Controlling Energy Consumption in Single Buildings

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This report contains guidelines for using microprocessor-based equipment to control energy in buildings. Energy conservation control strategies are discussed and simplified energy savings calculations explained. The results of a survey of currently available equipment suitable for use as energy controllers is included as well as selection guidance for which class of equipment will provide the needed features.
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This report was prepared as an account of work sponsored by an agency of the United States Government. Reference to any specific commercial product by trademark, manufacturer, or in any other manner does not constitute or imply its endorsement or recommendation by either the United States Government or the author of this report. The devices mentioned are intended to be representative of the various control devices currently being marketed and are not necessarily better than any competing product.
1. INTRODUCTION

This report contains a Microprocessor Based Equipment Guide. This guide was developed for the Naval Civil Engineering Laboratory, Port Hueneme, California under contract number N62583-81-MR-593.

This report has been designed to aid the public works engineer in the analysis and modification of existing buildings to reduce both fuel consumption and operating costs. The report offers an approach to identifying, analyzing, and recommending action on the options available to reduce energy use in most existing buildings. Besides a review of the principles of energy use and conservation, the report provides a step-by-step methodology for assessing and improving the year-round energy performance of buildings, and guidance in selecting equipment to implement these improvements. Through a careful application of the procedures described in this report, the energy conservation engineer should be able to make an accurate assessment of the opportunities for reducing the energy consumption of existing buildings. A cost benefit analysis provides the opportunity to make implementation decisions based on projected energy savings, investment costs, operational changes, and payback periods.

In addition, a survey of currently available Solid State and Microprocessor Based control equipment suitable for use in single building or small clusters of buildings was made and the results of this survey are tabulated in Section 5. A list of manufacturer's addresses and telephone numbers is contained in Appendix C. To effectively use this manual, an understanding of buildings and the mechanical equipment used to heat and cool them is helpful. Two publications that will assist in this understanding are:

Total Energy Management - published by the National Electrical Manufacturers Association

Energy Conservation with Comfort - published by Honeywell

Information on how to obtain these documents is contained in Appendix A, Table A.3.
All equations used in this report use the English system of units (°F, pounds, DFM, etc.).
II. ENERGY MANAGEMENT

Energy conservation has become an increasingly vital task in recent years. Federal agencies have been charged by Executive Order 12003 with reducing the energy consumption by twenty percent in the buildings under their control.

Efforts to comply with this requirement have ranged from delamping and replacement of obsolete equipment to the installation of large scale computer based central control systems. The entire program comes under the collective term "Energy Management".

Energy management, as the term implies, is a systematic, ongoing strategy for controlling a building's fuel-consumption patterns in such a manner as to reduce the waste of energy and dollars to the absolute minimum permitted by the climate in which the building is located, as well as by the condition of the building, its functions, occupancy schedules, and other factors. In short, an effective energy management program establishes and maintains a balance between a building's annual functional energy requirements and its annual actual energy consumption -- no more, no less.

The goal of energy management is the effective and efficient use of energy. Buildings consume energy in their normal operations. Energy is required to provide lighting, to power office equipment, and to provide heating and ventilation for occupant comfort. Each of these areas offers the potential for energy conservation. This manual will concentrate on the mechanical heating, ventilating and air conditioning (HVAC) equipment.

One of the major aspects of an energy management program is proper control of a building's mechanical equipment. Most mechanical systems are controlled by mechanical timeclocks, pneumatic control circuits, electric control circuits, or some combination of these devices. While these devices provide an acceptable level of control for most applications, their limitations do not allow the most energy efficient operation. This is especially true for older equipment. Often the energy savings due to improved
controls will provide sufficient cost savings to justify the replacement of obsolete equipment. Even with newer equipment, control modernization will often be economically feasible. Solid state electronics have made tremendous advances in the past few years in terms of the cost/capability ratio. Microprocessors have been developed which bring increased intelligence and capabilities to the control field. It is now possible, using these microprocessors, to scan sensors and to gather information such as temperature, humidity, and equipment status and to use this information to control equipment. In fact, it is now possible to obtain many of the features of large, computer based control systems in microprocessor based "stand alone" control devices suitable for use in a single building. The continuing downward trend in price for this hardware will make these applications increasingly attractive.

The report describes the capabilities of the new microprocessor based control devices and provides some guidance in how to apply them.
III. CONTROL STRATEGY DESCRIPTIONS

Before attempting to analyze a building for its energy conservation potential, two concepts must be defined. A mechanical system is defined as a group of mechanical devices which operate together to perform a common task. Individual items of equipment within a system are not considered to operate independently of one another; however, each system can be controlled independently of other systems in a building.

Mechanical systems will vary in configuration and details from building to building but all equipment serves one basic purpose; the maintenance of a set of desired conditions. In maintaining these conditions the equipment consumes energy. The key to reducing this energy consumption is intelligent control of the mechanical equipment. Various control strategies can be applied, depending on the installed equipment. While the details of implementation may vary, the energy conservation effects of these strategies will be similar.

A control strategy is defined as a specific operational procedure. A strategy generally consists of several independent activities, such as temperature measurement, linked by some form of logic to accomplish a specific purpose. It is important to realize that a control strategy affects an entire system and not just a particular component of the system. If consideration is given only to the operation of an individual element, say a motor, instead of to the total system of which that element is a part, operational problems may occur due to improper operation of other local controls and interlocks. This makes effective energy control and reduction difficult, if not impossible.

These strategies may be accomplished in a variety of ways depending on the particular hardware used to accomplish them, rather than the strategy itself. Therefore, it is possible to identify individual control strategies. The following paragraphs will identify the control strategies considered in this guide. These represent the most common strategies available from manufacturers today. While additional strategies can be identified and may provide some additional energy savings, those listed will most certainly provide the bulk of the potential savings.
SCHEDULED START/STOP

Scheduled start/stop consists of the starting and stopping of equipment based on the time and type of day. Type of day refers to weekdays, Saturdays, Sundays, holidays, or any other day which has a different schedule of operation. This is the simplest of all control strategies to install, maintain, and operate. It also provides the greatest potential for energy conservation if systems are currently being operated unnecessarily during unoccupied hours. HVAC systems using this strategy generally include a temperature sensor in a space which overrides the shutoff strategy if the temperature drops below a certain level.

OPTIMUM START/STOP

An additional feature of the scheduled start/stop of mechanical systems described above is optimum start/stop. Mechanical systems serving areas that are not occupied 24 hours per day should be shut down during the unoccupied hours. Traditionally, the systems are restarted before occupancy to cool or warm the space to comfort conditions. Under scheduled start/stop this is performed on a fixed schedule selected to meet worst case conditions, independent of existing weather or space conditions. The optimized start/stop strategy adjusts the start and stop times of the equipment to minimize the energy required to provide the desired environmental conditions during occupied hours. This strategy automatically evaluates the thermal inertia of the structure, the capacity of the system to either increase or reduce temperatures in the facility, start-up and shut-down times, and weather conditions to accurately determine the minimum hours of operation of the HVAC system necessary to satisfy the thermal requirements of the building.

DUTY CYCLING

The duty cycling strategy consists of stopping a piece of equipment for short periods of time during normal operating hours. This strategy is usually only applicable to HVAC systems. Its operation is based on the theory that HVAC systems seldom operate at peak output; thus if the
system is shut off for a short period of time, it has enough capacity to overcome the slight temperature drift which occurs during this shutdown. Although the interruption does not reduce the required net space heating or cooling energy, it does reduce energy input to constant auxiliary loads such as fans and pumps. This strategy also reduces outside air heating and cooling loads since the outside air intake damper is closed while an air handling unit is off. Systems are generally cycled off for some fixed period of time, say 15 minutes, out of each hour of operation. The off period length and its frequency should be adjustable. The off period length is normally adjusted for a longer duration during moderate seasons and shorter duration during peak seasons. Duty cycling does produce additional wear on belts and motor starting circuits. Further, it may affect building air balance between building zones if more than one air handler is in use. Analysis of these potential problems may preclude use of this strategy in certain cases.

DEMAND LIMITING

This strategy consists of stopping electrical loads to prevent setting a high electrical demand peak and thus increasing electrical costs where demand oriented rate schedules apply. There are many complex schemes for accomplishing this. They all generally monitor the electrical demand continuously. Based on the monitored data, demand predictions are made by the control equipment. When these predictions exceed preset limits, certain scheduled electrical loads are shut off by the controller to reduce the rate of consumption and the predicted peak demand. Additional loads are turned off on a priority basis if the initial load shed action does not reduce the predicted demand enough to satisfy the strategy's requirements. Generally, the loads to be shed are HVAC items. The reasoning used in the duty cycling discussion holds here also: allow a slight temperature drift in the space by shutting off the HVAC equipment. Utility rate schedules, which include "time of day" pricing, offer additional savings opportunities. Running of certain equipment, such as water well pumps, during off peak hours has significant impact under that type of schedule and should be thoroughly investigated.
Demand limiting is generally not applicable to single buildings as demand is not usually metered at this level. Instead the electrical consumption and demand are measured at a facility's main feeder and only the composite demand for the facility is recorded. Because of this, demand limiting is not analyzed in this manual. If demand limiting appears to be a viable strategy, further information is available in the Standardized EMCS Energy Savings Calculations Manual, available from the Naval Civil Engineering Laboratory at Port Hueneme, California.

DAY/NIGHT SETBACK

The energy required to maintain space conditions during the unoccupied hours can be reduced by changing the temperature set point for the space, depending on the climatic conditions. This strategy would apply only to facilities that are not occupied 24 hours per day. Normally, where applicable, this strategy would reduce the space temperature from the 65° winter inside design temperature to a 50° or 55° space temperature during the unoccupied hours or allow it to increase from the 78° inside condition during the summer.

ECONOMIZER

The utilization of an all outside air economizer control strategy can be a cost effective energy conservation strategy, depending on the climatic conditions and the type of mechanical system. Where applicable, the economizer control strategy uses outside air to satisfy all or a portion of the building's cooling requirements. Outside air is introduced through the mechanical system and return air is exhausted instead of the normal recirculation. A dry bulb economizer compares the outside air temperature to a fixed value, selecting outside air whenever it is below the switchover point.
ENTHALPY

An enthalpy control strategy uses a more sophisticated decision-making algorithm than an economizer. The enthalpy, or "total heat" content of both the outside air and the return air is determined by measuring the dry bulb temperature and the relative humidity of each air stream. The air stream having the lowest enthalpy is selected for use. This allows the enthalpy economizer control strategy to achieve greater savings by taking advantage of the outside air stream a greater portion of the time.

The evaluation of economizer and enthalpy control strategies is a complex process requiring many calculations. It is best accomplished using computer simulation. The Standard EMCS Energy Savings Calculations Manual describes both recommended computer techniques and a manual calculation procedure to approximate these savings.

VENTILATION AND RECIRCULATION

The thermal load imposed by outside air used for ventilation may constitute a substantial percentage of the total heating and cooling requirements for a facility, depending on the geographical location. This strategy controls the outside air dampers when the introduction of outside air would impose a thermal load and the building is unoccupied. This strategy would be used during warm up or cool down cycles prior to occupancy of the building and would also apply in certain facilities that require maintenance of environmental conditions for proper operation of electronic equipment, even though the building is unoccupied. During those times, the outside air dampers would be closed.

The evaluation of this strategy is also beyond the scope of this manual. The Standardized EMCS Energy Savings Calculations Manual contains a recommended procedure for evaluating this strategy.
HOT DECK/COLD DECK TEMPERATURE RESET

Mechanical systems such as dual duct systems and some multizone systems use a parallel arrangement of heating and cooling coils commonly referred to as hot and cold decks for the purposes of providing heating and cooling mediums simultaneously. Generally speaking, both heated and cooled air streams are mixed to satisfy the individual space thermal requirements. In the absence of optimization controls, these systems can waste energy because the final space control merely mixes the two air streams to produce the desired result. While the space conditions may be acceptable, the greater the difference between the temperatures of the two streams, the more inefficiently the system will operate. This strategy can select the individual areas with the greatest heating and cooling requirements, establish the minimum necessary hot deck and cold deck temperatures based on these extremes, and minimize the inefficiency of the system. The goal is to reduce the temperature difference between the two air streams to the minimum value which will still meet the space conditions.

A variation of the hot and cold deck multizone system is the air handler equipped with a cold deck and a bypass section at the mechanical system and individual heating coils in the reheat position downstream from the unit. The system operates with a constant cold deck temperature which is, in turn, mixed with the bypass air in an effort to satisfy individual zone requirements. Air supplied at temperatures below the individual space requirements is elevated in temperature by the reheat coil in response to signals from an individual space thermostat. Selection of the space with the greatest cooling requirements and resetting the cold deck discharge temperature in response to these requirements minimizes the energy used for reheat. Again the strategy is to minimize the temperature differences.

CHILLED WATER TEMPERATURE RESET

The energy required to generate chilled water in a reciprocating or centrifugal electric driven refrigeration machine is a function of a number of equipment characteristics including the temperature of the chilled water.
leaving the machine. Because the refrigerant suction temperature is a direct function of the leaving water temperature, the higher the two temperatures, the lower the energy input per ton of refrigeration. Chilled water temperatures are selected for peak design times and, in the absence of strict humidity control requirements, can usually be elevated during most operating hours. Depending on the operating hours, size of the equipment, and configuration of the system, energy savings can be effected by resetting the chilled water temperature to satisfy the greatest cooling requirements. Generally, this determination is made by the position of the chilled water valves on the various cooling systems. The positions of the control devices supplying the various cooling coils are monitored and the chilled water temperature is elevated until at least one control device is in the maximum position. Other control schemes may be used to satisfy different system configurations. Care must be taken not to exceed the chiller manufacturer's recommended limits when applying this strategy.

CHILLER DEMAND LIMIT

Centrifugal water chillers are generally equipped with a manually adjustable control system which limits the maximum current, and thus power, the machine may use. An interface between the control device and this control circuit allows the controller to reduce the limit setting in a load shedding situation and thus reduce the electric demand without completely shutting down the chiller. The method of accomplishing this function varies with the specific manufacturer of both the water chiller and the controller. The principle of operation is the same, however. When the chiller is selected for load shedding, a single stop signal is transmitted to the interface which then reduces the chiller limit adjustment by a fixed amount. **EXTREME CAUTION MUST BE EXERCISED WITH APPLICATION OF THIS STRATEGY.** Often, the actual setting of the chiller limit adjustment is not resettable or even detectable by the controller. Incorrect interface and control can cause the refrigeration machine to operate in a surge condition, ultimately causing considerable damage to the equipment.
Another parameter affecting the energy input to a refrigeration system is the temperature of the condenser water entering the machine. Conventionally, heat rejection equipment is designed to produce a specified condenser water temperature such as $85^\circ$ at peak wet bulb temperatures. In many instances, automatic controls are provided to maintain this specified temperature at conditions other than peak design. To optimize the performance of the condenser water system, however, these controls can be reset when outdoor temperatures will produce lower condenser water temperature. Where applicable, this strategy will reduce the energy input to the refrigeration machine.

All control strategies which affect chiller operation require extreme caution in their application to avoid damage to the equipment. The complexity and interrelation of these strategies puts them outside the scope of this manual. For further information consult the *Standardized EMCS Energy Savings Calculations Manual*. 

12.
IV. SAVINGS ANALYSIS

The first step in improving a building's energy performance is a physical survey of existing conditions. This survey may range from a simple walk through a small building to a detailed study for a large, mechanically complex building. However, all surveys require a certain minimum amount of information. The building's characteristics and operating schedule should be determined, paying special attention to areas such as computer rooms which require special conditions. In addition, the existing mechanical plant should be carefully surveyed to determine what systems are present. The equipment should be studied paying particular attention to the presently installed controls. At this time, all defective existing controls should be identified and repaired. No purpose is served in adding additional devices to a defective control system.

In the case of larger, more complex buildings, the survey should identify the equipment serving the various "zones" of the building. Occupancy schedules for each of these zones should be determined if there is a variation. Energy consumption records should be obtained wherever possible for study and evaluation. Patterns in the facility's energy consumption may point to energy conservation opportunities. Procedures and guidelines for performing such a survey may be found in the Standardized EMCS Energy Savings Calculations Manual and in manuals available from the commercial controls firms.

Armed with the survey data, the second step in the analysis procedure is to select control strategies appropriate to the installed equipment. Not all strategies are applicable to every mechanical system. In addition, operating constraints of the facility may eliminate some that are physically possible. Normally Scheduled Start/Stop and Optimum Start/Stop can be applied to all systems. Night Setback and Setup are also generally applicable. The amount of setup and setback will depend on the building's mission. The applicability of other strategies will depend on the mechanical systems present. Engineering judgement must be exercised to select the appropriate strategies for each building. Additional guidance in selecting appropriate strategies may be obtained from the publications listed in Appendix A, Table A.3.
The third step in the analysis is an estimation of the energy and cost savings associated with the control strategies being considered. Control strategies can be considered and analyzed on an individual basis. This approach to analysis allows a standard evaluation procedure to be developed for each strategy. These standard procedures may then be applied to various mechanical systems. Using the procedures outlined in this guide, estimates of the possible energy savings may be obtained for the most common control strategies. These potential energy savings and information on the cost of energy at a given location will yield the potential cost savings of a proposed control strategy.

One caution must be observed when using these procedures. Because each analysis is considered independently, no effort is made in the procedures to account for the interactive effects of one strategy on another. Engineering judgement and common sense must be employed when estimating savings for systems for which more than one strategy is being considered.

An estimate of the costs of implementing the identified control strategy is just as important as estimating the energy savings. This Guide contains pricing information for equipment obtained from various manufacturers. All prices represent quotes obtained for a base unit to an end user, quantity of one, and were valid as of August 1981. Because of the rapidly changing price structure of these devices, these prices should be used only for preliminary calculations. Local equipment representatives should be contacted for current pricing information as part of the project planning. An allowance for installation labor and other job conditions will also be required.

This information must be evaluated in a logical manner to allow intelligent decisions to be made on the allocation of monetary resources. The Energy Conservation Investment Program (ECIP) economic analysis procedure meets these requirements. An ECIP analysis produces three indices of merit: the E/C ratio (millions of BTU saved per thousand dollars of investment); the S/I ratio (life cycle dollar savings divided by the life cycle costs); and the simple payback period. These criteria may be used to evaluate, and rank alternative projects and to allocate funds for their implementa-
tion. The ECIP analysis procedure is designed to accommodate all types of energy conservation projects. The full analysis procedure is far more complicated than is warranted by the scope of the average project addressed by this manual. As a result, a simplified economic analysis procedure for control projects has been derived from the full ECIP Guidelines. Instructions for the simplified analysis for controls may be found in Appendix B.

Procedures for estimating the savings resulting from implementation of selected control strategies are presented in the remaining pages of this section. The energy savings aspects of these strategies are identified and a method of estimating these savings is identified. Not all strategies are discussed in this section as some require complex calculations or computer techniques to evaluate. For information on these strategies, consult the Standardized EMCS Energy Savings Calculations Manual.

Values for the various constants used in the equations presented in this manual and additional information may be found in Appendix A of this volume.

Scheduled Start/Stop

The savings attributable to this function are composed of three elements - the savings of heating energy during unoccupied hours, the reduction in ventilation air, and the shutdown of constant auxiliary loads such as fans and pumps. Each of these components must be estimated separately and then added to produce the savings attributable to this function.

Energy savings during unoccupied hours of the heating season are primarily the heating energy saved by reducing the space temperature and eliminating the ventilation air.
These savings are estimated using the following equation:

Heating BTUs saved = 
(Building Thermal Transmission Factor) x (Building Surface Area) 
× (Night Time Temperature Reduction) x (Hours/Week Temperature is Reduced) x (Weeks/Year in Heating Season)

The yearly heating energy savings from ventilation reduction may be estimated using the following equation:

Heating BTUs Saved = 
(Additional Hours/Week Equipment will be Off) x (Weeks/Year in Heating Season) x (Unit Capacity in 1000's of CFM) x (Percent of Outside Air) x (A Conversion Factor of 1.08)* x (Space Temperature - Average Outside Temperature)

*This factor has the units \( \text{MIN BTU} \) \( \frac{\text{hr ft}^3}{\text{oF}} \)

Yearly Cooling savings are estimated in a similar fashion:

Cooling BTUs saved/year = 
(Additional Hours/Week Equipment will be Off) x (Unit Capacity in 1000 CFM) x (Percent Outside Air) x (BTUs/Year of Required Cooling Energy)

Auxiliary savings result from turning off various motors when the equipment is not functioning. These savings are in kilowatt hours and are estimated as follows:

Auxiliary Savings = 
(Additional Hours/Week Equipment is Off) x (Weeks/Year Equipment is used) x (A Conversion Factor of .8)*

*The value .8 is a worst case power factor for an electric motor
Optimum Start/Stop

After a period of reduced temperature the heating system must be started prior to occupancy to bring the space to normal conditions. Simple scheduled operation provides enough time to meet the demands of the worst case situation. Optimum start/stop will automatically adjust the starting time of the heating equipment to provide the desired space conditions with a minimum of equipment operation. The savings result from a decrease in the electrical consumption of auxiliary equipment and an increased setback time. This time interval varies from day to day but is estimated to average 1/2 hour per day.

Later start of the equipment will reduce the amount of outside air which must be conditioned. The ventilation savings is only credited for the heating season as early morning temperatures are usually quite cool during the cooling season. The later start will also reduce the energy consumed by auxiliary equipment.

The equations used to estimate these savings are basically the same as for Time Scheduled Operation.

Heating BTUs Saved =
\[(2.5 \text{ additional Hours/Week of Equipment off Time}) \times \]
\[(\text{Weeks/Year in Heating Season}) \times (\text{Unit Capacity in 1000's of CFM}) \times (\text{Percent of Outside Air}) \times (A \text{ Conversion Factor of } 1.08)^* \times (\text{Space Temperature} - \text{Average Outside Temperature})\]

*This factor has the units MIN BTU
\[\frac{\text{Hr ft}^3 \text{ of}}{\text{OF}}\]

Auxilliary Savings =
\[(2.5 \text{ Additional Hours/Week of Equipment off Time}) \times \]
\[(\text{Weeks/Year Equipment is used}) \times (A \text{ Conversion Factor of } .8)^*\]

*The value .8 is a worst case power factor for an electric motor.
Duty Cycling

Duty cycling HVAC equipment saves energy in the same manner as scheduled operation. Stopping equipment operation eliminates the energy consumption of the auxiliary equipment and the need to heat or cool outside air during the off time. The reduced hours of operation will depend upon the area being served, the weather conditions and other factors, but will usually be in the range of 15-25% of the normal operating hours. The savings for the heating season, the cooling season, and the auxiliary equipment are each estimated separately and added to obtain the savings attributable to this function.

The hours/week equipment is cycled off is a function of the percent off time during normal occupied hours. It is calculated as:

\[
\text{Hours/Week cycled off} = (\text{Hours/Week of normal operation}) \times (\% \text{ off Time})
\]

The optimum \% off time must be determined by experiment and will vary from one application to another and may change according to season, but as a general rule of thumb, 15 to 25% is a good estimate.

Heating BTUs Saved =

\[
(Hours/Week cycled off) \times (Weeks/Year in Heating Season) \times (\text{Unit capacity in 1000's of CFM}) \times (\text{Percent of outside air}) \times (\text{A Conversion Factor of 1.08}) \times (\text{Space Temperature - Average Outside Temperature})
\]

*This factor has the unit \text{MIN BTU Hr Ft}^3 \text{IF}*

Auxiliary Savings =

\[
(Hours/Week cycled off) \times (Weeks/Year equipment is used) \times (\text{A Conversion Factor of .8})
\]

*The value .8 is a worst case power factor for an electric motor*

18.
Hot Deck/Cold Deck Reset

Many systems utilizing a hot and cold deck distribution system rely upon fixed coil discharge temperatures. Control is achieved at the space level by mixing the two air streams in proportion to the load, resulting in considerable energy waste. A coil discharge temperature which is reset from outside air temperature will reduce this but still results in a significant amount of mixing.

A controller capable of Hot Deck/Cold Deck Reset changes the discharge temperature of the coils in response to the worst space load. The optimum point is when the hot deck is just warm enough to satisfy the coldest space and the cold deck is no cooler than necessary to satisfy the warmest space's requirements. This point will minimize the mixing of air and thus reduce the energy consumption of the system.

The savings attributable to this function are dependent upon the average amount the discharge temperatures can be altered. This is a difficult value to estimate accurately as it depends on a large number of variables but, lacking any other input, a reasonable estimate of the savings may be obtained by using an average hot deck reset of 2°F during the heating season and 1°F during the cooling season. For the cold deck, a reasonable value is 1.5 BTU/Pound - a reset of approximately 2.5°F.

Heating BTUs Saved =

\[
\begin{align*}
((\text{Unit capacity in 1000's of CFM}) \times (\% \text{ of flow through hot deck}) \\
\times (A \text{ Conversion Factor of 1.08}^*) \times ((\text{Summer Reset}) \times (\text{Weeks/Year of Cooling Season}) \\
\times (\text{Winter Reset}) \times (\text{Weeks/Year of Heating Season}) \times (\text{Hours/Week of operation})
\end{align*}
\]

*This factor has the units MIN BTU

\[
\text{Hr Ft}^3 \text{ oF}
\]

19.
Cooling BTUs Saved =
(Unit capacity in 1000's of CFM) x (% of flow through cold deck)
 x (Reset) x (A Conversion Factor of 4.5) x (Weeks/Year of cooling season) x (Hours/Week of operation)

This factor has the units \( \frac{\text{MIN LB}}{\text{Hr Ft}^3} \)

If no better estimate of the flows through the hot and cold decks is available use 50%.
V. MICROPROCESSOR CONTROLLER SURVEY

The recent advances in solid state technology and dramatic decreases in the cost of electronics has resulted in the increased application of digital technology to control devices. The increased capability of these new digital controllers has made many of the more sophisticated control functions available to the energy conservation engineer. One element of this study was a survey of available digital control devices.

A survey of a field growing as rapidly as this can never be complete. Vendors and products are constantly entering the market. Rather than trying to present an exhaustive survey, effort was concentrated on obtaining data on a representative sample of controllers spanning the range of complexities and capabilities offered. A summary of the results of this survey is presented on the following pages as Tables 1 through 7.

For ease of use the data has been organized into six broad divisions based on functional capabilities. Table 1 is a guide to the capabilities of each group. Tables 2 through 7 summarize the characteristics of the specific devices within that class. This approach allows one to quickly identify the class of controller of interest, select some typical devices and locate more detailed information.
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TIMECLOCKS AND THERMOSTATS WITH TIMECLOCKS

The controllers in this class are primarily timing devices capable of performing scheduled start/stop. The thermostats with timeclocks are also capable of night setback.

Table 2 summarizes the capacity of the timeclocks as follows:

No. of Setpoints/Load means the number of different temperature settings at which the thermostat may be set for each load. At least two are necessary for night setback.

No. of Schedules/Load means the number of different daily on/off schedules per load for which the timeclock can be programmed.

No. of Switchovers/Day means the total number of on or off switches which may be scheduled for a load in one day.
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<th>120 V</th>
<th>NO. OF LOADS CONTROLLED</th>
<th>NO. OF SCHEDULES/LOAD</th>
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365 day calendar and 12 holiday capacity available as a $100 option.

Unit optimizes start/stop times based on outside air temperature.

Expandable to 12 control circuits.

May be used to duty cycle equipment.

Unit changes setting based on occupancy.
## Table 2

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<th>24 VOLS A.C., N</th>
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**BASIC 4 LOAD MODEL**

ADDITIONAL LOAD MODULES ARE $365.

EXPANDABLE IN INCREMENTS OF 4 TO 16 TOTAL AT

$192 to $600 PER WEEK TOTAL.

** TO BE ADDED TO EXISTING THERMOSTAT AND REQUIRES EXTERNAL TIMECLOCK

DUTY CYCLING AVAILABLE AS OPTION.
DEMAND LIMITERS AND DUTY CYCLERS

The control equipment in this class was selected because their primary functions are either demand control or duty cycling. Most are also capable of performing programmed start/stop of equipment. The control panels are generally contained in a lockable cabinet which is designed for mounting on a wall.

The "Soft Restore" column found in Table 3 designates those controllers which are capable of sequencing the start-up of multiple loads after a power outage or after they have been shed for demand control. The controllers have a variety of means of displaying information. Most display the loads which have (or don't have) power by means of indicator lights. The "Single Display: Select. Func." refers to a meter or digital readout which registers selectable functions chosen from a dial or keypad. "No. of Adjustable Setpoints" refers to the number of different KW demand limits which may be set for different time periods of the day.

27.
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<tr>
<th>MANUFACTURER &amp; MODEL NO.</th>
<th>LOAD IN MARRIOT</th>
<th>GIVE CIRCUIT</th>
<th>TROUBLE SHOOTER</th>
<th>USER OPTIONS</th>
<th>SELECT FACT.</th>
<th>VISIBLE DISPLAY</th>
<th>OR DISPLAY</th>
<th>OUTPUT</th>
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<th>AMOUNT NO. OF LONG</th>
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Optional panels can expand capabilities.

4 LOADS DUTY CYCLED 4 LOADS FOR DEMAND CONTROL Expandable in Increments of 2 at $161/increment.
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<th>FIXED INTERVAL</th>
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Expandable in increments of 8 at $110 per increment.
## Demand Limiters and Duty Cylers

### Table 3

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<th>Manufacturer &amp; Model No.</th>
<th>Load Shedding</th>
<th>Duty Cycling</th>
<th>Alarm Indication</th>
<th>Fixed Internal</th>
<th>Sliding Window</th>
<th>Type of Duty Compatible</th>
<th>Single Display: Select Point</th>
<th>% of Maximum Demand</th>
<th>Current In Value</th>
<th>No. of Adjustable Setpoints</th>
<th>No. of Loads in Basic Unit</th>
<th>Base Price</th>
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*REMOTE TELECOMMUNICATIONS OPTION AVAILABLE $1190*
EQUIPMENT CONTROLLERS

Equipment controllers are devices which optimize the startup and/or operation of various kinds of HVAC equipment. Many of these controllers also perform a night setback function. The control panels are generally contained in a lockable cabinet which is designed for wall mounting.

The "Control Point Adjustment" column found in Table 4 designates those controllers capable of changing the setpoint temperature of a system based on data acquired by the controller, such as chilled water reset of a chiller based on outside temperature. "Load Limiting" refers to capability of some chillers to perform a Chiller Demand Limit Strategy as described in Section III.
## Table 4: Equipment Controllers

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<tr>
<th>Manufacturer &amp; Model No.</th>
<th>High Set/Thermp</th>
<th>External Thermostat</th>
<th>Control Point Adjustment</th>
<th>Analog</th>
<th>Contact Closures</th>
<th>Electronic</th>
<th>115 V Volts</th>
<th>24 Volts</th>
<th>Base Price</th>
<th>Equipment to Be Controlled</th>
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<td>$675</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$1605</td>
<td>Price depends on number of stages capable of 4 to 10.</td>
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<td>$2750</td>
<td>Centrifugal Chiller</td>
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<td>SYSTEM 1500</td>
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<td>○</td>
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<td>$4800</td>
<td>Multiple chiller controlled by multiple units.</td>
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<td>$6750</td>
<td>Basic module - requires sensors &amp; outputs appropriate to equipment controlled.</td>
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<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td></td>
<td>$9375</td>
<td>Multiple chillers will also start air handlers. Price varies with configuration.</td>
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BUILDING CONTROLLERS

This class of equipment represents devices incorporating several functions in a single panel. These devices generally include the functions of a timeclock and a demand limiter/duty cycler as a minimum. They may also include some pre-defined functions that would otherwise require an equipment controller or a programmable controller to implement. They have been termed building controllers because they are generally configured to monitor and control a sufficient number of points to control an entire building's equipment. Although these devices are designed to stand alone, some incorporate computer interfaces and may be used to gather and report data to a central control device.
## Building Controllers

### Table 5

<table>
<thead>
<tr>
<th>MANUFACTURER &amp; MODEL NO.</th>
<th>START SETBACK</th>
<th>PROGRAMMED START/STOP</th>
<th>LOAD MODULATION</th>
<th>manual override</th>
<th>PROGRAM MEMORY</th>
<th>ANALOG INPUTS</th>
<th>STRATEGY 1/0</th>
<th>BASE I/O CAPACITY</th>
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- 24 Hour Battery Backup
- Available in models with from 24 to 124 I/O Channels
- 12 time channels 12 load shed channels
- System uses existing AC wiring as transmission media.
- 16 channel unit available for $3175. Remote communications option $350.
- Prices for basic CPU and 8 output module additional I/O and analog modules extra.
<table>
<thead>
<tr>
<th>MANUFACTURER &amp; MODEL NO.</th>
<th>NIGHT SETBACK</th>
<th>PROGRAMMED START/STOP</th>
<th>DUTY CYCLE</th>
<th>DEMAND MONITORING</th>
<th>LOAD SHEDDING</th>
<th>MANUAL OVERRIDE</th>
<th>PROGRAM BACKUP</th>
<th>ANALOG INPUTS</th>
<th>ANALOG OUTPUTS</th>
<th>BINARY 1/0</th>
<th>BASE 1/O CAPACITY</th>
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- Designed to monitor entire building's heating operation.
- Designed for control of building's hot water system.
- Computer interface available.
- USES POWER LINE CARRIER TRANSMISSION
- May be expanded in increments of 4 to 16 I/O channels.
- Solution 1600 is the same unit but capable of 1600 channels.
## TABLE 5

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<th>MANUFACTURER &amp; MODEL NO.</th>
<th>NIGHT SETBACK</th>
<th>PROGRAMMED START/STOP</th>
<th>DUTY CYCLE</th>
<th>DEMAND MONITORING</th>
<th>LOAD SHEDDING</th>
<th>MANUFACTURED OVERRIDE</th>
<th>PROGRAM BACKUP</th>
<th>ANALOG INPUTS</th>
<th>ANALOG OUTPUTS</th>
<th>BINARY I/O</th>
<th>BASE I/O CAPACITY</th>
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</table>

*48 HOUR BATTERY BACKUP

*24 HOUR BATTERY BACKUP

Power line carrier available.

*10 DAY BATTERY BACKUP

*Programs reside in unit control modules

This is a complete control system and price vary depending on number & type of units installed.
PROGRAMMABLE CONTROLLERS

Most of the programmable controllers surveyed were designed with the process control market in mind. Most use a ladder diagram type programming language. The size and capabilities of those listed in Table 6 are such that they could be programmed for energy management functions. Installation of these devices is moderately complex and would require a qualified electrician.

Most of these controllers are modular in design allowing easy expansion. Table 6 breaks down the expandability of the controllers by basic unit (additional modules or cards may be inserted into the basic electrical panel) and by system (additional panels or racks may be added to the basic unit). Some of the controllers are part of a manufacturer's equipment family, allowing interchange of equipment parts among different models.
<table>
<thead>
<tr>
<th>MANUFACTURER &amp; MODEL NO.</th>
<th>BASIC UNIT</th>
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<th>PRINTER</th>
<th>DISK</th>
<th>PORTABLE PROGRAMMER</th>
<th>TEST SIMULATOR</th>
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<th>MEMORY ACCESSIBLE</th>
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*Program stored in EPROM
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MICRO SYSTEMS

This category of equipment covers a broad range of devices, from single board dedicated controllers to small distributed processing networks. This group overlaps both programmable controllers and full scale EMCS installations. The primary distinguishing characteristics of these devices is the greater flexibility of programming and the use of higher level languages. The small system is more "computer-like" than a programmable controller. As the complexity of the small system increases the class overlaps the bottom end of the true EMCS.

Small systems give the energy conservation engineer the flexibility to implement innovative control strategies. The expandability and modular nature of these devices allows the creation of a small distributed system. With proper software this system could then be tied into a full scale EMCS.
<p>| MANUFACTURER &amp; MODEL NO. | CPU | RAME | LEM | POWER LINE INTERFACE | TYPICAL ACCESSORIES | TYPICAL ACCESSORIES | SERIAL PORT | STANDARD LANGUAGE | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | SERIAL PORT | BASE PRICE |
|--------------------------|-----|------|-----|-----------------------|--------------------|--------------------|-------------|-------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| ADVANCED LOGICAL SOLUTIONS TPC 2000 |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             | 26K          | 26K          |             |             |             |             |             |             | $2475       |
| AMI SYSTEM SOLVER 2      |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $7,000      |
| ANALOG DEVICES MAGNUS II |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $9,900      |
| ANSWER CONTROLS SUREKEEPER |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $12,000     |
| SUREKEEPER/J             |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $8,500      |
| SUNLOGGER                |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $14,200     |
| AC 256                   |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $8,600      |
| APPLIED SYSTEMS ENERGY CONTROL SYSTEM |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $2,000      |
| ATLANTIC ENERGY TECH. AST 816 |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | $3,950      |
| BARBER COLEMAN MICRO/8000 |     |     |     |                       |                    |                    |             |                  |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             |             | 16          |</p>
<table>
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### MICRO SYSTEMS

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- Accessory devices: Off, TTY, Phone, R/I-9 In, E/B
- Additional comments: Expandable to 30 per panel, +Program stored in EPROM.
APPENDIX A
REFERENCE DATA
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<th>BUILDING DESCRIPTION</th>
<th>TTF VALUE</th>
<th>EXTERIOR WALL CONSTRUCTION</th>
<th>FENESTRATION CONSTRUCTION</th>
<th>ROOF CONSTRUCTION</th>
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<td>Low-rise Apartment Building</td>
<td>.48</td>
<td>1/2&quot; lapped wood siding; 1/2&quot; plywood sheathing; 2&quot;x4 stud framing (16&quot; c.c.); 2-1/4&quot; fiberglass insulation, 1/2&quot; Gypsum wallboard.</td>
<td>Single-strength sheet; 30% sidewalls; 0% endwalls.</td>
<td>Asphalt shingles 1/2&quot; plywood sheathing, 3-1/2&quot; fiberglass insulation; 1/2&quot; Gypsum wallboard; ventilated attic; roof slope 3 in 12.</td>
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<td>Low-rise Apartment Building</td>
<td>.77</td>
<td>4&quot; common brick; 1/2&quot; plywood sheathing; light framing; no insulation end walls.</td>
<td>Single-strength sheet; 30% sidewalls; 0% end walls.</td>
<td>Asphalt shingles; 1/2&quot; plywood sheathing; 3&quot; fiberglass insulation; 1/2&quot; Gypsum wallboard; ventilated attic; roof slope 3 in 12. 4-ply built-up roofing with gravel; 2&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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<td>Office Building</td>
<td>.69</td>
<td>6&quot; precast concrete panels.</td>
<td>1/4&quot; plate; 30% all walls.</td>
<td>Metal deck; 4&quot; poured concrete roofing; structural steel framing; 1/2&quot; softwood hung ceiling. 4-ply built-up roofing with gravel; 2&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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<tr>
<td>Office Building</td>
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<td>1&quot; insulated sandwich panel with aluminum mullions; structural steel framing.</td>
<td>1/4&quot; plate; 50% all walls.</td>
<td>Metal deck; 4&quot; poured concrete roofing; structural steel framing; 1/2&quot; softwood hung ceiling. 4-ply built-up roofing with gravel; 2&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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<td>Retail Store</td>
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<td>12&quot; concrete block, painted both sides</td>
<td>1/4&quot; plate; 60% South wall; 0% all other walls.</td>
<td>4-ply built-up roofing with gravel; 2&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board. 4-ply built-up roofing with gravel; 2&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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<td>Single-strength sheet; 20% all walls.</td>
<td>4-ply built-up roofing with gravel; 1&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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<td>4&quot; common brick, no insulation, 4&quot; concrete</td>
<td>Single-strength sheet; 20% all walls.</td>
<td>4-ply built-up roofing with gravel; 1&quot; rigid insulation; steel decking; open web joists; 1/2&quot; soft-board.</td>
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50
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<th>WINTER LENGTH IN WEEKS</th>
<th>SUMMER AVG. DB</th>
<th>SUMMER LENGTH IN WEEKS</th>
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<th>$10^6$ BTU* OUTSIDE AIR COOLING LOAD</th>
<th>$10^6$ BTU* ECON. MIZER SAVINGS</th>
<th>EQUIV. FULL LOAD CLG. HOURS</th>
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* 1000 cfm to 55°F for cooling season, per hour.
@ 1000 cfm to 68°F for heating season, per hour.
### TABLE A.2 CONT'D

**WEATHER DATA**

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<th>WINTER LENGTH IN WEEKS</th>
<th>SUMMER AVG. DB TEMP</th>
<th>SUMMER LENGTH IN WEEKS</th>
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<th>EQUIV. FULL LOAD CLG. HOURS</th>
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@ 1000 cfm to 68°F for heating season, per hour.
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* 1000 cfm to 55°F for cooling season, per hour.
@ 1000 cfm to 68°F for heating season, per hour.
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* 1000 cfm to 55°F for cooling season, per hour.
@ 1000 cfm to 68°F for heating season, per hour.
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* 1000 cfm to 55°F for cooling season, per hour.  
@ 1000 cfm to 68°F for heating season, per hour.
### Table A.2 Cont'd

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* 1000 cfm to 55°F for cooling season, per hour.

** 1000 cfm to 68°F for heating season, per hour.
### TABLE A.2 CONT'D

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<td>0.136</td>
<td>2.236</td>
<td>0.214</td>
<td>2065 - 2630</td>
</tr>
</tbody>
</table>

* 1000 cfm to 55°F for cooling season, per hour.

@ 1000 cfm to 68°F for heating season, per hour.
<table>
<thead>
<tr>
<th>STATE</th>
<th>CITY</th>
<th>WINTER</th>
<th></th>
<th></th>
<th>SUMMER</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AVG. DB</td>
<td>IN</td>
<td>AVG. DB</td>
<td>IN</td>
<td>10^6 BTU</td>
<td>10^6 BTU</td>
<td>10^6 BTU</td>
<td>EQUIV. FULL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>LENGTH</td>
<td>WEEKS</td>
<td>LENGTH</td>
<td>WEEKS</td>
<td>OUTSIDE AIR</td>
<td>OUTSIDE AIR</td>
<td>ECONOMIZER</td>
<td>LOAD CLG.</td>
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<td></td>
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<td></td>
<td>TEMP</td>
<td></td>
<td>TEMP</td>
<td></td>
<td>HEATING LOAD</td>
<td>COOLING LOAD</td>
<td>SAVINGS</td>
<td>HOURS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTAH</td>
<td>Salt Lake City</td>
<td>36.5</td>
<td>30.2</td>
<td>79.0</td>
<td>19.9</td>
<td>1.027</td>
<td>0.503</td>
<td>0.307</td>
<td>740 - 940</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wendover</td>
<td>36.7</td>
<td>27.7</td>
<td>79.7</td>
<td>21.6</td>
<td>0.936</td>
<td>0.601</td>
<td>0.322</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VERMONT</td>
<td>Burlington</td>
<td>31.3</td>
<td>33.1</td>
<td>74.8</td>
<td>16.7</td>
<td>1.132</td>
<td>0.449</td>
<td>0.307</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIRGINIA</td>
<td>Richmond</td>
<td>40.9</td>
<td>20.9</td>
<td>77.8</td>
<td>26.8</td>
<td>0.612</td>
<td>1.213</td>
<td>0.302</td>
<td>1010 - 1285</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roanoke</td>
<td>39.8</td>
<td>23.4</td>
<td>78.9</td>
<td>26.3</td>
<td>0.713</td>
<td>0.916</td>
<td>0.346</td>
<td>940 - 1200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WASHINGTON</td>
<td>Seattle</td>
<td>43.7</td>
<td>37.3</td>
<td>70.9</td>
<td>9.4</td>
<td>0.979</td>
<td>0.315</td>
<td>0.503</td>
<td>580 - 735</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spokane</td>
<td>36.6</td>
<td>34.8</td>
<td>76.1</td>
<td>15.6</td>
<td>0.990</td>
<td>0.705</td>
<td>0.309</td>
<td>590 - 755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEST VIRGINIA</td>
<td>Charleston</td>
<td>38.4</td>
<td>23.7</td>
<td>78.4</td>
<td>26.1</td>
<td>0.758</td>
<td>0.697</td>
<td>0.253</td>
<td>910 - 1159</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clarksburg</td>
<td>36.5</td>
<td>29.1</td>
<td>75.2</td>
<td>22.5</td>
<td>0.990</td>
<td>0.705</td>
<td>0.309</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WISCONSIN</td>
<td>Madison</td>
<td>31.5</td>
<td>30.7</td>
<td>76.9</td>
<td>20.2</td>
<td>1.210</td>
<td>0.697</td>
<td>0.253</td>
<td>710 - 900</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green Bay</td>
<td>31.1</td>
<td>33.0</td>
<td>75.2</td>
<td>17.5</td>
<td>1.312</td>
<td>0.581</td>
<td>0.270</td>
<td>565 - 715</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Milwaukee</td>
<td>33.0</td>
<td>30.0</td>
<td>77.0</td>
<td>20.9</td>
<td>1.134</td>
<td>0.774</td>
<td>0.248</td>
<td>670 - 855</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 1000 cfm to 55°F for cooling season, per hour.
@ 1000 cfm to 68°F for heating season, per hour.
### TABLE A.2 CONT'D

#### WEATHER DATA

<table>
<thead>
<tr>
<th>STATE</th>
<th>CITY</th>
<th>WINTER AVG. DB</th>
<th>WINTER LENGTH IN WEEKS</th>
<th>SUMMER AVG. DB</th>
<th>SUMMER LENGTH IN WEEKS</th>
<th>$10^6$ BTU* OUTSIDE AIR HEATING LOAD</th>
<th>$10^6$ BTU* OUTSIDE AIR COOLING LOAD</th>
<th>$10^6$ BTU* ECONOMIZER SAVINGS</th>
<th>EQUIV. FULL LOAD CLG. HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>WYOMING</td>
<td>Casper</td>
<td>33.6</td>
<td>33.5</td>
<td>78.3</td>
<td>19.2</td>
<td>1.245</td>
<td>0.476</td>
<td>0.314</td>
<td>605 - 770</td>
</tr>
<tr>
<td></td>
<td>Cheyenne</td>
<td>34.4</td>
<td>33.9</td>
<td>76.0</td>
<td>18.3</td>
<td>1.230</td>
<td>0.438</td>
<td>0.364</td>
<td>580 - 740</td>
</tr>
<tr>
<td></td>
<td>Rock Springs</td>
<td>31.7</td>
<td>35.3</td>
<td>75.3</td>
<td>16.7</td>
<td>1.384</td>
<td>0.354</td>
<td>0.334</td>
<td>---</td>
</tr>
</tbody>
</table>

* 1000 cfm to 55°F for cooling season, per hour.
@ 1000 cfm to 68°F for heating season, per hour.
TABLE A.3
REFERENCE PUBLICATIONS

   Available from: Honeywell Building Services Division
   Dept. 80078 Honeywell Plaza
   Minneapolis, Minnesota 55408

   Available from: Superintendent of Documents
   U.S. Government Printing Office
   Washington, D.C. 20402
   Stock number 041-018-00080-1

   Available from: National Electrical Manufacturers Association
   2101 L Street, N.W.
   Washington, D.C. 20037


   Available from: Johnson Controls, Inc.
   507 E Michigan Street
   P.O. Box 423
   Milwaukee, Wisconsin 53201
APPENDIX B
ECONOMIC ANALYSIS GUIDE
The ECIP Analysis procedure provides a method for evaluating and comparing various energy conservation projects. It produces three values which measure the worth of a project:

1. The E/C ratio - The ratio of the yearly energy savings to the costs of the proposed project.
2. SIR (Savings to Investment Ratio) - The ratio of the project's savings to costs.
3. The Payback Period - How long will it take for the project savings to equal its costs.

These figures of merit allow dissimilar projects to be compared on an equal basis.

The ECIP Analysis procedure, because it was designed to accommodate many different types of projects, is somewhat complicated to use. A simplified procedure which produces these same three figures of merit for the control strategies discussed in this manual has been derived from the full ECIP procedure and is presented in this section. Table 3 is a list of the basic assumptions made in preparing this simplified analysis procedure.

Figure 1 is a sample analysis form. Direction for its use are outlined below:

Line 1a - These are the estimated costs for the control equipment and its installation, escalated to the anticipated project start-up time, if appropriate.

Line 1b - Programmable controllers, small systems, and some building controllers require some time to properly program. An allowance for an engineer's time should be included if the programming will be done in-house.
Line 1c  -  Total of all costs associated with this project.

Project Savings

The savings from implementation of a project are estimated by following the procedures described in this manual for the various strategies. Using these savings estimates, entries are made in the appropriate section of the form.

MBTU's of Energy - The quantity of energy in millions of BTU's that will be saved annually if this project is carried out. The energy source, gas, oil, electricity, or coal will depend on the equipment involved. A project can and often does save energy from more than one source.

Cost per MBTU - This is the cost per MBTU actually paid for energy derived from a given source. If the cost of energy is not available on a MBTU basis, the values in Table 1 may be used to convert costs in more conventional units to costs per MBTU.

If the project under consideration will be programmed for other than the current fiscal year, these costs should be escalated to the planned project start time. Table 2 contains projected escalation rates. Enter the costs in the appropriate savings section of Figure 1.

First year annual savings - This is the dollar value of the estimated energy savings for the first year after the project's completion. It is calculated by multiplying the estimated energy savings by the projected energy costs.

Differential escalation present worth factor - This is a constant factor which converts the expected savings due to implementation of the project to its "present worth". The factors on the form are the proper values to use in this analysis. They account for the differences in the projected energy costs of the various sources.
Discounted Savings - This value is the "present worth" of all the savings expected to accumulate during the economic life of the project. It measures the total value of the projected savings in "today's dollars."
FIGURE 1

ECONOMIC ANALYSIS SUMMARY

ACTIVITY & LOCATION

TITLE OF PROJECT

INVESTMENT

1. PROJECT COSTS (Economic life of 15 years)
   a. Project present worth cost ...................... $ _________
   b. Programmer's present worth cost (if necessary) $ _________
   c. Total Project present worth cost (a+b) ........... $ _________
   (Project costs should be escalated to project start-up, if appropriate)

SAVINGS

2. ANNUAL ENERGY SAVINGS:
   KWH:
   a. Equivalent energy: KWH x 0.0116 =
   MBTU's:
   b. Cost per KWH at end of program year .......... $ _________
   c. First year annual dollar savings (KWH x b) ...... $ _________
   d. Differential escalation present worth factor ...... 12.278
   e. Discounted savings (c x d) ..................... $ _________

3. ANNUAL ENERGY SAVINGS
   MBTU's OF COAL:
   a. Cost per MBTU at end of program year ........... $ _________
   b. First year annual dollar savings ................ $ _________
   c. Differential escalation present worth factor .... 10.798
   d. Discounted savings (b x c) ...................... $ _________
4. ANNUAL ENERGY SAVINGS
   MBTU's of Gas
   a. Cost per MBTU at end of program year $
   b. First year annual dollar savings $
   c. Differential escalation present worth factor 13.112
   d. Discounted savings (b x c) $

5. ANNUAL ENERGY SAVINGS
   MBTU's OF OIL
   a. Cost per MBTU at end of program year $
   b. First year annual dollar savings $
   c. Differential escalation present worth factor 13.112
   d. Discounted savings (b x c) $

6. TOTAL FIRST YEAR ANNUAL SAVINGS
   (2c+3b+4b+5b+6c) $

7. TOTAL DISCOUNTED SAVINGS
   (2e+3d+4d+5d+6e) $

8. TOTAL ANNUAL ENERGY SAVINGS
   MBTU (2+3+4+5)

COST ESCALATION

CURRENT COST FY- FY- FY- FY-

Electricity
Coal
Gas
Oil

67A
9. SAVINGS/INVESTMENT RATIO
   (Line 7/Line 1c)............... 

10. ENERGY/COST RATIO
    (Line8/(Line 1c/1000)) ...........

11. PAYBACK PERIOD IN YEARS*
    (Line 1c/Line 7)............... 

   *If payback period exceeds 15 years (assumed economic life),
project will not pay for itself.
### TABLE 1

**ENERGY CONVERSIONS**

For purposes of calculating energy savings, the following conversion factors will be used.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Electric Power</td>
<td>11,600 BTU/kwh</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
<td>138,800 BTU/gal</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
<td>Use average thermal content of residual fuel oil at each specific location.</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>1,031,000 BTU/1000 cu.ft.</td>
</tr>
<tr>
<td>LPG, Propane, Butane</td>
<td>95,500 BTU/gal</td>
</tr>
<tr>
<td>Bituminous Coal</td>
<td>24,580,000 BTU/Short Ton</td>
</tr>
<tr>
<td>Anthracite Coal</td>
<td>28,300,000 BTU/Short Ton</td>
</tr>
<tr>
<td>Purchased Steam</td>
<td>1,390 BTU/lb</td>
</tr>
</tbody>
</table>

### NOTES TO TABLE 1

1. Purchased energy is defined as being generated off-site. For special cases where electric power or steam is purchased from on-site sources, the actual average gross energy input to the generating plant plus distribution losses may be used but in no case shall the power rate be less than 10,000 Btu/kwh or the steam rate be less than 1200 Btu/lb.

2. The term coal does not include lignite. Where lignite is involved, the Bureau of Mines average value for the source field shall be used.

3. Where refuse derived fuel (RDF) is involved, the heat value shall be the average of the RDF being used or proposed.

4. When the average fuel oil heating value is accurately known through laboratory testing for a specific military installation, that value may be used in lieu of the amount specified in paragraph 5a.
5. Full energy credit may be taken for conversion from fossil fuels or electric power to solar, wind, RDF, or geothermal energy less the calculated average yearly standby requirement.
1. **Short Term Escalation**

Use the escalation rates given below for extending costs and benefits in the Economic Analysis to the end of the fiscal year in which the project is programmed if better local data are not available.

<table>
<thead>
<tr>
<th>Description</th>
<th>FY 81</th>
<th>FY 82</th>
<th>FY 83</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design, Construction,</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIOH</td>
<td>7.0%</td>
<td>7.0%</td>
<td>7.0%</td>
</tr>
<tr>
<td><strong>Maint. &amp; Rpr,</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O&amp;M, Salvage</td>
<td>5.6%</td>
<td>5.6%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Coal</td>
<td>10.0%</td>
<td>10.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>14.0%</td>
<td>14.0%</td>
<td>14.0%</td>
</tr>
<tr>
<td>Natural Gas &amp; LPG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity and Demand Charge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction</td>
<td>13.0%</td>
<td>13.0%</td>
<td>13.0%</td>
</tr>
</tbody>
</table>
### TABLE 3

**SIMPLIFYING ASSUMPTIONS**

1. All projects are control projects and therefore have an estimated economic life of 15 years.

2. Projects will not require an allowance for design costs.

3. Projects will have no salvage value.

4. Escalation rates assume a 10% discount rate.

5. Long term differential escalation rates were used to determine the "Differential Escalation Present Worth Factors" used in this analysis. These rates are:

<table>
<thead>
<tr>
<th>Resource</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>5.0%</td>
</tr>
<tr>
<td>Fuel Oil</td>
<td>8.0%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>8.0%</td>
</tr>
<tr>
<td>Electricity &amp; Demand</td>
<td>7.0%</td>
</tr>
</tbody>
</table>

6. Implementation of these projects will not result in labor savings.

7. All projects fall in the Energy Monitoring and Control Systems project category.
GLOSSARY

Algorithm:
A set of well defined rules or procedures for solving a problem or providing an output from a specific set of inputs.

Analog to Digital Converter:
A circuit or device whose input is information in analog form and whose output is the same information in digital form.

Architecture:
The general organization and structure of hardware and software.

ASCII:
American Standard Code for Information Interchange. An 8-bit coded character set to be used for the general interchange of data among information processing systems, communications systems, process control systems, and associated equipment.

Automatic Temperature Control (ATC):
A local loop network of pneumatic or electric/electronic devices which are interconnected to control temperature.

BASIC:
An acronym for Beginners All-Purpose Symbolic Instruction Code, a high-level, English-like programming language used for general applications.

Baud:
A unit of signalling speed equal to the number of discrete conditions, or signal events, per second.
Bit:
An acronym for binary digit. The smallest unit of information which can be represented. A bit may be in one of two states, represented by the binary digits 0 and 1.

Bootstrap:
A technique or device designed to bring a computer into a desired state by means of its own action.

Buffer:
A temporary data storage device used to compensate for a difference in data flow rate or event times, when transmitting data from one device to another.

Bus:
A circuit path (or parallel paths) over which data or instructions are transferred to all points in the computer system. Computers have several separate busses: the data, address, and control busses are those of greatest importance.

Byte:
A group of eight bits.

Central Memory:
Core or semiconductor memory which communicates directly with a CPU.

Central Processing Unit (CPU):
The portion of a computer that performs the interpretation and execution of instructions. It does not include memory or I/O.

Character:
One of a set of elementary symbols which normally include both alpha and numeric codes plus punctuation marks and any other symbol which may be read, stored, or written.
Clock:
A device or a part of a device that generates all the timing pulses for the coordination of a digital system. System clocks usually generate two or more clock phases. Each phase is a separate, square wave pulse train output.

Command Line Mnemonic (CLM):
A computer language consisting of a set of fixed, simplified English commands designed to assist operators unfamiliar with computer technology in operating the equipment.

Command Line Mnemonic Interpreter (CLMI):
Software used to implement the CLM language.

Control Point Adjustment (CPA):
The procedure of changing the operating point of a local loop controller from a remote location.

Control Sequence:
Equipment operating order established upon a correlated set of data environment conditions.

Control Strategy:
A procedure for controlling the operation of heating, ventilating and air conditioning (HVAC) equipment in an energy efficient manner.

Crowbar:
An electronic circuit which can rapidly sense an over voltage condition and provide a solid-state low impedance path to eliminate this transient condition.

Data Environment (DE):
The sensors and control devices connected to a controller from the equipment and systems sampled or controlled.
Data Transmission Media (DTM):
Transmission equipment including cables and interface modules (excluding MODEMs) permitting transmission of digital and analog information.

Deck:
In HVAC terminology, the air discharge of the hot or cold coil in a duct serving a conditioned space.

Demand:
The term used to describe the maximum rate of use of electrical energy averaged over a specific interval of time and usually expressed in kilowatts.

Demultiplexer:
A device used to separate two or more signals previously combined by compatible multiplexer for transmission over a single circuit.

Diagnostic Program:
Machine-executable instructions used to detect and isolate component malfunctions.

Direct Digital Control (DDC):
Sensing and control of processes directly with digital control electronics.

Digital to Analog (D/A) Converter:
A hardware device which converts a digital signal into a voltage or current proportional to the digital input.

Direct Memory Access (DMA):
Provision for transfer of data blocks directly between central memory and an external device.
Disk Storage:
    A bulk storage, random access device for storing digital information. Usually constructed of a thin rotating circular plate having a magnetizable coating, a read/write head and associated control equipment.

Distributed Processing System:
    A system of multiple processors each performing its own task, yet working together as a complete system under the supervision of a central computer, to perform multiple associated tasks.

Download:
    The transfer of digital data or programs from a host computer to another data processing system such as from central computer to microcomputer.

Executive Software:
    The main system program designed to establish priorities and to process and control other programs.

Facility Engineer:
    Person in charge of maintaining and operating the physical plant. In the Navy it is the Public Works Officer.

Fall-Back Mode:
    The pre-selected operating mode of a controller or the operating sequence of each local control loop when the controller to which it is connected ceases to function.

Firmware:
    An instruction set resident in ROM or PROM for accomplishing a special program or procedure.
**FORTRAN:**

An acronym for FORmula TRANslation. A high-level, English-like programming language used for technical applications.

**Hardware:**

Equipment such as a CPU, memory, peripherals, sensors, and relays.

**Initialize:**

To set counters, switches, and addresses to zero or other starting values at the beginning of or at prescribed points in a computer program.

**Input/Output (I/O) Devices:**

Digital hardware that transmit or receive data.

**Interactive:**

Functions performed by a process where the machine prompts or otherwise assists an operator to program the device while it continues to perform all other tasks as scheduled.

**Interpreter:**

A language translator which converts individual source statements into machine instructions by translating and executing each statement as it is encountered.

**Interrupt:**

An external or internal signal requesting that current operations be suspended to perform more important tasks.

**Large Scale Integration (LSI):**

The technology of manufacturing integrated circuits capable of performing complex functions. Devices of this class contain 100 or more logic gates.
**Line Conditioning:**
Electronic modification of the characteristic response of a line to meet certain standards. The characteristics include frequency response, signal levels, noise suppression, impedance, and time delay.

**Line Driver:**
A hardware element which enables signals to be directly transmitted over circuits to other devices some distance away.

**Local Loop Control:**
The controls for any system or sub-system which will continue to function when the EMCS microprocessor controller is non-operative.

**Machine Language:**
The binary code corresponding to the instruction set recognized the CPU.

**Memory:**
Any device that can store logic 1 and logic 0 bits in such a manner that a single bit or group of bits can be accessed and retrieved.

**Memory Address:**
A binary number that specifies the precise memory location of a stored word.

**Microcomputer:**
A computer system based on a microprocessor and containing all the memory and interface hardware necessary to perform calculations and specified transformations.

**Microprocessor:**
A central processing unit fabricated as one integrated circuit.
MODEM:
An acronym for MOdulator/DEModulator. A hardware device used for changing digital information to and from an analog form to allow transmission over voice grade circuits.

Multi-Tasking:
The procedure allowing a computer to perform a number of programs simultaneously under the management of the operating system.

Non-Volatile Memory:
Memory which retains information in the absence of applied power (i.e.; magnetic core, ROM, and PROM).

Object Code:
A term used to describe the machine language version of a program.

Operating System:
A complex software system which manages the computer and its components and allows for human interaction.

Optical Isolation:
Electrical isolation of a portion of an electronic circuit by using optical semiconductors and modulated light to carry the signal.

Point:
A single connected monitor or control device (i.e., relay, temperature sensor).

Program:
A sequence of instructions causing the computer to perform a specified function.

Protocol:
A formal set of conventions governing the format and relative timing of message exchange between two terminals.
Random Access Memory (RAM):
Volatile semiconductor data storage device in which data may be stored or retrieved. Access time is effectively independent of data location.

ROM, PROM, EPROM, EEPROM:
Read-Only-Memory, Programmable ROM, Erasable PROM, Electronically Erasable PROM. All are non-volatile semiconductor memory.

Real Time:
A situation in which a computer monitors, evaluates, reaches decisions, and effects controls within the response time of the fastest phenomenon.

Register:
A digital device capable of retaining information.

Resistance Temperature Detector (RTD):
A temperature sensor based on a linear relationship between resistance and temperature.

Software:
A term used to describe all programs whether in machine, assembly, or high-level language.

Throughput:
The total capability of equipment to process or transmit data during a specified time period.

Volatile Memory:
A semiconductor device in which the stored digital data is lost when power is removed.

Zone:
An area composed of a building, a portion of a building, or a group of buildings affected by a single device or piece of equipment.
APPENDIX D
LIST OF EQUIPMENT MANUFACTURERS
Advanced Logical Solutions
7074B Commerce Circle
Pleasanton, California 94566
415-462-0150

Aegis Energy Systems, Inc.
607 Airport Boulevard
Doylestown Pennsylvania 18901
215-348-7662

Allen Bradley
Systems Group
747 Alpha Drive
Highland Heights, Ohio 44143
216-449-6700

American Air Filter
P.O. Box 35530
Louisville, Kentucky 40232

AMF Paragon
606 Parkway Boulevard
P.O. Box 28
Two Rivers, Wisconsin 54241
Attn: EMS Group
414-793-1161

AMS
P. O. Box 873
Lake Elmo, Minnesota 55042
612-439-0022

Analog Devices, Inc.
Box 280
Norwood, Maine 02062
617-329-4700
Andover Controls
York and Haverhill Streets
Building 5, Floor 5
Andover, Massachusetts 01810
617-470-0555

Applied Systems Corporation
26401 Harper Avenue
St. Clair Shores, Michigan 48081
313-779-8700

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73 Tremont Street
Suite 926
Boston, Maine 02108
617-367-1602

Autotronics, Inc.
1399 Executive Drive West
Richardson, Texas 75081
214-238-7291

Barber-Colman Company
Controls Division
1300 Rock Street
Rockford, Illinois 61101
815-877-0241

Bohn A/C & R Division
Heat Transfer Group
Gulf & Western Manufacturing Company
Danville, Illinois 61832
217-446-3710
CESCO
1240 N. E. 175th Street
P. O. Box 55548
Seattle, Washington 98155
206-365-1234

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One Century Plaza
2029 Century Park East
Los Angeles, California 90067
213-553-8141

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Electronic Systems Division
Lebanon, Ohio 45036
513-494-5361

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919-851-3095

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617-655-1170

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23840 Industrial Park Drive
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213-479-8581

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Milwaukee, Wisconsin 53216
414-442-7800

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206-762-3933

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214-742-7231

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177 Main Street
W. Orange, New Jersey 07052
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203-865-3844

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General Purpose Control Department
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Bloomington, Illinois 61701

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419-381-2000

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1820 Shelburne Road
South Burlington, Vermont 05401
802-658-6445

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Morristown, Tennessee 37814

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206-623-9080

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Two Rivers, Wisconsin 54241
414-793-1161

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Suite 209
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813-535-0527

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215-925-2233

MCC Powers
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Printed Circuits International, Inc.
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Sunnyvale, California 94086
408-733-4603

Process Control, Inc.
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Temple, Arizona 85282
602-894-9105

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704-523-6373

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Metairie, Louisiana 70005
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Control Systems Division  
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Richmond, Virginia 23261  
804-288-3081

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Sedro Woolley, Washington 98284  
206-856-0836

Satchwell  
English Electric Corporation  
500 Executive Boulevard  
Elmsford, New York 10523  
914-592-4810

Scientific Atlanta  
Energy Management Division  
Box 105308  
Atlanta, Georgia 30348  
404-441-4112
Signaline
11440 E. Pine
Tulsa, Oklahoma 74116
918-438-1220

Solidyne Corporation
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Unit 380
Hoffman Estates, Illinois 60195

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Milwaukee, Wisconsin 53201
414-332-2000

Struthers-Dunn, Inc.
Systems Division
4140 Utica Ridge Road
P. O. Box 1327
Bettendorf, Iowa
319-359-7501

Temperature Corporation
1222 Ozark Street
North Kansas City, Missouri 64116
816-421-0723

Temperature System Inc.
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Manchester, New Hampshire 03108
603-623-9868
Texas Controls
13735 Omega
P.O. Box 59469
Dallas, Texas  75229
Texas Instruments Incorporated
P.O Drawer 1255
Johnson City, Tennessee  37601
615-461-2000

Titus Communications
Control Products Division
10920 Indian Trail
Building 203
Dallas, Texas  75229
214-243-0896

Tork Inc.
1 Grove Street
Mount Vernon, New York  10550
914-3542

Tour & Anderson
657 Glennbrook Road
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203-324-0160

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The Trane Company
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NAVREGMEDCEN PWO, Okinawa, Japan

NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA

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NSWSSES Code 0150 Port Hueneme, CA

NCTC CO (Code NAC50F) Orlando, FL; SCE, San Diego CA

NTIS Lehmann, Springfield, VA

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Counsel, Point Mugu CA; Security Offr. Point Mugu CA
PWC CO (Code 1003), Oakland, CA; CO (Code 100E). San Diego, CA; CO (Code 100E3). Oakland, CA; CO (Code 153). Guam; CO (Code 30). Pearl Harbor, HI; CO (Code 601). Subic Bay; CO (Code 610), Pensacola, FL; CO (Code 613). San Diego, CA; CO Norfolk, VA; CO Yokosuka, Japan. CO (Code 10). Oak; CA; CO, Great Lakes IL; CO, Pearl Harbor HI; CO, San Diego CA; CO, Subie Bay, R.P.; CO, 10. Great Lakes, IL; Code 100A, Great Lakes, IL; Code 101, San Diego, CA; Code 105 Oakland, CA; Code 110. Great Lakes, IL: Code 110, Oakland, CA; Code 116, Seattle, WA; Code 120, Oakland CA; Code 120, San Diego CA; Code 120C, Library) San Diego, CA; Code 154, Great Lakes, IL; Code 200 (H. Koubenc). Great Lakes IL; Code 200. Great Lakes IL; Code 240, Subie Bay, R.P.; Code 400. San Francisco, CA; Code 400, Oakland CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420, Oakland, CA; Commanding Officer, Guam; Code 420, San Diego, CA; Code 420. Norfolk, VA; Code 500. Norfolk, VA; Code 500. Great Lakes, IL; Code 500, Oakland, CA; Code 505A. Oakland CA; Code 600. Great Lakes; IL; Code 600A. Norfolk, VA; Code 610, San Diego CA; Code 700. Great Lakes, IL; Code 800, San Diego, CA; Library, Pensacola FL; Library, Guam; Library, Norfolk VA; Library, Pearl Harbor, HI; Library, Subie Bay, R.P.; Library, Yokosuka JA; Maint. Control Dept (R. Fujii) Pearl Harbor, HI; Production Officer. Norfolk, VA; Util Dept (R Pescua) Pearl Harbor, HI; Utilities Officer. Guam
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USNA Ch. Mech. Engr. Dept Annapolis MD; Code 170, Annapolis. MD; ENGRNG Div. PWD, Annapolis MD; Energy-Environ Study Grp. Annapolis, MD; Mech. Engr. Dept (C. Wu). Annapolis MD; PWD Suprt. Annapolis MD
TENNESSEE VALLEY AUTHORITY (Henshaw). Knoxville, TN
ALABAMA ENERGY MGT BOARD Montgomery, AL
ARIZONA Kroelinger Tempe, AZ; State Energy Programs Off., Phoenix AZ
AUBURN UNIV. Bldg Sci Dept, Leecher, Auburn, AL
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FRANKLIN INSTITUTE M. Padusis, Philadelphia PA
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA; Col. Arch, Benton, Atlanta, GA
HARVARD UNIV. Dept, of Architecture, Dr. Kim, Cambridge, MA
HAWAII STATE DEPT OF PLAN. & ECON DEV. Honolulu HI (Tech Info Ctr)
IOWA STATE UNIVERSITY Dept. Arch, McBrown, Ames, IA
WOODS HOLE OCEANOGRAPHIC INST. Woods Hole MA (Winget)
KEENE STATE COLLEGE Keene NH (Cunningham)
LAWRENCE BERK LAB Window & Lighting Prog. Berkeley, CA
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