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AUTOMATED ENERGY MANAGEMENT SYSTEMS FOR SMALL BUILDINGS

FINAL REPORT
VOLUME I - TECHNICAL DOCUMENT

August 1978

Prepared by
HONEYWELL, INC.
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for
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

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ABSTRACT

Energy controls can perform a valuable function in energy conservation or energy management strategy in buildings. Existing controls cover the gamut from relatively simple single function controls, such as time clocks, to computer-controller automation systems. While the more simple controls can be applied to virtually any building, the more complex automation systems are currently available only to large buildings where their greater costs may be justified. The latter, in theory at least, offer the capability of "total" energy management in a building. At the present time, however, there is a lack of similar effective, automatic energy management control practices and schemes available for application to small buildings. This is due, in large measure, to the absence of cost-effective integrated control equipment in the small building marketplace. Furthermore, a general philosophy or strategy, for the application of equipment for total energy conservation in small commercial buildings has not yet evolved.

Both technical and marketing issues related to the implementation of automation systems in small commercial buildings under 75,000 square feet gross area are explored. The functional requirements for small building automation systems are identified and determination of system costs and energy savings potential are made.

Market analyses identify cost and payback requirements as well as attitudes of potential equipment buyers in the small building market. Schools, apartments and offices, which together consume more than half the energy of the small building market, are used as analysis models.

The market and technical analyses are combined to formulate the potential marketplace for a small building AEMS in terms of building size, and building type. An AEMS concept is defined which embodies the necessary functional requirements within a framework of applied strategy to energy conservation in buildings.

PREFACE

The U.S. Department of Energy (DOE) is committed to development, demonstration and implementation of cost-effective energy conserving control systems for heating, ventilating, air conditioning, lighting and refrigeration systems in commercial and residential buildings. As part of this commitment, a program was undertaken to identify the potential for energy conservation through development and use of cost-effective Automated Energy Management Systems (AEMS) for small commercial buildings.

The results of this program, which was performed by the Honeywell Energy Resources Center (ERC) over an eleven-month period, are summarized in this report. Honeywell was assisted in this study by Marketec, Inc., a Minneapolis-based consulting market research firm; Syska and Hennessy, Engineers, through their New York office; and A.D. Little, Inc., of Cambridge, Massachusetts.

Results of this program are published in two volumes:

- Volume I Technical Document
- Volume II Market Assessment Reports, Phases I and II

Volume I provides complete documentation of the technical work performed under this study. Volume II contains the results and analysis of the focus group panel interviews conducted to determine general buying constraints in the small building controls market. Volume II also presents the results and analysis of statistical sampling of the small building marketplace to identify cost/payback constraints.

ACKNOWLEDGEMENTS

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Honeywell also expresses its appreciation to the following subcontractors for their respective contributions:

Marketec, Inc., Dr. Norman Sidley and Dr. Theo. Jolosky for their work in the performance and analysis of the Market Assessment study.

Syska and Hennessy, Irving Silverman, P.E., for contributions in identifying and categorizing HVAC systems and refit functions for AEMS applications.

A.D. Little, Inc., W. David Lee, for providing valuable comments and critiques of the program's objectives, scope and progress.

Finally, Honeywell expresses its appreciation to the participants of the focus group sessions. Their enthusiastic involvement bespeaks a high level of interest in energy conservation and implies a receptive attitude toward products and services that are directed toward their own uniquely perceived needs.

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1.0 INTRODUCTION

This study was undertaken to identify the potential for energy conservation in small commercial buildings through application of automated energy management systems (AEMS). Small buildings, for purposes of this study, were defined as those under approximately 75,000 square feet. Specific objectives for the study were to:

- Establish the technical feasibility and cost-effectiveness of an AEMS product concept.
- Define the product characteristics required for a successful AEMS product concept.

This study effort emphasized consistency with national energy policy objectives. As a result, the study concentrated on identifying sectors of the commercial building community wherein the largest potential for near-term energy savings for the nation could be realized through the availability of an AEMS. From a practical standpoint, this condition on the conduct of the study meant primary emphasis on conceptual development of an AEMS for retrofit of existing structures, largest portion of the commercial building inventory.

Figure 1 summarizes the overall study methodology, comprised of two general thrusts:

- Technical - Developing the engineering and cost savings rationale for a small buildings AEMS.
- Marketing - Identifying and establishing the constraints associated with the market for an AEMS. Both nationwide selective interview and mail survey techniques were employed.

Numbers associated with each block in Figure 1 refer to sections and subsections of this report that summarize specific results of study tasks.

Figure 1. Study Methodology

2.0 EXECUTIVE SUMMARY

2.1 SUMMARY OF STUDY RESULTS

From a macroscopic viewpoint, widespread usage of an AEMS in small buildings has the potential to save a considerable amount of the nation's energy. Small commercial buildings (under 75,000 square feet) consume a significant portion--approximately 10.2 percent--of the nation's energy.

U.S. energy consumption by small buildings is estimated to be over 6 quads of oil equivalent annually. Assuming AEMS could reduce each building owner's consumption by 20 percent, the annual equivalent of over 200 million barrels of oil could be saved. This savings would be sufficient to reduce oil imports by over 6 percent.

This program was directed toward identifying the technical and market characteristics for an AEMS that could help realize some of these energy savings. To achieve this goal, and to permit a study of sufficient depth within practical program constraints, three functional usage categories of small buildings were selected for detailed technical and market analysis:

- Multi-family dwellings;
- Offices;
- Schools.

Selection of these three particular building categories was based primarily upon the fact that they represent the three largest individual energy-consuming segments of all small building functional usage categories. In addition, their selection is significant because:

- Collectively, these three building categories consume 5.5 percent of the nation's energy.
- Collectively, these three categories consume a major portion (54 percent) of the energy for all 22 categories of small commercial buildings analyzed. Consequently, from a national energy policy viewpoint, the most significant impact in promoting energy savings could be realized by affecting multi-family dwellings, offices, and schools.
- Relative to all 22 small building categories examined, these three building categories dominate the potential

customer market in terms of number of buildings (70 percent) and floor space (55 percent).

- Each of the buildings differs from the others in occupancy schedule, zoning for heating/cooling, types of heating/cooling plants, and other relevant factors which affect the potential for energy savings through improved controls. This diversity presents a stiff challenge to the hypothesis that a universal AEMS device can be designed, produced, and marketed.
- None of these building categories are being actively pursued by suppliers of single-function control devices (e.g., load demand controllers). This differentiates these building categories from other types such as supermarkets, hotel/motels, and fast food chains where marketing efforts are more evident.
- Both private sector and public sector owners are represented.

2.1.1 Small Building Characteristics

An apparent - and extremely important - characteristic of small buildings is the wide diversity in design and usage characteristics. Each building is unique relative to the prospect for energy conservation through an AEMS; each differs as to age, size, shape, HVAC system, lighting, window exposure, type of construction, site orientation, geographic location, occupancy schedule, purpose of usage and number of occupants. In addition, many differing relationships between owners and tenants alter motivation toward energy conservation.

Notwithstanding this diverse state for the community of small buildings, the overall approach of the study was to examine general characteristics of the multi-family, office and school sectors for some correspondingly general method by which to apply an AEMS.

The initial task in this effort was to define criteria for selecting the set of AEMS control functions, which were later analyzed as to cost-effectiveness. These control function criteria required that the AEMS be able to:

- Promote Energy Savings - The basic notion is to determine areas of in-building energy waste, and to apply control functions to reduce the waste. Examples include night setback and optimal equipment startup.

- Promote Cost Savings - In this case, energy may not necessarily be saved, but cost to the consumer is reduced. An example is load shedding to reduce demand charges.
- Provide "No Cost" Benefits - In certain situations, an AEMS might be used to ring classroom bells, etc., at no appreciable installed cost premium.

Subsequently, the consumption of energy in small buildings was analyzed. In this exercise heating/cooling was identified as the single largest consumer of energy, as tabulated below:

	<u>Heating/Cooling</u>	<u>Lighting</u>	<u>Domestic Hot Water</u>	<u>Other</u>
Offices	82%	10%	8%	-%
Schools	79	9	11	-
Multi-family	69	8	17	6

All of these areas of energy consumption can be affected by some type of AEMS control function.

With determination that heating/cooling was the predominant in-building energy consumer, the characteristics of HVAC systems in small buildings were examined. A survey was made to identify the various existing types of HVAC systems. This survey showed that a large variety of different HVAC systems are currently utilized: at least 20 different types in small office buildings, 13 in schools, and 9 in multi-family buildings. This data also illustrated the relationships between type of HVAC system, building age, and geographic location.

The HVAC systems identified ranged from the simplest type in which one system provides heating/cooling to both perimeter and interior, to a more complex type which utilizes separate equipment to supply interior and perimeter heating/cooling. This wide diversity of equipment is the result of a complex mixture of such factors as local economic conditions, relative proximity between user/manufacturer, local supplier situation, and date of installation.

2.1.2 AEMS Functional Analysis

Functional analysis categorized the population of HVAC systems into four groups, and examined the applicability of various candidate AEMS control functions. This process resulted in the identification of a number of typical strong candidate AEMS control functions, as summarized below.

PRIMARY FUNCTIONS	APPLICABILITY
ELECTRICAL LOAD DEMAND CONTROL	Changing trends with utility/ consumer interactions make this a strong candidate for many buildings.
LOAD EFFICIENCY DEVELOPMENT <ul style="list-style-type: none">● Balance supply temperatures to load● Sequence heating/cooling● Chiller optimization	All are highly HVAC-system dependent, with implementation taking many forms. Appear to be strong candidate functions for AEMS.
VENTILATION CONTROL <ul style="list-style-type: none">● Minimum air for occupancy (warm-up cycle)● Enthalpy control● Outside air shut-off	In combination with installing and/or adjusting low-leak dampers, significant economic benefits can accrue with these AEMS functions. A retrofit application assumes economizer cycle already in a place and enhanced with these functions.
HVAC SCHEDULING <ul style="list-style-type: none">● Space temperature reset● Start/stop of motorized equipment● On/off light control	Probably justifiable only as AEMS add-on feature.
OPTIMAL START-STOP	HVAC and building dependent.

In all of the above primary control functions, the main objective for AEMS is to reduce energy waste by more closely matching energy usage to building needs.

All of the candidate AEMS control functions identified above are in practical usage today. A variety of suppliers for single-function controllers exist such as those for time-clocks, night setback thermostats, and load demand controllers. These devices are normally perceived to be cost-effective by consumers. Each control device generally attacks a single area of energy waste, and manufacturers normally cite case histories of attractive pay-back periods.

In addition to the primary control functions cited above, a number of "second generation" control functions should be considered for eventual AEMS add-on capabilities. These functions result principally from comments gathered during the study's market research analysis in which concern was expressed that an AEMS would become outdated because the consumer perceives rapidly progressing technological changes. In this case, market research indicates a possible consumer barrier to buying new control equipment because of the fear that "it will be out of date next year".

The best strategy counteracting this argument appears to be good salesmanship combined with a system which permits AEMS expansion capability. Toward this end, second generation functions which should be considered for future implementation include:

- Active Ventilation Control - Utilize AEMS to adjust outside air intake as a function of measured air quality such as odor, carbon dioxide content, etc., or other occupancy detection means.
- Combustion Efficiency Control - Utilize AEMS to control combustion parameters for optimum combustion efficiency utilizing combustion instrumentation equipment.
- Occupancy Control - Utilize AEMS to adjust lighting, ventilation and heating/cooling on a basis of actual occupancy rather than time-of-day scheduling.

Monitoring functions are also recommended for an AEMS. Specifically, these may include:

- Status Reporting - AEMS should provide user indication that it "is working" (i.e., no malfunctions). Also, a method should be implemented to prevent "defeat by humans". This requirement originates from comments gathered during the study that devices such as time clocks are often overridden by operating personnel to prevent occasional complaints about comfort. In this situation, the intended time clock function is reprogrammed or deleted, generally causing a permanent reconfiguration condition. Often the building owner assumes that the time clock is operating effectively when the unit may not be operating as intended. An AEMS should be capable of monitoring and correcting such a situation; for example, overriding human intervention after a period of time.
- Preventive Maintenance - AEMS should provide notification that some preventive maintenance action is required; change of a filter, for example.
- Self-Diagnosis - AEMS should be designed to help the building owner determine the nature and location of a system problem.
- Energy Usage Monitoring - AEMS should provide running or periodic accounts of energy usage, with comparable reference or standard information.

The latter three functions will be applications-dependent, and are considered as options to a basic system.

Overall energy savings which would result from providing these primary AEMS control functions were also analyzed. A combination of analysis, simulation and case history results were examined to determine a range of savings to be realized from various functions as summarized below:

AEMS PRIMARY CONTROL FUNCTION CATEGORY	RANGE OF OVERALL ENERGY SAVINGS (% of Total Building Energy)
ELECTRICAL DEMAND CONTROL	2 to 7
LOAD EFFICIENCY IMPROVEMENT <ul style="list-style-type: none"> ● Supply temperature reset ● Boiler optimization ● Chiller optimization ● Sequence heating and cooling ● Combustion efficiency 	2 to 10
VENTILATION <ul style="list-style-type: none"> ● Free cooling ● Warm-up cycle ● Enthalpy 	3 to 5
HVAC SCHEDULING <ul style="list-style-type: none"> ● Temperature reset ● Start-stop ● Optimal start ● Duty cycle 	3 to 5
TOTALS (DIRECT ADDITION)	10 to 27

As these results show, AEMS should be capable of reducing energy consumption by 10 to 27 percent. This generally agrees with industry sources who predict that 10 percent should be relatively easy to achieve, and 20 percent should be generally achievable. The objective of the DOE building conservation program is to reduce unit energy demand in existing buildings by 20 percent in 1985 and by 30 percent in 2000. The potential savings from AEMS of 10 to 27 percent, if realized, would contribute substantially to meeting these objectives.

Some manufacturers of control equipment (mostly single control function) have been known to advertise even larger energy savings - sometimes up to 50 percent. The equipment supplier may be taking advantage of coincidental savings due to system retuning or adjustment in this savings figure. For example, a common cause of energy waste is poorly-adjusted exhaust dampers. By readjusting the damper, or replacing it with a low leakage damper at the same time as controls are added, the control supplier claims an energy savings. Subsequent control additions thereby become more difficult to justify from a cost-effectiveness viewpoint.

2.1.3 AEMS Costs

The study also examined installed cost goals for an AEMS. Obviously, the wide range of variables--building sizes, energy costs, market size, desired payback period, complexity of installation, type of HVAC--makes this an extremely difficult parameter to specify. As a minimum an attempt was made to develop a number of costing guidelines to relate relevant parameters. At best, some estimates were made of a minimum AEMS cost.

The costing analysis stemmed from the market research effort, which indicated that payback period was a major buyer decision factor. Generally, small building owners feel that a simplified calculation to determine payback period is adequate, i.e.:

$$\text{payback period} = \frac{\text{AEMS installed cost}}{\text{resultant savings/period}}$$

In a survey of 413 owners of small schools, multi-family dwellings and office buildings, a range of less than one to no more than 10 years payback was required. Discussions with current control equipment suppliers indicated that a maximum 2.5-year payback period was considered "reasonable" to consummate a sale.

A statistical analysis showed that 64 percent (nearly two-thirds) of building owners preferred a 2.5-year or less payback period. Further analysis showed that schools accept a longer payback period (the majority of respondents prefer less than 2.8 years), whereas offices require the shortest period (2.1 years). The majority of multi-family building owners require a 2.5-year payback.

A first cut at determining an AEMS installed cost goal was made by relating present annual energy costs for buildings to the required 2.5-year payback period.

Data for office buildings, for example, show annual energy bills from about \$.40 (Pacific Northwest) to \$1.65 (Mid-Atlantic) per square foot (1975-76 data). These energy cost figures, in addition to a 2.5-year payback and a conservative 10 percent energy savings requirement, produce a range of AEMS installed costs that varies from \$500 to \$31,000 for corresponding building sizes of 5,000 to 75,000 square feet. The overall U.S. average was \$0.85 annual energy cost per square foot, which for a 30,000 square-foot building, indicates an AEMS installed cost goal of \$6,400 (with 2.5-year payback, 10 percent annual energy savings).

Because of this wide range of installed costs which are dependent on building size, an attempt was made to re-examine costs using more restrictive building size limits. In this case, the smallest building sizes - which coincidentally have relatively low energy costs and would be unlikely target markets for an AEMS - were eliminated.

Again, survey data collected from 431 small building owners were used to determine the following characteristics for the majority (64 percent) of the respondent's situations:

	Maximum Payback Period (years)	Minimum Building Size (feet)	Minimum Energy Costs (\$/ft ² /yr)
Offices	2.1	23,000	0.72
Schools	2.8	31,000	0.65
Multi-family	2.5	13,000	0.49

This data was used to determine that in the case of an AEMS that produces a 10 percent annual energy savings benefit, acceptable AEMS installed costs would be:

	Minimum Building Size (previous table)	Maximum Building Size (75,000 ft ²)
Offices	\$3,477	\$11,340
Schools	\$5,642	\$13,650
Multi-family	\$1,592	\$ 9,185

2.1.4 Currently Available Building Automation Equipment

A limited survey of the market for building automation equipment was made. It showed that a variety of manufacturers currently have available building automation equipment. This equipment may be categorized as:

- Limited Function Controllers - Generally dedicated to a primary function (e.g., time clock, demand controllers), but may also include additional control function options. These cost effective controllers perform the individual control functions recommended for AEMS.
- Multi-function, Central Automation Systems - Generally applied only to large (more than 100,000 square feet) buildings. Normally these systems provide all recommended AEMS functions in an integrated form, with computer-based hardware/software, but are not cost effective for small buildings.
- "New Generation" Systems - An emerging class of controllers, generally employing microprocessor technology. Impetus for development of many of these controllers appears to have risen from the needs of multi-mode control of solar heat applications, with some controllers also applying their inherent flexibility to control AEMS functions as well.

The elements of an AEMS are embodied in the above. All may be considered "AEMS controllers" in various given, appropriate applications.

2.1.5 Market Assessment Studies

Two phases of market research were performed during the study. Phase I involved interview (focus group) sessions with cognizant individuals representing multi-family, office, and school sectors. Focus group sessions were held in Boston, Minneapolis, Atlanta, and Los Angeles. Phase II involved a nationwide mail questionnaire with 431 respondents' replies tabulated and analyzed.

All focus group respondents perceived the nation's energy conservation problem as severe, both from a national and building sector viewpoint. Most respondents cited a number of factors in deciding the best possible way to solve their energy conservation problems. These factors included:

- economic

- technical
- regulatory
- psychological
- general

Economic considerations stressed the importance of availability of capital and the requirement for a specific payback period in purchasing an AEMS.

Technical factors stressed the importance of matching the appropriate energy saving equipment to the specific building under consideration. Respondents demonstrated the importance of providing some type of guarantee that an AEMS, if purchased, would save energy and money.

Regulatory considerations were also important in the decision to purchase an AEMS. Local regulations and codes, such as differing temperature and ventilation requirements, were noted.

Psychological factors were important purchase decision factors as well. In particular these included the willingness of building tenants to go along with energy saving programs, the belief that tenants would react negatively to any such program, lack of technical sophistication among building owners, and the technical know-how of building maintenance personnel.

Finally, the lack of understanding of potential solutions to energy conservation problems was identified as a general barrier to purchasing an AEMS.

Most focus group respondents reported that they were currently pursuing aggressive energy saving practices. These practices tended to be low cost or no cost procedures (e.g., turning off lights, night setback thermostats).

Most focus group respondents did not feel that installation of an AEMS would be a cost-effective means of conserving energy at the present time. The respondents generally perceived an AEMS as being unnecessary, too costly, or unsuitable to their buildings (primarily older buildings).

The second phase of the market research study examined statistical response data from 413 respondents. This study quantified such parameters as AEMS cost, criteria, payback requirements, methods of procuring an AEMS, and the decision factors in purchasing an AEMS. The survey also included information on building and HVAC characteristics and energy use parameters.

2.1.6 The AEMS Market

The study evaluated the role of currently available equipment in light of the needs of small building energy management and the cost constraints of the market. It is apparent that the functional requirements of an AEMS, as defined, could be met in buildings of any size by this equipment. The rationale to define and justify an AEMS for small buildings requires another dimension - applied controls strategy.

Ideally, such a control strategy for commercial buildings is based on the premise of potentially controlling all energy use within that building within the limits of cost effectiveness. It must go beyond the present-day approach of supplying one or more functions that offer relatively large payback potential. An AEMS developed to meet this strategy will seek and find even the one and two percent savings potentials to maximize energy and cost savings.

Forces are at work which give impetus to developing such strategies:

- Increasing energy costs
- Proposed retrofit codes (ASHRAE Standard 100P)
- Variable electrical rate structures and utility interaction with users

Lack of an applied controls strategy in today's market requires that a building's energy management requirements be satisfied from a piecemeal approach using individual controllers. Considerations of cost effectiveness and realization of energy savings potential were combined in Figure 2 to illustrate the coverage of today's market with current equipment.

AEMS will supplement and integrate with existing controls from a market viewpoint. Single function controls will and should continue to be used in applications where they meet requirements or are cost effective. However, an AEMS developed and implemented with an applied strategy toward total building energy management could likely make significant penetration into the larger buildings market. The AEMS market potential is thus seen to be larger than the 75,000 square-foot limit assumed for this study. Further, Figure 2 implies that the market for a small building AEMS will exist only if a concept of total energy management and conservation strategy is in force.

Figure 2. The Potential AEMS Market

2.2 CONCLUSIONS

The results of the study indicated that an AEMS system configuration should have the following characteristics:

- AEMS should incorporate all of the following typical primary control functions for application, as required, to a wide variety of small commercial buildings:
 - Electrical load demand control;
 - Load efficiency improvement:
 - Balance supply temperatures to load;
 - Sequence heating/cooling;
 - Chiller optimization;
 - Ventilation control:
 - Minimum air for occupancy (warm-up cycle);
 - Economizer/Enthalpy control;
 - Outside air shut-off;

- HVAC scheduling:
 - Space temperature reset;
 - Start/stop of motorized equipment;
 - On/off light control;
- Optimal start/stop;
- AEMS should readily provide owners and/or operators with monitoring and status information that includes:
 - System malfunction and self-diagnosis information;
 - Preventive maintenance notification requiring action;
 - Energy usage monitoring/record keeping;
- Consideration should be given to providing future control function add on capability as new technologies evolve;
- All control functions should be integrated into a single on-site energy control and management system.
- AEMS should provide automatic capability to remedy unintentional manual overrides.
- Operator and status display panels should be provided. The location, complexity, or type of man/machine interface has not been determined.
- The AEMS equipment should strive toward a common hardware design which accommodates a wide variety of building characteristics (size, mechanical systems, usage, layout, etc.). Toward this end, a micro-computer-based system incorporating software-alterable flexibility and hardware modularity appears to be the most cost-effective approach. Standardization interfaces between manufacturers would best serve consumer interests.
- The AEMS design should strive to minimize present labor cost intensity involved with sale, building survey, installation, and call-back of control equipment purchases. In particular, strong consideration should be given to methods of eliminating rewiring of existing buildings (e.g., power line carrier techniques).

In addition, a number of conclusions were reached concerning the market for an AEMS:

- Small commercial buildings offer significant potential to reduce the nation's energy consumption - by up to 3 percent. This building sector currently consumes 10.2 percent of the nation's total energy, which could be

reduced potentially by 10-27 percent through applications of an AEMS. Therefore, active pursuit by government and industry to apply AEMS to small buildings is a potentially rewarding activity.

- Of the three specific building categories analyzed in detail (multi-family dwellings, offices, schools), offices offer the most attractive AEMS market potential. Office building owners/managers are the most knowledgeable regarding potential effectiveness, are the most capable of obtaining necessary financing, and are the most sophisticated regarding investment/purchase decisions.
- The school and multi-family building sectors are less attractive markets than offices. The school sector, while generally knowledgeable about the benefits of an AEMS, has difficulty in securing necessary capital. Multi-family dwellings are characterized by great variability in building age, size, economic factors, etc. Consequently, there is considerable variation in the perceived need for an AEMS, and its potential effectiveness. Multi-family building owners also generally lack available capital.
- The small buildings market for an AEMS is slowly emerging, but is still in the infancy stage. Under present operating scenarios building owners will continue to conserve energy through low-cost or no-cost methods until they extract the greatest amount of energy and cost savings. When these savings have been realized, and when the energy availability and cost pictures change, an attractive large-scale market for an AEMS will be produced.
- Payback period, especially for the private sector, is the single most important factor in deciding on purchase of an AEMS. Generally speaking, purchasers desire a 2.5- to 3.5-year payback period for investment in an AEMS. Other factors key to the purchase decision include building size and age, owner's financial situation and availability of capital, total utility costs, and installed system price.
- Market research data indicates no set price that building owners are willing to pay for an AEMS. A purchase decision depends on a number of factors including building characteristics, required payback period, availability of capital, and total operating and energy costs. Although survey respondents indicated that the final decision to purchase an AEMS depends on price, prices ranged from about \$1,000 to over \$30,000.

- The most significant constraint on widespread market penetration of an AEMS is the economic factor. Lack of capital with which to purchase an AEMS, combined with uncertainties about future energy costs and energy/cost saving benefits of AEMS, is a major barrier to the sale of an AEMS.
- It is most important that an AEMS be capable of saving money at a rate commensurate with an acceptable payback period.
- Market research data illustrates that the two most important control functions for an AEMS are comfort and lighting controls. The least important functions are fire and burglary alarm functions.
- Research demonstrates that building owners strongly desire an energy usage analysis of their individual building in order to make a purchase decision on an AEMS. This analysis should consider specific energy conservation needs and solutions for the building.
- Building owners want a demonstration and guarantee that the AEMS would both function effectively and offer a favorable payback period. Since owners of buildings are often suspicious of manufacturers' claims on the merits of their products, a demonstration project ideally should be conducted by a credible source, such as an independent testing laboratory or a government agency. Industry should consider a guarantee plan to assure owners of advertised benefits.
- Market research data indicates that building owners prefer to purchase an AEMS outright or buy it on an installment plan, as opposed to leasing such a system.
- Owners strongly prefer to purchase or lease an on-site AEMS rather than using an off-site service.

2.3 RECOMMENDATIONS

This program, through its technical and market analyses, has raised several issues that can be resolved only through further research and development.

Overall, the credibility of building automation control as a viable energy conservation solution must be established with an "image saturation" strategy, similar to that which has occurred for

insulation and caulking. The public is relatively convinced today that insulation and caulking are cost-effective ways to save both energy and costs. It is likely that the highly mechanical, easily observable and understandable nature of insulation and caulking makes these items more acceptable to the public at the present time.

Controls, on the other hand, are electronic and more "black box"-oriented. Consequently, the public perceives controls as a more complex, less understandable, and more costly solution to energy control problems. Yet, in fact, building automation controls may offer the building owner a more cost-effective solution in many situations.

The following recommendations are offered as methods to enhance the overall market for an AEMS for small buildings, as well as means to develop sound strategies for applied controls in energy conservation:

1. Perform Proof-Of-Effectiveness Demonstrations -- The government should sponsor demonstration projects utilizing AEMS devices for purposes of refining equipment design characteristics and gathering technical data regarding energy and cost savings capability. Several design issues must be investigated during these demonstration projects:
 - A microprocessor-based device should be utilized to increase the small building owner's overall confidence level regarding the ability of computers to operate effectively and reliably;
 - The man-machine interface between the building owner and/or operators must be better defined such that energy usage information is fed back to the highest decision maker;
 - It must be demonstrated that the type of communication system, such as power line carrier, can operate reliably. In addition, the buildings must be instrumented such that technical performance data on the effectiveness of an AEMS can be collected. The results of these demonstration projects should be documented and distributed to the public to establish an increased level of credibility for an AEMS.
2. Sponsor Generic Advertising -- Government should sponsor generic advertising for an AEMS to notify buyers of its benefits. The majority of this advertising should take place following the

conclusion of the demonstration projects identified above. The primary goal of this advertising should be to place the proper perspective on controls as a viable solution to building energy management and conservation problems. The program should also inform buyers of the cost-effectiveness of AEMS devices, and assure tenants/occupants that controls do guarantee their comfort. Workshops, conducted for trade organizations and other interested parties, should also be an important consideration.

3. Develop Improved Individual Building Analysis Techniques -- Jointly, industry and government must develop improved analysis techniques to ascertain energy conservation and management needs for individual buildings. Building owners want the unique character of their building analyzed. The results should portray a realistic cost-benefit relationship between the AEMS and their building.
4. Increase Building Owner's Economic Incentives and Availability of Capital -- Small building owners lack adequate capital and economic incentive to purchase an AEMS even when offerings are available. The government can partially alleviate this situation in at least two ways. First, it can encourage the banking community to offer long-term loans for control equipment by educating bankers about energy and cost saving benefits. This effort could include direct persuasion methods and education programs (e.g., workshops). Second, the government can provide tax incentives consistent with the nation's energy policy. These incentives should be tailored to further improve the consumer's payback period for an AEMS.
5. Purchase Integrated AEMS -- Consumers should purchase a multiple-function control device with characteristics like the AEMS. Single-function controllers do work in most instances, but the cost-effectiveness of integrated control functions within an AEMS is more beneficial to the consumer in the long term. In addition, it is important that small building owners educate themselves or appoint an energy management specialist to assist in equipment purchase and building operation.

3.0 DETAILED STUDY RESULTS

This section details the specific analyses and findings leading to the definition of an AEMS concept.

3.1 SELECTION OF BUILDING TYPES

3.1.1 Summary

A primary objective of this study is to define an AEMS concept applicable to the entire range of small commercial building categories. While a worthwhile goal, this presents obvious problems when trying to get at specific issues within a limited scope of study. Thus it was decided to identify a few select categories of buildings using them as a focus for specific tasks and being alert to criteria that would allow extrapolation to the wider categories of buildings.

This first subsection, then, presents the rationale for selection, early in the study, of schools, offices and apartments for primary focus. The prime criterion was to choose buildings in which implementation of an AEMS would result in the greatest impact on national energy usage. This impact considered both quantity of energy used and potential market size.

The analysis eliminates buildings over 75,000 square feet gross floor space and apartments not deemed suitable for centralized control. Within this reduced set of buildings, the three building categories together consume about 54 percent of the energy of the small building sector. In numbers, they represent 70 percent of the number of small buildings.

While this selection satisfied our original criteria, apartment buildings dominate the statistics and, as will be seen later, present perhaps the weakest candidates and greatest challenges for an AEMS.

3.1.2. National Energy Usage and AEMS Study

Patterns of residential, industrial and transportation energy use in the U.S. for 1970 through 1985 (projected) are shown in Table I. For this period, total gross energy input is increasing at a compound rate of 2.75 percent per year, while the net energy used is increasing by 2.03 percent per year. In spite of this increase

Table I. Energy Input to the U.S. Economy (1970 to 1975) and Projections by Consuming Sector¹

IN QUADRILLIONS OF BRITISH THERMAL UNITS, EXCEPT PERCENT

ITEM	1970	1971	1972	1973	1974	1975 (Est.)	1970-75 Average	Projections	
								1980	1985
TOTAL GROSS ENERGY INPUT	67.1	68.7	71.9	74.7	72.9	71.1	71.1	87.1	103.5
TOTAL NET ENERGY USED *	56.2	57.0	59.4	61.3	59.3	57.5	58.5	68.9	77.5
RESIDENTIAL AND COMMERCIAL (PERCENT OF NET)	17.0 (30.3)	17.4 (30.5)	18.1 (30.5)	18.3 (29.9)	17.6 (28.8)	17.3 (30.1)	17.6 (30.2)	21.6 (31.4)	24.6 (31.7)
INDUSTRIAL (PERCENT OF NET)	22.5 (40.0)	22.3 (39.1)	23.2 (39.1)	24.0 (39.3)	23.3 (39.3)	21.7 (37.7)	22.8 (39.1)	25.9 (37.6)	28.8 (37.2)
TRANSPORTATION (PERCENT OF NET)	16.5 (29.4)	17.1 (30.0)	18.1 (30.5)	19.0 (31.0)	18.4 (31.0)	18.5 (32.2)	17.9 (30.7)	21.4 (31.0)	24.1 (31.1)

¹"Statistical Abstract of the United States - 1976," U.S. Department of Commerce, Bureau of the Census.

in total energy consumption, however, proportions of energy consumed by each of the consuming sectors are expected to remain relatively constant. Figure 3 shows average energy utilization by U.S. consuming segments for the five-year period from 1970 through 1975. The commercial and residential building sectors together consume 30.2 percent of the national energy. In Figure 4, the residential sector is further segregated by density according to U.S. Bureau of Census statistics. While this AEMS study is concerned with "commercial" buildings, it was deemed appropriate to include those portions of the residential sector which are "business buildings" likely to be amenable to centralized automatic control concepts: V12, multifamily and low-density housing. Together, the commercial and multiunit residential sectors consume about 13 percent of the national energy. However within these building sectors, there are a number of buildings over 75,000 square feet gross area and some, particularly multifamily, that are zoned by apartment relative to heating, cooling, ventilation and lighting systems. The size of the market to which an AEMS is applicable will be reduced when these factors are accounted for. During the course of this study, acquired data suggests that about 30 percent of the multifamily buildings were single zoned. Similar data for the low-density housing (one to four units) was not obtained, but for this initial analysis was assumed to be 50 percent single zone. If single-zone residential multifamily and low-density housing are eliminated from consideration, an AEMS is applicable to the group of buildings consuming about 10.9 percent of the national energy, derived as follows:

Commercial	=	7.9%
Multifamily (0.70 x 1.8%)	=	1.3%
Low Density (0.5 x 3.3%)	=	1.7%
TOTAL:		10.9% of national energy use

3.1.3 Small Building Inventory and Energy Usage

Further, the study is nominally addressed to buildings under 75,000 square feet gross area, a somewhat arbitrary definition of small buildings. Previous statistics cited include buildings of all sizes. As was implied by Figure 2, the 75,000-square-foot limit is not a firm boundary when considering the potential AEMS market. However, since this area limit has been applied in the study, an attempt was made to ascertain a national energy use breakdown by building size. A data source for commercial building size distribution on a national basis was not found. However, this

Figure 3. United States Net Energy Consumption
Averaged (1970 to 1975)^{1,2}

¹"Statistical Abstract of the United States - 1976,"
U.S. Department of Commerce, Bureau of the Census.

²"Federal Energy Administration, Project Independence,
Residential and Commercial Energy Use Patterns: 1970-1990,"
A.D. Little, Inc., 1974.

Figure 4. Commercial and Residential Energy Use Breakdown, Percent of National Total Energy^{1,2}

¹"Statistical Abstract of the United States - 1976," U.S. Department of Commerce, Bureau of the Census.

²"Federal Energy Administration, Project Independence, Residential and Commercial Energy Use Patterns: 1970-1990," A.D.Little, Inc., 1974.

study and others^{3,8} provided size distributions for various building sectors, but usually with a size bias." For example, this study focused on under 75,000 square feet: Reference 8 (BOMA) tends to reflect larger buildings. Noting that the distribution "curves" (number of buildings as a function of building size) resulting from these studies tended to be similar, a "composite distribution curve" was generated for the total number of United States commercial buildings (Figure 5a). This empirically derived representation does yield information supported by other sources. For example, piecewise integration to yield total commercial building inventory floor space gives a value of 26.1 billion square feet compared to source information of 26.9 billion square feet⁽³⁾ and 27.1 billion square feet⁽²⁾. This data allows an energy accountability to be determined as in Figure 5b. The assumption is made that energy usage is proportional to building gross area. The conclusion drawn is that buildings under 75,000 square feet gross area account for 93 percent of the energy used by the commercial building category. If this ratio is used to modify the previous calculation, the final AEMS application is determined to be on order of 10.2 percent of national energy usage:

Commercial (0.93 x 7.9)	=	7.3%
Multifamily (0.93 x 1.3)	=	1.2%
Low Density Apartments	=	1.7%
TOTAL		10.2% of national energy use

Summarizing these market reductions for further analysis we get:

Commercial Buildings	=	7% reduction
Multifamily	=	35% reduction
Low Density	=	53% reduction

Table II is a tabulation of building categories, including numbers of buildings and floor space, which were analyzed for selection as representative analysis models. Figure 6a ranks the major categories with respect to percent of national energy consumed. This criterion is given the greatest emphasis in building category selection since an objective of an AEMS concept is to impact the largest possible segment of the national energy user market. The energy use of the category has been reduced by the correction factors previously derived, so the total of all categories is 10.2 percent of the national energy use. By selecting schools, offices and multifamily housing for further consideration, 54 percent of the potential small building market is represented from an energy use viewpoint.

Figure 5. U.S. Commercial Buildings, 1975 Estimates of Size Distribution and Energy Accountability

Table II. Existing Business Building Inventory, 1975³

BUILDING CATEGORY	NUMBER OF BUILDINGS	FLOOR SPACE (FT ² X 10 ⁶)	INFORMATION SOURCE
<u>BUSINESS RESIDENTIAL (APARTMENTS)</u>			
MULTIFAMILY (MORE THAN 4 UNITS PER BUILDING) (11,792,000 UNITS)	865,000	12,971	U.S. HOUSING CENSUS ANNUAL HOUSING SURVEY, REF 2
LOW DENSITY (2 TO 4 UNITS PER BUILDING) (9,802,000 UNITS)	3,267,000	10,782	ESTIMATE ON NUMBER OF BUILDINGS
TOTAL RESIDENTIAL (21,594,000 UNITS)	(4,132,000)	(23,753)	
SCHOOLS (ELEMENTARY AND SECONDARY)	103,200	2,100	NAT. CENTER ED. STATISTICS
COLLEGE BUILDING	23,750	843	NAT. CENTER ED. STATISTICS
COLLEGE DORMITORY	11,400	276	NAT. CENTER ED. STATISTICS
<u>OFFICES</u>			
HIGH RISE (20 STORIES)	7,593	5,128	OFFICE OF INDUSTRIAL ECONOMICS (OIE)
LARGE OFFICE (5 TO 19 STORIES)	12,379		
SMALL OFFICE (5 STORIES)	247,403		
GOVERNMENT OFFICE	60,493	339	GENERAL SERVICES ADMINISTRATION (GSA)
<u>RETAIL</u>			
SHOPPING CENTER	47,500	3,100	OIE
STORES	378,750	1,899	OIE
WAREHOUSES	111,500	2,168	OIE
INDUSTRIAL PLANTS	138,700	4,920	OIE
PRIVATE INSTITUTION	79,980	1,637	RATIO TO SCHOOLS
HOTEL/MOTEL	29,750	796	OIE
MILITARY	77,553	614	GEA
GOVERNMENT INSTITUTION	14,074	320	STAT ABSTRACT, 1975
HEALTH CARE	22,004	223	NATIONAL HEALTH STATISTICS
HOSPITAL	7,481	142	NATIONAL HEALTH STATISTICS
TERMINALS	10,875	137	OIE
LIBRARY/MUSEUM	24,832	798	STATISTICAL ABSTRACT, 1975
OTHER	278,750	1,532	OIE
TOTAL COMMERCIAL	(1,647,967)	(26,980)	
TOTALS. ALL CATEGORIES	(5,779,967)	(50,733)	

³ Norman Associates Inc., "Inventory and Ranking of the Existing Building Market, 1975," Dr. Norm Sidley, 1976.

3.1.4 Market Size Considerations

Building category selection for AEMS product concept definition considers marketing aspects as well as the high energy consumption factor. Two marketing aspects considered are:

- Strong market potential within selected target market segments;
- Strong potential for a basic "universal" AEMS concept.

While AEMS applications to the buildings must await further analysis, some estimate may be made of potential market size, also considering the universality of an AEMS concept for buildings. The final AEMS product concept obviously will be production-volume sensitive. To estimate the minimum market size for a successful AEMS market segment, the following initial assumptions are made:

- Seven-year AEMS product life;
- Twenty-percent market penetration;
- Ten major suppliers, each requiring \$1 million in annual sales;
- Selling price of \$7500.

Under these assumptions, the required minimum market size is:

$$\frac{(\$1 \text{ million})(10 \text{ competitors})(7 \text{ years})}{(\text{year}) \quad (0.2) \quad (\$7500/\text{unit})}$$

or 46,670 buildings.

Figure 6b relates the number of buildings in each category to this minimum market criterion. The purpose of such a criterion is to address the possibility that an AEMS concept may be "building category dependent." Again, in this figure, the building numbers have been reduced by the correction factors previously determined to eliminate large and nonapplicable buildings. This dependency may not necessarily relate to AEMS functions, but may be more related to sales promotion techniques. Contractors or salesmen can often look for sales "multipliers," i.e., chains, franchises or other multiple ownership concepts. Furthermore, a multiplicity of similar installations increases familiarity with installation and tuneup problems, allowing for more accurate installation and energy savings estimates and thereby enhancing competitive position. Scanning the ads in trade journals shows that supermarkets, hotels and motels, department stores and others are being singled out for "Energy Management" and "Load Management" controls. In fact, partly because of this existing industry focus, we eliminated ed

Figure 6. Ranking of Energy Use and Building Population

the above, and other building categories, from concentrated consideration in this program. The existence of these controllers on the market is de facto evidence that various automation concepts are technically feasible, at least for these particular building sectors.

It remains to be determined whether these controllers actually satisfy the criteria to be developed relating to AEMS concept requirements.

Other building categories that were eliminated include:

- Industrial Plants - Considered out of scope because we are dealing with commercial categories. However, these plants will have lights and HVAC equipment amenable to control just like any other building. Industrial processes are also considered out of scope; process energy control in an industrial plant will likely include HVAC energy as well.
- Hospitals - Characterized by high energy use. However much of this "excess" energy is related to equipment and services dictated by patient's needs and other health standards--usage patterns that are difficult to alter. Although successful energy management programs have been documented for hospitals, their uniqueness makes them an unsatisfactory vehicle for a general study of this nature.

3.1.5 Conclusions on Building Selection

Schools, apartments and offices were retained as the primary building categories for AEMS applications study. In the studies and analyses to follow, these buildings will be the primary focus of attention.

It was recognized of course, that this focus could overlook some significant market potentials in other building sectors. However, the selection rationale was regarded as sound, and as the study progressed, particular means were sought to extrapolate findings to other building categories. From a marketing viewpoint, such extrapolation could be used on private versus public sector--both represented. Technically, the application of AEMS may be determined more by type and usage of HVAC systems and occupancy patterns than by building category per se, and this point is also addressed.

Also in retrospect, after completing the analyses, apartments proved to be a weak candidate for central AEMS automation as currently envisioned. However, because of their statistical domination in energy use, they remain a challenge for automated control, and areas where this might be feasible are discussed.

3.2 HVAC SYSTEMS

3.2.1 Summary

The approximate division of building energy usage is shown in Figure 7. The obvious domination of space heating and cooling suggests that consideration of energy control concepts focus in that area.

Consequently, surveys were made of the HVAC systems found in representative buildings throughout the U.S. These were then analyzed to determine where areas of energy waste could be identified. In particular, waste that could be reduced through application of controls was of primary interest. These control areas are described in general terms and are later developed into particular control functions.

Of particular interest in this subsection is the multiplicity of HVAC types. It is noted that, within the three building categories, virtually "all" potential HVAC systems and combinations thereof are represented. Specific extrapolations to other building categories are not made, but the implied extrapolation to other buildings is significant.

3.2.2 Building HVAC Systems in Offices, Schools and Apartments

Since the nature and effectiveness of an energy management controller in a given building is dependent to a large degree on the installed HVAC system(s), a survey* was made to identify such HVAC installations. Consistent with the program scope, this survey focused on schools, office buildings and apartments.

Building systems may vary from the simple type, which provides heating and cooling to both the perimeter and the interior, to a more complex type, which serves the perimeter with different equipment than that which serves the interior. Some systems include perimeter equipment to provide both heating and cooling; other systems have independent perimeter heating and cooling equipment. A heat pump is an example of the former, while a radiator for heating and a through-the-wall cooling unit are examples of the latter.

* Based on information obtained from the firsthand knowledge and experience of HVAC engineers at the offices of Syska and Hennessy, Consulting Engineers; the engineers surveyed were employed in the New York City, Washington, D.C., Los Angeles and San Francisco offices of the firm. Buildings under 75,000 square feet gross area were stressed.

Figure 7. Distribution of Energy Use in Buildings²
(BTU Basis-1970)

²Federal Energy Administration, "Project Independence, Residential and Commercial Energy Use Patterns: 1970-1990," A.D.Little, Inc., 1974.

Various combinations of this equipment are described in the tables that follow. Each combination of equipment that provides heating and cooling for the perimeter and the interior is designated by a "system type" number, which applies to all components of the combinations.

The tabulation includes only those combinations or "system types" most commonly found throughout the country. It does not include those systems found only in climates where either heating or cooling is not required. However, in colder climates, it is not unusual to find older school buildings with no cooling since they are closed during the summer months. These have been included in the tabulation.

In apartment houses and small schools, since most of the occupied areas are on the perimeter, no interior system category has been indicated. The tabulation of the systems is arranged according to building category (see Index of HVAC Tabulations, Table III). The tabulations include the following information for each system type:

- Room Terminal Equipment - Includes fan-coil units, incremental room units, radiators, air outlets, heat pump units, unit ventilators, and through-the-wall air conditioning units.
- Distribution System - Includes one-pipe hot water, two-pipe hot water, steam or chilled water, air ducts, multi-zone ducts, electric wiring or none.
- Generating Equipment - Includes central boilers, electric reheat coils, central chiller, central self-contained AC unit, rooftop water and air-cooled condensers, auxiliary boilers, central furnace, self-contained direct expansion cooling.
- Control Type - Appropriate controls are defined for each of the above segments of the HVAC systems and are indicated by the numbers defined in Table IV. (Note: These are the usual controls associated with the equipment, not AEMS controls.)

The distribution of these systems by climate and by relative age is shown in Table V. They are categorized by climate rather than by geographic or political region since the design of heating and air conditioning systems in any large geographic region is dependent on the climate, which may vary considerably within the region.

Table III. Index to Tabulation of HVAC Systems

SYSTEM TYPE NUMBER	TABLE NO.
<u>OFFICE BUILDINGS</u> <u>Systems 1 through 4</u> Perimeter Heating Perimeter Cooling Interior Cooling <u>Systems 5 through 16</u> Perimeter Heating Combined Perimeter Heating and Cooling <u>Systems 17 through 20</u> Combined Perimeter Heating and Cooling Interior Cooling	VI VII VIII VI IX X XI
<u>SCHOOL BUILDINGS</u> <u>Systems 1 through 13</u> Heating Cooling	XII XIII
<u>APARTMENT BUILDINGS</u> <u>Systems 1 through 9</u> Heating Cooling	XIV XV

Table IV. Control Types

NUMBER	CONTROL TYPE	FUNCTION
1.	Boiler Burner	Controlled by boiler steam pressure controller or hot water thermostat, respectively. Control set points are reset manually or by a controller as the outdoor temperature varies. Modulating burner control on larger installations; on-off on smaller installations.
2.	Warm Air Furnace (direct-fired oil/gas)	Burner controlled by discharge air temperature controller, usually high-low-off control on large installations; on-off on smaller installations.
3.	Electric Heating Coils	In central air conditioning equipment or ducts. Discharge Air Controller: multistage. SCR (Silicon Control Rectifier) for modulating control on newer installations. Duct reheaters controlled by room or zone thermostat, usually one- or two-stage.
4.	Steam or Hot Water Coils	Air handler discharge controller modulates steam or hot water valve. Duct reheaters controlled by room or zone thermostat.
5.	Unit Ventilators	a. Steam or hot water: individual thermostatically controlled valve, or face and bypass damper control. Wall or unit mounted thermostat. b. Electric heating: one- or two-stage thermostatic control, interlocked with blower.
6.	Individual apartment boilers, furnace	Space thermostat controls burner, on-off.
7.	Electric Boiler	Multistage control of boiler water temperature by immersion type thermostat.
8.	Multizone Unit	Return air and outside air dampers are modulated to take advantage of outdoor air cooling when and where applicable, with fresh air dampers at minimum setting during extremes of weather. Hot deck controlled as for Control Type 2 or 4, as applicable. Cold deck controlled as for Control Type 10, or as applicable.
9.	Direct Radiation	Individual valve controlled by room thermostat. For electric radiation an integral thermostat or a wall mounted thermostat is provided. For continuous finned pipe hot water radiation, control is by rescheduling water temperature based on outside air temperature sensor.
10.	DX-System for Multizone Unit	Any zone calling for cooling will operate refrigeration compressor. A hot gas bypass control is sometimes provided as integral equipment.
11.	Chiller	Chilled water discharge temperature controller loads and unloads compressor in stages. On larger projects a centrifugal type chiller may be used. The discharge controller modulates variable inlet vanes on the chiller to maintain chilled water temperature. Controls generally furnished with equipment.
12.	Self-Contained Air Conditioning	Room thermostat cycles refrigeration.
13.	Fan-Coil	Three speed fan switch and/or valve controlled by integral thermostat. If electric coil, coil is interlocked with fan switch (in steps if provided).
14.	Central Air-Handling Unit	Outside air/return air dampers, cooling coil valve and heating coil valve are modulated sequentially to maintain discharge air temperature (multizone application) or room temperature (single zone application). In dry climates with infrequent high temperatures, 100 percent outside air is used during cooling mode and then modulated during heating mode.
15.	Variable Air Volume (V.A.V.) Control	Inlet vanes on the supply fan (and return fan) are controlled by a static pressure controller to reduce air quantity as the V.A.V. boxes are throttled by their respective room thermostats.

Table V. Climatic and Age Distribution of HVAC Systems.

BUILDING CATEGORY	CLIMATE AGE ZONE	COOL	TEMPERATE	WARM-DRY	WARM-MOIST
Schools	Older	1, 2, 5, 6, 9	1, 2, 6, 9, 11, 12, 13	4, 6	8, 10
	Newer	2, 5, 7, 9	2, 3, 4, 7, 8, 9, 10	4, 8, 10	4, 8, 10
Apartments	Older	1, 2, 3, 4, 9	1, 2, 3, 4	1, 2, 3	
	Newer	1, 2, 3, 4, 6, 9	1, 2, 3, 4, 6	4, 5, 7, 8	5, 7, 8
Offices	Older	1, 3, 5, 6, 9, 11, 12	1, 2, 3, 4, 5, 6, 9, 11, 12, 13, 15	13, 15, 9	2, 4, 13, 15
	Newer	1, 3, 5, 6, 7, 8, 9, 10, 11, 17, 18	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20	13, 16, 19, 20	2, 4, 13, 14, 15, 19, 20

* Numbers listed are HVAC system type numbers as listed in Tables VI through XV.

Table VI. Office Buildings, Perimeter Heating

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Fan-Coil Units (Two-Pipe)	13	Two-Pipe Hot Water	-	Central Boiler	1	Gas or Oil	Individual Room
2	Fan-Coil Units with Integral Electric Heat- ing Coil	13	None	-	None	-	Electricity	Individual Room
3	Incremental Type Room Units with Hot Water Coil	Integral Thermostat	Two-Pipe Hot Water	-	Central Boiler	1	Gas or Oil	Individual Room
4	Incremental Type Room Units with Electric Coil	Integral Thermostat	None	-	None	-	Electricity	Individual Room
5	Direct Radiation	9	Two-Pipe Hot Water or Steam	-	Central Boiler	1	Gas or Oil	Single or One per Exposure
6	Direct Radiation	9	Two-Pipe Hot Water or Steam	-	Central Boiler	1	Gas or Oil	Single or One per Exposure
7	Direct Radiation	9	Two-Pipe Hot Water or Steam	-	Central Boiler	1	Gas or Oil	Single or One per Exposure
8	Direct Radiation	9	Two-Pipe Hot Water or Steam	-	Central Boiler	1	Gas or Oil	Single or One per Exposure

Table VI. Office Buildings, Perimeter Heating
(Concluded)

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
9	Air Outlets	-	Air Ducts; Re- heat Coils; Two-Pipe Hot Water	4	Central Boiler	1	Gas or Oil	Individual Room
10	Air Outlets	-	Air Ducts; Re- heat Coils; Two-Pipe Hot Water	4	Central Boiler	1	Gas or Oil	Individual Room
11	Air Outlets	-	Air Ducts; Re- heat Coils; Two-Pipe Hot Water	4	Central Boiler	1	Gas or Oil	Individual Room
12	Air Outlets	-	Air Ducts; Re- heat Coils; Two-Pipe Hot Water	4	Central Boiler	1	Gas or Oil	Individual Room
13	Air Outlets	-	Air Ducts		Electric Reheat Coils	3	Electricity	Individual Room
14	Air Outlets	-	Air Ducts		Electric Reheat Coils	3	Electricity	Individual Room
15	Air Outlets	-	Air Ducts		Electric Reheat Coils	3	Electricity	Individual Room
16	Air Outlets	-	Air Ducts		Electric Reheat Coils	3	Electricity	Individual Room

Table VII. Office Buildings, Perimeter Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Fan-Coil Units (Two-Pipe)	13	Two-Pipe Chilled Water	-	Central Refrigeration Unit Water Chiller	11	Electricity	Individual Room
2	Fan-Coil Units (Two-Pipe)	13	Two-Pipe Chilled Water	-	Central Refrigeration Unit Water Chiller	11	Electricity	Individual Room
3	Incremental Type Room Units	Integral Thermostat	None	-	Self-Contained	-	Electricity	Individual Room
4	Incremental Type Room Units	Integral Thermostat	None	-	Self-Contained	-	Electricity	Individual Room

Table VIII. Office Buildings, Interior Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Air Outlets	-	Central Air Handling Unit with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	Single or Multizone
2	Air Outlets	-	Central Air Handling Unit with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	Single or Multizone
3	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Unit, Water or Air-Cooled Condenser	12, or 8 and 10	Electricity	Single or Multizone
4	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Unit, Water or Air-Cooled Condenser	12, or 8 and 10	Electricity	Single or Multizone

Table IX. Office Buildings, Combined Perimeter - Interior Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
5	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Unit, Water or Air Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	8 and 10	Electricity	Multizone
6	Air Outlets	-	Central Air Handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	Multizone
7	Air Outlets	-	Central Air Handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	V.A.V.* Individual Room
8	Air Outlets	-	Air Ducts	-	Rooftop Self-Contained Air Conditioning Unit, Air-Cooled Condenser	11	Electricity	V.A.V.* Individual Room

* See V.A.V. Control Description, Type 15.

Table IX. Office Buildings, Combined Perimeter - Interior Cooling
(Concluded)

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
9	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Unit, Water or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	12	Electricity	Single or Reheat Zones
10	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Unit, Water or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	-	Electricity	V.A.V.*
11	Air Outlets	-	Central Air Handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	Single or Reheat Zones
12	Air Outlets	-	Central Air Handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	V.A.V.*
13	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	12	Electricity	Single or Reheat Zones

* See V.A.V. Control Description, Type 15.

Table IX. Office Buildings, Combined Perimeter - Interior Cooling
(concluded)

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
14	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	12	Electricity	V.A.V.*
15	Air Outlets	-	Central Air-handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	Single Reheat
16	Air Outlets	-	Central Air-handling Units with Chilled Water Coil, Two-Pipe Chilled Water and Air Ducts	14	Central Refrigeration Unit Water Chiller	11	Electricity	V.A.V.*

* See V.A.V. Control Description, Type 15.

Table X. Office Buildings, Combined Perimeter Heating and Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
17	Water Source Heat Pump Unit	Integral Thermostat	Two-Pipe Water Loop	-	Auxiliary Electric, Gas or Oil Boiler	7 or 1	As Applicable	Individual Room
18	Water Source Heat Pump Unit	Integral Thermostat	Two-Pipe Water Loop	-	Auxiliary Electric, Gas or Oil Boiler	7 or 1	As Applicable	Individual Room
19	Air Source Heat Pump Units with Electric Heating Coil	Integral	None	-	None	-	Electricity	Individual Room
20	Air Source Heat Pump Units with Electric Heating Coil	Integral	None	-	None	-	Electricity	Individual Room

Table XI. Office Buildings, Interior Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
17	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water-Cooled Condenser	12	Electricity	Single
18	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water-Cooled Condenser	12	Electricity	V.A.V.*
19	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water- or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	12	Electricity	Single
20	Air Outlets	-	Air Ducts	-	Central Self-Contained Air Conditioning Units, Water- or Air-Cooled Condenser or Rooftop Self-Contained, Air-Cooled Condenser	12	Electricity	V.A.V.*

* See V.A.V. Control Description, Type 15.

Table XII. School Buildings, Heating

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Direct Radiation	9	Two-Pipe Steam or Two-Pipe Hot Water	-	Central Boiler	1	Oil or Gas	Individual Classroom
2	Unit Ventilators	5a	Two-Pipe Steam or Two-Pipe Hot Water	-	Central Boiler	1	Oil or Gas	Individual Classroom
3	Unit Ventilators	5a	Two-Pipe Steam or Two-Pipe Hot Water	-	Central Boiler	1	Oil or Gas	Individual Classroom
4	Unit Ventilators	5a	Two-Pipe Steam or Two-Pipe Hot Water	-	Central Boiler	1	Oil or Gas	Individual Classroom
5	Air Outlets	-	Multizone Warm Air Ducts	8	Central Boiler. HV Units with Steam or Hot Water Coils	1 with 4	Oil or Gas	Multizone or Individual Classroom
6	Air Outlets	-	Multizone Warm Air Ducts or Dual Duct	8	Central Direct- Fired Warm Air Furnace	2	Oil or Gas	Multizone or Individual Classroom
7	Air Outlets	-	Multizone Warm Air Ducts	8	Central Roof- top Multizone Unit with Direct-Fired Heater or Electric Heating Coil	8	Gas or Electricity	Multizone or Individual Classroom

Table XII. School Buildings, Heating
(Concluded)

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
8	Air Outlets	-	Multizone Warm Air Ducts	8	Central Roof- top Multizone Unit with Direct-Fired Heater or Electric Heating Coil	8	Gas or Electricity	Multizone or Individual Classroom
9	Unit Ventilators	5b	None	-	Electric Heating Coil In Unit Ventilator	5b	Electricity	Individual Classroom
10	Unit Ventilators	5b	None	-	Electric Heating Coil In Unit Ventilator	5b	Electricity	Individual Classroom
11	Air Outlets	-	None	-	Individual Warm Air Furnace	2	Gas	Individual Classroom
12	Air Outlets	-	Warm Air Floor	-	Central Warm Air Furnace with Electric Reheat in Classroom	2 and 3	Gas	Individual Classroom
13	Air Outlets	-	Warm Air Floor	-	Individual Warm Air Furnace with Electric Reheat	2	Gas and Electric	Individual Classroom

Table XIII. School Buildings, Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	None	-	None	-	None	-	None	None
2	None	-	None	-	None	-	None	None
3	Unit Ventilators	Integral Thermostat	None	-	Self-Contained DX	-	Electricity	Individual Classroom
4	Unit Ventilators	Integral Thermostat	Two-Pipe Chilled Water	-	Central Chiller	11	Electricity	Individual Classroom
5	None	-	Two-Pipe Chilled Water	-	None	-	Electricity	Individual Classroom
6	None	-	Two-Pipe Chilled Water	-	None	-	Electricity	Individual Classroom
7	None	-	Two-Pipe Chilled Water	-	None	-	Electricity	Individual Classroom
8	Air Outlets	-	Multizone Ducts	-	Self-Contained Roof-top DX Air-Cooled Refrigeration Unit	8	Electricity	Multizone or Individual Classroom
9	None	-	None	-	None	-	None	None
10	Unit Ventilators	Integral Thermostat	None	-	Self-Contained DX	-	Electricity	Individual Classroom
11	None	-	None	-	None	-	None	None
12	None	-	None	-	None	-	None	None
13	None	-	None	-	None	-	None	None

Table XIV. Apartment Buildings, Heating

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Direct Radiation	-	One-Pipe Steam or Two-Pipe Hot Water	-	Central Boiler	1	Oil or Gas	None
2	Direct Radiation	-	One-Pipe Hot Water	-	Individual Apartment Boiler	6	Gas	One Per Apartment
3	Air Outlets	-	Warm Air Ducts or None	-	Individual Apartment or Room Furnace	6	Gas	One Per Room or Apartment
4	Direct Radiation	9	Electric Wiring	-	-	-	Electricity	One Per Room
5	Air Outlets	-	Air Ducts	-	Electric Heating Coil in Apartment Fan-Coil Unit	5	Electricity	One Per Apartment
6	Through-Wall Pump Unit with Supplementary Electric Heating Coil	Integral Thermostat	None	-	Electric Heating Coil	-	Electricity	One Per Unit
7	Through-Wall Heat Pump	Integral Thermostat	None	-	Heat Pump Only	-	Electricity	One Per Unit
8	Through-Wall AC Unit with Electric Heating Coil	Integral Thermostat	None	-	Electric Heating Coil	-	Electricity	One Per Unit
9	Fan-Coil Hot Water or Electric*	13	None	-	Central Boiler or Electric Coil	1 or 5	Oil/Gas, Electricity as Applicable	One Per Room

* In older buildings.

Table XV. Apartment Buildings, Cooling

SYSTEM TYPE NUMBER	ROOM TERMINAL EQUIPMENT	CONTROL TYPE NUMBER	DISTRIBUTION SYSTEM	CONTROL TYPE NUMBER	GENERATING EQUIPMENT	CONTROL TYPE NUMBER	ENERGY SOURCE	ZONING
1	Window AC Unit or Through-Wall AC Unit	Integral Thermostat	None	-	None	-	Electricity	One Per Unit
2	Window AC Unit or Through-Wall AC Unit	Integral Thermostat	None	-	None	-	Electricity	One Per Unit
3	Window AC Unit or Through-Wall AC Unit	Integral Thermostat	None	-	None	-	Electricity	One Per Unit
4	Window AC Unit or Through-Wall AC Unit	Integral Thermostat	None	-	None	-	Electricity	One Per Unit
5	Air Outlets	-	Direct Expansion Split System Apartment Fan-Coil Unit with Air Ducts	-	Roof-Mounted Air-Cooled Condensing Unit	12	Electricity	One Per Apartment
6	Through-Wall Heat Pump Unit	Integral Thermostat	None	-	Self-Contained	-	Electricity	One Per Unit
7	Through-Wall Heat Pump Unit	Integral Thermostat	None	-	Self-Contained	-	Electricity	One Per Unit
8	Through-Wall AC Unit	Integral Thermostat	None	-	Self-Contained	-	Electricity	One Per Unit
9	Fan-Coil	13	None		Central Chiller	11	Electricity	One/Room

It would be impractical, in the context of this study, to break the U.S. into small areas, each having a distinct type of climate. Climatic conditions have been designated as cool, temperate, warm-dry and warm-moist.

Considering the wide variety of heating and cooling equipment available, economics, location of the building relative to the equipment manufacturer and changing developments in the industry, it is not surprising to find a large variety of combinations of equipment in any given locality. The distribution tabulation reflects this variety of systems.

3.2.3 Population of HVAC Systems

The original survey of HVAC systems did not include quantitative information on the frequency of occurrence of particular systems. In an attempt to derive this information, a question was included in the mailed survey during the second phase of the market analysis. The question was couched in the common terms used as general descriptions of such systems, and did not probe as deeply into the details of the system as the original HVAC survey.

The resultant data are presented in Volume II of this report, correlating HVAC type with building sector, age and size of building. This data has not been cross-correlated with the original survey, primarily due to lack of time between processing of the data and writing of this report. Nevertheless, some total results are presented here to set the stage for some of the analysis to follow.

Figure 8 is a summary of distribution of HVAC types. One aspect of the market survey makes this data difficult to interpret. Each respondent, if he had control over more than one building, selected one for his responses to the questions. As it turned out, each respondent controlled an average of 30 buildings. This statistic in itself is significant if one considers the "multiplier factor" considered in sales. However, it is not known by what rationale the respondent selected his "typical" building, although 49 percent of the buildings were 10 years old or less.

3.2.4 AEMS Control Potential - HVAC Systems

The wide variation in HVAC types identified in the previous paragraphs implies a similar wide potential of control applications for energy management. The various features of these systems are explored for such application. Commonality of system elements are

Figure 8. Frequency of Occurrence of HVAC Types by Building Sector

used as the basis for this analysis, recognizing that this approach provides an extrapolation across building types, thereby extending the scope and applicability of results.

The various HVAC systems are now presented in a somewhat different fashion, in block diagram format, in Figures 9 through 15. These figures group the major elements, central generating equipment, distribution system and room terminal equipment, showing the combinations of systems sharing common elements and arranged by building category.

Inspection of these block diagrams reveals two important distinctions--location of energy generating equipment and types of control concepts generally employed. These will be identified and categorized to develop rationales for central control concepts and to identify areas of potential wasteful energy practices.

3.2.4.1 Central Versus Local Generating Equipment--It is noted that the various heating and cooling systems can be immediately categorized on the basis of whether the energy generating systems are centrally located in the building or distributed locally by room, zone or apartment. This breakdown is shown in Tables XVI and XVII, which will be used to summarize the data that follow in an attempt to delineate the potential applications of AEMS control referenced to type of HVAC. In Column 1 of the referenced tables, the system classification numbers defined earlier are shown. Offices generally are characterized by centrally based generating systems, apartments by local, and schools about equally divided between the two types of equipment.

The distinction of local versus centralized equipment presents no direct limitation to the concept of centralized control. Remote units, of course, may be "controlled" from a remote central location. Depending on the level of control under consideration, it may have a significant impact on installation requirements.

One fact does stand out, however, in terms of energy waste. Local units, although characterized by "efficient" closed-loop, single-zone operation, as will be discussed next, represent an "uncontrolled" source of energy usage, subject to the whims and motivation (or lack thereof) of the individuals responsible for their operation.

3.2.4.2 Basic HVAC System Control Concepts--The way systems operate under normal control is known to be quite often wasteful of energy. An open window in an overheated apartment is often cited as a simple example. The same thing occurs in more complex systems

INSET NUMBERS
 • REFER TO BASIC
 CONTROL TYPE, TABLE IV

Figure 9. Office Systems 1-4: Perimeter Heating; Perimeter Cooling; Interior Cooling

Figure 10. Office Systems 5-16: Perimeter Heating; Combined Perimeter and Interior Cooling

Figure 11. Office Systems 17-20: Combined Perimeter Heating and Cooling; Interior Cooling

Figure 12. School Systems 1-13: Heating System Variations

Figure 13. School Systems 1-13: Cooling

Figure 14. Apartment Systems 1-9: Heating

Figure 15. Apartment Systems 1-9: Cooling

Table XVI. Summary of Analysis of Heating Systems

GENERATING EQUIPMENT	DESCRIPTION OF SYSTEM				1			2	3	4	5	6	7		
	DISTRIBUTION SYSTEM		ROOM TERMINAL EQUIPMENT	ZONING	SYSTEM NO.			CONTROL TYPE (SEE TEXT)	SEQUENCE HEATING/COOLING	LOAD EFFICIENCY IMPROVEMENT SUPPLY TEMPERATURE RESET	VENTILATION WARM-UP CYCLE	OPERATION START-STOP RESET	CONTROL OPTIMAL START		
	PRIMARY	SECONDARY			OFFICE	SCHOOL	APARTMENT								
CENTRAL	CENTRAL BOILER	TWO-PIPE HOT WATER OR STEAM	CONSTANT VOLUME, TERMINAL REHEAT COILS OR MULTIZONE	INCREMENTAL	INDIVIDUAL ROOM	3			C		X		X	X	
				FAN-COIL		11		9	C		X		X	X	
				DIRECT RADIATION	SINGLE OR ONE PER EXPOSURE	5,6,7,8	1		B		X		X	X	
				UNIT VENTILATORS	INDIVIDUAL CLASSROOMS		2,3,4		C		X		X	X	
				AIR OUTLETS	INDIVIDUAL ROOM	9,10,11,12	5		A,D	X	X	X	X	X	
		ONE-PIPE STEAM OR HOT WATER		DIRECT RADIATION	NONE			1	B		X		X	X	
	AUXILIARY BOILER	TWO-PIPE HOT WATER	-	WATER SOURCE HEAT PUMP	INDIVIDUAL ROOM	17,18			A				X	X	
	CENTRAL WARM-AIR FURNACE	MULTIZONE WARM AIR DUCTS	-	AIR OUTLETS	MULTIZONE		6		C		X	X	X		
		DUAL DUCT DUCTS		WARM AIR FLOOR-ELECTRIC REHEAT	INDIVIDUAL CLASSROOMS		12		A			X	X		
ROOFTOP MULTIZONE	MULTIZONE DUCTS	-	AIR OUTLETS	MULTIZONE OR INDIVIDUAL		7,8		C	X	X	X	X			
LOCAL	AIR SOURCE HEAT PUMP	AIR DISCHARGE	REHEAT COIL	AIR OUTLET	INDIVIDUAL ROOM OR APARTMENT	19,20		6,7	A, A	X			X, X		
	-	-	ELECTRIC COILS	DIRECT RADIATION				4	A				X		
				INCREMENTAL		4			A				X		
				FAN-COIL		2		5	A				X		
				UNIT VENTILATORS			9,10		A				X		
	THROUGH-THE-WALL UNIT	-	REHEAT COIL	AIR OUTLET				8	A				X		
	INDIVIDUAL BOILER	ONE-PIPE HOT WATER	-	DIRECT RADIATION				2	A				X		
	INDIVIDUAL FURNACE	DISCHARGE OR DUCT		ELECTRIC REHEAT COIL	AIR OUTLETS			11	3	A	X		X	X	X
								13		A	X		X	X	
	AIR-HANDLING UNIT-DUCTS	ELECTRIC COILS	AIR OUTLETS			13,14,15,16			A	X					

Table XVII. Summary of Analysis of Cooling Systems

GENERATING EQUIPMENT		DESCRIPTION OF SYSTEM				1			2	3	4	5	6
		DISTRIBUTION SYSTEM		ROOM TERMINAL EQUIPMENT	ZONING	SYSTEM NO.			POTENTIAL WASTE AND OPERATIONAL CONTROL FUNCTIONS				
						OFFICE	SCHOOL	APARTMENT	CONTROL TYPE (SEE TEXT)	SEQUENCE HEATING AND COOLING	LOAD EFFICIENCY IMPROVEMENT	VENTILATION CONTROL ENTHALPY	OPERATIONAL CONTROL START-STOP RESET
CENTRAL	CENTRAL CHILLER	TWO-PIPE CHILLED WATER	-	FAN COIL UNITS	INDIVIDUAL ROOM	1, 2		9	C		X		X
			AIR-HANDLING UNIT, DUCTS	AIR OUTLETS	SINGLE OR MULTIZONE	1, 2			A,B		X	X	X
					MULTIZONE	6			B		X	X	X
					V.A.V INDIVIDUAL ROOM	7, 12, 16			C	X	X	X	X
					SINGLE OR REHEATING ZONES	11, 15			C	X	X	X	X
			-	UNIT VENTILATORS	INDIVIDUAL CLASSROOM		4		C		X		X
	SELF-CONTAINED, WATER/AIR-COOLER CONDENSER OR ROOFTOP SELF-CONTAINED, A/C-COOLED CONDENSER	AIR DUCTS	-	AIR OUTLETS	SINGLE OR MULTIZONE	3, 4, 17, 19			A,B		X	X	X
					MULTIZONE	5			B		X	X	X
					V.A.V INDIVIDUAL ROOMS	8,10,14, 18,20			D	X	X	X	X
					SINGLE OR REHEAT	9, 13			C	X	X	X	X
SELF CONTAINED ROOFTOP D-X	MULTIZONE DUCTS	-		MULTIZONE OR INDIVIDUAL CLASSROOMS		8		C	X	X	X	X	
ROOFTOP AIR-COOLED CONDENSER UNIT	DIRECT EXPANSION SPLIT SYSTEM AIR DUCTS	-	FAN-COIL UNIT	APARTMENT			5	C		X		X	
SELF-CONTAINED	-	-	UNIT VENTILATORS INCREMENTAL	INDIVIDUAL ROOM	3, 4	3,10					X		
THROUGH-THE-WALL A/C UNITS	-	-	AIR OUTLET	PER APARTMENT			1,2,3, 4,8	A				X	
THROUGH-THE-WALL HEAT PUMP	-	-	AIR OUTLET				6,7				X		

where the same air is both heated and cooled before delivery to the space. In both cases, the basic problem is that the heating and/or cooling energy employed is not directly related to the needs of the space in question. This concept will be explored by evaluating the control schemes used in the various systems.

3.2.4.2.1 Single-Zone, Closed-Loop (Control Type A)--This system, shown conceptually in Figure 16, is presented as the "ideal" control. Demands of the space directly control energy output of the heating or cooling device. The energy conversion efficiency of that device (EER, COP, etc.) is not an issue here, being a characteristic over which there is no control in a retrofit situation. Flue losses or combustion efficiency is a factor of interest and will be discussed later.

*DIRECT RADIATION
INCREMENTAL UNIT
FAN-COIL
UNIT VENTILATORS
THROUGH-THE-WALL A/C UNIT
HEAT PUMPS
INDIVIDUAL FURNACE

Figure 16. Single-Zone, Closed-Loop (Control Type A)

The Type A control thus is seen as a system having no inherent waste aspect in its operation, given that it's operation is not defeated by external considerations such as open windows, bad thermostat location, etc. Further, such systems, when supplying both heating and cooling, by design prevent both from being employed at the same time. When used independently with other heating or cooling systems, the possibility of simultaneous heating and cooling does exist. A potential for AEMS control is seen as providing interlocks to prevent or minimize this waste.

Control Types A are shown in Column 2 of the summary tables (XVI and XVII), and those that allow simultaneous heating and cooling are so indicated in Column 3. AEMS could provide, where appropriate, temperature setback, or setup, start/stop, electrical demand control and heating/cooling interlock.

3.2.4.2.2 Open-Loop (Control Type B)--Figure 17 illustrates a system operating open-loop with respect to the needs of the space(s) being supplied. It primarily represents the case of a central boiler providing steam or hot water to a series of radiators. The generation system is closed-loop, controlled manually or often with outdoor air temperature. With no measure of internal loads at the space to be heated, there is little likelihood that the amount of heat delivered is correct; more likely, the amount is too much or too little.

Selected samples of zone demands could be sensed by an AEMS control, adjusting boiler output to follow demand. If enough zones are sampled, the coldest zone may be the criterion for heat supplied, but that still leaves all the other zones with too much heat. Refitting all of the other zones with local control loops would further unload the boiler and improve operating efficiency. It is not unreasonable to accept this as a part of AEMS control, with the central control monitoring individual thermostat demands to determine the minimum level of heat required so that only one valve is fully open.

Again such a concept could be defeated with an open window or air conditioner. While an interlock is conceivable between the air conditioner and the radiator system, how does one interlock a window or open door? This implies there is an underlying "social" problem that must be solved by other than control means.

We will assume that AEMS control is applicable to this case, and further that refit with local controls on individual radiators is inherent. In this case, the control type reverts from B to C. AEMS control could provide night setback, on-off control and optimum start, as appropriate to given applications.

3.2.4.2.3 Series Open/Closed-Loop (Control Type C)--This type combines efficient closed-loop control of space temperature with the less efficient open-loop generating equipment (Figure 18). An example is a central boiler feeding the heating coils in a fan-coil unit. Control Types C are indicated in Column 2 of the summary tables (XVI and XVII).

Figure 17. Open Loop (Control Type B)

*CENTRAL BOILER
CENTRAL FURNACE
CENTRAL CHILLER

Figure 18. Series Open/Closed-Loop (Control Type C)

Again the load efficiency of the entire system may be improved by closing the loop from space demand to the central generating system. Depending on the system, such sampling may be via zone valves, dampers or thermostats. About half the heating and cooling systems fall into this category. Waste reduction again is limited by the fact that only "one" space may be thus optimized, as in the previous example. It should also be recognized that for buildings with relatively steady and predictable loads, it may be possible to "tune-up" outdoor air control of a central boiler to very closely approach the above-described efficiency. Thus, economic benefits of such an approach will in turn be limited.

Possibility of simultaneous heating and cooling also exists with certain of the Type C systems, and these are indicated in the summary tables (XVI and XVII).

3.2.4.2.4 Multiple Open/Closed-Loop (Control Type D)--With this type, we have a series of open-loop controllers before the loop is closed around the space conditions (Figure 19). As may be expected, the potential inefficiencies climb with such an arrangement. An example may be a central chiller providing chilled water to coils in a cold deck, which is controlled to provide constant temperature output. An air-handling unit supplies this cooled air to the space, where it is reheated to meet the demands of the space. This roughly describes a terminal reheat system. Other systems employing this control concept are indicated in the summary tables (XVI and XVII).

AEMS control will use sensed space demands to modify both the initial and intermediate control loop outputs. Because of the known large inefficiencies of such systems, there are a number of controllers available in the marketplace to accomplish this function.

3.2.4.3 Ventilation Control--Code requirements for fresh air impose a significant, but necessary, part of the load in commercial buildings. Apartments, in general, are excepted from this consideration. Several factors are discussed with respect to ventilation from the viewpoint of an AEMS controller. These factors mostly relate to reducing the amount of introduced outdoor air to the minimum level possible. Outdoor air may be introduced through either the heating or cooling system and either through air-handling units (more amenable to central control) or through individual units such as fan-coil. In this case, local individual control is normally employed and may be more cost effective.

Figure 19. Multiple Open/Closed-Loop (Control Type D)

3.2.4.3.1 Minimum Air--Introduction of outdoor air is another case of "open-loop" control with respect to the requirements of a space. Recent changes to standards have changed the criterion from building area to number of occupants, a decided improvement, which generally reduces the amount of air required and which can and should be done in any building independently of other control considerations. Where building occupancy varies significantly, even this criterion may be grossly conservative. A viable "occupancy sensor" could be used to "close the loop" on the occupancy criterion. Of course, this still does not address the real requirement, that of desired air quality within the space. Air quality sensors would close the correct loop, assuming air quality standards can be adequately defined. Both of the above concepts are in various stages of development within the industry, and an AEMS concept should consider these possibilities toward ventilation minimization.

Because the criterion relates directly to occupancy, means should be provided in fresh air systems to effect closing off the outside air during periods of nonoccupancy. This includes periods when the systems are running to maintain reduced temperatures and during the warm-up period following shutdown. If such HVAC control is provided from AEMS control, ventilation should also be included as a controlled parameter.

3.2.4.3.2 Free Cooling--In air-handling systems that are or can be economically arranged to supply up to 100 percent outdoor air, and that have provision to exhaust or relieve the same amount of air to the outdoors, various versions of "free cooling" can be considered for AEMS. Systems with this capability generally employ an economizer cycle, wherein maximum outdoor air is admitted whenever the outside air dry-bulb temperature is less than the space design condition.

The local temperature controls change the damper settings for minimum outside air when the dry-bulb setting is exceeded. This dry-bulb economizer cycle results in excessive space humidity conditions when the outdoor air humidity is high. Consequently, in areas where the outdoor wet-bulb temperatures frequently exceed the space design wet-bulb conditions, the dry-bulb changeover point is set and remains at a much lower temperature. This assures comfort conditions throughout the range of humidity conditions that might be encountered during the cooling season, but does not take advantage of outdoor cooling capacity when the outdoor humidity drops to usable levels. Packaged local electronic/pneumatic controls are available that control the dampers by comparing measured outdoor air enthalpy with indoor design enthalpy and the return air dry-bulb temperature. An AEMS can refine this approach by comparing outdoor enthalpy of the measured return air enthalpy.

Such controls may be implemented locally at the appropriate dampers. However other AEMS considerations, such as the previously mentioned sequencing of heating and cooling, lead to the consideration of using the free cooling capability as the first stage of cooling, with enthalpy control as an override. Versions of this type of control are available and are listed in the section on current equipment.

Ventilation considerations for AEMS are summarized in Tables XVI and XVII. In general, this type of control is most easily implemented in central systems. However, the possibility of retaining central control over individual ventilation and or exhaust unit should be a consideration in any type of centralized system that is attempting to provide maximum control over energy usage in a building.

3.2.5 Miscellaneous HVAC Controls and Summary--It has been indicated that a large number of the various HVAC systems identified for schools, offices and apartments, and presumably most other small buildings, operate in an energy wasteful manner that is amenable to controls. Primarily, this requires improving the efficiency of operation of heating, cooling and ventilation with

respect to the loads actually present, removing much of the open-loop aspect of their operation. This "load efficiency" improvement will be developed further as the AEMS functions are detailed in the next section.

These systems, in addition to those which already operate in an energy efficient manner, may also be subjected to centralized control from the viewpoint of start-stop, temperature reset (setback or setup), optimum start time, as well as heating-cooling interlocks.

From the summary tables (XVI and XVII) we can see that virtually all HVAC systems identified may be considered as candidates for AEMS control. The economics of such considerations will be explored in subsequent sections.

3.3 FUNCTIONAL ANALYSIS

The objective of this task was to provide a slate of candidate control (and other) functions to serve as the basis for further analysis and, hopefully, to define a basic "feature-set" for a viable AEMS concept.

Of primary importance, since any system must "pay its way," are those functions that save money. The savings could result from a reduction in energy usage, a potential for manpower reduction or cost avoidance, as in electrical demand reduction.

Of secondary importance, but considered nevertheless, are those functions that enhance or expand the capabilities of an AEMS but are difficult to justify on a cost-savings economic basis. These include classroom bells, monitoring or maintenance alarms, security or fire alarm systems, etc. Such adjuncts could potentially enhance a sale or perhaps provide such capability more reasonably than a stand-alone system.

In the following sections, some candidate control functions are identified and defined, along with appropriate rationales for their exclusion or inclusion as part of an AEMS concept. It should be recognized, however, that the recommended functions are not intended to be all-inclusive or final, but rather to represent a set that is felt to be adequate to demonstrate the feasibility of the AEMS concept that evolves therefrom.

3.3.1 Energy and Cost Savings Functions

The functions are recognizable, all known to save energy and can be implemented today by manual means or through currently available equipment.

3.3.1.1 Electrical Demand Limiting Control--Electrical demand limiting as an AEMS function requires serious consideration from two points of view--short and long term. By short term we refer to a solution of reducing demand charges currently being imposed by utilities. Common methods employ means of deferring electrical loads to even out the peaks and valleys of electrical demand and consumption. The economic benefit to the commercial user has been clearly established by the many devices available on the market.

The impact of such devices on the utilities' problems of electrical generation requirements is less clear.⁴ For a given customer, his electrical loads may, in fact, be deferring to the utility's peak times. This leads to the second point, long term consideration. Utility industry studies⁴ and actions point to increasing entry of utilities into point-of-use control of electrical demand and consumption, as well as time-differentiated and other price structures, as means of indirect control.

Even this "long" term aspect is nearly upon us. Cobb County, Georgia, will have a system operational in 1980 that will be installed in 50,000 homes, providing utility initiation of load-shedding and visual indication of time-differential pricing periods. Manual override will be provided to the homeowner should he elect to reinstate his loads during the high-priced time period.

Consequently, in one form or another, we can reasonably expect that electrical demand control must be considered an essential function of an AEMS. If the concept becomes universally applied, even to the level of single-family homes and individually metered apartments, then it may well become the primary AEMS function, with other load management functions provided as additional features or options. For the purpose of this evaluation, however, we will focus upon the "conventional" concept, it being better defined and allowing some initial economic analysis.

This is probably conservative, since load control will return significantly greater benefits under alternate pricing schemes. Interface with utilities is presumed.

⁴Electric Utility Rate Design Study, "Rate Design and Load Control," Sponsored by EPRI, et al, November 1977.

3.3.1.1.1 Description--Electrical demand limiting is basically the deferring of electrical loads to even out the peaks and valleys of electrical demand and consumption. The theory and fundamentals of load demand control will not be discussed, as such information can be found in numerous sources ^{5,6}.

Load demand limiting can be accomplished in several ways: by providing for the automatic shedding and restoration of loads on a priority basis; by scheduling or sequencing on-times of equipment (duty cycling) to limit the maximum number of loads on at one time; and, of course, manually. Of interest here is automatic shedding. Duty cycling will be discussed under a later function and may provide adequate demand limiting in certain applications.

3.3.1.1.2 AEMS Applicability--A number of conditions must be met in a building to justify consideration of demand load limiting. These are presented as rules of thumb often used by the industry:

- Central metering;
- Minimum electrical bill of \$1000/month;
- Twenty percent of building electrical loads sheddable;
- Demand profile characterized by spikes or peaks, short term with respect to demand interval used by utility in computing demand charges,

Prime candidate buildings are generally characterized by large numbers of devices, reciprocating or centrifugal chillers, or with electric heat or reheat systems.

Establishments such as hotels, motels, supermarkets, retail stores and restaurants readily meet these qualifications. As a consequence, there is available a plethora of load demand controllers that are directed toward these markets, and these represent "competition to an AEMS where suitable conditions exist.

⁵Sedgwich, J.D., and E.R. Williams, "Reducing Utility Costs through Load Management," Refrigeration Service and Contracting, January 1978.

⁶Elliot, Thomas C., "Demand Control of Industry Power Cuts Utility Bills, Points to Energy Savings," Power, June 1976.

The buildings selected for analysis in this study are, in general, poor candidates for the conventional load limiter:

- Offices - Except for electric heat or reheat systems, major electrical loads are associated with lights and single large air conditioning and/or blower systems. Sheddable loads are generally small compared to total load. However, even small loads may lead to sufficient economic benefit for AEMS. For example, in an analysis of a 30,000 square foot office building in Atlanta, if an 11 kw water heater were scheduled to operate only during compressor off-times, savings in a 2-1/2-year payback period would amount to \$1116.
- Schools - Because of lack of air conditioning systems in a large segment of the sector, their capability for electrical load demand is weakened. However, this is compensated somewhat by the tendency toward multizone units, which will increase the number of systems available for load control.
- Apartments - Since apartments are heavily implemented with single-zone, individual apartment systems and tend to be individually metered, the market for conventional load demand control is expected to be weak.

This weakness of the market for conventional load demand control may well work to the advantage of AEMS. Competition from those devices may not be a problem since, as mentioned earlier, they generally look for the "20 percent" potential. AEMS will be satisfied with less since demand control is only a part of its intended energy/cost saving capability.

From this consideration, as well as the long term potential for utility-interfaced demand control, this function is felt to be a viable candidate for AEMS.

3.3.1.2 Load Efficiency Improvement

3.3.1.2.1 General Description--In this category are those functions that attempt to alleviate the energy waste associated with simultaneous heating and cooling identified in the preceding section. Examples of this waste are open windows in an apartment heated from a central boiler or excessive simultaneous heating and cooling in multizone or reheat systems in an office building. These functions are particularly significant to an AEMS system since

there is no serious manual competition, although there are separate controllers available that provide various levels of optimization on these factors.

In principle, these functions require an active measurement of the space and/or building load and subsequent modification of the heating or cooling discharge temperatures in a prescribed fashion. Three specific examples of this type of function are given.

3.3.1.2.1.1 Reheat Optimization--One of the prototypical buildings devised for the energy and cost savings analysis for this study was assumed to have a constant volume, terminal reheat interior heating and cooling system. This system has achieved some notoriety as a classical example of wasteful energy practices developed during our cheap energy era. It is characterized by delivering a constant volume of constant temperature air, usually 55°F, to each zone, based on worst-case design conditions occurring simultaneously in all zones. Local zone thermostats then supply the impetus to add the required heat to this air at each zone to satisfy the zone's thermostat set point. Control modification requires that the cooling element in the system be controlled such that the supply or discharge air temperature is modified to meet exactly the needs of the zone requiring the most cooling, as determined by feedback from zone dampers, valves or thermostats.

Thus, at least one zone requires no reheat, and consequently all other zones require less reheat, as illustrated conceptually in Figure 20. The practical limit of optimization depends on ventilation requirements, season and dehumidification requirements and variation in internal loads. This concept also applies to dual duct and multizone systems, which together comprise a significant number of office and school buildings and, to a lesser degree, apartments (see Figure 8). In these cases, both hot and cold deck supply temperatures are modified to meet the needs of the coldest and hottest zones, respectively. The heating and cooling media (hot or chilled water, for example) can then be further modified as discussed below.

3.3.1.2.1.2 Boiler Optimization--Where a central boiler provides the heating source to a large number of zones, without feedback from those zones the potential for energy waste can be significant. Typically, in such applications, seasonal control of boiler steam pressure or water temperature is provided manually or adjusted automatically with outdoor temperature. The potential for better closed-loop control lies in providing a measurement of actual building load. This can be accomplished by monitoring zone valves, dampers, thermostats or strategically placed temperature

Figure 20. Concept of Reheat Optimization as Applied to Terminal Reheat System

sensors to develop the data required to modify boiler output to more closely match the actual load.

In principle, operation of this concept is similar to that previously discussed for the reheat system, with boiler output set to provide heat that is just adequate for the coldest zone.

3.3.1.2.1.3 Chilled Water Reset--Chilled water systems are listed as an element of some HVAC systems. In the potential AEMS market, these systems will generally be found only at the larger end of the building spectrum as they are generally not economically practical for smaller buildings.

Optimization of chiller operation may involve several factors. A rough rule of thumb for the energy savings that can be effected by this strategy is a one percent decrease in kilowatt input for each degree Fahrenheit the chilled water supply temperature is raised. The percentage is applied to the kilowatt requirement at the specific load condition--not the rated compressor load. Under light loads, a larger increase in chilled water temperature may be acceptable, but the one percent savings is applied to the lower kilowatt input at this light load. Raising chilled water temperature decreases the latent cooling capacity of the cooling coils. Therefore, space or return air humidity sensors must be installed and provisions made to limit the increase of chilled water temperatures such that acceptable humidity as well as dry-bulb space temperatures can be maintained. The feedback required for the AEMS is the chilled water temperature, the load on all chilled water using equipment, as well as the humidity conditions of the spaces they serve. The load conditions can be "read" from the position of the various control valves or from the branch line air pressure that controls the valve position. This control strategy can be effected by conventional pneumatic controls, as well as by AEMS. The AEMS would most likely be more cost effective at installations having a large number of chilled water using equipment.

While the load and power consumption decreases with an increase in chilled water discharge temperature, its efficiency decreases. The efficiency can be improved by decreasing the temperature of the water supplied to the chiller by the cooling towers at the expense of increased running time of the cooling tower equipment. Optimization of both parameters could be effected by AEMS control. Such optimization might also include operation of multiple chillers.

3.3.1.2.2 Summary--In the discussion of HVAC systems, many types were identified which operate and are controlled in an inefficient manner with respect to actual space loads. Implementation of corrective controls will take many forms, as shown in the preceding discussion, but where applicable will be a major element in an AEMS concept. Savings, of course, will also vary, but this type of function is the basis for many current controllers. with case histories showing very favorable return on investment.

3.3.1.3 Ventilation Control--As representative of one of the major heating loads, control over outside air must be considered part of an AEMS configuration. However, a number of factors combine to make economic benefits difficult to derive in many applications. Possible ventilation control concepts have already been discussed under HVAC systems, and the following discussion relates them to AEMS control.

3.3.1.3.1 Minimum Air for Occupancy--In conventional usage, this is a static consideration. Minimum levels should be measured and set according to current standards. The set minimum position then becomes a point to which AEMS will refer under specified conditions. No benefit of an AEMS accrues, unless this static adjustment occurs as a consequence of AEMS installation. (This is not an uncommon practice in installation of some current equipment.) Closed-loop control over minimum air, through air quality and/or occupancy sensors, would be a viable, beneficial AEMS function.

3.3.1.3.2 Outside Air Shutoff--A corollary to the above occurs whenever outside air is shut off during programmed, or sensed, periods of nonoccupancy. If this is already implemented manually or with low-cost timers, AEMS will not derive its potentially substantial cost benefits. Unit ventilator integral controls, for example, provide a warmup stage wherein the outdoor damper is closed until the room temperature reaches its desired level.

3.3.1.3.3 Free Cooling, Enthalpy Control--This function actually includes a number of separate features, the applicability of which is entirely dependent on the actual installation to which the AEMS retrofit is applied. The features include enthalpy control, use of up to 100 percent outside air as the first stage of cooling, and/or sequencing or interlocking ventilation--cooling and heating. With the wide variation in duct/coil configurations, the implementation of these functions is also varied, but the concept remains the same. That is, use of outside air is maximized in conjunction with the heating and cooling requirements of a system optimized to actual cooling and heating loads. Many existing air-handling installations, however, have been arranged for minimum

fresh air only, with no provision for relieving larger amounts of air. Retrofitting these systems would in most cases prove too costly, even if existing space and architectural considerations permitted.

It is concluded that controls related to ventilation must be considered in an AEMS concept. Where central air-handling systems permit, the functions will derive their greatest applicability and universality. They will also become elements in some of the load efficiency improvement functions.

Where ventilation is provided through individual units, the concept of AEMS control will meet increasing cost constraints with local controls proving more cost effective.

3.3.1.4 Scheduled Start-Stop (or On-Off) Control of Motorized Equipment and Lighting Circuits--Relays and/or contactors must be retrofit into existing starting equipment and lighting panel circuits. They must be installed by an electrician and wired to the AEMS. Routing of wiring in some instances may require redecorating.

Programming of schedules must be easily changed by authorized personnel.

When use of building areas is required during periods outside the programmed schedules, provision must be made to permit operation of the lights and equipment serving those areas. This can be accomplished by providing local program overriding controls or by an administrative procedure implemented by the building management. The former requires additional wiring and controls; the latter would involve an agreement between the manager and the user as to procedures, access to controls, overtime costs for building personnel, etc.

This program is not applicable in apartment buildings. Most of the systems and equipment must operate around the clock, with lighting control a tenant function.

Cost effectiveness of lighting controls is dependent on existing switching arrangements, location of lighting panels, and whether or not the panels are restricted to lighting circuits only.

3.3.1.5 Optimal Start-Stop--In office and school buildings, cost effectiveness of this program would depend on the type of HVAC system, its capacity and response characteristics, the building mass and its response characteristics, as well as the daily

range of temperatures. For example, an oversized, direct-fired warm air system will bring the space up to temperature much more quickly than a steam or hot water radiation system. In this example the building manager might start the warm air system only a half hour before arrival of the first occupants, confident that it is sufficient to account for all weather variations during the season. However, the manager of a building with a radiation system would have to allow much more time. The radiation system, when controlled by an optimal start program, therefore affords significantly more opportunity to reduce operating hours than the warm air system.

To reduce the operating hours to an absolute minimum, an optimal start program must be capable of recognizing all the characteristics and conditions mentioned above. Appropriate algorithms must be provided, the building and system characteristics investigated, and a multiplicity of temperatures and solar sensors installed. Since it is difficult to obtain accurate data for some of the parameters of the algorithm, particularly in existing buildings, assumptions must be made initially and adjustments made by trial and error. These adjustments would require the services of the AEMS installer.

An optimal start program is not applicable in apartment buildings.

In any building where serious energy conservation measures have been employed, thermostat heating set points will have been reduced (or set up for cooling). Further, systems will have been turned off or set points modified to reflect periods of non-occupancy. This may have been done manually with dual set point clock thermostats, timers or other relatively simple measures.

In replacing these functions, AEMS should take credit only for the economic benefit from improved operation, if any.

The rationale for including such functions in an AEMS concept must be predicated on providing more positive control over total building energy use. As energy costs increase and potential energy codes are enacted, it may well become imperative that control be removed from individuals and centrally located. The problem of controls being defeated is very real, and centralized monitoring may be used to identify and override such attempts.

3.3.2 Second Generation Functions

Up to now, all of the functions discussed have been quite commonplace, representing practices in use today. New products and

continuing research involve techniques intended to more closely match the use of energy with actual, measured needs.

In studying AEMS control, potential interface with advanced concepts should also be considered. This consideration is partly an outgrowth of market assessments, where concern is expressed about the state of the art of current controls. The respondents seem to sense or be aware of rapid technological growth, and express the fear that a purchase may soon be out of date. "Tomorrow they'll have something better." This is not unlike engineers in recent years waiting for the price and capabilities of pocket calculators to meet their perceived needs.

AEMS should therefore have the advertised and demonstrated capability of expanding its functions to include changing developments and standards. Some specific areas that may become commonplace are:

- Active Ventilation Control - Systems are available that will adjust outside air volume on the basis of air quality or sensed numbers of occupants. The ventilation control concepts remain the same, but the logic for control will include alternate sensors and criteria.
- Combustion Efficiency Control - Flue gas analyzers with adequate response times may be used to control and adjust the combustion parameters to improve efficiency.
- Occupancy Control - Various means are being studied to determine occupancy, with the goal of adjusting lighting, cooling and ventilation on the basis of actual need rather than predetermined time-of-day scheduling.

The role of a central AEMS is perhaps not clear when considering the interface with these types of concepts. At the very least it should be recognized that the direction of control is that of directly matching needs with response. Thus new developments may well preempt central control functions that are considered viable and accepted today. Programmable controllers are a case in point. One of the issues that would have to be decided if an AEMS were designed today is how best to set up the operator interface to obtain all the flexibility needed. Since most of this flexibility is in programming related to predetermined estimates of occupancy, the problem might be eliminated if a viable means of sensing occupancy were used. However, since most existing heating systems would not respond fast enough to provide the necessary comfort if some lead time were not provided, a need for programming schedules is likely to remain.

This analysis will stay with the conventional items--leaning toward the energy savings functions that require implementation regardless of future developments.

3.3.3 Monitoring Functions

The level of monitoring to be provided in an AEMS involves many considerations and can take many forms. Their benefits do not, in general, result in measurable short term cost savings and hence are difficult to justify in a conventional, simple payback analysis. If perhaps a manpower reduction ensues, as is often implied in automation systems, then the benefit is immediately effected. However, in the small building environment of interest, this may not be a significant factor.

Some specific monitoring functions are discussed:

- Status - The AEMS should at the very least say, "I'm working." A particular problem with many simple, normally effective devices in use today is that they are easily defeated. Time clocks are an example which, if defeated by a maintenance man after several complaints, may be non-functional for extended periods before detected by those who pay the bills. A permanent record of periods of nonoperation may be beneficial.
- Preventive Maintenance - In large, complex systems it may well be an advantage to indicate when a filter needs replacement, etc. For small buildings, regularly scheduled preventive maintenance modified by experience will likely be the more cost effective approach.
- Self-Diagnosis - The need for this capability will depend on the complexity and design of an AEMS. In effect, the existence of this capability is an admission of guilt of having designed a too-complex or accident prone system. Unless it is intended to help the building owner, not the serviceman, this function should be minimized to the point of status indications of respective modules (if so designed). Diagnostic tools for the serviceman are a viable adjunct to an AEMS concept.
- Energy Monitoring - The concept of providing running or periodic accounts of energy usage, perhaps coupled with a comparison to some standard or reference, is intriguing.

Such systems are being developed.⁷ They imply a high degree of sustained motivation and possible continuing action on the part of the responsible person to keep the system in tune. The AEMS concept should be predicated on automatic operation with a minimum operator interface. Permanent records of past energy usage of various elements in the building may be of use, but represent a duplication of status monitoring and well maintained systems.

3.3.4 Miscellaneous Functions

Large-building automation systems frequently provide options of life safety (fire alarms) and security systems. Such functions, of course, are not energy related and should be considered only if they become a significant factor related to marketing an AEMS. This does not appear to be the case, as indicated by the low rankings applied to these capabilities by those participating in the market analysis study.

Furthermore, the stress in this AEMS study is directed toward the retrofit market. In these cases, buildings that require such systems probably already have them. The same consideration also applies to classroom bells in a school installation.

3.3.5 Summary

Table XVIII summarizes the potential AEMS functions. These will be further evaluated in terms of cost versus potential savings.

It is obvious that a universal, single-configuration AEMS is unlikely. It should be recognized that the listed functions are being implemented separately, with the obvious implication that, in the right application, they are cost effective functions.

3.4 COST GOALS - PAYBACK AND SAVINGS ANALYSIS

We have seen that the type of HVAC system will dictate to a large degree what functions may be considered in an AEMS. Other functions will be defined as a consequence of particular building operations or occupancy patterns. Finally, electrical utilities may (and are expected to) "dictate" others. When a buying decision is made, cost effectiveness will be a dominant issue and

⁷Consumer Reports, July 1978.

Table XVIII. Summary of AEMS Function Applicability

FUNCTION	AEMS APPLICABILITY
Electrical Demand Control	AEMS should focus on developing trends in utility interaction. Small kilowatt demand reduction should be considered a universal function.
Load Efficiency Improvement (Balance supply temperatures to load, Sequence heating and cooling, Chiller optimization)	Highly HVAC system dependent. Implementation will take many forms. AEMS must provide these functions, although they are not universal.
Ventilation Control (Warmup cycles, Enthalpy control, Cooling stage)	Same comments as above. AEMS application should include lower minimums, low-leak dampers, etc., if not implemented. Would increase economic benefits significantly.
HVAC Scheduling (Space temperature reset, Start-stop, Lights)	Universal functions, but likely to replace existing systems or procedures. Economic benefits small by definition. Requires justification for AEMS application and viable only as add-on option to other functions above. Lighting control weak AEMS retrofit function.
Optimal Start	HVAC and building characteristics dependent. Definite economic benefit where applicable. A part of start-stop or temperature reset functions.
Monitoring	A universal function. Status should be indicated to a functional or, if applicable, to the modular level.

this will impose limits on what functions are feasible for a given building.

Our market analysis supports approaching this issue from a relatively simple standpoint. The research indicates that the criterion of payback is a major factor in the buying decision, with installed cost secondary. Accepting this criterion, cost effectiveness may be determined by the simple relation:

$$\frac{\text{System installed cost}}{\text{System dollar savings/period}} \leq \text{required payback period}$$

Simple payback computation, as opposed to life-cycle cost procedures, is felt justified for the relatively short payback periods evolving from the study. Further, in the face of rising energy costs it is probably conservative.

In this section we explore the factors related to cost savings of AEMS functions and combine these with payback period requirements from the market survey. This gives us the third term in the cost-effectiveness expression--system installed cost. This, in effect, is then an AEMS "cost goal."

3.4.1 Payback Requirements

When the market focus groups indicated payback as a major purchase criterion, the followup statistical survey attempted to quantify the distribution of payback periods. Figure 21 summarizes the responses from 413 respondents and includes all three building sectors. Volume II of this report includes breakdown by sector. Figure 22 is a cumulative summary of the percent of market that falls within a given payback period.

With this information, a rationale may be developed to select a payback period for further analysis. Early in this program, discussions with marketing and sales personnel indicated that a 2.5-year payback was a sort of breakpoint where increased sales resistance was encountered. From Figure 22 we see that 64 percent of the market will accept this payback. Tax incentives (or perhaps a concerted rational argument) may further increase this percentage.

For the subsequent analyses we will use 2.5-year payback or 64 percent of market, whichever is appropriate--recognizing that these are only rough guidelines, but ones which will allow further quantification of AEMS cost goals. Sufficient data are presented to allow the reader to select others.

Figure 21. Distribution of Payback Period Requirements

Figure 22. Percent of Potential Market Falling Within a Given Payback Period

3.4.2 Generalized Installed Cost Goals

Before specific energy savings estimates are made, the scope of the situation relating energy costs, savings, payback, and building size and costs to equip will be developed.

The small building market is itself diverse, representing wide ranges of energy costs, building size and usage and operating factors. Virtually any situation could be postulated and a real-life equivalent found. If we look at office buildings, for example, we can find ranges of total annual energy bills from \$0.40 to \$1.65 per square foot (Figure 23). Using this range of energy cost data, we can make a crude but adequate calculation of justifiable AEMS control system costs, considering both energy savings and payback. Assume the following:

- Savings = 10 percent of total energy bill;
- Payback required = 2.5 years;
- Building size - 5000 (arbitrary minimum) to 75,000 square feet.

A control system budget, or cost goal, is developed from the above values:

$$\text{Minimum: } \frac{\$0.40}{\text{ft}^2/\text{year}} \times 5000 \text{ ft}^2 \times 2.5 \text{ years} \times 0.1 \text{ savings} = \$500;$$

$$\text{Maximum: } 1.65 \times 75,000 \times 2.5 \times 0.1 = \$31,000;$$

$$\text{"Average": } 0.83 \text{ (Figure 23)} \times 16,500 \text{ (Table II)} \times 2.5 \times 0.1 = \$3400$$

It is clear that even if one tries to use average values as an absolute goal, the variations therefrom are significant when specific buildings are considered.

Actual AEMS installed costs will likely be influenced by building size but probably not in direct proportion. However, justifiable costs, or cost goals, may be determined from building size proportionately--at least for this initial analysis. This assumption was used to prepare Figure 24, which may be used to evaluate the cost effectiveness of any given function or combination of functions. This figure shows that if payback is the

Figure 23. Annual Energy Costs, Office Buildings⁸

⁸ Building Owners and Managers, International (BOMA), "Downtown and Suburban Office Building Experience Exchange Report," 1977.

EXAMPLE: IN A 60,000 SQUARE FOOT BUILDING WITH AN ANNUAL ENERGY COST OF \$1.65/FT², A \$50,000 AEMS SAVING 20 PERCENT OF TOTAL ENERGY BILL WOULD SATISFY A 2.5-YEAR PAYBACK REQUIREMENT.

Figure 24. Justifiable Cost Range of AEMS for Various Building Size, Energy Cost and Energy (Cost) Saving (Simple 2.5-year Payback Assumed)

sole purchase criterion, AEMS costs upwards of \$90,000 may be justified if the appropriate cost savings accrue from its implementation.

At this high end of the small building range, "large" building automation systems, as typified by the Barber Colman ECON VI, Esterline Electronics Series 6503, Honeywell Delta 1000 and others, may even be economically feasible. (Table XXVIII)

It is obvious, perhaps intuitively so, that AEMS price structures must be variable to reflect the diverse conditions illustrated.

Since AEMS cost constraints derive from the "bottom" of the market, a rationale is developed to define this low end of cost goals.

From available data it is possible to develop minimum cost goals related to the three sectors emphasized in this study by using a potential market size criterion. The scope of building diversity will then be reduced, thereby developing a more realistic range of cost goals.

In Figure 25, the sector breakdown of payback requirements is summarized from Volume II of this report. If we use a 64 percent market segment as a criterion, the payback requirements for the three sectors are:

- Schools - 34 months (2.8 years);
- Apartments - 30 months (2.5 years);
- Offices - 25 months (2.1 years).

Figure 26 relates the distribution of building size within the under 75,000 square foot category. To consider 64 percent of the market, AEMS must accommodate buildings greater in size than:

- Schools - 31,000 square feet;
- Apartments - 13,000 square feet;
- Offices - 23,000 square feet.

Finally, energy costs are also determined on a percent of population basis in Figure 27. This figure was generated using BOMA office data and extrapolating that to apartments and schools by ratioing mean values from the cited reference. Sixty-four percent of the buildings will have energy costs exceeding:

Figure 25. Payback Requirements by Building Sector

Figure 26. Distribution of Building Size (Buildings Under 75,000 square feet)

- Schools - \$0.65/square feet/year;
- Apartments - \$0.49/square feet/year;
- Offices - \$0.72/square feet/year.

Figure 27. Percent of Market Versus Total Energy Costs for Offices⁸ and Schools and Apartments¹⁰.

⁸ Building Owners and Managers, International (BOMA), "Downtown and Suburban Office Building Experience Exchange Report," 1977.

¹⁰ U.S. Department of Energy, "Phase I/Base Data for the Development of Energy Performance Data for New Buildings," 12 January 1978.

Using the above determined values of the primary cost parameters, Figures 28, 29 and 30 are generated using the following relationship:

$$\text{AEMS Cost Goal} = (\text{Energy Cost}) (\text{Payback}) (\text{Savings}) (\text{Building Size}).$$

Since AEMS savings have not been quantified as yet, the cost goals are shown with respect to a range of energy cost savings of 10 and 15 percent of total building energy used. Also shown is a market cost factor (MCF) to be defined later.

In Table XIX, maximum, minimum and average cost goals are summarized for each building sector, normalized to each percent of energy cost savings. The "average" calculation is based on the building size represented by the midpoint (32 percent) of the building size distribution curves (Figure 26).

Figure 28. AEMS Cost Goals for Schools as a Function of Potential Assumed AEMS Savings

Figure 29. AEMS Cost Goals for Apartments as a Function of Assumed Potential AEMS Savings

Figure 30. AEMS Cost Goals for Offices as a Function of Potential AEMS Savings

Table XIX. AEMS Cost Goals (Dollars per Percent Energy Cost Savings)

	MINIMUM	AVERAGE	MAXIMUM
Offices	347.70	695.50	1575.00
Schools	564.20	855.40	1365.00
Apartments	159.20	367.50	918.75

As energy measures are implemented in a building, the returns diminish as additional functions are added. When the returns fall to the one- to two-percent level, the allowable equipment cost increment becomes increasingly restrictive. For example, if an AEMS device is installed in the smallest office building (23,000 square feet) and saves 20 percent of energy costs, the justifiable cost is $(20) \times (347.70) = \$6954.00$. If a function saving an additional one percent of energy is added, that "functional module" must cost \$347.70, or less, unless the basic equipment has not "used up" its allocation of \$6954. It is assumed that an AEMS would be evaluated on a total system basis with respect to cost versus savings.

3.4.2.1 Market Size Cost Constraints

A market must be of sufficient size to attract investors in equipment for that market. A determination is now made of what "average" AEMS installed sales price will support and encourage the entry of competitors into the AEMS market. Using an algorithm similar to that used in Paragraph 3.1.4 to help select building categories, and using the following assumptions, we can calculate this "market cost factor" for each of the three sectors.

- 20 percent market penetration of 64 percent of buildings;

- Ten competitors each requiring annual sales of \$1,000,000;
- Seven-year product life;
- 50 percent ratio, product to installed costs;
- 304,000 office buildings (From Table II, reduced
96,000 school buildings per Paragraph 3.1.2 and
3,035,000 apartment buildings 3.1.3)

$$\text{Material Cost Factor (Installed Cost)} = \frac{(\$1,000,000)(10)(7)}{(0.2)(0.64)(\text{No. of buildings})(0.5)}$$

For each of the three building sectors, this market cost factor (MCF) is:

Schools: \$11,400
 Apartments: \$ 360
 Offices: \$ 3,600

These "required" costs (MCF) are shown as Figures 28, 29 and 30 where they are compared to "allowable" costs determined earlier. The MCF represents a cost floor for AEMS when a single market sector is considered. Because of their smaller numbers, schools are shown to require a higher level of savings to provide an adequate market volume within the assumptions stated.

The market cost factor may be useful in examining a particular market segment as to its viability as an AEMS market. However, there is no inherent technical reason to presume that each market building sector is unique from the viewpoint of a basic AEMS concept. If fact, since the required functions are more HVAC than building dependent, the limits implied by this market segment analysis are not seen as an implementation barrier to AEMS.

3.4.3 Projected Savings with AEMS Functions

Candidate AEMS functions have been defined and payback and cost constraints delineated for potential AEMS market segments. This analysis employed energy cost saving assumptions for a total AEMS system. The logical progression calls for assigning functions to these markets and then assessing the actual amount of savings possible therefrom. Recalling the multiplicity of HVAC systems and potential functions, it is obvious that considerable combinations thereof will result. Further, in attempting to amass such savings data, one is faced with reviewing or generating simulation, analysis and case history data. Each of these sources is based on single, unique applications, requiring specification of all the many parameters affecting energy usage such as operating procedures, building characteristics, occupancy patterns, etc.

Generalizations are difficult to draw from specific results, but one fact stands out following review of such data--ten percent total energy cost savings are relatively easy to obtain. In fact, savings of 20 percent or more are often cited.

Recall that our previous analysis used "percent of total building energy" as a parameter. Simulation and analysis results often quote more restrictive parameters such as percent heating energy, increasing the percentage number. Furthermore, functions are often combined, further complicating the identification of single-function cost savings.

Consequently, this present analysis will stay with a conservative 10 percent indication of percent energy cost savings arising from an AEMS system. Both general and specific data are presented to support this stand.

3.4.3.1 General AEMS Function Savings--Honeywell's "Bottom Line" program is an analytical procedure that processes data related to building characteristics, operating procedures and building equipment to arrive at and recommend solutions to areas of energy waste in that building. Table XX is a summary of results from a compilation of analyses of 964 buildings. The average values presented give an indication of potential savings on a general basis, which is useful for our purposes here. The buildings are not limited to "small buildings," however, selected review of

Table XX. Bottom Line Savings from Energy Conservation (\$/Year/1000 ft² Floor Area)

BOTTOM LINE CONSERVATION ITEMS	TYPE OF BUILDING *	OFFICE	INDUSTRIAL	COLLEGE	HOSPITAL	SCHOOL	STORES	HOTELS- APARTMENTS	CHURCHES	AEMS FUNCTION CATEGORY
	TOTAL ENERGY COST WITHOUT CONSERVATION	\$1320	\$1540	\$919	\$1100	\$650	\$890	\$1460	\$730	
	1 Adjust Controls	9.5/126	2/31	6/55	0.8/9	5.8/38	5.4/48	4.9/71	17.7/129	Load Efficiency Improvement
	2 Reduce Ventilation	4.6/61	3.6/55	4.9/45	2.7/30	5.2/34	3.4/30	4.4/64	5.9/43	Ventilation
	3 Schedule Heating and Cooling	3.6/47	4.5/69	7/64	2.0/22	4.6/30	2.7/24	4.7/69	3.6/26	HVAC Scheduling (Optimal Start, Start-Stop) Ventilation (Warmup Cycle)
	4 Reduce Electric Peaks	2.7/36	2.9/44	2.4/22	1.5/17	2.6/17	2.1/19	1.8/27	2.3/17	Electrical Demand Control
	5 Set Cooling at 78°F	1.5/20	0.7/11	1.7/16	3.6/40	1.2/8	2.9/26	4.1/60	1.0/7	HVAC Scheduling (Not AEMS)
	6 Turn off Lights	2.6/34	0.9/14	0.8/7	0.6/7	1.2/8	1.2/11	0.5/8	0.8/6	HVAC Scheduling (Weak AEMS)
	7 Run Heating, Cooling Part Time	1.3/17	1.2/19	2.2/20	1.9/21	1.7/11	2.0/18	2.7/39	1.2/9	HVAC Scheduling (Duty Cycle, Temperature Reset)
	8 Reduce Heat Nights/Weekends	1.1/14	1.4/21	1.7/16	0.8/9	0.5/3	0.2/2	0.5/8	2.3/17	HVAC Scheduling (Night Setback)
	9 Set Heating at 68°F	0.4/5	0.4/6	1.0/9	1.4/15	0.2/1	0.2/2	0.3/4	3.6/26	HVAC Scheduling (Not AEMS)
	"TOTAL SAVING" for Total Building Type	\$360	\$270	\$254	\$170	\$150	\$180	\$350	\$280	

NOTE: Table Entries are (%/\$)

specific small building results indicates general applicability of the data to small buildings.

While data on energy savings presented for a given building are additive, the numbers in the table should not be so considered since a general building will not normally utilize all functions.

3.4.3.2 Case Studies--A simulation study of the Trafton Science Center at Mankato (Minnesota) State University was made to identify energy conservation measures. The complex consisted of inter-connected three-story buildings and greenhouse:

- North wing 71,413 square feet
- Center section 41,306 square feet
- South wing 80,097 square feet
- Greenhouse 3,650 square feet

Results included the following controls-related recommendations, which are, incidently, scheduled for implementation:

Table XXI. Functional Savings Projected for Trafton Science Center¹¹

CONTROL FUNCTION	ANNUAL SAVINGS		INSTALLED COST (\$K)	PAYBACK (YEARS)
	(PERCENT)	(\$K)		
Reheat Optimization	21	40	50-60	0.8 to 1.5
Fan Cycling/Optimum Start-Stop	18	34	35-55	1 to 1.6
Combined	32	61	85-115	1.4 to 1.9

Typical buildings were also analyzed to determine functional cost savings. Some assumptions were made to define the analysis starting

¹¹ "Energy Analysis of Trafton Science Building - Mankato State University," Honeywell Inc., Energy Resources Center Report, 7 January 1977.

point, based on the market survey results that said low- and no-cost procedure would probably be in effect before AEMS application (Table XXII). This affects the economic analysis since some functions that logically belong in an AEMS may be replacing existing functions. The rationale for including such functions includes better efficiency, potential manpower reduction, central monitoring, etc. Efficiency improvement was quantified.

Table XXII. Assumed Building Conditions for AEMS Analysis

	OFFICE	APARTMENT	SCHOOL
Heating Setpoint ($^{\circ}$ F)	68	68	68
Cooling Setpoint ($^{\circ}$ F)	78	78	78
Heating Night Setback or Unoccupied Minimums ($^{\circ}$ F)	55	62	55
Cooling Off When Unoccupied	Yes	Yes	Yes
Boiler Temperature (Pressure) Scheduled With Outdoor Air Temperature	Yes	Yes	Yes
Minimum Outdoor Air Set to Current Standards (Percent)	15	NA	15
Economizer/Dry-bulb Reference	Yes	No	Yes
Occupancy Program (Manual or Time Clocks, Lights, HVAC Equipment)	Yes	NA	Yes

The specific buildings and analysis methods are described in Appendix A. The examples include an office building with a high potential for energy conservation measures by virtue of a constant-volume, terminal reheat system in an older building. A school building with multizone HVAC units represents an average application, and an apartment with central heat and air conditioning represents a weak controls application. In all cases, various geographical locations were assumed to identify potential influence of location.

The office building results are summarized in Table XXIII, including the assumption that AEMS may replace existing functions. Similar data for a school building is given in Table XXIV.

3.4.4 Savings Summary

Data from the preceding analysis is summarized in Table XXV. The variation in numbers indicates that there is a range of savings with no possible way to generate an actual average value for a given function. Further, functions tend to be somewhat inter-related, particularly when considered cumulatively in a given installation. The final column is merely an attempt to indicate a functional level of savings that might be recognized by others as being typical, representative and somewhat conservative when used in a general fashion.

Accepting this premise, the table serves to indicate that there are energy savings possibilities, that they will save energy and money, and that the resultant savings fit into and support the general discussion of AEMS cost goals presented earlier in this section.

Note also that the savings values reflect the assumption that the building is as energy efficient as is possible with simple measures.

3.5 CURRENT EQUIPMENT

In previous sections of the report, equipment was alluded to that currently exists to provide the functions delineated as relevant to an AEMS. Detailed below are results of surveys to identify some of this equipment and to give indications of capabilities and other product characteristics considered applicable to an AEMS concept.

The data were obtained primarily from the JRB report¹² and augmented with information obtained directly from manufacturers during this study. Cost data therein are compatible with energy cost data used in preceding analyses, generally of 1976 vintage.

¹² JRB Associates, Inc., "Survey Existing Microprocessor Systems, Components and Software", unpublished report (Federal Programs Office, Conservation and Solar Applications, Department of Energy).

Table XXIII. Office Building Savings as Percentage of Total Energy Costs for AEMS Functions (30,000 Square Foot-Constant-Volume, Terminal Reheat System)

LOCATION	ALBUQUERQUE		OMAHA		ATLANTA		NEW YORK	
Base Energy Used (BTU/square foot/year)	150,900		201,433		129,833		186,467	
TOTAL ENERGY COST (\$/square foot/year)	0.89		0.82		0.78		1.30	
FUNCTION	ANNUAL SAVING							
	%	\$	%	\$	%	\$	%	\$
Electrical Demand Control	5.0	1332	5.0	1237	5.0	1165	5.0	1946
Start-Stop	4.5	1198	5.3	1313	4.2	975	5.5	2153
Optimal Start	1.7	451	2.7	670	2.9	666	2.9	1122
Reheat Optimization	3.7	989	2.5	628	2.5	590	2.6	1022
Boiler Optimization	0.2	42	0.1	34	0.1	33	0.2	72
Enthalpy Control	0.3	86	0.2	54	0.2	53	0	0
Totals	15.0	4098	16.0	3936	15.0	3482	16.0	6315
AEMS Cost Goal With 2.1-year Payback		8606		8266		7312		13262
SAVING AND COST GOALS IF AEMS REPLACES EXISTING START-STOP WITH 10 PERCENT EFFICIENCY IMPROVEMENT								
Totals	11.0	3020	11.0	2754	10.0	2605	11.0	4377
AEM Cost Goals		6342		5783		5469		9192

Table XXIV. School Building Energy and Cost Savings as Percentage of Total Energy Usage (40,000 Square Foot--Multizone Rooftop Units)

LOCATION	ALBUQUERQUE		OMAHA		ATLANTA		NEW YORK	
Base Energy Used (BTU/square foot/year)	150,900		201,433		129,833		186,467	
Total Energy Cost (\$/square foot/year)	0.89		0.82		0.78		1.30	
FUNCTION \ SAVING	%	\$	%	\$	%	\$	%	\$
Electrical Demand Limiting (Estimate)	7	1889	7	1711	7	1688	7	2709
Start-Stop	2.7	728	3.2	787	2.4	569	3.3	1283
Optimal Start	0.9	245	1.0	240	0.7	174	2.7	1039
Optimize Hot and Cold Deck	2.4	658	2.3	568	2.2	528	2.0	789
Totals	13.0	3520	13.5	3306	12.3	2959	15.0	5820
AEMS Cost Goal (2.8-year Payback)		9857		9256		8283		16295
SAVINGS AND COST GOAL IF START-STOP FUNCTION REPLACED BY AEMS WITH 10 PERCENT IMPROVEMENT								
Totals	10.6	2865	10.6	2598	10.1	2447	12.0	4665
AEMS Cost Goal		8021		7274		8651		13062

Table XXV. Summary of AEMS Functional Cost Savings (Percentage of Total Energy Usage) 2,9,11,13

DATA SOURCE	BOTTOM LINE SUMMARY 12		TRAFTON SIMULATION 11	A.D. LITTLE 2	AEMS ANALYSIS 9	ASSUMED REFERENCE RANGE FOR ANALYSIS (AEMS ESTIMATE)
BUILDING CATEGORY	OVERALL	SCHOOL OFFICE APT	SCHOOL		SCHOOL, OFFICE	OVERALL
ELECTRICAL DEMAND CONTROL	1.5-2.9	1.8-2.7			5-7	2-7
LOAD EFFICIENCY IMPROVEMENT <ul style="list-style-type: none"> • Supply Temperature Reset • Boiler Optimization • Chiller Optimization • Sequence Heating and Cooling • Combustion Efficiency 	0.8 to 17.7	4.9 to 9.5	21		2-4	2-10
VENTILATION <ul style="list-style-type: none"> • Free Cooling • Warm-up Cycle • Enthalpy 	2.7 to 5.9	4.4 to 5.2			0.3	3-5
HVAC SCHEDULING <ul style="list-style-type: none"> • Temperature Reset • Start-Stop • Optimal Start • Duty Cycle 	4.7 to 10.9 (Items 3, Added)	6.0 to 7.9 7 and 8	18	9-20	3.1-8.4	3-5 (AEMS will replace most of this category)
TOTALS (DIRECT ADDITION)	9.7 to	34.5	32 (actual)		10.4 to 19.7	10-27

2 Federal Energy Administration, "Project Independence, Residential and Commercial Energy Use Patterns: 1970-1990," A.D. Little, Inc., 1974.

9 AEMS Market Survey

11 "Energy Analysis of Trafton Science Building - Mankato State University," Honeywell Inc., Energy Resources Center Report, 7 January 1977.

13 Air Conditioning, Heating & Refrigeration News, "Big Buildings a Big Market for Energy-Saving Retrofit," 27 February 1978

The equipment tends to fall into three categories:

- (a) Limited function controllers - Generally dedicated to a primary function but may have additional function options. Typified by time clocks, boiler temperature reset controls, demand controllers and multizone controllers. From this source of information it is possible to establish a range of installed costs/functions useful for preliminary functional economic analysis. Implementation may be electromechanical, solid state or micro-processor based.
- (b) Multifunction, central automation systems - Typified by the Johnson JC/80, Barber Colman ECON VI, Honeywell Delta 1000 and others. AEMS could actually be considered a "small building" version of these larger systems, which are generally aimed at the market consisting of buildings significantly larger than the 75,000 square foot limit imposed in this study. The basic and optional energy savings functions offered by these systems encompass those identified for AEMS. Implementation includes computer control and software option packages.
- (c) "New Generation" - An emerging class of controllers, generally implemented with microprocessor technology. A number are being developed for small building solar application. General purpose controllers, factory adaptable to given applications, are also available.

3.5.1 Limited Function Controllers

Table XXVI is a partial list of equipment available for the primary functions for AEMS. Such a listing is rapidly outdated, but serves to illustrate the range of available equipment. As discussed in the introduction to this report, they represent an active force today in energy management in buildings of all sizes. In general, they do not meet the guidelines for a controls energy management strategy associated with an integrated AEMS concept. It is conceded, however, that this equipment may well provide the flexible price structure needed to extend AEMS capability to buildings of all sizes, particularly smaller ones. Further, in this buildings, energy and operational audits may indicate that the practical limit of energy controls measures may be satisfied with that genre of equipment alone.

In effect, it is concluded that "AEMS equipment" does exist today--and that this equipment must be worked into and integrated with an overall AEMS strategy and concept.

Table XXVI. Functional Capabilities
by Manufacturer¹²

FUNCTIONAL CAPABILITIES		SCHEDULED EQUIPMENT SHUTDOWN	OPTIONAL START	TEMPERATURE RESET	ECONOMIZER	ENTHALPY	SUPPLY TEMPERATURE RESET	CHILLER OPTIMIZATION	BOILER OPTIMIZATION	ELECTRICAL DEMAND	DUTY CYCLE	BASIC CONTROL	PREVENTIVE MAINTENANCE	LIFE SAFETY	SECURITY
EMS HARDWARE BY MANUFACTURER															
CENTRAL AUTOMATION SYSTEMS	MANUAL CENTRAL CONSOLE														
	Barber Colman, ECON VI											✓			
	MICROPROCESSORS CENTRAL CONTROL														
	Barber Colman ECON VI AS9400	✓								✓	✓				
	Honeywell Delta 1000	✓	✓							✓	✓	✓		✓	✓
	Honeywell Delta 1000 with options	✓	✓			✓	✓			✓	✓	✓		✓	✓
	Delta 2000	✓										✓		✓	✓
	MINI-COMPUTER CENTRAL CONTROL														
	Barber Colman AS9500	✓										✓			
	Esterline Electronics 6503	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓
	Honeywell 2500	✓										✓		✓	✓
	Honeywell 2500 with options	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Johnson JC/80 Loop	✓										✓			
	Johnson JC/80 Loop with options	✓	✓		✓	✓		✓	✓			✓			
	Johnson JC/80	✓										✓			
	Johnson JC/80 with options	✓	✓		✓	✓		✓	✓			✓			
	Powers System .570	✓										✓		✓	✓
	Powers with options	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓
	Robertshaw	✓										✓		✓	✓
	Robertshaw with options	✓	✓				✓			✓		✓	✓	✓	✓
LIMITED FUNCTION CONTROLLERS	TIME CLOCK														
	Barber Colman AE170	✓													
	Honeywell S659A	✓													
	Powers SW222	✓													
	OPTIONAL START TIME														
	Barber Colman AE191	✓	✓												
	Powers NR-6 SAVER 1		✓												
	Johnson C-7500		✓												
	TEMPERATURE RESET THERMOSTAT														
	Dyn. Electronics Controls SST-3AC			✓											
	Johnson T-4502			✓											
	Johnson T-4502 with optional reset		✓	✓											
	Honeywell T882A														
	ECONOMIZER														
	Honeywell W859A				✓										
	Honeywell Enthalpy W859D and H205A					✓									
	Johnson N-9000					✓									
	Powers				✓										
	BOILER TEMPERATURE RESET														
	Honeywell W902A						✓								
	Johnson T-5303						✓								

Table XXVI. Functional Capabilities by Manufacturer (Continued)

FUNCTIONAL CAPABILITIES		SCHEDULED EQUIPMENT SHUTDOWN	OPTIONAL START	TEMPERATURE RESET	ECONOMIZER	ENTHALPY	SUPPLY TEMPERATURE RESET	CHILLER OPTIMIZATION	BOILER OPTIMIZATION	ELECTRICAL DEMAND	DUTY CYCLE	BASIC CONTROL	PREVENTIVE MAINTENANCE	LIFE SAFETY	SECURITY	
EMS HARDWARE BY MANUFACTURER																
LIMITED FUNCTION CONTROLLERS (CONTINUED)	MICROPROCESSOR CONTROLS															
	Barber Colman CP8171				✓											
	Barber Colman with Enthalpy THg-2**					✓										
	Barber Colman with Demand Control**					✓				✓						
	Barber Colman CP9137-64*				✓	✓	✓									
	Barber Colman CP88-069*					✓	✓									
	Barber Colman with Enthalpy THC-2					✓	✓			✓						
	Barber Colman with Dem. Control*				✓											
	Honeywell W945**					✓										
	Honeywell with Enthalpy H-205A**			✓	✓											
	Honeywell with Temperature Reset S6598			✓	✓											
	Honeywell W936*				✓	✓	✓									
	Honeywell with Enthalpy H-205A*					✓	✓									
	Honeywell with Temperature Reset*			✓	✓	✓										
	Powers NR6 SAVER II						✓									
	Powers NR65 SAVER II with Economizer				✓											
	Powers NR6 SAVER II and with Temperature Reset			✓												
	Powers NR6 SAVER II and with Supply Temperature Reset							✓								
	POWER DEMAND															
	Allen Bradley 1810C									✓						
	Allen Bradley Prog. 1810P									✓						
	Barber Colman CP8471-130									✓						
	IBM System 7 PM									✓						
	IBM System 7 PM II		✓							✓						
	Pacific Tech 310 (Duty Cycle)									✓	✓					
	Pacific Tech 4/4									✓						
	Pacific Tech 400									✓						
	Pacific Tech 412									✓						
	Process Systems 1260									✓						
	Process Systems 1270		✓							✓						
	Process Systems 1290		✓							✓			✓			
	Square D Type DC-1									✓						
	Square D Type DC-21									✓						
	Square D Type DC40/45									✓						
	Digital Equipment PM 301		✓							✓						
	Digital Equipment PM 501		✓							✓						
	Digital Equipment PM 701		✓							✓						

* Multizone

** Single Zone

Cost data of representative equipment are presented in Table XXVII, summarized from the JRB report.

Table XXVII. Cost Ranges of AEMS Function Implementation with Current Equipment

FUNCTION	INSTALLED COST RANGE
Scheduled equipment shutdown (Time Clock)	\$ 155 - \$ 195
Optimum start time	670 - 1,170
Temperature reset (Master Thermostat)	472 - 592
Outside air shutoff (Timeclock, Dampers and Motors)	585 - 735
Enthalpy control (Replaced Dampers and Motors)	1,790 - 2,025
Supply temperature reset (Multizone System)	1,180 - 1,605
Boiler optimization	445 - 470
Chiller optimization	1,520 - 2,580

3.5.2 Central Automation Systems

Table XXVI also lists some of the available central systems. In concept, these systems provide the capability of meeting an integrated control strategy for buildings. Their current cost range generally limits their application to buildings larger than those considered herein. A listing of the functions normally supplied or offered as software package options is listed in Table XXVIII, together with base and option costs (1976 data).

The list indicates general agreement as to required functions and, except for cost, could represent an AEMS concept for small buildings. Costs are approximately an order of magnitude larger than acceptable AEMS costs, agreeable with the increased size proportion of their intended market compared to the assumed AEMS market.

Other features of the large automation systems, such as the auxiliary functions and complexity, are most likely incompatible with the small building market. Our market analysis indicates low

Table XXVIII. Summary of Software Functions Options--Central Automation Systems
(Functions Available Indicated by Cost in Dollars)¹²

SYSTEM FUNCTIONS	A	B	C	D	E	F
APPROXIMATE BASE PRICE	60,000	47,000	33,000	40,000	58,000	27,000
<u>Energy Control</u>						
Electrical Demand Control	12,000	2,500	5,000	2,900	5,000	2,500
Outdoor Air Enthalpy/Economizer	4,500	2,500	5,000	2,900	5,000	1,500
Optimal Start Time	5,000	3,000	5,000	2,900	5,000	7,000
Chiller Profile	v					
Chiller Optimization	v		5,000	6,600	v	v
Solar Heat Program	v					
Supply Temperature Reset		6,000	5,000	2,900		included
Temperature Reset		2,000			5,000	
Event initiated action	15,000					
<u>Other Functions</u>						
Watchman Tour	5,000+				v	2,000
Fire/Smoke Evacuation Program	v					
Run Time Tabulation		2,000	5,500	1,370	25/point	included
Preventive Maintenance		8,000			v	3,000
Event Indicator		1,000				

v = variable cost

¹² JRB Associates, Inc., "Survey Existing Microprocessor Systems, Components and Software," unpublished report (Federal Programs Office, Conservation and Solar Applications, Department of Energy).

preference for these capabilities, and it is assumed they would play a very minor role in retrofit applications.

3.5.3 New Generation

The equipment previously described is not in a static situation. Manufacturers are introducing new lines of equipment, taking advantage of new technology to make their equipment more flexible and expanding it's capabilities. Keyboard data entries are common. Review of promotional literature supplied by various manufacturers indicates that the emphasis remains on specific markets and specific functions with many of these newer systems.

Others appear to be addressed to the AEMS strategy of total energy control within a building. Curiously, these latter also appear to have been developed originally as advanced controllers of solar installations. The need for multiple modes, numerous sensor inputs and integration with alternate energy source systems have dictated a degree of flexibility that lends itself to AEMS application. At least one system has extended its application to commercial buildings, including capability of demand limiting, duty cycling, enthalpy control, outdoor reset, night setback and start-stop programming.

3.5.4 Summary

In reviewing the equipment currently available on the market which will provide the functions required for AEMS, it must be concluded that "AEMS" does exist today at least from an equipment viewpoint. On the one hand we have the "single-function" equipment, which has been demonstrated to fulfill some energy conservation needs in small buildings. The price structure varies, but lower cost functions are available and compatible with the cost goals of AEMS at the low end of the market. On the other hand, we have the large automation systems, which were shown to be appropriate for very large buildings and are potentially feasible for the high end of this small building market.

The latter equipment or systems meet the intent of the AEMS goal of an integrated energy management system. The former generally do not, and further are applied without benefit of an overall energy controls strategy.

However, it is apparent that industry is beginning to respond to the need for integrated AEMS control concepts within the small building range. In Section 3.7 of this report, rationale is offered to establish the need for an AEMS and set the stage for the strategy required to develop and market such systems.

3.6 MARKET ASSESSMENT STUDIES

It was recognized early in the program that the primary issues related to development and implementation may well lie with the perceived needs of the marketplace. The existence of the numerous energy saving and energy management devices and systems in the marketplace today was considered *prima facie* evidence of the value and cost effectiveness of such items. It was also known that the world was not beating a path to the door of the manufacturers.¹⁴ While the technical phase of the program was concerned with identifying functional and other capability requirements of an AEMS, concurrent market assessment efforts were conducted.

It was the intent of those efforts to identify constraints arising from opinions and requirements of potential buyers that would have an effect both on the AEMS design concept and its subsequent commercialization.

The first phase of this study deals with four broad assessments of market need for an AEMS within the market segment generally defined as small buildings (75,000 square feet or less). Thus, determinations were made, using carefully selected focus groups, of the following issues: (1) market perception of the severity of the energy conservation problem in general and in the market segment in particular; (2) attitudinal statements concerning the solution of these problems; (3) current and projected energy saving practices by the respondents from the market segment; and (4) an estimate of market potential of an AEMS from an analysis of the focus groups. The second phase of this investigation dealt with larger national samplings from the same market segments and used a questionnaire technique.

3.6.1 Methodology

Three small building sectors were chosen to represent the total small building market: (1) apartments, (2) schools, and (3) offices. In the aggregate, these three sectors represent 50 percent or more of the energy consumed, square footage and number of buildings of that total market.

¹⁴ Energy User News, "Queries Heavy, Sales Remain Light," January 16, 1978

In examining alternative strategies for the market research, a focus group design was selected for the following reasons. First, the qualifications of the respondents would be clear and offer the degree of precision that small sample research requires. Secondly, the "open-ended" format of a focus group would provide new insights into market issues as well as comparable answers to issues already defined. Finally, the information gained from the focus group effort would serve as firm guidance for the breadth required for Phase II of the market program.

Focus group discussions were held in four cities (Minneapolis, Los Angeles, Atlanta and Boston) with purchasing influences in each of the three sectors. Two criteria were used in inviting the 32 focus group respondents: (1) that they be related to the purchasing process in the energy conservation area, and (2) that they have some technical understanding of energy-saving hardware. Each focus group meeting was 3-1/2 to 4 hours long and required the active involvement of the respondents.

3.6.2 Findings - First Phase of Market Analysis

In general all focus group respondents perceived the energy conservation problem as severe, both nationally and within their sector. Moreover, most respondents reported considering a number of interrelated factors when determining the best possible ways to solve their energy conservation problems. These factors were grouped into five categories: (a) economic, (b) technical, (c) regulatory, (d) psychological and (e) general.

Economic considerations included the availability of capital and the requirement of a specific payback period related to the purchase of energy saving equipment. Technical factors generally referred to matching the appropriate energy saving equipment to the specific buildings under consideration and demonstrating that such equipment will actually save energy and money in these buildings. Diverse local regulations and codes (e.g., temperature and ventilation requirements) also were reported to affect purchase decisions. The human elements also were described as considerable, especially the willingness of building tenants to go along with energy saving programs, their frequently negative reactions to such programs, and the lack of technical sophistication and know-how of building maintenance personnel. Furthermore, a number of general factors were identified as influencing these individuals--for example, a lack of understanding of a wide range of potential solutions to energy conservation problems.

Most focus group respondents reported that aggressive energy saving practices were currently being employed. These tended to be "first-stage," low-cost practices: the implementation of procedural changes (e.g., turning off lights) and the installation of energy saving devices (e.g., a night setback thermostat). Substantial energy and cost savings reportedly have been realized by these practices. Respondents relied on technical and experiential sources of information when planning future energy conservation programs. Technical data comes from trade journals (which provide objective, impartial reports) and manufacturers (who provide the hardware solutions to identified problems). Colleagues and co-workers provide important experiential data based on first-hand experience and knowledge.

The installation of an AEMS was not viewed by most respondents as an effective method of conserving energy at the present time. Although many respondents agreed that an AEMS would be helpful in newer or larger buildings, generally speaking such a system was viewed as being unnecessary (given that substantial savings are currently being realized), too costly (given that money is tight), and/or unsuited to many of their buildings (given that many buildings are too old and/or too small to efficiently use an AEMS).

Negative economic factors facing these building sectors were identified as the most pressing constraints. The private sector (offices and apartments) differs from the public sector (schools) in how money is obtained and spent; but the overall economic pressures, combined with the perception of other energy saving practices being effective, militate against AEMS being viewed as a desirable or necessary energy conservation step at the present time.

3.6.3 Second Phase

Following this initial focus group analysis, several issues were felt to be of sufficient importance to explore in greater detail. Using a mailed interview technique, a statistically significant sample of responses was obtained to determine payback and cost data. Among other items, supplementary data on types of HVAC systems was also included in the survey, since information on HVAC population was found to be difficult to obtain by other means.

3.7 CONSTRAINTS

By constraints is meant (a) what factors must be considered in the design of an AEMS and (b) what barriers exist in the marketing of such a system. Further, the two issues are mutually inter-

active. Examples of the former are cost, complexity, functions, strategy and capability. The latter considers not only the above but also advertising, credibility of claims and motivation, etc. By proper consideration of these constraints, a suitable product may be designed and effectively and successfully marketed.

Both the marketing studies and technical analyses were oriented to address the issues of constraints. To a large degree, these efforts duplicate the development of a product within an industry. The results, in turn, evolve into preliminary design functional specifications and/or the need for further research and development, as well as the development of strategies to implement the product in the marketplace.

3.7.1 The AEMS Market-Technical Constraints

The AEMS market has been reviewed from several viewpoints: HVAC systems, functions required and cost constraints. Further, existing energy management systems and devices have been evaluated to determine their basic costs and capabilities. To offer a clearer picture of AEMS and its relation to building controls strategy, various parameters will be discussed relative to the entire building markets, drawing therefrom technical considerations and constraints on AEMS concepts.

3.7.1.1 Functions--Functions have been discussed and identified from three viewpoints:

- Those required for AEMS;
- Those provided by today's single-function equipment;
- Those provided by Large Automatic systems.

These lists were all seen to agree. The complete slate of functions represents a "shopping list," with any given building using only those that are appropriate and cost effective. Both of these latter parameters are considered in the following discussion.

Figure 31 shows generally how functions may be cost-effectively applied to the building market. Each function is limited in applicability at the "low" end by cost effectiveness and other factors. Electrical load demand is carried to the full range of building size by virtue of planned utility activities, as discussed in earlier text. At the 1000 square foot size, clock thermostats are also effective energy devices. Other boundaries are not as clearly defined, nor is it particularly important at

Figure 31. General Applicability of Control Functions

this point that they are. The intention is to indicate that, as we consider the market in increasing building size, the number of relevant cost effective functions becomes greater. Further, we can expect that the same holds true for the number of applicable functions in any given building.

The implication for AEMS is that there may be one or two universal functions, but others will be considered in various combinations. AEMS must provide this flexibility.

3.7.1.2 Function Application Limitations--In Section 3.6 we saw that today's energy management controls are being applied to many buildings over the full range of building size. We will introduce another parameter--energy savings potential--as a means to ascertain a level of effectiveness of applied controls strategy. If we accept the premise that the national goal is to maximize energy savings, then the goal or strategy of AEMS must be to provide all the savings economically feasible in a given building. By definition, economic feasibility is what the market will bear. In this study we determined that 2.5-year payback is the appropriate criterion (with variations by market segment).

With the above considerations in mind, the large building automation systems are "evaluated" in Figure 32. We noted earlier that 75,000 square foot buildings, given sufficient savings and high energy costs, were coming within the range of applicability of such systems. The figure uses this as a starting point.

At some larger size, it is assumed that the large systems have the capability to be cost-effectively applied to all buildings and that they maximize the energy savings, at least in principle if not in practice.

It is assumed, without verification, that the large systems are applied with the strategy of maximizing energy savings. It should be recognized that many of these systems were originally offered as manpower reduction systems, with energy savings a plus feature.

There is also the indication from this figure that the arbitrary 75,000 square foot limit of AEMS perhaps should be extended to meet the curve indicated.

A similar evaluation is now made of the so-called single-function controllers available on the market. Recall that these include clock thermostats, multizone controllers, timers, load demand limiters, etc. It is obvious that they are also cost-effective

Figure 32. Percentage of Buildings Suitable for Large Automation Systems by Building Size

devices in themselves, each meeting or exceeding the appropriate payback criterion. As more functions become feasible for a given building, several controllers may be added to collectively form a "system." As buildings further increase in size, multiple units of the same device or controller are often used. Thus, in principle, these single-function controllers can be put into any size building with the implication that they "fill the gap" shown in Figure 33, and hence there is no need or market for "AEMS."

This is a misconception brought about by the piecemeal approach to energy conservation without benefit of an applied controls strategy. As a consequence, the following conditions or situations exist in varying degrees:

- Controllers may be installed in buildings with inefficient energy practices. The installer benefits from these making favorable payback relatively easy to attain. The tendency then is to accept less savings rather than fine-tune the system and risk callbacks to answer complaints.

- The controllers generally are priced such that relatively large savings must be obtained to justify the system. One or two such installations removes the probability of further consideration of controls, likely far short of potential.
- The installation of several products, even from the same manufacturer (which may not be the case), implies a reduction in cost effectiveness due to duplication of parts, marketing, distribution and sales costs.
- Although most manufacturers offer building analysis prior to or concurrent with installation, the primary purpose of this analysis is to sell the product, not to maximize total building energy cost savings. Economic necessity requires such analysis to be a rather crude estimation procedure. This is not to fault the manufacturers.

The sum total of these considerations can be depicted as shown in Figure 33. Note that the ordinate is "system cost effectiveness". Obviously, it is impossible to quantify the lack of "system" energy savings effectiveness of single-function equipment associated with the above qualitative issues.

The actual AEMS market is now redefined as the area of unrealized savings potential on the figure. The market size is actually larger than originally presumed.

Figure 33. Energy Savings Capability of Present-Day Control Strategy from a System Concept Viewpoint

The AEMS market is thus seen as a vital and required element in an overall controls strategy. It will integrate with those systems and controls presently on the market.

It is further clear that the existence of AEMS is predicated on the development of controls application strategies. Essential elements of such a strategy include:

- Maximization of energy conservation per function. This implies "smarter" functional control concepts that are self-tuning. Closed-loop operation in all functions and building systems should be the goal.
- Integration of functions, to assure that interaction between functions are not self-defeating.
- Establishment of the place of controls strategy within the overall strategies of building energy conservation measures.

3.7.2 Marketing Constraints on Technical Design

Very few issues were uncovered in the market analysis which have a direct influence on the design of an AEMS, *per se*. One of these is cost, and involves several variations. Buyers will expect AEMS to save energy costs. Capital expense problems vary between sectors, but there is general unanimity in evaluating a purchase on its return on investment or payback. Payback requirements are relatively short, allowing this parameter to be used to identify AEMS cost constraints and to be used as a sales tool. Tying AEMS cost to savings requires a determination of savings, both as a design parameter (as in this study) and as a subsequent point of sale determination. To those working with such savings evaluations, it is well understood that each building requires individual analysis. Surprisingly, this fact is also known or sensed by the potential buyers, analysis being cited as a prerequisite to purchase.

Consequently, cost is a major issue as in any major product, however the concept of the product paying for itself over a determinable period relieves much of the constraint. The basic cost constraint affecting design is to provide the cost flexibility required to "cover the market" over the wide range of cost goals possible, considering all the variables that impinge upon the cost picture.

A second technical issue raised is that of obsolescence. A strong implication is that AEMS should offer both growth and expansion capability, to meet the buyer's needs for more functions as energy costs increase and as new capabilities are devised. Some potentially new growth functions have been identified in Section 3.3.

Complexity of operator interface is a very real constraint that must be addressed by an AEMS designer. Many current controllers require "programming" of occupancy patterns and other parameters. Various manufacturers have solved this in their own way--with dials, switches and/or touch-pads, complete with manuals to explain the operation thereof. Buyers will demand simplicity. Whatever that is requires further research and demonstration to ascertain. Obviously, the less operator interaction the better. Therein lies the greatest constraint and challenge to AEMS designers. It has been mentioned elsewhere that if viable occupancy sensors were developed, perhaps much of the interface requirement would be relieved. In practice, however, this will not be obtainable when considering slow response times of some heating systems. Means of increasing response times could be developed, e.g., radiant panels, but in a retrofit situation, they would not be cost effective. It should be a goal of AEMS designers to approach the ideal concept of closed-loop operation whenever possible.

Granting even this possibility, operational flexibility will undoubtedly still be required through operator interface. For modular AEMS concepts that provide functional flexibility, shared data entry capability through touch-pads will probably offer cost minimization.

Finally, during the focus group discussions of energy conservation, the subject of occupant attitudes toward comfort continually arose. There appeared to be a correlation in their minds between energy conservation and discomfort. Obviously AEMS should be dedicated to maintaining comfort conditions at a minimum energy (cost) expenditure. Comfort is a reference to which AEMS must operate. Current research¹⁵ into maximizing comfort and minimizing energy use may eventually provide alternate techniques and parameters which AEMS must accommodate.

¹⁵ ASHRAE Technical Committee 2.1, Physiology and Human Environment, ASHRAE Std. 55-74.

3.8 AEMS CONCEPT

The various constraints and requirements of an AEMS have been cited in previous sections. They include:

- Required functions;
- Function flexibility or modularity;
- Cost constraints and flexibility;
- Operator interface considerations;
- Growth capability;
- Applied strategy.

Converting these requirements into a practical mechanization is a major task, well beyond the scope of this present investigation. Furthermore, given the same set of requirements, it is not likely that any two designers or companies would provide the same solution. Evidence of this is easily found in reviewing existing controls. Consequently it is felt to be presumptuous to impose recommended mechanizations for AEMS.

However, from a conceptual viewpoint, one may visualize a mechanization that draws upon current and evolving state-of-the-art in hardware and software to provide the stated requirements.

3.8.1 Hardware

Figure 34 illustrates an AEMS hardware organization concept. This consists of standardized, off-the-shelf hardware modules with the following features:

- Microelectronics technology used for minimum cost per function - both recurring and nonrecurring.
- System is expandable and updatable by using a common communication bus to standardize interfaces.
- Future large scale integration of electronics will be plug-compatible to sensors and actuators.
- Compatible with distributed intelligence (smart sensor) developments.

Figure 34. AEMS Hardware Concept

3.8.2 Software and Application

Software must be developed to embody the functional requirements and strategies of AEMS. Expanding memory technology will permit the development of software modules with over-capability. Thus, software may be preprogrammed at the factory with all major functions delivered as pre-stored capabilities. Field selection of functions, assignment of inputs and outputs, addition of minor functions and setpoints will be accomplished by means of a "system initialization panel." This panel, which will not remain at the site, will minimize on-site hardware.

An operator interface will be provided for setpoint, occupancy schedules and override inputs. A strategy goal for AEMS is to minimize the complexity and amount of interface required, through automatic or closed loop adjustment of now-conventional operator-adjustable parameters. The AEMS may also provide displays and data storage for those owners desiring to actively monitor and track their energy usage performance. An AEMS application concept is shown in Figure 35.

3.8.3 Strategy

The appearance on the marketplace of controllers that exhibit many of the above features is *prima facie* evidence that feasibility exists. Such controllers are already in the \$10,000 range, with the potential for further cost reductions. However, their mere existence is not enough. From an AEMS viewpoint, it is vital that such controllers be developed and marketed within a framework of objectives and goals which have been loosely defined herein as "strategies." The main elements of the strategies are summarized below. If satisfied, they will contribute to AEMS impact on the nation's energy usage.

- An AEMS must be directed towards total energy conservation in a given building, "pushing" the various functions to their maximum potential, without thereby creating tenant discomfort and subsequent callback needs for retuning. This will require smarter algorithms, capable of self adjustment if necessary. This must also be accomplished within the needs and economic limits of the owner/manager. As the economic and energy climate changes (higher energy costs, tax incentives, refit energy codes, etc.) the installed AEMS should be capable of meeting expanded needs in a cost effective manner. These considerations imply the need for building analysis programs perhaps more sophisticated than those now widely used by industry as sales tools.

Figure 35. AEMS Application Concept

- The AEMS is a part of an overall building conservation strategy that must include insulation, building and equipment modifications, conservation practices, and the like, with each being stressed as potentially viable measures. This implies the need for significant industry and government programs for analysis, promotion, demonstration and advertising relative to the role of the "black box" in building conservation programs.

3.8.4 Concept Summary

The controls industry is not only aware of energy conservation needs and solutions in buildings today, but is providing equipment to meet these needs. There is perhaps little question that "AEMS systems" will evolve from these efforts. The actual mechanization of AEMS is not important, recognizing that AEMS and its market exist as a concept through definition of given strategies. Cost effective mechanizations must follow from application of these strategies.

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APPENDIX A

STATEMENT OF WORK

STATEMENT OF WORK

The statement of work included in the contract covering work described in this report is reproduced below.

Task 1 - Project Plan

Submit within 15 days of execution of a contract, a detailed project plan, which indicates more completely than the proposal does, final allocation of financial and personnel resources, timing of principal events that are to occur during the execution of the project, decision points and major milestones, management plan, and other items of direct relevance to timely and successful accomplishment of the project objectives. The contractor shall not proceed with Task 2 or beyond, until this plan is approved by the BNL program manager. No changes to the plan shall be made without approval of the program manager.

Task 2 - Data Collection

Assemble necessary data on building characteristics and categorize according to building size, usage, energy consumption patterns, space conditioning equipment inventory, lighting systems, present control hardware and methods, specific energy usage, operating costs, regional considerations, and other relevant information required to address the proposed analysis. The type buildings to be considered are commercial buildings under 75,000 square feet. These may include, but not be limited to, offices, stores, apartments, medical buildings, food outlets, warehouses, schools, etc. The result of this task should be the selection of three or four building types, representative of small commercial buildings, which can be used for the remaining portion of the study. The building types selected should offer the best opportunities for energy conservation through improved automated controls, taking into account total impact on the nation's energy consumption.

Task 3 - Functional Analysis

Perform functional analysis of the typical control systems and practices utilized in the selected types of small buildings. Identify the strengths and weaknesses of those systems in terms of

energy conservation and life cycle costing (first, operational and maintenance costs). Specific existing control techniques should be identified and relative energy consumption and operating costs should be calculated or documented. Where calculations are made, examples should be given.

Identify commercially available energy conservation automated control hardware and techniques which could be either refit into existing small buildings or utilized in new designs to reduce energy consumption. Analyze their impact on small building operation, including energy savings, life cycle costing, reliability, installation costs, etc. Recommendations as to the use of automated control techniques based upon current systems should be stated and the interface with sensors, control devices and logic systems should be detailed. Costs of the new refit equipment, based on available technology, should be given. Calculations should be provided to demonstrate energy cost saving over a seasonal period. These calculations should be performed for at least three representative climatic regions representing extremes in weather for both heating and cooling.

Task 4 - Energy Conservation and Cost Goals

Based on the above tasks, define realistic energy conservation goals and allowable cost goals for automated energy management systems for small buildings. A payback period of two to five years should be strived for. The definition of an automated energy management system might be a centrally located, operated, and monitored control system capable of efficiently controlling the operation of a building. The AEMS could consist of a hard-wired logic system encompassing several individual controllers or could consist of a computerized system controlling several control devices through the use of energy conservation software packages.

In developing and analyzing the cost requirements for such a system, the possible ancillary benefits which are not energy related, but which enter into a cost benefit analysis should be considered. These might include the use of an AEMS for such functions as fire and security control.

Task 5 - Concept Development

Prepare a conceptual design of an AEMS, based on the previous analysis and market considerations. The paper design shall address hardware, logic, and software concepts. It shall identify

the functional categories capable of being controlled and the general manner of accomplishing the control. The principal purpose of this task is to ensure that the concepts developed can be implemented for the defined costs.

Task 6 - Market Assessment

Perform sufficient analysis to assess the market potential for the control systems recommended with due consideration for all costs and other constraints such as those associated with building codes, and other impediments which might prevent or limit implementation.

Task 7 - Recommendations for RD&D

Prepare a list of recommended projects which would lead to the development and commercialization of the design concepts developed in the study. Prepare estimates of the energy savings that such improved systems could provide and the cost of such systems, including installation and operating costs.

Prepare the inputs required for, and conduct with ERDA an updated Threshold Criteria analysis for each of the recommended systems. Refer to sample forms, Enclosure 1.

Formulate study recommendations in a comprehensive final report sufficient to form the basis for planning toward implementation of an AEMS for small commercial buildings. Besides the development of system requirements, commercialization plans and requirements should be developed for both the public and private sectors.