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Building Research Board
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PREFACE

As a result of technological advances in the past two decades, new control devices and control strategies have been developed for heating, ventilating, and air-conditioning that promise 1) improved environmental conditions in occupied spaces; 2) reduced energy consumption in buildings; and 3) increased control-system reliability. The technological advances have been largely driven by the development of computer-based controls and control strategies. As a result of these developments it is likely that the next decade may well see the complete replacement of traditional pneumatic and electric controls with electronic computer-based control systems. This evolutionary change, however, has caused and will continue to cause some difficulties for end users in both the private and the public sectors.

Because of the problems encountered by federal agencies over the past 15 years, the sponsoring agencies of the Federal Construction Council asked the Building Research Board of the National Research Council to establish a committee to investigate the situation. In the course of its investigation the committee explored the following issues:

- Why have federal agencies had difficulties with controls and control systems?
- Are the experiences of federal agencies different from those of the private sector, and, if so, why?
- What will the future bring in the way of new control systems; what problems will be caused by these future changes in controls; and how can the construction industry in general and the federal agencies in particular minimize future problems?
- What are the reasons, if they can be discerned, for the particular problems experienced by federal agencies in the past?
- How can federal agencies best cope with the evolving control technology in order to obtain the benefits of the emerging systems while avoiding the types of problems that have been experienced in the past?

In addressing these issues, the committee was seeking answers to the broader question of how federal agencies can utilize the new technology without incurring an increased risk of receiving control systems that do function properly or can not be maintained economically over a long period of time.

With restricted financial resources, the committee was unable to conduct original research. It relied primarily on the collective experiences of its membership, input from federal agency liaison members, and discussions with designers, manufacturers, and installers of control systems.

The committee is grateful for the help of the Building Research Board staff and, in particular, Henry Borger, Executive Secretary of the Federal Construction Council, and Joann Curry and Lena Grayson for their secretarial assistance. The committee is also grateful to the liaison members of the federal agencies who were most helpful in summarizing the control issues that they have faced in the recent past.

Finally, on a more personal note, I would like to express my thanks to the entire committee for their professional response to difficult questions, for the time they spent discussing the issues with other members of the construction industry to ensure that all significant viewpoints were expressed, and, most important, for developing the conclusions included with this report in a collegial and open fashion.

Donald E. Ross
Chairman
Committee on Controls For Heating, Ventilating, and Air-Conditioning Systems

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EXECUTIVE SUMMARY

Since the late 1970s, federal agencies have experienced numerous problems with controls used in heating, ventilating, and air-conditioning (HVAC) systems. As a result, federal agencies have taken or are considering a variety of actions aimed at eliminating or minimizing the problems. However, the advisability or effectiveness of many of these actions has been questioned by some agency officials as well as some consulting engineers and control manufacturers. Therefore, the agencies that sponsor the Federal Construction Council asked the Building Research Board to form a committee to further review the situation.

The committee met six times in the course of the study. Two of the meetings were with representatives of manufacturers of controls and other organizations having an interest in the subject.

The committee found the study difficult because of the inherent complexity of the subject and because there are a number of potentially significant changes taking place or being considered that could drastically change both the technology and the acquisition process for HVAC controls. In its investigation the committee reviewed the state of the art in HVAC controls, analyzed basic issues involved, critiqued various actions taken or contemplated by federal agencies to solve their HVAC control problems, and explored additional remedies agencies might consider.

STATE OF THE ART

During the past 20 years automatic controls for HVAC systems have changed dramatically. The two main driving forces behind the speed-up in the normal evolutionary process have been higher energy costs, due to the large price increases that occurred in the 1970s, and the availability of increasingly sophisticated digital computers and microprocessors at lower and lower costs.

The state of the art in building controls is best understood by looking at three perspectives: (1) local loop controls, (2) energy management and control systems, and (3) a combination of local loop controls and energy management and control systems.

Local loop controls refer to the control systems for individual elements such as air conditioning units and heat exchangers. These types of controls usually operate independently from one another and may or may not be connected to a central control system.

Energy monitoring and control systems (EMCS), which are also known as energy management systems, are centralized, building-wide systems that control energy-using equipment through a combination of global and independent strategies. An EMCS was originally a separate entity from the local loop controls. Today, however, there is a trend towards a blending of the two types.

A combination of local loop controls and energy management and control systems usually manifests itself today in the form of an EMCS having remote panels that are capable of local loop control.

By far the most significant recent development in HVAC control technology is the emergence of the direct digital control (DDC) concept in which local digital processors are used to perform controlling actions in liew of pneumatic or electronic analog devices. Introduced to the commercial building market in the late 1970s, DDC is in the process of revolutionizing the HVAC controls industry.

Direct digital control is based on the use of microprocessors which can be programmed to perform a variety of control functions ranging from local loop control to energy management. Manufacturers of packaged HVAC components like chillers, boilers, and air-handling equipment are also beginning to supply their equipment with factory-installed DDC controllers. The use of DDC is hampered by the fact that there are no industry standards for communications protocols for HVAC controls. Consequently, DDC controllers of different manufacturers cannot be interchanged or interconnected.

OVERRIDING ISSUES

The committee identified three issues as being of overriding importance because they deal with the fundamental questions of whether federal agencies need to take any special action to correct the problems they have experienced with HVAC controls and, if so, what the general direction of those actions should be. The three issues were: (1) whether HVAC control problems are serious enough to justify federal action; (2) whether HVAC problems are inevitable and thus unavoidable in the current circumstances; and (3) whether federal agencies have experienced more problems than private owners, and, if so, why?

The committee's conclusions were that: (1) the HVAC control problems being experienced by federal agencies are indeed serious enough to warrant action by federal agencies; (2) while many of the problems agencies have experienced might have been inevitable, and thus unavoidable, when new control technologies (particularly technology involving the use of microprocessors) were first being applied, they are no longer inevitable; thus efforts by federal agencies to improve the situation will not necessarily be in vain; and (3) federal agencies have experienced more problems with HVAC controls than private owners, which suggests that agencies might solve some of their problems by adopting appropriate practices from the private sector.

CRITIQUE OF FEDERAL ACTIONS AND PLANS

Because of their concern about continuing serious HVAC control problems, several federal agencies have taken or have proposed to take drastic actions during the past few years to try to correct the situation. As part of its investigation, the committee reviewed the most notable examples of such actions; specifically:

- The issuance by the Air Force of a directive (Engineering Technical Letter 83-1) requiring consulting engineers* to develop highly detailed HVAC control drawings when designing HVAC systems. The Air Force's objectives were to minimize uncertainty during construction about what is needed and to ensure that Air Force maintenance personnel receive good control drawings. The result of the directive was to transfer to consulting engineers responsibility for detailed design work that traditionally has been performed by control system vendors, and in particular responsibility for developing control drawings that can be used for maintenance as well as installation.
- The development by the Army's Construction Engineering Research Laboratory (CERL) of a family of standard control systems and standard control panels to be used in lieu of proprietary systems and panels. The panels, which are the key elements of the systems, are generic electronic analog devices that can be supplied by any control manufacturer that chooses to make them. Among the benefits CERL claims for its standard systems and panels relative to comparable proprietary products are: (1) easier maintenance due to the use of standard control strategies and the incorporation of features to facilitate maintenance; (2) reduced maintenance due to the use of high quality components and simplified control strategies; and (3) better performance through use of high quality components. The Air Force has indicated that it intends to require the use of the CERL systems and panels on its projects. The Army has funded the development of another family of standard systems and control panels by a private consulting engineering firm; the Army panels differ from the CERL panels in several respects, but the fundamental difference is that they employ microprocessors. The adoption of either the CERL/Air Force approach or the Army approach would have the effect of making HVAC controls a generic commodity like bricks or lumber.

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*Not all HVAC systems in federal building are designed by consulting engineers. For example, some systems are designed by engineers employed by architectural firms and some systems are designed by government personnel. However, since the vast majority of systems are designed by consulting engineers, designers of HVAC systems are referred to as consulting engineers throughout this report.

- The development of special procurement procedures by several agencies aimed at making it possible for the government to consider such factors as performance and maintainability as well as price when procuring HVAC control systems.
- The imposition by a number of agencies of bans on the use of direct digital controls (DDC)--the latest development in control technology. Originally, the bans were imposed because of concern about the reliability of DDC system, the bans have been continued because of other concerns, but especially the fear that DDC systems will be expensive to maintain because they are complex and proprietary.

In general, the committee shares the agencies' concerns about and dissatisfaction with HVAC controls. However the committee has serious reservations about the wisdom of two of the actions that federal agencies have taken or have proposed to take to correct the situation; specifically:

- The committee does not believe that consulting engineers should be required to develop design drawings that are sufficiently detailed to be used for repair and maintenance purposes. The committee agrees that agencies need and deserve to have such drawings; however, it believes that they should be provided by control vendors, not by consulting engineers.
- The committee does not believe that the idea of federal agencies developing standard nonproprietary control systems and control panels for use on their projects is practical or that it would provide the benefits agencies expect.

The committee generally agrees with the other two actions that have been taken by federal agencies; i.e., the use of special procurement procedures for energy monitoring and control systems and the temporary ban on the use of direct digital control systems. However, the committee believes that agencies need to consider even more changes in their procurement procedures (as discussed in the next chapter) and that the ban on DDC should be removed as soon as possible.

PROPOSED ADDITIONAL REMEDIES

While the committee doubts the efficacy of some of the corrective actions being considered by federal agencies and believes that other actions that have been proposed or implemented do not go far enough, it recognizes that agencies still have serious problems with HVAC controls that must be addressed. The committee, therefore, explored the following additional steps that the agencies might consider.

1. Making Fuller Use of HVAC Consulting Engineers

The committee concluded that the relatively lower rate of HVAC control problems on private projects can be attributed at least in part to the fact that the consulting engineers who design private systems play a larger role in the design and construction process than designers do on federal projects. The committee therefore developed the following recommendations:

a. Agencies should encourage consulting engineers to propose the use of control schemes and devices other than those covered in agency design manuals and guide specifications whenever they believe the government would benefit. Agencies should consider proposed deviations from established design standards conscientiously and expeditiously.

b. Agencies should require consulting engineers to write performance specifications that rigorously define the location and the accuracy of the instrumentation to be furnished for a particular control function; the precise control sequence required for the system (e.g., when a damper or valve should open and what should cause it to open); and the exactly defined result to be provided by the control sequence in actual operation

c. Agencies should retain HVAC consulting engineers to observe the installation of their systems, to answer questions that arise during construction, and to help ensure that their systems are installed and tested properly.

d. Agencies should retain HVAC consulting engineers to observe the start up of their systems and the training of agency operators to ensure that the systems are made fully operational before they are turned over to the government and that agency personnel are properly instructed in accordance with the project specifications.

2. Ensuring the Qualification of HVAC Consulting Engineers

The committee concluded that some recent control problems have occurred because some consulting engineers have an inadequate understanding of control theory in general and modern digital controls in particular. The committee further concluded that if agencies are going to rely more heavily on consulting engineers than they do currently to help ensure that they get HVAC systems and controls that work properly, as the committee has recommended, agencies must make a special effort to ensure that the consulting engineers they use are well qualified. Taking into consideration the fact that most HVAC consulting engineers are subcontractors to architectural firms having prime design contracts, the committee recommended that agencies base the award of prime design contracts in part on the qualifications of the HVAC designers identified on the Standard Forms 255 submitted by firms seeking prime design contracts. The committee also recommended that agencies: (1) indicate in their announcements of need for design services that the qualifications of HVAC designers--and in particular their knowledge of controls--will be a major consideration in the contract award; and (2) carefully review the information submitted regarding the qualification of HVAC designers and their work on previous projects when selecting a prime design firm.

3. Developing More Effective Design Criteria and Guide Specifications

Most federal agencies publish two types of standards dealing with the design of buildings and building systems (including HVAC systems): design criteria and guide specifications. These general standards compliment the project-specific criteria that agencies develop for each individual project. Design criteria and guide specifications serve several important functions for federal agencies: They establish minimum requirements, they help ensure that errors made and problems encountered on one project will not be repeated on subsequent projects, they identify suitable types of products, and they minimize the likelihood of protests from contractors and manufacturers because of violations of federal acquisition regulations.

The committee concluded that whereas the federal approach of requiring architects and engineers to follow agency design criteria and to use agency guide specifications generally has produced satisfactory results, it has not worked well in recent years with regard to HVAC controls primarily because HVAC control technology has been evolving very rapidly. The committee believes that the key to coping with rapidly changing technology is to adjust quickly and decisively to changes. Unfortunately, the government's criteria and specification development process is inherently cumbersome and time consuming, and thus slow to react.

The upshot is that government agencies are in a predicament for which there is no easy solution. They cannot change their design criteria and guide specifications quickly enough and often enough to reflect changes in the technology, but they cannot dispense with their design standards without risking a multitude of protests and disputes on every project.

While the committee does not see any complete solution to the agencies' dilemma, it has recommended the following interim steps to help the situation until the rate of change in HVAC control technology decreases to a reasonable level:

a. Agencies should modify their directives to HVAC consulting engineers to encourage them to propose the use of systems and requirements that differ from agency design criteria and guide specifications whenever they believe the government would benefit.

b. Agencies should establish mechanisms for quickly reviewing and acting on requests from consulting engineers for waivers from the provisions of published design criteria and guide specifications.

c. Agencies should adopt the practice of reviewing and updating HVAC design criteria and guide specifications annually to incorporate recent changes in control technology.

Finally, the committee believes that the current guide specifications of some agencies may be unnecessarily permissive with regard to HVAC controls. Therefore, the committee recommends that agencies review their guide specifications to determine if some additional restrictions and requirements aimed at improving the quality and maintainability of controls installed on government projects might be in order; e.g., see quality-related requirements in ETL 83-1.

4. Ensuring the Qualification of Installers of HVAC Control Systems

The one factor that was mentioned frequently by HVAC specialists from whom the committee received input as a cause of problems with HVAC controls in federal buildings was the failure of federal agencies to restrict bidders on government projects. However, the Federal Acquisition Regulations (48 CFR CH 1, part 9) actually require contracting officers to ensure that an organization being considered for a contract award is "responsible" (i.e., fully qualified to fulfill the contract).

It would appear, therefore, that contracting officers already have sufficient authority to ensure that contractors and subcontractors on government projects are qualified. The committee has recommended that agencies use that authority fully with regard to installers of HVAC control systems.

5. Promoting the Development of Control Standards

One of the main concerns agencies have about using proprietary HVAC control systems for which all components are supplied by a single vendor is that once such a system is installed, all spare parts (and in some cases all repair service) and all parts to expand the system must be obtained from the original vendor. This situation eliminates competition, which the agencies believe increases their maintenance, repair, and alteration costs.

The problem is not serious with traditional pneumatic and electronic analog controls because the components of the various manufacturers of such systems often are similar enough that they can be intermixed without too much difficulty. The problem is very serious, however, with modern highly integrated digital control systems. The components used in these systems employ microprocessors that respond to and/or generate specific digital signals, and unless the signals are in precisely the right form they are meaningless to the microprocessors. The rules that define the nature and meaning of the signals used in a control system are known as protocols. Currently, the digital-based control components of different manufacturers cannot be mixed and interconnected because of the absence of standards for control system protocols.

The committee concluded that the development of protocol standards for HVAC controls would be of great benefit to all building owners, including federal agencies. In fact, the committee believes that the development of open protocols is the single most pressing need with regard to HVAC controls.

The committee recognizes, however, that the development of a protocol standard would be a very difficult task. Not only would the effort be technically challenging, but it would also generate heated disputes among the various control manufacturers. In the circumstances, there is no assurance that the effort would be successful. However, the potential benefits are sufficiently great that federal agencies ought to encourage and support the initiation of the effort.

Of the various protocol-development projects reviewed by the committee, the one proposed by the Intelligent Building Institute (IBI) would appear to have the best chance of producing worthwhile results in a reasonable period of time. The committee has recommended, therefore, that agencies give favorable consideration to requests from IBI for financial support. However, the committee also recommends that the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the National Bureau of Standards also be involved in the effort.

6. Using a New Approach to Contracting for Maintenance

In recent years, more and more federal agencies have been contracting for building maintenance and repair work, especially for complex items like HVAC control systems. Three factors have contributed to this trend: The growing complexity of building systems, reductions in government staff levels, and increased emphasis on the government policy to procure goods and services from the private sector whenever it is cost effective. Consequently, the committee looked for ways of improving agency procedures for contracting for the maintenance and repair of HVAC controls.

After analyzing the situations, the committee concluded that the best organization to get to maintain a control system would be the original manufacturer since its personnel should know better than the personnel of any other organization how the system was installed and how it should function. Indeed, with some especially sophisticated systems it is possible that only the original manufacturer has the knowledge needed to maintain it. However, if the original manufacturer is hired, it would be a sole-source procurement, which is almost always more expensive than a procurement involving competition.

To reduce the cost of such maintenance contracts, the committee has recommended that agencies try an approach in which manufacturers are required to include the cost of long term service (e.g., 5 years) in their bids for supplying the system initially--the objective being to force manufacturers to compete on service cost as well as first cost in order to win an installation contract.

7. Developing and Maintaining Federal Expertise in Controls

Even though federal agencies depend heavily on private consulting engineers, manufacturers, and contractors to design, manufacture, install, and maintain HVAC control systems, the committee believes that agencies need to have at least a few full time employees who are experts in HVAC controls to perform such functions as preparing design criteria, writing guide specifications, evaluating the capabilities of consulting engineers seeking design contracts, reviewing proposed system designs, evaluating vendor proposals, inspecting and testing completed systems, evaluating the work of maintenance contractors, and generally helping to resolve problems that occur. To ensure that agencies retain an adequate level of in-house expertise, the committee has recommended that agencies form special permanent teams of HVAC control experts to handle all important tasks relating to the acquisition of HVAC controls.

2

INTRODUCTION

Since the late 1970s, federal agencies have experienced numerous problems with controls used in heating, ventilating, and air-conditioning (HVAC) systems. The nature and causes of these problems have been discussed in two previous Federal Construction Council (FCC) reports (FCC Standing Committee on Mechanical Engineering, 1981, and FCC Consulting Committee on Energy Monitoring and Control Systems, et al, 1984) and in a paper on the results of a laboratory study of HVAC systems by the Army's Construction Engineering Research Laboratory (Hittle, et al, 1982).

Faced with evidence of widespread problems with HVAC controls, federal agencies have taken or are considering a variety of actions aimed at eliminating or minimizing the problems. However, the advisability or effectiveness of many of these actions has been questioned by some agency officials as well as some consulting engineers and control manufacturers. Therefore, the agencies that sponsor the Federal Construction Council asked the Building Research Board to form a committee to further review the situation and, if possible, to recommend guidelines for selecting HVAC controls for federal buildings that would help ensure that federal agencies receive effective and reliable controls.

HOW THE STUDY WAS CONDUCTED

The committee met six times in the course of the study. The first meeting was devoted to a review of the concerns of the federal agencies and the objectives of the committee. At the second meeting the committee received briefings from representatives of seven manufacturers of controls or related HVAC equipment: American Automatrix, Andover Controls, Carrier, Honeywell, Johnson Controls, MCC Powers, and Trane. Each manufacturer was asked to discuss seven questions:

1. Where will the control business be in two to five years?
2. What product developments are expected to influence the types of control systems that could or should be purchased by government agencies for federal buildings in the future?
3. Where will conventional electric or pneumatic controls find application in the future?

4. When and how will direct digital control (DDC) technology replace conventional controls and at what risk, if any, to the facility's owner?
5. Where should computer based technology be applied and where should it not be employed?
6. Are open protocols likely to be developed in the future, and what are the advantages and disadvantages of such protocols?
7. Why have government agencies experienced operating problems in the past and how can they be averted in the future?

The Committee also received written responses to these questions from Garra Tech. Ltd.

At the third meeting the committee heard presentations by the IBM Corporation on their efforts to link building control systems through a "General Purpose Automation Executive" (GPAX) system and by the Army's Construction Engineering Research Laboratory on the results of their tests of HVAC controls and systems.

Subsequent meetings were devoted to reviewing and analyzing information assembled by the committee in preparing this report.

ORGANIZATION OF THE REPORT

Under any circumstances a study of HVAC controls would be challenging inasmuch as HVAC control technology is inherently complex and the process through which HVAC control systems (like all systems in buildings) are designed and installed is very complicated. The subject is especially difficult now, however, because there are a number of potentially significant changes taking place or being considered that could drastically change both the technology and the acquisition process for HVAC controls. The situation is further complicated by the fact that some of these changes are being promoted by various federal agencies while others are occurring independently of (or in spite of) the policies of federal agencies. Similarly, some of the changes would tend to complement each other while others are mutually exclusive. The upshot is that the committee experienced considerable difficulty coming to grips with the problem and then presenting its views clearly.

Eventually the committee settled on an organization involving, first, a review of the state of the art in HVAC controls; second, a discussion of three basic issues of overriding importance; third, a critique of various actions taken or contemplated by federal agencies to solve their HVAC control problems; and finally, a discussion of remedies proposed by the committee.

TERMS OF REFERENCE

Because the subject of HVAC controls is so complex and the time and resources available for the study were limited, the committee had to establish boundaries on its investigation and report; specifically:

1. The committee accepted as fact the assertions of federal agencies that they have frequently experienced difficulty getting HVAC controls to operate as expected and keeping them maintained. The committee accepted the agencies assertions on these points first because it would have been prohibitively expensive (if not impossible) to verify them independently, and second because they were not at odds with the personal experiences of the committee members. However, the committee did examine the symptoms and reasons for the problems and whether government agencies have experienced more problems than private owners.

2. The committee has included only a broad general review of HVAC control technology. The committee assumed that most readers of the report would have sufficient general knowledge of the subject to understand the technical issues being discussed without a detailed explanation of the basics. Furthermore, the subject is too complex to be covered in detail a report like this one. A glossary of some key HVAC control terms has been included as an appendix for those readers who are not familiar with the terminology.

3. The committee has focused on controls for HVAC systems in buildings that are designed on the basis of project-specific occupancy needs. These engineered buildings include most buildings other than single-family residences. The report encompasses all types of controls used in engineered buildings, including energy monitoring and control systems.

4. The committee has addressed both technical and nontechnical aspects of the subject. The committee found that the technology of HVAC controls and the processes by which controls are designed, procured, and installed are so intimately linked that it is not feasible to consider one without considering the other. However, except with regard to certain specific issues, the report does not address the procurement and administrative processes of individual agencies. Rather, it addresses these aspects of the subject in terms of federal agencies in general.

Finally, the committee wishes to emphasize that many environmental problems in buildings are not related to HVAC controls and that other aspects of the subject also deserve study.

3

STATE OF THE ART IN HVAC CONTROLS

During the past 20 years, automatic controls for HVAC systems have changed dramatically. The two main driving forces behind the speed up in the normal evolutionary process have been higher energy costs, due to the large price increases that occurred in the 1970s, and the availability of increasingly sophisticated digital computers and microprocessors at lower and lower costs.

Due to the extent and rapidity of the changes that have occurred in HVAC control technology in the last two decades, there is currently some confusion and disagreement about HVAC control concepts and terms, which makes the subject difficult to discuss. The committee has prepared this chapter primarily to explain its method of classifying systems and its terminology for various control concepts.

The committee recognizes that many readers will probably disagree with some of its view of the technology. (Indeed the committee itself is not in full accord on all terminology.) However, this is not a major concern since the committee is not recommending that its terminology be adopted by others. It is only important that the reader understand the committee's meaning when various terms are used and concepts are discussed in subsequent chapters.

OVERVIEW

At this time, the state of the art in building controls and automation is best understood by looking at three perspectives: (1) local loop controls, (2) energy management and control systems, and (3) a combination of local loop controls and energy management and control systems.

Local loop controls refer to the control system operating individual systems such as an air conditioning unit or a heat exchanger. These types of controls usually operate independently from one another and may or may not be connected to a central control system.

Energy monitoring and control systems (EMCS) are also known as energy management systems (EMS), engineering data and control systems (EDCS), facilities management systems (FMS), and building automation systems (BAS). An EMCS generally denotes a centralized, building-wide system (or base-wide system in the case of many military installations) that controls energy-using equipment through a combination of global and independent strategies. An EMCS was originally a separate entity from the local loop controls. Today, though, there is a trend towards a blending of the two types.

A combination of local loop controls and energy management and control systems usually manifests itself today in the form of an EMCS having remote panels that are capable of local loop control. Frequently, these local panels utilize direct digital control.

LOCAL LOOP CONTROLS

The state of the art in local loop controls can be viewed along the traditional lines of: (1) electric, (2) pneumatic and (3) electronic controls. The most recent change in local loop controls is the application of microprocessors in what is known as direct digital control (DDC). This last category is a development of the eighties.

Electric controls are usually considered to be of two types: (1) two-position electric switch devices, and (2) modulating potentiometric devices. In terms of two-position electric controls, little has changed over the decades and the state of the art is pretty much the same today as it was 30 years ago. Potentiometric modulating controls underwent significant changes in the 1970's when the fragile balancing relay was replaced by a sturdy electronic equivalent. The heart of the modulating electric system is the actuator, which today is a versatile unit. It accepts the traditional potentiometric input signal or a variety of modulating signals used in electronic control systems.

Pneumatic control is a traditional form of control using compressed air in a pressure range of 3 to 15 psig to open or close a damper or valve. Pneumatic controls have changed little in the last decade except for the widespread substitution of plastic components for metal components, which is viewed as an undesirable change by some people. The major developments in pneumatic controls have been the modulating fluidic devices introduced in the late 1960's and the modular devices introduced in the early part of this decade.

With the advances being made in electronic and direct digital controls, traditional pneumatic controllers are being used less frequently in new projects. It would not be rash to project that by the next decade pneumatic controllers might be manufactured mostly for spare parts and expansion of existing systems, although this still remains to be seen. Pneumatic actuators though, because of their low cost, simplicity and reliability, will undoubtedly continue to be used as much as ever even in electronic and direct digital control systems.

Electronic control systems underwent major changes in the 1960's due to developments in solid state technology. Today's electronic systems have refinements made possible by advances in integrated circuit technology; however, electronic systems have not been popular for three reasons: (1) an electronic actuator has not yet been developed that is as fast and reliable as a pneumatic actuator, (2) traditional pneumatic mechanically-minded building operating staff, and (3) direct digital control is used in many situations where electronic controls could find applications.

A recent development in electronic control systems has resulted from work done by the U.S. Army's Construction Engineering Research Laboratory (CERL). Responding to complaints of malfunctioning controls, CERL tested some commercially available controllers and carried out experiments to determine ways of addressing identified problems, such as controller inaccuracies and instability, misapplications, and improper maintenance. Standardized electronic control panels have resulted from this work and are starting to be used by parts of the U.S. Air Force. These panels are discussed in some detail in chapter 5.

By far the most significant expression of the state of the art is direct digital control (DDC). Introduced to the commercial building market in the late 1970's, DDC is in the process of revolutionizing the commercial controls industry.

Direct digital control is based on the use of a microprocessor programmed to duplicate the control functions of analog electronic or pneumatic controllers. Although early computer based systems used computer power resident in a central processing unit (CPU), the evolving technology and the decreasing cost of the microprocessor has resulted in the development of smaller packages serving individual building systems and even individual control loops. The ultimate realization of this trend is the development of the totally distributed DDC system. In such a DDC system, a microprocessor is directly in the control loop. The result is that the DDC controller is dedicated to a defined and limited control function. The DDC controller receives, from the controlled system, and transmits, to the controlled system, digital information. It uses the logic of the microprocessor to determine the particular control action to be taken. At this time, these controllers are highly proprietary to the system manufacturer and most must be programmed in the field.

The trend is that the microprocessor is getting closer to the individual control loop level, resulting in the development of application-specific control systems that are able to communicate with other individual loops or with centralized units installed by the same manufacturer. Microprocessor-based control systems in the form of DDC controllers that are application-specific are now offered as factory-installed elements with such equipment as chillers and air handling units. This packaging of equipment and controls is a significant change that is of major interest to the committee and will undoubtedly have considerable impact on the agencies and their installations in the future.

ENERGY MONITORING AND CONTROL SYSTEMS

The state of the art in energy monitoring and control systems is best seen along the lines of: (1) system architecture, (2) distributed intelligence, and (3) instrumentation.

EMCS architecture has changed considerably since the first systems were developed circa 1970. From a totally centralized design in which a central processing unit (CPU) was connected to various field points through multiplexers that provided communication to the CPU only, EMCS architecture has evolved to today's version which has multiple intelligent (i.e., microprocessor based) stand-alone units connected together on a local area network and needing no CPU at all.

The CPU, if any, is often a personal computer used as a man-machine interface and not as an active source of the memory and intelligence for the work carried out by the stand-alone field panels.

Distributed intelligence is the state of the art in EMCS. Intelligent stand-alone field panels can be programmed with portable programming units or by downloading from a CPU, if one is provided. The availability of inexpensive memory permits a user to program intelligent field units using a fairly high level programming language and to program many functions that go beyond simple data gathering and equipment control. It is possible to enter complex strategies to save energy, although some people prefer to remain with simpler strategies until the industry and users gain more experience.

Energy control strategies require accurate measurements of the variables involved. This is causing the instrumentation connected with today's EMCS to be of a higher standard and also, to some degree, to be more standardized. In particular, where open loop readings are needed, platinum resistance temperature detectors (RTD's), as contrasted with less expensive nickel RTD's or thermistors, are finding wider application. Moreover, the availability of increased intelligence in the DDC controller allows software to adjust for the inaccuracies inherent in certain instrumentation as, for example, an orifice plate flow meter. In cases where flow readings are used to generate invoices for energy use, accurate devices such as vortex, turbine, or magnetic flow meters are used. In short, better quality, more reliable instrumentation is finding its way into today's systems. This should improve system performance in the future.

Manufacturers have agreed, to a large extent, on the types of input signals acceptable by their field panels; the industry standard of a 4-20 mA signal can be used with virtually every manufacturer's product. Consensus is still required, though, on the raw resistance signal from an RTD. Accordingly, a particular RTD will not necessarily be acceptable to all manufacturers. Nevertheless, substantive improvements in the types of sensors being employed are occurring and some standardization is being experienced. Ultimately, full interchangeability of sensors may occur, although this is not presently the case.

LOCAL/CENTRAL COMBINATIONS

The designation "local/central combination" can be used to examine the state of the art from four points of view: (1) mixed use configurations, (2) standards, (3) communications protocols, and (4) factory-mounted devices.

The mixed-use configuration results from distributed intelligence and direct digital control and represents the state of the art today. In this configuration, the field panels used for DDC are the same remote field panels of the EMCS. With today's lower electronic prices, this is frequently a more economical configuration than the combination of a traditional EMCS with standard pneumatic controls.

Standards for combinations of local controls and EMCS boil down to four main items: (1) instrumentation, (2) control sequence, (3) programming, and (4) communications. Standards in instrumentation have already been addressed.

Generally, control sequences are specified on a project-by-project basis by the system designers. Theoretically each system could have a unique set of sequences but in practice different designers generally specify similar sequences for a particular type of system. Accordingly, control sequences for a particular type of system often are quite similar from one project to another; however, there is, unfortunately, no industry standard, and two different designers may well develop different sequences for a particular system. More important, there is no standard means to transmit a control sequence to a control manufacturer. Consequently, similar projects can look totally different, and be interpreted and installed differently. The programming aspect of the computer for the EMCS raises other problems. For example, programming languages can vary widely from one manufacturer to another. This can create user problems and discourage the user from mixing competing equipment on the same project.

Currently available EMCS and DDC systems of a particular manufacturer employ proprietary communication protocols. This prevents systems supplied by different manufacturers from talking to each other. Part of this communication incompatibility has been due to the fact that the use of digital controls in buildings is a relatively new idea and there is a wide diversity of opinions on the best approach to use for system architecture, the distribution and storage of information, and the implementation of different control functions.

Accordingly, each control company has developed its own system with differing architecture and different computers to drive the system. The lack of compatibility between computers of different manufacture has been a fact of life in the computer industry until the development of the IBM personal computer, which became the defacto industry standard when it took a major share of the market. Even IBM, in its larger computers, is having difficulty developing a successful local area network to permit its machines to transfer data or communicate with each other. In addition, it has been in the commercial interest of the major control companies to perpetuate this situation, since it resulted in their having customers who, upon buying a control system, are unable to upgrade or expand it without going back to the original manufacturer. From the control company's point of view, this is good business; from the customer's point of view it is undesirable because it locks him into a particular supplier and prevents him from expanding or modifying his system without going to the original vendor, which usually means paying higher prices due to the lack of competition.

Beyond that, the lack of an industry standard in communications protocols prevents different manufacturer's systems from sharing information effectively. In addition, multi-building owners are inhibited in their choices of equipment for expansion; they don't want to use different systems if they are not compatible, and they don't want to use the same manufacturer because of the possibility of uncompetitive pricing.

IBM, as a multi-building owner and a major user of building control systems, has developed its own control standard. IBM insists however, that it is not intended as an industry standard. The IBM standard is called Facilities Automation Communications Network (FACN). It allows PC-based control systems to communicate with an IBM Series 1 host computer using the D revision of an operating system called General Purpose Automation Executive (GPAX). The present version works only with an IBM Series 1 host computer, which can interface with a total system through IBM or IBM-compatible PC computers.

The fact is that the current situation in the computer based control industry, from a large EMCS to a multiple DDC type facility, is one of proprietary communications protocols. The significance of this and possible approaches to eliminating the existing situation, are discussed further in later sections of this report.

As was noted previously, DDC controls are increasingly being installed in the factory by manufacturers of chillers, air handling units, and other HVAC equipment. Factory mounted controls represent an area of growing importance relative to the state of the art for two main reasons: First, the use of modern controls tends to improve the performance of the equipment on which it is installed; second, it offers an opportunity to tie such equipment into the overall HVAC control system. However, the absence of an industry standard for HVAC controls precludes owners from taking advantage of that opportunity.

4

ISSUES OF OVERRIDING IMPORTANCE

In the course of its investigation, the committee identified three issues as being of overriding importance because they deal with the fundamental questions of whether federal agencies need to take any special action to correct the problems they have experienced with HVAC controls and, if so, what the general direction of those actions should be. The three issues, which are discussed separately below, are: (1) whether HVAC control problems are serious enough to justify federal action; (2) whether HVAC control problems are inevitable and thus unavoidable in the current circumstance; and (3) whether federal agencies have experienced more problems than private owners, and if so why.

SERIOUSNESS OF HVAC CONTROL PROBLEMS

As indicated in the introduction, the committee does not dispute the assertions of federal agencies that they have experienced numerous problems with HVAC controls. However, the committee did not accept as self evident that the problems being experienced are serious enough to warrant drastic corrective actions--such as those discussed in chapter 5. Consequently, the committee made an effort to objectively evaluate the seriousness of the HVAC control problems of federal agencies.

Unfortunately, the committee was unable to find much data on such relevant factors as the amount of money agencies spend on repairing HVAC controls, the number or percentage of HVAC control systems that are not operating properly, or the amount of energy being wasted because of poor HVAC controls. In fact, the committee found only three papers that even addressed the subject obliquely: Hittle et al (1982), Kao (1985), and FCC Consulting Committee on Mechanical Engineering (1981).*

*The liaison member from the Corps of Engineers reported that the Army's Construction Engineering Research Laboratory had sponsored a detailed field study of HVAC controls, which verified that a serious problem exists. However, he was not at liberty to provide the committee with a written report on the study.

Hittle, et al (1982), reported that laboratory tests of various HVAC components had revealed numerous serious problems with such components, particularly controls. As discussed in the next chapter, these findings convinced the military agencies of the need to take action to improve the performance of their HVAC controls.

Kao (1985) reported on the results of a computer analysis of the impact of various sensor errors in controls on a variable air volume HVAC system. Kao found, for example, that:

- A sensing error of 5F on the low side in the return air dry-bulb temperature would result in a yearly waste of energy for cooling of about 2.5 percent.
- A sensing error of 5F on the high side in the outside dew-point temperature would result in a yearly waste of energy for cooling of about 3.0 percent.
- A sensing error of 5F on the low side in the mixed air temperature would result in a yearly waste of energy for heating of about 30.0 percent.
- A sensing error of 5F on the low side in the cooling coil discharge air temperature would result in a yearly waste of energy for heating of about 30.0 percent.

Kao's analyses indicated neither the size of sensor errors likely to be encountered in actual operating systems nor the amount of energy waste that would result from control system problems other than sensor errors. Nevertheless, Kao's results demonstrate rather dramatically that HVAC control problems can result in very substantial energy waste.

The FCC Standing Committee on Mechanical Engineering (1981) reported on the results of a survey of the experiences of federal agencies with 21 variable-air-volume HVAC systems. The committee found that malfunctioning controls and variable-air-volume boxes were a cause of problems in 9 of 21 systems (approximately 43 percent). Although the small size of the sample makes the finding less than conclusive, it is nevertheless, significant because it tends to substantiate the firm conviction of many federal agency engineers that the HVAC control problems are commonplace.

In addition to looking for and reviewing published evidence, the committee also considered the experiences of various committee members. Those experiences tended to substantiate the views of federal agency personnel that the problems federal agencies have had with HVAC controls are very serious indeed. Consequently, even though the available hard evidence is somewhat meager, it together with the experience of committee members convinced the committee that the situation is serious enough to warrant decisive action by federal agencies.

INEVITABILITY OF HVAC CONTROL PROBLEMS

As discussed in the previous chapter, HVAC control technology has undergone rapid changes in the past two decades. Inasmuch as a certain amount of chaos is a natural by-product of rapid change (particularly in a free-market society) the committee asked itself the somewhat philosophical question of whether the HVAC control problems that agencies and others are experiencing are inevitable and thus unavoidable. This question is important because if HVAC control problems are inevitable, efforts to avoid them are doomed to fail.

The committee concluded that a large percentage of the problems federal agencies and other owners have experienced in recent years were an unavoidable by-product of the adoption of the new control technologies being introduced. While agencies could have avoided some problems by limiting the use of the new technologies, had they done so they would have had to forgo an apparent opportunity to save energy, and, given the government's emphasis on energy conservation during the 1970s and early 1980s, that would not have been politically feasible. Although with the benefit of hindsight it is apparent that the agencies could have done some things better, it is doubtful that they could have avoided many of the control problems they have experienced.

The fact that some of the recent HVAC control problems may have been unavoidable is of historical interest, but it does not necessarily mean that agencies are doomed to continue to experience problems in the future regardless of their efforts to avoid them. Indeed, the committee believes that the two factors that made problems inevitable--rapid basic changes in the technology and political and economic pressure to adopt energy-saving ideas quickly--no longer exist to the extent they once did. (However, the goals are still in effect.)

While HVAC control technology is still evolving quickly, most of the changes now occurring are essentially variations on and refinements of the once-revolutionary idea of using microprocessors in HVAC control systems. Now that most control manufacturers, installing contractors, and system designers have learned the fundamentals of microprocessor-based controls, they should be able to adapt to future refinements in the technology with less difficulty. Furthermore, it seems unlikely that there will be additional changes in control technology as basic as the application of microprocessors in the near future.

In addition, now that energy costs are no longer rising (and in some cases that are even decreasing), agencies are under less pressure than in the past to use new products and concepts before they have been fully refined and proved reliable.

COMPARISON OF THE EXPERIENCES OF AGENCIES WITH PRIVATE OWNERS

It is generally acknowledged that all classes of building owners have encountered problems with modern control system during the past two decades. However, in meetings with the committee, several control manufacturers asserted that federal agencies have experienced far more problems than private owners. The committee decided to test the validity of this assertion because, if found to be true, it would indicate that agencies might be able to eliminate some problems by imitating the practices and procedures of private owners wherever possible. To test the assertion the committee reviewed the experiences of the consulting engineers on the committee who have worked with both federal agencies and private owners and published information on the subject.

Experiences and Views of Committee Members

The consensus among committee members--based on their personal experiences--was that federal agencies have indeed had significantly more HVAC control problems than private owners. The reason for the disparity is not self evident since public and private buildings generally employ similar HVAC control systems that are designed by the same consulting engineers, are made up of components supplied by the same manufacturers, are installed by the same contractors, and cost about the same amount of money. So what is wrong? Something is amok, but, since all of the essential players are the same, the problem has to be elsewhere, in something or some system that is handled differently in the federal sector than in the civilian sector.

It is difficult to generalize about differences between public and private sector owners because there is not a uniform approach or process in either sector; however, the committee found that there are enough similarities in the operating philosophies of the individual owners in the respective sectors to permit some generalizations to be made. Specifically, the committee concluded that federal agencies have significantly different policies and practices than the average private owner with regard to five issues: The selection of contractors, the content and enforcement of specifications, the commissioning of buildings, and the method used to maintain controls after installation. Each of these is procedural in nature, which means each could be changed if necessary (though making a change might not be easy). This does not mean that the private sector norm in these areas is without fault or problems; however, the committee is convinced that the end result with the private sector approach generally is better. Consequently, throughout the study the committee tended to evaluate all current practices and proposed actions of federal agencies and proposed recommendations to federal agencies in terms of their similarity to practices in the private sector.

In discussing the situation among themselves and with other HVAC specialists, the committee found that the first two issues mentioned above were particularly significant; i.e., the selection of contractors and the content and enforcement of specifications. They are also probably the most difficult practices to change.

Data From The Literature

The committee also sought verification of the assertion that federal agencies have experienced more problems than private owners in the literature, but it was unable to find any hard data on the subject. However, the committee found one report that addressed the question indirectly. That report--FCC Consulting Committee on Energy Monitoring and Control Systems, et al (1984)--discussed the nature of and reasons for the difficulties federal agencies experienced when they tried to procure energy monitoring and control systems in the late 1970s and early 1980s. The report implied that federal agencies themselves believe that they experienced more problems and more serious problems with energy monitoring and control systems than private owners. The agencies attributed their extra difficulties in large part to their procurement regulations. Since such regulations affect all federal acquisitions, it can be assumed that federal agencies have encountered extra difficulties procuring all types of HVAC controls, not just energy monitoring and control systems, and that these difficulties continue to be experienced.

SUMMARY

The committee's judgement is that: (1) the HVAC control problems being experienced by federal agencies are indeed serious enough to warrant action by federal agencies; (2) while many of these problems might have been inevitable, and thus unavoidable, when new control technologies (particularly technology involving the use of microprocessors) were first being applied, they are no longer inevitable; thus efforts by federal agencies to improve the situation will not necessarily be in vain; and (3) federal agencies have experienced more problems with HVAC controls than private owners, which suggests that agencies might solve some of their problems by adopting appropriate practices from the private sector.

5

REMEDIES PROPOSED BY FEDERAL AGENCIES

Federal agencies regularly review and update their design criteria and guide specifications for construction materials, products, and systems--including controls for HVAC systems--to reflect changes in technology and problems experienced with current criteria and specifications. Generally, changes in agency specifications and criteria are evolutionary rather than revolutionary. Even when agencies make major modifications to their specifications and criteria--as the military agencies did in the late 1970s when they experienced numerous problems with energy monitoring and control systems--they seldom adopt requirements that are at odds with established business arrangements or call for the use of products that are significantly different from those commonly used in private facilities.

It is notable, therefore--and indicative of the depth of agency concern about their HVAC control problems--that in the past few years several federal agencies have taken or have proposed to take drastic actions to try to correct the situation. The nature and purposes of these actions and committee comments on them are summarized below.

EXPANDING THE DESIGN RESPONSIBILITIES OF CONSULTING ENGINEERS

In February, 1983, the Air Force Directorate of Engineering and Services issued Engineering Technical Letter (ETL) 83-1 (USAF Directorate of Engineering and Services, 1983) with the broad objective of "improving the design, maintainability, and operating efficiency of HVAC systems" at Air Force bases. The letter explained that "many existing HVAC systems have design deficiencies which hamper efficient operation and routine recurring maintenance." The letter outlined corrective actions to be taken in two areas: "design for maintainability" and "design documentation."

Tom (1985), reported that ETL 83-1 had been issued because the Air Force had become very concerned about the difficulties being experienced in maintaining HVAC controls at the Air Force bases. He explained that the problems are "compounded by the frequent rotation of military personnel between bases." He noted that "Air Force personnel must be prepared to deploy to any base in the world and . . . we cannot retrain those people every time they encounter a new control system."

With regard to design for maintainability, ETL 83-1 called for three features to be included in all Air Force HVAC control system designs:

(1) Use of remote sensors so that controllers can be centrally located in the mechanical room.

(2) Logical grouping of controllers, adapters, relays and power supplies in an easily accessible controls cabinet mounted away from vibrating machinery.

(3) Inclusion of pneumatic test ports and electronic-system terminal strips cross-referenced to the control schematic to facilitate trouble shooting and calibration.

The most controversial part of ETL 83-1--and the part that is of concern to the committee--dealt with design documentation. In essence the ETL required designers of HVAC control system for Air Force bases (who in most cases are consulting engineers*) to prepare contract drawings in sufficient detail that they can be used both for procurement purposes and later for maintenance work. Specifically, ETL 83-1 directed that design documents must, as a minimum, include:

(1) A fully labeled control schematic which details all set points, throttling ranges, actions, spans, proportional bands, and any other adjustment.

(2) A fully labeled elementary diagram (ladder diagram).

(3) A sequence of control on the drawings cross-referenced to the control schematic and elementary diagram.

(4) A generic, functional description of each control component shown on the drawings.

Requiring the inclusion of such material in design documents was controversial because traditionally it has been developed by control system vendors after the award of a contract, and the ETL in effect transferred the responsibility to consulting engineers, which greatly expanded their duties.

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*Not all HVAC systems in federal buildings are designed by consulting engineers. For example, some systems are designed by engineers employed by architectural firms and some systems are designed by government personnel. However, since the vast majority of systems are designed by consulting engineers, designers of HVAC systems are referred to as consulting engineers throughout this report.

This shift in responsibilities was justified in ETL 83-1 on the grounds that:

> "the installation documents provided by the contractor usually contain proprietary symbology and terminology that are nonstandard. This documentation does not provide adequate information necessary for the construction inspection or the overall system logic required by Base Civil Engineer technicians to calibrate, maintain, or repair the system once installed."

Since the Army Corps of Engineers and the Naval Facilities Engineering Command are responsible for managing most Air Force construction projects, it has been up to those agencies to implement the Air Force concept.

Committee Observations and Comments

As part of this study, one committee member, Raymond Alvine, interviewed personnel at the Omaha, Nebraska, Division of the Corps of Engineers to determine how the new Air Force policy was working out. It was the view of the Corps personnel that the Air Force requirements were not being fulfilled in the way the Air Force expected. They reported that consulting engineers are not sufficiently experienced with detailed control system design to do the type of work required by ETL 83-1. When the new policy was first implemented several consulting engineers tried, unsuccessfully, to prepare the required detailed drawings themselves. Eventually, Corps personnel helped the consulting engineers complete the work. These Corps personnel were able to help because they had received special training in designing HVAC controls. They noted, however, that the training program is expensive because the course lasts several weeks and involves travel for most personnel. Furthermore, additional personnel must be trained each year to replace previously trained personnel who have left the organization or who have been given new assignments. Other Corps personnel who had not received training indicated that they would not have been able to help the consulting engineers.

The Corps personnel reported that on later projects consulting engineers often hired a control manufacturer to prepare the required drawings. Surprisingly, in some cases even control manufacturers had difficulty preparing the types of drawings required by ETL 83-1.

Ultimately, the control drawings prepared by (or under the jurisdiction of) consulting engineers often were of no value anyway. This is because government specifications allow various alternative types of control systems to be supplied. Consequently, the system actually supplied on a project often was different from the one the consulting engineer had assumed would be used when he made (or had a manufacturer prepare) detailed control drawings. When that happened, the supplier of the system actually used had to prepare and submit detailed drawings for his own system.

The committee believes that the Air Force was correct in trying to get accurate detailed drawings of its HVAC control systems. The committee does not believe, however, that consulting engineers are the best source of such drawings.

As the experience of the Omaha Division of the Corps of Engineers indicates, consulting engineers are not equipped by training or experience to prepare detailed control drawings. Furthermore, even if they were able to prepare such drawings, doing so would be a waste of their effort on many government projects. This is because detailed drawings must be related to the products of a particular manufacturer; however, with open specifications, the manufacturer is not known until after bids are received--long after the consulting engineer has completed his work. It is also possible that the existence of detailed drawings could complicate contract enforcement when a system other than the one on which the drawings are based is installed. In such cases, inspectors might have two conflicting sets of drawings or a system that does not match the drawings.

The committee believes that standardized detailed control drawings can and should be obtained from control system vendors by tightening and/or more strictly enforcing the requirement already in most control specifications that the control system vendors provide detailed drawings after installation. Agencies should require that the drawings be prepared in accordance with ANSI/ISA-S5.1-1984, "Instrumentation Symbols and Identification" and ANSI/ISA-S5.2-1976 (R1981), "Binary Logic Diagrams for Process Operations" and should be prepared on standard sheets of mylar which should be turned over to the agency upon project completion.

DEVELOPMENT AND USE OF STANDARD CONTROL SYSTEMS AND PANELS

In the early 1980s, the Army's Construction Engineering Research Laboratory (CERL) conducted a series of laboratory tests of several full scale HVAC systems made up of various commercially available components. These tests revealed numerous problems with HVAC components, particularly controls (Hittle, et al, 1982). For example, the pressure at which various pressure volume regulators on VAV boxes responded varied considerably from one regulator to another, three out of five pneumatic temperature transmitters that were tested were found to be out of calibration; all six fluidic receivers/controllers tested drifted out of calibration within 72 hours after having been calibrated; and finally, two out of three pneumatic humidity transmitters tested were found to be highly inaccurate (with an actual relative humidity of 62 percent, one transmitter registering 88 percent and the other registered 96 percent).

On the basis of the CERL work, Hittle concluded that "many, if not all, of the problems detected by the heavily instrumented HVAC system experiments would be undetected in a field application where there is little or no instrumentation," and further that "if differences like the ones CERL encountered were undetected for the life of the system, much more energy would be used than was intended."

As noted previously, Kao (1985), demonstrated by computer analysis that sensor errors of the type found by CERL in HVAC controls could indeed result in significant energy waste.

The results of the CERL tests tended to substantiate the views and experiences of the agency liaison members of the committee that many HVAC control systems are not performing up to expectation.

On the basis of the CERL tests, Hittle concluded that HVAC control systems should be as simple as possible, should be composed of reliable, high quality components, and should include built-in diagnostic and calibration features.

The CERL/Air Force Approach

Subsequent additional testing of HVAC controls by CERL tended to substantiate the initial CERL conclusions (Hittle and Johnson, 1985; and Hittle and Johnson, 1986). The CERL investigators also apparently concluded--though they did not state it explicitly--that the traditional vendors of HVAC control systems would not voluntarily develop and market the types of control systems they felt were needed. Consequently, using funding from the Air Force and the Army Corps of Engineers, CERL designed and developed a family of standard control systems as well as standard, nonproprietary control panels to be used with the control systems. In the development process CERL made many computer analyses. The problems that the new standard systems and panels were expected to solve are summarized in Table 1.

Hittle and Johnson (1986), indicated that the control systems were designed to be as simple as possible and yet ensure high HVAC operating efficiency. They also noted that the systems ordinarily are expected to be hybrids, "using pneumatic control components for damper and valve actuators and in less critical room temperature control subsystems together with electronic components for measuring and controlling more critical mixed air and coil discharge temperatures."

Originally, the systems were referred to as "retrofit" systems. However, they are now proposed for use in both new and retrofit projects. Representatives of the Air Force have informed the committee that the use of the CERL-developed standard systems and control panels will be required on future Air Force projects, except in special circumstances (USAF Directorate of Engineering and Services, 1987). Representatives of the General Services Administration report that they are also considering adoption of the CERL approach.

To facilitate the use of the systems, CERL has developed design instructions (Hittle, et al, 1986a) and a guide specification (Hittle, et al, 1986b). These documents describe in detail the equipment and control diagrams for a wide variety of HVAC control systems, including

TABLE 1 Summary of Key Problems Solved by the New Approach

Problem	Solution
The complexity and variety of control strategies used in Air Force facilities makes it difficult for O&M staff to learn the principles of operation and maintain the controls properly; during repair attempts, operators "simplify" the systems by disconnecting components.	Use standard control strategies to reduce the number of strategies which O&M staff must learn. Keep control strategies as simple as possible. Provide adequate documentation to explain the operating principles of the standard control strategies.
O&M staff are unable to keep control panels in proper working condition because the components require excessive maintenance and recalibration is a difficult, time-consuming process.	Use control panels which emphasize low maintenance features, including: • Temperature sensors which never require recalibration • High-quality analog electronic controllers with drift-free characteristics. • Built-in diagnostics to permit rapidly checking the system.
In particular, enthalpy-based economizer cycles are found to be malfunctioning in most systems; it is standard practice to disconnect these at many bases because of the extraordinary maintenance requirements of the humidity sensors.	Enthalpy-based economizer cycles are prohibited. Use an economizer cycle based on a simple comparison of dry-bulb temperatures of return and outside air.

Source: Hittle, et al, (1986a)

Table 1 continued

Thermal stratification occurs in mixed air section during cold weather and causes excessive tripping of freezestat, frozen coils or poor temperature control of mixed air.	Provide proper ductwork design to minimize thermal stratification and provide an averaging sensor to enable accurate sensing for control loop.
O&M staff are unable to obtain accurate control in some systems because control valves or dampers are oversized.	Provide valves and dampers of the correct size for each application.
Pneumatic components malfunction and extensive repair is required because of oil, lint, and dirt in the pneumatic air supply.	Use positive positioners for all pneumatic operators except those for VAV terminal units or small valves on reheat coils.
	Eliminate the use of pneumatic components which are especially sensitive to air quality and impose stringent requirements for air supply maintenance (such as pneumatic receiver-controllers); use oilless air compressors to minimize problems with oil and provide properly-designed air filtration systems.
O&M staff receive excessive occupant complaints because of poor control of room temperature.	Locate room thermostats in areas with good air distribution, avoiding exposure to direct sunlights, dead end locations, etc.
O&M staff receive occupant complaints which arise from building pressurization problems in facilities with return fans.	Provide proper design for control of the return fan in VAV systems.
O&M staff is burdened with excessive maintenance for systems with return fans in many systems which do not need them.	Always perform calculations to determine if return fans are really needed; avoid return fans for VAV systems when possible by changing sizes or return air ductwork or other means.

systems for variable air volume controls, room air temperature control, supply air temperature control, mixed air temperature control, direct static pressure control, return fan control, single zone system control, dual duct system control, humidity control, hot water temperature control, and heating boiler control. The Air Force believes that the adoption of these control systems as standard systems will obviate the need for consulting engineers to custom design control systems for most applications.

Hittle and Johnson (1986b), have indicated that the key to the success of CERL control systems is a family of CERL-designed, nonproprietary, electronic control panels, which CERL believes will be:

- More accurate and more reliable than conventional panels because of the use of industrial grade component instead of commercial grade components.*
- Easier to maintain than conventional panels because (a) they have built-in diagnostic meters; (b) they will be standardized, thus eliminating the need for maintenance personnel to learn about different equipment; and (c) the control system concepts governing the use of the panels have been kept simple.

Although CERL has designed the panels, they will be built by control equipment manufacturers to CERL specifications. CERL has told the committee that several manufacturers have indicated their intention of building panels for projects on which they are specified.

For the present, CERL has decided not to develop direct digital control panels or systems. Although Hittle and Johnson (1986) have indicated that CERL might develop direct digital control systems in the future, the liaison member from the Corps of Engineers has reported that it is unlikely to occur anytime soon.

The Corps of Engineers Approach

The Corps of Engineers has adopted CERLs basic concept--namely, that federal agencies should develop and require the use of standard control systems and standard control panels instead of relying on control vendors to design control systems on the basis of performance specifications developed by consulting engineers. However, for reasons that are not entirely clear to the committee, The Corps of Engineers did not adopt the guide specification and design instructions for HVAC controls that CERL developed, even though the Corps helped fund the CERL work. Instead the Corps hired the Kling-Lindquist Partnership, Inc. to prepare another series of guide specifications and a design manual to be used by consulting engineers when designing HVAC control systems for Army facilities.

*See Haines (1982) for a discussion of the difference between industrial and commercial grade components.

The committee has been told that the Corps originally expected to get a comprehensive design manual plus three guide specifications for HVAC controls: one covering traditional electric/electronic analog control systems (similar to the CERL systems); another covering microprocessor-based local-loop control systems; and a third covering full DDC control systems.* The committee understands that the Corps subsequently dropped plans to develop the analog systems specification and deferred development of the DDC systems specification. Instead, efforts are being concentrated on the specification and design manual for the microprocessor-based local-loop control systems, which are compromise systems that accept analog input and provide analog output but use microprocessors that work with digital data to provide the control action: In order to function, the systems convert the incoming analog data into digital form for processing and then later converts the data back into analog form.

The committee has received and reviewed the first draft of the specification on microprocessor-based local-loop control systems (Kling-Lindquist Partnership, Inc., 1986). The specification, which runs 136 pages, is highly detailed. It describes the control sequences and all of the components needed for a wide variety of standard HVAC control systems, including: Variable air volume systems, multi-terminal unit control air volume systems, single zone constant air volume systems, dual duct variable air volume systems, bypass multizone systems, and hydronic systems.

The Corps of Engineers' approach is similar to the CERL/Air Force approach in that the basic objective is to get standardized HVAC control systems with standardized components on Army facilities instead of proprietary systems in order to minimize the operating and maintenance problems caused by the current multiplicity of different systems. The Corps' approach differs from the CERL/Air Force approach in three respects: (1) the use of microprocessors in lieu of electronic control devices; (2) giving control system designer more options to choose from; and (3) giving control system contractors and vendors more freedom to determine the exact nature of the system to be installed.

To date none of the systems or panels described in the Kling-Lindquist-developed guide specification have been used with a working HVAC system. The committee has been informed that the Corps expects to test the systems and panels by using the specification on a trial basis for two or three years.

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*Inasmuch as all microprocessors work with digital data, microprocessor-based controls are, by definition, digital controls. The difference between microprocessor-based controls and DDC is in the amount and complexity of control functions performed by a given control box. In a microprocessor-based system, each microprocessor chip controls just one control loop, and any decision-making with regard to controls is performed at the EMCS level. In a DDC system a single remote control box often controls several local loops and also performs decision making functions.

Representatives of the Air Force have expressed great interest in the Corps approach, and they have indicated their intention of adopting the concept after it is fully developed and tested.

Committee Observations and Comments

The use of standard HVAC control systems with nonproprietary control panels as recommended by CERL represents a new and potentially better way of designing and procuring HVAC controls. In essence, the intent is to make control panels a generic commodity like bricks, or structural steel, or lumber, which could be supplied by any one of a number of manufacturers. Their application--i.e., the detailed design of overall control systems--would be the responsibility of consulting engineers, not the manufacturers of controls. However, the freedom of consulting engineers to custom design unusual control systems would be greatly restricted in that they would have to use the government's standard control system designs whenever applicable.

The new approach would, if implemented, cause government agencies to abandon the long standing practice of procuring HVAC controls in the form of proprietary systems. This would result in a major shift in the division of responsibilities and duties for the design and application of HVAC controls between those involved (federal agencies, consulting engineers, manufacturers of controls, and contractors). It is difficult to predict how responsibilities would ultimately be divided under the new approach; however it would appear that agencies would end up with most of the responsibility.

The Committee understands the desire of the Army and Air Force to standardize their HVAC control systems in order to ease their maintenance problems. However, for reasons discussed below the committee doubts the wisdom of both the CERL/Air Force and Corps of Engineers approaches to achieving this end. Since there are currently very few of the standardized panels in use, the committee had little hard evidence on which to base its evaluation. Consequently most of the committee's views are based on experience and judgment.

1. If for some reason a system obtained using either the Army or the Air Force approach does not perform properly after installation, an agency might find it difficult to force the contractor or manufacturer to correct the problem if their culpability is not readily apparent. In the absence of clear cut blame, everyone involved--the manufacturers of the components used, the installing contractor, and the designing consulting engineer--could disclaim responsibility on the grounds that they were merely complying with agency requirements.

2. The first cost of the standardized systems might be significantly higher than commercially available systems. The committee was told by one manufacturer that the CERL standard control panels might cost as much as 30 percent more than comparable commercial panels. (It is believed this estimate was based on the assumption that

the panels would be manufactured infrequently in small numbers; if demand were higher, the price of the panels probably would drop.)

3. The savings in maintenance costs from the use of the standard systems might not be as great as expected. Although the controls for each particular type of HVAC systems would be standardized, there are many different types of HVAC systems, each of which could have different controls, and there might be several different HVAC systems at a given facility. Consequently, even with standardization, agency maintenance personnel might still have the problem of a multiplicity of controls to maintain.* Furthermore, in the case of an existing facility, the maintenance personnel would have to continue to service the nonstandard controls already in place as well as the new standard controls. Finally, even though the control systems are standardized, the components used in different systems--including the control panels--will come from different manufacturers and, therefore, in many cases will not be interchangeable, thus forcing agencies to keep a multiplicity of replacement parts on hand.

4. The cost of keeping agency design manuals and guide specifications for standard control systems up to date could be very high--possibly much higher than agencies realize. By assuming a large measure of responsibility for the detailed design of standard control systems and standard control panels, agencies also assume responsibility for analyzing the inevitable problems that occur with complex control systems and issuing corrective information as needed. They would also assume responsibility for keeping fully abreast of current technology and updating their documents as technology evolves.

SPECIAL PROCUREMENT PROCEDURES

As mentioned previously, federal agencies (particularly the military agencies) encountered numerous problems with energy monitoring and control systems (EMCS) in the late 1970s. The number of problems dropped significantly when agencies revised their EMCS specifications and as EMCS vendors refined their technology. However, some problems continued to be experienced, and additional solutions were sought.

A number of government procurement specialists noted that the procedures traditionally used to procure construction--i.e., the awarding of fixed-price contracts on the basis of sealed bids (a process commonly referred to as formal advertising in government procurement circles)--is not well suited to the procurement of complex, proprietary items like EMCS (FCC Consulting Committee on Energy Monitoring and Control Systems, et al, 1984). Contracts for such systems cannot be awarded fairly on the basis of price alone because the products of different manufacturers are not equal. For example, in some cases similarly priced systems have far different performance

*However, the extent of differences generally would be less with standardized controls than with proprietary controls.

characteristics; one system may be ideally suited to one application while another system is perfect for a different application. In selecting a system, therefore, the nature of the application can be an important consideration. For just a few dollars extra, it is sometimes possible to get a far superior system. In other cases there can be a large difference in price between systems of almost equal quality; thus, it may be possible to save a substantial amount of money by accepting a slight reduction in performance.

Recognizing the existence of this situation, the Corps of Engineers and the Naval Facilities Engineering Command in 1984 began awarding some EMCS contracts through a process referred to as "competitive negotiations." As explained in Federal Construction Council Technical Report No. 83 (FCC Consulting Committee on Procurement Policy, 1986), with competitive negotiations a contractor is selected through face-to-face negotiations with a number of offerers. Usually the selection process involves the evaluation of a number of proposals by a team of agency specialists in terms of an announced set of factors. Agencies ordinarily assign numerical weights to the factors to indicate their relative importance; the agencies generally do not reveal the value of the weights to offerers. Price is one of the factors considered, but not necessarily the controlling one. If an agency receives a large number of proposals for a project, it may elect to negotiate only with those offerers who are judged to be in the competitive range. Both the Corps of Engineers and NAVFAC report that the process has worked well, but that it cannot be used when an EMCS is being procured as part of a large construction project, the contract for which is awarded on the basis of sealed bids.

The committee has been informed that because some EMCS suppliers have complained about not being awarded contracts when they have been the low bidder, the Army is planning to modify the process to have price considered separately from the other factors and to require procurement officers to justify an award to other than the low bidder.

Other agencies have tried other nontraditional methods of procuring EMCS. The Department of Interior, for example, has reported that it has successfully used a process called "two-step formal advertising" (FCC Consulting Committee on Procurement Policy, 1986). Two-step formal advertising is a two-part sequential procedure for selecting contractors on the basis of both technical qualifications and price. In the first step, a panel of experts evaluates unpriced technical proposals of various offerors against certain performance requirements, which are stated in the original request for technical proposals (RFTP). Those offerors whose technical proposals are found to be acceptable are invited to submit price proposals. Offerors whose technical proposals are deemed not acceptable do not participate in the second step. The contract is awarded to the offeror with the lowest price, provided the price is determined to be fair and reasonable for the work to be performed. There is no price negotiation. The Department of Interior reported that the process has worked well, but that it is time consuming.

Committee Observations and Comments

The committee fully agrees with the idea that sophisticated systems like EMCS should not be procured on the basis of price. The experiences of the agencies to date suggests that the use of procurement techniques that permit both price and technical factors to be considered in awarding contracts have been successful, which is not surprising since such techniques have been used widely and successfully for many years in the private sector to procure a wide variety of products. Federal agencies probably would benefit greatly from expanded use of the techniques. To permit the techniques to be used to procure sophisticated systems in new buildings, agencies might consider awarding separate contracts for such systems. The action of the Army to preclude the simultaneous consideration of price and performance appears to be a step in the wrong direction.

BANS ON THE USE OF DIRECT DIGITAL CONTROLS

After experiencing numerous problems with energy monitoring and control systems when they were first marketed, federal agencies became very cautious about adopting new HVAC control technology. Thus, when the direct digital control (DDC) concept was first introduced in the early 1980s, several federal agencies (including all three military services) directed their installations not to use it. Most of these bans on the use of DDC have been in effect ever since. Federal agencies have not suggested that such bans are a remedy for HVAC control problems; however, the agencies are convinced that the bans help keep the problems from getting worse. Therefore, the committee believes that a discussion of the DDC bans is appropriate in this chapter. The subject is also worthy of discussion on the grounds that it is very unusual for federal agencies to prohibit the use on government projects of new technology that has been widely accepted in the private sector. The unusualness of the federal agencies' action is further indication of the depth of their concern about HVAC control problems.

Originally, the bans on the use of DDC systems were stimulated primarily by unfamiliarity with and lack of confidence in the new technology. Those who first imposed the bans probably expected to lift them quickly, as soon as the reliability of the technology had been demonstrated. The bans, however, have not been lifted; most now have been in place for five or more years. The primary reasons for the bans, however, have changed. Although some agency representatives still express misgivings about the reliability of DDC components, it is generally agreed that most such components are at least as reliable as most traditional control components. Agency concerns about DDC systems now center on other factors:

- The need to program most DDC controllers in the field. It is widely believed the programming process is complex, the number of qualified personnel is few, and likelihood of errors is high.

- The cost and difficulty of training agency personnel to maintain DDC systems or of finding competent private repair contractors. There is fear that because of the complexity and newness of the DDC concept there is an acute shortage of properly trained repair technicians and that finding or training the needed personnel would be difficult and expensive.
- The lack of standard communication protocols for DDC. Because different manufacturers have different communications protocols, DDC components of different manufacturers cannot be mixed; thus owners of DDC systems are almost completely dependent on the original supplier for spare parts, for expansion of the system, and for most repair work.
- The high rate of change in DDC technology. There is great concern that current DDC systems will become obsolete very quickly and that spare parts for such systems will be difficult to get and/or prohibitively expensive long before the end of the economic life of the system.
- The high cost of DDC systems. Although reliable cost information on DDC systems is hard to obtain, many agency engineers believe that such systems are significantly more expensive than traditional HVAC controls and many agencies have serious doubts that the benefits of DDC systems are sufficient to justify the added cost.

These concerns seem to be shared by most federal agencies. Nevertheless, some agencies (e.g., the Veterans Administration) have never banned the use of DDC, and several agencies that have banned them (e.g., the military services) are currently investigating the possibility of lifting their bans.

Committee Observations and Comments

The committee is convinced that DDC is a major improvement over conventional control systems and that DDC is well on the way to becoming the predominant form of HVAC control. The trend toward DDC is gaining momentum as more consulting engineers recognize the benefits of the concept and as more HVAC equipment manufacturers install DDC controllers on their equipment (e.g., see Bradler and Sutter, 1984). The committee is also convinced, however, that many of the agencies' concerns about DDC are valid.

The committee was split on the question of whether the undeniable benefits of DDC are sufficient to offset the current problems and uncertainties associated with the technology. Some members expressed the opinion that agencies are being unrealistic to try to resist accep tance of a proven technology, even if it does create new problems. They note that in spite of the bans agencies have imposed on DDC, many DDC systems are nevertheless being installed in government buildings. Other committee members expressed the view that the agencies have been wise to ban DDC system and that they should continue the bans in hopes that their existence will help prod manufacturers to address the agency concerns, which are shared by many private owners. All of the committee members were in agreement, however, that DDC is gaining more acceptance all the time and that the current agency bans cannot be continued much longer.

SUMMARY

In general, the committee shares the agencies' concerns about and dissatisfaction with HVAC controls. However, the committee has serious reservations about the wisdom of two of the actions that federal agencies have taken or have proposed to take to correct the situation; specifically:

- The committee does not believe that consulting engineers should be required to develop design drawings that are sufficiently detailed to be used for repair and maintenance purposes. The committee agrees that agencies need and deserve to have such drawings; however, it believes that they should be provided by control vendors, not by consulting engineers.
- The committee does not believe that the idea of federal agencies developing standard nonproprietary control systems and control panels for use on their projects is practical or that it would provide the benefits agencies expect.

Most of the committee members generally agree with the other two actions that have been taken by federal agencies; i.e., the use of special procurement procedures for energy monitoring and control systems and the temporary ban on the use of direct digital control systems*. However, the committee believes that agencies need to consider even more changes in their procurement procedures (as discussed in the next chapter) and that the ban on DDC should be removed as soon as possible.

*One committee member, Donald Coggan, believes that the temporary ban on the use of DDC systems was a mistake from the beginning.

6

REMEDIES PROPOSED BY THE COMMITTEE

As indicated in the previous chapter, the committee doubts the efficacy of some of the corrective actions being considered by federal agencies and believes that other actions that have been proposed or implemented, while helpful, do not go far enough. The committee, therefore, explored the following additional steps that the agencies might consider:

1. Making Fuller Use of HVAC Consulting Engineers
2. Ensuring the Qualification of HVAC Consulting Engineers
3. Developing More Effective Design Criteria and Guide Specifications
4. Ensuring the Qualification of Installers of HVAC Control System
5. Promoting the Development of Control Standards
6. Using An Innovative Approach to Contracting for Maintenance
7. Developing and Maintaining Federal Expertise in Controls

These steps are discussed below. It will be noted that the first four items are basically intended to bring the practices of federal agencies more in line with practices in the private sector.

MAKING FULLER USE OF HVAC CONSULTING ENGINEERS

As discussed in chapter 4, the committee is convinced that federal agencies have experienced far more problems with HVAC controls in recent years than private owners. As part of its investigation, therefore, the committee compared the practices and procedures of federal agencies with those of private owners in search of possible remedies for federal problems.

One notable difference in the practices of most federal agencies compared to those of most private owners is in the extent of reliance on the professional architectural and engineering firms that are hired by the owner to design a desired facility. Specifically, whereas most federal agencies limit the role of professional design firms to the development of designs in accordance with the agency's design criteria and guide specifications (which are often quite detailed), most private owners give design firms a relatively free hand to execute designs as the designers deem best. In addition, private owners usually retain the design firm to observe the construction and start up of the facility to ensure that the drawings and specifications are properly interpreted and followed.

The committee is convinced that the relatively lower rate of HVAC control problems on private projects can be attributed at least in part to the fact that the consulting engineers who design private systems play a larger role in the design and construction process than designers do on federal projects. Apparently the Air Force had reached essentially the same conclusion when it issued Engineering Technical Letter (ETL) 83-1 (USAF Directorate of Engineering and Services), which greatly expanded the responsibility of consulting engineers with regard to the design of HVAC controls. However, as discussed in Chapter 5, the committee believes that the approach outlined in ETL 83-1 (requiring consulting engineers to prepare highly detailed control drawings) is unrealistic. The committee proposes, therefore, to expand the role of the HVAC consulting engineer on agency projects in a different fashion.

The committee recognizes that the laws and regulations governing federal procurement preclude federal agencies from adopting the policies and practices of the private sector in toto. However, the committee is certain that agencies could significantly expand the duties and responsibilities of HVAC consulting engineers without violating any laws or regulations, and that the agencies would benefit from doing so. Specifically, the committee recommends the following:

1. Agencies should encourage consulting engineers to propose the use of control schemes and devices other than those covered in agency design manuals and guide specifications whenever they believe the government would benefit. Agencies should consider proposed deviations from established design standards conscientiously and expeditiously.

2. Agencies should require consulting engineers to write performance specifications that rigorously define the location and the accuracy of the instrumentation to be furnished for a particular control function; the precise control sequence required for the system (e.g., when a damper or valve should open and what should cause it to open); and to exactly define the result to be provided by the control sequence in actual operation.

3. Agencies should retain HVAC consulting engineers to observe the installation of their systems, to answer questions that arise during construction, and to help ensure that their systems are installed and tested properly.

4. Agencies should retain HVAC consulting engineers to observe the start up of their systems and the training of agency operators to ensure that the systems are made fully operational before they are turned over to the government and that agency personnel are properly instructed in accordance with the project specifications.

The committee recognizes that these recommendations are at odds with the current practices of many agencies and that their adoption may require some changes in the policies and contracting procedures of such agencies. The committee is convinced, however, that agencies will reduce the number of problems they experience with HVAC controls by making fuller use of the talents of HVAC consultants than they currently do.

ENSURING THE QUALIFICATIONS OF HVAC CONSULTING ENGINEERS

Obviously, all HVAC consulting engineers are not equally qualified, and finding consulting engineers who are truly experts in HVAC controls can be difficult. Indeed, at least a portion of the problems owners have experienced with controls in recent years can be attributed to the inadequate understanding of many consulting engineers of control theory in general and modern digital controls in particular. If, therefore, agencies are going to rely more heavily on consulting engineers than they do currently to help ensure that they get HVAC systems and controls that work properly, as the committee has recommended, agencies must make a special effort to ensure that the consulting engineers they use are well qualified.

The problem is that except in the case of alteration projects involving just HVAC systems, agencies do not have a direct contractual relationship with HVAC design firms. Usually, agencies contract with an architectural firm, which in turn subcontracts with an HVAC consulting engineer firm for the HVAC portion of the design. Although agencies require that the architectural firms being considered for a prime design contract name the HVAC consulting engineer firm they expect to use, the qualifications of the HVAC design firm is seldom an important factor in the award of a prime design contract, and after a contract has been awarded, agencies usually work with the HVAC consulting engineer only through the prime architect.

This arrangement, which is also the rule in the private sector, is generally favored by procurement specialists because it centralizes responsibility for the design effort. This simplifies the task of administering the design contract, and it generally produces satisfactory results. Therefore, it would not be practical for agencies to award separate contracts for the design of HVAC systems.

The solution, the committee believes, is for agencies to base the award of prime design contracts in part on the qualifications of the HVAC designers identified on the Standard Forms 255 submitted by firms seeking prime design contracts. Specifically, the committee recommends that agencies (1) indicate in their announcements of need for design services that the qualifications of HVAC designers--and in particular their knowledge of controls--will be a major consideration in the contract award; and (2) carefully review the information submitted regarding the qualification of HVAC designers and their work on previous projects when selecting a prime design firm.

DEVELOPING MORE EFFECTIVE DESIGN CRITERIA AND GUIDE SPECIFICATIONS

Most federal agencies publish two types of standards dealing with the design of buildings and building systems (including HVAC systems): Design Criteria (sometimes referred to as design manuals or design guidelines) and guide specifications (sometimes called master specifications or model specifications). These general standards complement the project-specific criteria that agencies develop for each individual project. Architects and consulting engineers are given both the applicable general standards and project-specific criteria when they receive a design contract.

Design criteria documents set forth an agency's general requirements and prohibitions regarding the design of buildings and related facilities and the systems of which they are composed. Typically, criteria documents describe the various systems and subsystems that can be used and indicate where each may and may not be employed. Frequently, criteria documents also present general performance requirements for systems and indicate by descriptive material or reference to other published documents the analytical procedures to be used in designing the systems in question.

Guide specifications are model specifications that, after editing, become project specifications--i.e., they become part of the construction contract package. Guide specifications indicate for each material, component, and system that might be installed in the facilities of an agency the commercial or government standards to which the item should conform or be tested, the performance requirements for the item, any special features to be included or materials to be used, and the procedures to be followed or precautions to be taken in assembling, installing, or erecting the item. Guide specifications also sometimes include additional requirements like special labels to be provided and special tests to be conducted.

Design criteria and guide specifications serve several important functions for federal agencies: They establish minimum requirements, they help ensure that errors made and problems encountered on one project will not be repeated on subsequent projects, they identify suitable types of products, and they minimize the likelihood of protests from contractors and manufacturers because of violations of federal acquisition regulations. The latter function is particularly important since federal regulations prohibit the inclusion in government specifications of the type of arbitrary or restrictive requirements often found in private specifications. In order to avoid having projects delayed due to protests or be the cause of litigation, most agencies have developed guide specifications and insist on their use by designers. Agencies have issued guide specifications because they have found that writing specifications that protect the government's interests and at the same time satisfy the federal procurement regulations can be difficult and that few private architects or engineers have the time or experience needed to develop government-type specifications.

In most cases the federal approach of requiring architects and engineers to follow agency design criteria and to use agency guide specifications has produced satisfactory results. However, the approach obviously has not worked well in recent years with regard to HVAC controls.

The committee suspects that the government approach has not worked with HVAC controls in recent years primarily because it is designed mainly to ensure free and open competition, and this depends on the availability of a number of similar items of essentially equal quality from several different suppliers. This situation usually exists after a technology has matured because, over time, the products offered by manufacturers tend to fall naturally into categories, and products within a given category are roughly equivalent. This categorization process occurs as manufacturers learn what works and what does not work and what sells and what does not sell. In some cases the product categories are codified through the development of formal consensus standard. In other cases, product categories remain informal. Regardless, once product categories have developed, it is possible to prepare standard design criteria and generic guide specifications for the products in question. Inasmuch as HVAC control technology has been evolving rapidly in recent years, the natural categorization process has not had a chance to work for newer control concepts and products. Consequently, the modern HVAC controls available from manufacturers are not sufficiently similar to permit generic specifications and standard design criteria to be prepared.

As discussed in the previous chapter, various federal agencies have developed new criteria, specifications, and procedures that inter alia are intended either directly or indirectly to address problems caused by the newness of HVAC control technology. However, as also discussed in the previous chapter, the committee doubts that the agency actions will succeed. The committee believes that the key to coping with rapidly changing technology is having the ability to adjust quickly and decisively to changes. Unfortunately, the government's approach tends to be inflexible and slow to react because the criteria and specification development process is inherently cumbersome and time consuming.

The upshot is that the government is in a predicament for which there is no easy solution. In order to deal effectively with the rapid developments taking place in the HVAC controls industry, the agencies cannot continue to use traditional design criteria and guide specifications, but they cannot dispense with their design criteria and guide specifications for controls without risking a multitude of protests and disputes on every project.

While the committee does not see any complete solution to the agencies' dilemma, it believes that there are several interim steps that the agencies can take that will help the situation until the rate of change in HVAC control technology decreases to a reasonable level; specifically; the committee believes that agencies should:

1. Modify their directives to HVAC consulting engineers to encourage them to propose the use of systems and requirements that

differ from agency design criteria and guide specifications whenever they believe the government would benefit.

2. Establish mechanisms for quickly reviewing and acting on requests from consulting engineers for waivers from the provisions of published design criteria and guide specifications.

3. Adopt the practice of reviewing and updating HVAC design criteria and guide specifications annually to incorporate recent changes in control technology.

Finally, the committee believes that the current guide specifications of some agencies may be unnecessarily permissive with regard to HVAC controls. When reviewing samples of agency guide specifications the committee found, for example, that some agencies permitted virtually any type of system (except DDC) to be used at the contractors discretion, and that some agencies included few requirements regarding the quality of the control components to be installed. While the committee is not expert in federal acquisition regulations, it appears that some current guide specifications are excessively permissive. Therefore, the committee recommends that agencies review their guide specifications to determine if some additional restrictions and requirements aimed at improving the quality and maintainability of controls installed on government projects might be in order. Although, as discussed in chapter 5, the committee does not agree with the general concept of the CERL standard panels or some of the provisions of ETL 83-1, the committee believes that the specifications for the CERL panels and ETL 83-1 both include a number of worthwhile detailed requirements that should be incorporated in traditional guide specifications. Given the extent of problems agencies have experienced, it would seem that agencies could justify being somewhat more demanding than they have been in the past.

ENSURING THE QUALIFICATIONS OF INSTALLERS OF HVAC CONTROL SYSTEMS

The one factor that was mentioned more than any other by all categories of HVAC specialists from whom the committee received input (government engineers, consulting engineers, and manufacturer representatives) as a cause of problems with HVAC controls in federal buildings was the failure of federal agencies to restrict bidders on government projects. Indeed, the procurement practice of the federal government that sets it apart most from other building owners is the inability or unwillingness of federal agencies to place restrictions on who can bid on or supply products for federal projects--except in very unusual situations.

Although the Federal Acquisition Regulations (48 CFR CH 1, part 9) require contracting officers to make an affirmative determination that an organization being considered for a contract award is "responsible" (i.e., fully qualified to fulfill the contract), in practice organizations are seldom judged not to be responsible because of the difficulty of substantiating such a determination. The federal government also has a mechanism for precluding contractors that have performed unsatisfactorily in the past from receiving another contract for a period of time (generally not more than 3 years). However, because the procedures for getting a contractor debarred are complex and timeconsuming, agencies use them infrequently. Thus, most government contracts are awarded to the organization that submits the lowest bid and can obtain a performance bond. This practice has two detrimental effects:

- First, it leaves government agencies without recourse to one of the most effective methods consumers have of convincing contractors and manufacturers to fulfill their obligations to give satisfactory service or provide satisfactory products; namely, the threat of the loss of future business.* By choosing not to place restrictions on bidders and suppliers, agencies give up the threat to penalize a contractor or manufacturer on future projects. Contractors and manufacturers know that almost no action short of outright fraud will cause them to lose the right to bid on future government work. Consequently, incompetent or lax firms have little incentive to improve their performance and unscrupulous firms know they are at liberty to use every loophole and ambiguity they can find in the specifications without fear of retribution.
- Second, it virtually precludes agencies from requiring that suppliers of complex systems be experienced. Having experience is particularly important with systems like HVAC control systems that involve not just equipment but also application engineering. If necessary, individual pieces of equipment can be inspected and tested before installation to ensure that they will perform properly. However, complex systems often cannot be evaluated until they have been put into operation and by that time it is too late to make major changes. The best way to ensure the performance of complex systems is to use only suppliers with proven records on accomplishment. Federal agencies, however, find it difficult to do this.

As discussed in chapter 5, several agencies have developed special procurement procedures that address this problem by awarding contracts for complex systems like EMCS on the basis of proposals, with the qualifications of the contractors being one of the factors considered. While this approach seems appropriate when a complex system is being procured separately, it would seem to be inappropriate when the system

*This threat can be particularly effective if the architect and consulting engineer are involved during the construction phase since a recalcitrant contractor or manufacturer risks losing not just the owner's future business but also work on future projects the architect/engineer designs. This is another reason for adoption of the committee's previous recommendations about making full use of HVAC consulting engineers.

is being procured as part of a building for which a fixed-price contract is to be awarded on the basis of sealed bids. In such cases, which are common, agencies probably need to treat HVAC controls like all other building systems.

Private owners can deal with the situation arbitrarily by, for example, stipulating which subcontractors can be used on a project. The committee understands that federal agencies cannot make arbitrary decisions as private owners do. However, the committee believes that agencies could be somewhat more selective than they are now. In fact, the Federal Acquisition Regulations seem to require it. As noted above, the regulations require contracting officers to verify that a prospective contractor is responsible before awarding a contract. The regulations indicate that in order to be judged responsible a prospective contractor must have adequate financial resources; be able to comply with the required delivery or performance schedule; have a satisfactory record of performance; have a satisfactory record of integrity and business ethics; have the necessary organization, experience, operational controls, and technical skills; have the necessary equipment and facilities; and if the situation warrants, meet other responsibility standards that the contracting officer may impose. In addition, the regulations indicate that the burden of proving responsibility is on the prospective contractor and that the contracting officer should make a determination of nonresponsibility if the information obtained does not indicate clearly that the prospective contractor is responsible.

The regulations also indicate that responsibility requirements can be imposed on subcontractors (which HVAC control vendors usually are). The regulations state that a prospective prime contractor may be required to provide written evidence of a proposed subcontractor's responsibility and that a determination regarding the prime contractor's responsibility can be linked to the subcontractors responsibility.

Contracting officers appear, therefore, already to have sufficient authority to ensure that contractors and subcontractors on government projects are qualified. The committee recommends that agencies use that authority fully with regard to installers of HVAC control systems.

PROMOTING THE DEVELOPMENT OF CONTROL STANDARDS

As noted previously, one of the main concerns agencies have about using proprietary HVAC control systems for which all components are supplied by a single vendor is that once such a system is installed, all spare parts (and in some cases all repair service) and all parts to expand the system must be obtained from the original vendor. This situation eliminates competition, which the agencies believe increases their maintenance, repair, and alteration costs.

The problem is not serious with traditional pneumatic and electronic analog controls because the components of the various manufacturers of such systems often are similar enough that they can be intermixed without too much difficulty. The problem is very serious, however, with modern, highly integrated digital control systems. The components used in these systems employ microprocessors that respond to and/or generate specific digital signals, and unless the signals are in precisely the right form they are meaningless to the microprocessors. The rules that define the nature and meaning of the signals used in a control system are known as protocols. These protocols, which can be very complex, currently are developed separately by the various system manufacturers, and the absence of standards for control system protocols precludes the mixing of components of different manufacturers or interconnecting one manufacturer's system with another manufacturer's system.

For the reasons mentioned above, federal agencies are frustrated about the current situation and their frustration is likely to increase as the use of direct digital controllers becomes more widespread and as more and more manufacturers of HVAC equipment (e.g., chillers, air handling units and other packaged equipment) begin using microprocessors to optimize the performance of their units. Most owners recognize that the situation can be corrected only if standardized communications protocols for HVAC control systems are developed.

Efforts to Date

The difficulties owners experience because of their inability to interconnect the control components and systems of different manufacturers are not unique to the building controls field. Similar problems exist in the data processing industry, and some steps have been taken by that industry to reduce interconnection problems. In the late 1970s, for example, Technical Committee 97 (on Information Processing) of the International Organization of Standardization (ISO) developed the Reference Model of Open System Interconnection (OSI) to serve as the framework for development of future standard protocols for networks of heterogeneous systems. In the OSI reference model, the problem of inter-systems communication is approached using a layering architecture to break the problem into manageable pieces. Seven layers were identified starting with the application layer as the highest and proceeding through the presentation, session, transport, network, data link, and the physical layer, which is the lowest.

One protocol, which is based on the ISO seven-layer reference model, and which is becoming very important in the industrial controls area, is the Manufacturing Automation Protocol (MAP), which was introduced in July 1984 by General Motors (GM) and seven other participants. While further development of the MAP standard is needed, the main impediment to the use of MAP in building control processes is its high cost. Even if the cost per node connection of an MAP-based system were to drop to $2,000 over the next two years as expected, MAP would still be too expensive and have too many capabilities for building control applications, where low first cost is critical and communication requirements are not excessive.

A different approach to linking multiple independent control systems to obtain a coherent facilities management system has recently been adopted by the IBM Corporation. As noted in chapter 3, IBM has developed a "Facilities Automation Communication Network" (FACN) protocol specification. It is based on the use of IBM PC's as "translators" for connecting non-IBM microprocessor-based DDC systems with an IBM "facility host" computer running version "D" of IBM's "General Purpose Automation Executive" (GPAX-D) program. To date several control companies have completed the acceptance testing requirements for bidding on IBM projects using the FACN protocol, and more companies are expected to meet these requirements in the near future. One limitation on the application of this approach in the public sector is that it requires the use of IBM or IBM-compatible PC's at the front end and an IBM Series 1 computer as the host to the several systems.

Two other developments that have the potential to improve communication between building control systems supplied by different vendors are the "Public Host Protocol 1," which American Auto-Matrix has offered to the industry as a possible standard, and software recently released by several companies that allow EMCS from different manufacturers to be linked to a single IBM PC or compatible computer. While the latter software is not the same as full integration of different systems, it does reduce the user interfacing problems associated with having to deal simultaneously with a number of different EMCS. However, like the IBM approach, these systems are concerned only with linking a host computer to an EMCS.

Review of Options and Opportunities

It is clear from the above discussion that there is widespread recognition of the need for a communication protocol standard for computerized HVAC control systems and that some laudable efforts related to the development of a standard have already been initiated. However, none of the actions taken to date are likely to bring about the degree of industry-wide protocol standardization that building owners seek. Similarly, although several control vendors indicated in meetings with the committee willingness to consider participating in the development of a protocol standard, most of the vendors were obviously not enthusiastic about the idea and would not take the lead in the effort. The lack of enthusiasm among vendors for protocol standards is probably due to their concerns about the possibility of greater price competition and the possible stifling of innovations in controls. While the committee understands such concerns, it believes the potential advantages of open protocol far outweigh the potential disadvantages. It, therefore, investigated various options and opportunities for getting protocol standards developed.

One possibility that the committee considered was to have the federal agencies take the lead in developing a standard protocol. The U.S. Government, with all its military and civilian facilities, buys enough HVAC control systems each year to dictate the communications protocol that these systems will use. One problem, however, is that the military and civilian applications are very diverse and it is unlikely that there is one solution that is best under all circumstances. Also, it is important that any protocol supported by the government also meet the needs of the private sector. The committee concluded that this probably would not occur if the government controlled the effort to develop a standard.

After learning that the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) had formed a special project committee to define a standard communications protocol for EMCS, the committee investigated the likelihood that the ASHRAE effort would result in the development of the type of standard it believes is needed. The committee was unable to arrive at a firm conclusion because the nature and scope of the ASHRAE effort is still evolving. However, it is believed that the ASHRAE committee will concentrate initially on developing an upper level protocol for linking an EMCS to a host computer. Also, the leader of the ASHRAE effort (Mr. Michael Newman of Cornell University) has indicated that the speed with which a standard is developed depends on how quickly and how intensely vendors get involved. Inasmuch as vendors have expressed little enthusiasm for a protocol standard, the committee doubts that the ASHRAE effort will bear fruit very soon, especially with regard to lower level protocols.

The committee also explored the possibility of getting another private organization to take on the task of developing protocol standards. It found that the Intelligent Building Institute (IBI), a trade association dedicated to promoting building automation, had already started work on the task. However, the committee also discovered that IBI expected the project to be expensive and that it doubted the work could be completed without outside financial support. IBI noted that it hoped to develop protocols to support various building systems besides HVAC systems; e.g., lighting systems, life safety systems, and security systems.

The committee was impressed with the IBI approach because it is based on a sound overall concept involving four levels of protocols:

- Level I would permit point to point or sensor to sensor communication.
- Level II would permit remote intelligent microprocessors, to which sensors are connected, to communicate with other intelligent microprocessors. (This level would cover DDC modules communicating with other DDC modules.)
- Level III would permit host level computers to communicate with other host level computers. (These host computers could be either PC's or minicomputers.)
- Level IV would permit communication at the Information Management Network Level.

Under the IBI concept, the protocol at each level would conform to the OSI seven-layer model. To save money and time, protocols that already exist would be used to the extent possible. IBI expressed the belief that available protocols could in fact be used for level I and level IV protocols. IBI estimated that the development of level II and level III protocols might take 5 to 6 years and could cost $4 million.

The IBI proposal is very interesting, and it includes a realistic time-table and cost estimate. Also, the IBI membership includes many of the control companies that would have to participate in the protocol development process. The estimated cost is relatively high, but the potential benefits are also high. Although a portion of the cost might be borne by private companies, IBI would probably need some funding from federal agencies to complete the work in a reasonable period of time.

Conclusions and Recommendations

The development of protocol standards for HVAC controls would be of great benefit to all building owners, including federal agencies, because it would increase competition, particularly for spare parts and maintenance service, and it would simplify the job of operating personnel who are responsible for facilities in which a variety of different control systems are installed. Protocol standards would be especially helpful to federal agencies because it would ease the task of preparing non-proprietary specifications, which agencies are almost required to use by the Federal Acquisition Regulations. In fact, the committee believes that the development of open protocols is the single most pressing need with regard to HVAC controls, and it unanimously endorses the development of protocol standards. The committee believes that there is an especially pressing need for a protocol standard to permit DDC modules of different manufacturers--including the DDC modules now being installed by HVAC equipment manufacturer on their units--to communicate with one another.

The committee recognizes, however, that the development of a protocol standard would be a very difficult task. Not only would the effort be technically challenging, but it would also generate heated disputes among the various control manufacturers striving to gain or maintain a competitive advantage. In the circumstances, there is no assurance that the effort would be successful. However, the potential benefits are sufficiently great that federal agencies ought to encourage and support the initiation of the effort, and the sooner the effort begins, the sooner the agencies and the industry as a whole could realize the benefits.

Of the various protocol-development projects reviewed by the committee, the one proposed by the IBI would appear to have the best chance of producing worthwhile results in a reasonable period of time. The IBI program appears to be well planned and based on a sound concept, and most important, it is the only program that appears likely to produce the all-important Level II protocol standard (i.e., the standard for DDC modules) in the foreseeable future. The committee recommends, therefore, that agencies give favorable consideration to requests from IBI for financial support.

The committee further recommends that any IBI effort be actively reviewed for acceptability by the ASHRAE group involved in developing a protocol standard. In addition, the committee also believes the

National Bureau of Standards should have a supportive role in reviewing the technical work of both IBI and ASHRAE.

AN INNOVATIVE APPROACH TO CONTRACTING FOR MAINTENANCE

Building owners expect some maintenance problems with complex systems; however, agencies believe that their problems with HVAC control systems in recent years have been excessive. The nature of, possible reasons for, and various ideas for solving the problems agencies have encountered have been discussed at length in previous sections of the report. One important issue that has not been addressed, however, is the quality of the maintenance work performed on government HVAC controls.

Traditionally, most federal agencies have used government employees to maintain most of their building systems, including HVAC controls. (One exception to this general rule has been elevators, which usually have been maintained by private firms under contract.) In recent years, however, more and more agencies have been contracting for building maintenance and repair work, especially for complex items like HVAC control systems. Three factors have contributed to this trend: The growing complexity of building systems, reductions in government staff levels, and increased emphasis on the government policy to procure goods and services from the private sector whenever it is cost effective.

Federal agencies could not provide the committee with statistics on the percentage of their HVAC control systems that were maintained by government employees and the percentage that were maintained under contract or the relative effectiveness of the two approaches. However, it was the general feeling of the agency personnel who worked with the committee that the contract maintenance approach generally has given good results, but that it is expensive. These views are in line with the experiences of most of the committee members. Consequently, as part of its study, the committee looked for ways of improving agency procedures for contracting for the maintenance and repair of HVAC controls.

After analyzing the situations, the committee concluded that the best organization to get to maintain a control system would be the original manufacturer since its personnel should know better than the personnel of any other organization how the system was installed and how it should function. Indeed, with some especially sophisticated systems it is possible that only the original manufacturer has the knowledge needed to maintain it. Also, the original manufacturer has a special incentive to make sure that the system continues to operate properly since its reputation is at stake if the system fails.

The problem with insisting on hiring the original manufacturer, or any other specific organization, to maintain the system is that it becomes a sole-source procurement, which is almost always more expensive than a procurement involving competition. However, a member of the committee--Donald Coggan--has proposed a solution to this problem. In Gaining Control--the Building Control Newsletter (August 1984), Coggan suggested that owners require manufacturers to include the cost of long term service (e.g., 5 years) in their bids for supplying the system initially. By so doing, he said, owners would force manufacturers to compete on service cost as well as first cost. He estimated that with competition the annual cost of a service contract would drop from between 12 percent and 15 percent of the first cost of the system to between 4 percent and 5 percent of the first cost of the system.

Another potential benefit of the concept is that it would encourage manufacturers to supply highly reliable components and to make sure that they are installed properly in order to minimize future service costs.

There are of course many details associated with the use of the concept that would have to be worked out. For example:

1. How to apply the concept on projects involving the construction of an entire building in which the HVAC control system is just one small element, and the prime contractor ordinarily submits a lump sum bid for the total project. One solution would be to issue a separate invitation for bids for the HVAC control system and award a separate contract for it. Another solution would be to require each prime contractor to include in his bid, as options, at least three separate sub-bids from HVAC control manufacturers, any one of which the agency could select.

2. How to cancel the agreement in the event the service provided is unsatisfactory. One solution would be to require the service contractor to pay a prescribed penalty if the government cancels the agreement for poor contractor performance; the amount of the penalty to be paid presumably would decrease with time.

Although the approach outlined might be cumbersome to use in some cases, it appears to offer several advantages over other methods of contracting for service for HVAC controls. The committee recommends, therefore, that agencies use it at least on a trial basis on several projects.

DEVELOPING FEDERAL EXPERTISE IN CONTROLS

Even though federal agencies depend heavily on private consulting engineers, manufacturers, and contractors to design, manufacture, install, and maintain HVAC control systems, agencies need to have at least a few full time employees who are experts in HVAC controls to perform such functions as preparing design criteria, writing guide specifications, evaluating the capabilities of consulting engineers seeking design contracts, reviewing proposed system designs, evaluating vendor proposals, inspecting and testing completed systems, evaluating the work of maintenance contractors, and generally helping to resolve problems that occur.

Agencies need employee experts to carry out such functions with regard to all facets of construction; however, whereas experts in most construction specialties are in abundant supply, experts in modern HVAC controls are scarce. This is mainly because control technology has changed so dramatically in the past few years that only a few engineers have had a chance to become thoroughly familiar with the new concepts, and those who do understand them are in great demand. Agencies must, therefore, take special measures to insure that they maintain an adequate level of in-house expertise.

Currently, most agencies seem to have at least a few engineers who are well informed on the subject. The immediate challenge for the agencies is to make effective use of those limited resources. In the future the supply of experts in HVAC controls undoubtedly will expand. However, that will not necessarily ensure agencies of an adequate level of in-house expertise in the technology. This is because control technology is so complex that an engineer must work with it continually in order to maintain his expertise. Consequently, even after HVAC control experts are no longer scarce, agencies will need to take steps to ensure that their in-house experts are used properly.

The committee believes that the best solution to both the short-term and long-term problems is for agencies to form special permanent teams of HVAC control experts to handle all important tasks relating to the acquisition of HVAC controls. The committee is convinced that a centralized approach is needed because of the unusually complex nature of the technology.

GLOSSARY

Adductor	A device either electrically, pneumatically, or hydraulically operated, which changes the position of a valve or damper.
Algorithm	A procedure for solving a recurrent mathematical problem.
Digital Data	Data in the form of digits or interval quantities.
Digital Device	A device that operates on the basis of discrete, numerical techniques in which the variables are represented by coded pulses or states.
Direct Digital Control	A control loop in which a digital controller periodically updates the process as a function of a set of measures control variables and a given set of control algorithms.
Central Processing Unit	The portion of a computer that performs the interpretation and execution of instructions. It does not include memory or I/O
Chiller	A refrigeration machine using mechanical input to drive a compressor to generate chilled water.
Control, Integral	A control algorithm or method in which the final control element is moved in a corrective direction at a rate proportional to the deviation (error) of the controlled variable until the controller is satisfied or until a movement in the other direction is called for. Also called proportional speed floating control.
Control, PI	Proportional/Integral Control. A control algorithm that combines proportional (proport-ional response) and integral (reset response)

	control algorithms. Reset responds to correct the offset resulting when proportional control alone is used. Also called proportional-plus-reset control and two-mode control.
Control, Proportional	Control action in which there is a continuous linear relation between the output and the input. This condition applies when both the output and the input are within their normal operating ranges.
Economizer Cycle	A method of operating a ventilation system to reduce refrigeration load. Whenever the outdoor air conditions (lower air temperature and/or humidity) are more favorable than return air conditions, outdoor air quantity is increased.
Local Loop Controls	The controls for any system or subsystem which existed prior to the installation of an EMCS and which will continue to function when the EMCS is non-operative.
Microprocessor	A central processing unit fabricated as one integrated circuit.
Protocol	A formal set of conventions governing the format and relative timing of message exchange between two terminals.
Sensors	Devices used to detect or measure physical phenomena.
Software	A term used to describe all programs whether in machine, assembly, or high-level language.
Variable Air Volume	An air distribution system that meets the needs of the conditioned space by varying the amount of conditioned air brought to the space.

ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CERL	Construction Engineering Research Laboratory
CPU	Central Processing Unit
DDC	Direct Digital Control
EMCS	Energy Management and Control Systems
FACN	Facilities Automation Communication Network
FCC	Federal Construction Council
GPAX	General Purpose Automation Executive
HVAC	Heating, Ventilating, and Air Conditioning
IBI	Intelligent Buildings Institute
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Standards Organization
MAP	Manufacturing Automation Protocol
OSI	Open System Interconnection
PI	Proportional plus Integral
PID	Proportional plus Integral plus Derivative

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