters. Although sections are combined together into a packaged unit, the blower unit becomes energized by a central control point.

Typical applications would be warehouses, exchanges and commissary shops.

Control points for a self-contained system consist of individual room control and system control. Individual room controls consist of room thermostats which activate cooling or heating section. System controls consist of air temperature thermostats located in the air stream to control leaving air temperature. Monitoring and control points for this system are listed in Table 5-2.

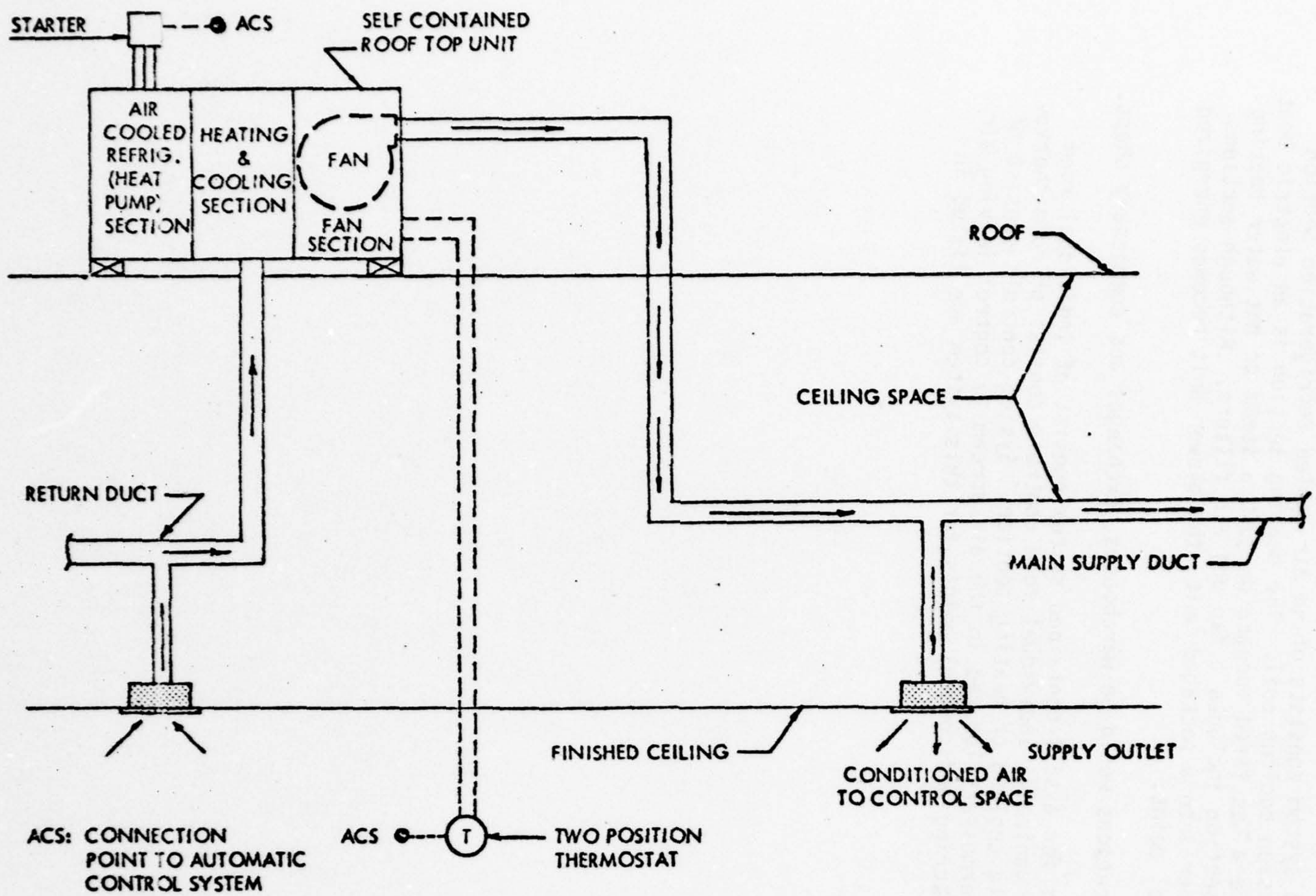


FIGURE 5-2. SELF-CONTAINED HVAC SYSTEM

TABLE 5-2

MONITORING AND CONTROL POINTS FOR SELF-CONTAINED HVAC SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Two Position Thermostat (Scheme 3)*		1		1
Air Circulation Fan (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.3 Single Zone System

The single zone system consists of a supply fan, heating coil, cooling coil air cooled refrigeration system, outside air and return air dampers, and a supply air duct. As the room thermostat calls for heating or cooling, it would energize the air cooled refrigerant system or electric heating coil, until thermostat is satisfied.

A typical application would be a small store, shop, warehouse, residence or a theater.

The control points of the system are the heating-cooling thermostat and enthalpy sensors on the return and outside air ductwork. There is a system control point at a starter for the supply fan. Monitoring and control points for this system are listed in Table 5-3.

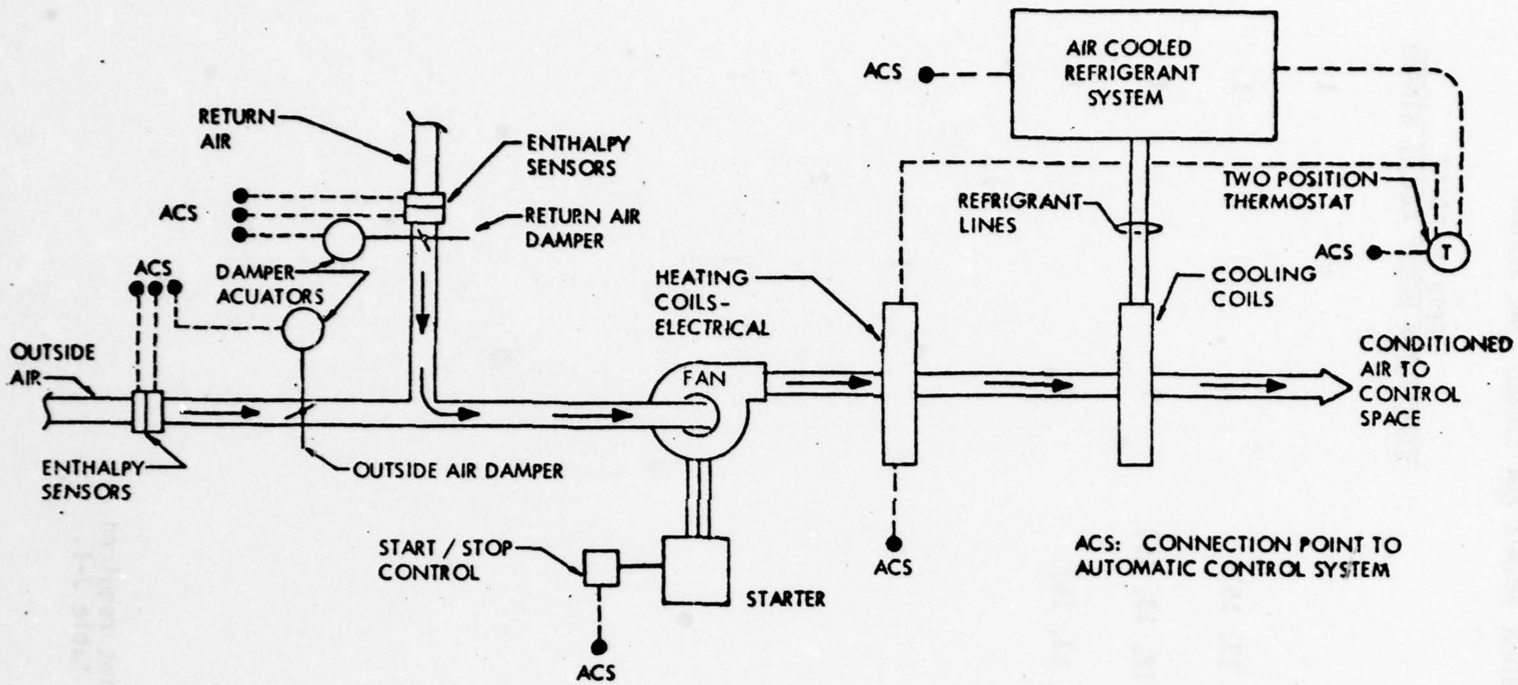


FIGURE 5-3. SINGLE ZONE DIRECT EXPANSION SYSTEM

TABLE 5-3

MONITORING AND CONTROL POINTS FOR SINGLE ZONE SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Two Position Thermostat (Scheme 3)*		1		1
Heating Coils (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Refigerant System (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Air Fan (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6 & 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.4 Fan-Coil System

Fan-coil system consists of a boiler, hot water supply loop, cooling tower, condenser water supply loop, chiller, chilled water supply loop and a series of fan-coil units connected in parallel to the hot water and chilled water supply loops. Circulation pumps provide forced flow condenser, hot and chilled water flow through the supply loops. The condenser water loop serves only the chiller.

A typical application would be family housing and office buildings, bachelor quarters, barracks, and hospitals.

The control points for this system would consist of individual heating-cooling thermostats located in the area served by that fan-coil unit. Other control points are for energizing cooling tower with affiliated condenser pump, supply fan, return fan, boiler with circulating pump, chiller with chilled water pump. The cooling tower controls the water temperature of the condenser water as it is recirculated through the chiller condenser section. The chiller maintains the set point of the chilled water supply loop. Monitoring and control points for this system are listed in Table 5-4.

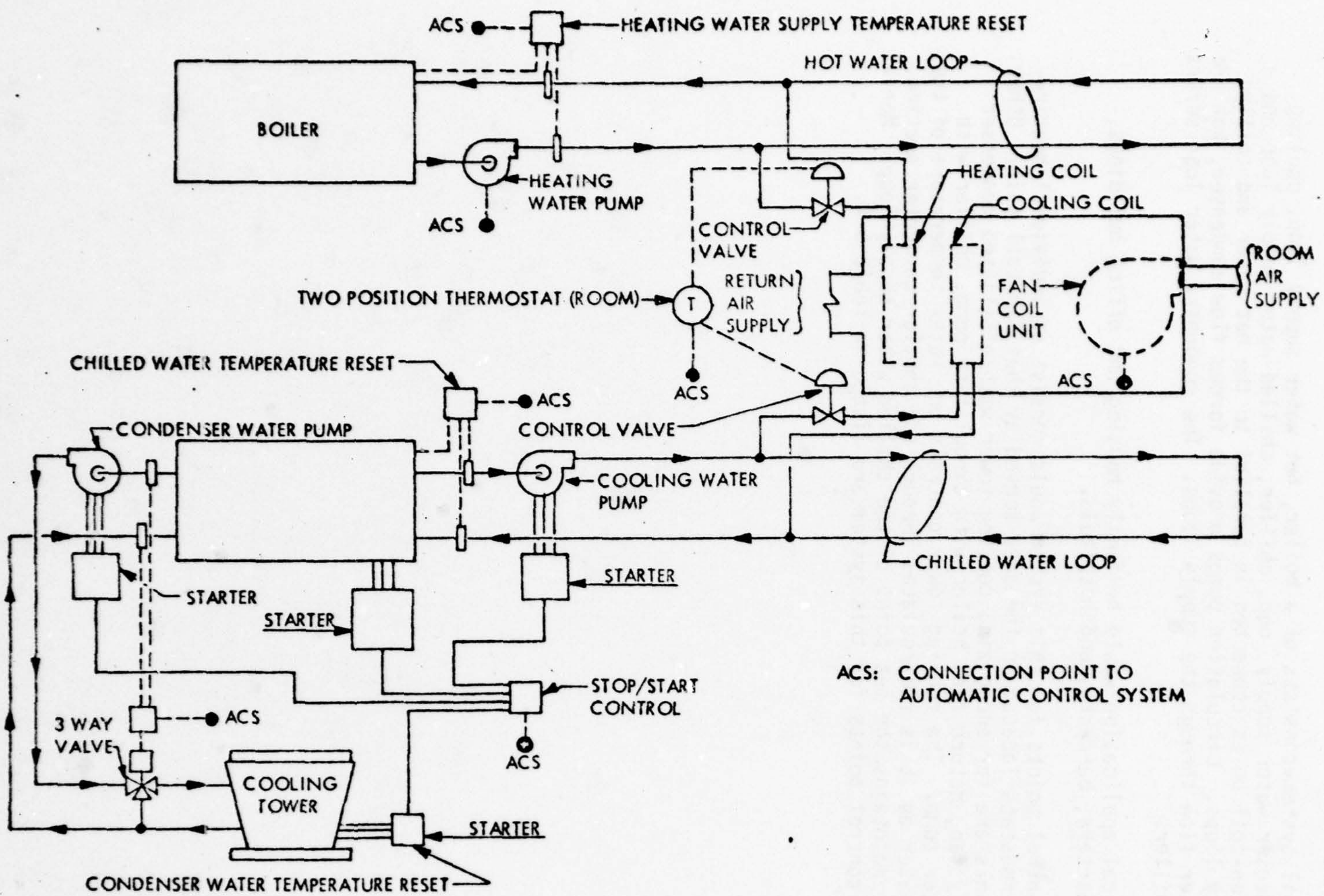


FIGURE 5-4. FAN COIL SYSTEM

TABLE 5-4

MONITORING AND CONTROL POINTS FOR FAN COIL SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Two Position Thermostat (Scheme 3)		1		1
Air Fan (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Heating Water Pump (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Boiler (Schemes 1, 3, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Chiller (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Pump (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 3, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.5 *Terminal Reheat System*

This system is basically the same as a fan-coil system with these exceptions:

(a) This system has a central fan which constantly supplies tempered air throughout main trunk line.

(b) The local zone thermostat controls space temperature with the aid of a reheat coil in the branch ductwork.

A typical application would be a headquarters or office building.

Control points for this system consists of individual room controls and system controls. Individual room controls consist of thermostats which activate a control valve on the individual reheat coil, which allows boiler hot water to flow through the coil thus adding additional heat to the zone air flow until that respective thermostat is satisfied. System controls are the same as the fan-coil system. Monitoring and control points for this system are listed in Table 5-5. Use of two position room thermostats would not be effective in saving energy with the system. However, it is possible to save energy in both chilling and reheating by altering the temperature of supply air during periods of low occupancy. Maximum chiller temperature is limited by demands of the areas being served.

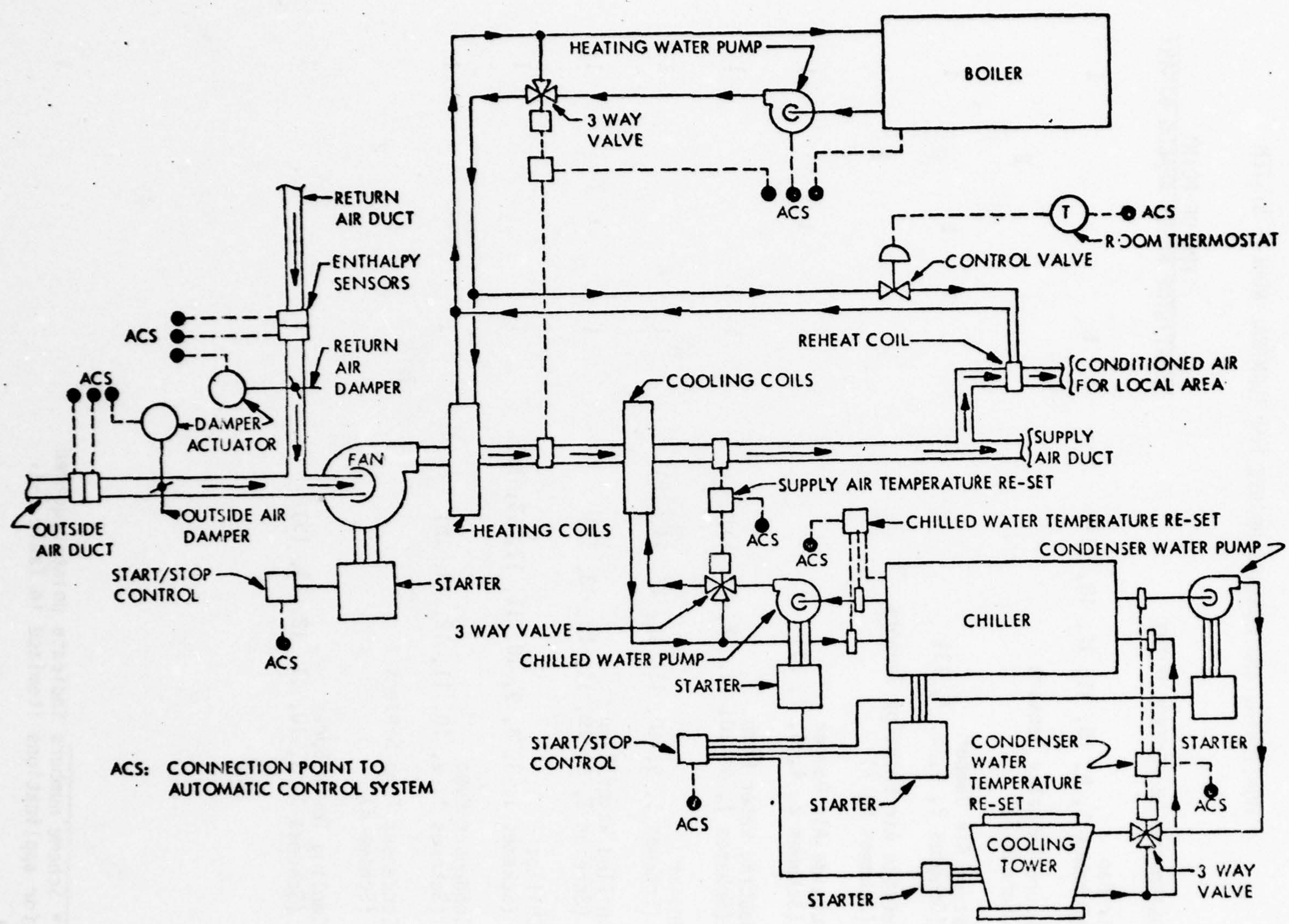


FIGURE 5-5. TERMINAL REHEAT SYSTEM

TABLE 5-5

MONITORING AND CONTROL POINTS FOR TERMINAL REHEAT SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Boiler (Schemes 1, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chiller (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.6 Dual Duct System

The dual duct system is similar to the fan-coil system with the exception of the following:

(a) There is a large central supply fan.

(b) There is a large central return fan.

(c) The main supply trunk line splits into two ducts.

(d) One main duct has a cooling coil in it and the other housing a heating coil.

(e) The dual duct mixing unit is served with a hot duct supply and a chilled air duct supply.

A typical application would be office buildings, schools and hospitals.

The control points for this system would consist of an individual room thermostat which controls the mixture dampers at the dual duct mixing unit. System control points include duct sensing thermostats controlling valves allowing chilled water and hot water to flow through the coils and maintain a constant supply air temperature at the main ducts. The other control points are typical of the fan-coil system operating major system components. Monitoring and control points for this system are listed in Table 5-6. Use of two position room thermostats would not be effective in saving energy with this system. However, altering hot and cold duct supply temperatures during periods of low occupancy is possible. Adjustment range is limited by the demands of the areas being served.

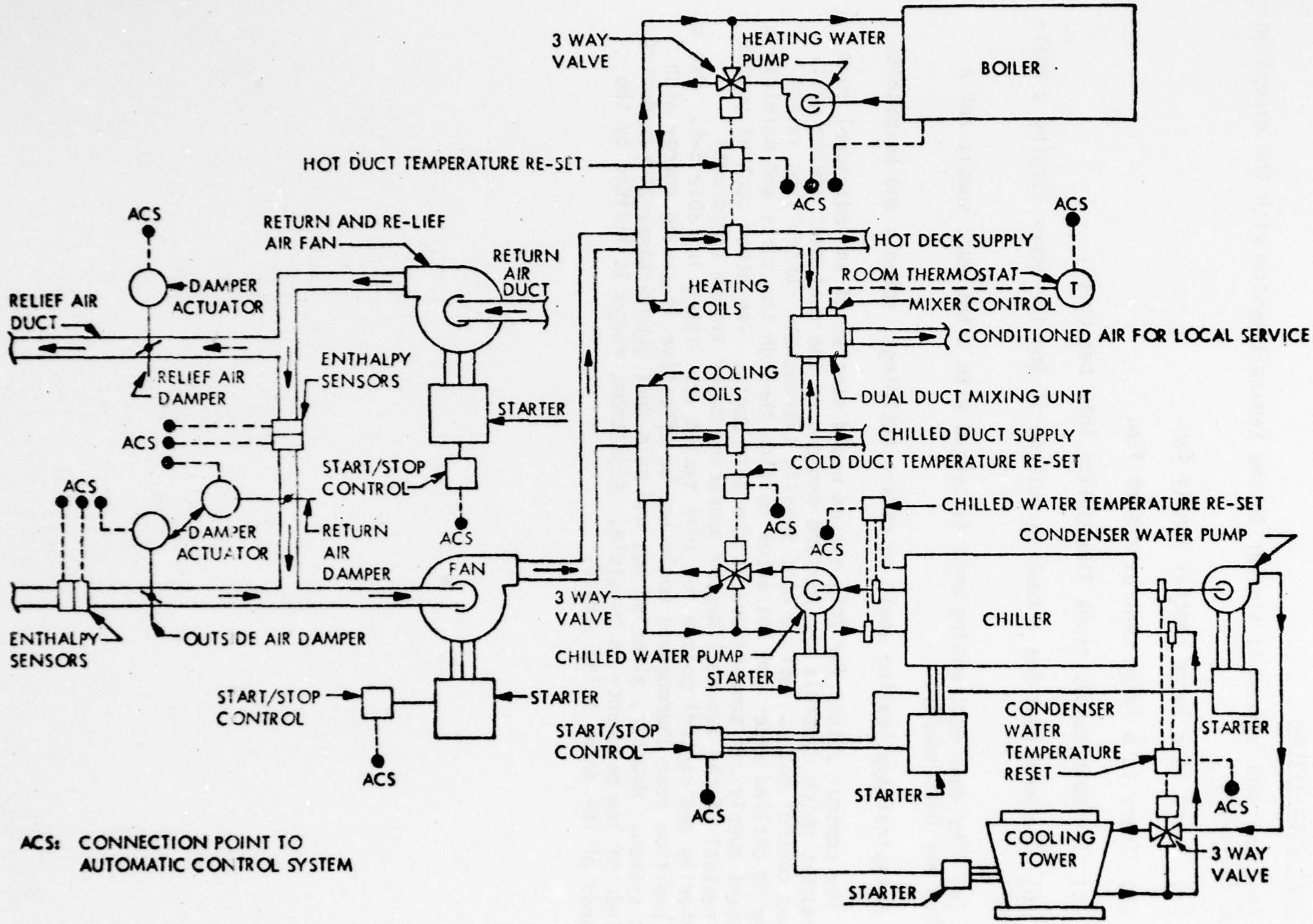


FIGURE 5-6. DUAL DUCT HVAC SYSTEM

TABLE 5-6

MONITORING AND CONTROL POINTS FOR DUAL DUCT SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Supply Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Relief Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Boiler (Schemes 1, 3, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chiller (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.7 Multi-zone System

The multi-zone system is basically the same as the fan-coil system with the exception of the following.

(a) There is a large central supply fan.

(b) There is a hot deck (heating coil) and a cold deck (cooling coil).

(c) The hot and cold deck have separate motorized dampers controllable from central control points.

A typical application would be schools, office buildings, hospitals and bachelor quarters.

The control points for this system would consist of individual heating-cooling thermostats at their respective zones. System control points also include duct type thermostats which control valves to allow flow of chilled water or hot water to maintain a constant temperature of discharge air leaving both decks. The other control points are typical of the fan-coil system operating major system components. Monitoring and control points for this system are listed in Table 5-7. Use of two position room thermostats in this system would not be effective in saving energy. However, temperatures of the hot and cold air supplies may be reset during periods of low occupancy to minimize mixing loss.

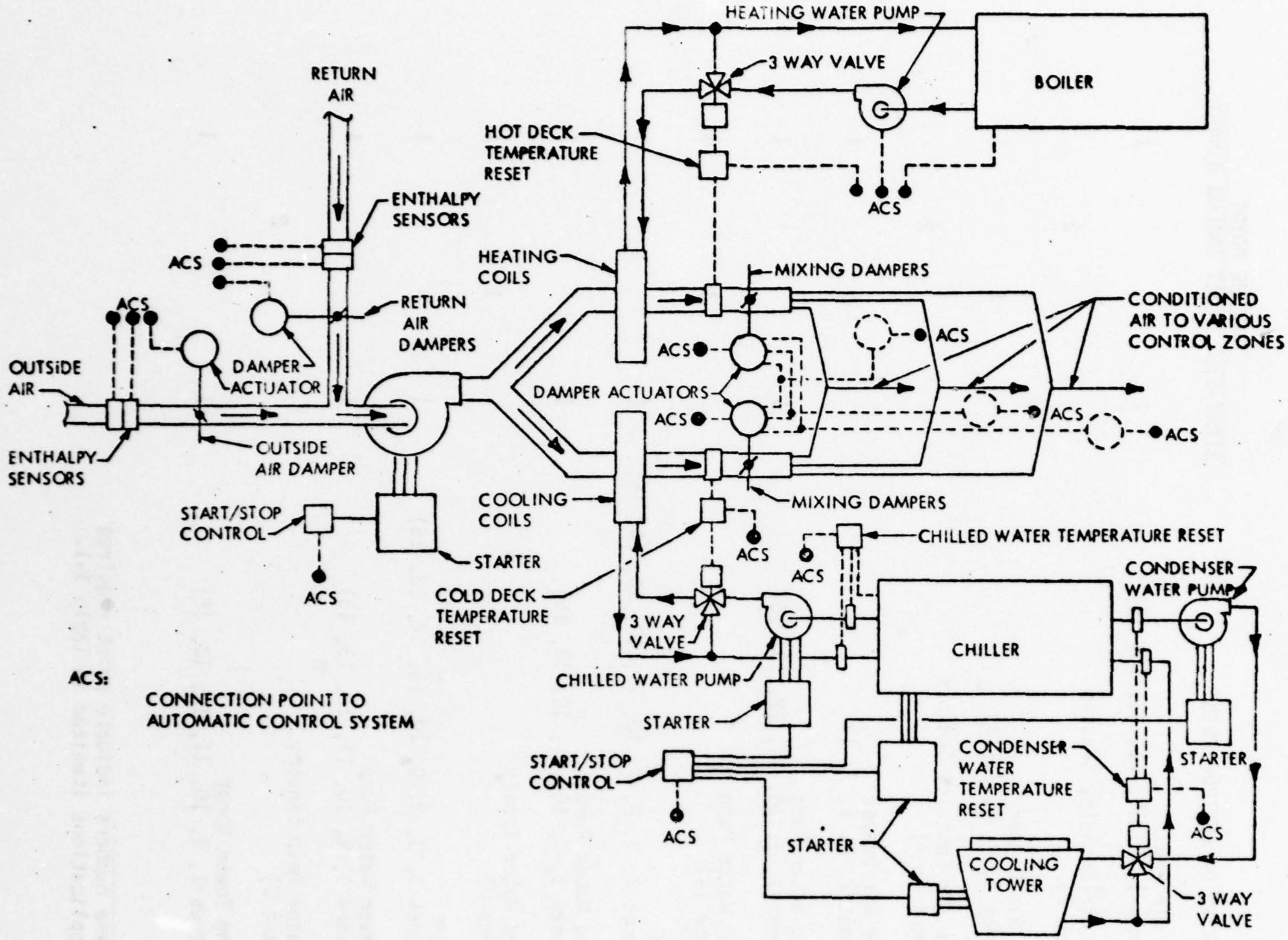


FIGURE 5-7. MULTIZONE SYSTEM

TABLE 5-7

MONITORING AND CONTROL POINTS FOR MULTI-ZONE SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT			
	START/STOP	RESET	ANALOG	BINARY
Supply Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Heating Water Pump (Scheme 14)		1		1
Boiler (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chilled Water Bypass (Scheme 8)		1		1
Chiller (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.8 Constant Air Volume System

The constant air volume system is basically the same as the fan-coil system with the following exceptions:

(a) There is a large central supply fan.

(b) There is a large central cooling coil and heating coil on the suction side of the fan.

(c) There is a main air supply trunk line.

(d) There are branch ducts supplying individual terminal units for each zone.

A typical application would be an office building.

The control points are individual heating cooling thermostats located at their respective zone areas, controlling the damper at the terminal unit. Monitoring and control points for this system are listed in Table 5-8. Due to the nature of the constant air volume system, temperature reset during periods of low occupancy will be difficult to implement. Both two position room thermostat and chillers (boiler) temperature reset mechanism may be required.

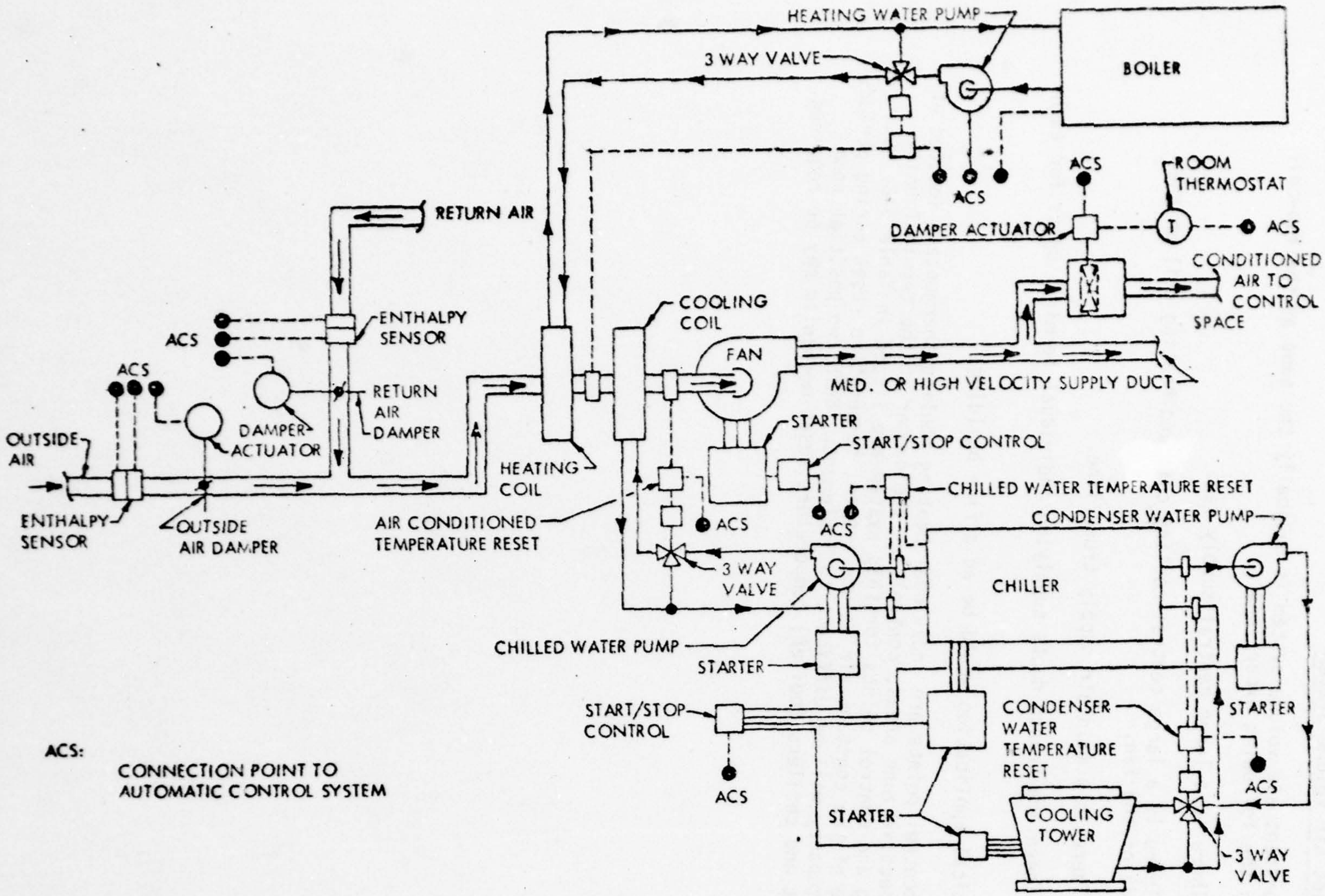


FIGURE 5-8. CONSTANT AIR VOLUME SYSTEM

TABLE 5-8

MONITORING AND CONTROL POINTS FOR CONSTANT AIR VOLUME SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT			
	START/STOP	RESET	ANALOG	BINARY
Supply Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Heating Water Bypass (Scheme 14)		1		1
Boiler (Schemes 1, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chilled Water Bypass (Scheme 8)		1		1
Chiller (Schemes 1, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.9 Variable Air Volume System

The variable air volume system is basically the same as the fan-coil system with the exception of the following:

(a) There is a large central supply fan.

(b) There is a large central cooling coil and heating coil on the discharge side of the fan.

(c) There is a main air supply trunk line.

(d) There are branch ducts supplying individual terminal unit for each zone.

A typical application would be an office building.

The terminal unit of this system varies from the constant air volume unit because this unit has controllable mixing dampers which govern air quantities supplied to the room. As the room thermostat senses satisfaction, the terminal unit will close the supply air port and open the relief port and discharge the air to a ceiling space. The supply fan furnishes a constant air volume to the terminal unit. The room thermostat selects the volume delivered to the room. Monitoring and control points for this system are listed in Table 5-9. Due to the nature of the variable air volume system, temperature reset during periods of low occupancy will be difficult to implement. For a specific installation, both two position room thermostats and chiller (boiler) temperature reset mechanism may be required.

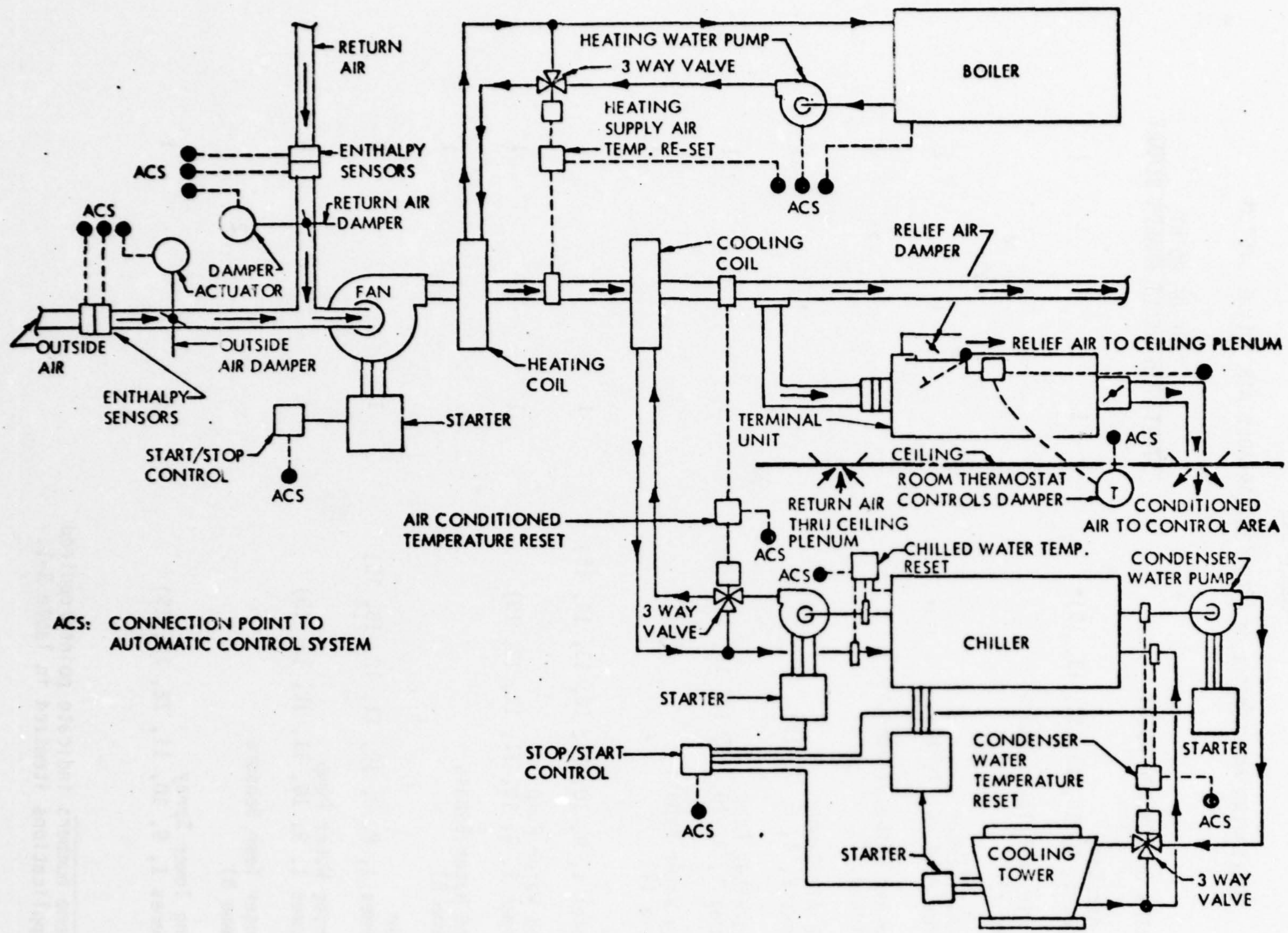


FIGURE 5-9. VARIABLE AIR VOLUME SYSTEM

TABLE 5-9

MONITORING AND CONTROL POINTS FOR VARIABLE AIR VOLUME SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Supply Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Heating Water Bypass (Scheme 14)		1		1
Boiler (Schemes 1, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chilled Water Bypass (Scheme 8)		1		1
Chiller (Schemes 1, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

5.10 Induction HVAC System

The induction system is identical to the constant air volume system with the exception of the following:

(a) There has been a return air fan added.

(b) There is a re-heat coil in the induction unit to control space conditions.

Typical application would be schools and offices.

The control points for this system include a heating-cooling thermostat controlling the re-heat coil and a set of start/stop controls for the return air fan. All other system control points are identical to constant air volume systems. Monitoring and control points for this system are listed in Table 5-10. Use of two position room thermostats would not be effective in saving energy with this system. Temperature of supply air may be altered during periods of low building occupancy. Maximum chiller temperature will be limited by the demands of the areas being served.

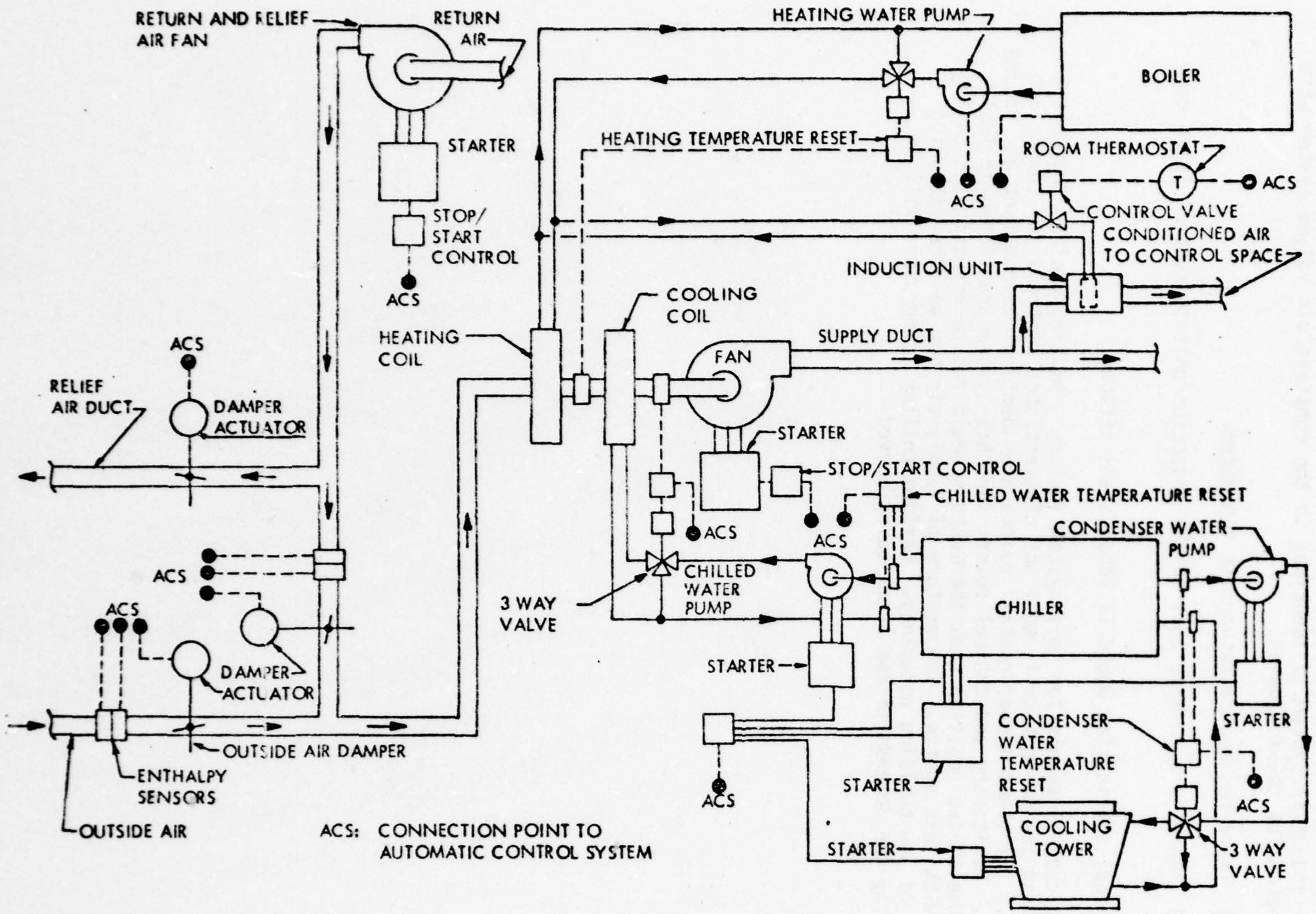


FIGURE 5-10. INDUCTION HVAC SYSTEM

TABLE 5-10

MONITORING AND CONTROL POINTS FOR INDUCTION HVAC SYSTEM

MONITORING OR CONTROL POINT	TYPE OF POINT START/STOP	RESET	ANALOG	BINARY
Supply Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)*	1			1
Return Air Fan (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Relief Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Return Air Enthalpy Sensors (Scheme 7)			2	
Return Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Outside Air Enthalpy Sensors (Schemes 6, 7)			2	
Outside Air Damper (Schemes 2, 4, 6, 7, 13)		1		1
Heating Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Heating Water Bypass (Scheme 14)		1		1
Boiler (Schemes 1, 3, 9, 10, 11, 12, 13, 14, 15)	1			1
Chilled Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Chilled Water Bypass (Scheme 8)		1		1
Chiller (Schemes 1, 3, 8, 9, 10, 11, 12, 13, 15)	1			1
Condenser Water Pump (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1
Condenser Temp Sensors (Scheme 8)			2	
Cooling Tower Spray (Schemes 1, 9, 10, 11, 12, 13, 15)	1			1

* Scheme numbers indicate point required for applications itemized in Table 3-1.

TABLE 5-11

APPLICABLE CONTROL SCHEMES FOR VARIOUS HVAC SYSTEMS

	1. Scheduling of Loads	2. Shutoff of Outside Air Intake	3. Temperature Setback	4. Outside Air Reduction	5. Lighting Control	6. Enthalpy Control	7. Enthalpy Optimization	8. Chiller Optimization	9. Optimal Start/Stop	10. Load Cycling	11. Predictive Load Demand	12. Run Time Totalization	13. Equipment Malfunction Detection	14. Boiler Plant Optimization	15. Energy Cost Allocation
1. Hydronic Heating System	X		X						X	X	X	X	X	X	X
2. Self-Contained HVAC	X		X						X	X	X	X	X		X
3. Single Zone System	X	X	X	X		X	X	X	X	X	X	X	X		X
4. Fan Coil System	X		X					X	X	X	X	X	X	X	X
5. Terminal Reheat System	X	X	X	X		X	X	X	X	X	X	X	X	X	X
6. Dual Duct System	X	X	X	X		X	X	X	X	X	X	X	X		X
7. Multizone System	X	X	X	X		X	X	X	X	X	X	X	X	X	X
8. Constant Air Volume System	X	X		X		X	X	X	X	X	X	X	X	X	X
9. Variable Air Volume System	X	X		X		X	X	X	X	X	X	X	X	X	X
10. Induction HVAC System	X	X	X	X		X	X	X	X	X	X	X	X	X	X

CHAPTER 6 - CLASSIFICATION OF CONTROL SYSTEMS

Control systems which were investigated for this study ranged in capability from mechanical time clocks suitable for load cycle control to general purpose minicomputers with full software programming capability. In an effort to bring order to the situation, control systems were grouped according to their capabilities. Review of sales and engineering literature suggested that available equipment could be divided into four rather distinct classes. These classes, which span the range of capabilities currently available, are described below.

6.1 Dedicated System for Local Installation

These units are typically preprogrammed with time clock switching capabilities and certain power management routines. This class represents the minimum system capability which is considered adequate. Units may be either mechanical time clocks or computer based system. User control is limited to entering on-off schedules and other coefficients. Control capacity ranges from 1 to 16 loads. Necessary interface and input/output devices are built into the system. An illustration of a processor suitable for dedicated local control is shown in Figure 6-1.

Dedicated systems for local installations are most often used in small to medium size buildings that serve a single functional use. A store, office building, or laboratory would be a typical application. For large buildings, the number of control circuits may be increased by the installation of additional control units. Preprogrammed logic generally provides for on-off time control and for cycling of loads. The more elaborate units provide for demand control by shedding of loads as necessary to avoid exceeding specified demand limits.

6.2 Dedicated System for Central Installation

These units have greater capacity than systems of the preceeding type, but still provide no user programmed software capability. Systems are capable of handling 16 to 256 remote panels each having from 16 to 30 input/output connections. Central console devices are provided to perform routine data logging, status checks, and signaling for out-of-range alarms. Interface and input/output equipment are supplied by the system vendor as part of the package. An illustration of a central console and remote panel for a dedicated control system is shown in Figure 6-2.

Dedicated systems for central installations are most often used for large single buildings or in building complexes. Hospitals, schools and factories are typical applications. Units are suitable for on-off time control and for cycling of loads, and generally provide run time totalization for connected loads. Most units provide for load shedding to avoid exceeding specified demand limits. As the number of loads being controlled is generally large, the effectiveness is greater than if done on a building by building basis.

6.3 Programmable Controller System for Central Installation

Programmable controllers offer user developed control programming capability to complement standard preprogrammed functions stored in read-only memory. Word length (typically 8 bits) is sufficient for process control logic applications but is generally not suitable for performing floating point arithmetic. Controllers in this class can support 16 remote panel terminals each having 16 input/output connection points. Interface and input/output units are supplied by the system vendor as part of the package. An illustration of components in a programmable controller system is shown in Figure 6-3.

Programmable control systems for central installations provide adequate resources to handle an entire military facility. Vendors generally provide a wide range of standard control programs which can be modified slightly to meet the special requirements of specific applications. The central processor will have sufficient capability to handle enthalpy control and may be able to provide certain optimization functions.

6.4 General Purpose Minicomputer System

Minicomputer systems provide the maximum flexibility and expansion capability available for an automated control system. Systems of this type are referred to as Energy Monitoring and Control Systems (EMCS). These systems utilize microprocessor based Field Interface Devices (FID's) at individual buildings which function much as a dedicated system for local installation. The FID's are connected and slaved to a central computer which monitors, and stores operational data from the FID's as well as altering set points according to software and operator instructions. A tri-service guide specification for the purchase of these systems is available. (TS 13941, 2, 3, 4, 5 and TS 13946). This specification describes the system architecture and vendor responsibilities in detail. The specification calls for a distributive processing type of arrangement which is that described above, where the local processing is handled at the site with supervisory control coming from the central computer. An illustration of the control processor and terminal of a general purpose minicomputer is shown in Figure 6-4. The hardware configuration for an EMCS is shown in Figure 6-5.

A general purpose minicomputer system provides sufficient resources to handle all EMCS applications described in Chapter 3 including optimization routines. Minicomputer units are traditionally used as process controllers in large factories and as data processing devices in commercial applications but have been used in several large EMCS applications. Use of Fortran language permits easy customization of standard control routines to meet the exact requirements of the facilities engineer. Multiple job processing capabilities allow new application programs to be developed and tested at the same time the machine performs its assigned EMCS function.

FIGURE 6-1. ILLUSTRATION OF PROCESSOR FOR DEDICATED LOCAL CONTROL SYSTEM

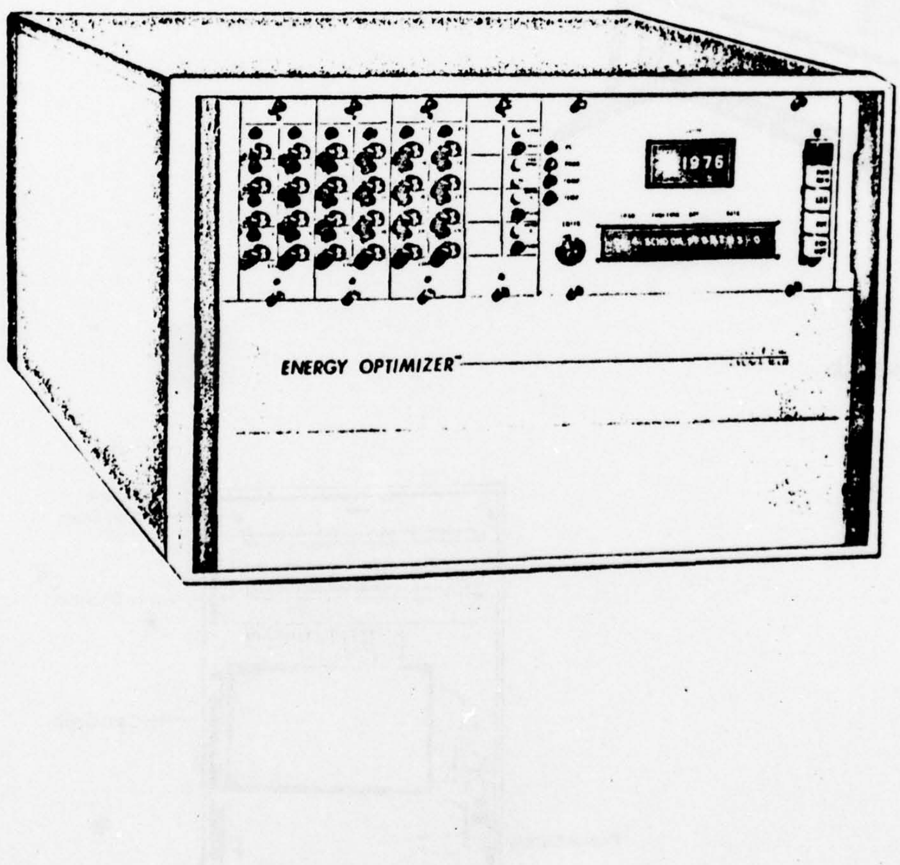
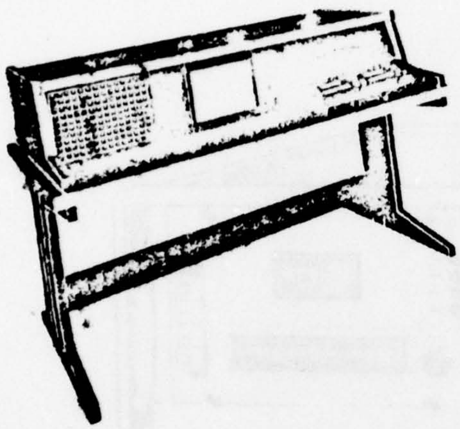
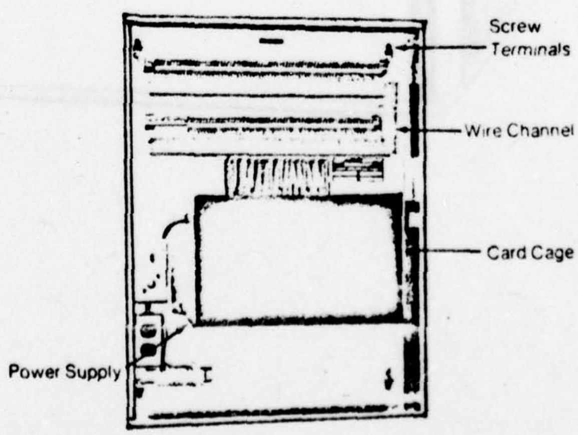


FIGURE 6-2. ILLUSTRATION OF CONSOLE AND REMOTE PANEL FOR DEDICATED CENTRAL CONTROL SYSTEM



CONSOLE



REMOTE PANEL

FIGURE 6-3. ILLUSTRATION OF SYSTEM COMPONENTS USING PROGRAMMABLE CONTROLLER

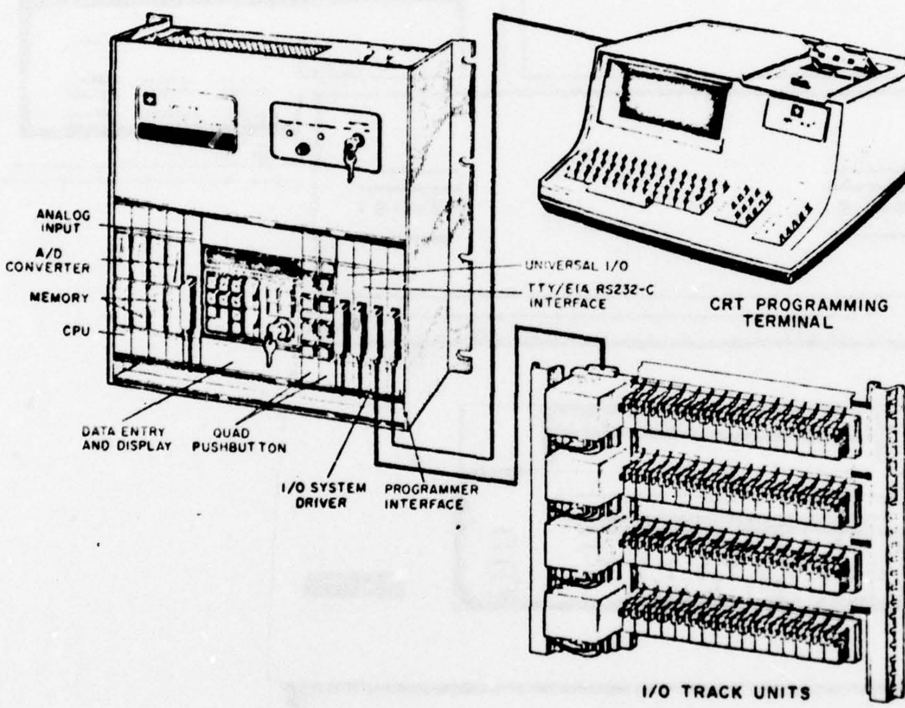
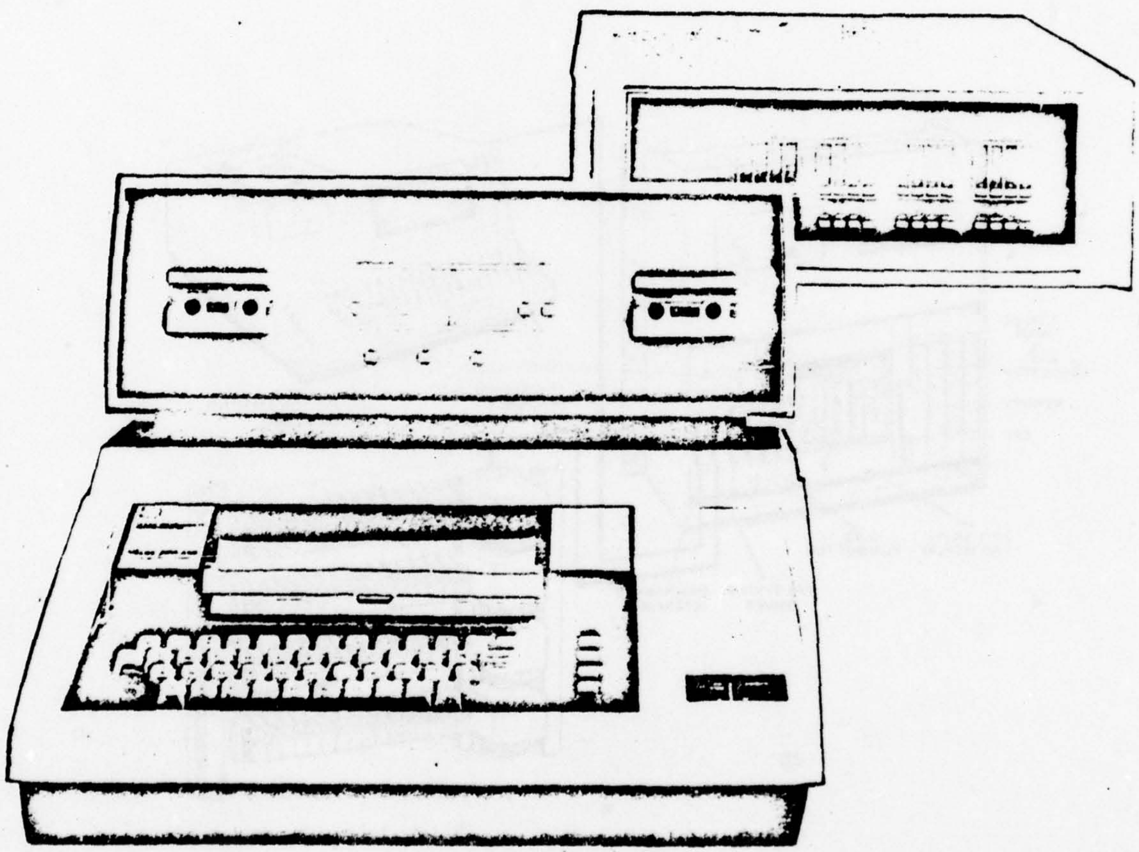


FIGURE 6-4. ILLUSTRATION OF PROCESSOR AND TERMINAL FOR GENERAL PURPOSE MINI COMPUTER



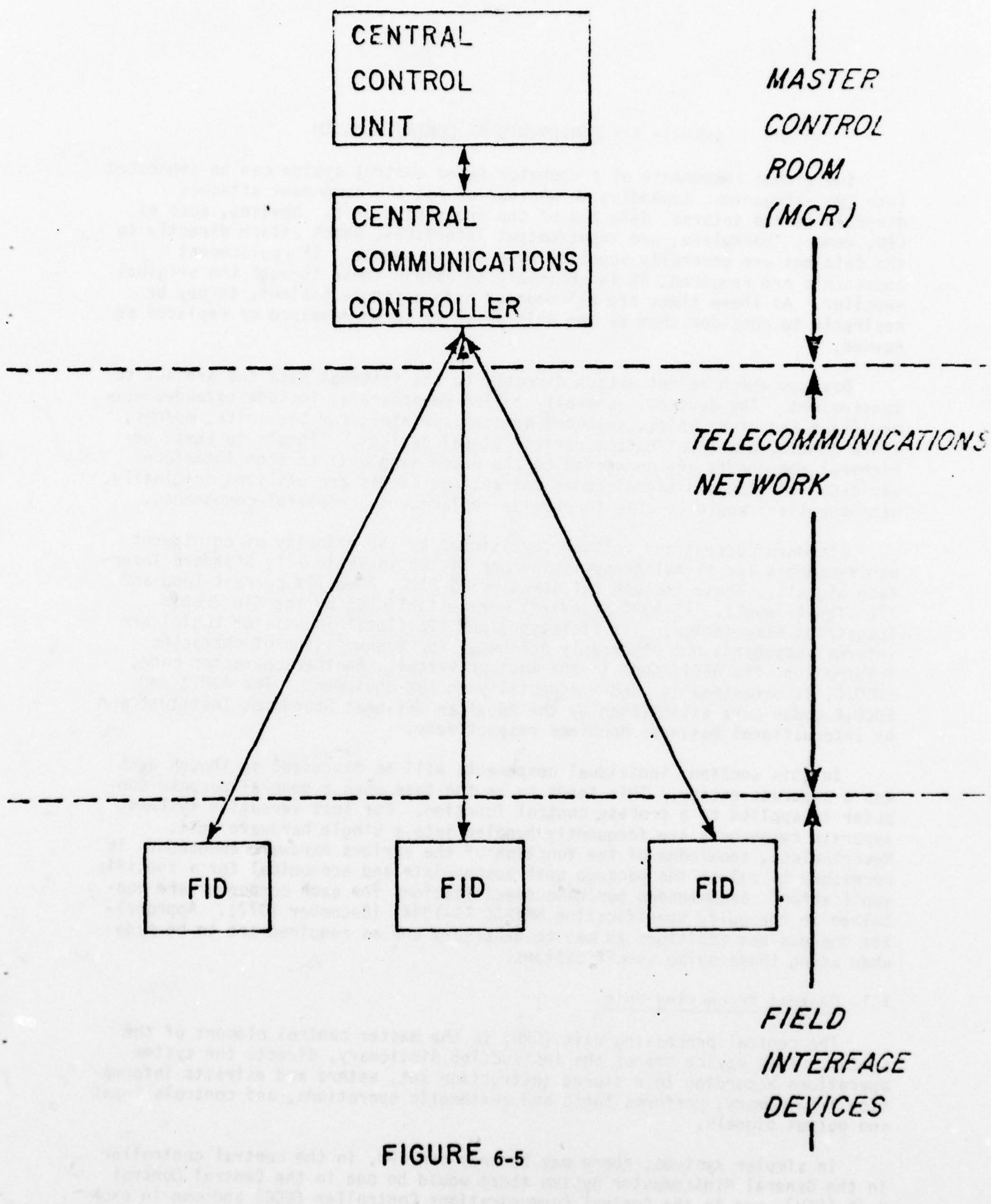

CENTRAL
CONTROL
UNIT
CENTRAL
COMMUNICATIONS
CONTROLLER
MASTER
CONTROL
ROOM
(MCR)
TELECOMMUNICATIONS
NETWORK
FID
FID
FID
FIELD
INTERFACE
DEVICES

FIGURE 6-5

CHAPTER 7 - COMPONENTS OF CONTROL SYSTEM

Individual components of a computer based control system can be separated into two categories, depending on whether or not the component attaches directly to the internal data bus of the processing unit. Devices, such as CPU, memory, backplane, and input/output interfaces, which attach directly to the data bus are generally supplied by a single source. If replacement components are required, it is necessary to obtain these through the original supplier. As these items are all mounted onto a single cabinet, it may be desirable to consider them as one unit which is to be repaired or replaced as needed.

Devices which do not attach directly to the internal data bus are not so constrained. The devices, generally called peripherals, include extended memory (tape and disk) units, keyboard devices, printers and CRT units, modems, alarm panels, and input/output control signal devices. Signals to these peripheral components are connected to the processing unit through interface devices. If standard signal codes and voltage levels are utilized originally, many suppliers would be able to provide replacement peripheral components.

Standard current and voltage levels used by the majority of eqiuipment manufacturers for signal transmission are listed in Table 7.1, Standard Interface Signals. These include EAI Standard RS-232C, 20ma TTY current loop and TTL signal levels. RS-232C Standards were established by the Electronic Industries Association. TTY (Teletype) and TTL (Total Transistor Logic) are informal standards not rigorously defined. For transmission of character information, the ASCII Code is the most universal. Another character code, EBCDIC, is occasionally used - especially on IBM equipment. The ASCII and EBCDIC codes were established by the American National Standards Institute and by International Business Machines respectively.

In this section, individual components will be discussed as though each was a separate entity. This tends to be the case when a general purpose computer is applied to a process control function. For less versatile systems, separate components are frequently bundled into a single hardware unit. Nevertheless, knowledge of the function of the various hardware components is necessary to select the package most appropriate and economical for a specific application. Recommended purchase specifications for each component are contained in the guide specification NAVFAC TS-13941 (December 1977). Appropriate changes and additions as may be necessary and as required are to be made when using these guide specifications.

7.1 Central Processing Unit

The central processing unit (CPU) is the master control element of the system. This device stores the instruction dictionary, directs the system operations according to a stored instruction set, enters and extracts information from memory, performs logic and arithmetic operations, and controls input and output signals.

In simpler systems, there may be only one CPU, in the central controller. In the General Minicomputer System there would be one in the Central Control Unit (CCU), one in the Central Communications Controller (CCC) and one in each Field Interface Device (FID).

The CPU consists of a single LSI (large scale integration) chip, referred to as a microprocessor. When connected to a small amount of memory, input/output devices and a crystal controlled clock chip, the resulting package is referred to as a microcomputer. CPU devices generally use a 16 bit memory address. This permits identification of 65,536 addressable memory locations. Word size of both 8 and 16 bits are common. The 8 bit word is sufficient for most logic and integrated arithmetic operations. A 16 bit word size is desirable for arithmetic operations involving BCD (binary coded decimals) characters or extensive data processing functions

7.2 Addressable Memory

Addressable Memory is used to store data and instruction to be processed by the CPU. Each memory location has a unique numerical address. An address word length of 16 bits is commonly used. This provides 65,536 unique numerical addresses.

Memory devices consist of special purpose LSI chips attached to printed circuit boards. A typical circuit board may provide from 1024 to 4096 words of memory. Some systems may start with limited memory, say 4096 words, and be expanded at a later time if desired. Design of the internal data bus and cabinet allows this additional memory to be installed on a plug-in basis.

Memory chips consist of two types: RAM and ROM. RAM (originally an acronym for random access memory) devices can support both read and write functions, data can be both stored in and recalled from the specified address. RAM memory units currently used are volatile; if the power to the system is interrupted, the stored information will be lost. Thus, battery backup is desirable to prevent loss of memory during momentary power failures.

ROM (read only memory) devices can support the read function only. The information on data in the memory units are permanently "burned" into the device, and are not affected by loss of power. When power is restored, information stored in ROM will still be available. It is thus desirable to store as much information as possible on ROM devices. This would include the control program and operating instructions plus nominal values for operating limitation and time clock control coefficients. RAM is used for operating (scratch) memory, for storage of operational data, and for changes to the nominal coefficients.

The ROM chip that would be most adaptable to the applications described in this manual is the EPROM (Erasable Programmable Read Only Memory) device. These can be programmed by the user with standard equipment available for that purpose. If it is later desired to change the information in storage, the EPROM is erased by exposure to an ultraviolet light source. This returns the module to a cleared state suitable for reprogramming.

7.3 Input/Output Interface

Information is transferred within a typical processor using 16 parallel lines to specify the address and 8 parallel lines to specify data. To service most external devices, it is necessary to provide an output interface device to capture the data signals, to transform them into serial characters, and to release the output as required by the peripheral device. In a converse manner, input interface devices are needed to accumulate the serial input data, translate the data into parallel signals, and release the information to the internal data bus when requested by the CPU.

To assure multiple suppliers for replacement of peripheral components such as printers, CRT units, keyboards, and modems, communications between the interface device and the peripheral should conform with an industrial standard. The standard character set for printers, teletypes, and similar equipment is the ACSII code. Standard signal levels are the 20ma TTY current loop and the EIA Standard RS-232C interface. Communications with I/O devices using discrete signals should use standard TTL voltage levels. Analog I/O devices should use a signal range not exceeding $\pm$ 10 volts or $\pm$ 20ma.

7.4 Power Supply, Cabinet, and Backplane

The power supply, cabinet, and backplane are necessary to support the CPU, memory, and I/O interfaces. The power supply provides current at the voltage levels required by the processor (typically $\pm$ 5V, $\pm$ 12V, and ground). Battery backup at the power supply prevents loss of volatile memory during short periods of power outage. Capacity of the battery backup is generally sized to provide sufficient power to retain memory for a 2 to 8 hour period. Battery capacity does not provide for normal processor operation during these periods of power outage.

The cabinet provides a holder for the individual printed circuit boards containing the CPU, memory I/O interfaces, etc. Frequently, the cabinet is in the form of a desk or table. These configurations provide a place for setting peripheral equipment or work space for the system operator.

The backplane may be part of the cabinet, a separate printed circuit board, or a specially designed edge connector. It functions to connect the individual printed circuit boards into the common internal data bus. This arrangement permits quick interchange of individual printed circuit boards for maintenance purposes. It is desirable to obtain a cabinet and backplane arrangement that will support reasonable expansion in memory size and number of I/O interfaces.

7.5 Extended Memory

Extended memory devices most commonly associated with microcomputers consist of cassette tapes and floppy disk units. Conventional disk units and core storage are used in minicomputer systems. Core memories are solid state structures utilizing magnetic charges to store data. Core memory is non-volatile but seldom used with microcomputer systems because of their cost. Cassette tapes used for data storage purposes are similar in most respects to those used for voice recording purposes. The quality and cost of cassette equipment designed specifically for data storage purposes is generally higher. Use of cassette tapes is slow and prone to a high error rate.

Speed can be increased and error rate reduced by use of magnetic disk devices. Both the standard disk or the newer floppy disk which was developed from the more refined disk pack systems permits prompt random access of any portion of the record. In operation, the read/write head moves radially across the surface to the specified track while the disk rotation brings the specified section into position. A single floppy disk can store 256.2 thousand bytes of data. A transfer rate of 250 thousand bits per second can be achieved. Conventional disk units provide greater speed and storage capacity than floppy disk and are generally more expensive. At present, the recommended purchase specification does not permit floppy disk installation.

Disk and tape units should be installed in the dual mode. Besides providing twice the storage capacity, it allows the computer to take information from one device (the original), operate upon it, and record the results on the second device (the updated) without destroying the original information. Copies of both the original and the updated information can thus be retained as long as necessary.

To assure maximum commonality among components, all extended memory devices should be compatible with EIA or TTY signal levels and accept ASCII standard character sets.

7.6 Keyboard Devices

Keyboard devices permit entry of address and data information into the controller. Devices available for this purpose include the following:

1. Binary switches,
2. Numerical keyboard,
3. Dedicated pushbuttons and thumb wheel switches,
4. Standard keyboard.

Direct data entry from binary switches is the most basic arrangement available. A series of two position switches are set to represent the binary values of the address and data being entered. Discrete values can then be entered through a TTL interface. Entering of data in a binary mode is slow and prone to errors, particularly when a large amount of data is to be entered. As a result, binary switch entry systems are found only on equipment designed for limited applications.

Use of a numerical (or hexidecimal) keyboard reduces the effort required to enter address and data information. A hexidecimal character may be used to represent a series of four binary characters. The hexidecimal character set is represented by the numbers 0 to 9 and letters A through F. Entering of the information in hexidecimal form reduces the number of key strokes required and the errors associated with the data entry process. The keyboard automatically transforms the key stroke into its binary equivalent for transmission to the appropriate interface device.

Dedicated pushbuttons and thumb wheel switches are sometimes used to enter information. Typically, these devices provide discrete binary signals to a TTL interface. Their use is easily learned and not prone to error. Possible uses would be for alarm acknowledgement, device actuation, or for entering frequently changed data values. As each device must have a dedicated function, use of pushbutton and thumb wheel switches tend to be limited.

The standard keyboard permits entry of information by using a typewriter-like keyboard. A full set of printable characters is available using the standard ASCII code. A TTY (teletype) or EIA interface converts the coded characters into appropriate signals for the processor. Using a standard keyboard device, the burden of correct data entry can be significantly shifted from the user to the terminal software. For this reason, keyboards are generally associated with printers or CRT units that incorporate considerable independent processing power. A standard keyboard is required if use is to be made of assembly languages or higher level language such as BASIC or FORTRAN.

7.7 Printers and CRT Units

Printers and CRT units are discussed together because of the similarity of their functions. Each provides a mechanism for providing information output to the system operator. A printer provides this information in a form suitable for long term storage. The CRT unit provides information in a display mode which may be erased and rewritten whenever desired.

Printers currently available span a wide range of capabilities. They range from moderately fast line printers capable of 60 lines or more per minute output to relatively slow teletype devices with speeds as low as 15 characters per second. Special features available include dual color print control. One color could be used for normal output and a contrasting color could be used for alarm conditions. Careful consideration should be given to the proper selection of a printer. As they are a complex electromechanical device, they tend to be expensive to purchase and require frequent maintenance. If the printer is to be the sole output device, features such as dual color print may be desired. If a CRT display is also planned for the system, the prime purpose of the printer would be to provide a permanent record of system operation parameters. In this case, an unadorned teletype terminal may be preferred.

A CRT display is very desirable if significant programming changes or software development is planned. Large quantities of output can be viewed on the scope without having to be printed on hard copy. This both reduces the amount of hard copy that must be printed and stored, and permits the printer to be used exclusively for generating records of system status, alarms, and operating summaries. The presence of a CRT display would also provide a means for sustaining system operation during times when the printer is off line for repair or maintenance.

Available CRT units range in capability from those that display only lines of alpha numeric characters in black and white to devices capable of displaying complex visual patterns in full color. For control of HVAC systems and program development, a black and white character display device would be adequate. However, capabilities for displaying block diagrams, schematics, and graphs would be of unquestioned value. Full color images would contribute to operator awareness. Display capability is a function of the internal software and signal generator. These capabilities vary greatly from supplier to supplier.

Both printers and CRT units should use EIA or TTY interface standards and the ASCII character set. This is especially important in selecting a printer as these units tend to have the highest failure rate of any component in the system. Use of a standard interface signal will facilitate use of equipment by alternate suppliers if desired for either a permanent or temporary basis.

7.8 Modems

Modems are devices for converting digital information to and from audio tones suitable for transmission over a telephone network. The operation of modems is discussed in Chapter 10. If telephone lines are used to transmit data to and from remote sites, modems will be required at each telephone line connection. Modems should use TTY or EIA standard type interfaces to assume maximum commonality for future equipment replacement. For the same reason, interfaces for these devices should use the ASCII standard character set.

7.9 Alarm Panels

Alarms described in this section include visual and audio which might signal fire detection, unauthorized entry, or loss of critical data input signals. Generally, it is desirable that these be immediately acknowledged by the system operator. Each alarm, therefore, requires one output line (alarm) and one input line (acknowledge). The alarm panel would interface with the central controller through a simple TTL interface.

7.10 Data and Control Signals

Data and control signals consist of two classes; analog and discrete. Analog signals represent numerical quantities by varying the amplitude of control signals. Discrete signals utilize the presence or absence of a control signal to represent the status of a two position system.

Analog input signals originate from measurement devices such as pressure differential meters and temperature sensing devices. Analog output signals are used to provide positioning of dampers, valves, or other devices capable of adjustment over a continual range. For input, signals should be no greater than $\pm$ 10V or $\pm$ 20ma. For output, required signal strength should be less than $\mp$ 10V. Analog signals require use of an A to D converter for input data and a D to A converter for output with a typical conversion accuracy of 0.5 percent. Instruments used in HVAC equipment typically has an accuracy level of 2 percent of full scale. Controllers using either 8 or 16 bit word sizes are capable of processing the analog data from the HVAC system. An 8 bit word length permits the representation of 256 unique positions. Thus, no point can be further than 1/512 of full scale from a represented digital value. Thus, the error resulting from use of 8 bit representation is less than 0.2 percent. By similar logic, the error resulting from using 16 bit word representation is less than 0.008 percent.

Discrete input signals originate from measurement devices such as thermostats and switches. Discrete output signals are used to control binary operation such as motor operation and alarm activation. For maximum commonality, discrete input and output signals should conform to TTL standards.

TABLE 7-1

STANDARD INTERFACE SPECIFICATIONS

Characteristic	Specification/Description
Peripheral Input Lines	
EIA Data	-3 V to -25 V for logic 1 +3 V to +25 V for logic 0
EIA Control	+3 V to +25 V for logic 1 -3 V to -25 V for logic 0
TTY Data and Control	Short circuit for logic 1 Open circuit for logic 0
TTL Data and Control	+3 V to +5 V for logic 1 0 V for logic 0
Module Output Lines	
EIA Data	-5 V to -11 V for logic 1 +5 V to +11 V for logic 0
EIA Control	+5 V to +11 V for logic 1 -5 V to -11 V for logic 0
TTY Data and Control	20 mA current loop for logic 1 Open circuit for logic 0
TTL Data and Control	+3 V to +5 V for logic 1 0 V for logic 0
Transmission Rates	110, 150, 300, 600, 1,200, 1,760, 2,400, 2,800, and 9,600 baud.

CHAPTER 8 - COMPARISON OF CONTROL SYSTEMS

Four classes of automatic control systems were identified in Chapter 6. In this chapter capabilities of the four different classes will be compared. The control system which will provide the best performance at the most economical price will depend upon the specific application. No single control system is best for all applications.

To select which of the four classes of automatic control systems is best suited for a particular EMCS application, the potential usem must compare the needs of the system as dictated by the control schemes to be implemented against the capabilities of each class of system. For example, simple control schemes such as scheduling of loads require minimal control system capability. Complex control schemes such as optimal start-stop and boiler optimization require data processing capability. A guide to identify the control capability of the various classes of control systems is provided in Table 8-1. Information in this and other tables in this chapter is based upon hardware and software capabilities of actual devices considered typical of each class.

8.1 Comparison of Hardware

The design of computer hardware establishes the ultimate capability of the control device. The CPU, memory, and I/O structure provide the foundation of the system. The more powerful this foundation, the more software and peripheral devices can be accommodated. A summary table of hardware capability is presented in Table 8-2.

8.1.1 Expansion Capacity

As a minimum, hardware should support immediate demands of the EMCS application. In addition, careful attention should be given to the economic feasibility of providing hardware with sufficient capability to support reasonable system expansion. Preprogrammed controllers have limited expansion capability. Programmable controllers offer extensive capacity for growth and expansion.

8.1.2 Word Size

The ability of the controller to effectively perform certain mathematical operations is limited by word size. Four bit word sizes would limit the device to relay simulation tasks. A device using an eight bit word size is suitable for use as a logic processor. It could handle addition and subtraction of discrete numbers, and can represent analog values with a resolution of 1 part in 256. Additional data processing capability is available with devices using a 16 bit word size. A 16 bit word size can handle binary coded decimal (BCD) notation. BCD notation permits transmission and storage of noninteger values and faciliates efficient multiplication and division operation. This feature is desirable if the optimization schemes described in Chapter 3 are to be used.

8.1.3 Memory Size

Memory size utilized in EMCS applications range from as little as 1,000 words to 128,000 words. A memory size of 16,000 to 32,000 words probably would be sufficient for all applications described in this manual. Memory devices should consist of a mixture of volatile RAM and nonvolatile EPROM chips or cards. EPROM units throughout the system should be physically interchangeable to assure ease of EPROM updating. This allows EPROM units to be programmed at a central control site and then simply exchanged with another memory unit at the remote site.

8.1.4 Program Interrupts

Program interrupts provide a means of quickly diverting control of the CPU from the normal order of instructions. The number of interrupts is generally the same as the word size. Certain of these are available to the user and certain are dedicated to internal functions, such as responding to power loss, power recovery, and signal error detection. Eight interrupts levels should be sufficient for the necessary dedicated functions required for EMCS applications.

8.1.5 Instruction Cycle Time

Instruction cycle time is a measure of the speed with which the CPU executes instructions. The two programmable devices described in this manual had instruction cycle times in the range of current technology, 2 to 4 microseconds. Modern language instructions take from one to three cycles to execute. Assuming two cycles as typical, these systems could execute 125 to 250 thousand lines of program each second. This is adequate for all anticipated EMCS applications.

8.1.6 Peripheral Devices

Peripheral devices form the link between the user and the processor. Peripheral devices compared in Table 8-2 are scope, printer, mass storage, and data input devices. The types of peripheral devices needed are determined by these applications. If compatible with the original CPU hardware, peripheral devices can often be added to the EMCS at a future date. For display of instantaneous numeric and graphic display, the scope is generally the preferred device. Both of the programmable control devices described previously, plus some preprogrammed control devices will support a scope. For permanent data storage of operating logs, alarms, or system status summaries, a printer is desirable. All but the smallest local controllers will support a teletype printer. The more powerful processors will support line printers having a considerable higher output speed. If the processor is to serve in a data processor function, rapid output compatability would be important.

Mass storage devices are generally supported by the programmable control devices. Some form of data storage is desirable for program security, for development work, and for collecting data for future analysis. Floppy disk and cassettes are the typical mass storage devices, although core storage devices are sometimes used. Cassettes and floppy disk provide a permanent storage media and a mechanism for exchanging of large quantities of data between users.

All control devices must have some mechanism for entering of data. Preprogrammed controllers need only minimum capacity devices such as numerical keyboards or thumbwheel switches. Programmable controllers generally require a standard ANSI keyboard. For restart of a program after the volatile memory (RAM) has been lost, reading data previously stored on cassettes on floppy disk is preferred. Certain systems used a paper tape for this purpose.

8.1.7 Input/Output Devices

Instrumentation and control signals can take four forms: discrete output, discrete input, analog output, and analog input. Programmable devices will generally support all four forms. Smaller preprogrammed controllers, however, will frequently support only discrete input and output. At the very low price range, controllers will only provide discrete output signals. Thus, they function only as elaborate time clocks. Instrumentation and control signal requirements are set by the HVAC system design and control scheme selected. The number and type of instrumentation and control points (or lines) required for various applications was summarized in Tables 5-1 through 5-10.

8.2 Comparison of Software

Software is the term used to describe the control instructions which direct the actions of the automatic control system. The automatic control system can only do those functions for which software is available. Various criteria of software performance are described in this section. Based upon these criteria, the four classes of control systems are compared in Table 8-3.

At this time, recommended preliminary specifications require that software for the complete EMCS be supplied by the vendor. Software documentation should also be supplied to permit modification as future system requirements change or as new equipment is added.

8.2.1 Expansion Capability

An important aspect of system performance is its ability to support software growth or expansion. It is likely that certain functional requirements of an EMCS will change with time as a result of normal equipment changes or as a desire to improve performance. Both the programmed devices have sufficient adaptability to support reasonable growth and expansion. The local controller is not capable of any growth or expansion beyond controlling a fixed number of off/on control points. Software changes to the preprogrammed central control unit can be made only by the original supplier.

8.2.2 Language

The most basic instruction form is machine language. Operations and program commands are entered as a numerical sequence. Both programmable devices being compared could utilize machine language. As machine language is difficult to work with, many processors offer an equivalent mnemonic language. Alphanumeric names are used to represent various instructions. Names have been selected to represent the operation (i.e., HLT represents the HALT operation). Both programmable devices being compared could utilize mnemonic language.

High level languages generally take the form of mathematical statements. A single statement could represent 10 to 20 machine language statements. Being very standardized, programs written in high level language can be easily understood by people with minimum training and can be transferred from machine to machine with minimum difficulties. Typical high level languages are BASIC and FORTRAN. (BASIC is not an approved DOD language at present.) Of the four classes of controllers being compared, only the general purpose minicomputer offered both BASIC and FORTRAN. BASIC is available for the programmable central controller.

When a higher level language is used, either an interrupter or a compiler is required to convert the source program instruction statements into a machine language equivalent. An interpreter will translate and execute each single program statement before proceeding to the following statement. The machine language translation is not saved and is repeated each time the program is executed. A compiler converts all statements during a single step and provides a machine language equivalent for later use in program loading and executing. A compiled program will thus execute faster than one which must be interpreted. The choice between a compiler and an interpreter is generally governed by the capabilities of the host computer.

8.2.3 Error Diagnostic Packages

Software error diagnostic packages provide a convenient feature for locating and correcting errors originating from either hardware failure or signal transmission error. Action consists of either a warning being issued, the fault being localized and identified, or remedial action being taken. The two preprogrammed devices in this comparison both provide error detection and correction logic. Limited error detection and warning logic is also incorporated into the two preprogrammed devices.

8.2.4 Software Interrupts

Software interrupts are a desirable feature which permit rapid response to specified conditions. Upon receiving an interrupt command, the computer breaks from its normal execution sequence in such a way that the program can resume from that point at a later time. Software interrupts may be used for either routine or emergency situations. The programmable controller has 3 interrupts available whereas the general purpose minicomputer has 13 interrupts available. Three interrupts is probably the minimum number that would permit satisfactory software development flexibility. Thirteen interrupts are considered more than necessary for any proposed application.

8.2.5 Operational Security

Operational security is desirable to prevent unauthorized changes being made in the control system. The preprogrammed local controller and the general purpose minicomputer provided key locks to limit data entry into the system. No security features are incorporated into either the preprogrammed central controller or the programmable central controller. For these devices, data entry terminals should be located in secure areas having restriced admittance.

8.2.6 Multiprogramming Capability

Multiprogramming capability is a feature that is especially useful during software development. Control programs can be modified or updated while the EMCS simultaneously fulfills its designated function. The programmable central controller provides this feature through an independent intelligent terminal having its own 12 K memory. Changes to programs can be entered into the intelligent terminal and tested by simulation before being transfered to the central and remote processors. The general purpose minicomputer had a resident operating system capable of controlling concurrent execution of multiple tasks. Automatic functions include task scheduling, interrupt handling, and I/O servicing. Four levels of program priority are provided. Any number of tasks may be included at each level. This capability far exceeds the requirements of any anticipated application.

TABLE 8-1. COMPARISON OF CONTROLLER CAPABILITIES

Automatic Control System Classification	Preprogrammed Local Controller	Preprogrammed Central Controller	Programmable Central Controller	General Purpose Central Mini Computer
1. Scheduling of Loads	Yes	Yes	Yes	Yes
2. Shutoff of Outside Air Intake	Yes	Yes	Yes	Yes
3. Temperature Setback	Yes	Yes	Yes	Yes
4. Outside Air Reduction	Yes	Yes	Yes	Yes
5. Lighting Control	Yes	Yes	Yes	Yes
6. Enthalpy Control	No	No	Yes	Yes
7. Enthalpy Optimization	No	No	Maybe	Yes
8. Chiller Optimization	No	No	Maybe	Yes
9. Optimal Start/Stop	No	No	Maybe	Yes
10. Load Cycling	Yes	Yes	Yes	Yes
11. Predictive Demand Limit	Yes	No	Yes	Yes
12. Run Time Totalization	No	Yes	Yes	Yes
13. Equipment Malfunction Detection	No	Yes	Yes	Yes
14. Boiler Plant Optimization	No	No	Maybe	Yes
15. Energy Cost Allocation	No	Yes	Yes	Yes

TABLE 8-2. COMPARISON OF HARDWARE

Automatic Control System Classification	Preprogrammed Local Controller	Preprogrammed Central Controller	Programmable Central Controller	General Purpose Central Mini Computer
Capacity for Hardware Growth or Expansion	None	Limited	Extensive	Extensive
Word Size	--	--	8	16
Max Memory	--	--	64K	128K
Interrupt Capability	No	No	8 Levels	16 Levels
Instruction Cycle	--	--	2 μs	4 μs
Peripheral Devices				
Scope	No	No	Yes	Yes
Printer	No	Yes	Yes	Yes
Mass Storage	No	No	Cassette	Disk
Input				
Initialization	Thumbwheels	Numerical Key Board	ANSI Keyboard	ANSI Keyboard
Restart	Thumbwheels	Paper Tape	Cassette	Disk
I/O Devices				
Discrete Output	Yes	Yes*	Yes	Yes**
Discrete Input	One Only	Yes*	Yes	Yes**
Analog Output	No	No	Yes	Yes**
Analog Input	No	Yes*	Yes	Yes**

* Compatible with Manufacturer's Instrumentation Only
** Compatible with EIA and TTL Devices Only

FIGURE 8-3. COMPARISON OF SOFTWARE

Automatic Control System Classification	Preprogrammed Local Controller	Preprogrammed Central Controller	Programmable Central Controller	General Purpose Central Mini Computer
Capacity for Software Growth or Expansion	None	Limited	Good	Extensive
Machine Language	None	None	Yes	Yes
Mnemonic Language	None	None	Yes	Yes
High Level Language	None	None	Basic	Basic and Fortran
Error Diagnostic	None	None	Yes	Yes
Software Interrupts	None	Date Line Failure Alarm	3 Allowed	13 Allowed
Operational Security	Key Lock	None	None	Key Lock
Multiprogramming Capability	No	No	Intelligent Terminal	Foreground/Background

CHAPTER 9 - COST OF CONTROL SYSTEMS

During the preparation of this manual over 80 different manufacturers of automatic control systems suitable for energy management functions were identified. Names and addresses of these manufacturers are listed in Appendix A. Although this list is extensive, it should not be regarded as complete. The field of energy management is currently in a dynamic state resulting from the introduction of logic control systems based on the inexpensive microprocessor. Sensing that a new market is developing, both new and old companies are aggressively expanding into the energy management field. It is noted that manufacturers listed in Appendix A include the traditional companies supplying instrumentation and control devices, companies which manufacture data processing equipment, and firms whose speciality is development of computer control logic (software).

As the capabilities of a computer based system increase, one would expect a corresponding increase in the purchase price. This is indeed the case as will be shown in this chapter. The increase in price, however, is not nearly as great as that which existed only a few years ago. Major technical advances made in LSI (large scale integration) components have resulted in prices of logic components being reduced several orders of magnitude. One popular microprocessor chip which uses an 8 bit and a 16 bit memory address is now available for less than $18. RAM memory chips cost less than 25 cents per thousand bits storage capacity. Cost of the data processing elements is seen to be but a small fraction of the total system cost.

Cost of mass memory devices have also declined modestly as cassettes and floppy disk tend to replace expensive type drives and disk pack units. Other peripheral components, such as CRT units, printers, keyboard devices, modems, and power supply devices have remained fairly stable. Cost of installation of the systems, including sensors and control devices, have tended to increase in response to the general economic escalation in the construction industry.

To facilitate making an economic comparison of the various classes of control systems, a representative installation configuration is defined. The configuration was chosen to represent the application of control system to a typical large U. S. Army base. Nominalgy, it consists of a central control site and a number of remote sites. Remote processors or panels are connected to the central processor by existing telephone lines (one twisted pair of wires) or by coaxial cable. All sensors and control devices are considered to be located within 500 feet of a remote panel. Remote sites are sized to permit control of 16 circuits.

Each remote site would serve clusters of buildings in a specific area. Generally, buildings which serve as prime and support facilities for a specific activity will be located in clusters. Examples of activity associated clusters are office buildings, training facilities, barracks, maintenance shops, etc. Individual load clusters may often be separated from one another by distances up to several miles. The exact number of remote sites would naturally depend upon the actual base being evaluated and may be influenced by the capabilities of the control system finally selected.

Control equipment cost information was requested from numerous suppliers. Equipment cost data for 15 different suppliers is contained in Appendix B. The information presented in this appendix is based upon published price schedules, correspondence, conversations, and previously published information.

The purpose of Appendix B is to provide the equipment cost data necessary to evaluate the economies of the various classes of control systems. To guide the facilities engineer, cost for representative systems for each class are developed in the following sections.

9.1 Dedicated System for Local Installation

Cost estimates for a control system using a dedicated local control device were developed for two systems using equipment of differing capability. The first uses a mechanical time clock suitable for load scheduling. A unit to control a single circuit cost $100. Based upon 16 circuits at each remote site, cost of equipment for each remote site is $1600.

The second system being considered provides an energy management/predictive power demand control featuring:

- Sliding window predictive demand control
- Daily on/off scheduling & daily cycling
- Automatic adjusting demand limit
- Alarm indicating loss of meter input pulses
- Front panel data input through push buttons and thumbwheel switches
- All output contacts rated at 24 VDC and up to 200 MA

Control capability is limited to turning equipment on and off. The only signal input permitted is from the demand meters. Standard features include a desk top cabinet, input from 1 or 3 utility meters, and a battery backup system. A single unit capable of controlling 16 load circuits lists for $8575.

Both types of local control units will require local wiring as described in Chapter 10. There would be no central control panel or communications between remote sites. All data must be individually entered into the controllers at the remote sites. Controller cost (not including wiring) is shown in Figure 9-7 as a function of the number of remote sites.

9.2 Dedicated System for Central Control

Cost estimates for a control system using a dedicated central control device were developed from representative cost data for a typical facility application. The preprogrammed device provides start/stop control and monitors equipment instrumentation. Standard features include an operator's console with numerical push button keyboard and digital display, a printer interface for a teletype printer, and software programs for energy management. It is desirable to provide a teletype printer to obtain printouts of system status and trend logs. Preprogrammed routines perform the following functions:

1. Automatic or programmed starting (on/off control) of equipment according to a time schedule stored in memory.

2. Automatic alarming of analog values whenever they exceed individual memory stored high and low loads.

3. Automatic alarming of equipment which has exceeded individual memory stored elapsed run time value in order to perform preventative maintenance routines.

An optional control device is necessary to provide demand control. The operator is able to change start/stop times and alarm limits for all equipment at the control console.

A data acquisition panel (DAP) is required at each remote site to transmit and receive data from the central control panel. Each DAP can support 32 binary I/O points. If start/stop control is required, 1 to 16 of the 32 binary points are used for status. Each DAP can also support 31 analog points including up to 8 being used for control point adjustment. All DAP's requiring CPA or analogs contain A/D converters so that analog signals are converted to digital words for transmission. The control console can support a total of 7874 individual I/O points.

Data transmission between the central console and the DAP's uses one pair of twisted wires. If more than 4000 feet is required to connect the two, a separate station must be used. DAP's may be connected in either series or parallel fashion. A typical connection is shown in Figure 9-1.

Total cost for a dedicated central control system was calculated from component prices as shown in Table 9-1. Cost for the control terminal is $66,700. Cost for the remote terminals is $1,700. each. These cost include the price of the required modems but do not include cost of transmission or local wiring or of equipment adapter panels, control activators, or instrumentation. Effective cost of control as a function of the numbers of remote sites is shown in Figure 9-7.

FIGURE 9-1. INSTALLATION DIAGRAM FOR DEDICATED CENTRAL CONTROL SYSTEM

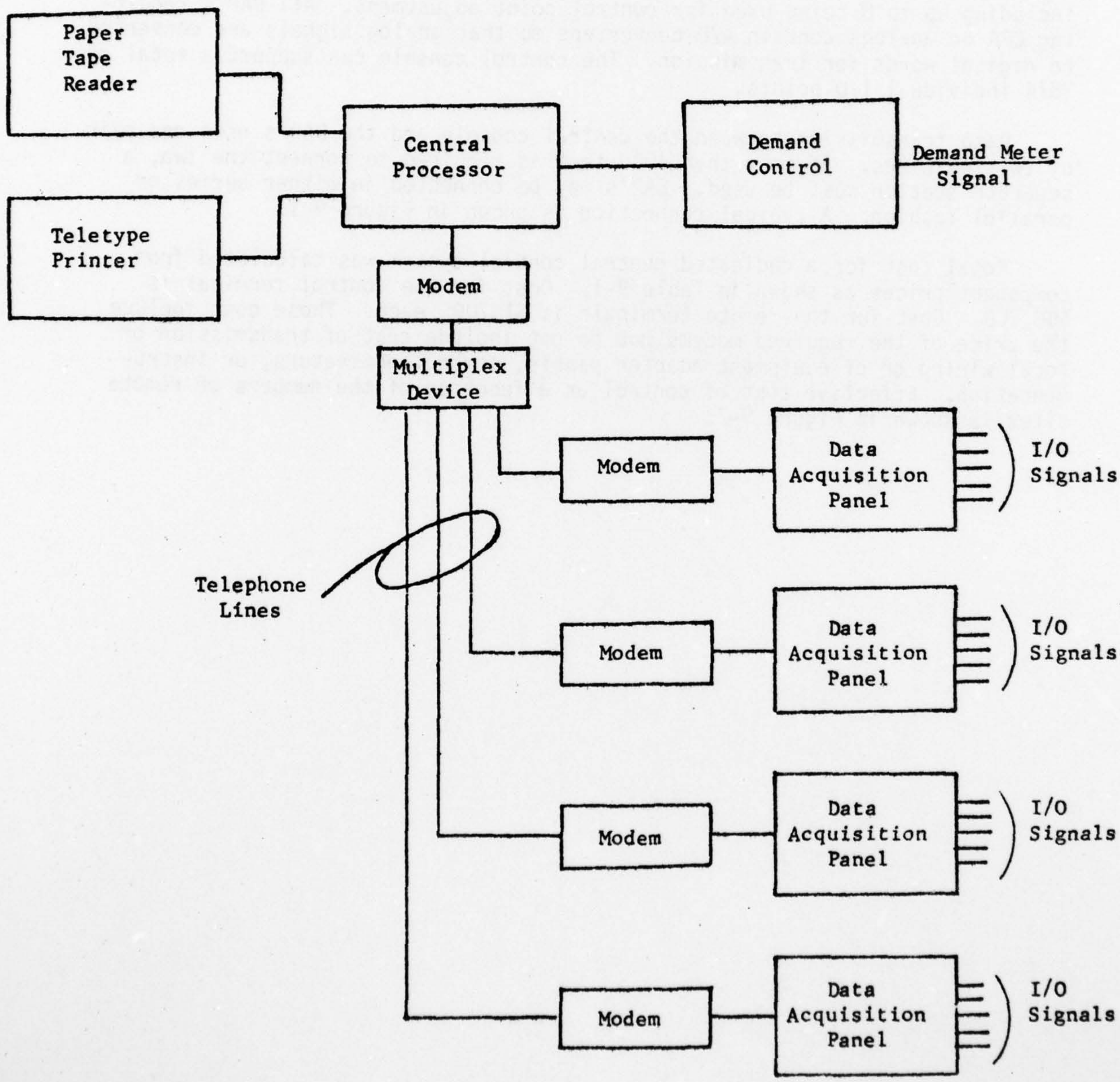


TABLE 9-1

LIST OF HARDWARE FOR DEDICATED CENTRAL CONTROL SYSTEM

Central Terminal	
Processor	$ 26,000
Demand Controller	3,000
Paper Tape Device	1,700
Printer	6,000
Modem	500
Multiplex Device	10,000
Software Program Package	19,500
	$ 66,700
Remote Terminal	
Data Aquisition Panel	$ 1,200
Modem	500
	$ 1,700

9.3 Programmable Controller for Central Installation

An industrial control system based upon a popular microprocessor chip was selected as representative of this class of control system. The system has the capability for arithmetic computation and a wide variety of digital, analog, and peripheral control. The system consists of a variety of components that can be designed into configurations ranging from advanced programmable logic control capability to complex continuous process control. A modular design allows the same basic hardware to be used for a variety of control situations. System hardware consists of four basic components; chassis and power supply, processor, I/O interface, and the programming terminal. The terminal supply is a rack-mounted housing compatible in design with the processing unit. The power supply furnishes all the power required by the processor unit. An internal battery back-up system will maintain 4K of RAM memory for up to 7 hours. External batteries can be added to extend RAM memory retention. The chassis design makes use of a mother board and individual module slot concept that allows the user to "design" his own system for each application and also to expand his system without costly wiring changes. This flexibility enables the system to be used for applications ranging from machine control and power demand control to data acquisition and complete process control.

The processor consists of the central processing unit (CPU), memory, input/output interface modules, peripheral interface modules, and data entry and display modules. A diagram showing placement of major components of the system is presented in Figure 9-2. Figures 9-3 and 9-4 show detailed component assembly for main and remote terminal applications.

The Central Processing Unit Module is based on a microprocessor chip, which is the heart of the system. The chip is an 8 bit microprocessor which has a typical execution speed of two microseconds per instruction. Directly adjacent to the CPU is the library memory. The library contains routines which are commonly used in industrial applications, such as timers, temperature controllers, etc. By putting these routines in a library, they are made available to the user simply by calling them. Next to the library memory is the user memory modules, of which there are three types available: modules containing 4K of EPROM, modules containing 4K of RAM, and modules containing a mixture of both EPROM and RAM. The maximum memory capability of the system is 48K. This can be intermixed between RAM and EPROM.

The input/output interfaces consist of two distinct types. One type is a TTY interface required to connect the processor with standard peripheral components, such as printers, modems, etc. A second type of interface is used for input and output of data for instrumentation and control purposes. Both types of interfaces are components that plug into slots in the chassis.

The I/O system for instrumentation and control consists of system driver modules, track units, and individual track modules. The system driver module fits in the chassis. The system driver module is interfaced to the track unit through an 18 twisted pair, overall shielded cable. This cable can be up to 500 feet long. That is, the last track unit can be 500 feet from the main chassis. Up to 16 track units, each with up to 16 track modules, can be connected to each system driver module. Thus, each driver is capable of addressing 256 track input or output modules. A system can have up to 8 system drivers for a total capacity of 2048 connection points.

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ENERGY MONITORING AND CONTROL SYSTEM. (REPORT UPDATE - 1978).(U)
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The following types of track I/O modules can be intermixed on the same track in any configuration:

120 VAC Input
240 VAC Input
1-32 VDC Input
120 VAC Output
240 VAC Output
4-55 VDC Output

The track I/O system and the power supply are each immune to ± 600 volts peak noise superimposed on the 120 Volt RMS line. Each module also provides 2324 volts peak optical isolation between the external high voltage signals and the internal TTL logic.

An intelligent CRT terminal is used to program the system. The CRT Programming Terminal has 12K of internal memory (16K optional), a 12 X 80 character screen, and a dual cassette tape drive. All programs are generated on the CRT programmer which also is used to load the memory and monitor the system on line. The CRT programmer is capable of directly loading a program into RAM memory. However, it is not capable of directly setting EPROM memory. To set EPROM, a programmer module is used.

The flexible hardware structure of the control system allows varied configurations to be developed specifically for the application requirement. Modules are selected, located within the chassis, and the final system characteristics determined by the designer. Selection of various module functions allows most control requirements to be readily implemented by the user. The system layout described is for illustration purposes only. The actual configuration will depend upon the specific application. Figure 9-3 shows a configuration suitable for use as a central control processor. A configuration suitable for use as a remote site controller is shown in figure 9-4. The costs of components for these two configurations are listed in Tables 9-2 and 9-3 respectively. Cost for the central control terminal is $29,575. Cost of the remote terminals is $7,271. each. These costs include the price of the required modules but do not include cost of transmission or local wiring or of equipment adapter panels, control actuators, or instrumentation. Effective cost of control as a function of the number of remote sites is shown in Figure 9-7.

FIGURE 9-2. INSTALLATION DIAGRAM FOR PROGRAMMABLE CONTROLLER

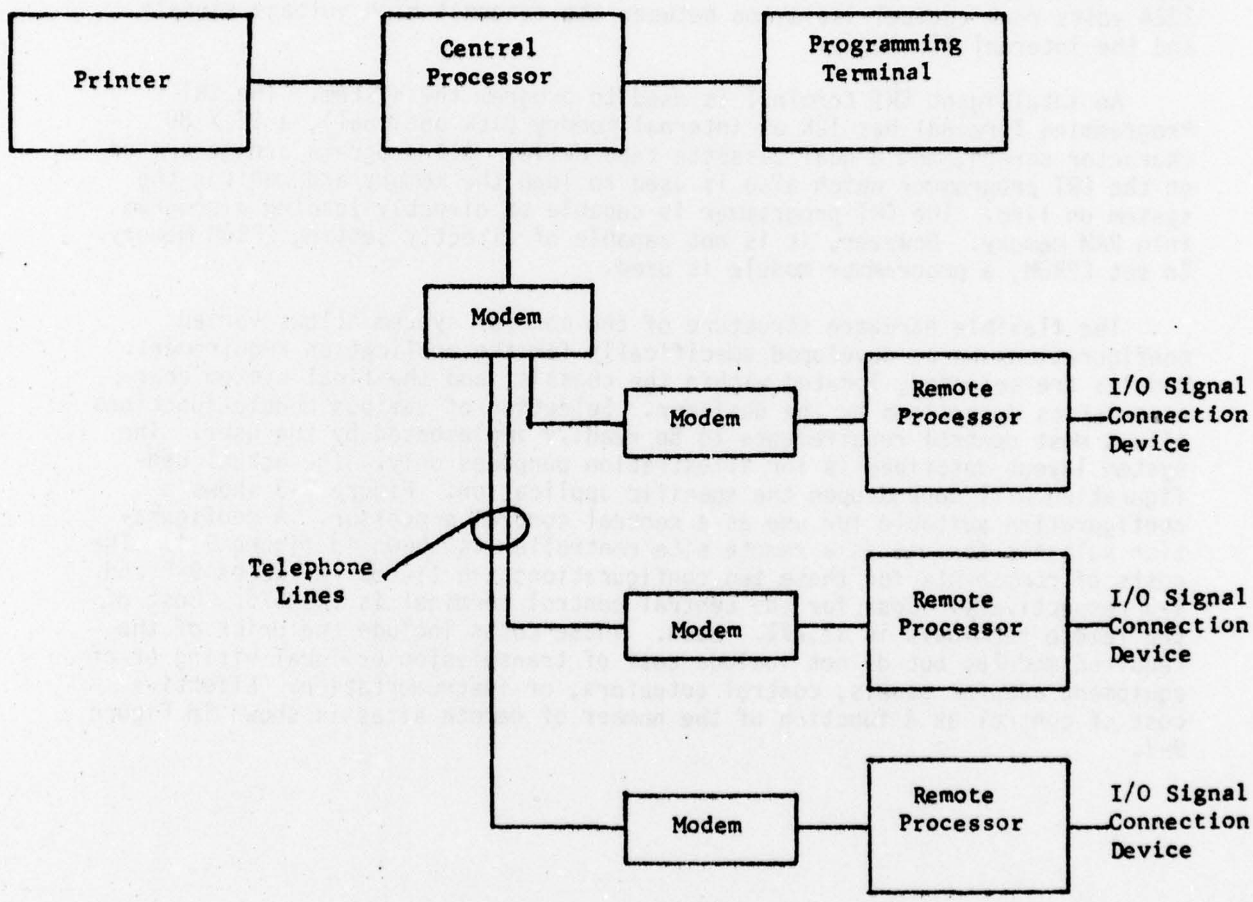


FIGURE 9-3. DIAGRAM OF MAIN TERMINAL HARDWARE FOR PROGRAMMABLE CONTROLLER

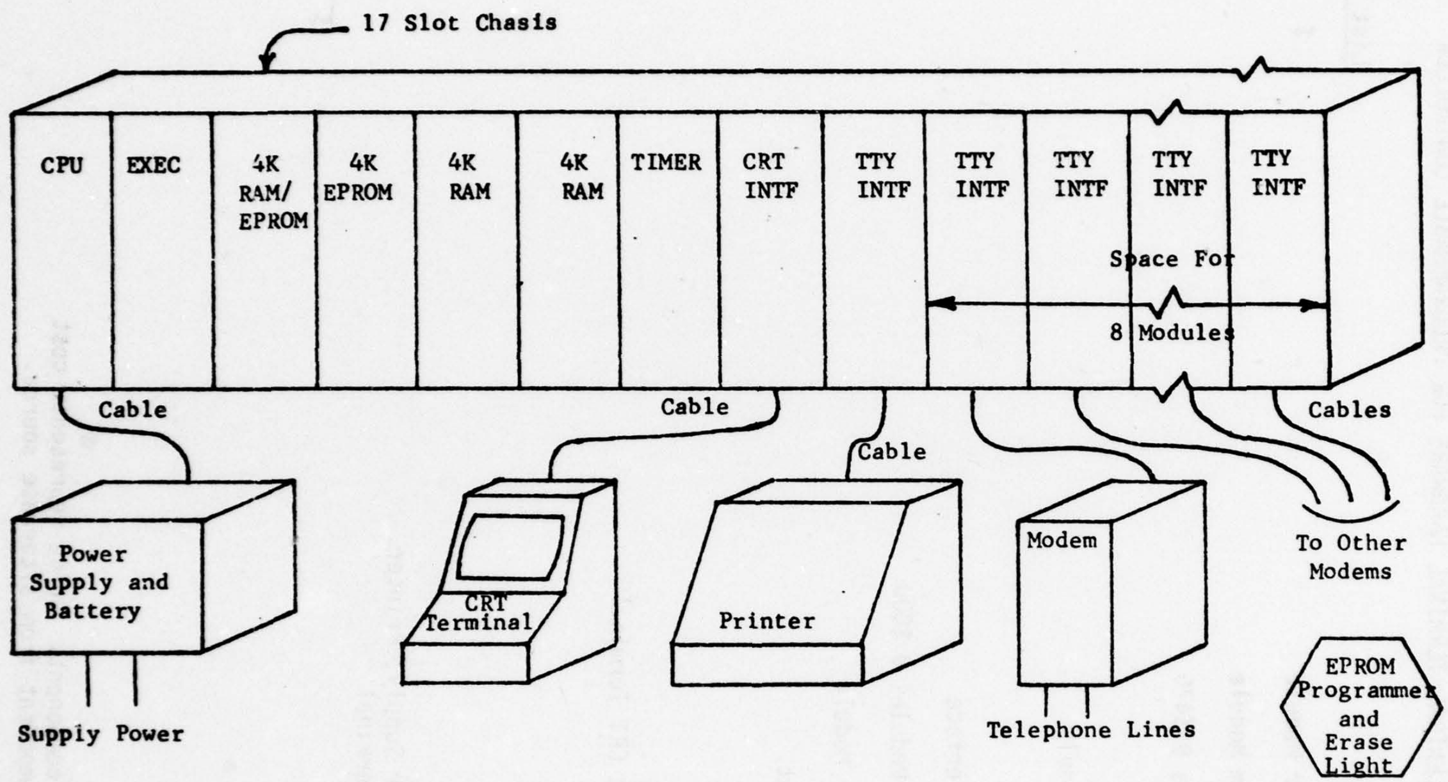


TABLE 9-2

LIST OF CENTRAL TERMINAL HARDWARE FOR PROGRAMMABLE CONTROLLER

Component	List Price
Central Processor Module	$ 795
Executive Program Module	830
2-4 K RAM Modules @ $475	950
4 K EPROM Module	780
4 K RAM/EPROM Module	625
Timer Module	275
CRT Terminal Interface	250
9 TTY Interface Modules @ $800	3,600
EPROM Programmer Module	300
EPROM Erase Light	265
Power Supply	1,090
17 Slot Chasis	520
16 K Intellegent CRT Terminal	10,995
10 Spare Tapes	160
Printer	3,100*
8 Modems @ $600	4,800*
Cables for Power Supply, Printer, Modem and CRT Terminal	240
	$ 29,575

* Not supplier component. Price represents cost of similar component from alternate source.

FIGURE 9-4. DIAGRAM OF REMOTE TERMINAL HARDWARE FOR PROGRAMMABLE CONTROLLER

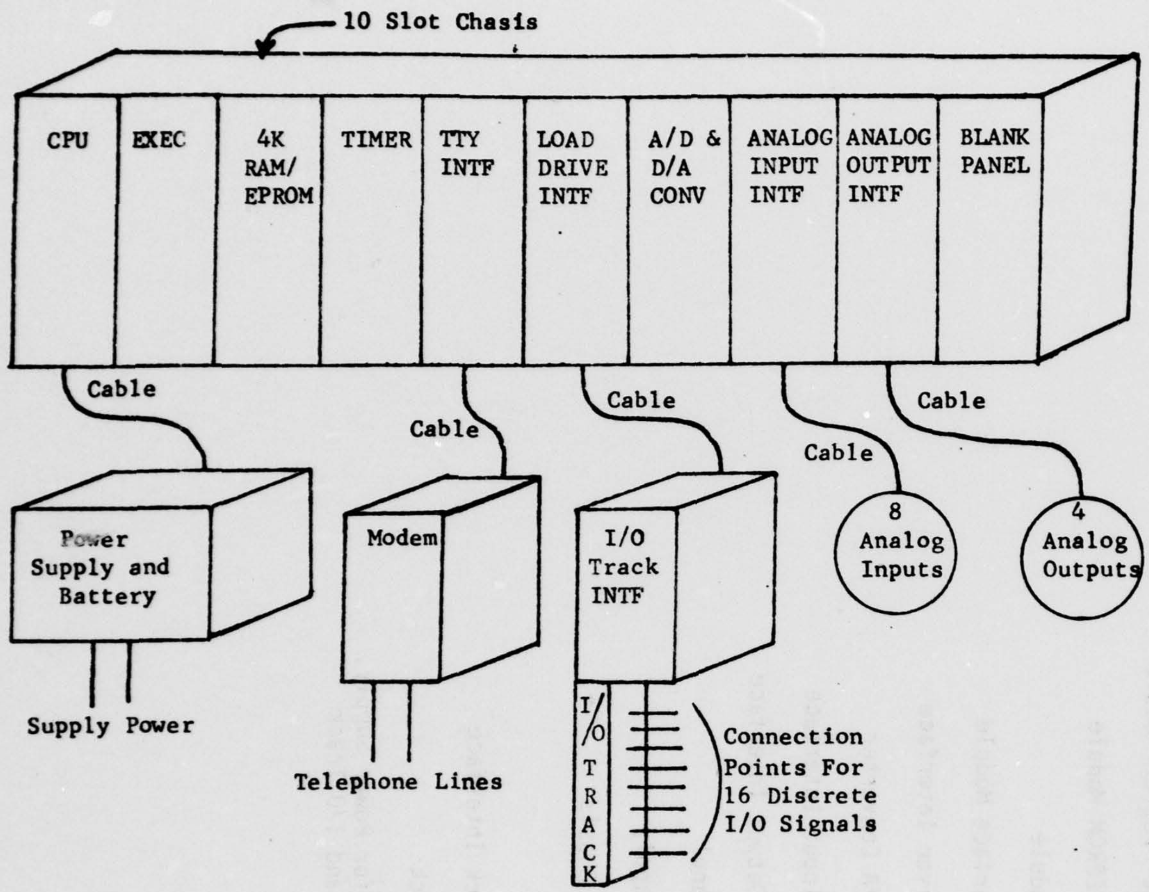


TABLE 9-3

LIST OF REMOTE TERMINAL HARDWARE FOR PROGRAMMABLE CONTROLLER

Component	List Price
Central Processor Module	$ 795
Executive Program Module	830
4 K RAM/EPROM Module	625
Timer Module	275
TTY Interface Module	400
Load Driver Interface	465
A/D & D/A Converter	200
Analog Input Interface	405
Analog Output Interface	450
Blank Panel	16
Power Supply	1,090
10 Slot Chasis	350
Modem	600*
I/O Track Interface	335
I/O Track	320
Cables for Power Supply, Modem and I/O Track	115
	$ 7,271

* Not supplier component. Price represents cost of similar component from alternate source.

9.4 General Purpose Minicomputer System

A general purpose minicomputer provides the power and flexibility required for a multitude of applications from miniaturized controllers to large data base management and information systems. An extensive selection of peripheral components is available from the various manufacturers. These include CRT terminals, I/O interface modules, disk storage, and hard copy printers.

A 16-bit machine device was selected as being representative of these systems. The device provides 16 interrupts. A memory mapping feature providing memory protection and privileged instructions support memory expansion to one million 16-bit words. A 16-bit parallel data bus, offering asynchronous operation and highspeed I/O, links CPU, memory and peripheral devices.

A comprehensive software package, supplied with the system permits the user to generate, edit, assemble, and evaluate programs. The standard software includes a debug monitor, which combines a powerful interactive debugging facility with system support functions, and a keyboard command interpreter for full user control of the system. A cassette-based source editor operates under control of the debug monitor and provides a facility that enables the user to generate, edit, and save source programs. A one-pass assembler processes source input from cassettes and generates relocatable, linkable object modules. A link editor accepts object modules generated by the assembler and loads them into memory as an executable program. The user may then execute the program directly or under the control of the debug monitor. With the debug monitor, the user can examine and modify parts of memory and registers, set multiple breakpoints and, if necessary, execute with a complete trace.

Standard software includes both memory-resident and disk-based operating systems suited for real-time, multi-tasking environments. The programming languages encompass FORTRAN IV, COBOL, and BASIC. Software development utilities are available to facilitate application program editing and testing. A completed program may be saved on cassette or may be directly burned into EPROM with the optional EPROM programming unit.

The high-level languages allow application software to be written in a format that is easy to undertand and maintain. Memory can be expanded to a total of 128K words using a combination of RAM and EPROM. An optional battery pack is available to prevent memory loss of RAM during interruption of main power.

The manufacturer of this sytem does not provide standard software packages for energy management and demand control. Nor does he supply the modules necessary for connection of instrumentation and control devices to the I/O interfaces. Suppliers of comparable equipment offer both appropriate software and device connection modules.

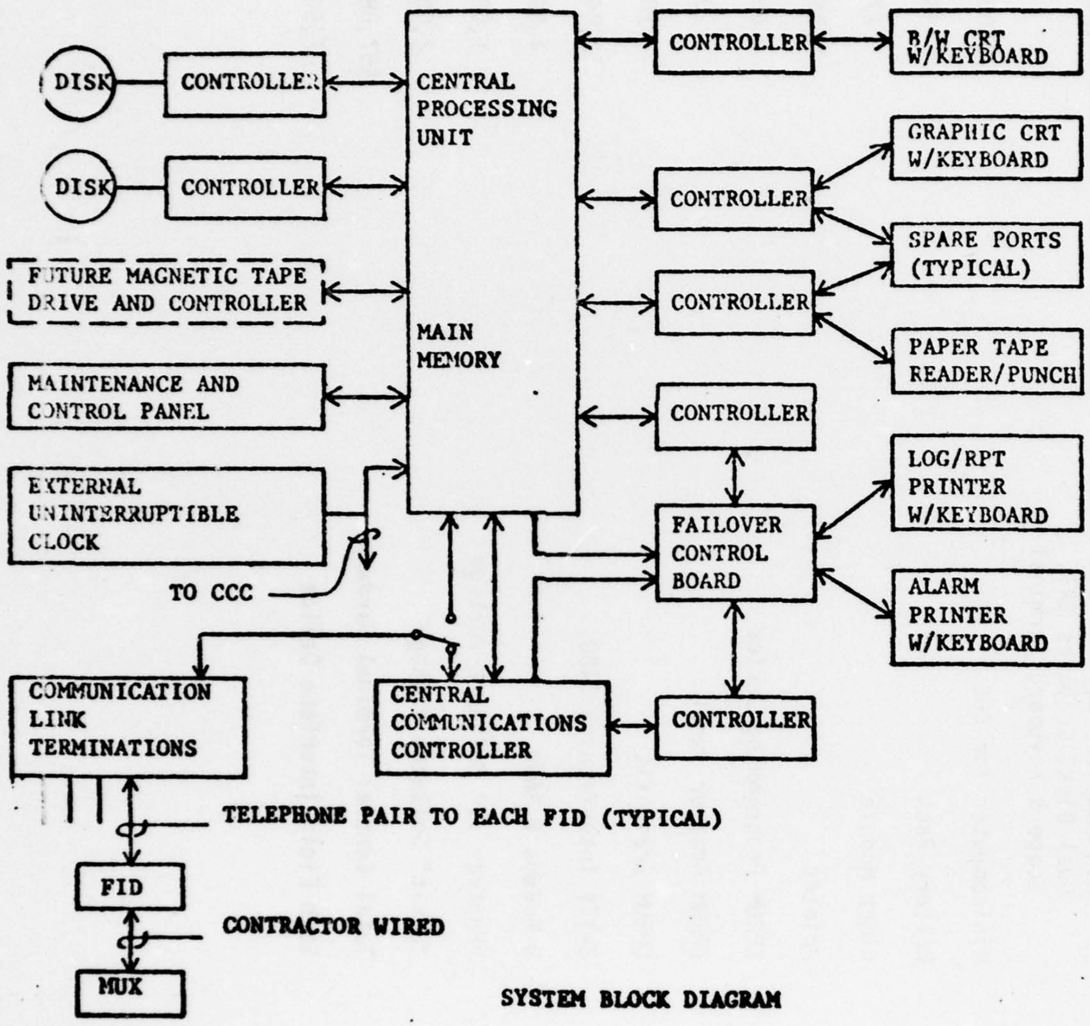
A system layout for a minicomputer based EMCS system is shown in Figure 9-5. This is the distributive processing configuration described by the tri-service guide specification. Example cost of components for this configuration are listed in Table 9-4. Cost for the central control center is $57,080. Cost for each Field Interface Device is $7,500. These costs include the price of the required modules but do not include cost of transmission or local wiring or of equipment adaptor panels, control actuators, or instrumentation. Effective cost of control as a function of the number of remote sites is shown in Figure 9-6.

TABLE 9-4

LIST OF HARDWARE FOR GENERAL PURPOSE MINICOMPUTER SYSTEM

Component	List Price
32 K Minicomputer With Dual Disk, Graphics CRT, Scope & Keyboard Terminal	$ 30,000
Minicomputer for CCC	10,000
Battery Pack	350
Clock Module	275
Printer	3,865
EPROM Programming Device	650
EPROM Adapter Panel	200
EPROM Erase Kit	100
8-TTY Interfaces @ $480	3,840
8 Modems @ $600	4,800
"Fortran IV" Software Package	1,000
"Basic" Software Package	2,000
Total Central Terminal Hardware	$57,080
Each Field Interface Device	7,500

FIGURE 9-5. DIAGRAM OF HARDWARE FOR CENTRAL PURPOSE MINICOMPUTER SYSTEM



SYSTEM BLOCK DIAGRAM

Next page is page 109

9.5 Effective Cost Per Remote Site

Cost of control devices for the facility is the sum of the central control unit cost and costs of all the remote terminal devices. For control devices having a central terminal, the effective cost per remote site declines as the number of remote sites being controlled increases. Figure 9-6 shows the effective cost per site for the various classes of control systems. The indicated reduction in effective cost will eventually become offset by a lack of sites with suitable conservation potential as less desirable remote sites are added to the control system.

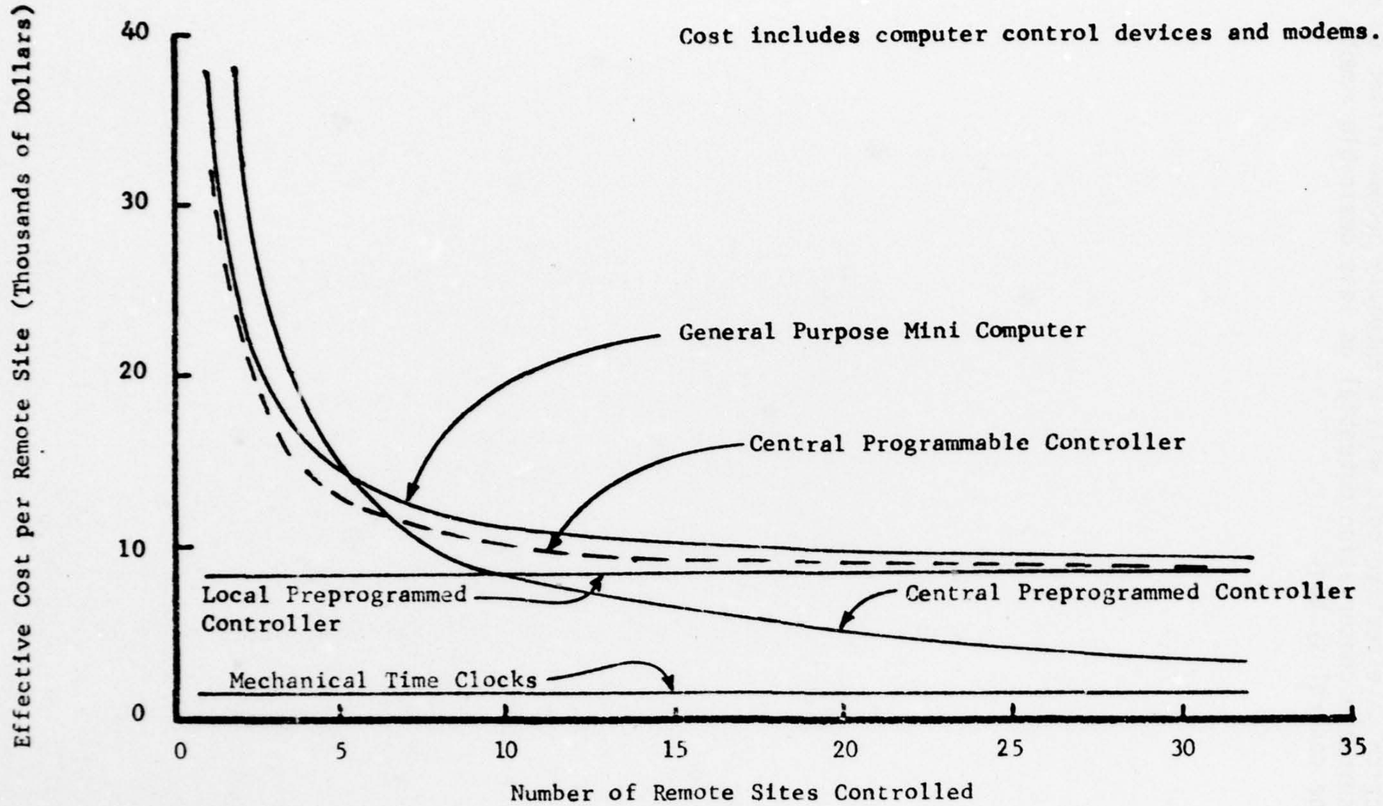


FIGURE 9-6. EFFECTIVE COST PER REMOTE SITE

CHAPTER 10 - WIRING AND SIGNAL TRANSMISSION

Wiring requirements for an automatic control system can be divided into three categories:

(1) Branch circuit wiring which is necessary to provide power for EMCS equipment.

(2) Control signal circuit wiring which is necessary to provide the electrical link between equipment control points and the local control device.

(3) Trunk line transmission circuit wiring which is necessary to connect the local control device with the central control unit.

The function of each of these circuits is discussed and equipment necessary to facilitate the connections is described in this chapter. Methods for estimating wiring costs for a typical installation are also presented.

10.1 Branch Circuit Wiring

Motor starting surges and other momentary disturbances on two wire distribution circuits can cause adverse effects in data processing equipment. These effects can be minimized by connecting the data processing components to the nearest distribution panel. The required 115 volt service must be installed in conduit. No other outlets or equipment should be connected to this circuit. The cost for a branch circuit may be estimated as follows: The equipment location and nearest power panel are assumed to be in an equipment room with 30 feet of wall distance between them. With routing of the branch circuit, the wiring will be 50 feet long, approximately. The installed cost of a circuit breaker is $10, the wiring and conduit cost at $6.00 per foot is $300, and connection costs are $10 each. This yields a total cost of $330 for the branch circuit.

Related to the branch circuit is the surge grounding circuit. The data transmission trunk wiring is sensitive to randomly induced surge voltages, mainly from lightning. This signal wiring and the equipment's metallic frame require a separate grounding circuit isolated from the branch circuit wiring. Typically, an AWG Number 6 wire is used and it may be installed in conduit also to provide it with mechanical protection. This wire is connected to the building's grounding conductors at the nearest available point. Surge arrestors of the type to protect the trunk cable termination within the equipment require this grounding circuit.

The cost of this circuit is estimated by the same method employed for the branch circuit. Figure 10-1 illustrates these circuits.

10.2 Control Signal Circuit Wiring

A typical HVAC device that the EMCS is to control is shown in Figure 10-2. This illustration shows a compressor located in a utility room of a building. It typically has an electric motor drive with the motor controlled by an electric-motor starter. This starter is the basic on-off device for the compressor which closes and interrupts the motor's electric power circuit. Two EMCS control points are illustrated as an example of control signal circuit wiring for this compressor: a control on-off point and a status on-off point.

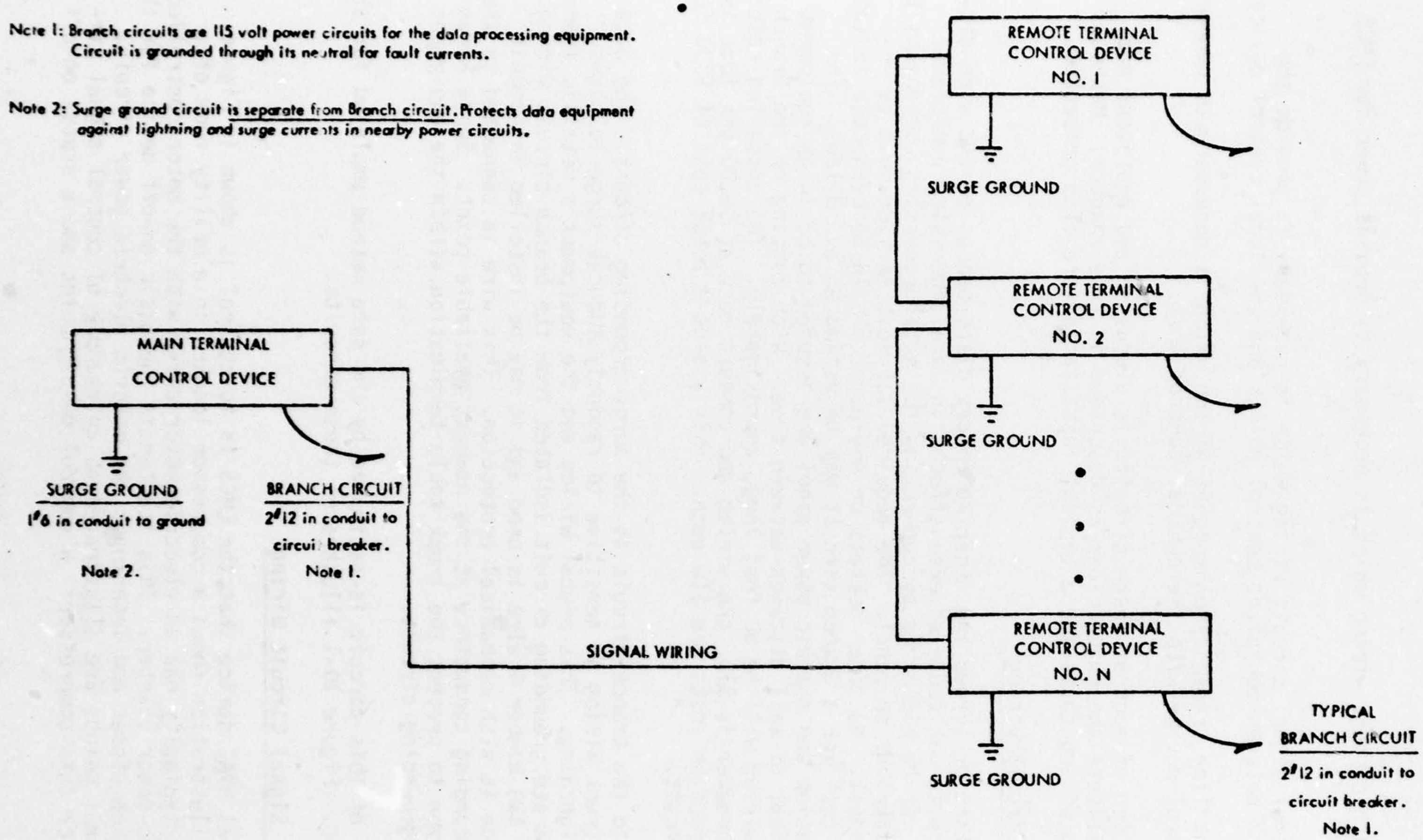


FIGURE 10-1. BRANCH CIRCUIT WIRING AND PROTECTIVE GROUNDING

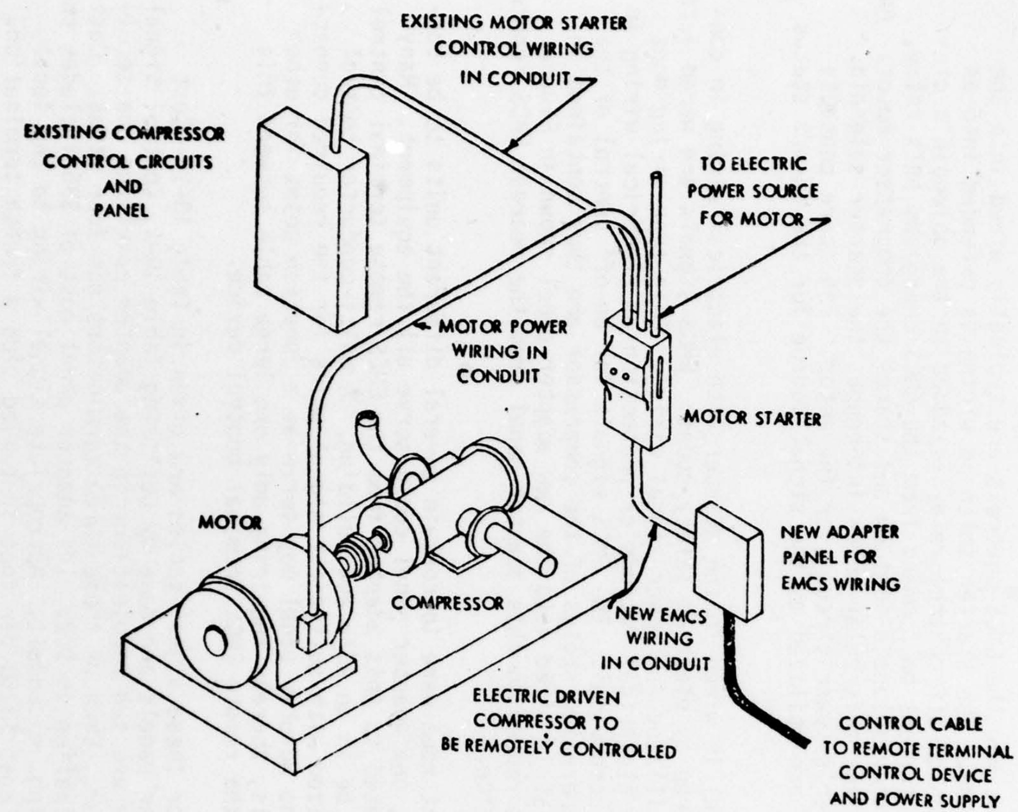


FIGURE 10-2. EXISTING COMPRESSOR TO BE ON-OFF CONTROLLED

The compressor's existing control circuits are wired into the motor starter. These may typically include high and low pressure limit switching, interlocks or safety limits, etc. In the event of EMCS system malfunction, or power loss, these circuits are to retain their function; therefore, the wiring for the EMCS will be added in such a way as to accomplish this requirement. Figure 10.3 shows the schematic wiring for the starter.

Figure 10.4 shows how the EMCS controls are typically wired into the existing control wiring. The starter solenoid wiring is extended into an adapter panel where an on-off control relay is added to the solenoid's circuit. An electrical current on command from the EMCS energizes this relay, which closes the starter solenoid in turn and starts the compressor motor. An off command de-energizes this relay which interrupts the starter solenoid. This opens the starter's power circuit for the motor. The spare contacts shown in Figure 10-3 are utilized as the signal source for the on-off status of the compressor.

The adapter panel is wired to the starter with electrical wiring in conduit. This is required by electric safety codes. EMCS signals are wired into the adapter panel utilizing low power signal wiring. This type wiring does not require the same electrical ratings or protection as electrical wiring in conduit and is more economical. The EMCS signals for on-off control of the compressor and the operating status of the compressor are thus contained in the control cable that is wired into the new adapter panel shown in Figure 10-2. This cable is routed to this adapter panel from the nearest EMCS remote terminal control device.

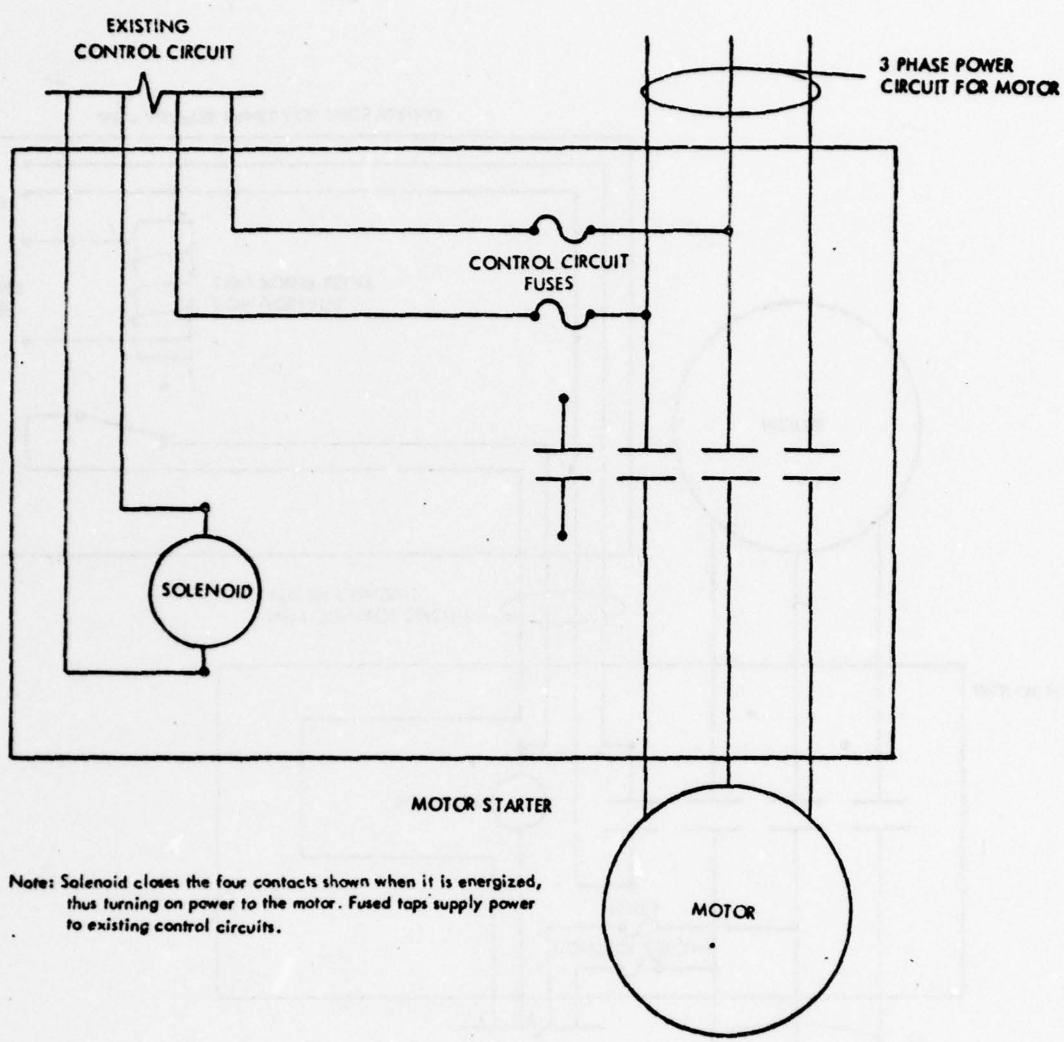
If one equipment room were to contain several different units to be controlled by the EMCS, one adapter panel could serve all the equipment. Many signals could be routed to this adapter from the EMCS remote terminal control device, which might be in an adjacent building. A multi-conductor control cable would be utilized with sufficient signal pairs for the required connections. Moreover, one adapter panel may serve as a junction point for other nearby adapter panels, thereby requiring only one large cable between this junction panel and the remote EMCS terminal control device.

Wiring costs for these signal cables are given in Table 10-1. Cost estimates for adapter panels are made by utilizing Table 10-1, Control Signal Circuit Cost. There are two terminations in the adapter panel and one termination in the starter. Each of these three terminators has four wires. Cost of a four-wire termination is $22. The adapter panel cost of $35 includes the short length of wiring in conduit. Appropriate signal wiring to the local control device will cost $3.50 per foot installed plus a fourth termination.

The total cost of this control signal circuit is thus $123 plus $3.50 per foot of signal wire required.

10.3 Trunk Line Communications

If a central control system is desired, a means of transmitting information from remote terminal control devices to and from the central contoller must be provided. Radio transmission, coax cable, and phone lines are among the methods that are used in signal transmission. Base Communications Command representatives should be consulted during the early stages of any design effort. The representatives can provide guidance in the selection and use of proposed data transmission systems.



Note: Solenoid closes the four contacts shown when it is energized, thus turning on power to the motor. Fused taps supply power to existing control circuits.

FIGURE 10-3. ELECTRICAL SCHEMATIC FOR EXISTING MOTOR STARTER

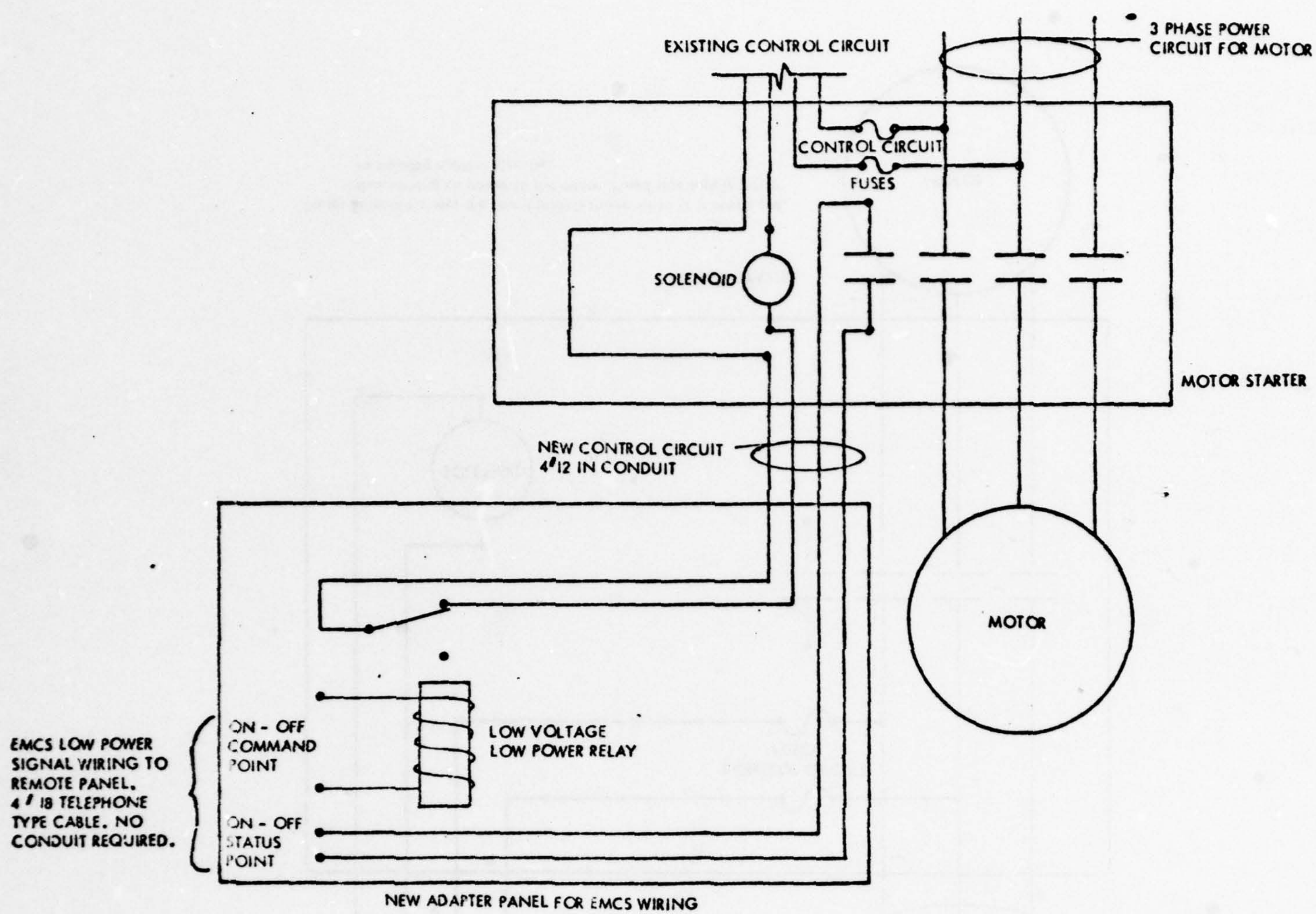


FIGURE 10-4. EMCS CONTROL WIRING SCHEMATIC ADDED TO EXISTING MOTOR STARTER WIRING

TABLE 10-1

CONTROL SIGNAL CIRCUIT COST

Adapter Panel Cost

35 Dollars Per Unit of Equipment

Control Signal Wiring Cost

Number of Remote Points	Number of Multi Conductor Wires in Single Cable	Installed Cost per Foot	Installation Cost per Termination
1-2	2-4	$ 3.00	$ 11.00
3-4	6-8	3.50	22.00
5-6	10-12	4.50	33.00
7-8	14-16	6.00	44.00
9-10	18-20	6.50	55.00
11-12	22-24	6.75	66.00
13-14	26-28	7.00	77.00
15-16	30-32	7.50	88.00
17-18	34-36	9.50	99.00
19-20	38-40	10.50	110.00
21-22	42-44	11.00	120.00
23-24	46-48	13.00	130.00

10.3.1 Radio Transmission

Data communications between remote terminal control devices and the central console is accomplished by VHF radio frequency signals. Frequency and emission of such radio systems are governed by Federal Communications Commission's Authorizations. Data communication is achieved by noncontinuous scanning of remote status. Transmission speed is 120 Baud (bits per second). VHF radio control switches cost $75 each. VHF transmitter/receiver units for remote sites cost $3400. Cost of a base station encoder, transmitter and receiver is approximately $12,000.

10.3.2 Coax Cable

Coaxial cable can be used to connect remote terminal control devices with the central control unit as shown in Figure 10-5. Some manufacturers have their own special cable for this purpose, however, it is assumed that the price of coaxial cable is representative for cost estimation purposes. Installation of the coaxial cable can be made by attachment to pole lines or by direct burial. Aerial wiring can generally be accommodated on existing poles. From the installed cost data in Table 10-2 it is seen that, except for the most unusual routing situations, attachment to existing poles is the most economical alternative. For runs in excess of 5000 feet repeater amplifiers may be required. Cost of these repeaters is added to the coaxial cable cost to determine total line cost.

The method for determining coaxial cable costs for the base is as follows:

(a) map the locations of equipment and draw in routes as described previously,

(b) Determine lengths using direct burial routes and pole line routes,

(c) multiply the lengths of the routes by their respective cost per foot found in Table 10-2,

(d) multiply the cost of splices and termination by the number of remote panels,

(e) add (c) and (d)

(f) decide on whether to use direct burial or pole.

Example: Determine the cost of a coax cable installation serving 8 remote sites, requiring either 20,000 feet if direct burial is used or 25,000 feet if attached to existing pole lines.

Solution: Using direct burial:
(20,000 ft)(3.50 $/ft) + (8 Sites) (35 $/Site) =
$70,280.00

Solution: Using existing pole lines:
(25,000 ft)(0.90 $/ft) + (8 Sites) (35 $/Site) =
$22,780.00

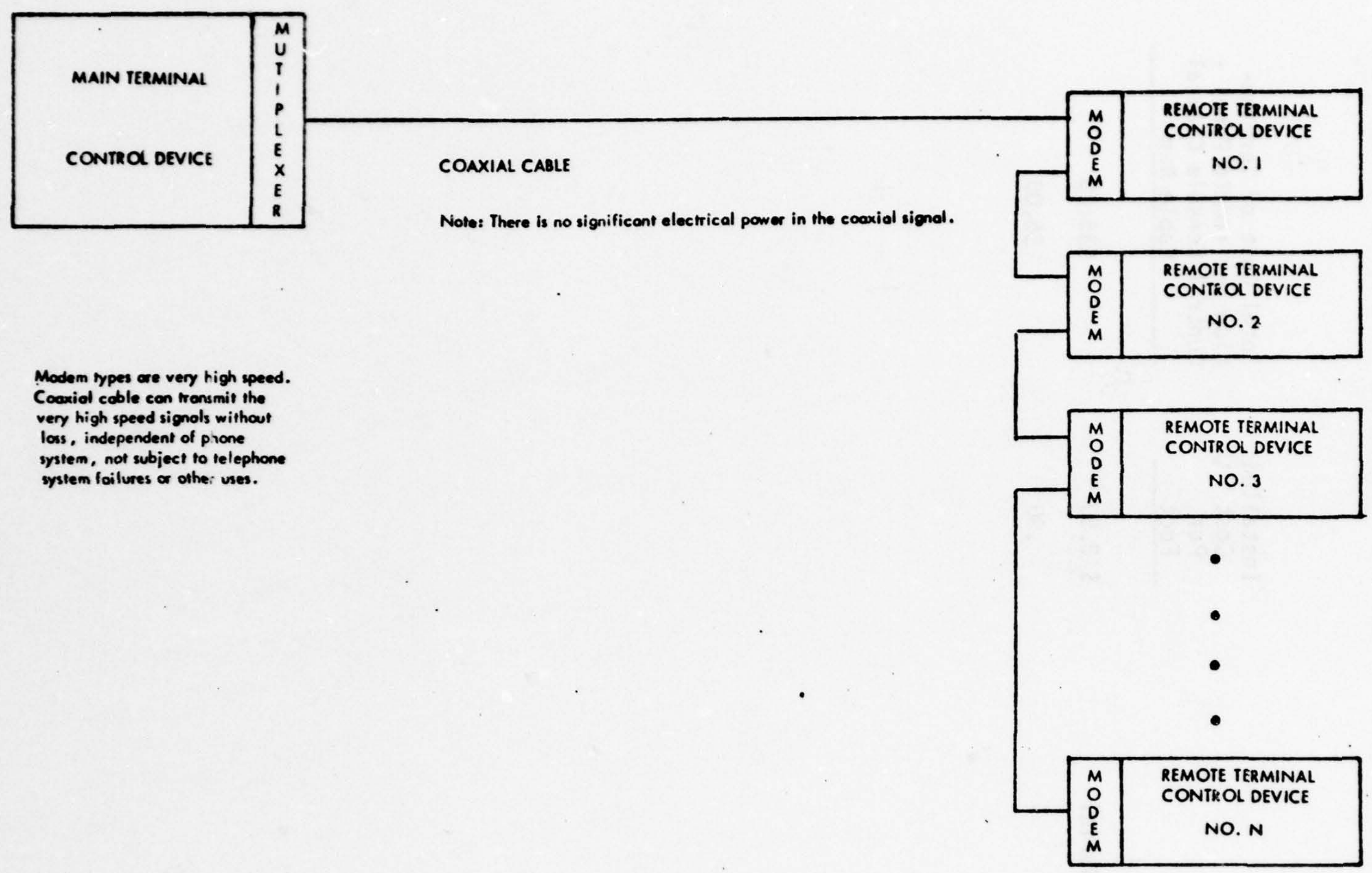


FIGURE 10-5. TRUNK LINE COMMUNICATIONS USING COAXIAL.CABLE

TABLE 10-2

COAXIAL CABLE COST

	Installed Cost Per Foot	Total Cost of Termination per remote Panel - Control Console Coaxial Cable Run
Direct Burial	$ 3.50	$35.00
Poles	.90	35.00

10.3.3 Telephone Lines

As an alternative to the high installation costs of coax cables, existing telephone lines can be used. Both the central control unit and the local control devices are linked to the telephone line through modems using EIA Standard RS-232C I/O interfaces. Figure 10-6 illustrates the use of telephone lines in linking central control devices with remote devices. The modem at the central processor and control unit converts the signal pulses (digital signals) from the computer to tones (modulated audio signals) for transmission over the telephone network. The receiving modems at the remote panel converts the tone signal back to serial pulses.

Ordinary transmissions over the telephone network make use of communication channels having bandwidth limitations suitable for voice frequencies. If one half to one tone cycle is needed for recognition, line speeds are limited to approximately 6,000 Baud (bits per second). In practice, telephone network transmission line speeds are limited to approximately 2400 Baud.

Three types of transmission modes are available; full duplex, half duplex and simplex. Only full duplex and half duplex have the capability of bidirectional signal transmission. Full duplex transmission generally utilizes two pairs of wires. One pair is dedicated to data receiving and the other is dedicated to data transmission. The full duplex system is capable of simultaneous transmission and reception. A half-duplex transmission system is capable of transmitting data in only one direction at a time. As the modem switches from a transmitter role to a receiver role, a turn-around delay is encountered which also reduces line speed.

Many modems provide a choice of operating in either the synchronous mode or the asynchronous mode. Using the asynchronous transmission mode, extra bit characters are transmitted with each word of data to identify the beginning and the end of the word. This method allows data transmission from sources with highly irregular data input rates. The probability of cumulative errors is minimized but effective line speed is reduced because of the extra bits that must be transmitted along with the data. Using the synchronous transmission mode, data is transmitted in a large block with synchronizing characteristics required only at the beginning and end of the block. This mode permits higher data transmission rates but is more susceptible to error. One bit added to or missing from the data stream would cause the entire block of data to be in error. The final choice of transmission mode will be based upon the quality of the telephone service connection and the data rate necessary for system control purposes.

Whether or not existing telephone lines can be utilized for data transmission depends on the availability and acceptable quality of spare pairs in the telephone cables running 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. The Base Communications Command representative should be consulted to determine the adequacy of existing facilities.

There are four major series of modems furnished by the major phone company. The 100 series modem is used for low speed data transmission and has a maximum data rate of 300 bps in the asynchronous mode. The 200 series modem,

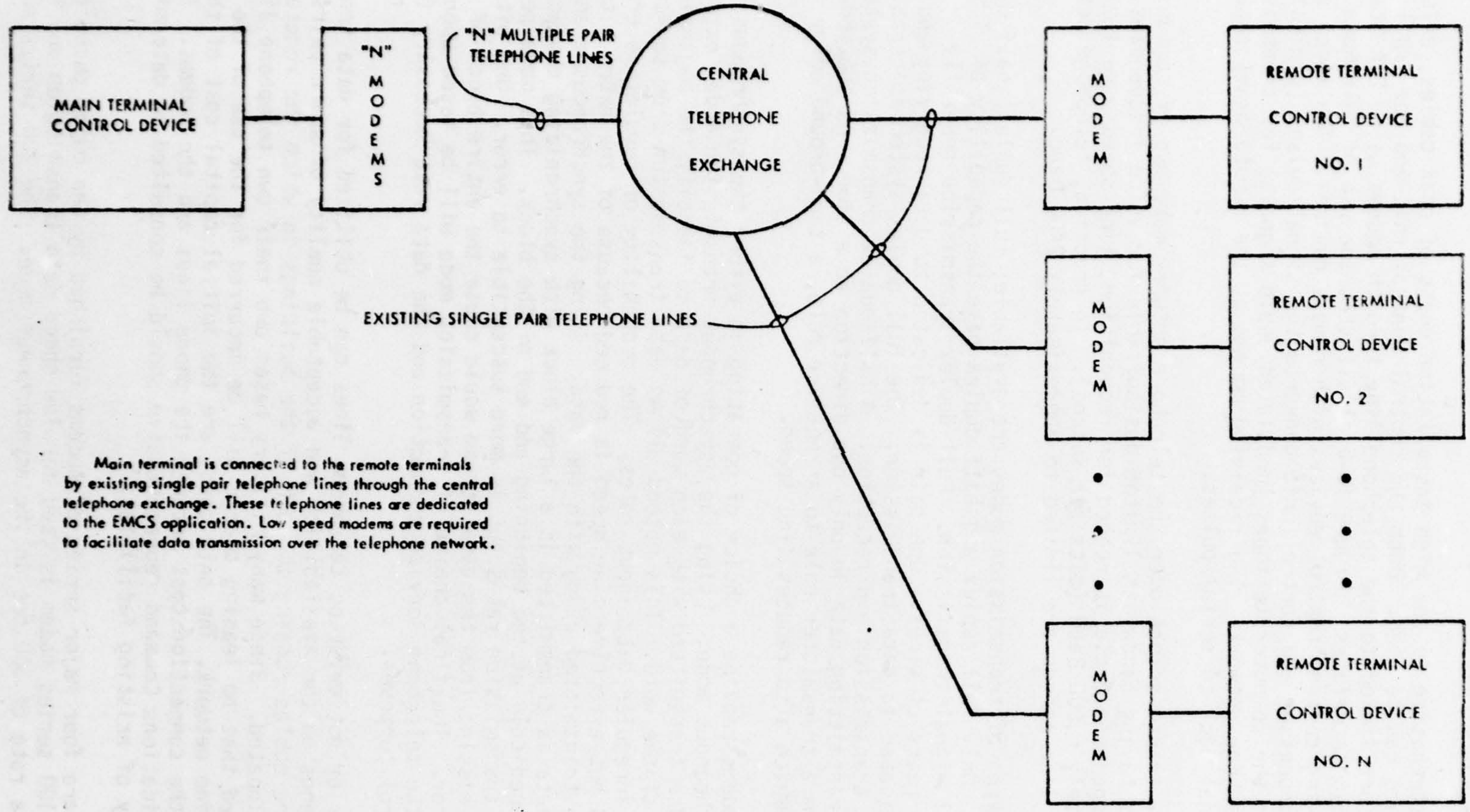


FIGURE 10-6. TRUNK LINE COMMUNICATIONS USING TELEPHONE LINES

considered meduim speed, can transmit up to 1200 bps in asynchronous and 3600 bps in the synchronous mode. The 300 series is used for very high speed (460K bps) or wide baud transmission. The 400 series is used for transmitting and receiving tones in parallel. Neither the 300 or the 400 series modems are generally used in EMCS applications.

Modems can be leased from the major phone company for connection to their equipment. Independent suppliers sell "Bell" compatible equipment with a wide range of capabilities. Costs of modems available from several independent suppliers are listed in Table 10-3.

TABLE 10-3. COST OF MODEMS

Vendor	Type of Unit	Unit Cost	General Comments
Vadic Corporation	VA 300 Series (Equivalent to Bell 100 Series)	$180.00 (GSA Price)	Data Rate: 0-300 Bits/Sec. 2 Wire Full Duplex Dedicated System
Vadic Corporation	VA 1200 Series (Equivalent to Bell 200 Series)	$250.00 (GSA Price)	Data Rate: 0-1200 Bits/Sec. 2 Wire - No Reverse Half Duplex
Vadic Corporation	VA 3400 Series (Equivalent to Bell 200 Series)	$700.00 (List Price)	Data Rate: 1200 Bits/Sec. Full Duplex on 4 Wire
General Datacomm Industries	Model 108 (Equivalent to Bell 100 Series)	$275.00 For GSA Pricing Deduct 5%/Unit	Data Rate: 300 Bits/Sec. 2 Wire Full Duplex
General Datacomm Industries	Unit 202-0 (Equivalent to Bell 200 Series)	$380.00 For GSA Pricing Deduct 5%/Unit	Data Rate: 1200 Bits/Sec. 2 Wire Half Duplex

CHAPTER 11 - ECONOMIC EVALUATION OF EMCS

Energy monitoring and control systems are designed to meet specific control requirements for particular applications. With such specialization, capital and operating cost associated with each system are unique to a particular application. Thus, the point at which increasing costs fail to yield increasing benefits will vary from installation and even among individual facilities within a single installation. For this reason, it is necessary to measure the investment merits of energy monitoring and control systems on a case by case basis.

A detailed study must be made to determine applicability and economics of various equipment for energy control at military installations. As a result of variations in building size, construction, and usage, most military installations will use a mix of time clocks, local controls, and central controls to minimize cost and maximize energy savings. At the completion of a thorough economic study, one should have all buildings on the installation classified into one of the four groups:

a) Buildings considered suitable for central control.
b) Buildings considered suitable for local control.
c) Buildings considered suitable for time clock control.
d) Buildings considered not suitable for any additional control.

In performing the evaluation, all buildings over 5,000 square feet shall be considered possible candidates for connection to a central control system. An initial estimate of energy savings can be based upon the implementation of load scheduling, outside air shutoff, and enthalpy control as these schemes provide the largest conservation potential. Expected savings for each building are then compared with the costs of connecting the building to the central system. These costs include expenses for trunk line communication, remote terminal (FID), and necessary monitoring and control points. Buildings having cost/benefits ratios which do not justify connection to a control system are then evaluated for local control system and time clock implementation.

After identifying buildings that are acceptable candidates for central control, it is necessary to determine the size and capability required for the central control unit. Required size and capability depends upon the number of monitoring and control points and the complexity of the energy conservation schemes being utilized. To determine an economic preference, the savings resulting from the implementation of each of the various control schemes should be tabulated and compared with the incremental cost imposed upon the control system. These incremental costs shall include the expense of monitoring and control points not otherwise required, the "extra" cost of the central control system necessary to perform the function, and the cost of any special software required. Starting with the most demanding schemes such as the optimization functions, savings are compared with the incremental cost to determine if the additional control capability is economically justified.

If a survey reveals that only a few buildings are acceptable candidates for central control it may be economical to utilize a central control unit at another installation. By connection through phone lines, installations hundreds of miles apart can be handled effectively with a single large computer. Lease charges for the telephone lines used must be included in the economic analysis.

11.1 Life-Cycle Analysis Methodology

Executive Order 12003 and recent legislation require an economic analysis based upon present worth techniques to determine a benefit/cost ratio for each project being considered. The economic comparison of alternate energy management and control systems is accomplished by performing an economic analysis using the life-cycle costing technique. Life-cycle costing is a method of financial evaluation which recognizes all the financial requirements and benefits of a system in terms of cash outlays and benefits. This technique measures the discounted present value of an investment against the discounted present value of its corresponding benefits based upon the timing of cash flows. This method provides a simple, straightforward methodology for developing life-cycle cost/benefit rates of alternative EMCS designs.

The ECIP is a Military Construction (MILCON) funded program for retrofitting existing DOD facilities to make them more energy efficient while providing substantial savings in utility costs. It is an integral part of the DOD Energy Conservation Program and is designed to achieve a major portion of DOD energy conservation goals for existing facilities as required by Executive Order 12003. The appropriate form for an ECIP analysis is presented in Appendix C.

When a project does not meet the criteria established for funding by ECIP, or where a more detailed approach is required, the Economic Analysis and Program Evaluation for Resource Management format should be used. This format is described in DOD directives and in AR 11-28. Appropriate forms from AR 11-28 are presented in Appendix D.

11.2 Nonrecurring Costs

Nonrecurring costs include construction and supervision, inspection, overhead, final design costs and other initial one-time costs. For the EMCS, nonrecurring costs are the initial captial investments in a system plus fixed capital replacement costs. In addition to these, housing for a central control system must be considered. If surplus space is not available, it will be necessary to provide a 900-square foot special building or an equivalent addition to the present facilities. Construction costs will vary from area to area and will escalate with time. Rates of escalation should be reviewed with current documents, such as Engineering News Record trend summaries. A 1978 value of $30 per square foot is considered reasonable for cost estimation purposes.

11.3 Recurring Costs

Recurring costs include operating and maintenance expenses plus a continuing cost for maintaining a high level of operator competence. In the case of central control systems, operational costs must include the salary of the operator, which is estimated to be $14,000 per year per shift. In addition to this, it is necessary to add supervision costs to all salaries plus benefit provisions as recommended in AR 11-28, AR 37-108 and Federal Personnel Manual supplements 831-1, 870-1 and 890-1. Thus, the total salary may become n x $14,000 x 1.25 (supervision) x 1.29 (benefits) where n is the number of shifts manned. Training cost for five man-days of vendor instruction bi-annually is estimated as $1,500. Since the training is free at the time of installation, the project years when training must be included are 3, 5, 7 and 9.

Several maintenance options are available. A full service maintenance agreement could be negotiated with the supplier. This would provide for on-site service of equipment and for replacement of components as necessary. Annual cost of this type service runs approximately 15 percent of the equipment purchase price.

A second maintenance option is the on-call agreement where the supplier will furnish on-site repair as requested. Charges are based upon a designated hourly rate plus cost of parts required. Annual cost of this type of service depends upon the failure rates of the individual equipment, parts cost, and the speed with which the failures can be diagnosed and repaired. As existing staff could perform limited maintenance, cost of this service should be somewhat lower than for a full service maintenance agreement.

A third maintenance option is to provide in-house maintenance capability in facilities engineering staff. This option would require purchase of certain testing and diagnostic equipment, a variety of spare components, and periodic staff training. Users of computer equipment estimate that an adequate spare parts inventory and limited testing equipment would cost between 15 and 20 percent of the initial hardware cost. Spare components, consisting of LSI chips, circuit boards, and functional modules, would be selected based upon the manufacturer's recommendation for the particular system chosen. As these spares are used, inventory must be replaced with new or repaired items. Computer users estimate that annual cost spare parts replacement and outside repair will be approximately 5 percent of hardware cost. Salary and training expenses for maintenance personnel are similar to those of an operator.

11.4 Benefits

Based upon the data developed in Chapters 3 and 4, the projected heating and cooling energy savings can be calculated in Btu's per year for the given combination of control schemes. These savings are converted to dollars using Table 4-9 and Section 11.6. Savings in demand charges are calculated directly in dollars.

11.5 Economic Factors

The actual value of economic factors depend upon the location of the facility and will change with time. Exact values for local energy cost can be determined by the facilities engineer from recent supplier billing data. Applicable escalation factors can be obtained from government economic forecast. Example values for economic factors necessary for analysis of alternate cases are summerized below.

Economic Life of Equipment	-	15 Years
Heating Oil Cost	-	$2.80/10^6$ Btu
Heating Oil Escalation	-	14%/Year
Electricity Cost	-	$0.0350/kWh
Electric Cost Escalation Factor	-	13%/Year

Natural Gas Cost	-	$1.75/10^6 Btu
Natural Gas Escalation Factor	-	14%/year
Salary Cost Escalation	-	6%/year
Training Cost Escalation	-	6%/year
Construction Cost Escalation	-	6%/year
General Cost Escalation	-	6%/year

Table 11-1 shows the annual escalation factors for 6%, 13%, and 14% rates. Escalation factors should not be confused with the discount factor used for determining present value of future cost and benefits.

TABLE 11-1

ESCALATION FACTORS

Proj. Year	6% Escalation Factor	13% Escalation Factor	14% Escalation Factor
1	1	1	1
2	1.06	1.13	1.14
3	1.12	1.28	1.30
4	1.19	1.44	1.48
5	1.26	1.63	1.69
6	1.34	1.84	1.93
7	1.42	2.08	2.19
8	1.50	2.35	2.50
9	1.59	2.66	2.85
10	1.69	3.00	3.25
11	1.79	3.39	3.71
12	1.90	3.84	4.23
13	2.01	4.33	4.82
14	2.13	4.90	5.49
15	2.26	5.53	6.26
16	2.40	6.25	7.14
17	2.54	7.07	8.14
18	2.69	7.99	9.28
19	2.85	9.02	10.58
20	3.03	10.20	12.06
21	3.21	11.52	13.74
22	3.40	13.02	15.67
23	3.60	14.71	17.86
24	3.82	16.63	20.36
25	4.05	18.79	23.21

11.6 Discounted Present Value and Benefits

The determination of discounted present value of EMCS costs and benefits is performed in accordance with DOD directives, which consider the time value of money. That is, a future cost 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. The DOD has recommended that a 10% discount rate be used. The discounted present worth factor automatically provides for general inflation during the economic life of the project. Tables 11-2, 11-3 and 11-4 provide single amount and cummulative uniform series discount factors for a disconnect rate of 10% and differential escalation rates or 0, 7 and 8%.

TABLE 11-2

PRESENT-WORTH DISCOUNT FACTORS
Differential Inflation Rate = 0%
Discount Rate = 10%

Economic Life Years	One Time Cost Factors	Recurring Benefits/Costs Factors
1	0.954	0.954
2	0.867	1.821
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
11	0.368	6.815
12	0.334	7.149
13	0.304	7.453
14	0.276	7.729
15	0.251	7.980
16	0.228	8.209
17	0.208	8.416
18	0.189	8.605
19	0.172	8.777
20	0.156	8.933
21	0.142	9.074
22	0.129	9.203
23	0.117	9.320
24	0.107	9.427
25	0.097	9.524

TABLE 11-3

PRESENT-WORTH DISCOUNT FACTORS
Differential Inflation Rate = 7%
Discount Rate = 10%

Economic Life Years	One Time Cost Factors	Recurring Benefits/Costs Factors
1	0.986	0.986
2	0.959	1.946
3	0.933	2.879
4	0.908	3.787
5	0.883	4.670
6	0.859	5.529
7	0.836	6.364
8	0.813	7.177
9	0.791	7.968
10	0.769	8.737
11	0.748	9.485
12	0.728	10.212
13	0.708	10.920
14	0.688	11.608
15	0.670	12.278
16	0.651	12.930
17	0.634	13.563
18	0.616	14.180
19	0.600	14.779
20	0.583	15.363
21	0.567	15.930
22	0.552	16.482
23	0.537	17.019
24	0.522	17.541
25	0.508	18.049

TABLE 11-4

PRESENT-WORTH DISCOUNT FACTORS
Differential Inflation Rate = 8%
Discount Rate = 10%

Economic Life Years	One Time Cost Factors	Recurring Benefits/Costs Factors
1	0.991	0.991
2	0.973	1.964
3	0.955	2.919
4	0.938	3.857
5	0.921	4.777
6	0.904	5.681
7	0.888	6.569
8	0.871	7.440
9	0.856	8.296
10	0.840	9.136
11	0.825	9.961
12	0.810	10.770
13	0.795	11.565
14	0.781	12.346
15	0.766	13.112
16	0.752	13.865
17	0.739	14.603
18	0.725	15.329
19	0.712	16.041
20	0.699	16.740
21	0.687	17.427
22	0.674	18.101
23	0.662	18.762
24	0.650	19.412
25	0.638	20.050

11.7 Example of Economic Evaluation

An example problem, illustrating the method of evaluating the economics of a proposed EMCS alternative, is presented in Appendix E. The example was chosen to provide computational guidance and is not meant to represent a comprehensive look at an actual EMCS application. However, data used in the example is based upon actual buildings and conditions at Fort Belvoir, Virginia.

11.8 Calculation Program

Information presented in the report forms the basis of the economic and energy analysis required to justify funding request. If the calculations involve a large number of buildings, a considerable amount of time and effort will be required. A program, documented in REPORT FESA - RT - 2033, is available which automates the procedure. The program calculates the energy savings achievable in terms of BTU's and dollars, implementation costs and equipment requirements, and gives the economic analysis for single or multiple buildings (facilities and installations).

A summary of the program description and user instructions is presented in Appendix F. The documentation, approved for unlimited distribution to the public can be obtained from U. S. Army Facilities Engineering Support Agency, ATTN: Research and Technology Division, Fort Belvoir, Virginia 22060.

CHAPTER 12 - EVALUATION OF SUPPLIERS

Once it has been determined that a purposed EMCS installation is feasible, plans and specifications for the system will be developed and bids solicited from manufacturers who are capable of supplying the selected type of equipment. It is reasonable to expect variations in the specific details of each suppliers equipment and in the overall capability of the systems and the suppliers themselves. These variations must be evaluated to determine which bid is most attractive to the Government. The purpose of this chapter is to provide guidance in the evaluations of potential EMCS suppliers.

The evaluation criteria is divided into three categories: technical, support and financial. Technical criteria are used as the basis for evaluating computer architecture, required I/O devices, peripherals and auxiliary storage, ease of programming, quantity and quality of supporting software, and potential growth and expansion capability and modularity. Support criteria are used to evaluate reliability of equipment, level of hardware and software maintenance, quality of documentation, extent of vendor or manufacturer cooperation and warranty. The financial criteria are used to measure prices, discount terms, price-performance ratios, the level of system assembly and field maintenance required, and the financial stability of the hardware manufacturer.

12.1 Technical Criteria

Computer architecture describes the internal communication structure used by the controller. This structure governs the address length, the word length, and the computational speed. These items are discussed in Chapter 7. An architecture suitable for EMCS application would provide either an 8 bit or 16 bit word length and 16 to 32 K memory. Sufficient I/O interface ports must be available to provide attachment to desired peripheral devices and modems.

Input/output devices, peripheral equipment, and auxilary storage devices are discussed in Chapter 7. Modems, which may also be considered as a peripheral device, are discussd in Chapter 10. As these items will affect total EMCS performance, they must be suitable for performing their system function. Important parameters to be considered are operational speed, accuracy, reliability, service and parts availability and replaceability. Special care should be given to identifying components whose failure may jeopardize the operation of the entire system.

Ease of programming is obtained by providing a programming language such as FORTRAN or BASIC which are relatively easy to learn. Mnemonic languages require special training and are more time consumming to utilize. Preprogrammed controllers are not user programmable in the traditional sense, but still require operating data to be entered into the system. Ease of programming, for these devices, would refer to the training and effort needed to enter and change data coefficients in the controller.

Supporting software includes the programs needed to perform the energy conservation functions as well as the operating systems necessary control I/O and peripheral equipment. Minimum supporting software should provide for all control schemes initially being considered plus provide a reasonable base for future program development and modificiation.

Growth and expansion capability is desirable to allow for both foreseen and unforeseen developments. It is desirable to be able to increase memory size, add additional interface ports, and significantly alter the control programs. Growth and expansion capability is aided by modularity in design, permitting replacement of individual components within the existing system architecture.

12.1 Support Criteria

Equipment reliability is measured in terms of mean time between component failure. Past experience is useful in identifying components with high failure rates. For high system reliability, components subject to frequent failure should not be placed in a critical capacity. Evaluation of equipment maintenance is based on the manufacturers reputation for service, the nearness of service centers, and the availability of maintenance service contracts. Software maintenance refers to treatment of initial loading failures, periodic program updates, and willingness to work on non-standard programs. Quality of documentation can be judged from information provided by the manufacturers. Documentation should be clear to avoid confusion and sufficiently thorough to cover important questions which may be expected to arise in normal operations. Vendors cooperation is a measure of the willingness of sales and engineering personnel to discuss system application, selection, and component prices. Cooperation may range from mailing non-technical promotional literature to personally discussing detailed operating capabilities. Warranty protection is desirable to protect the purchaser from the risk of obtaining equipment which is initially faulty or which fails soon after installation. For evaluation, a one year warranty period is considered acceptable.

12.3 Financial Criteria

The price criteria is used to measure the willingness of the suppliers to provide component price data upon which economic evaluations could be based. System assembly and maintenance criteria relates to the willingness of the suppliers to perform complete system assembly and checkout. It also relates to the availability of long term maintenance agreements. Alternate suppliers are desirable to assure competition if components or major subsystems must be replaced. Equipment that is compatible with only components from the original suppliers should be avoided. Peripheral equipment should utilize standard interfaces connections. Central controllers design should be compatible with any remote site controllers through standard modem connections.

Financial stability of the manufacturer is important in evaluating whether future service guarantees will be honored, or even whether replacement components will be available when needed. The company size will often affect the extent of geographic coverage and the number of field service centers. Being located near a field service center should result in less outage time due to the faster service and better availability of parts.

GLOSSARY OF TERMS AND ACRONYMS

ADDRESS - A coded representation of the origin or destination of a data message.

ALARM - A warning signal indicating that a condition is not normal and not within operating limits.

ALGORITHM - A rule of procedure for solving a recurrent mathematical problem.

ALPHANUMERIC - Alphabetic characters, numeral or specific symbols.

ANALOG - A continuously varying signal value (temperature, current, pressure, etc).

ARCHITECTURE - The general organization and structure of hardware and/or software.

ASCII - (American Standard for Coded Information Interchange): Coded character set to be used for the general interchange of information among information processing systems, communication systems and associated equipment.

ASSEMBLER - Utility program which translates assembly language source code into the machine-executable object code.

ASSEMBLY LANGUAGE - A low-level language used to program and manage the operations of a computer.

ASYNCHRONOUS - Each event or the performance of each operation starts as a result of a signal generated by the completion of the previous event or operation, or by the availability of the parts of the computer required for the next event or operation.

BACK PLANE - A device for connecting individual cards or printed circuit boards used in a micro computer.

BASIC - A programming language noted for its ease of learning.

BAUD - Modulation rate used to describe the speed of serial data transfers of information bits (bits/sec).

BCD - Binary Coded Decimal; a method for representing non-integer number in a computer. (See Integer)

BIT - A data element which is either a "zero" or a "one". A contraction for the words "Binary Digit".

BIT ERROR RATE - The number of incorrect or erroneous bits divided by the total number (correct plus incorrect) over some stipulated period of time.

BOOTSTRAP	- A technique or device designed to bring a computer into a desired state by means of its own action.
BREAK POINT	- A point in a program where an instruction or other condition enables a programmer to interrupt the running of a program by external intervention or a monitor routine. Used in debugging.
BUFFER	- A device which stores information temporarily during data transfer.
BYTE	- A group of eight bits.
CABLE	- Insulated electrical conductor(s) covered with a protective sheath.
CALL	- A term used to designate the software procedure by which software control is transferred to a callable subroutine.
CALLABLE	- A subroutine module to which software control can be transferred.
CARD	- A hardware component of an electronic system, generally consisting of a single printed circuit, designed for ease of removal and replacement.
CATHODE RAY TUBE (CRT)	- An electron beam tube in which the beam is focused to a small cross section on a luminescent screen and varied in position and intensity to produce a visible pattern.
CENTRAL COMMUNICATIONS CONTROLLER (CCC)	- The subsystem of the MCR performing data gathering and dissemmination from and to the FIDs as well as providing limited backup to the CCU.
CENTRAL MEMORY	- Core or semiconductor memory communicating directly with a central processing unit.
CENTRAL PROCESSING UNIT (CCU)	- The portion of the computer (CCU) that performs the interpretation and execution of instructions. It does not include memory or I/O.
CENTRAL CONTROL UNIT (CCU)	- A process control digital computer that includes a CPU, central memory and an I/O bus.
COMMAND LINE MNEMONIC (CLM) INTERPRETER (CLMI)	- A set of fixed, simplified English commands designed to assist operators unfamiliar with computer technology in operating the EMCS.
COAX (COAXIAL CABLE)	- Specially constructed cable having specific electrical characteristics for transmission of data information, generally consisting of a central insulated wire and a surrounding conductive sheath which is protected by an insulative cover.

COBOL	- A programming language noted for its application to business and data handling problems.
COMPILER/ INTERPRETER	- System software used for converting high level language instructions into the machine language of the computer.
COMPUTER	- A device capable of solving problems by accepting data, performing prescribed operations with the data and producing results of such operations.
CONTROLLER	- A device that measures changes in controlled variables and sends an appropriate signal to adjust such system functions.
CONTROLS	- Devices which govern the performance of a system.
CONTROL SEQUENCE	- Equipment operating order established upon a correlated set of data environment conditions.
CYCLE TIME	- In microseconds/word for central memory is the minimum time interval that must elapse between the starts of two successive accesses to any one storage location.
DATA	- A collection of facts, numeric and/or alphabetical characters which are processed for or generated by a computer.
DIGITAL	- A non-continuous signal. In radix 2 the signal is either on or off (zero or one).
DIRECT MEMORY ACCESS (DMA)	- Provision for transfer of data blocks directly between central memory and an external device interface.
DISK MEMORY	- A bulk storage, random access device for storing digitally coded information, usually constructed of a thin rotating circular plate containing a magnetizable coating, a read/write head and associated control equipment.
DISTRIBUTED PROCESSING SYSTEM	- A system of multiple, programmable processors each performing its own task, yet working together as a complete system to solve still other tasks.
DISCRETE	- Data describing the status of a two-position control point, either "zero" or "one".
DRIVER/HANDLER	- Software which manages input/output to and from a given peripheral device.
DUPLEX	- Simultaneous two-way independent transmission.

EMCS	- Energy Monitoring and Control System; a system designed and operated to control the energy-consuming equipment of an institution or installation of buildings. The system includes control points, signal transmission, computer components and attendent software.
EIA	- A component or coupling device that conforms to Electronic Industries Association standards, which specializes in the electrical and functional characteristics of interface equipment.
EXECUTIVE PROGRAM	- The main system program designed to establish priorities and to process and control other programs. Sometimes called the Operating System.
FIELD INTERFACE DEVICE (F.I.D.)	- A small, intelligent hardware device containing software which implements the distributed processing aspects of operation with the central computer as well as maintaining effective control of field control loops in the absence of higher level influence. Operating constants are changed by down-line loading from the CCC as well as from within the FID.
FORTRAN (FORmula TRANSlator)	- A high-level, English-like programming language used for technical applications.
FUNCTION KEYS	- Keys which, when depressed, are interpreted by the computer as a specific command.
HALF DUPLEX	- A method of operation of a communications line in which each terminal can transmit and receive, but not simultaneously.
HARDWARE	- The EMCS equipment such as CPU, peripherals etc. as opposed to software.
HARDWARE VECTORED INTERRUPTS	- Hardware feature which allows the CPU to directly determine the identity of an interruptive device and to automatically transfer control to a program which will service the interrupt.
INDICATION	- A visual display of status.
INTEGER	- A number having no fractional part.
INTERFACE	- A common boundary between computer systems or parts of a single system.
INTERRUPT	- An externally generated signal requesting that current operations be suspended to perform more important tasks.
I/O	- Input/Output

I/O BUS	- The connection through which data is transmitted and received from peripheral devices wishing to interact with the processor.
K	- (as in 64K words) 1K = 1024
LARGE SCALE INTEGRATION (LSI)	- Manufacturing technology in micro-miniaturization in which many thousands of components are packaged into a small "chip".
LINE DRIVER	- A hardware element which enables digital signals to be directly transmitted over circuits to other devices some distance away.
LINE PRINTER	- A printer device that can simultaneously print several character graphics as a permanent record.
LOADER	- A program used to prepare the computer and store other programs into memory locations in preparation for machine execution.
MACHINE LANGUAGE	- A programming language which allows computer control and management at the "zero" and "one" (digital) level.
MACRO	- A single programming symbolic instruction that generates multiple absolute language instructions.
MEDIUM SCALE INTEGRATION (MSI)	- As in LSI to a lesser degree.
MASTER CONTROL ROOM (MCR)	- The central facility containing the operator console, CCU, CCC, and related equipment for control and supervision of the complete EMCS.
MEMORY	- A device or media used to store information.
MEMORY MODULES	- Increments of memory, usually 4K, 8K, or 16K words in length.
MICRO-COMPUTER	- A small computer consisting of a microprocessor together with memory, I/O interfaces and peripheral devices. Microcomputers typically provide an 8 bit word length.
MICRO-PROCESSOR	- A large scale integration processing unit containing a single integrated circuit (IC) chip or a set of IC chips with limited memory.
MINI-COMPUTER	- A small computer with word length, storage, and processing capabilities generally exceeding that available in a microcomputer. The mini-computer typically provides a 16 bit word length and used prepherial equipment originally designed for full size business and scientific computers.

MNEMONIC	- A symbolic representation or abbreviation designed to help operators remember.
MODEM (MODULATOR-DEMODULATOR)	- A hardware device for converting digital information to and from a form suitable for transmission over a telephone system.
MULTIPLEX (MUX)	- A device which combines multiple signals on one transmission media.
NONVALATILE MEMORY	- A memory which retains information in the absence of applied power.
OBJECT CODE	- A term used to describe machine language code.
OPERATING SYSTEM	- A complex software system which manages the computer and its components and allows for human interaction.
PARAMETER	- A variable that is given a constant value for a specific purpose or process.
PARITY	- A checking code within a binary word used to help identify errors.
PERIPHERAL EQUIPMENT	- Equipment used for man-machine communications and further support of a processor.
POINT	- Actual input to or output from the EMCS from or to the systems being monitored and controlled.
PREDICTOR/CORRECTOR PROGRAM	- Continuous prediction of a future value and subsequent correction based on actual measurements.
PROGRAM	- A series of instructions which define in detail the computer steps necessary to perform a function.
PROCESS AUTOMATION	- Process control without human intervention.
PROCESS CONTROL	- The collective functions performed by the equipment which is to control a variable.
PROMPT/RESPONSE SEQUENCE	- Man-Machine dialogue by which the computer asks questions and requests responses from the operator.
RAM	- Random Access Memory.
REAL-TIME	- A situation in which a computer monitors, evaluates, reaches decisions and effects controls within the relaxation time of the fastest loop or specified response time.
REGISTER	- A digital-computer device capable of retaining information often that contained in a small subset of the aggregate information.

ROM, PROM, EPROM	- Read-Only-Memory, Programmable-Read-Only Memory, Erasable-Programmable-Read-Only-Memory.
RTDOS/E	- Real-Time Disk Operating System/Executive.
RS-232C	- A standard developed by the Electronic Industries Association applicable to the interfacing of data terminal equipment.
RELAY	- A device for converting an electrical or pneumatic signal into an electromagnetic switching device having electrical contactors energized by electrical current through its coil.
SCAN	- To examine stored information for a specific purpose as for content and arrangement; to examine the status of input/output channels to determine whether data is being received or transmitted.
SCHEME	- Energy control method.
SELECTIVE GENERATION	- Where the management of input/output is restricted to selected peripherals.
SENSORS	- Devices used to detect or measure physical phenomena.
SINGLE STEPPING	- Procedure by which the next statement in a core resident program is executed by depressing a switch.
SNAPSHOT	- Picture of the instantaneous status and state of a system.
SOFTWARE	- A term used to describe all programs whether in machine, assembly, or high-level language.
SOURCE CODE	- A term used to describe assembler and high level programmer developed code.
STAND-ALONE	- A term used to designate a device or system which can perform its function totally independent of any other device or system.
SUPERVISORY CONTROL	- Separate (and usually remote) control and monitoring of local control loops. (see Direct Digital Control).
SYSTEM STATUS	- The condition of a particular point of a system such as: Normal, Abnormal, On, Off, Up, Alarm, and Overload.
TRUE DIGITAL	- A representation of any value by symetric digits, used to form fixed length words.
TTL	- An interface compatible with total transistor logic components suitable for discrete data transmission.

TTY - An interface compatible with teletype equipment suitable for serial data transmission.

TRUNK WIRING - The transmission circuit used to send signals between the central control console and the remote sites.

UNIT - Description of equipment (chillers, boiler, etc.) which may contain any combination of points.

WORD - A set of binary bits handled by the computer as the primary unit of information.

ZONE - An area composed of a portion of a building, a building, or a group of buildings affected by a single device or equipment.

LIST OF SUPPLIERS OF AUTOMATIC CONTROL SYSTEMS

Adcom Systems Corp., 31 East 28 St., New York, N.Y. 10016
Advanced Energy Control Systems, 20 Booker St., Westwood, N.J. 07675
Aegis Energy Systems, Technology Center, Montgomeryville, Pa. 18936
Allen-Bradley, 1201 S. Second St., Milwaukee Wis. 53204
American Multiplex Systems, 1600 N. Orange Thrope Way, Anaheim, Calif. 92801
Andover Control Corp., York and Haverhill Sts., P.O. Box 34, Andover, Mass. 01810
Applied Control Systems, 1828 Jefferson St., N.E. Minneapolis, Minn. 55418
Athena Controls, 2 Union Hill Rd. Conshohocken, Pa. 19428
A.T. American Leasing Inc., 65 E. Elizabeth Ave., Suite 500, Bethlehem, Pa. 18018
Automated Logic, 2675 Cumberland Pkwy., Atlanta, Ga. 30339
Automation Product, 3030 Max Ray St., Houston, Tex. 77008
Automation Systems Inc., P.O. Box K, Lancer Park, Iowa 52748
Barber-Coleman Corp., 1300 Rock St., Rockford, Ill. 61101
Borktronics, P.O. Box 2398, Miami, Fla. 33140
Careco Systems, Inc., 1533 E. Spruce St., Olathe, Kan. 66061
Chesterfield Products Inc., 511 Victor St., Saddle Brook, N.J. 07662
Compugard Corp., 709 Baum Blvd, Pittsburgh, Pa. 15213
Conservation Controls Corp., 295 Freeport St., Boston, Mass. 02122
Control Analysis Corp., 800 Welch Rd., Palo Alto, Calif. 94304
Controlled Electrical Energy Systems Inc., 4201 Cathedral Ave. N.W., Washington, D.C. 20016
Controlled Energy Systems Co., 11716 15th St., N.E., P.O. Box 55165, Seattle, Wash. 98155
Controlled Power Corp., 17921 S. Western Ave., Gardena, Calif. 90248
Conversational Systems, 31 E. 28th St., New York, N.Y. 10016
CSL Industries, 1830 Second Ave., Rock Island, Ill. 61201
Datrix Corp., 1810 Palmer Ave., Larchmont, N.Y. 10538
Digital Equipment Corp., 146 Main St., Maynard, Mass. 01754
Dynalco Corp., 5200 N.W. 37th Ave., P.O. Box 8187, Ft. Lauderdale, Fla. 33310
Dynapar Corp., 1675 Delany Rd., Gurnee, Ill. 60031
Eagle Signal Div., Gulf & Western Manufacturing Co., 736 Federal St., Davenport, Iowa 52803
Econowatt Corp., P.O. Box 321, Pelham, N.Y. 10803
Electrolock Energy Management Systems Inc., 1280 Court St., Clearwater, Fla. 33516
EM Group LTD., Center Marketing, 6104 East 32nd St., Tulsa, Okla. 74135
Encon Systems, Energy Conservice Co., Main St., South Salem, N.Y. 10590
Energy Automation Inc., 41 River Road, Summit N.J. 07901
Energy Management Corp., 1107 Kenilworth Dr., Towson, Md. 21204
Energy Management Systems, 202 Lane Ave., Gloucester, N.J. 08030
Esterline Electronics, 3501 Harbor Blvd., Costa Mesa, Calif. 92626
Flex-Core, 9345 Susses Dr., Cleveland, Ohio 44138
Foxboro Corp., 120 Norfolk St., Foxboro, Mass. 02035
General Electric Co., P.O. Box 2913, Bloomington, Ill. 61701
Gould Inc., Control & Systems Div., 47 Concord St., North Reading, Mass. 08164
Hamilton Standard, Windsor Locks, Conn. 06906
Haughton Elevator Co., 671 Spencer St., Toledo, Ohio 43609
Honeywell Inc., 10800 Lyndale Ave., Bloomington, Minn. 55420
Hughes Aircraft Co., 500 Superior Ave., Newport Beach, Calif. 92663
IBM, General Systems Div., P.O. Box 2150, Atlanta, Ga. 30301
Indocomp Inc., 5038 Leafdale Blve., Royal Oak, Mich. 48073
International Energy Conservation Systems, Suite 100, Prado West, 5600 Roswell Rd., N.E. Atlanta, Ga. 30342
ITE Datametrics, 340 Fordham Rd., Wilmington, Mass. 01887

International Energy Management Corp., 5650 W. 85th St., Indianapolis, Ind., 46278
Interactive Systems Inc., 3980 Varsity Dr., Ann Arbor, Mich. 48104
J&C Lamb Corp., 2420 Jackson Ave., Long Island City, N.Y. 11101
Johnson Controls Inc., Milwaukee, Wis. 53201
Kenmark Crandall Inc., 20 Woodsbridge Rd., Katonah, N.Y. 10536
KVB Inc., 17332 Irvine Blvd., Tustin, Calif. 92680
Leeds & Northrup, North Wales, Pa. 19458
LFE Corp., Control Systems Industries, 2920 San Ysidro Way, Santa Clara, Calif. 95050
Lockheed Electroncis Inc., U.S. Highway 22, Plainfield, N.J. 07061
The Madsen Co., 23465 Madison St., Torrance, Calif. 90505
McQuay Group, Mcquay-Perfex Inc., 13600 Industrial Park Blvd., P.O Box 1551, Minneapolis, Minn. 55440
Measurex, One Results Way, Cupertino, Calif., 95014
Micro Control Systems Inc., 6111-ON, Teutonia Ave., Milwaukee, Wis. 53201
Modicon Corp., P.O. Box 83T, Shawsheen Village Station, Andover, Mass. 01810
National Semiconductor, Systems Div., 1130 Kifer Rd., Sunnyvale, Calif. 94086
Pacific Technology Inc., 235 Airport Way, Renton, Wash. 98055
Powers Regulator Co., 3400 Oakton St., Skokie, Ill. 60076
Process Systems, Inc., P.O. Box 15451, Charlotte, N.C. 28210
Radix II Inc., 6192 Oxon Hill Rd., Suite 505, Oxon Hill Rd., Md. 20021
Realistic Controls Corp., 404 West 35th St., Davenport, Iowa 52806
Reliance Electric Co., 24701 Euclid Ave., Cleveland, Ohio 44117
Robertshaw Controls Co., P.O. Box 27606, Richmond, Va. 23261
Sangamo Electric Co., Energy Management Div., P.O. Box 3347, Springfield, Ill. 62714
Seaboard Systems, Pembroke 1, Virginia Beach, Va. 23462
Sentinel Electronics Corp., 1306 West County Rd. F., St. Paul, Minn. 55112
Sigma Instruments, Inc., 170 Pearl St., Braintree Mass. 02185
Solar State Systems, 2821 Ladybird Lane, Dallas, Tex. 75220
Solid State Systems Inc., 1990 Delk Industiral Blvd., Marietta, Ga. 30062
Square D Co., P.O. Box 472, Milwaukee, Wis. 53201
Surgeonics, P.O. Box 493, Bedford Hills, N.Y. 10507
Systems Technology Corp., 18845 W. McNichols, Detroit, Mich. 48219
TA Controls, 36 Sherwood Pl., Greenwich, Conn. 06830
Tech-S Inc., 32720 Plymouth Rd., Livonia, Mich. 48150
Texas Controls Inc., 2525 Walnut Hill Lane, Dallas, Tex. 75229
Texas Instruments Inc., Control Products Div., 30 Forest St., Attleboro, Mass. 02703
Thermo Electron Co., 85 First Ave., Waltham, Mass. 02154
Tri City Electric, 5713 Azle St., Ft. Worth, Tex. 76114
TRW Inc., Datacom Div., 10880 Wilshire Blvd., Los Angeles, Calif. 90024
U.S. Energy Savers Inc., 78-40 164th St., Flushing, N.Y. 11366
Versatex, P.O. Box 354, Brighton, Minn. 48116
Wachenhut Electronics Systems Corp., 1742 N.W. 69th Ave., Miami, Fla. 33126
Warner & Swansey, 7412 Washington Ave. S., Minneapolis, Minn. 55435
Weltronic Co. Inc., 495 E. Holley St., Clare, Mich. 48617
Westinghouse Electric Corp., Industrial Systems Div., 200 Beta Dr., Pittsburgh, Pa. 15238
Westinghouse Electric Corp., Madison Heights, Mich. 48071
Xencon, 50 Michell Blvd., San Rafael, Calif. 94903

APPENDIX B

CONTROL EQUIPMENT COST INFORMATION

Control Equipment Cost Information

Cost information for control equipment is presented in Table B-1 through B-15. Data is based upon price schedules, correspondence, conversations, and previously published information. It is noted that equipment availability and prices are subject to frequent change. The prices shown in this appendix are adequate for the usage intended - to provide a source for equipment cost needed for feasibility studies. Final economic evaluations should be based upon prices in effect at the time of implememtation.

TABLE B-1

AMERICAN MULTIPLEX SYSTEMS

Central Equipment	Cost
Minicentral Multiplex Terminal	$ 3,400.00
Program Control Unit	720.00
Printer (including cable and interface)	2,520.00
Graphic Slide Projector*	3,000.00
Display Module Chassis Including: a) Display Status Module	1,700.00
Manual Control Panel	1,300.00
Central Station Transmitter	1,350.00
Program Control Module	1,900.00
Remote Equipment (no remote intelligence)	
Miniremote Multiplex Terminal	200.00
Miniremote Multiplex Universal Terminal	400.00
Analog-Digital Convert with Digital Transmitter per remote panel	600.00
Software	
Outdoor Air/Return Air Optimization Program	4,500.00
Run Time Totalization Program	1,500.00
Optimum Start/Stop Program	5,000.00
Load Management Forecast Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

* Components not compatible with recommended purchasing specification.

TABLE B-2

AMF PARAGON

Local Equipment	Cost
7 Day Time Clock (Mechanical)	$ 100.00
7 Day Time Clock with Energy Time Optimizer (Mechanical)	500.00

TABLE B-3

BARBER-COLEMAN

Central Equipment	Cost
Central Processor	$ 26,000.00
Demand Controller	3,000.00
Paper Tape Device	1,700.00
Printer	6,000.00
Modem	500.00
Multiplex Device	10,000.00
Remote Equipment (no remote intelligence)	
Data Acquisition Panel	1,200.00
Modem	500.00
Software	
Outdoor Air/Return Air Optimization Program	4,500.00
Load Management Forecast Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

TABLE B-4

DIGITAL EQUIPMENT CORPORATION

Central Equipment	Cost
PM701 Power Management System Including:	
a. medium-scale real-time, program development and control system with 64 K byte	
b. two 1.2 m-word disks	
c. industrial control subsystem	
d. keyboard printer	
e. DEC cassette	
f. software	$ 46,800.00
Remote Equipment (with remote intelligence)	
PM301 Power Management System Including:	
a. PDP 11/10 Processor with 32 K byte memory	
b. DEC writer terminal	
c. dual DEC cassette	
d. ICS	
e. software	18,750.00

Software

Power management software
included in equipment price.

TABLE B-5

EAGLE SIGNAL

Central Equipment	Cost
Central Processor Module	$ 795.00
Executive Program Module	830.00
RAM Module	475.00
EPROM Module	780.00
RAM/EPROM Module	625.00
Timer Module	275.00
CRT Terminal Interface Modules	250.00
TTY Interface Modules	800.00
Blank Panels	16.00
EPROM Programmer & Erase Light	565.00
Power Supply & Chasis (17 Slot)	1,610.00
Power Supply & Chasis (10 Slot)	1,440.00
Intellingent CRT Terminal	10,995.00
Spare Cassette Tapes	10.00
Cables for Central Controller	135.00
Remote Equipment (with remote intelligence)	
Load Driver Interface	465.00
A/D and D/A Converter	200.00
Analog Input Interface Module	405.00
Analog Output Interface Module	450.00
I/O Track Interface & I/O Track	655.00
(Other remote equipment same as central equipment)	

Software

Power management software included in equipment price.

TABLE B-6

ESTERLINE ELECTRONIC CORPORATION

Central Equipment	Cost
CPU 16 K Memory and Accessories	$ 13,519.00
Disc Equipment 2.5 Mega-Word Dixc Drive and Controller	14,257.00
Keyboard CRT	6,780.00
ASR-33 Teletype	2,089.00
Quad Interrogator and Control Assembly	4,293.00
Enclosures, System Hardware, Cabling, etc.	5,486.00
System Integration, Test and Standard Software	7,127.00
Remote Equipment (no remote intelligence)	
Remote panel (transponder) with 16 remote point capacity	650.00
Software	
Run Time Totalization Program	2,000.00
Outdoor Air/Return Air Optimization Program	4,500.00
Load Management Forecast Program	5,000.00
Optimum Start/Stop Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

TABLE B-7

FISHER-PIERCE

Central Equipment	Cost
Base Station Controller including:	
a. encoder	
b. decoder	
c. display module with lights and (2) analog displays	$ 8,000.00
Printer/CRT Interface	1,000.00
Additional Channel Interfacing	(No Charge)
Transceiver (each)	2,000.00
Printer	2,000.00
CRT With Keyboard	2,000.00
Remote Equipment (no remote intelligence)	
Remote Station includes:	
a. two-way transmission capability	
b. antenna	3,400.00
Remote Station Includes:	
a. one-way transmission capability	
b. antenna	500.00
Remote Switch Includes:	
a. receiving capability	
b. antenna	75.00

TABLE B-8

HONEYWELL

Central Equipment	Cost
Central Console	
a. central processing unit	
b. operator's console	
c. Honeywell 316 computer w/16 k core	
d. CRT w/keyboard	
e. basic programs	$ 83,000.00
Model 33 Printer	8,200.00
Model 35 Printer	10,500.00
256 Word Analog Memory	
a. w/start/stop and limits	6,300.00
Each Additional Memory	900.00
Second Channel	2,100.00
Third through Ninth Channel (each)	1,100.00
81 Slide Projector and Slides with Automatic System Display	12,500.00
81 Slide Projector and Slides without Automatic System Display	5,800.00
Remote Equipment (no remote intelligence)	
Data Gathering Panel w/Analog-Digital Converter	2,000.00
Software	
Basic Program Costs	(included)
Return Air/Outdoor Air Optimization Program	4,646.00
Run Time Totalization	5,457.00
Load Management Forecast Program	5,000.00
Optimum Start/Stop Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

TABLE B-9

HUGHES AIRCRAFT COMPANY

Central Equipment	Cost
Control Console Including:	
a. DEC PDP11/40 Computer	
b. operator's console with printer	
c. CRT with keyboard	
d. core or MOS memory	
e. dual disk pack	
f. Basic programs	$ 40,000.00
Interface Translator and Central Modem	3,000.00
Remote Equipment (no remote intelligence)	
Monitor and Control Terminal	3,000.00
Remote Modem	75.00
Software	
Basic Software Package	(included)
a. logging and totalizing	
b. demand monitoring and load shedding	
c. start time optimization	
d. chiller/boiler optimization	

TABLE B-10

JOHNSON CONTROLS

Central Equipment	Cost
Model JC/80/55 Central Console a. JII 32k computer with 524k disc b. paper tape reader c. communications package for loop interface	$ 76,150.00
80 Slide Projector	3,000.00
Slides (each)	125.00
Teletypewriter ASR-38 (read/write with black and red)	6,120.00
Line Printer	6,120.00
CRT With Keyboard	6,150.00
Intercom	250.00
Loop Interface Package	6,700.00
Remote Equipment (no remote intelligence)	
Loop Controller a. programmer's console b. 24k memory	22,800.00
Loop Remote Extender a. 23 modems (maximum allowed)	37,160.00
Extended Loop Remote a. modem	2,500.00
Loop Remote	2,614.00
Software	
Basic Programs	10,200.00
Return Air/Outdoor Air Optimization Program	3,200.00
Run Time Totalization Program	1,300.00
Optimum Start/Stop Program	5,000.00
Load Management Forecast Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

TABLE B-11

POWERS REGULATOR COMPANY

Central Equipment	Cost
Central Console including:	
a. minicomputer with 32K storage	
b. CRT with keyboard	
c. intercom	
d. (2) extel printers	
e. basic programs	$ 57,100.00
256 K Disc	20,000.00
Manual Backup Unit	5,040.00
Slide Porjector	4,400.00
Remote Equipment (no remote intelligence)	
Remote Panel with 120 Remote Point Capacity	2,895.00
Analog-Digital Converter	(included)
Software	
Run Time Totalization Program	25.00/Point
Outdoor Air/Return Air Optimization Program	5,000.00
Load Management Forecast Program	5,000.00
Optimum Start/Stop Program	5,000.00
Chiller Optimization Program	5,000.00
Temperature Reset Program	5,000.00

TABLE B-12

PROCESS SYSTEMS

Central Equipment	Cost
16 k Nova-line Minicomputer Including:	
a. basic programs	
b. ASR-33 printer	$ 15,000.00
Chassis with:	
a. power supply	
b. buffers	
c. 288 input/output capacity	4,900.00
Set of 32 Input/Ouput Lines Used in Above Chassis (each)	475.00
First Digital Interface-16 Input/Ouput	1,300.00
Per Set Additional Digital Interface Sets of 16 Input/Output Up to a Total of 288 Input/Ouputs (each)	825.00
Remote Equipment (no remote intelligence)	
Termination Panel With 16 Input/Ouput Capacity	780.00
Termination Panel With 32 Input/Ouput Capacity	1,480.00
Software	
Standard Power Demand Control Programs	8,000.00

TABLE B-13

ROBERTSHAW

Central Equipment	Cost
Basic Console	$ 40,000.00
Color CRT	8,500.00
Printer	5,000.00
Intercom	900.00
Battery Backup	5,000.00
Remote Equipment (no remote intelligence)	
Start/Stop	625/point
Temperature Indication	625/point
Humidity Indication	750/point
Contact Alarm	410/point
Remote Control Point Adjustment with Temperature Indication	750/point
Software	
Standard Energy Management Software	(included)

TABLE B-14

TECH-S

Local Control Equipment	
Model 180 Controller (16 line output capacity)	$ 8575.00
Software	
Power Demand Control and Energy Management Programs	(included)

TABLE B-15

TEXAS INSTRUMENTS

Central Equipment	Cost
990/10 Development System Includes:	
32k minicomputer, dual floppy disk, scope and keyboard terminal	$ 13,500.00
Battery Pack	350.00
Printer	3,865.00
EPROM Adapter Panel Programming Device and Erase Kit	950.00
TTY Interface	480.00
Modem	600.00
Remote Equipment (with remote intelligence)	
8k Minicomputer	1,975.00
Battery Pack	350.00
TTY Interface	480.00
Modem	600.00
I/O Interface Module	300.00
A/D Converter	1,450.00
D/A Converter	1,800.00
Software	
Fortran IV	1,000.00
Basic	2,000.00
Cobol	2,750.00

APPENDIX C

TABLE C-1

ECIP COST ANALYSIS FORM

COSTS

1. Non-recurring Initial Capital Costs
   a. CWE $______
   b. Design $______
   c. $______
   d. Total $______

BENEFITS

2. Recurring Benefit/Cost Differential Other Than Energy
   a. Annual Labor Decrease (+)/Increase (-) $______/Yr.
   b. Annual Material Decrease (+)/Increase (-) $______/Yr.
   c. Other Annual Decrease (+)/Increase (-) $______/Yr.
   d. Total Costs $______/Yr.
   e. 10% Discount Factor $______
   f. Discounted Recurring Cost (d x e) $______

3. Recurring Energy Benefit/Costs
   a. Type of Fuel ______
      (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
      (2) Cost per MBTU $______/MBTU
      (3) Annual Dollar Decrease/Increase ((1) x (2)) $______/Yr.
      (4) Differential Escalation Rate (_%) Factor $______
      (5) Discounted Dollar Decrease/Increase (3) x (4) $______
   b. Type of Fuel Electricity
      (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
      (2) Cost per MBTU (Based on Source ENERGY) $______/MBTU
      (3) Annual Dollar Decrease/Increase ((1) x (2)) $______/Yr.
      (4) Differential Escalation Rate (_%) Factor ______
      (5) Discounted Dollar Decrease/Increase ((3) x (4))$______
   c. Type of Fuel ______
      (1) Annual Energy Decrease (+)/Increase (-) $______ MBTU
      (2) Cost per MBTU $______/MBTU
      (3) Annual Dollar Decrease/Increase ((1) x (2)) $______/Yr.
      (4) Differential Escalation Rate (__%) Factor ______
      (5) Discounted Dollar Decrease/Increase ((3) x (4))$______
   d. Type of Fuel ______
      (1) Annual Energy Decrease (+)/Increase (-) ______ MBTU
      (2) Cost per MBTU $______/MBTU
      (3) Annual Dollar Decrease/Increase ((1) x (2)) $______/Yr.
      (4) Differential Escalation Rate (___%) Factor ______
      (5) Discounted Dollar Decrease/Increase ((3) x (4))$______
   e. Discounted Energy Benefits (3a(5)+3b(5)+3c(5)+3d(5) $______

4. Total Benefits (Sum 2f + 3e) $______

5. Discounted Benefit/Cost Ratio (Line 4 ÷ Line 1d) ______

6. Total Annual Energy Savings (3a(1)+3b(1)+3c(1)+3d(1) ______ MBTU

7. E/C Ratio ((Line 6 ÷ (Line 1a/1000)) ______

8. Annual $ Savings (2d+3a(3)+3b(3)+3c(3)+3d(3) $______

9. Pay-back Period ((Line 1a - Salvage) ÷ Line 8) ______ Yr

APPENDIX D

EMCS COST ANALYSIS FORMS

TABLE D-1. FORMAT FOR EMCS COST ANALYSIS

1. Submitting Organization: ______________________________

2. Date of Submission: ______________________________

3. Project Title: ______________________________

4. Description of Project Objective: ______________________________

5. Alternative: ______________________ 6. Economic Life: ______________

7. Outputs:

   a. Dollar Quantifiable Outputs: (describe and justify)

   b. Other Quantifiable Outputs: (describe and justify)

   c. Non-quantifiable Outputs: (describe and justify)

Source: AR 11-28

TABLE D-2. FORMAT FOR EMCS COST ANALYSIS

8. Source/Derivation of Outputs: (use as much space as required)

a. Dollar Quantifiable Outputs:

b. Other Quantifiable Outputs:

c. Non-quantifiable Outputs:

9. Name & Title of Principal Action Officer Telephone Number:	Date
10. Name & Title of Approving Authority	Date

Source: AR 11-28

TABLE D-3. FORMAT FOR EMCS COST ANALYSIS

1. **Submitting Organization:** ______
2. **Date of Submission:** ______
3. Project Title: ______
4. Description of Project Objective: ______
5. Alternative: ______ 6. Economic Life: ______

7. Fiscal Year	8. Appropriation Identification	9. Program (if OMA)	10. Program/Project Costs a. R&D	b. Investment	c. Operations	d. Annual Cost (a+b+c)	e. Discount Factor	f. Present Value Annual Cost (d x e)
19__	______	______	______	______	______			
19__	______	______	______	______	______			
	______	______	______	______	______			
11. TOTALS								

12a. Total Project Cost, Discounted (11f) ______
12b. Uniform Annual Cost (Before Allowance for Terminal Value) ______
13. Less Terminal Value, Discounted ______
14a. Net Total Project Cost, Discounted (12a-13) ______
14b. Uniform Annual Cost (After Allowance for Terminal Value) ______

Source: AR 11-28

TABLE D-4. FORMAT FOR EMCS COST ANALYSIS

13. Source/Derivation of Cost Estimates: (use as much space as required)

a. Research and Development:
b. Investment:
c. Operations:
d. Net Terminal Value:
e. Other Considerations:

14. Name & Title of Principal Action Officer Telephone Number:	Date
15. Name & Title of Approving Authority	Date

Source: AR 11-28

TABLE D-5. FORMAT FOR EMCS COST ANALYSIS

1. Submitting Organization: ____________
2. Date of Submission: ____________
3. Project Title: ____________
4. Description of Project Objective: ____________
5a. Present Alternative: ____________ 6a. Economic Life: ____________
5b. Proposed Alternative: ____________ b. Economic Life: ____________

7. Fiscal Year	8. Appropriation Identification	9. Program (if OMA)	10. Operations a. Present Alternative	b. Proposed Alternative	11. Differential Cost (10a - 10b)	12. Discount Factor	13. Present Value Differential Cost (11X12)
19__							
19__							
14. Totals							

TABLE D-6. FORMAT FOR EMCS COST ANALYSIS

13. Present Value of New Investment:
 a. Land and Buildings ________
 b. Equipment ________
 c. Other (identify nature) ________
 d. Working Capital (change-plus or minus) ________

14. Total Present Value of New Investment (i.e., Funding Requirements) ________

15. Plus: Value of existing assets to be employed on the project ________

16. Less: Value of existing assets replaced ________

17. Less: Discounted terminal value of new investment ________

18. Total New Present Value of Investment $ ________

19. Present Value of Cost Savings from Operations (Col 11) ________

20. Plus: Present Value of the Cost of Refurbishment or Modifications Eliminated ________

21. Total Present Value of Savings $ ________

22. Savings/Investment Ratio
 (Line 21 divided by Line 18) ________

TABLE D-7. FORMAT FOR EMCS COST ANALYSIS

23. Source/Derivation of Cost Estimates: (use as much space as required)

a. Investment:
(1) Costs
(2) Net Terminal Value

b. Operations:
(1) Personnel
(2) Operating
(3) Overhead Costs
(4) Other Costs

c. Other Considerations:

24. Name & Title of Principal Action Officer Telephone Number:	Date
25. Name & Title of Approving Authority	Date

Source: AR 11-28

Appendix E - Example

To clarify the use of this manual, an example of the procedure for energy savings and cost estimation is included in this section. This example is written to provide computational guidance and is by no means a comprehensive look at an actual EMCS appliation. Buildings used in the example are based on acutal buildings from a feasibility study of automatic control at Fort Belvoir, Virginia.

After reading Chapter 3 of this manual, our hypothetical facilities engineer makes a decision to analyze energy conservation by load scheduling, outside air shutoff, and enthalpy control using a central programmable controller.

This example is calculated for one class of controller only since computation is similar for other classes. This selection in no way constitutes an endorsement or an encouragement to perform an analysis of one class of controller only.

In this example, only nine buildings of various types are used in order to avoid undue complication of computational procedures. It is anticipated that the facilities engineer, after applying the criteria of Chapter 4, Building Selection Criteria, would arrive at a longer list of buildings, many of which would be similar to those presented in this example.

E.1 Energy Savings

The first step in the analysis is to estimate the energy savings for the selected schemes. In order to do this, we must fill out the Energy Savings Forms for both heating and cooling. One set of these forms must be filled out for each scheme. The forms as completed for this example are presented in Tables E-1 through E-5.

The first information to be filled in is the building number and its square footage of conditioned area. Next the building type is found from the list in Table 4-1 and entered on the form. These three columns will not vary from scheme to scheme.

The next step is to enter the appropriate energy savings factor from the tables in Chapter 4. The factors for load scheduling appear in Table 4-3; for outside air shutoff in Table 4-4; and for enthalpy control in Table 4-5.

The geographical adjustment factor is now calculated by dividing the number of degree days for the locality under consideration (from Table 4-6) by our baseline figures of 4167 Heating and 1550 Cooling degree days for Washington, D.C. In this example, we use Washington for the specific as well as baseline locality resulting in an adjustment factor of unity.

Our total energy savings figure for the building (Column D) is then the product of the square footage (column A) by the savings factor (Column B) by the adjustment factor (Column C). This total is in terms of thousands of Btu's per year. The sum of all the buildings' savings is the sytems savings for that control scheme heating or cooling.

Total savings for this example are tabulated below.

	Savings (KBTU/yr) Heating	Savings (KBTU/yr) Cooling
Load Scheduling	3.576×10^6	0.671×10^6
Outside Air Shutoff	5.819×10^6	1.049×10^6
Enthalpy Control	0	1.420×10^6
	9.405×10^6	3.140×10^6

This is 9.045×10^9 Btu and 3.140×10^9 Btu per year respectively. From Chapter 4, we may calculate the dollar value of this savings. We will assume that all heating is done by fuel oil and cooling is by electricity. Using the conversion factors in Table 4-7, we can perform the following claculation.

$$3{,}140\ 10^9 \text{ Btu/yr} \div 3.41\ 10^3 \text{ Btu/kWh} = 920{,}821 \text{ kWh/yr}$$

Using the cost figures from Table 4-8, we may further calculate:

$$9.405 \times 10^9 \text{ Btu/yr} \times \$2.80/10^6 \text{ Btu} = \$26{,}334/\text{yr}$$
$$920{,}821 \text{ kWh/yr} \times \$0.035/\text{kWh} = \$32{,}229/\text{yr}$$

for a total of $58,563/yr savings. This figure is then used in Chapter 11 for benefit analysis over the life of the project.

EXAMPLE

TABLE E-1

ENERGY SAVINGS-HEATING

LOAD SCHEDULING

Building No.	Building Type	Building Floor Area (ft^2) (A)	Savings Factor (KBtu/yr ft^2) (B)	Geographic Adjustment (C)	Total Heating Savings (KBtu/yr) (D)
200	1	22,436	46.3	4167/4167=1	1.039×10^6
231	7	11,746	60.5	1	0.711×10^6
240	2	15,552	47.0	1	0.731×10^6
1,199	3	20,400	24.9	1	0.508×10^6
211	15	30,435	0.8	1	0.024×10
1,200	4	20,045	23.1	1	0.463×10^6
507	16	16,416	0.6	1	0.010×10^6
1,189	5	34,000	2.5	1	0.085×10^6
238	6	26,160	0.2	1	0.005×10^6
				Total	3.576×10^6

Calculate $D = A \times B \times C$

EXAMPLE

TABLE E-2

ENERGY SAVINGS-COOLING

LOAD SCHEDULING

Building No.	Building Type	Building Floor Area (ft 2) (A)	Savings Factor (KBtu/yr ft2) (B)	Geographic Adjustment (C)	Total Heating Savings (KBtu/yr) (D)
200	1	22,436	5.3	1550/1550=1	0.119×10^6
231	7	11,746	8.9	1	0.105×10^6
240	2	15,552	5.3	1	0.082×10^6
1,199	3	20,400	1.8	1	0.037×10^6
211	15	30,435	0.7	1	0.021×10
1,200	4	20,045	3.4	1	0.068×10^6
507	16	16,416	0.5	1	0.008×10^6
1,189	5	34,000	6.4	1	0.218×10^6
238	6	25,160	0.5	1	0.013×10^6
				Total	0.671×10^6

Calculate D = A x B x C

EXAMPLE

TABLE E-3

ENERGY SAVINGS-HEATING

OUTSIDE AIR SHUTOFF

Building No.	Building Type	Building Floor Area (ft 2) (A)	Savings Factor (KBtu/yr ft2) (B)	Geographic Adjustment (C)	Total Heating Savings (KBtu/yr) (D)
200	1	22,436	75.5	4167/4167=1	1.693×10^6
231	7	11,746	98.6	1	1.158×10^6
240	2	15,552	76.6	1	1.191×10^6
1,199	3	20,400	40.6	1	0.828×10^6
211	15	30,435	1.3	1	0.040 x 10
1,200	4	20,045	37.7	1	0.756×10^6
507	16	16,416	1.0	1	0.016×10^6
1,189	5	34,000	4.1	1	0.139×10^6
238	6	25,160	0.3	1	0.008×10^6
				Total	5.829×10^6

Calculate D = A x B x C

EXAMPLE

TABLE E-4

ENERGY SAVINGS-COOLING

OUTSIDE AIR REDUCTION

Building No.	Building Type	Building Floor Area (ft 2) (A)	Savings Factor (KBtu/yr ft2) (B)	Geographic Adjustment (C)	Total Heating Savings (KBtu/yr) (D)
200	1	22,436	8.7	1550/1550=1	0.195×10^6
231	7	11,746	11.4	1	0.134×10^6
240	2	15,552	8.8	1	0.137×10^6
1,199	3	20,400	2.9	1	0.059×10^6
211	15	30,435	1.1	1	0.033×10
1,200	4	20,045	5.6	1	0.112×10^6
507	16	16,416	0.8	1	0.013×10^6
1,189	5	34,000	10.1	1	0.343×10^6
238	6	25,160	0.9	1	0.023×10^6
				Total	1.049×10^6

Calculate D = A x B x C

EXAMPLE

TABLE E-5

ENERGY SAVINGS-COOLING

ENTHALPY CONTROL

Building No.	Building Type	Building Floor Area (ft^2) (A)	Savings Factor (KBtu/yr ft^2) (B)	Geographic Adjustment (C)	Total Heating Savings (KBtu/yr) (D)
200	1	22,436	13.7	1550/1550=1	0.307×10^6
231	7	11,746	6.6	1	0.078×10^6
240	2	15,552	8.3	1	0.129×10^6
1,199	3	20,400	10.6	1	0.216×10^6
211	15	30,435	1.8	1	0.055×10
1,200	4	20,045	18.6	1	0.373×10^6
507	16	16,416	3.8	1	0.062×10^6
1,189	5	34,000	5.6	1	0.190×10^6
238	6	25,160	0.4	1	0.010×10^6
				Total	1.420×10^6

Calculate $D = A \times B \times C$

E.2 Installation Cost

Total cost of the EMCS installation being considered in this example is the sum of cost for (a) the central terminal hardware, (b) the remote terminal hardware, (c) branch circuit wiring, (d) trunk line wiring, (e) local wiring, and (f) control point cost.

A representative central programmable controller was described in Section 9.3. The central terminal hardware cost was seen to be $29,575. Each remote terminal hardware cost $7,271. It has been assumed that a separate remote terminal will be required in each of the nine buildings being considered in this example. Total cost of remote terminal hardware is thus $65,464.

Branch circuit wiring required to provide electrical power to computer equipment is discussed in Section 10.1. The central terminal and each remote terminal will require a separate circuit. In section 10.1, these circuits were estimated to cost $330 each. Thus, the 10 circuits required will cost a total of $3,300.

It is planned to use existing phone lines for trunk line communication in this example. As phone systems are owned by the government at most military facilities, these lines were assumed to be available without charge. The cost of modems required at both central and remote sites are included in their respective hardware cost. Thus the cost of trunk line communications was zero.

Central signal wiring is used here to refer to wiring from a remote terminal to a control point or sensor as described in Section 10.2. This wiring consists of two classes. The first is the wiring from the remote panel, which we assume to be in the equipment room to other equipment in the room. The second is wiring from the remote panel to equipment not located in the equipment room.

In this example, the only equipment in the equipment room requiring connection is the chiller, which requires only one control point. We will use an average conduit run of ten feet and from Section 10.2, we get a cost of $3.50 per foot plus $135.00 for connection and associated hardware totaling $170.00 per chiller. There are a total of five chillers for the nine buildings being considered in this example. Therefore, the cost of wiring in the equipment rooms will be:

(5 chillers) ($170/chiller) = $850.00

We require one control point for each Air Handling Unit, Exhaust Fan, and set of dampers. We will assume all of these units to be located remotely, on the roof. Further assume an average conduit run of 50 feet.

$1,505 + $2,345 = $4,075

Using the same procedure as above, the cost of wire, termination and adapter panel for each connection is $310.00. There are a total of 21 air handlers, 11 exhaust fans, and 11 dampers in the buildings being considered in this example. Total cost wiring to equipment not in the equipment room is therefore:

(43 units) (310.00 $/unit) = $13,330

The total local wiring cost for the system is the sum of both components.

$850 + 13,330 = $14,180

Control point cost will vary greatly depending upon the nature of the instrumentation and control actuating mechanism already employed. In this example, it is assumed that all instrumentation and control points must be furnished with the EMCS installation. To estimate cost, the total number of each type of point is determined and multiplied by the average cost for that type point. This procedure is shown in Table E-6. The toal cost for the control points in this example is found to be $40,342.

The need for a central facility to house the central controller and operator was discussed in Section 11.3. Based upon the data provided in that section, cost of an adequate facility is estimated to be $27,000.

The total cost of the propsed EMCS can now be determined as shown below:

(a)	Central terminal equiment cost	$ 29,575
(b)	Remote terminal equipment cost	65,439
(c)	Branch circuit wiring cost	3,300
(d)	Trunk line wiring cost	0
(e)	Control signal wiring cost	14,180
(f)	Control point cost	40,342
(g)	Central Facility	27,000
		$179,836

E.3 Recurring Cost

Recurring cost, discussed in Section 11.4, include operation and maintenance expenses. The implementation of an EMCS should reduce manpower requirements for operation and maintenance. It is reasonable to assume that this reduction would be sufficient to provide necessary personnel required by the EMCS with existing staff. Training expenses, estimated at $1,500 per year, provide for one training course per year. Materials and outside repair expenses are estimated as 15 percent of initial central and remote terminal (FID) cost, or $14,248 in this example. Total annual recurring cost are thus:

$1,500/year + $14,248/year = $15,748/year

E.4 Benefit/Cost Summary

As a result of the calculations shown in this example, the facility engineer now has the estimated costs and potential energy savings. For this example, annual savings of $58,563 are reduced by annual recurring cost of $15,748 yielding a net annual benefit of $42,815. A period of 4.2 years would be required to recover the initial investment of $179,836. By referring to Section 11, the facility engineer can determine the economic feasibility in accordance with his organizations criteria.

An ECIP evaluation form was completed for the sample problem. This form, presented in Table E-7, shows a discounted benefit/cost ratio of 3.42, an E/C ratio of 117, and payback period of 4.2 years. Reference to the ECIP Guidance Report indicates that this example problem would meet the established criteria for funding under this program.

TABLE E-6

REMOTE POINT COST TOTALS

	Start/Stop		Reset		Analog		Binary		
Building No.	No.	Cost/Point	No.	Cost/Point	No.	Average Cost/Point	No.	Average Cost/Point	Total
200	9	$ 400	3	$ 330	2	$ 406	2	$ 260	$ 5,922
240	3	400	3	330	2	406	2	260	3,522
1,199	2	400	3	330	2	406	2	260	3,122
1,200	9	400	6	330	4	406	4	260	8,244
1,189	3	400	3	330	2	406	2	260	3,522
238	4	400	6	330	4	406	4	260	6,244
231	2	400	3	330	2	406	2	260	3,122
211	2	400	3	330	2	406	2	260	3,122
507	3	400	3	330	2	406	2	260	3,522
								Total	$40,342

TABLE E-7

ECIP EVALUATION FORM FOR EXAMPLE PROBLEM

COSTS		
1. Non-recurring Initial Capital Costs		
a. CWE	$179,836	
b. Design	$	
c.	$	
d. Total		$179,836
BENEFITS		
2. Recurring Benefit/Cost Differential Other Than Energy		
a. Annual Labor Decrease (+)/Increase (-)	$ /Yr.	
b. Annual Material Decrease (+)/Increase (-)	$ /Yr.	
c. Other Annual Decrease (+)/Increase (-)	$-15,748 /Yr.	
d. Total Costs	$-15,748 /Yr.	
e. 10% Discount Factor	$ 7.980	
f. Discounted Recurring Cost (d x e)		$-125,669
3. Recurring Energy Benefit/Costs		
a. Type of Fuel Fuel Oil		
(1) Annual Energy Decrease (+)/Increase (-)	9,405 MBTU	
(2) Cost per MBTU	$ 2.80 /MBTU	
(3) Annual Dollar Decrease/Increase ((1) x (2))	$ 26,334 /Yr.	
(4) Differential Escalation Rate (8%) Factor	$ 13.112	
(5) Discounted Dollar Decrease/Increase (3) x (4)	$345,291	
b. Type of Fuel Electricity		
(1) Annual Energy Decrease (+)/Increase (-)*	11,672 MBTU	
(2) Cost per MBTU (Based on Source ENERGY)	$ 2.76 /MBTU	
(3) Annual Dollar Decrease/Increase ((1) x (2))	$ 32,229 /Yr.	
(4) Differential Escalation Rate (7%) Factor	12.278	
(5) Discounted Dollar Decrease/Increase ((3) x (4))	$395,708	
c. Type of Fuel		
(1) Annual Energy Decrease (+)/Increase (-)	$ MBTU	
(2) Cost per MBTU	$ /MBTU	
(3) Annual Dollar Decrease/Increase ((1) x (2))	$ /Yr.	
(4) Differential Escalation Rate (%) Factor		
(5) Discounted Dollar Decrease/Increase ((3) x (4))	$	
d. Type of Fuel		
(1) Annual Energy Decrease (+)/Increase (-)	MBTU	
(2) Cost per MBTU	$ /MBTU	
(3) Annual Dollar Decrease/Increase ((1) x (2))	$ /Yr.	
(4) Differential Escalation Rate (%) Factor		
(5) Discounted Dollar Decrease/Increase ((3) x (4))	$	
e. Discounted Energy Benefits (3a(5)+3b(5)+3c(5)+3d(5)		$740,999
4. Total Benefits (Sum 2f + 3e)		$615,330
5. Discounted Benefit/Cost Ratio (Line 4 ÷ Line 1d)		3.42
6. Total Annual Energy Savings (3a(1)+3b(1)+3c(1)+3d(1)		21,077 MBTU
7. E/C Ratio (Line 6 ÷ (Line 1a/1000))		117
8. Annual $ Savings (2d+3a(3)+3b(3)+3c(3)+3d(3)		$42,815
9. Pay-back Period ((Line 1a - Salvage) ÷ Line 8)		4.2 Yr

* Equivalent source energy is 3.4 times electric energy directly consumed.

APPENDIX F

INSTALLATION ENERGY CONTROL SYSTEM ANALYSIS CALCULATION PROGRAM

1.0 Introduction

A program, documented in Report FESA-RT-2033 is available which automates the procedure required to obtain economic and energy analysis needed for funding request. The program calculates the energy savings achievable in terms of Btu's and dollars, implementation costs and equipment requirements, and gives the economic analysis for single or multiple buildings (facilities and installations).

2.0 Input Data

2.1 General Information

As presently written, up to 120 buildings can be run on the program and analyzed. This can be expanded by increasing the dimensions. Data must be developed on the buildings equipment to be analyzed. The equipment items are:

Air Handlers (number)
Chillers (number)
Exhaust Fans (number)
Dampers (number)

If these pieces of equipment don't adequately describe the system, they can serve as an equivalent replacement for the undescribed item from a control point of view.

The type of system in the building must be known to be able to select the energy savings scheme to be applied. For example, you can't use a temperature reset savings scheme with a fan coil unit or you can't use enthalpy control or optimization if a building has no ventilation system. Thus, a building survey, requiring up to no more than two hours per building, is necessary to obtain the input information. A good rule of thumb is to start with all buildings larger than 8,000 square feet. This number may then be lowered if economics are favorable.

During the building equipment survey, the items of equipment, the repair or renovation or replacement equipment required for control or regulation of the HVAC equipment should be noted and listed for each building. The cost of the repair or new construction necessary for feasible control may be estimated or calculated. The seriousness of the estimate may be based on the degree of accuracy required by the analysis. Thus, a first cut analysis would not require the refinement necessary for a final sophisticated design calculation.

2.2 Building Types

Buildings have been categorized into 19 types of functional use. This breakdown was used to correspond to the energy usage data gathered, known and calculated.

2.3 Climatic Effects

For simplicity and to include effects of humidity, a table has been prepared listing large cities in the U.S. and the associated number assigned. This table is to be used to account for the climatic changes associated with location. For a given installation, pick the closest or most descriptive climatic city to account for the difference in heating, cooling and humidity in relation to Washington, D.C. Data inherent in the program is associated with conditions in the Washington, D.C. area and must be normalized for different locations.

2.4 Energy Saving Schemes

The various conservation schemes are:

2.4.1. Scheme 1, Equipment Shutdown. Programmed shutdown of building heating and cooling equipment during unoccupied periods results in significant energy savings. The magnitude of the savings depends on the heat transfer characteristics of the building, equipment capacity, type, and operating efficiency, and outside temperature conditions.

2.4.2 Scheme 2, Outside Air Shutoff. Programmed shutoff of outside air consists of closing outside air intakes and shutdown of exhaust fans when the building is unoccupied. For buildings where equipment operates continuously, the savings in energy cost can be large. It is recommended that Scheme 2 be used in conjunction with Scheme 1.

2.4.3 Scheme 3, Outside Air Reduction. Many building systems have been found to draw in more outside air than is required for adequate ventilation. Therefore, each building system should be investigated to determine how much the outside air quantity may be reduced. An adjustment of the minimum outside air damper setting to decrease the outside quantity could be a one time adjustment or could be combined with variable setting equipment as in Scheme 2, 4, or 5. Scheme 2 and 3 should be used in conjuction.

2.4.4 Scheme 4, Option 1, Enthalpy Control. A popular energy conserving scheme is enthalpy control. By measuring the temperature and the relative humidity an estimate of the total heat content (sensible and latent) of both return and outside air streams can be made. Then the air stream requiring the least amount of energy to maintain the proper comfort level is used for the supply air.

Scheme 4, Option 2, Enthalpy Optimization. An extension of the concepts described in enthalpy control is that of enthalpy optimization. This control scheme mixes the air streams (outside air or return air) which will impose the lowest cooling load on the mechanical equipment. It should be noted that either savings of Scheme 4 should be used but not both. The savings are similar.

2.4.5 Scheme 5, Temperature Reset. Energy savings are available through reset or adjustment of air temperature in a mixed air system like double duct and multizone. The basic concept is to decrease the amount of mixing by reducing the temperature difference between the hot and cold air streams.

2.4.6 Scheme 6, Forecasting Peak Reduction. Peak reduction under this scheme is accomplished by shutting down selected equipment (shedding) when desirable to reduce a peak during any demand interval.

3.0 Calculations

The consumption and estimated savings have been updated using known data from the installations in the Washington, D.C. area. If building energy consumption is known, either from metering or an energy audit of consumption (i.e., oil delivery receipts), then those values can be input. If the savings for a particular scheme or additional savings can be quantified, these savings can also be included. Dollar savings for maintenance, labor, or other cost avoidance may be pro-rated for the buildings and incorporated into the calculations. The simple payback period calculations assume that operating and maintenance costs (recurring costs) are balanced or offset by annual maintenance and operating savings.

4.0 Output Data and Interpretation

Each output listing gives the information on each building corresponding to the column heading at the top. The building numbers are repeated in the order entered except for the economic analysis output. The building order for the economic output is ranked from the highest overall economic benefit to lowest.

4.1 Energy Saving Listing

The initial listings are the total heating and total cooling savings for each scheme in GBTU/year. Totals for each scheme are given at the bottom. Following the listing by scheme, the yearly building energy savings for each building is given in GBTU/year and in $/year.

4.2 Building Control Point Tabulation

Following is the building control point tabulations giving the number of each type of control point required for the building and the individual and cumulative totals.

4.3 Equipment Costs

Equipment costs listed include local wiring costs, remote point costs, telephone line equipment costs, estimated building repair costs, estimated new equipment costs, and total building costs, as applicable, for five typical industry suppliers. The five suppliers were arbitrarily used from Reference 1 as typical and representative of industry.

The estimated repair and new equipment costs have to be input, otherwise zero costs are assumed.

4.4 Economic Analysis

The economic analysis listing presents the buildings by relative merit of savings minus cost of implementation. Operating and maintenance costs and EMCS implementation costs are given as well as the cumulative total cost. The Discounted Payback Period is presented in years. All cost savings are escalated to the expected year of operation for simple payback. The cumulative Btu's saved per dollar invested is given as well as the cumulative total energy savings per year in dollars.

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