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Retrofit of Standard Analog-Electronic Control Panels at Existing Army Facilities

by
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The U.S. Army Construction Engineering Research Laboratory (USACERL) previously developed designs and guidance documents for Standardized Heating, Ventilating, and Air-Conditioning (HVAC) Control Systems. These Standard Control Systems, using analog electronic controllers, would save money by reducing energy consumption and maintenance requirements through improved control of HVAC processes and reliability of components.

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The U.S. Army Construction Engineering Research Laboratory (USACERL) previously developed designs and guidance documents for Standardized Heating, Ventilating, and Air-Conditioning (HVAC) Control Systems. These Standard Control Systems, using analog electronic controllers, would save money by reducing energy consumption and maintenance requirements through improved control of HVAC processes and reliability of components.

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FOREWORD

This study was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) under Facilities Engineering Applications Program (FEAP) Work Unit EB-FK9, "Retrofit of Standard HVAC Controls." Mr. Bernie Wasserman was the original Technical Monitor, and Mr. Chris Irby assumed responsibility in February 1989.

The research was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Mr. Bill Dolan was the Principal Investigator (PI) from January 1984 until October 1985, Mr. Bill R. Taylor was PI from October 1985 until August 1987, Mr. Dave M. Underwood was PI from August 1987 until August 1988, and Mr. Glen A. Chamberlin was PI after August 1988. Dr. G. R. Williamson is Chief of USACERL-ES.

Appreciation is extended to Directorate of Engineering and Housing (DEH) personnel at Fort Lewis, Fort Sill, and Fort Leonard Wood for their assistance with this project.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Heating, ventilating, and air-conditioning (HVAC) systems are responsible for a significant portion of energy use in Army buildings. In recent years, many innovative HVAC control components and schemes have been developed in an attempt to reduce the facility energy cost. These components and schemes are designed to save energy by tightening control over HVAC systems and taking full advantage of favorable outdoor conditions.

However, complaints about controls--that they do not work, waste energy, or are maintenance intensive--have been widespread. The U.S. Army Construction Engineering Research Laboratory (USACERL) investigated a variety of devices and control schemes typically used in Army facilities and found that many had poor performance. Thus, a new approach to Army HVAC control systems was needed to reduce maintenance requirements, improve energy efficiency, and enhance thermal comfort in occupied spaces. USACERL, with assistance from Army and Air Force agencies, began a program to develop control systems to meet these needs.

The result was the development of standardized HVAC control system designs and hardware which would reduce routine maintenance requirements, improve system diagnostic capabilities, and save energy through better control and reliability. The standard control systems developed consisted of available, high-quality components rather than new technologies. Off-the-shelf, high-quality electronic-analog sensors and controllers were interfaced with pneumatic actuators to provide reliable, easy-to-maintain controls. The standard HVAC control systems were intended for use in new and retrofit applications, and the standard HVAC control panels are now available from several HVAC control suppliers.

USACERL constructed, installed, and tested several prototype versions of the analog-electronic standard HVAC control panel in the laboratory and developed documents detailing how to design and specify the control systems.[1] However, prior to implementation of the new control system designs and hardware throughout the Army and Air Force, a field test of the panels on a limited number of Army HVAC systems was undertaken to verify the accuracy and reliability of the new control systems and to quantify the energy savings resulting from their use.

Objective

The objective of this research was to quantify the benefits of retrofit applications of standard control systems by comparing energy consumption of existing and retrofit control systems. Maintenance requirements, reliability, and control accuracy were also compared.

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[1] D.C. Hittle and D.L. Johnson, *New Control Design Principles Based on Measured Performance and Energy Analysis of HVAC Systems*, Technical Report E-85/02/ADA151708 (USACERL, January 1985).

Approach

1. HVAC system types typically used in Army facilities were selected for the demonstration.

2. Three Army installations having commonly used Army facilities and experiencing climatic variation were selected as demonstration sites, and buildings at each installation with large HVAC systems that were significant energy users were identified for retrofit panel installation.

3. A retrofit package was developed for each site, and control hardware, including the standard panels, was installed and commissioned.*

4. Using a data acquisition plan developed by an architecture/engineering contractor, researchers collected data comparing the energy use, maintenance requirements, and control accuracy of the new control systems compared to existing systems.

5. The data was analyzed, and results and conclusions were developed.

Mode of Technology Transfer

It is recommended that this report be summarized in a DEH Digest article and used to guide development of the Corps of Engineers guide specification (CEGS) and technical manual (TM) on HVAC controls now being drafted.

*"To commission" means not only to make operational but also to verify that equipment is functioning as designed.

2 OVERVIEW OF THE ANALOG-ELECTRONIC STANDARD HVAC CONTROL SYSTEMS

Development

In the early 1980s, USACERL began a program to investigate the performance of HVAC system components, including HVAC controls, and to develop HVAC systems that could make both new construction and existing buildings more energy efficient. In a project funded by the U.S. Department of Energy, USACERL built a full-scale HVAC test facility, which included a commercially available pneumatic control system. The purpose of the facility was to measure the energy performance of HVAC systems and components, and the investigation revealed that the pneumatic control system components performed poorly. Despite efforts by the manufacturer's engineers and USACERL personnel, the controls would rapidly drift out of calibration, and the system would eventually be out of control, causing poor comfort conditions and excessive consumption of energy.

Test facility controls were typical of those used in Army applications, so researchers concluded that many Army buildings might be experiencing similar control system problems. Information obtained from engineers in the field indicated that controls were a major problem at Army installations. Publication of the laboratory results[2] caused nationwide feedback confirming problems with accuracy and long-term performance of control systems. USACERL then embarked on a program to investigate the causes and solutions, both in the field and in the laboratory. The results of the investigations are summarized below.

Some control system problems result from overly general system specifications for control systems and component functions. In addition, quantitative performance requirements of the control system usually are not developed. Also, complex control system designs combined with low first cost requirements and no quantitative performance requirements often result in an unsuccessful system. Thus, researchers concluded that HVAC control system design should be simplified, and performance specifications for control components and systems should be required.

Problematic equipment was identified. For instance, pneumatic temperature control devices are fairly inaccurate and require a very clean air source, which is often difficult to maintain. Electronic thermistor temperature detectors are prone to drifting and have to be calibrated often. Horse-hair pneumatic humidity sensors are prone to rapid drift, are only fairly accurate, and are difficult to calibrate in the field, making implementation of enthalpy economy cycles almost impossible. Some devices were found to operate reliably, however. For example, pneumatic actuators are cheaper and require less maintenance than electric actuators. Proportional-plus-integral (PI) control schemes can provide significant operating cost savings over conventional proportional-only (P) control schemes. These findings led to the guideline specifying that only accurate, reliable sensors, controllers, and other components, which are factory calibrated and easily replaced if defective, should be used in Army HVAC control systems.

Army HVAC control systems were not properly maintained, and several reasons were cited. First, control systems typically are custom designed and fabricated for each job, and thus maintenance personnel have to learn to operate and maintain many different unique control systems. Second, many HVAC control systems are maintenance intensive and complex, and most Army installations have too few skilled

[2] D.C. Hittle; W. Dolan, D.L. Leverenz, and R. Rundus, "Theory Meets Practice in a Full-Scale Heating, Ventilating, and Air-Conditioning Laboratory," *ASHRAE Journal*, Vol 24, No. 11 (November 1982), pp 36-41.

personnel to make the systems perform as designed. Third, the lack of detailed, system-specific maintenance instructions also contributes to insufficient system maintenance. Finally, the lack of working diagnostic equipment makes troubleshooting control problems difficult and time consuming. These findings led researchers to conclude that system design and hardware implementation via premanufactured panels should be standardized so technicians can avoid learning how to operate and maintain many different systems. They also concluded that documentation to assist technicians in maintaining control systems should be included with all newly installed systems and that all essential diagnostic components should be included in the hardware panel to eliminate the need for special instruments and tools.

Description

Following the above guidelines, USACERL began the development of standard control systems and panels. From a variety of typical HVAC system types, USACERL identified four basic HVAC systems commonly used in Army and Air Force facilities worldwide: variable air volume (VAV), single zone, multizone, and hot water systems. Standard control system schematics and panel designs were produced for each of these four HVAC system types, and prototype control panels were procured from control system suppliers. Eight panel designs were required to implement the standard control system designs for the four system types. Documentation was developed, such as electric ladder diagrams, operation sequence, commissioning instructions, maintenance instructions, and technical specifications for the standard control systems, as well as instructions for designing the control systems. Detailed documentation for these systems is shown in Appendix A. A brief description of the standard control hardware follows.

Standard panels use resistance-temperature-detectors (RTDs) for temperature sensing, industrial-grade electronic proportional-plus-integral (PI) controllers, and electric-to-pnuematic (E/P) transducers for operating actuators and other devices. RTDs are used instead of other types of temperature sensors because they are accurate and maintain calibration, and electronic controllers were selected instead of commonly used pnuematic controllers for the same reasons. E/P transducers, which convert the electronic controller output signal to a pneumatic pressure, were selected to allow the use of pneumatic actuators/devices, which have been shown to be reliable and economical. This also allows the use of existing actuators on retrofit systems.

One of the advantages of standardized panels is that diagnostics can be done at the panel without using additional hand instruments. For example, the control panel in Figure 1 has the following main diagnostic features:

1. The front panel meter (1) displays the temperature, controller setpoint, or controller output values. Thus, hardware malfunctions of the sensors or controllers can be easily detected and identified.

2. For each controller in the panel, a SET Button (2) permits the operator to vary the pneumatic output to the actuator by turning the MANUAL ADJUST knob (3). Thus, nonresponsive system devices (valves, dampers) are easily detected. Automatic control resumes when the operator depresses the RESET button (4) or when the TIMER (5) returns to zero. The timer prevents inadvertently leaving the system in a manual position indefinitely.

3. For each controller output, a pneumatic pressure gauge (6) displays the magnitude of the pnuematic signal. By comparing the pneumatic gauge reading to the electric output of the controller, the operator can easily detect malfunctions in the electric-to-pneumatic conversion of the output signal.

4. Position indicator gauges (7) show the operating position of actuator and control devices.

5. A SUPPLY AIR gauge (8) indicates main air availability.

6. The PUSH TO DUB buttons (9) insert a test resistance in place of the RTD sensor. The source of erroneous temperature readings, whether in-panel circuitry or out-of-panel sensors or wiring, can be distinguished.

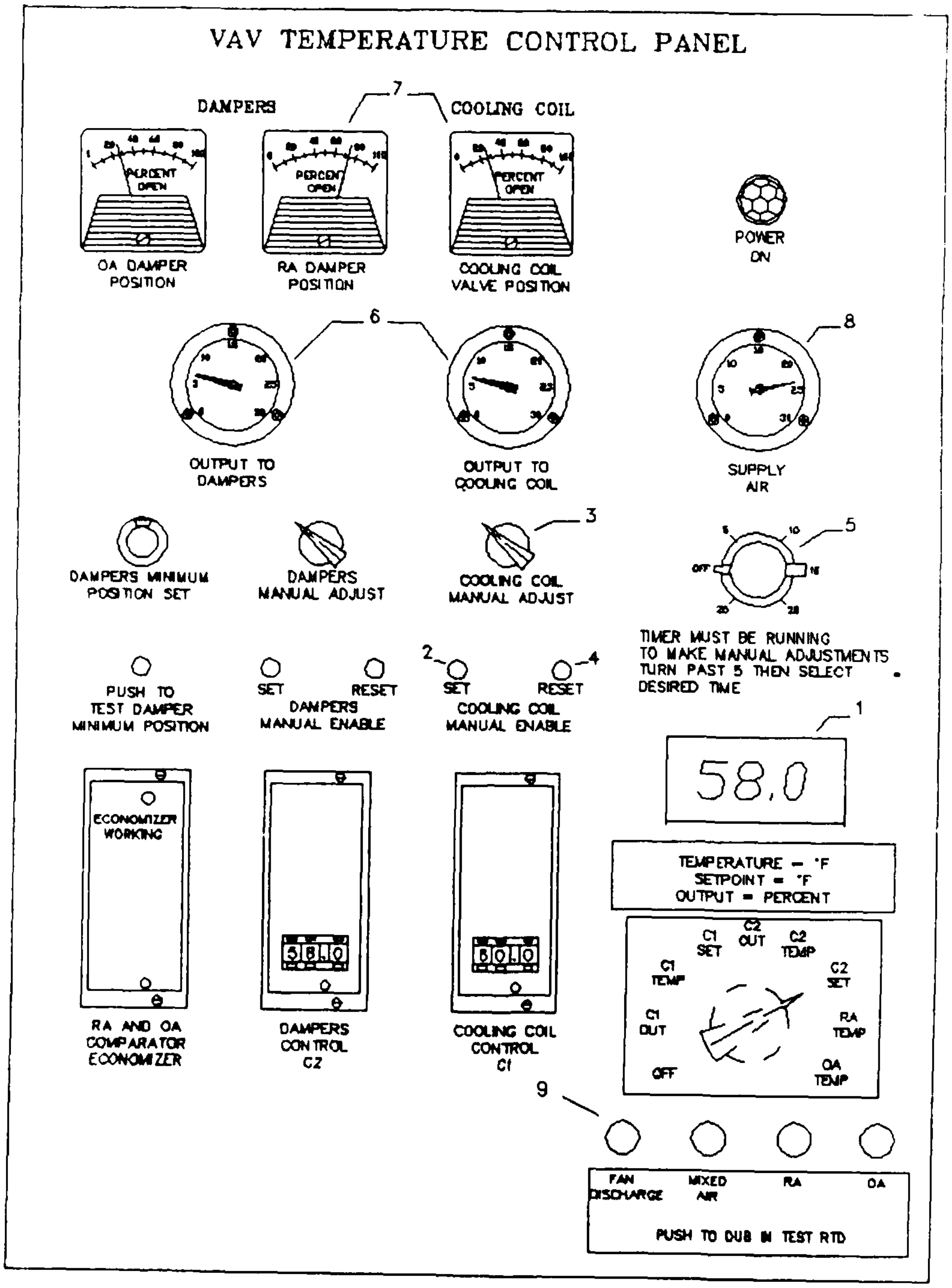


Figure 1. VAV temperature control panel with text reference.

3 STANDARD PANELS USED IN THE DEMONSTRATION PROJECT

The first step in this demonstration was to select the HVAC system types to be studied. VAV and hot water systems were selected as representative. Control of a VAV system requires a static pressure control panel for fan control and a VAV temperature control panel for outside air and cooling coil control. Hot water converter systems would require a hot water temperature control panel. An overall description of the panels used is provided in this section; a complete description is in Appendix A.

Static Pressure Control Panel

The static pressure control panel controls the supply duct static pressure of a VAV system by controlling either supply fan inlet guide vanes or a variable frequency drive, thus ensuring that adequate air flow is supplied to the VAV terminal boxes. Figure 2 is a schematic of a typical static pressure control panel application. The differential pressure transducer (DP1) converts the duct static pressure into an electronic signal, which is input to the electronic controller (C3). The electronic controller maintains the duct static pressure setpoint by changing the supply air flow. The supply air flow is changed by varying the signal sent to the inlet guide vane actuator.

Figure 3 is the front panel of a typical static pressure control panel. The static pressure controller (C3) has adjustment knobs for setting the static pressure setpoint, the proportional gain, and the integral reset time. All the inputs and outputs to and from the static pressure controller can be displayed on the front panel meter and gauges. The static pressure signal can be read on the sensed static pressure gauge, enabling the technician to check the accuracy of the static pressure sensor. The accuracy of the E/P can be checked by noting the sensed pressure value on the front panel meter and comparing it to the sensed static pressure gauge's value. The setpoint of the static pressure controller can be read at the controller or the front panel meter. The action of the controller can be determined by reading the electronic output of the controller on the front panel meter. If inlet guide vanes are used, the accuracy of the E/P can be determined by noting its value on the OUTPUT TO ACTUATOR gauge and comparing it to the value shown on the digital meter. A gauge shows the fan discharge static pressure directly downstream from the fan, thus allowing the technician to detect high duct pressures. The fan can be put in manual control for a limited time by turning the TIMER switch, pressing the SET button, and turning the MANUAL ADJUST knob This feature allows the technician to check the operation of the supply fan actuator and inlet guide vanes. The SUPPLY AIR gauge indicates whether supply air is present at the panel. This panel is not intended for a two-fan VAV system since it does not have controls for the return fan.

VAV Temperature Control Panel

The VAV temperature control panel (1) controls the discharge air temperature by modulating the cooling coil valve; (2) controls the mixed air temperature by modulating the outside, return, and exhaust air dampers; and (3) determines whether to use outside air for energy conservation. A schematic of a typical temperature control panel (Figure 4) shows that RTDs T1 through T4 sense air temperatures, which are input to the cooling coil (CC) controller (C1) and the damper controller (C2) via the comparitor and high signal select module. The controllers maintain the temperature by adjusting the valve or damper positions. The electronic signal from the controllers are transduced by E/Ps into pneumatic signals, which then modulate damper actuators or valve actuators. This panel is equipped with an economizer card which

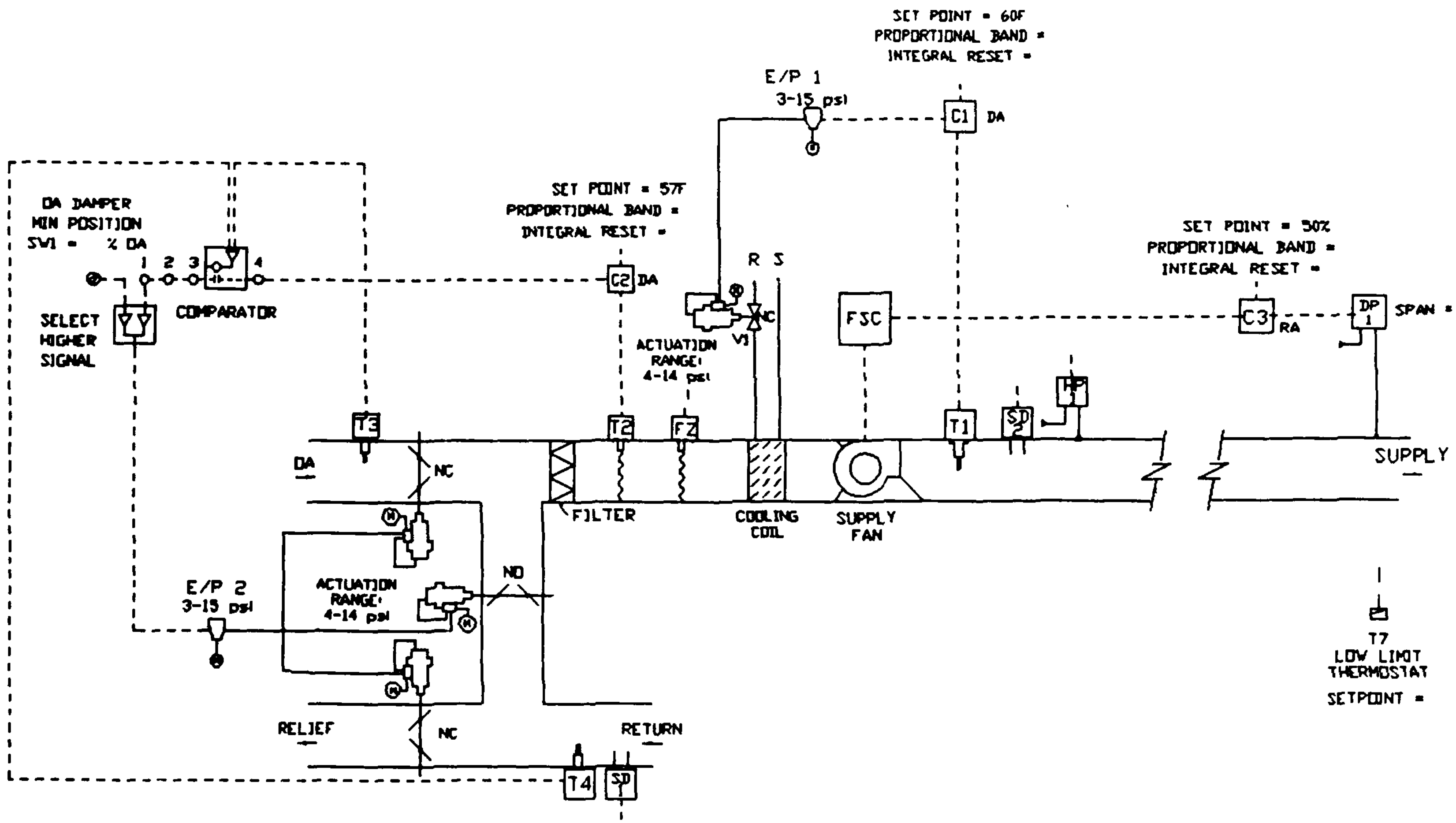


Figure 2. VAV inlet vane damper (IVD) control diagram.

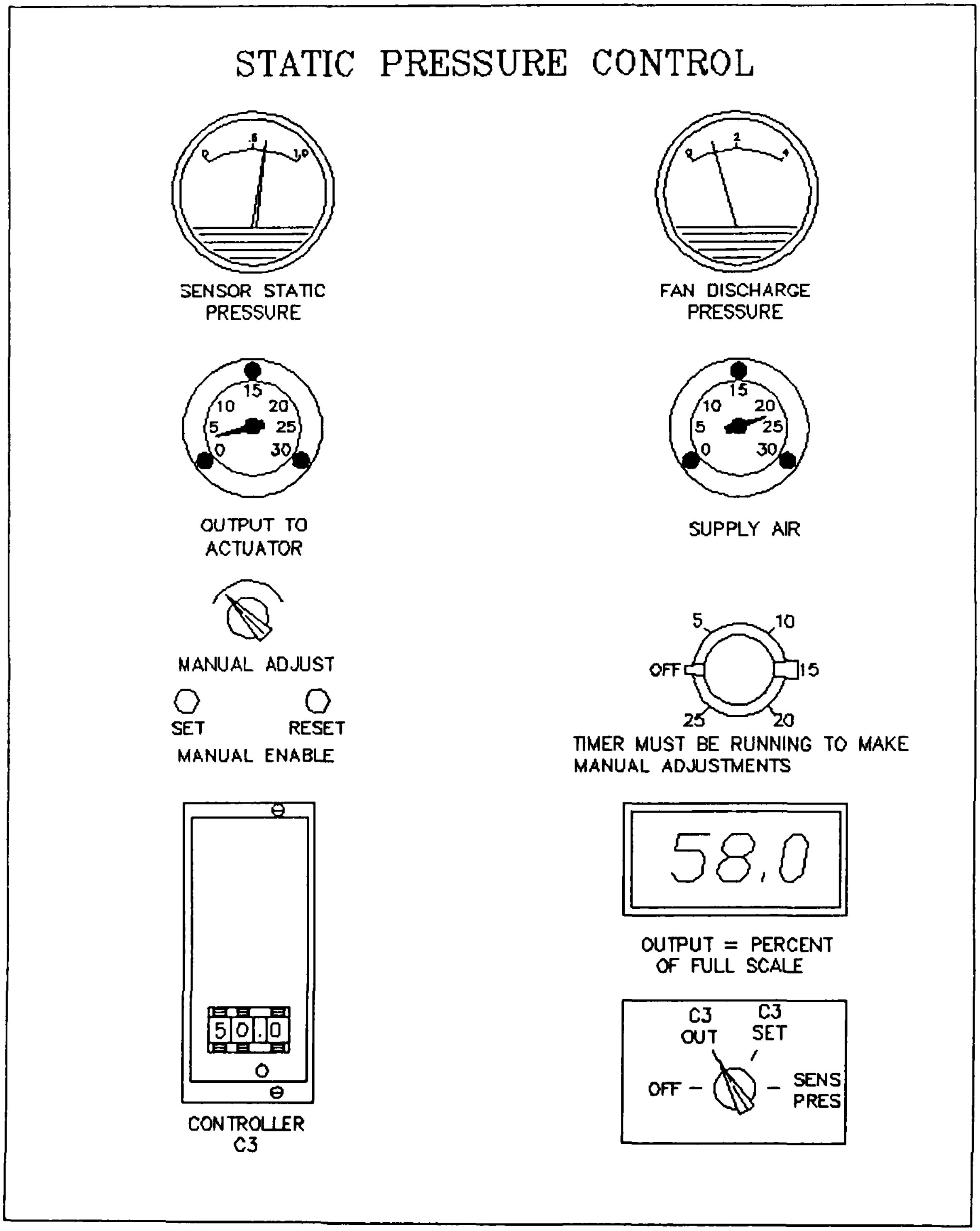


Figure 3. Static pressure control panel for IVD system.

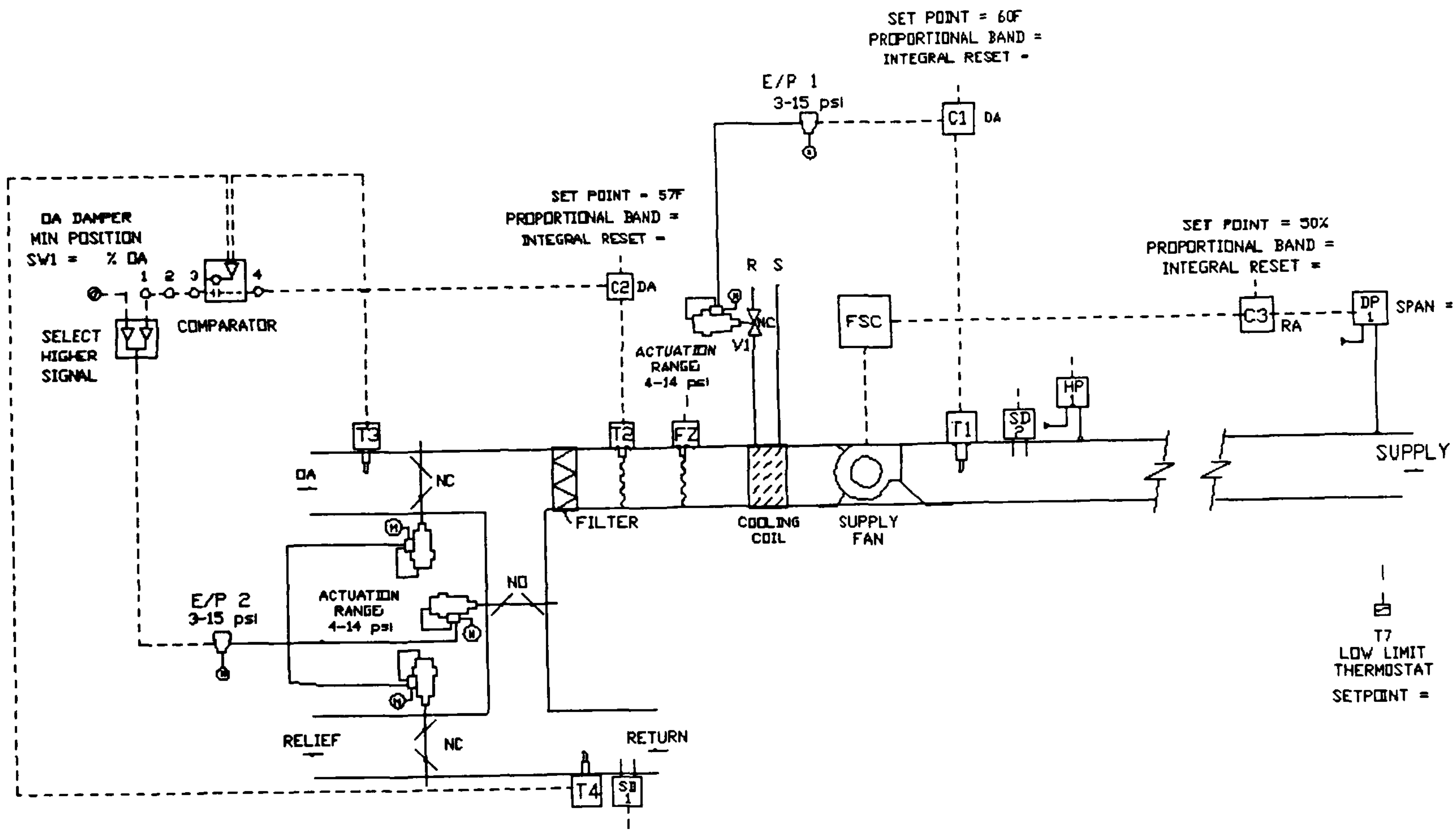


Figure 4. VAV inlet vane damper (IVD) control diagram.

compares the outside and return air temperatures and determines whether outside air could be used to reduce the cooling load. When the economizer determines that outside air use would be beneficial, it sends a signal to the damper controller, which then allows outside air, exhaust air, and return air dampers to modulate to maintain the mixed air setpoint temperature.

On the front panel of a typical VAV temperature control panel (Figure 5), the controllers, C1 and C2, have adjustment knobs for setting temperature setpoint, proportional gain, and integral reset time. All inputs and outputs to and from the controllers can be displayed on the front panel meter and gauges. The signal from the RTDs can be displayed on the front panel meter. To check the accuracy of the temperature-sensing bridge in the controllers and module, resistors corresponding to a specified temperature can be inserted into the circuit. The response of the controller or module can be checked by reading the electronic output on the front panel meter. The accuracy of the E/Ps can be determined by noting their value on the OUTPUT TO DAMPERS or OUTPUT TO VALVE gauge and comparing it to the value shown on the front panel meter. A damper minimum position set knob is available for adjustment of minimum outside air. The panel can be put in manual control for a limited time by turning the TIMER switch, pressing the SET button, and turning the MANUAL ADJUST knobs. This allows the technician to check the operation of the dampers, valve, and actuators. Position indication gauges tell the technician if the actuators are operating properly. The SUPPLY AIR gauge indicates whether supply air is present at the panel.

Hot Water Temperature Control Panel

The hot water temperature control panel controls the hot water supply temperature to a building for heating. A schematic of a typical hot water temperature control panel (Figure 6) shows that RTDs sense the outside air and hot water supply temperatures, which are the input to the outside air (OA) reset module (C2) and the hot water valve controller (C1). The hot water valve controller maintains the hot water supply temperature by adjusting the valve position. The electronic signal from the hot water controller is transduced into a pneumatic signal by an E/P, which then modulates the valve actuator. The panel is equipped with an outside air reset module, which resets the setpoint of the hot water temperature controller according to a reset schedule.

On a typical hot water temperature control panel (Figure 7), the hot water valve controller (C1) has adjustment knobs for setting the proportional gain and integral reset time. The outside air reset module has knobs for setting up the temperature reset range. All inputs and outputs to and from the controller and module can be displayed on the front panel meter and gauges. The signal from the RTDs can be displayed on the front panel meter. To check the accuracy of the temperature-sensing bridge in the controllers, resistors corresponding to specified temperatures can be inserted into the circuit. The response of the controller or module can be checked by reading the electronic output of the controller or module on the front panel meter. The accuracy of the E/P can be determined by noting its value on the OUTPUT TO VALVE gauge and comparing it to the C1 OUT value shown on the digital meter. The panel can be put in manual control for a limited time by turning the TIMER switch, pressing the SET button, and turning the MANUAL ADJUST knobs. This feature allows the technician to check the operation of the valve actuator. The accuracy of the RESET module can be checked by adjusting the OA ADJ knob and monitoring the setpoint of the hot water CONTROLLER. The SUPPLY AIR gauge indicates whether supply air is present at the panel.

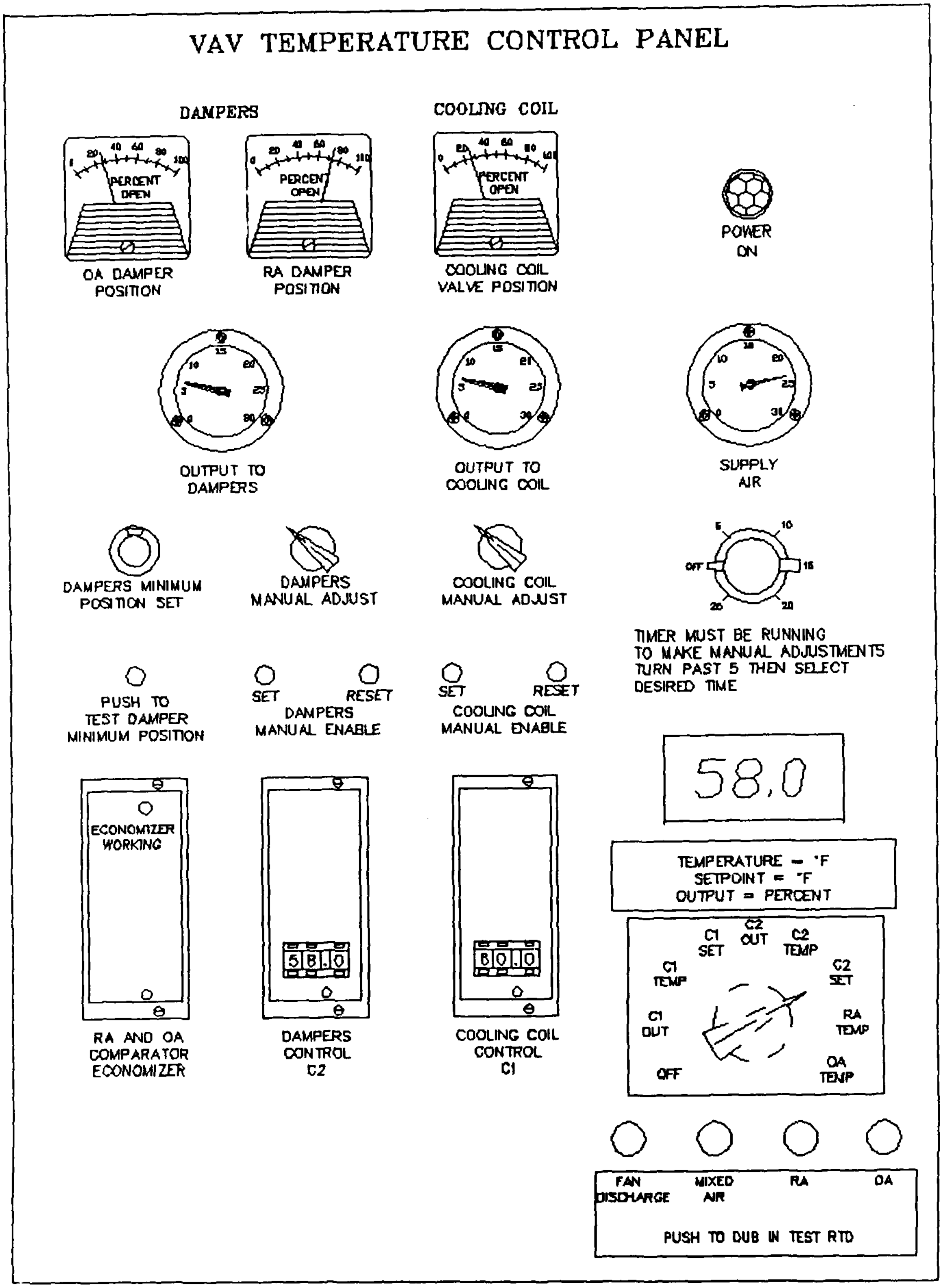


Figure 5. VAV temperature control panel.

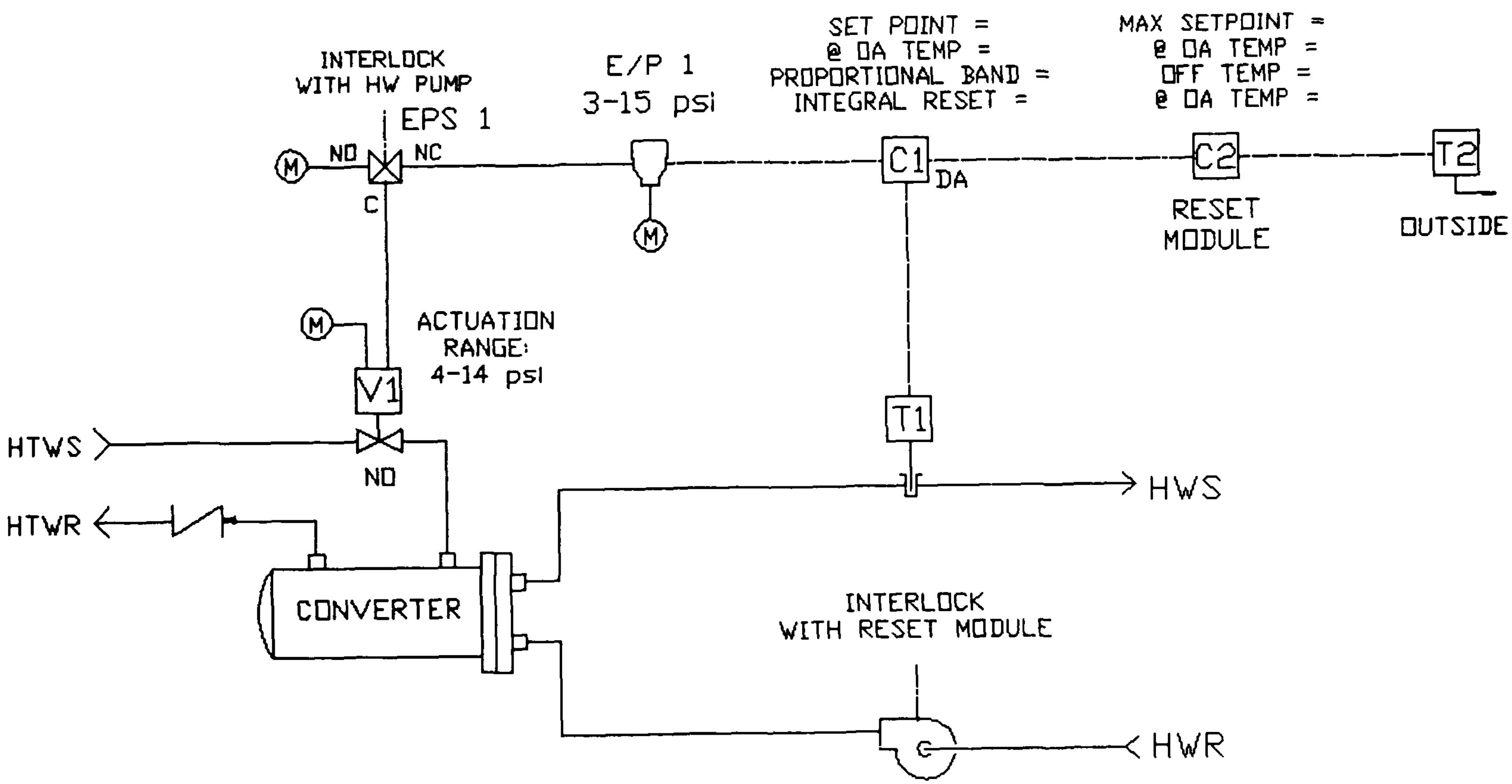


Figure 6. High temperature hot water convertor.

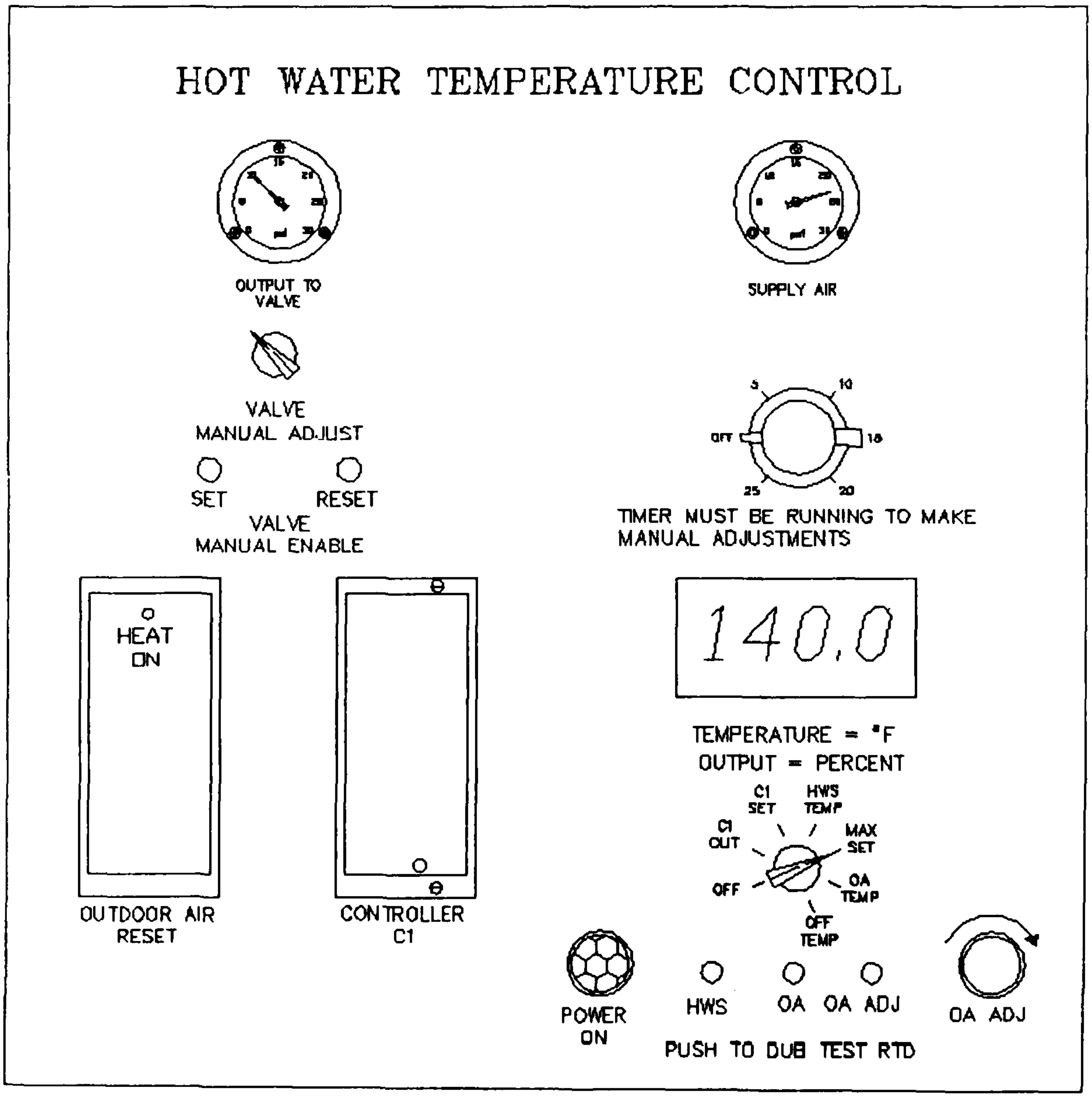


Figure 7. Hot water temperature control panel.

4 SELECTED DEMONSTRATION SITES AND PANEL INSTALLATION

Criteria

Several characteristics guided selection of sites where panels would be installed:

- commonly used Army facilities,
- large systems that are significant energy users, and
- multiple sites with various climates.

Based on these criteria, facilities at three installations were chosen for the demonstrations.

Fort Leonard Wood, MO

Two buildings were selected for retrofitting standard panels at Fort Leonard Wood, which has hot, humid summers and cold winters. The first was a rolling-pin barracks, a building of medium-size, approximately 41,000 sq ft*. The building has three floors and is used mainly for housing soldiers. Fan-coil units provide heating and cooling to the rooms. For the demonstration a single hot water temperature control panel was connected to the heat exchanger which supplies hot water to the fan coil units. According to Fort Leonard Wood personnel the existing controls for the heat exchanger were performing satisfactorily.

The other building studied was Brown Hall, a larger building, used for vertical skills training (i.e., plumbing, electricity, and carpentry). Brown Hall contains classrooms, shop rooms, and administrative offices. It has three floors totaling approximately 114,000 sq ft. The top two floors are classrooms and offices, and the first floor contains administration offices and all shop rooms. Two VAV systems with return fans provide cooling and ventilation for the administration offices and the second and third floors; cooling and ventilation is not provided to the shop rooms. Air handler No. 1 is a VAV system with a maximum design capacity of 16,600 cu ft/min. The setpoint of the static pressure is 2.5 in. of water column. This air handler unit services the third and first floors of the building. Air handler No. 2 is a VAV system with a maximum design capacity of 14,000 cu ft/min. The setpoint of the static pressure is 2.5 in. of water column. The unit services the second floor of the building. A heat exchanger provides hot water to unit heaters and convectors, which supply heating throughout the building. Both VAV air-handling units (AHUs) were retrofitted with VAV temperature control panels and static pressure control panels, and the heating system was retrofitted with a hot water temperature control panel. The existing control system was used to control the return air flow. The building's heating and VAV systems and their controls were in good working order, according to installation personnel; however, the VAV systems were not used for ventilation in winter because the occupants complained about cold drafts. (Figures 8 and 9 are instrumentation diagrams for the Brown Hall heating system and cooling system.)

The original HVAC control systems were pnuematic. The control logic was the same as that used by the retrofit panels; however, the pneumatic receiver controllers in the existing system were proportional-only controls (except for the return fan control, which was PI), the existing economizer was based on enthalpy control logic, and the control signal of the existing system was 9 to 15 lb per sq in. (psi).

*Metric conversion table is on page 48.

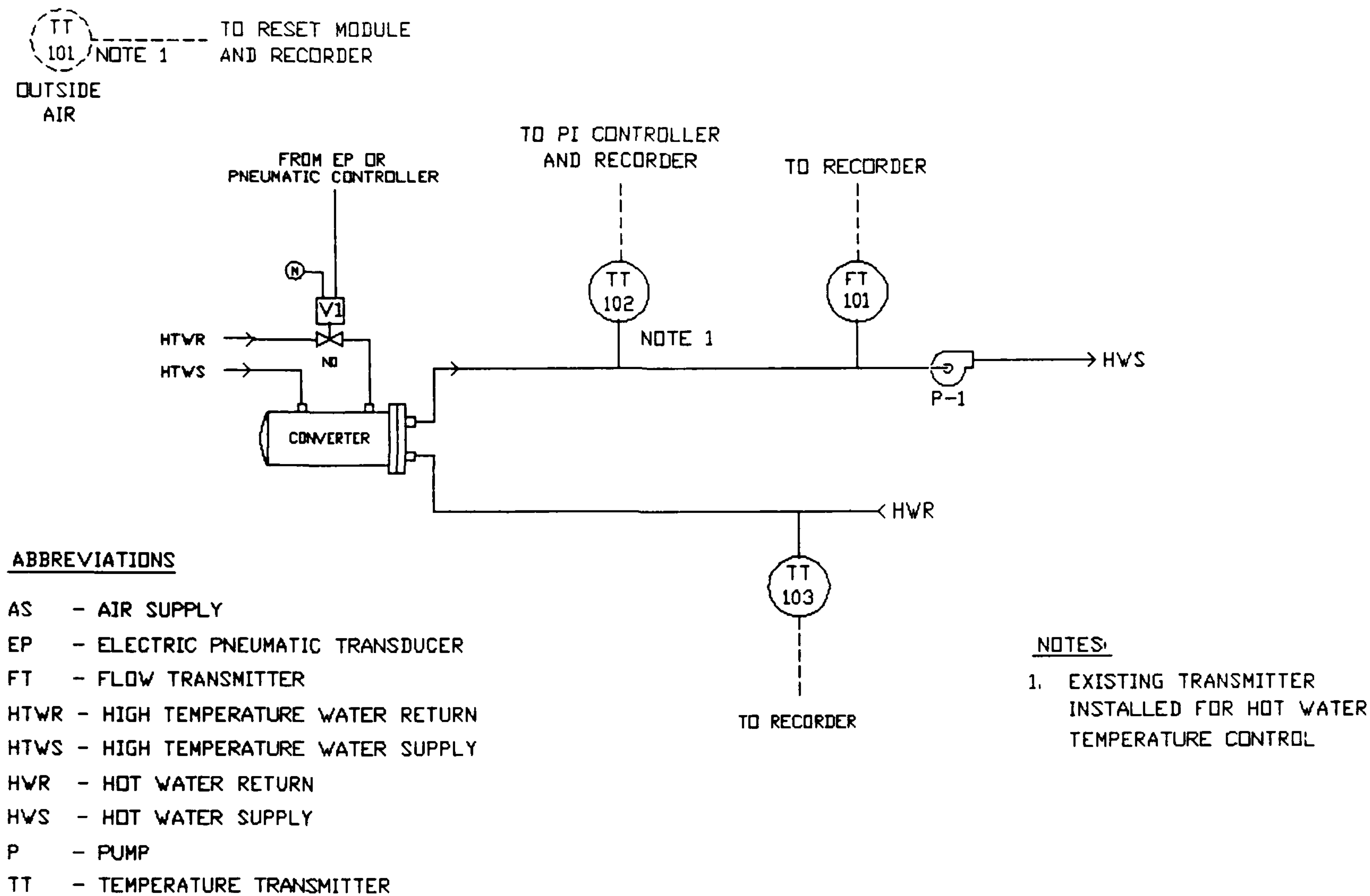
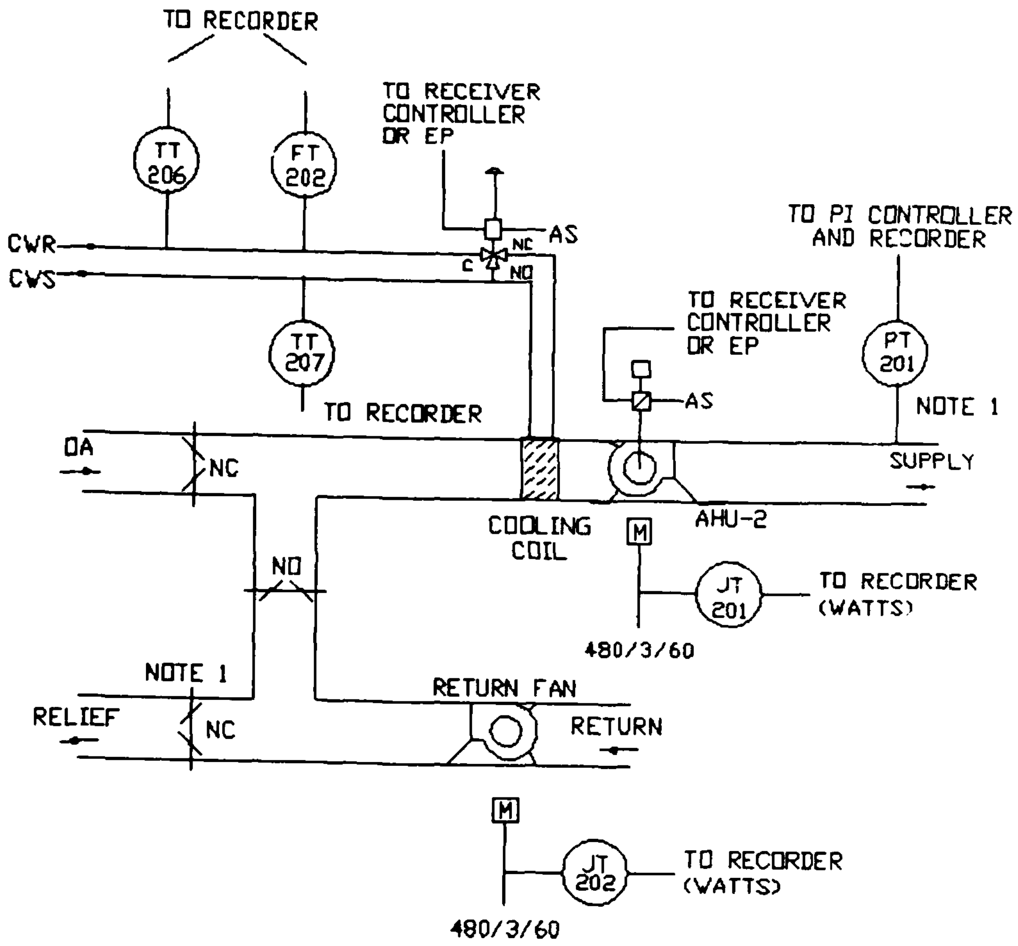


Figure 8. Instrumentation diagram for the Brown Hall heating system.



ABBREVIATIONS

AS - AIR SUPPLY
C - COMMON
CWR - CHILLED WATER RETURN
CWS - CHILLED WATER SUPPLY
EP - ELECTRIC PNEUMATIC TRANSDUCER
FT - FLOW TRANSMITTER
JT - POWER TRANSMITTER
NC - NORMALLY CLOSED
NO - NORMALLY OPEN
TT - TEMPERATURE TRANSMITTER

Figure 9. Instrumentation diagram for the Brown Hall cooling system.

Fort Sill, OK

Fort Sill has hot, dry summers and mild winters. Two large buildings, approximately 330,000 sq ft each, were selected for demonstration at Fort Sill. The buildings, referred to as starship barracks, house approximately 1000 soldiers and contain living quarters, dining halls, exercise rooms, laundry facilities, and administrative offices. The standard panels were installed on the AHUs which supplied heating and cooling to part of the dining halls and the interior zone of a sleeping bay. The system used hybrid multizone-VAV air handlers, and the standard panels were set up only to control the temperature of the cooling coil discharge air. The existing air handling control systems, which were pnuematic, proportional-only control, were used to control the remainder of the HVAC system. The HVAC system had had difficulty maintaining space temperatures in both winter and summer.

Fort Lewis, WA

Three buildings at Fort Lewis, which has a mild climate year round, were selected to have standard panels installed. The first was a flight simulator building, which contained classrooms, administration offices, simulator rooms, and a computer suite. Five VAV systems with return fans provided cooling, heating, and humidification. Static pressure control panels were installed on two AHUs, and existing pneumatic, proportional-only controls were used for the remaining HVAC system. The systems had experienced duct overpressurization problems, humidity control problems, temperature control problems, and return fan control problems.

The second building was a large warehouse building, which had been converted into office spaces. The building was served by two constant-flow single-zone systems, which provided both heating and cooling. Temperature control panels were installed to control the cooling coil discharge air temperature on each AHU. The existing control systems were pneumatic, and there were major problems maintaining space temperatures at comfortable levels.

The third building was the officer's club, served by a constant-flow single-zone system. A temperature control panel was installed to control the cooling coil discharge air temperature. The existing control system was pneumatic, and space temperature control had been a problem.

Development of Retrofit Packages for Each Site

During development of the retrofit packages for each facility selected, the facility's system design had to be matched with one of the standard system types used by USACERL. This often proved difficult. For example, the USACERL-recommended standard VAV system has no return air fan, and, hence, no standard schematic or standard panel was produced for the return fan control. Thus, when the retrofit package was developed for the Brown Hall VAV system, which has a return fan, the portion of the existing pneumatic control system operating the return fan had to be left in place. Another example was the hybrid multizone-VAV system in the barracks at Fort Sill. No standard design was available for this system, and the new panels could be used to control only a portion of the system.

Panel Installation and Commissioning

USACERL procured the required panels using the technical specification in Appendix A. Two vendors supplied the panels. In each case the panels were assembled by the manufacturer and shipped to USACERL. They were then transported to the demonstration site and installed at each location according to the technical specifications. The panels were mounted on unistrut rails near the existing controls. RTD sensors were installed in the appropriate places, and wires were run to the panels. One exception to a typical retrofit application was that the standard panels were installed with the outputs to the controlled devices connected in parallel with the existing pneumatic controller outputs to facilitate performance comparisons of the two control systems. To do this, pneumatic t's were installed so the signals from either existing or standard panel controllers could be sent to the controlled device. Each standard panel was commissioned according to the technical specifications instructions. An exception to typical commissioning was that pilot positioners were left at the original 9- to 15-psi range to accommodate existing controller output ranges.

Panel installation and commissioning were completed at Fort Sill and Fort Leonard Wood during FY86 and at Fort Lewis in FY88. Table 1 shows the complete list of facilities and panels installed during this project.

Table 1

Standard Panels Installed During Project

Fort Leonard Wood	
Bldg 5400 (Brown Hall)	2 VAV temperature control panels 2 static pressure control panels 1 hot water control panel
Bldg 1069 (barracks)	1 hot water control panel
Fort Sill	
Bldg 6007 (barracks)	3 VAV temperature control panels
Bldg 6050 (barracks)	3 VAV temperature control panels
Fort Lewis	
Flight simulator bldg	2 static pressure control panels
Electronics warehouse	2 VAV temperature control panels
Officer's Club	1 VAV temperature control panel

5 DATA ACQUISITION FOR ENERGY CONSUMPTION COMPARISON

Original Plans and Procedures

Limited time and resources were the main constraints in determining a data acquisition plan for estimating the energy savings of HVAC systems retrofitted with analog-electronic standard panels. This estimate was to be made by comparing the energy consumption of HVAC systems using existing pneumatic controls with that of systems using standard panels. Information concerning control performance and reliability would also be collected and analyzed. An architecture/engineering (A/E) firm was contracted to develop a test plan (Appendix B) for data acquisition and an instrumentation plan which could be used to collect the data required for the energy comparison. Although the plan was designed specifically for the Brown Hall HVAC systems, USACERL researchers used it to analyze the HVAC systems at the other demonstration sites.

According to the test plan for heating and cooling HVAC systems, data would be collected for 2 weeks during the heating season and 2 weeks during the cooling season, during which time the existing and standard control systems would alternate control of the HVAC system every 2 to 4 hours. Figures 8 and 9 are schematics of the HVAC systems at Brown Hall. The following data was to be collected.

Heating system:

- outside air temperature,
- hot water supply temperature,
- hot water return temperature,
- hot water flow rate,
- instantaneous heat exchanger output, and
- total heat exchanger output.

Cooling system:

- outside air temperature,
- chilled water supply temperature,
- chilled water return temperature,
- chilled water flow rate,
- total cooling coil output,
- supply fan power output,
- return fan power output, and
- supply air static pressure.

Data was to be collected under two scenarios, controlled conditions and field conditions. Controlled-condition tests held constant specific parameters, such as lighting loads and occupancy, during data acquisition so they would not affect energy consumption during changing outdoor conditions. The field condition tests imposed no restrictions on any parameters.

Information gathered during the controlled-condition tests would then be used to extrapolate the data from the field condition tests over a year to estimate annual energy consumption for the HVAC system under each control system. This plan required data collection under a wide range of outside air temperatures (OATs). The data would be organized into energy use versus outside air temperature profiles (Figure 10). Once the profiles were developed for the 2-week-period data, historical weather data for the demonstration site could then be used to extrapolate energy use for a year.

Both control systems were not to be calibrated immediately before the tests began so field performance of the systems could be measured.

Instrumentation

The data points noted earlier, such as OAT and hot water supply temperature (HWST), were recorded using a data logger and downloaded for storage to floppy disks using a portable computer. British thermal unit (Btu) meters were used to read the water flow rates and water temperatures, to calculate total Btu usage instantaneously, and to send the values to the data logger. Vortex shedding flowmeters were used to measure water flowrates. Water temperatures were measured by thermistors. Air temperature and static pressure values were recorded from the EMCS terminal of the standard panel. Watt-hour meters recorded the power use of the fan motors. The data acquisition equipment used in the test is more fully described in *System Description* (Appendix B).

Data Acquisition at Fort Sill

Because the demonstration at Fort Sill involved only cooling comparisons, only the cooling data portion of the test plan was used. An initial attempt to collect cooling season data was made during June 1987. However, an essential flowmeter was not operating properly, and data was not obtained. Computer problems during July 1987 prevented data transfer from the data logger to floppy disks.

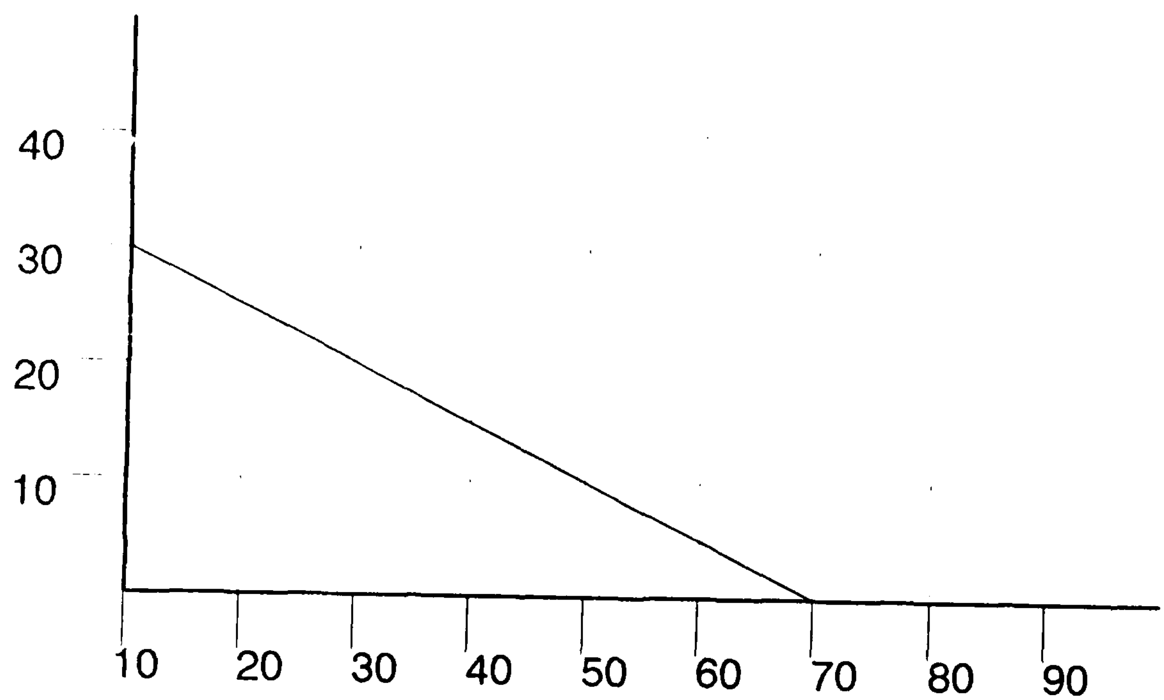


Figure 10. Energy usage versus OAT profile.

Data was finally gathered at Fort Sill in mid-September 1987 on two of the AHUs in one of the barracks. The instrumentation specified in the test plan was used; however, watt transducers, instead of the watt-hour meters, were used to record power use of the fan motors. The watt transducers were used because the lead time to get the watt-hour meters would have prevented testing during 1987.

A survey of the collected data and observation of the Fort Sill HVAC system indicated that the cooling coil valve remained wide open most of the time. Further investigation determined that the cooling coil discharge air temperature (DAT) setpoint was almost never reached. The cooling coil capacity was not sufficient to cool the mixed air to the DAT setpoint when the outside air temperature was above 85°F. Because of the HVAC system problems, no meaningful data could be collected to compare performance of the control systems, and data acquisition was discontinued.

Data Acquisition at Fort Leonard Wood

General

Data was collected both on VAV cooling systems and on the heating system in Brown Hall. Data was to be collected on the heating system in the barracks, but problems developed with the data logger, and data acquisition was discontinued. Data was gathered every minute, instead of every 15 minutes as proposed in the test plan, to determine the stability of the controllers.

Brown Hall Heating System Data Acquisition

Problems obtaining data acquisition equipment delayed data collection for the heating system in Brown Hall until March 1987. Data to test heating system controls at full load was to be collected for 2 weeks, according to the test plan. But because outdoor ambient temperatures were so mild, the heating system rarely reached full load and data was collected for only 1 week. A summary of the data acquisition on the heating systems is included here.

Controlled test No. 1, which occurred when the lights and the AHUs were off and the building was unoccupied, was performed according to plan, except that the outside air temperature ranged from 50 to 70 °F instead of the desired 0 to 30 °F range, and the control systems were switched every 4 hours instead of every 2 hours to facilitate data collection. In addition, beginning data acquisition times were delayed while data from the previous interval was downloaded from the data logger onto floppy disks.

Controlled test No. 2, which had the ventilation and lights turned on and the building unoccupied, was not performed because of time constraints due to researchers' prior commitments.

Field condition tests, where no constraints were put on the building conditions, were performed as stated in the test plan (Appendix B).

Btu meters were not available at this time, so the energy use of the heating system was calculated afterwards, using the return and supply water temperatures and the water flowrate values. Figure 11 shows a typical data set recorded for the heating system. In addition, windspeed, precipitation, open windows and doors, building occupancy, and condition of lights were also noted. The occupancy of the building was determined from class attendance charts.

Brown Hall VAV Cooling Systems Tests

The first attempt at data collection for the VAV cooling systems was during August 1987. No useful data was collected because of data logger problems. The problems were solved and data was collected for 1 week during September 1987. However, further problems with the data acquisition equipment and questions about the usefulness of the data being collected convinced USACERL to discontinue further data gathering. None of the test plan's controlled tests for the VAV systems were performed. However, field condition tests, having no building condition constraints, for the VAV cooling systems were performed as stated in the test plan.

Figure 12 is a typical data set recorded for the VAV cooling system. In addition, windspeed, precipitation, open windows and doors, building occupancy, and condition of lights were also noted. The occupancy of the building was determined from class attendance charts.

The instrumentation specified in the test plan was used; however, watt transducers, instead of the watt-hour meters, were used to record the power use of the fan motors. The watt transducers were used because the lead time to get the watt-hour meters would have prevented the testing during 1987.

Several problems occurred during data acquisition or became obvious after an overview of the data. Btu meters were installed during the August visit, but problems with their use were discovered during the September visit. According to the test plan, calibration of the Btu meters was to be verified by the A/E lab. However, the Btu meters arrived late, and the calibration check was skipped so data acquisition could be accomplished on time. In addition, the original Btu meter design was to accept pulsed signals from the flowmeters, but the flowmeters at Fort Leonard Wood had analog current outputs. The Btu meters were modified by the manufacturer to accept current inputs, but in the field, problems developed matching Btu meter input range to flowmeter output range. Efforts to alleviate the problem were unsuccessful; thus, erroneous Btu output values were calculated. Efforts to correct the problem were discontinued because of time constraints. Btus were calculated from the temperature difference of the water and flowrate values, which were recorded separately.

The data logger had several malfunctioning data input ports, which caused some delays, and occasionally malfunctioned, causing some data to be lost. Reasons for these malfunctions were never determined.

Time required for downloading information was not included in the scheduling plan. Downloading data required 45 to 60 minutes, and thus did not allow the schedule to be maintained.

The flowmeter was set up to measure total flow of the system, not flow through the coil (Figure 9). This was acceptable since the temperature difference of the total water flow was also recorded. The reason for measuring energy use in this way was because short pipe lengths did not allow the flowmeter to be placed in the pipe that supplied water to only the coil. The temperature difference experienced by the total water flow was minimal, 0 to 2 °F, and the accuracy of the temperature difference sensing loop of the Btu meter was 0.5 °F. Since this temperature difference value was used to calculate the Btus, accuracy of the Btu comparisons was not high.

The return fan speed of both AHUs was always controlled by the pneumatic system. The pneumatic controllers did not have good control of the return fan and caused inaccurate air flows, which affected the performance of the standard panel's control of the supply fan. During the investigation it was determined that the air side of the HVAC systems was not balanced. The outside air temperature was being recorded using the OAT sensor in the outside air duct. Data analysis determined that the OAT sensor was tracking the return air temperature (RAT). It was later determined that the return fan was forcing air out the OA duct.

HOUR	MIN	OA TEMP	SW TEMP	RW TEMP	GPM
12	50	62.58	108.094	106	184.2
12	51	62.369	106.914	106	183.7
12	52	62.568	114.464	105.8	182.6
12	53	62.626	106.984	105.6	183.9
12	54	62.291	106.873	105.5	184.6
12	55	61.945	108.088	105.4	184.8
12	56	61.863	112.027	106.1	182.5
12	57	61.957	108.801	106.9	183.3
12	58	62.109	108.263	107.4	184.4
12	59	62.035	108.444	107.8	183.3
13	0	62.085	107.936	107.4	183.4
13	1	61.965	109.18	107.6	183.4
13	2	61.851	110.016	107.5	183.1
13	3	61.735	108.509	107.2	182.7
13	4	61.672	110.209	107.5	184
13	5	61.731	108.865	108	185.4
13	6	61.571	109.116	108.4	183.5
13	7	61.778	114.673	108.1	184.3
13	8	61.77	108.789	107.6	183.1
13	9	61.965	108.596	107.2	183.5
13	10	62.198	109.916	107.4	183.3
13	11	62.015	109.175	108.3	183.9
13	12	62.28	109.309	108.7	183
13	13	62.459	109.736	109.2	183.9
13	14	62.307	109.385	108.9	183
13	15	62.436	108.906	108.5	183
13	16	62.377	109.385	109.1	182.5
13	17	62.152	109.496	109.1	182.7
13	18	62.144	109.163	108.8	184.2
13	19	61.957	109.455	109.2	184
13	20	61.789	111.167	108.9	182.7
13	21	61.886	110.776	108.4	182.6
13	22	61.805	109.233	108.3	183.4
13	23	61.735	113.978	108.3	182.8
13	24	61.851	109.315	108.1	184.2
13	25	61.878	116.989	108	182.6

Figure 11. Example of heating system data.

HOUR	MIN	OA TEMP	RA TEMP	MA TEMP	SA TEMP	DELTA T	GPM	C1 OUT%	SP OUT%	SP SENS	SF WATT	RF WATT	KBTUPHC
15	50	86.822	76.589	74.562	54.751	2.1	136.125	33.128	55.454	2.052	5.224	1.264	186.6
15	51	86.857	76.658	74.643	54.768	2.1	136.416	33.122	61.221	2.22	5.181	1.27	116
15	52	86.868	76.542	74.631	54.896	2.1	136.27	33.128	59.688	2.659	5.538	1.25	115.4
15	53	86.81	76.281	74.474	54.681	2.1	137.722	33.128	53.09	2.764	5.507	1.2	165.1
15	54	86.799	76.188	74.382	54.896	2.1	136.27	33.122	47.781	2.55	5.259	1.241	136.8
15	55	86.834	76.35	74.44	54.861	2.1	136.27	33.128	50.598	2.17	5.562	1.255	167.5
15	56	86.81	76.681	74.596	54.768	2.1	136.27	33.122	57.051	2.136	5.459	1.243	114.9
15	57	86.787	76.751	74.695	54 78	2.1	136.27	33.128	59.676	2.316	4.954	1.234	115.6
15	58	86.77	76.432	74.62	54.751	2.1	137.577	33.128	49.373	2.963	5.266	1.25	114.9
15	59	86.746	76.031	74.341	54.768	1.7	134.819	33.128	34.975	2.925	5.355	1.25	138.2
16	0	86.717	76.048	74.219	54.89	1.7	134.964	33.128	25.206	2.709	5.328	1.301	138
16	1	86.787	76.542	74.405	54.832	2.1	136.27	33.128	30.602	2.064	5.704	1.248	136.1
16	2	86.818	76.94	74.657	54.878	2.1	137.677	33.124	40.424	2.009	4.987	1.217	116.1
16	3	86.805	76.967	74.784	54.748	2.1	136.248	33.12	46.182	2.291	5.172	1.208	116
16	4	86.789	76.324	74.594	54.64	2.1	134.774	33.124	40.331	2.847	5.349	1.267	117.1
16	5	86.602	75.916	74.249	54.852	1.7	134.941	33.126	33.486	2.744	5.12	1.267	137.4
16	6	86.456	75.944	74.138	54.792	2 1	137.577	33.128	29.98	2.512	5.46	1.2	136.1
16	7	86.521	76.241	74.278	54.707	1.7	136.393	33.126	34.601	2.066	5.574	1.235	136.2
16	8	86.526	76.705	74.509	54.966	2.1	134.819	33.128	45.377	1.902	5.159	1.224	115.4
16	9	86.487	76.858	74.663	54.733	2.1	137.823	33.124	54.866	2.033	5.392	1.176	114.1
16	10	86.585	76.683	74.673	54.777	2.1	136.248	33.126	53.435	2.705	5.435	1.31	116.6
16	11	86.619	76.108	74.395	54.754	2.1	134.796	33.126	45.99	2.829	5.047	1.245	167.1
16	12	86.631	75.91	74.186	54.754	1.7	136.103	33.126	40.839	2.454	5.415	1.189	136.7
16	13	86.7	76.194	74.26	54.821	2.1	134.964	33.128	42.107	2.28	5.403	1.218	115.6
16	14	86.677	76.432	74.393	54.914	2.2	134.964	33.128	47.77	2.142	5.032	1.211	115.4
16	15	86.583	76.471	74.467	54.795	2.1	136.451	33.124	49.271	2.558	5.418	1.28	115.6
16	16	86.515	76.27	74.424	54.707	2.1	136.248	33.126	40.699	2.904	5.543	1.312	116.4
16	17	86.491	76.008	74.254	54.809	1.7	134.964	33.122	27.291	2.963	5.261	1.231	136.3
16	18	86.491	75.996	74.155	54.821	2.1	136.27	33.128	21.199	2.647	5.44	1.224	135.9
16	19	86.525	76.25	74.305	54.893	1.7	136.306	33.13	29.587	1.901	5.234	1.285	116.2
16	20	86.556	76.671	74.546	54.846	2.2	136.393	33.126	43.853	1.837	4.961	1.266	114.8
16	21	86.561	76.803	74.678	54.739	2.1	136.27	33.122	53.409	2.077	5.482	1.259	116
16	22	86.579	76.416	74.615	54.759	2.2	134.941	33.126	53.877	2.541	5.38	1.164	114.7
16	23	86.631	76.061	74.366	54.806	2.2	135.087	33.126	49.904	2.614	5.361	1.282	116.7
16	24	86.694	75.967	74.201	54.797	1.7	136.416	33.128	51.58	2.226	5.553	1.294	136.8
16	25	86.736	76.253	74.325	54.846	2.1	134.941	33.126	62.547	1.817	4.997	1.248	114.3
16	26	86.694	76.606	74.509	54.855	2.1	136.27	33.128	74.364	1.902	5.096	1.196	114.3
16	27	86.689	76.689	74.609	54.748	2.1	136.393	33.126	80.04	2.358	5.467	1.257	116.2
16	28	86.683	76.205	74.48	54.67	1.7	136.27	33.128	71.222	2.759	5.217	1.278	115.4
16	29	86.595	75.863	74.184	54.826	1.7	134.819	33.128	59.252	2.866	5.517	1.234	136.6
16	30	86.566	75.892	74.08	54.873	2.2	136.416	33.122	48.205	2.745	5.518	1.238	136.2

Figure 12. Example of VAV cooling system data.

The standard panels used 3- to 15-psi-output signals, whereas the pneumatic actuators were originally calibrated for psi ranges of 9 to 13, 8 to 13, and 10 to 14. Fort Leonard Wood management did not want USACERL to change the spring ranges of the actuators, which thus caused some control stability problems for the standard panel.

The economizer card of the standard control panel for AHU No. 1 was not functioning and thus did not allow operation of the economizer to be checked. In addition, both pneumatic systems' enthalpy economizer controls had been disconnected because of maintenance problems; thus no direct comparison between the two control strategies could be performed.

Data Acquisition at Fort Lewis

Coordination problems delayed completion of the installation and commissioning of the standard panels at Fort Lewis until August 1988. Data was not collected at these sites because the cost would have been high, and lessons learned from data collection at Fort Sill and Fort Leonard Wood indicated the data would be of limited value.

6 DATA ANALYSIS

Brown Hall HVAC systems data was the only data analyzed because HVAC equipment problems, computer problems, and equipment installation delays prevented acquisition of usable data at the other sites. The data collected for the VAV cooling systems in Brown Hall was analyzed by the A/E firm. The heating system data was analyzed by USACERL personnel.

VAV Cooling System Energy Comparison Results

An analysis of fan power use by AHU No. 1 showed a slight increase (1.7 percent) in energy use when the fan was controlled by the standard panel, but the accuracy of the data was ± 17 percent. An analysis of fan power use by AHU No. 2 showed a slight increase (0.5 percent) in energy use when the fan was controlled by the standard panel, but the accuracy of the data was ± 19 percent. These values were insufficient to allow a determination of fan energy according to AHU control system.

An analysis of the chilled water energy use showed some differences in energy use, but it was inconclusive since the discharge air temperature setpoints of the two control systems were different. AHU No. 1 used 10 percent less energy when controlled by the standard panel, but the DAT setpoint was 2 °F lower than for the pneumatic system, and the accuracy of the data was ± 23 percent. AHU No. 2 used 29 percent less energy when controlled by the pneumatic system, but the DAT setpoint was 4 °F higher than for the standard panel, and the accuracy of the data was ± 24 percent.

Cooling System Discharge Air Temperature Control Loop Performance

Figures 13, 14, and 15 are discharge air temperature (DAT) histograms for the AHUs. The histograms show that the standard control system maintained the DAT for AHU No. 1 between 53 and 57 °F, with the majority of the readings being 54 and 55 °F. The setpoint of the controller was 55 °F. The pneumatic control system maintained the DAT for AHU No. 1 between 53 and 58 °F, with the majority of readings being 53, 54, and 55 °F. The setpoint of the controller was 53 °F. For AHU No. 2, the histograms show that the standard control system maintained the DAT between 54 and 58 °F, with the majority of readings being 54 °F. The setpoint of the controller was 55 °F. The pneumatic control system maintained the DAT between 58 and 60 °F, with almost all of the readings being 58 or 59 °F. The setpoint for the controller was 59 °F.

Figures 16, 17, 18, and 19 show air temperature variations for AHU No. 1 controlled by the pneumatic and standard control systems. The graphs show that when the mixed air temperature (MAT) was above 76 °F, each control system was able to maintain the DAT, but when the MAT dropped below 76 °F a cycling of the DAT began. The cause of this cycling was not determined, but obviously the control systems were unable to control the DAT correctly when the load was low. The cycling may have been eliminated if larger actuator ranges had been used, especially for the standard control system, since it usually operates on a 3- to 15-psi range instead of the range of 9 to 15 used.

Figures 20, 21, 22, and 23 show air temperature variations for AHU No. 2, controlled by the pneumatic and standard control systems. The graphs again show cycling of the DAT, but this time the cycling point appears to start at 74 °F. In addition, when the MAT was above 74 °F, the standard control system was able to maintain the setpoint at a constant 54 °F, while the pneumatic control system rapidly varied the DAT between 62 and 58 °F.

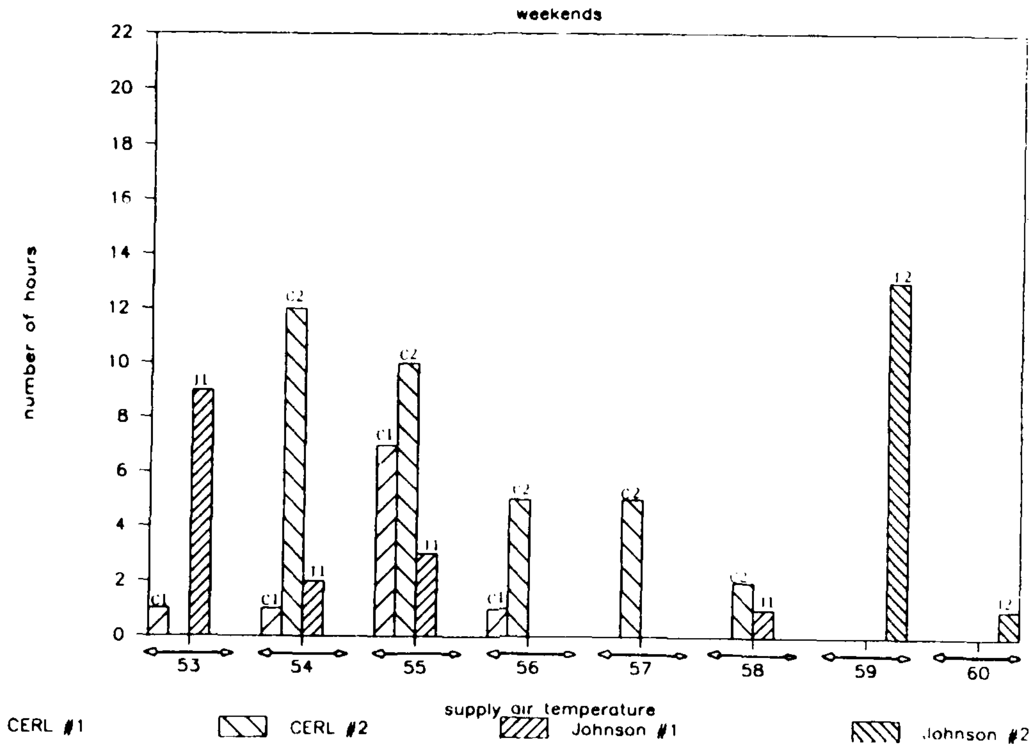


Figure 13. Supply air temperature histogram--weekends.

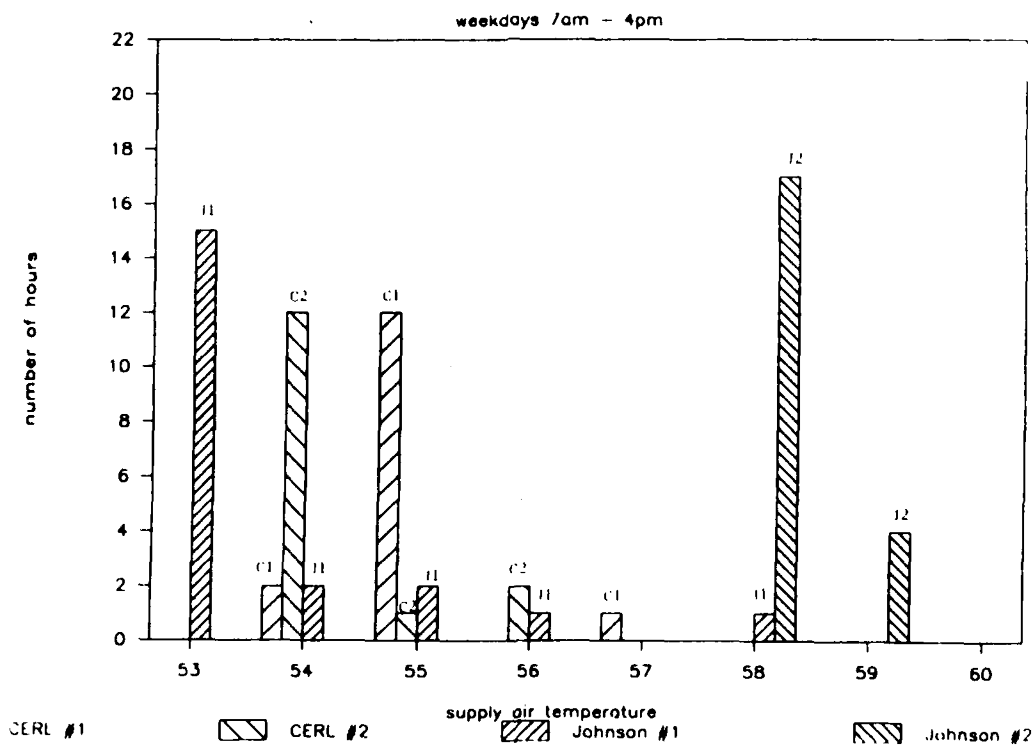


Figure 14. Supply air temperature histogram--weekdays.

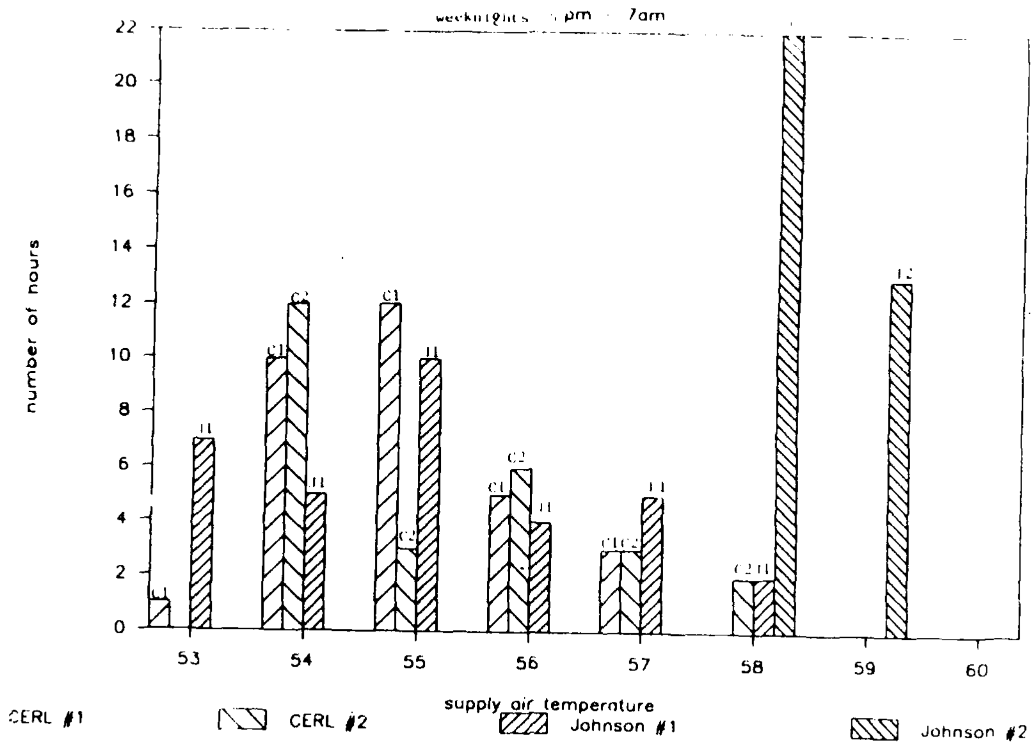


Figure 15. Supply air temperature histogram--weeknights.

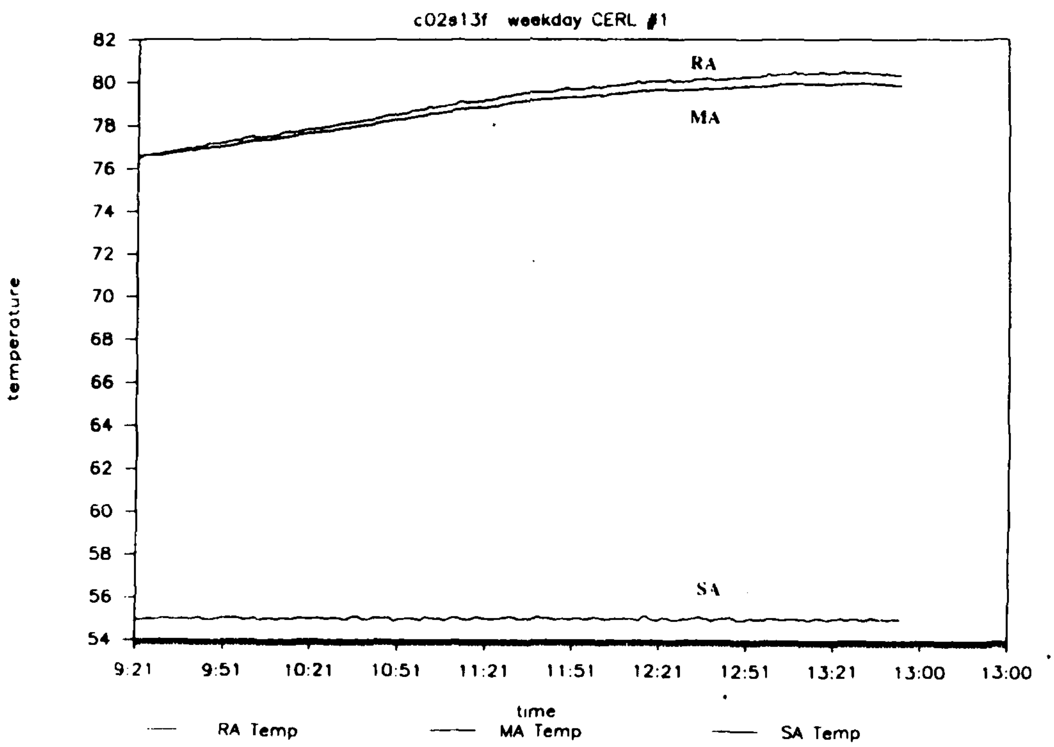


Figure 16. Air temperature profile of VAV AHU No. 1 under standard panel control (1).

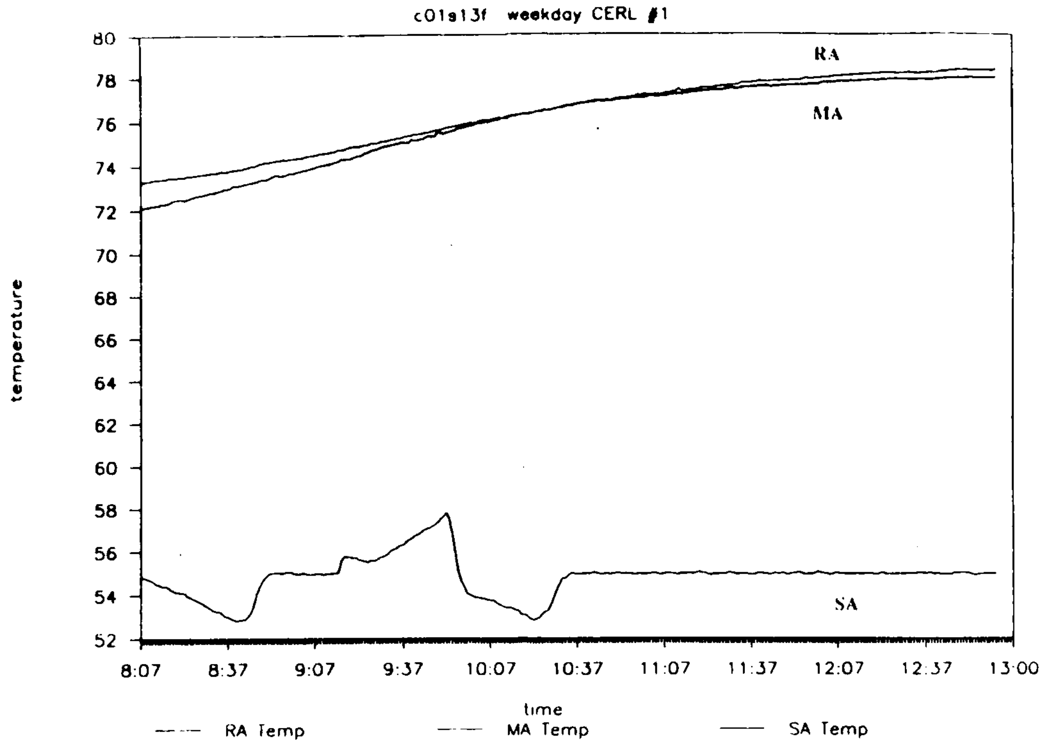


Figure 17. Air temperature profile of VAV AHU No. 1 under standard panel control (2).

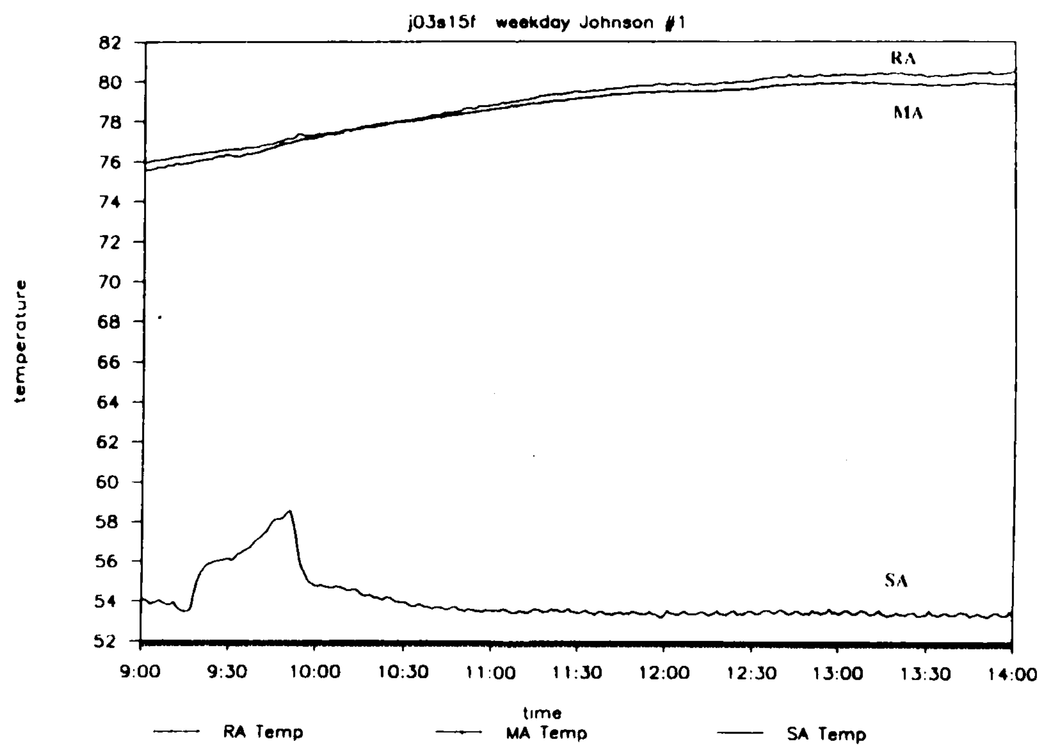


Figure 18. Air temperature profile of VAV AHU No. 1 under pneumatic panel control (2).

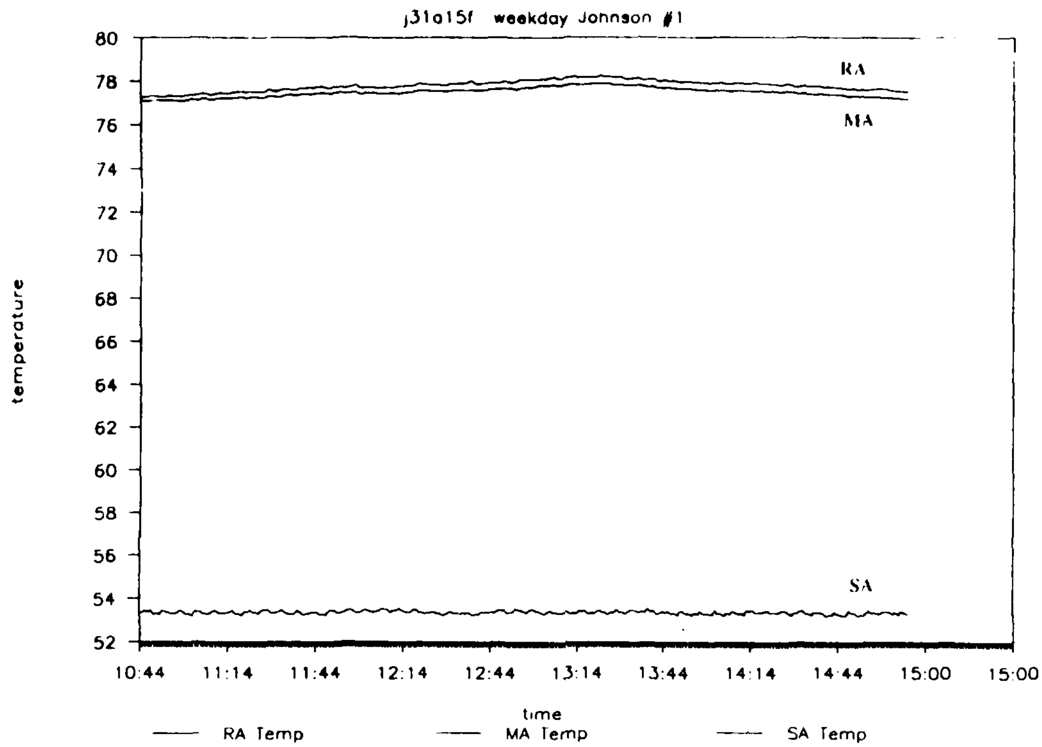


Figure 19. Air temperature profile of VAV AHU No. 1 under pneumatic panel control (2).

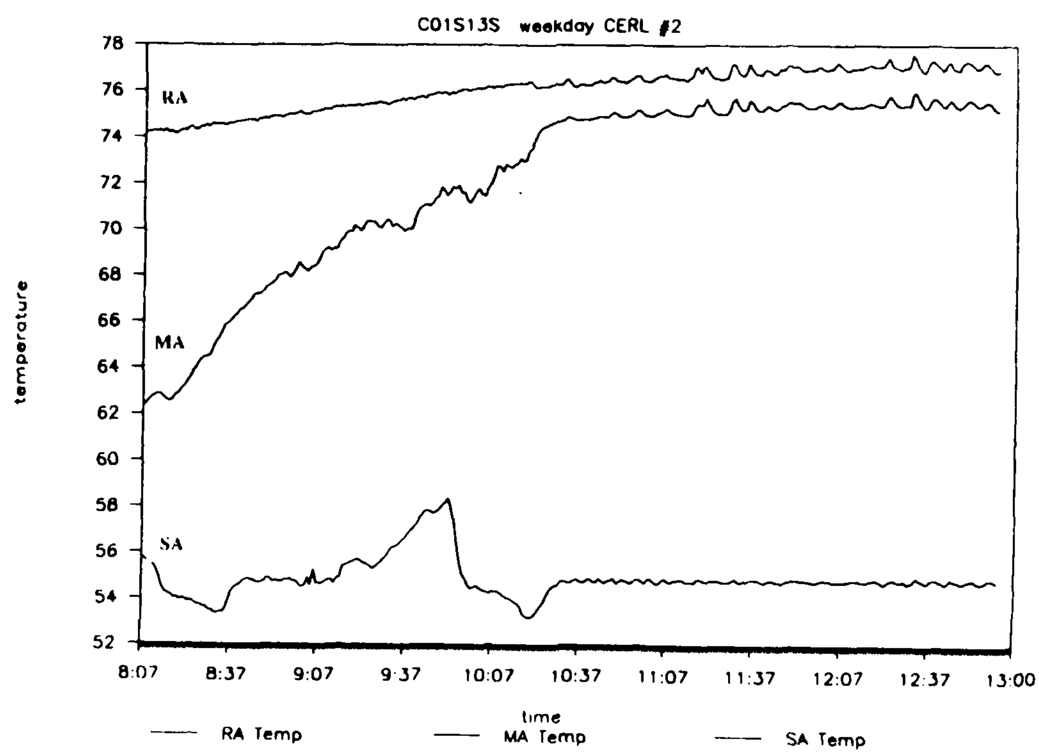


Figure 20. Air temperature profile of VAV AHU No. 2 under standard panel control (1).

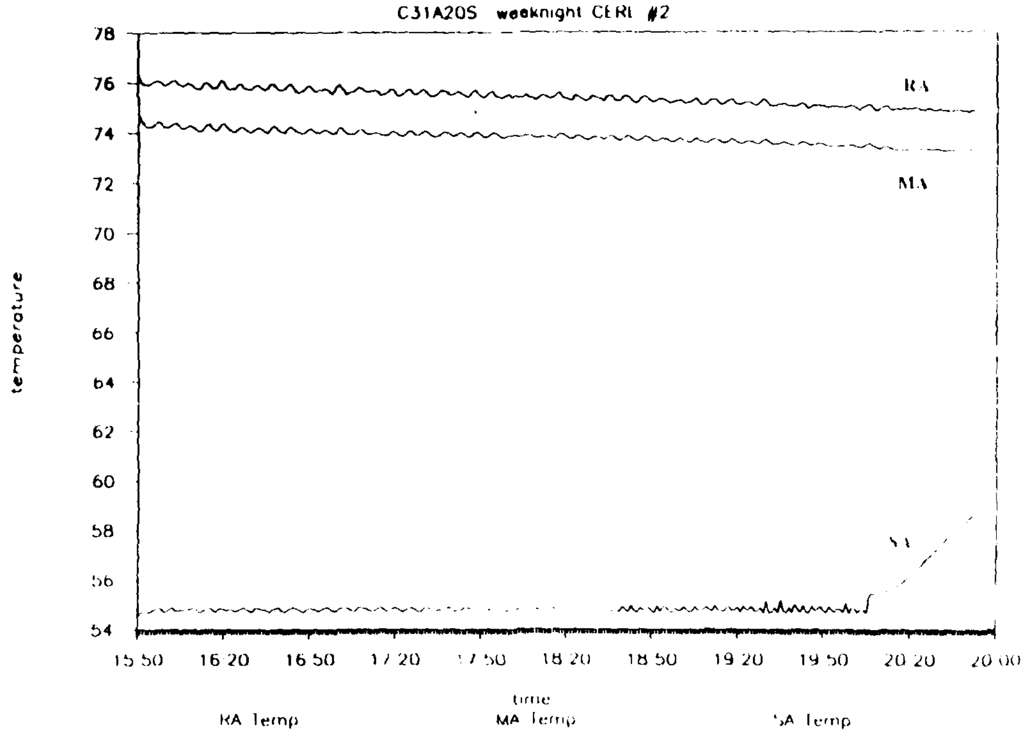


Figure 21. Air temperature profile of VAV AHU No. 2 under standard panel control (2).

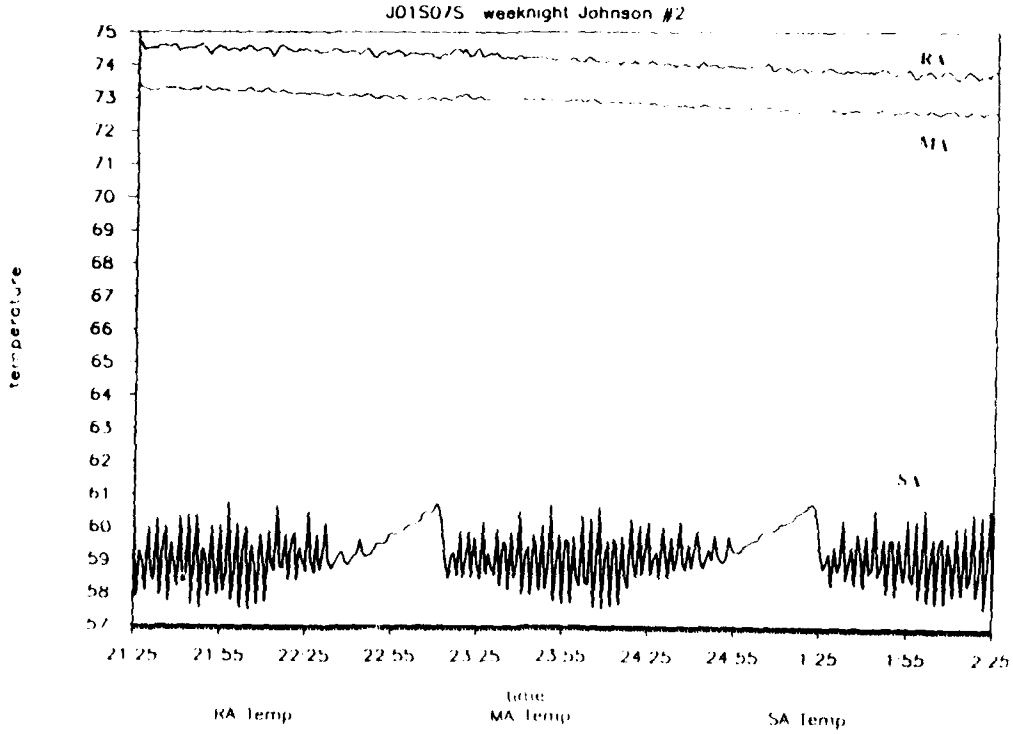


Figure 22. Air temperature profile of VAV AHU No. 2 under pneumatic panel control (1).

The data shows that for AHU No. 1 both control systems were able to maintain the DAT setpoint when the MAT was above 76 °F. For AHU No. 2 the standard control system did a better job of maintaining the DAT setpoint than did the pneumatic system when the MAT was above 74 °F.

Temperature Comparison Versus Enthalpy Economizer Control

Limited data and nonfunctioning enthalpy economizers prevented comparisons of this function. Figure 24, however, shows that the standard control system's temperature economizer was functioning on AHU No. 2.

Control of the Mixed Air Temperature

The low air temperatures (below 55 °F) required to evaluate this control loop were not experienced during the time data was recorded.

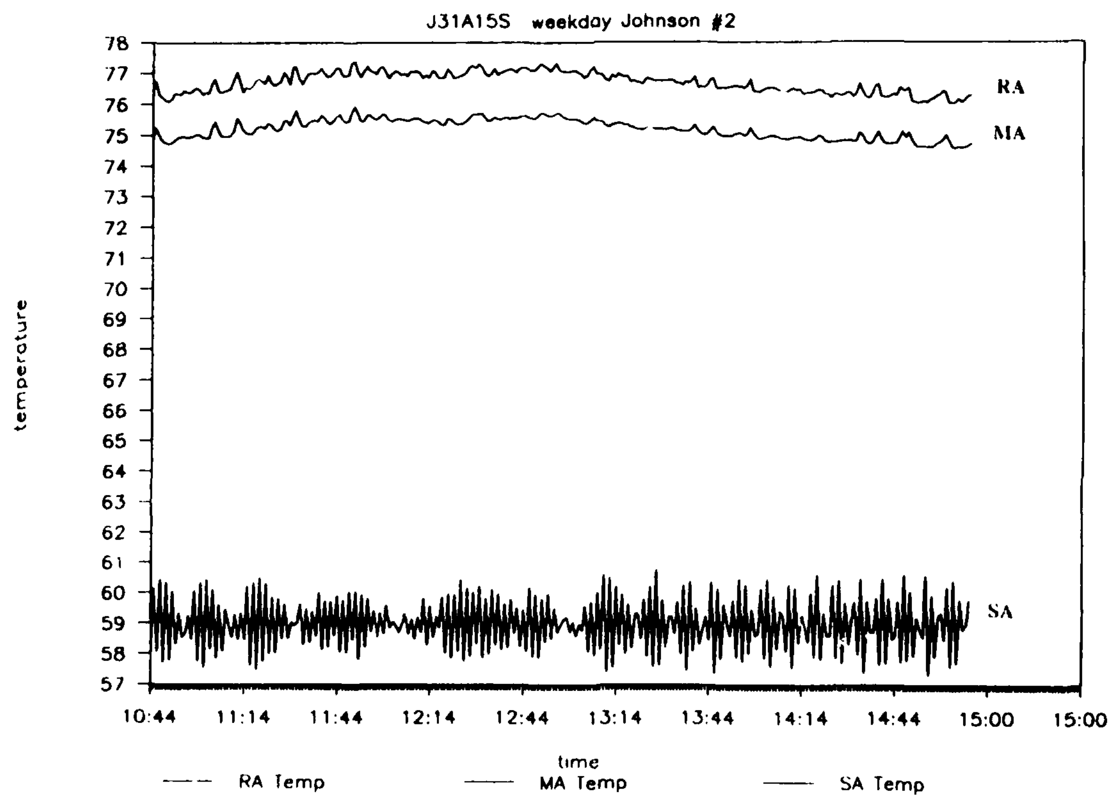


Figure 23. Air temperature profile of VAV AHU No. 2 under pneumatic panel control (2).

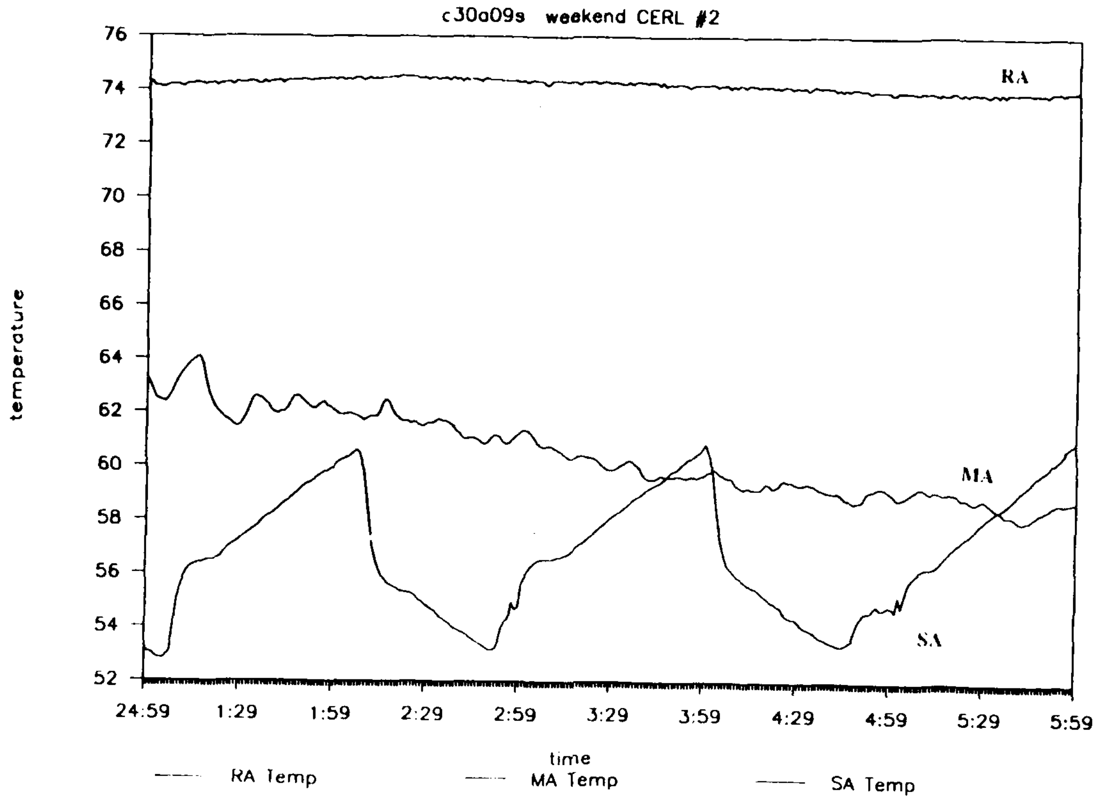


Figure 24. Air temperature profile of VAV AHU No. 2 under standad panel control (3).

The minute-by-minute data gathered for the pneumatic control system showed a large variation in Btu/hr use for specific outdoor air temperatures (Figures 25 and 26). The data for the standard control system showed similar variations (Figure 27). This could be expected because the values were instantaneous readings, and small variations in minute-to-minute temperatures and flowrates would result in large hourly differences. The minute-by-minute Btu/hr data for each control system was averaged for each outside-air temperature bin range to produce energy use profiles for the heating system. Figure 28 graphs the energy use profile, Btu/hr versus OAT, for the Brown Hall heating system. The points are an average of all Btu/hr readings taken during the night/unoccupied period for each control system. As can be seen from the graph, the OAT ranged from 45 to 70 °F, which was the upper end of the expected heating range. The largest amount of data was recorded in the 50 to 65 °F range and shows virtually no difference in energy usage for the heating system while under control of the two control systems. However, the actuator range differences may have affected the results. The values of the points at each end are questionable since little time was spent when the temperature was in these ranges; thus, the values may not indicate the actual energy use.

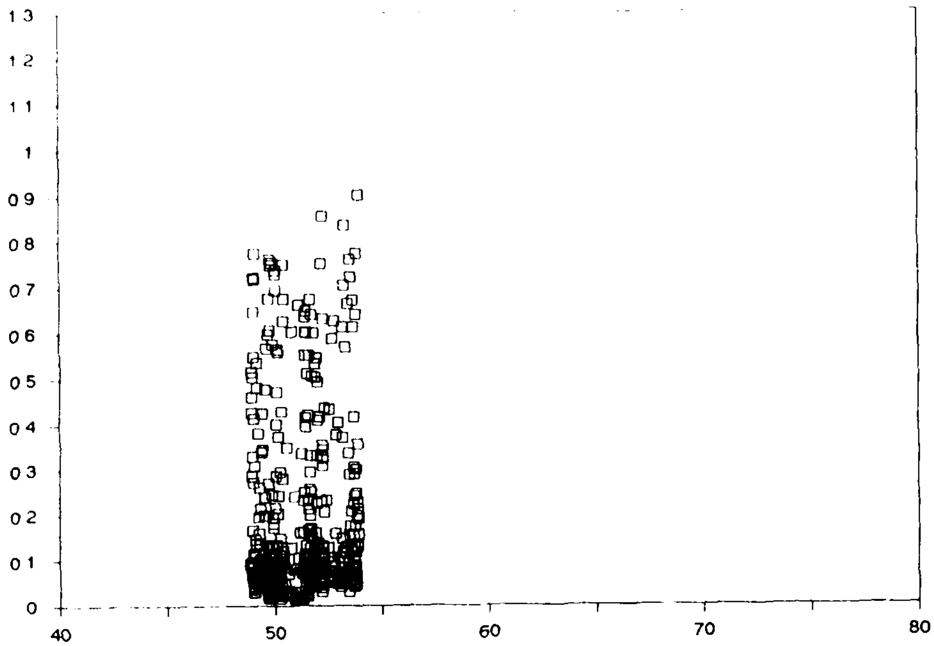


Figure 25. Heating system energy use profile—pneumatic control, night, unoccupied.

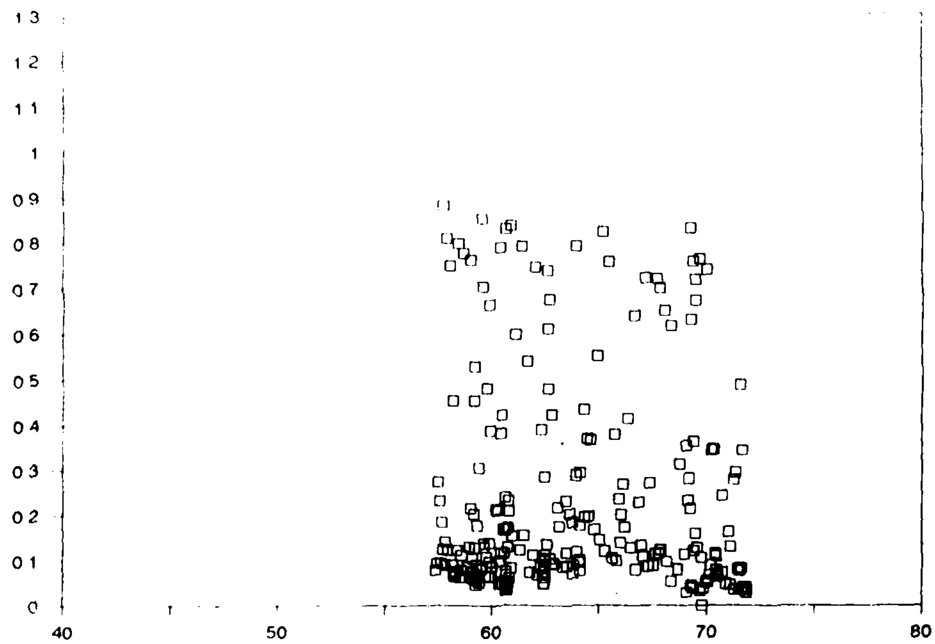


Figure 26. Heating system energy use profile—pneumatic control, evening, unoccupied.

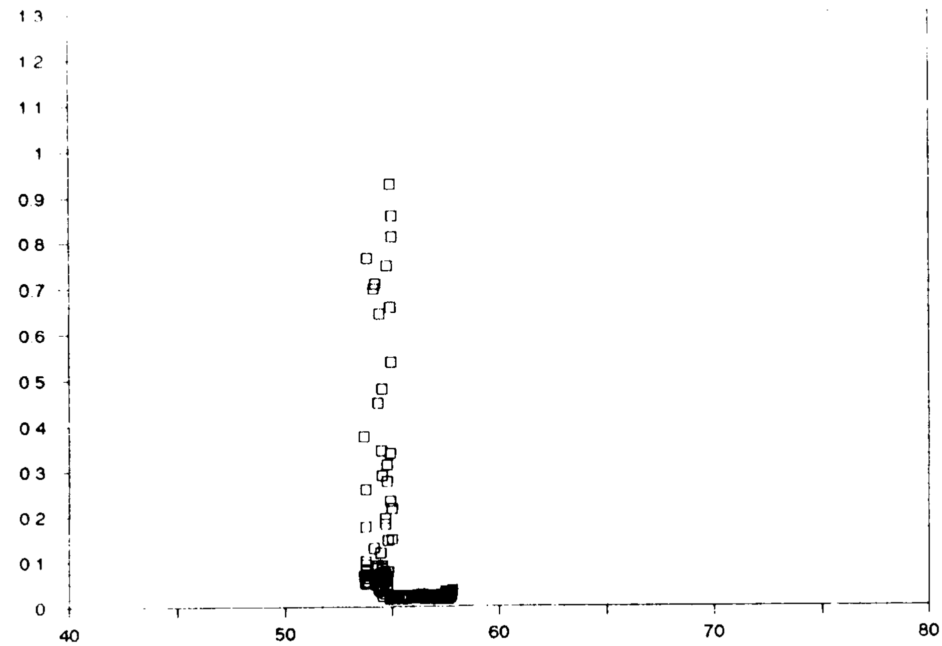


Figure 27. Heating system energy use profile—standard control, night , unoccupied.

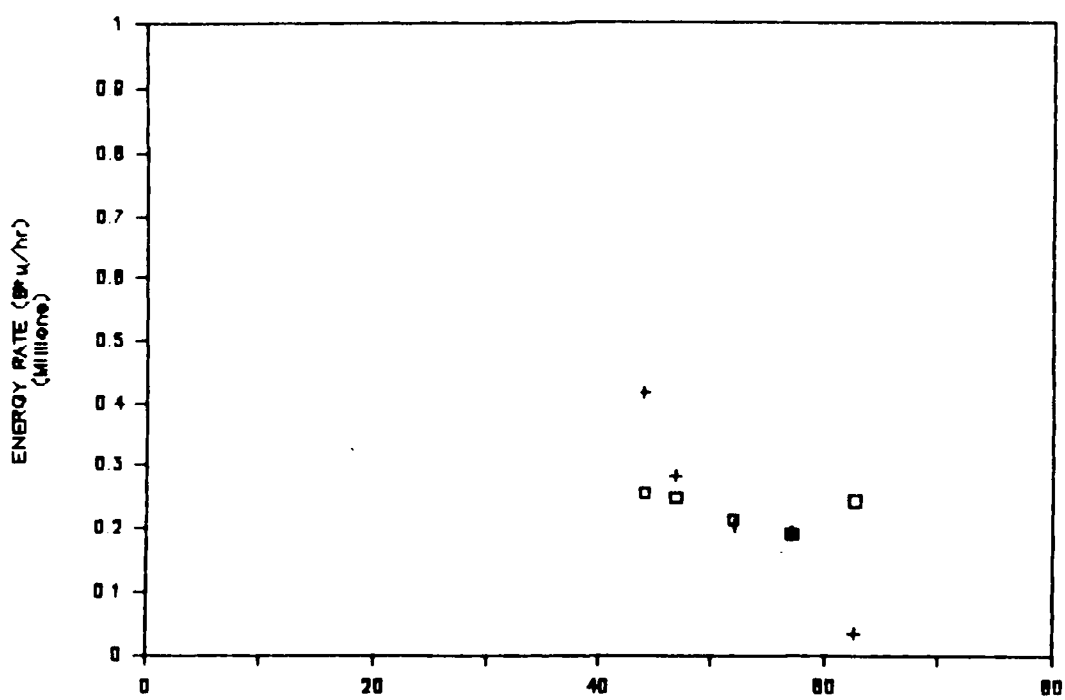


Figure 28. Heating system energy use profile—standard/pneumatic control, night, unoccupied.

Hot Water Supply Temperature Control Loop Performance

Figure 29 graphs the hot water supply temperature (HWST) versus the OAT for the heating system controlled by the standard panel. The reset schedule for the setpoint of the HWST was the following:

HWST	OAT
200	0
100	65

The standard panel correctly maintained the HWST at the desired setpoint except when the OAT was above approximately 55 °F. The reason was not determined, but it may have been due to the actuator range.

Figure 30 graphs HWST versus OAT for the heating system controlled by the pneumatic panel. The pneumatic panel maintained a HWST at about 10 °F above the desired setpoint.

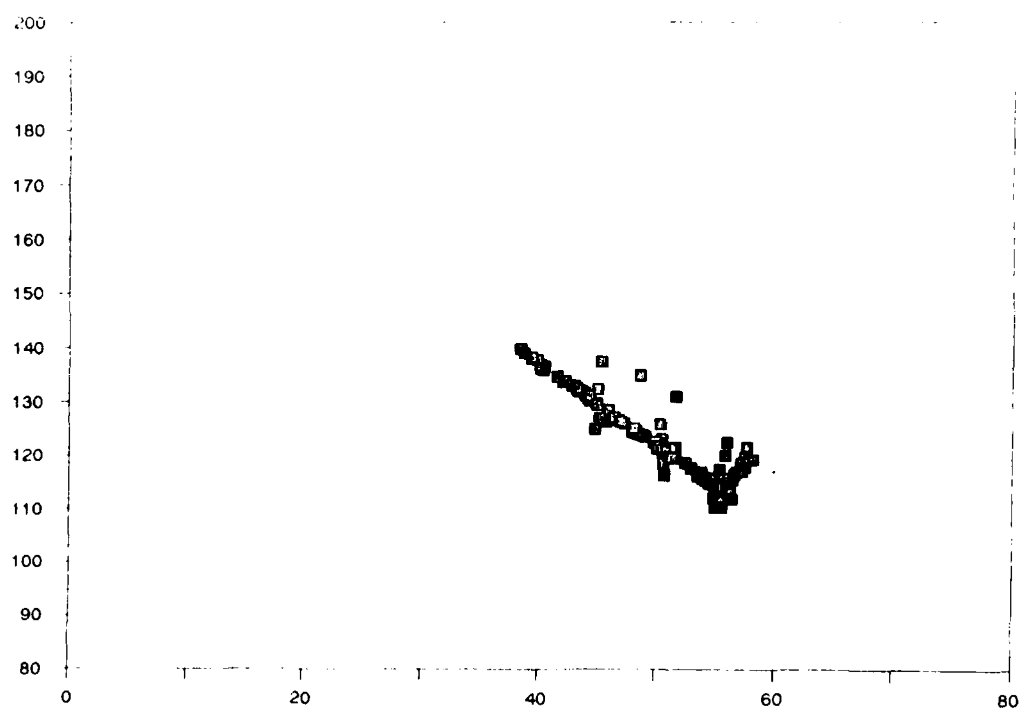


Figure 29. Hot-water supply temperature versus outside air temperature—standard panel control.

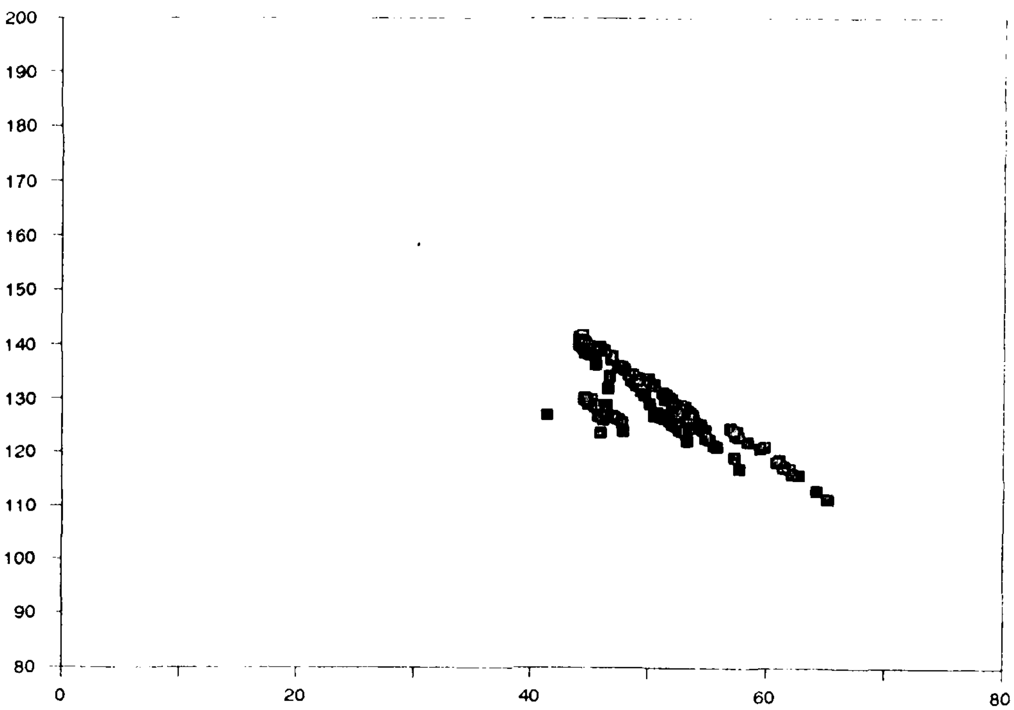


Figure 30. Hot-water supply temperature versus outside air temperature—pneumatic panel control.

7 LESSONS LEARNED

During this study, USACERL personnel procured, installed, and commissioned 17 analog-electronic control panels in seven different facilities at three Army installations. It was apparent that standardized control panels could be successfully used in retrofit applications on typical Army HVAC systems. However, the demonstration was unsuccessful at quantifying the actual energy savings which might result from such a retrofit.

Selection of Demonstration Sites

USACERL and the installation DEHs preferred to retrofit HVAC systems experiencing control problems. But USACERL had difficulty finding problematic HVAC systems like the recommended standard control systems. The HVAC systems chosen for the study did not match the standard control system or panel designs. This meant the standard panels developed by USACERL could not be used as exact replacements for existing control systems, for example, the two-fan VAV systems at Fort Leonard Wood. The VAV standard control systems developed by USACERL did not include return fan control because return fan systems were difficult to control properly. Thus, no standard panel was developed for return fan control, and the existing pneumatic system had to be used to control the return fan. Additional analog-electronic panel designs must be developed if standard panels are to be used to retrofit all existing Army HVAC control systems.

Installation and Commissioning

USACERL personnel procured the required hardware, did most of the installation, and performed all commissioning of the control panels used in this demonstration. Of course, having USACERL procure, install, and commission control systems does not test the process which will take place at the DEHs when the panels are retrofitted. Therefore, future projects should have all work performed by DEH or contractor personel so the process and contract documents can be tested.

HVAC System Operation and Maintenance

Commissioning and operating the new hardware made it obvious that new control systems are not a cure-all for HVAC problems. USACERL sought to retrofit HVAC systems that had been experiencing control problems. However, these problems were often caused by incorrect design, unbalanced systems, or improperly operating HVAC equipment, and thus the new control systems were unable to solve the problems. For example, the HVAC systems at Fort Sill could not maintain the cooling coil discharge air setpoint temperatures because the cooling coil capacities were insufficient; thus, both control systems maintained the cooling coil valve in a fully open position, making energy consumption comparisons incomplete. New guidance is now being developed by the Corps for testing, adjusting, and balancing HVAC systems to help identify problematic HVAC equipment after installation. Also under development is guidance for preliminary site surveys for retrofit projects. This will help identify problematic HVAC equipment or incorrect design before retrofit occurs.

Instrumentation and Test Plan

The test plan's concept was to develop energy use profiles based on data collection over 2 weekends. But after conducting part of the test, the researchers realized that encountering the wide range of temperatures necessary to develop the profiles would probably require more data collection--4 to 6 weekends, depending on the temperature variation. Also, variations in energy use show that many hours of data are needed to develop a good representation of the relationship between energy use and outside air temperatures. For example, the heating system data collected for pneumatic panel control (Figure 26) shows a wide scatter of points. To develop a best fit curve for this set of points is difficult; having more data would help define the profile line.

Attempting to estimate energy consumption by switching from one control system to another every 2 hours is questionable because the dynamics and heat capacities of the building may not suit switching this often. One control system's influence on the temperature of a building may affect the action of the other control system and lead to erroneous results. (For example: For a cooling system, control system No. 1 is not controlling correctly and allows the zone setpoint temperatures to be exceeded. Control system No. 2 is controlling correctly and returns the zone temperatures to setpoint. System No. 2, although controlling correctly, uses more energy than system No. 1.) Even the use of a 4-hour interval is questionable. A better approach would be to alternate systems on a full day schedule and be sure that the zone setpoint temperatures are maintained.

The test plan assumed that the space temperatures would be maintained, which was not always the case. The test plan was designed to analyze energy consumption strictly on the basis of the energy used by the cooling coil or the heat exchanger. Space temperature variations were not accounted for in the plan.

The test plan attempted to compare energy profiles with some variables unaccounted for and an unestablished baseline. Many conditions and variables contribute to the HVAC system's energy use:

1. The HVAC system can be in good or poor condition.

2. The HVAC system can have nonfunctioning components.

3. The calibration accuracy of the control systems can be excellent, good, fair, or poor.

4. The control systems can have nonfunctioning components.

5. Many outside conditions and many different internal loads can exist.

6. The control systems could be operating under P or PI control.

The plan did not set up a base condition from which all variables could be accounted for. The controlled tests considered the internal loads, outside conditions, and P or PI control, but did not account for the condition of the HVAC system and control systems. The first part of the controlled test should have established a baseline condition in which energy use of the HVAC system over the range of outside conditions and internal loads was determined, controls were properly tuned, all components were functioning properly, and the HVAC system was in good operating condition. The next test could have dealt with energy use when controls are not calibrated but all components are working and the HVAC system is in good shape. The final test could have dealt with energy usage when certain control components fail, such as an economizer loop.

It is difficult to develop an energy profile for a system when the data is taken during periods several months apart. Drifting control and HVAC component accuracy could give certain relations between energy use and OAT during the first test, but data taken during a later period, after drifting has occurred, may show different relations, thus making it difficult to determine the energy use profiles accurately. Conditions under which the control systems were calibrated and commissioned also affect energy use profiles. If one system was calibrated under high gain (load) conditions and the other under low gain (load) conditions, results would be skewed in favor of the system for which favorable conditions existed at the time of data collection.

The flowmeters and temperature sensors should have been placed to measure only flow through the coil and temperature change of water going through the coil. This would have allowed better analysis of energy use by the cooling coil because temperature differences would have been greater. Also, placing the flowmeter thus would have allowed better analysis of cooling coil valve control. This placement would have required adding pipe so the proper length of pipe before and after the flowmeter could be achieved.

The accuracy of the temperature measurement loop was not sufficient for conditions. The Btu meter was designed to give an accuracy of 0.5 °F when the temperature difference ranged from 0 to 2 °F. Either a more accurate Btu meter should have been used, or variable sensing should have been relocated, as stated above.

The data logger should have been set up to measure the instantaneous Btu, flowrate, and temperatures and to eliminate the need for the Btu meter. This would have simplified data acquisition and eliminated some of the error associated with the equipment.

The test plan recommended using thermistors for measuring water temperatures. Thermistors typically do not stay in calibration very long; RTDs are more reliable. RTDs could have been equipped with 4 to 20 mA transmitters and used instead of thermistors.

Finally, in future tests data should be recorded every minute so results can be better analyzed to determine why one control system saves more energy than another.

Reliability

Overall, the reliability of the standard control system hardware was good. All RTD sensors and E/P transducers performed correctly without any failures. The economizer control loops performed correctly except for one economizer card at Brown Hall. No other controller failures occurred. The temperature sensing loops of the two VAV temperature control panels at Brown Hall did show some errors. However, the temperature control panels at other locations, which were manufactured by another company, were error free. Further, the diagnostic capabilities of the standard control panels allowed quick identification of the faulty economizer card and the incorrect temperature readings.

Application of Standard Control Panels

Air Force Applications

Based on the overall good performance of the standard analog control panels from initial stages of this project and from other work, the Air Force decided to mandate the use of the panels in July 1987 through

Engineer Technical Letter (ETL) 83-1 Change 1. The documents included in Appendix A form the technical specifications and design instructions for Air Force control system designs.

Army Applications

The U.S. Army Corps of Engineers is developing a new CEGS and TM for HVAC controls for use in the design and retrofit of Army facilities. The CEGS and TM are based on the concept of standard control system designs implemented by reliable electronic hardware. However, the standard hardware will be based on the use of single loop digital controllers instead of electronic analog controllers. In addition, only one standard panel will be developed, which will be configurable for any type of HVAC system, including the systems where no analog electronic panels are available. CEGS 15950, *Heating, Ventilating, and Air Conditioning HVAC Control Systems*, was released in July 1990, with the TM 5-815-3, draft to be released soon.

8 CONCLUSIONS

Energy savings resulting from retrofitting standard analog-electronic control panels could not be quantified. Data analysis showed no energy savings from using the standard analog panels, but problems with the HVAC systems, data acquisition equipment, and calibration of the controls made the results unrepresentative.

This project demonstrated that standard analog-electronic control panels could be procured from the control industry and installed and commissioned to correctly control HVAC systems in the field. Overall, the performance and reliability of the standard panels and associated hardware were excellent.

To analyze the effect of a control system on HVAC system energy use, the HVAC system must be designed correctly; all components must be functioning correctly, and the system must be properly commissioned. The existing and standard control systems should be tuned and operating properly before monitoring is started. A followup test the following year could be done to determine drifting of controls and the resulting energy consumption.

The data acquisition plan developed for this study was very difficult to implement in the field. Although the plan may have been sufficient to estimate energy consumption under ideal conditions, it failed to account for the impact of all variables influencing energy consumption. An energy savings analysis should concentrate more on the end result of an HVAC system, which is to maintain the temperature of the space. Performing an energy consumption analysis over a short period of time and extrapolating the results over the whole year proved impossible following the test plan.

Finally, a good control system is not a cure-all. It will not reduce energy consumption or compensate for poor performance of an HVAC system that has design flaws, is not properly commissioned, or has defective components.

METRIC CONVERSION TABLE

1 ft	=	0.305 m
1 in.	=	25.4 mm
1 lb	=	0.453 kg
°F	=	(°C x 9/5) + 32
1 psi	=	6.89 kPa

APPENDIX A:

SEQUENCE OF OPERATION FOR HVAC CONTROL SYSTEMS

CONTENTS

List of Figures

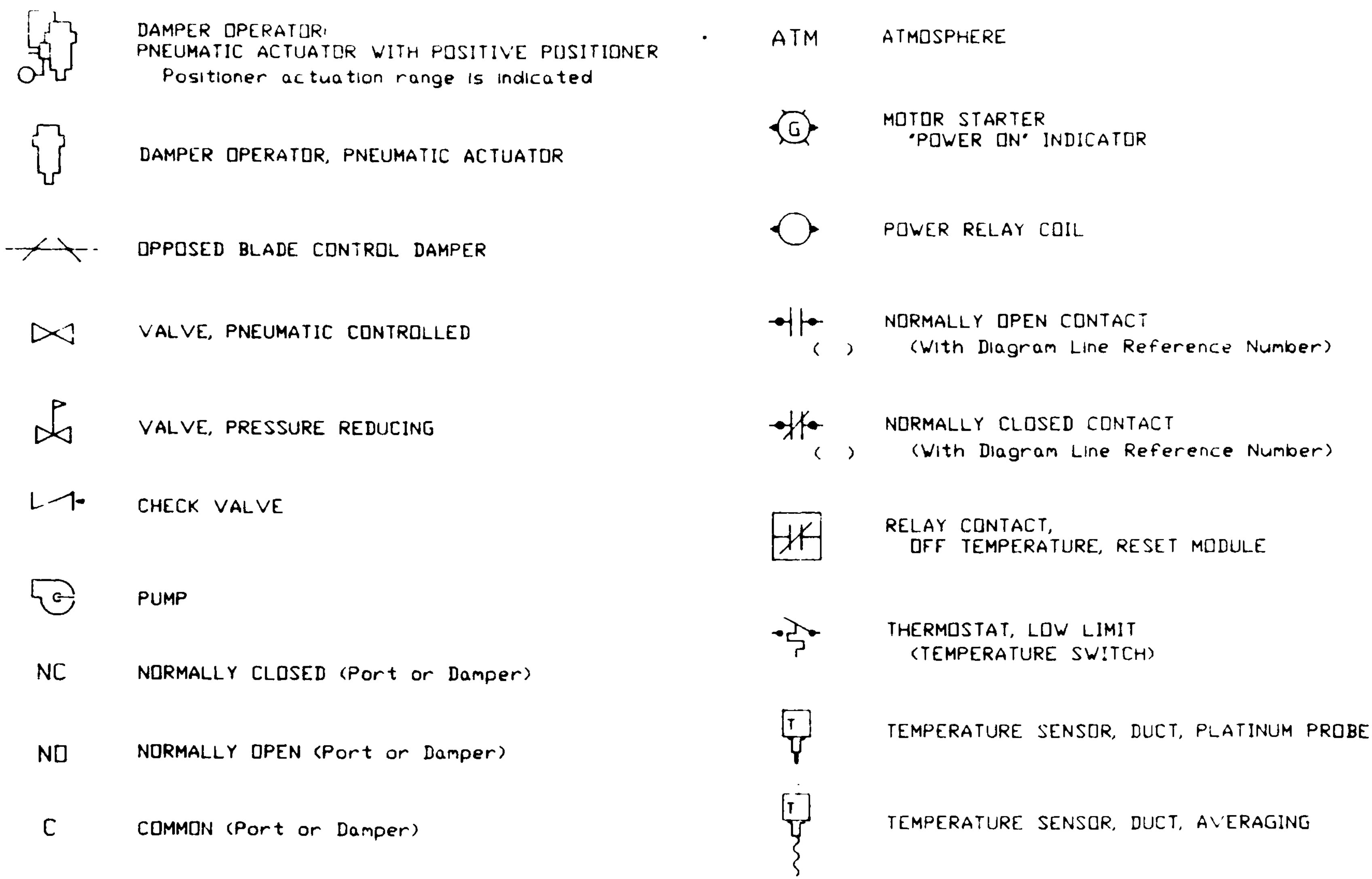


Figure A-1. Legend

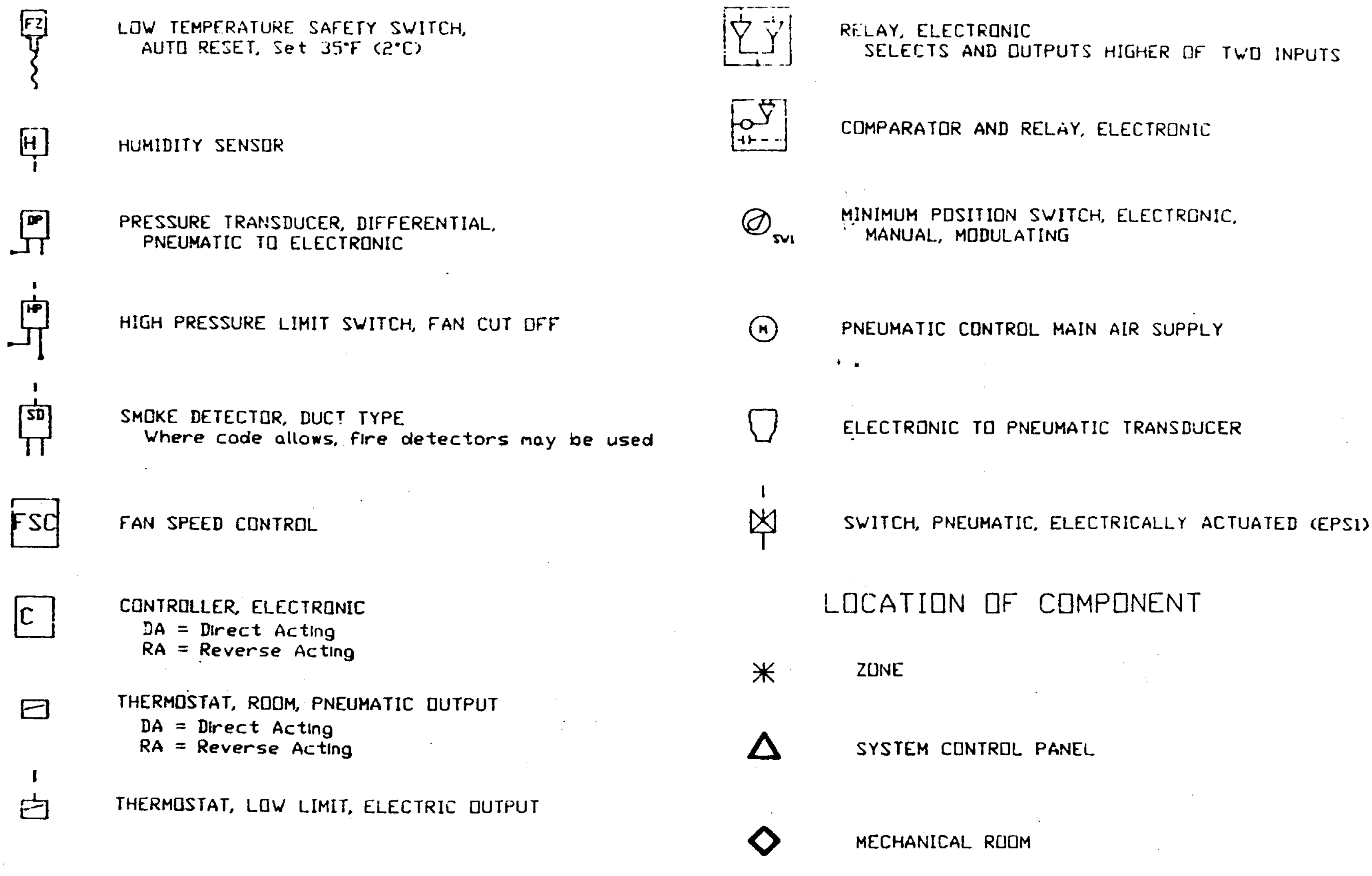


Figure A-1. Legend

VAV SYSTEM, SPEED CONTROL, RADIATION, NO RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts M1-1, M1-2, and M1-3 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-1. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contact R1-3, the fan motor starter is energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact M1-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heater in the zone controlled by the room thermostat. With the fan on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is connected to the fan motor speed controller FSC on the supply fan.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from controller FSC. After the delay, the output from CONTROLLER C3 is reconnected to controller FSC allowing the supply fan to run. The set point is gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to controller FSC. After a delay of about 15 seconds, the input to controller FSC is reconnected and the voltage output to controller FSC is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drive from tripping their circuit breakers. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates baseboard heater valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the baseboard heaters is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM"

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switch (HP1) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

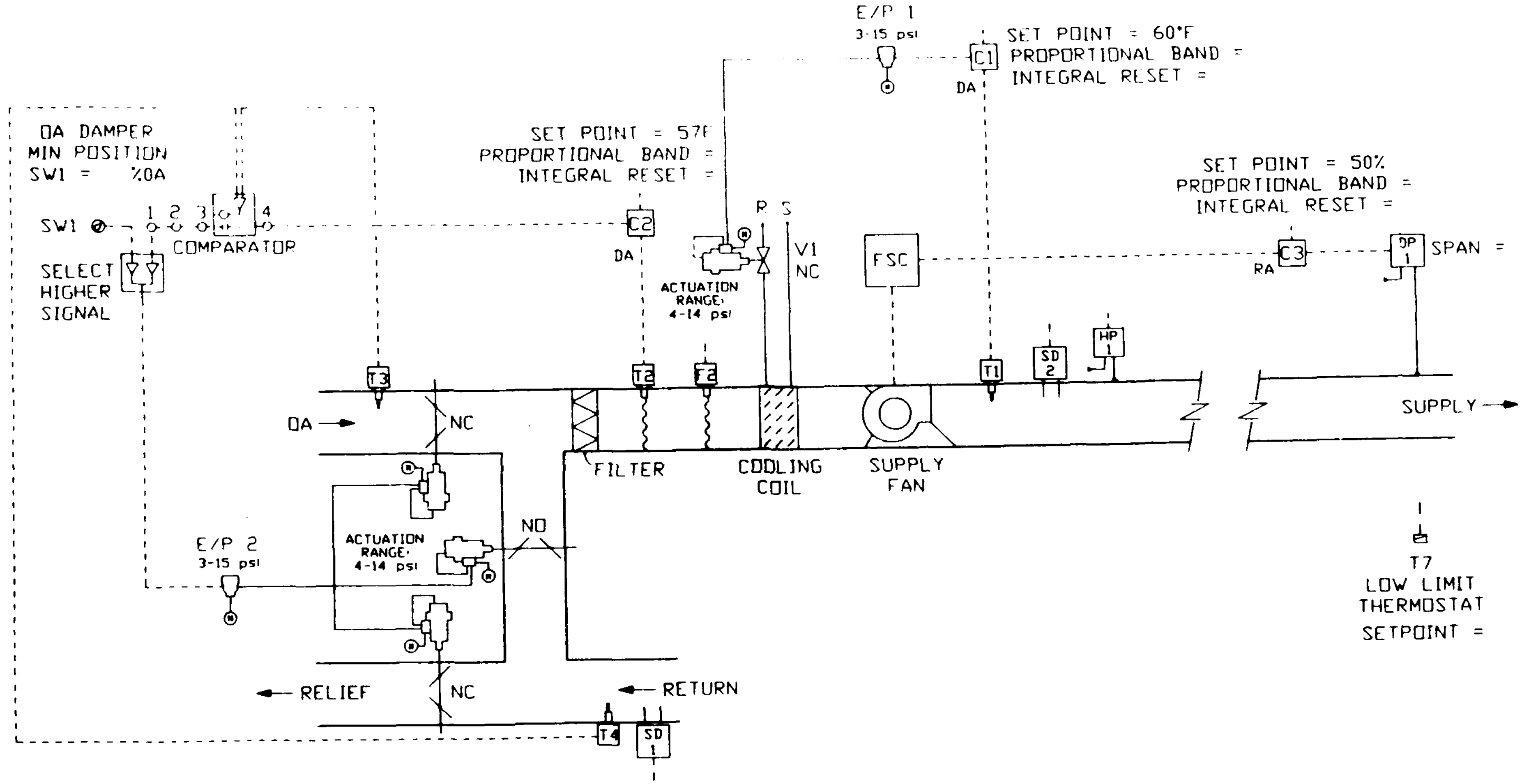


Figure A1-1. VAV Fan Speed Control (FSC) Control Diagram

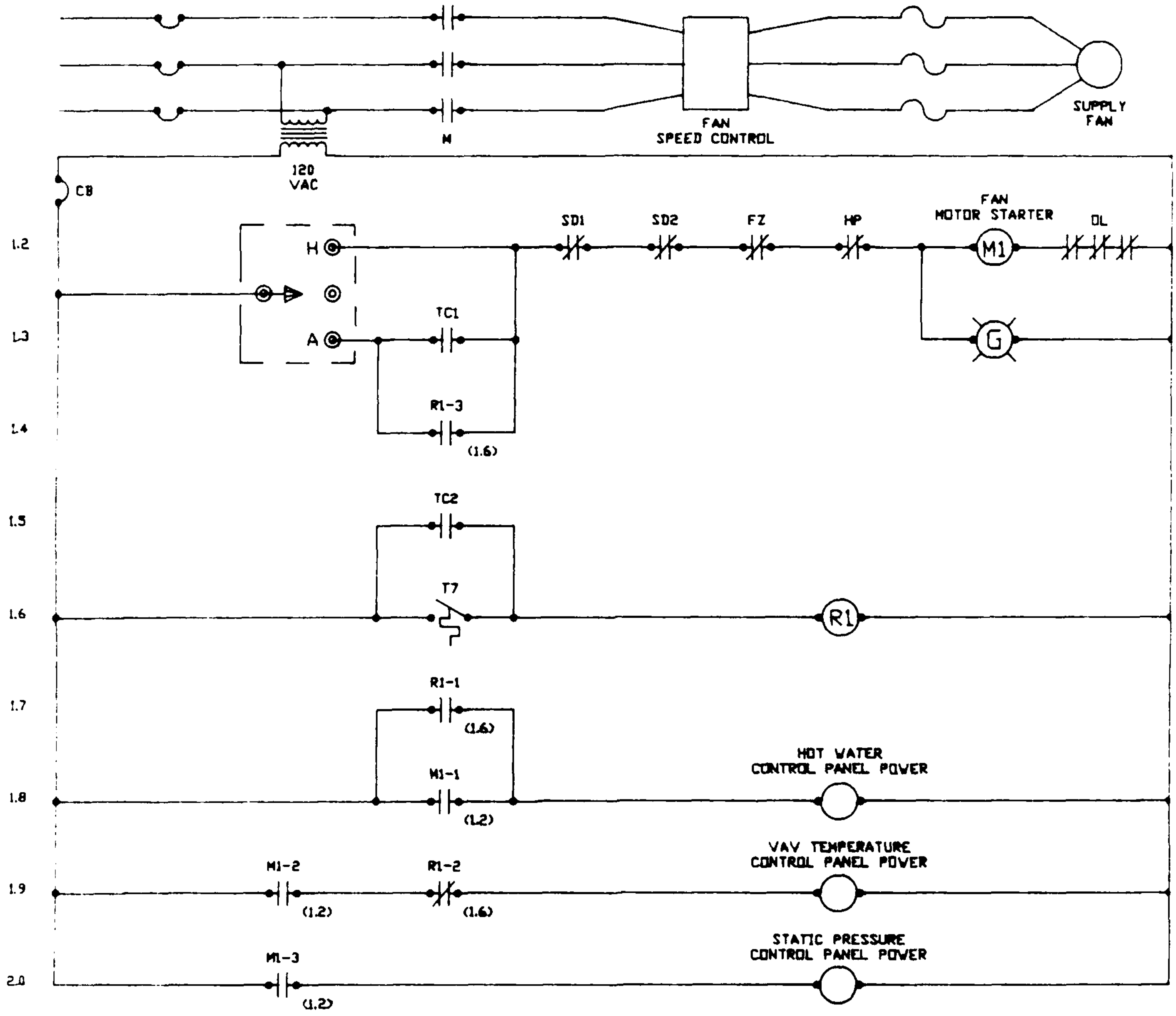


Figure A1-2. Ladder Diagram for FSC System

VAV SYSTEM, SPEED CONTROL, REHEAT, NO RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
   1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts M1-1, M1-2, and M1-3 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-1. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contact R1-3, the fan motor starter is energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact M1-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is provided through a reheat coil in the zone's duct controlled by the room thermostat. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

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4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to controller FSC. After a delay of about 15 seconds, the input to controller FSC is reconnected and the voltage output to controller FSC is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drive from tripping their circuit breakers. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

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3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates reheat coil valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the reheat coils is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

1. Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switch (HP1) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

VAV SYSTEM, SPEED CONTROL, RADIATION, RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan and return fan may be started and stopped in one of two ways:

   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on each fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

   1.2 Automatically: with the fan motor starter switches in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starters, M1 and M2, and relay R2. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts R2-1, R2-2, and R2-3.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relays, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-3. If the temperature drops belowthe set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contacts R1-3 and R1-4, the fan motor starters are energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact R2-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heater in the zone controlled by the room thermostat. With the fans on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is connected to the fan motor speed controllers FSC on both the supply fan and return fan.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from controllers FSC. After the delay, the output from CONTROLLER C3 is reconnected to controllers FSC allowing both the supply fan and return fan to run. The set point is gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to controllers FSC. After a delay of about 15 seconds, the input to controllers FSC is reconnected and the voltage output to controllers FSC is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drives from tripping their circuit breakers. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fans were just being started. The timer or RESET button shall only enable the soft start circuit

when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates bas board heater valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the baseboard heaters is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switches (HP1 and HP2) are wired in series with fan motor starter relay M1 to stop the fans in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

VAV SYSTEM, SPEED CONTROL, REHEAT, RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan and return fan may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on each fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

1.2 Automatically: with the fan motor starter switches in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starters, M1 and M2, and relay R2. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts R2-1, R2-2, and R2-3.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relays, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-3. If the temperature drops belowthe set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contacts R1-3 and R1-4, the fan motor starters are energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact R2-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is provided through a reheat coil in the zone's duct controlled by the room thermostat. With the fans on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is connected to the fan motor speed controllers FSC on both the supply fan and return fan.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from controllers FSC. After the delay, the output from CONTROLLER C3 is reconnected to controllers FSC allowing both the supply fan and return fan to run. The set point is gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to controllers FSC. After a delay of about 15 seconds, the input to controllers FSC is reconnected and the voltage output to controllers FSC is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures and keep the fan motor drives from tripping their circuit breakers. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fans were just being started. The timer or RESET button shall only enable the soft start circuit

when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates reheat coil valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the reheat coils is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switches (HP1 and HP2) are wired in series with fan motor starter relay M1 to stop the fans in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

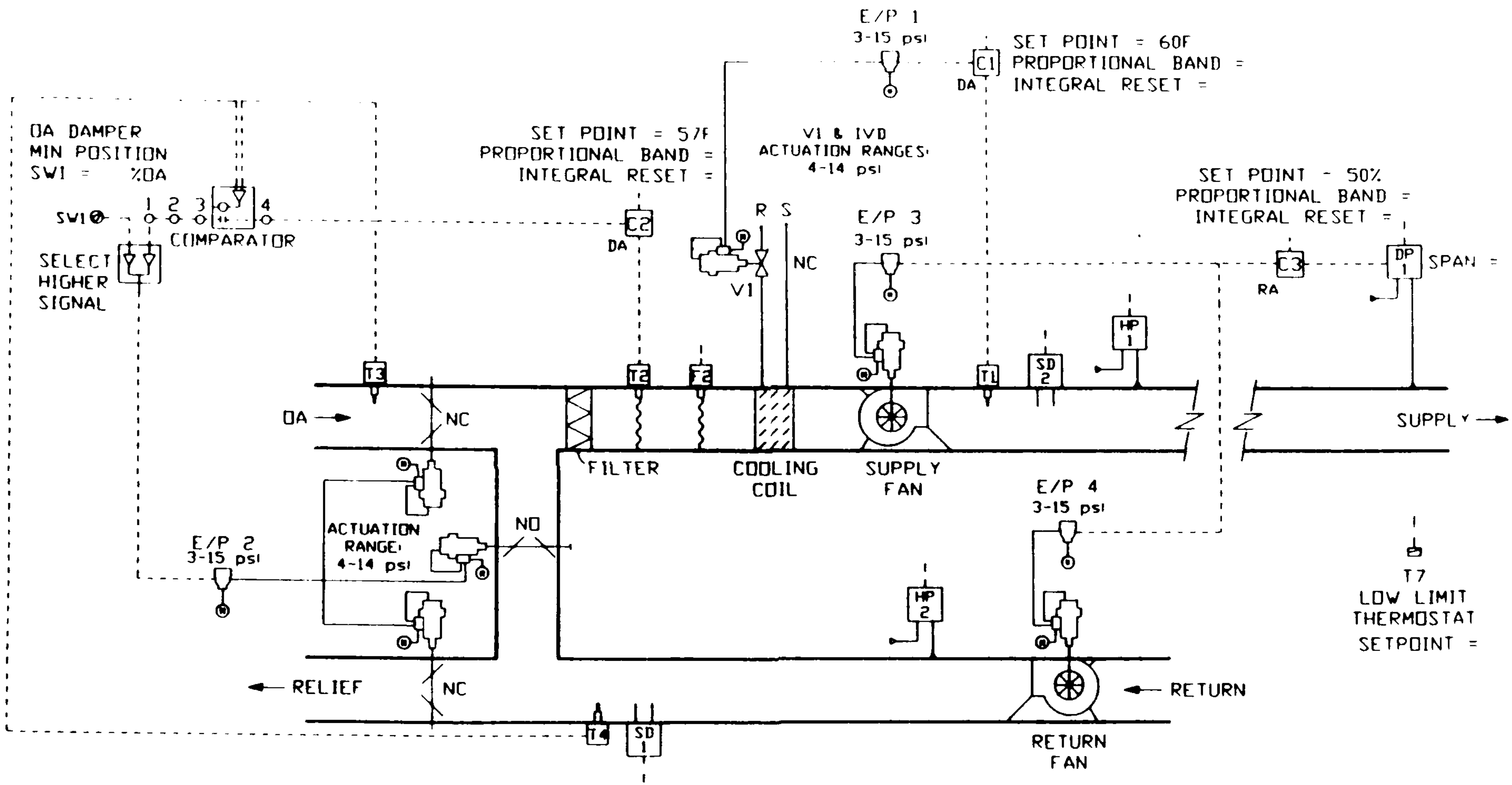


Figure A1-3. VAV FSC (with Return Fan) Control Diagram

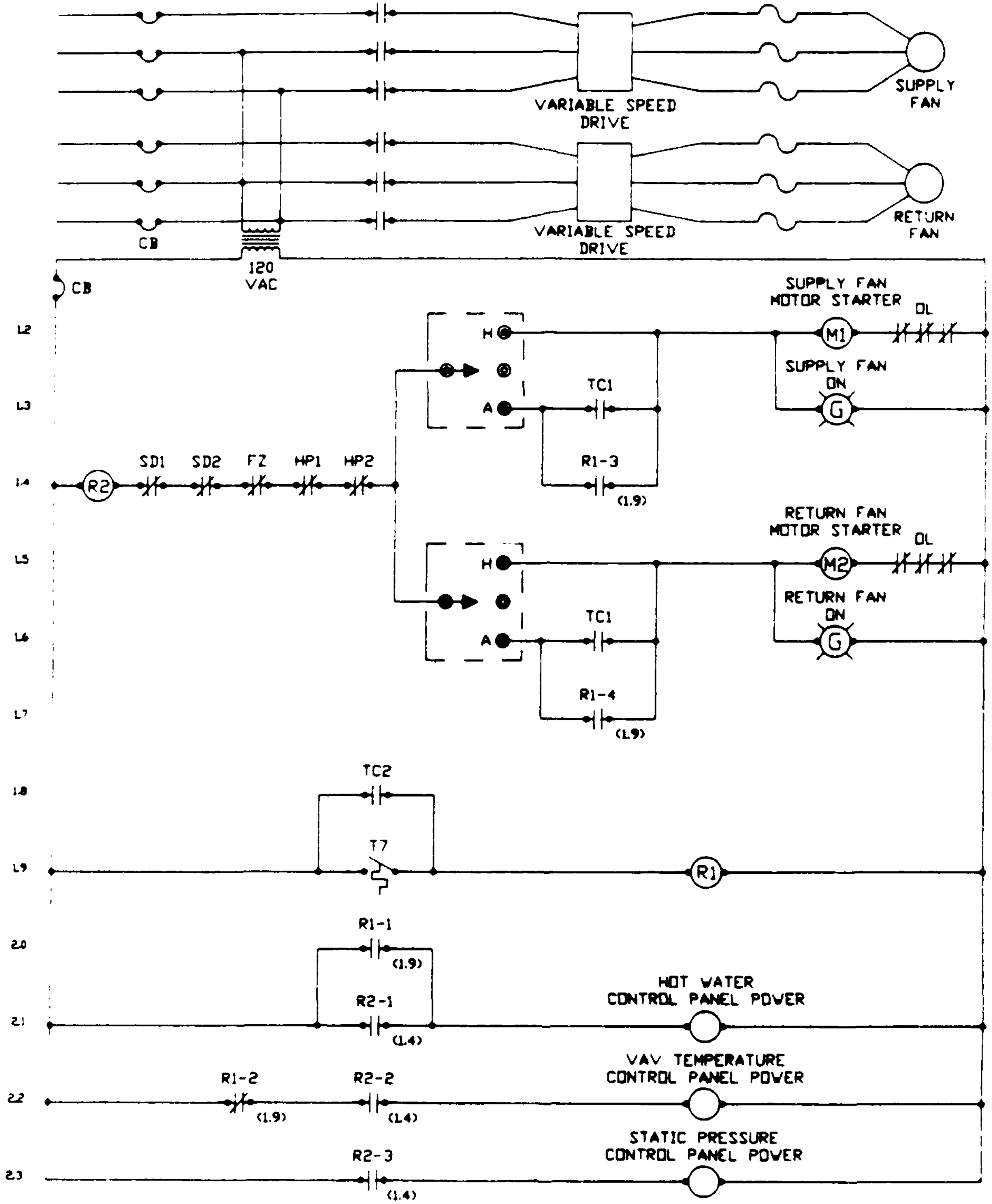


Figure A1-4. Ladder Diagram for FSC System with Return Fan

VAV SYSTEM, INLET GUIDE VANES, RADIATION, NO RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
   1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts M1-1, M1-2, and M1-3 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-5. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contact R1-3, the fan motor starter is energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact M1-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heater in the zone controlled by the room thermostat. With the fan on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is converted to a pneumatic signal through electronic to pneumatic transducer E/P-3. this pneumatic signal modulates the inlet guide vanes on the supply fan, mantaining a constant static pressure in the duct.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from E/P-3. After the delay, the output from CONTROLLER C3 is reconnected to E/P-3 and the set point is gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to E/P-3. After a delay of about 15 seconds, the input to E/P-3 is reconnected and the voltage output to E/P-3 is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates baseboard heater valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the baseboard heaters is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switch (HP1) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

VAV SYSTEM, INLET GUIDE VANES, REHEAT, NO RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts M1-1, M1-2, and M1-3 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in FIG. A1-5. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contact R1-3, the fan motor starter is energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact M1-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is provided through a reheat coil in the zone's duct controlled by the room thermostat. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is converted to a pneumatic signal through electronic to pneumatic transducer E/P-3. this pneumatic signal modulates the inlet guide vanes on the supply fan, mantaining a constant static pressure in the duct.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from E/P-3. After the delay, the output from CONTROLLER C3 is reconnected to E/P-3 and the set point is gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to E/P-3. After a delay of about 15 seconds, the input to E/P-3 is reconnected and the voltage output to E/P-3 is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates reheat coil valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the reheat coils is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switch (HP1) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

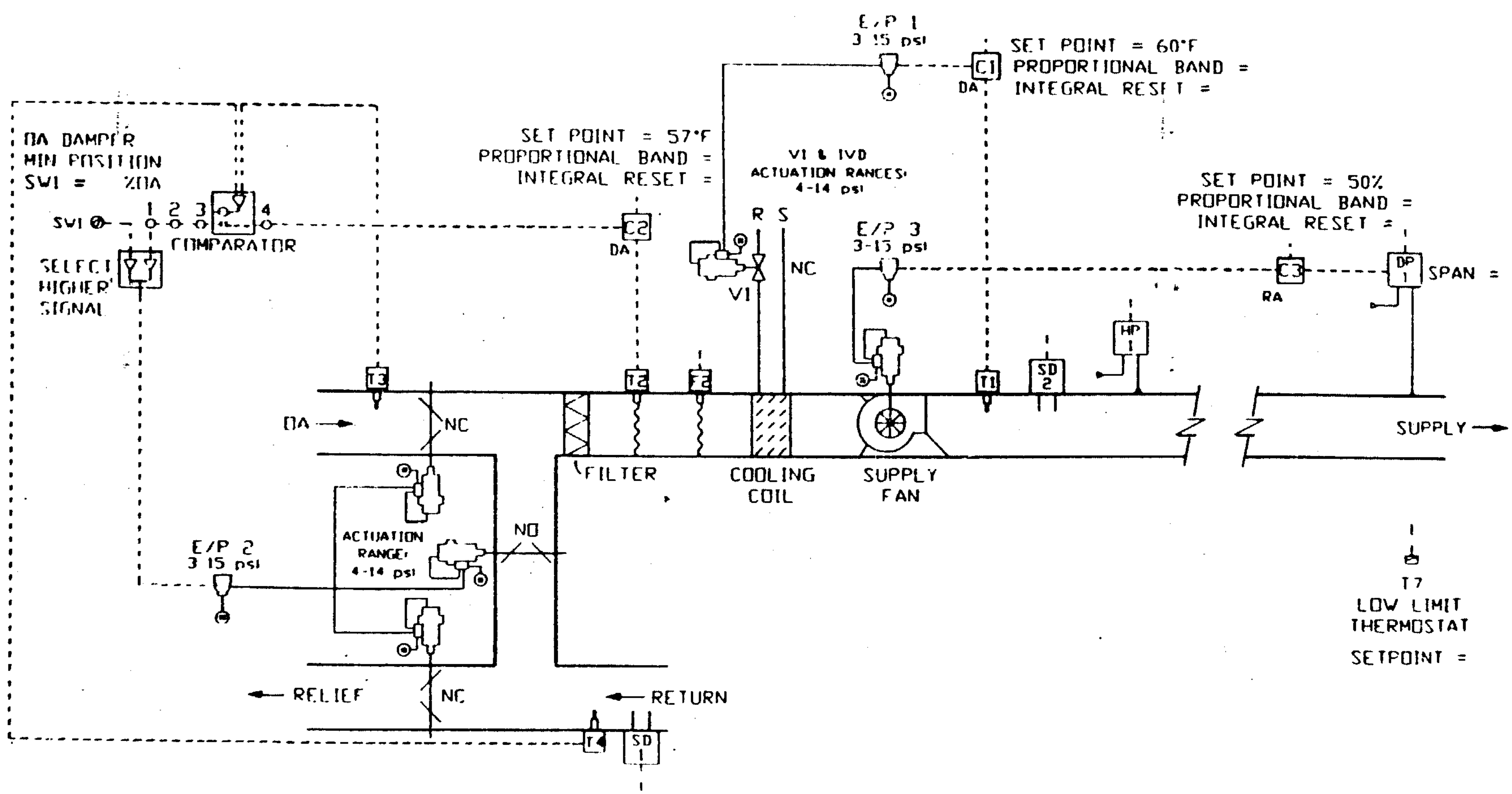


Figure A1-5. VAV Inlet Vane Damper (IVD) Control Diagram

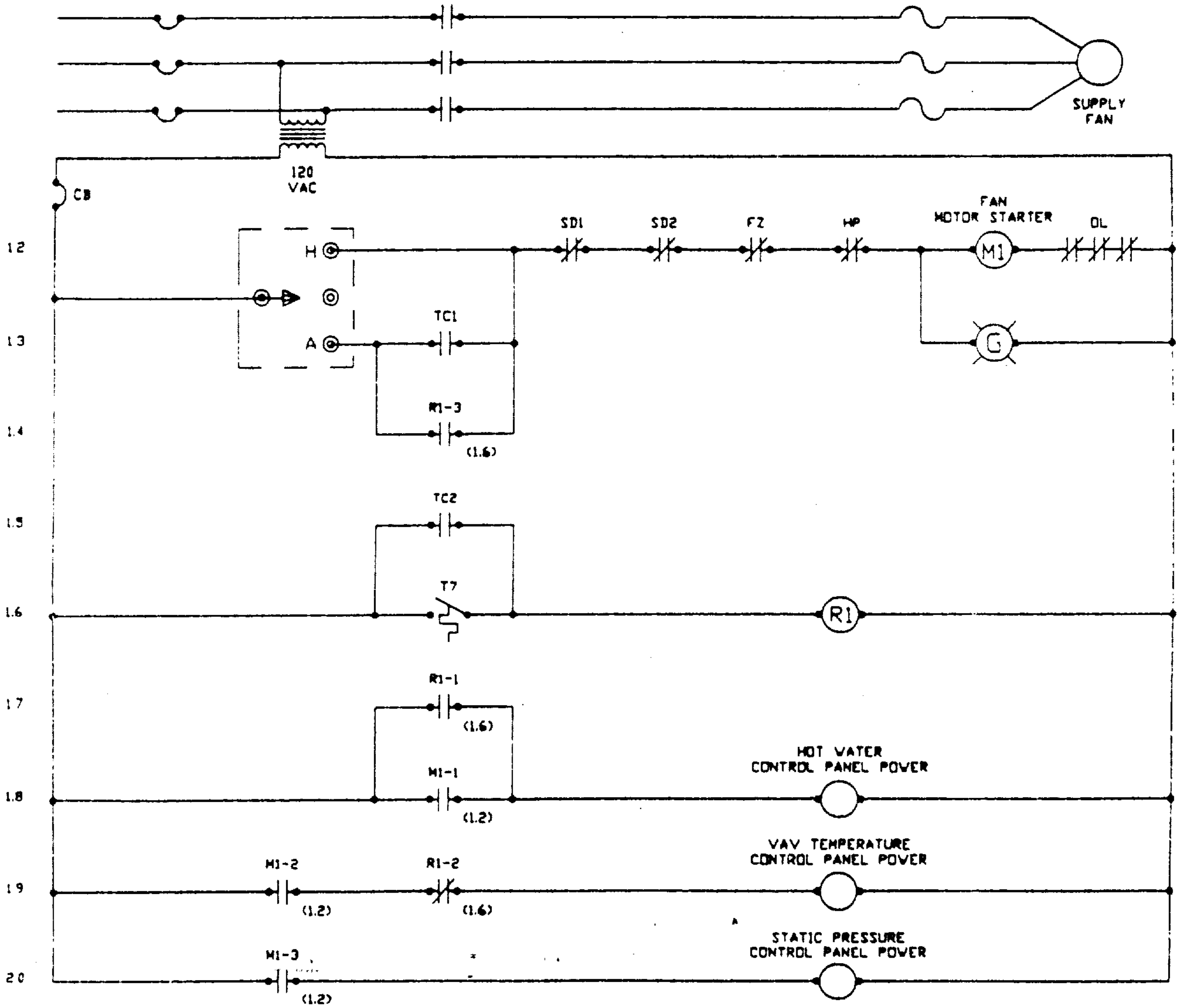


Figure A1-6. Ladder Diagram for IVD Control System

VAV SYSTEM, INLET GUIDE VANES, RADIATION, RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan and return fan may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on each fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

1.2 Automatically: with the fan motor starter switches in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starters, M1 and M2, and relay R2. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts R2-1, R2-2, and R2-3.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relays, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-7. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contacts R1-3 and R1-4, the fan motor starters are energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact R2-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is delivered through a baseboard heater in the zone controlled by the room thermostat. With the fans on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is converted to pneumatic signals through electronic to pneumatic transducers E/P-3 and E/P-4. This pneumatic signal modulates the inlet guide vanes on both the supply and return fans.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from E/P-3 and E/P-4. After the delay, the output from CONTROLLER C3 is reconnected to E/P-3 and E/P-4. The set point is then gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to E/P-3 and E/P-4. After a delay of about 15 seconds, the input to E/P-3 and E/P-4 is reconnected and the voltage output to E/P-3 and E/P-4 is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates baseboard heater valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the baseboard heaters is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switches (HP1 and HP2) are wired in series with fan motor starter relay M1 to stop the fans in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

VAV SYSTEM, INLET GUIDE VANES, REHEAT, RETURN FAN

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan and return fan may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on each fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.

1.2 Automatically: with the fan motor starter switches in the "AUTO" position, the VAV heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starters, M1 and M2, and relay R2. Power to the HOT WATER TEMPERATURE CONTROL PANEL, VAV TEMPERATURE CONTROL PANEL, and STATIC PRESSURE CONTROL PANEL is supplied through auxiliary contacts R2-1, R2-2, and R2-3.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan starter relays, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig. A1-7. If the temperature drops below 0he set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the HOT WATER TEMPERATURE CONTROL PANEL and, through an electric to pneumatic switch (not shown), pressure is supplied to the room thermostats. Auxilliary contact R1-2 (normally closed) opens and the VAV TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contacts R1-3 and R1-4, the fan motor starters are energized and power is supplied to the STATIC PRESSURE CONTROL PANEL (through auxiliary contact R2-3). With no power to the VAV TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. Heat is provided through a reheat coil in the zone's duct controlled by the room thermostat. With the fans on, heat is distributed evenly throughout the building. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. STATIC PRESSURE CONTROL

1. The static pressure at a representative point in the duct work is held constant by the STATIC PRESSURE CONTROL PANEL.

2. A tube connects a static pressure tap in the duct work to static pressure sensor DP1 located in the STATIC PRESSURE CONTROL PANEL. The electronic output of the pressure sensor is compared to the static pressure set point in electronic PI CONTROLLER C3. The electronic output of CONTROLLER C3 is converted to pneumatic signals through electronic to pneumatic transducers E/P-3 and E/P-4. This pneumatic signal modulates the inlet guide vanes on both the supply and return fans.

3. The panel is equipped with a soft start circuit. When power is supplied to the STATIC PRESSURE CONTROL PANEL, through auxiliary contact M1-3 on the fan motor starter, a delay of about 15 seconds occurs while the output of CONTROLLER C3 is ramped to zero. During this delay, the output of CONTROLLER C3 is disconnected from E/P-3 and E/P-4. After the delay, the output from CONTROLLER C3 is reconnected to E/P-3 and E/P-4. The set point is then gradually ramped from zero up to the desired set point (as determined by the set point adjustment knob) after which the soft start circuit no longer affects the control system.

4. The panel is equipped with manual control features which, by turning the timer and pressing the SET button, allow the output of the panel to be adjusted by turning the MANUAL ADJUST knob. When the panel is switched to manual mode, the soft start circuit first disconnects the input to E/P-3 and E/P-4. After a delay of about 15 seconds, the input to E/P-3 and E/P-4 is reconnected and the voltage output to E/P-3 and E/P-4 is ramped from zero to the desired voltage as determined by the position of the MANUAL ADJUST knob. Once the manual adjustment voltage is reached, any manual output changes (ie. manually changing the output from 0 to 100%) will pass through a voltage buffer to prevent sudden changes from causing excessive duct pressures. The system is returned to automatic control when the timer runs down or when the RESET button is pushed. When this occurs, the soft start circuit functions exactly as if the fan were just being started. The timer or RESET button shall only enable the soft start circuit when the system is being switched from manual to automatic control. This shall prevent the timer from cycling the system after it has been placed in the automatic mode via the RESET button.

C. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by electronic PI CONTROLLER C1 located in the VAV TEMPERATURE CONTROL PANEL.

2. The mixed air temperature is controlled by electronic PI CONTROLLER C2 located in the VAV TEMPERATURE CONTROL PANEL.

3. The cooling coil chilled water valve V1 is modulated by CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is 60 F.

4. The outside, relief, and return air dampers are modulated by CONTROLLER C2 using the sensed mixed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C2 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C2 is 60 F minus the temperature rise across the fan (under full air flow conditions).

5. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

6. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

7. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

D. ROOM AIR TEMPERATURE CONTROL

1. Room air temperature control is achieved by pneumatic room thermostats modulating individual VAV boxes. When heating is required, the room thermostat also modulates reheat coil valve V2.

2. Thermostat calibration and selection of actuator spring ranges shall be coordinated to provide the control action shown in Figures 3-3 and 3-4 labeled "ROOM TEMPERATURE CONTROL PROFILE".

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the reheat coils is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2), low temperature safety switch (FZ), and high pressure limit switches (HP1 and HP2) are wired in series with fan motor starter relay M1 to stop the fans in the event of smoke, extremely low temperatures, or damagingly high pressures. The ladder schematic on the drawings shows how equipment is to be interlocked.

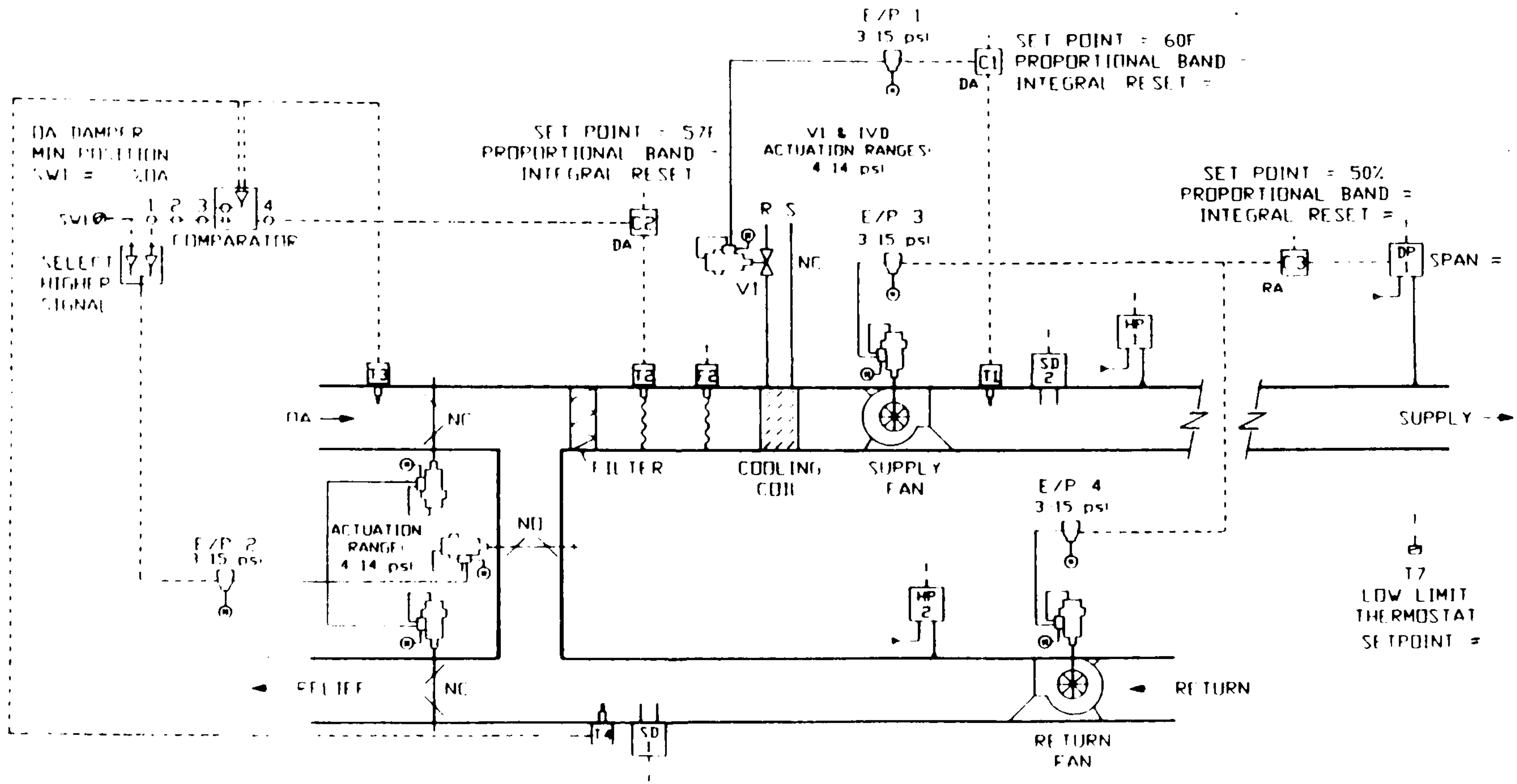


Figure A1-7. VAV IVD (with Return Fan) Control Diagram

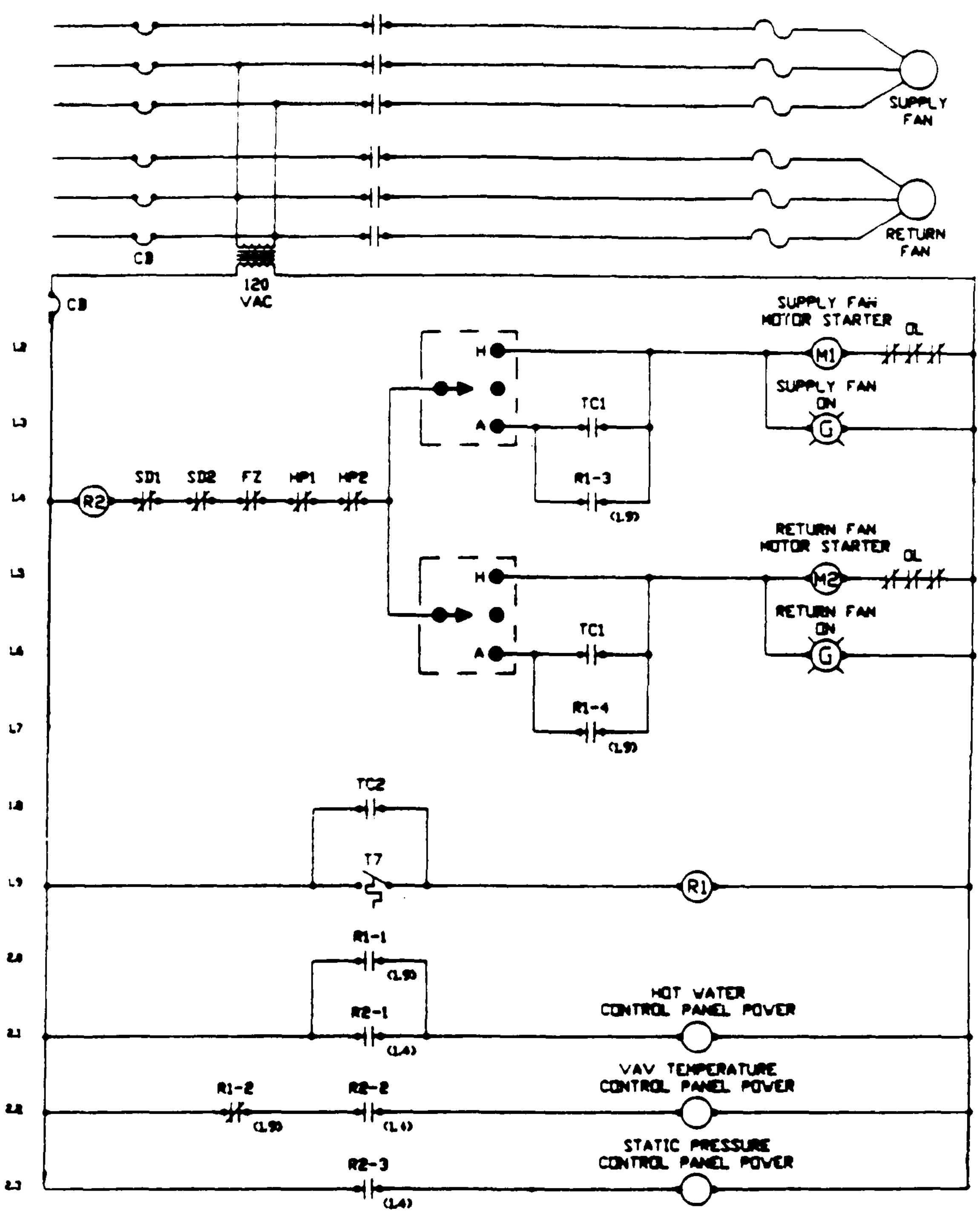


Figure A1-8. Ladder Diagram for IVD System with Return Fan

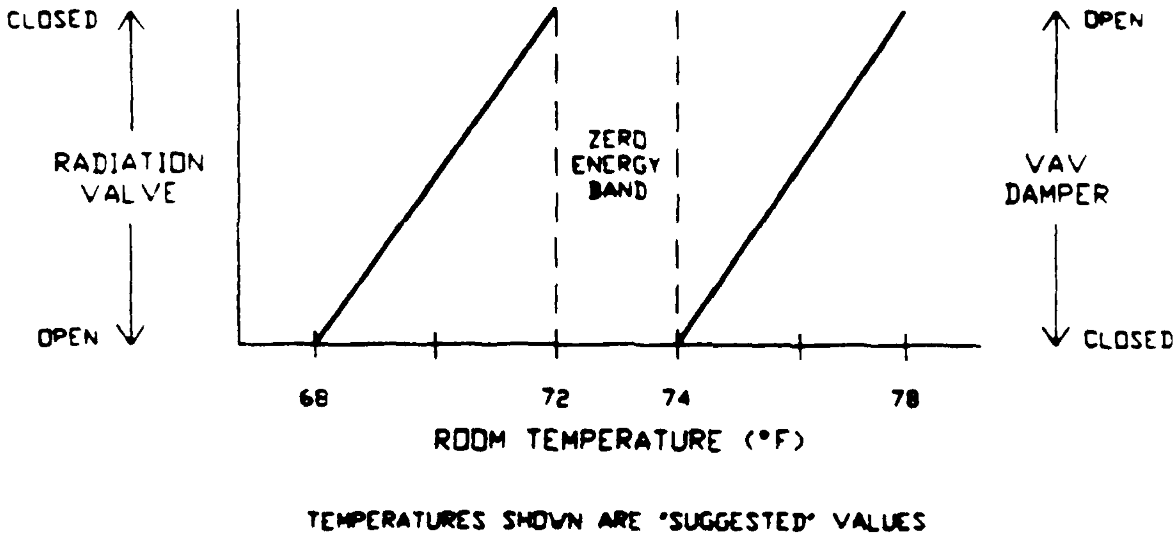


Figure A1-9(a). Room Temperature Control Profile for "Zero Energy Band" Thermostat.

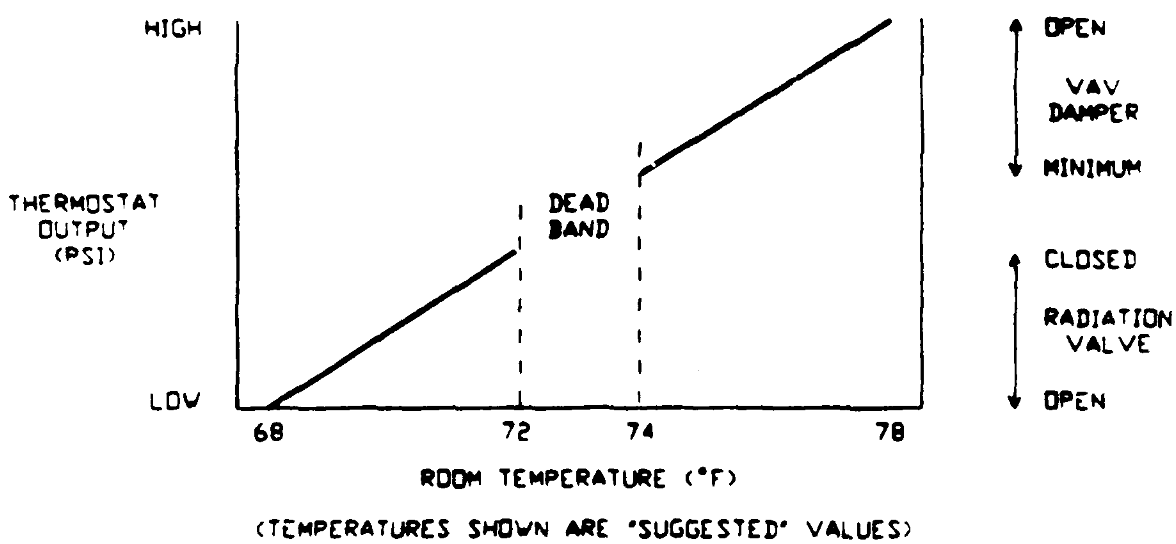


Figure A1-9(b). Room Temperature Control Profile for "Dead Band" Thermostat.

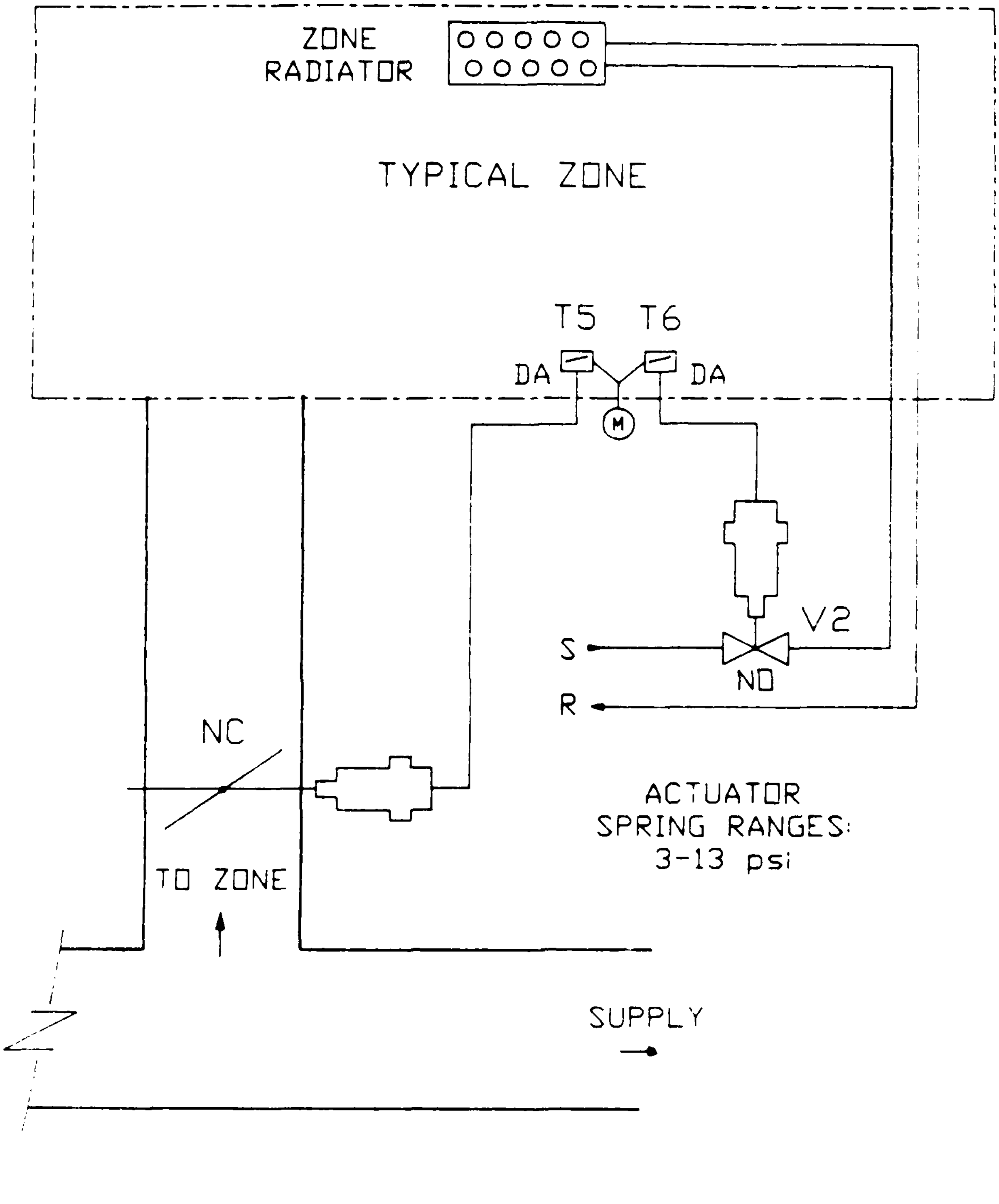


Figure A1-10. Zone with Radiator

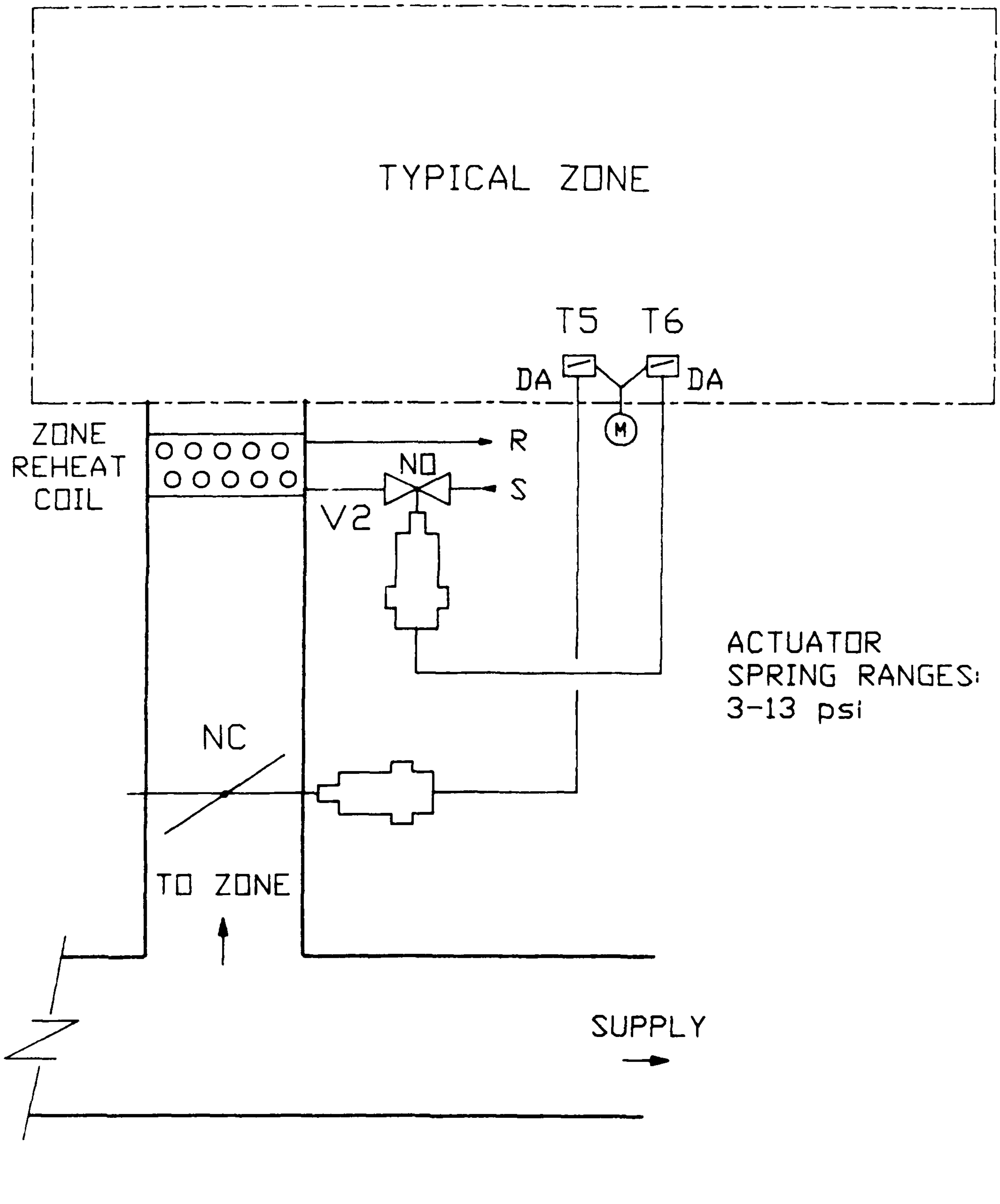


Figure A1-11. Zone with Reheat Coil

STEAM/HOT WATER CONVERTOR, STEAM VALVE CONTROL

SEQUENCE OF OPERATION

A. START-UP

1. Pump may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the pump motor starter can be set in the "HAND" (or "ON") position to start the pump and in the "OFF" position to stop the pump.

1.2 Automatically: with the pump motor starter switch in the "AUTO" position, the hot water temperature control system has two modes of operation - off and normal.

2. Normal operation begins when the HOT WATER TEMPERATURE CONTROL PANEL is energized, possibly through an interlock with a fan motor starter as described in VAV SYSTEM - SEQUENCE OF OPERATION. This interlock energizes relay coil R1 which in turn provides power to the HOT WATER TEMPERATURE CONTROL PANEL. If heating is required, the OFF TEMP relay contact C2-1 will be in its normally closed position and the pump motor starter M1 will be energized. Auxiliary contact M1-1 on the pump motor starter closes and the three-way electrically actuated pneumatic switch EPS1 is energized. With EPS1 energized, the pneumatic control signal from electronic to pneumatic transducer E/P-1 is sent to the steam valve actuator V1 and the valve is controlled. If heating is not required, the OFF TEMP relay contact will open, de-energizing M1 and EPS1. Thus the pump is off and, when EPS1 is de-energized, the pneumatic switch returns to its normal state and supply air is sent to V1 causing the steam valve to close. If the H-O-A switch is switched from "AUTO" to "OFF", auxiliary contact M1-1 will open and the steam valve will be closed.

B. TEMPERATURE CONTROL

1. The HW supply temperature is controlled by electronic PI CONTROLLER C1 using the sensed water temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position the steam valve, maintaining the required hot water supply temperature. The set point of CONTROLLER C1 is determined by the output of electronic proportional CONTROLLER C2 using the sensed outside air temperature from temperature sensor T2 -- the hot water temperature controller is reset on the basis of outside air temperature as shown in the Temperature Control Profile.

2. The control panel is equipped with manual control features which are enabled by turning the timer on and pushing the SET button. The valve may then be adjusted by turning the VALVE MANUAL ADJUST knob. The valve returns to automatic control when RESET is pushed or the timer times out.

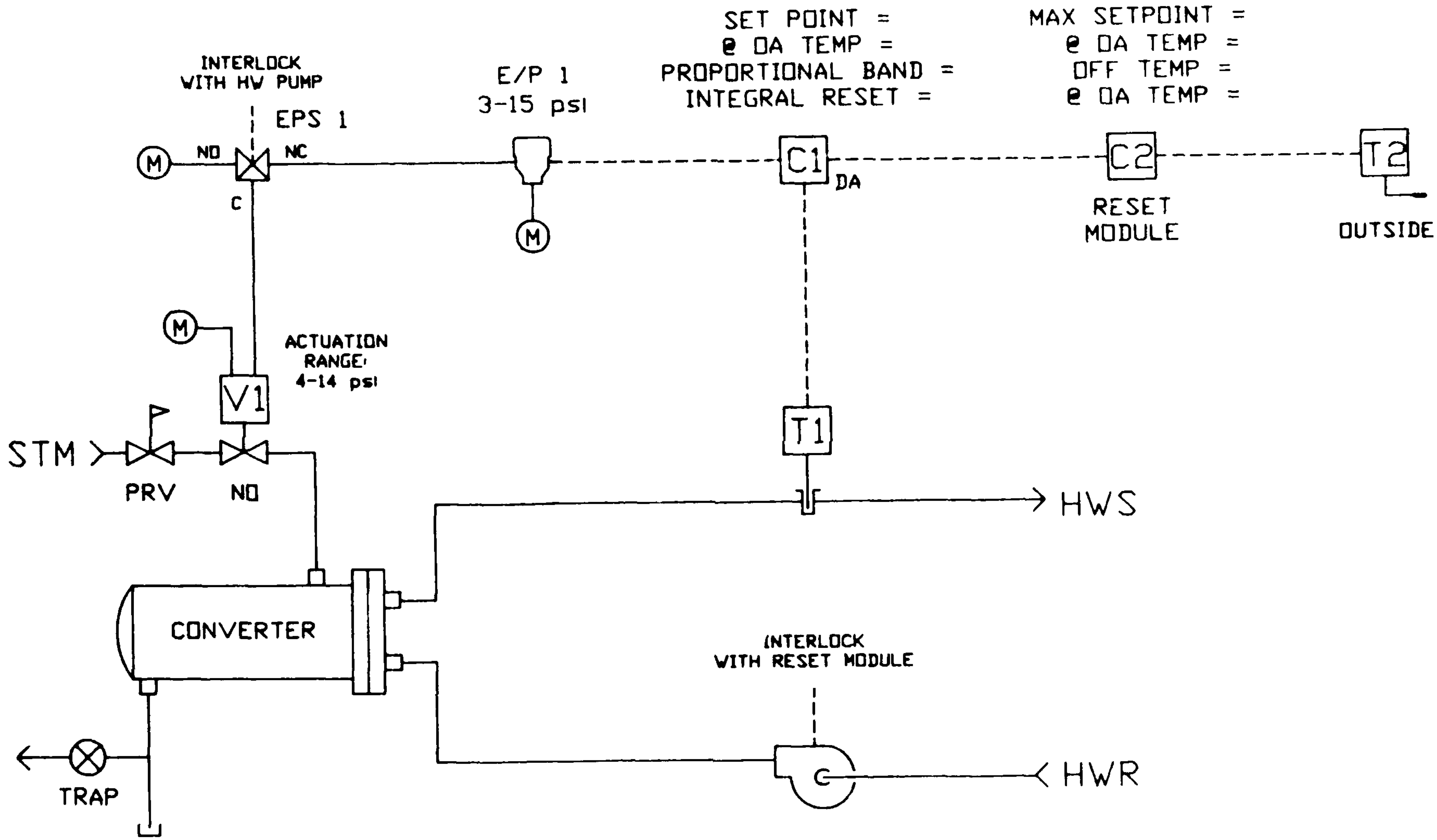


Figure A2-1. Steam to Hot Water Convertor, Steam Valve Control

STEAM/HOT WATER CONVERTOR, MIXING VALVE CONTROL

SEQUENCE OF OPERATION

A. START-UP

1. Pump may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the pump motor starter can be set in the "HAND" (or "ON") position to start the pump and in the "OFF" position to stop the pump.
   1.2 Automatically: with the pump motor starter switch in the "AUTO" position, the hot water temperature control system has two modes of operation - off and normal.

2. Normal operation begins when the HOT WATER TEMPERATURE CONTROL PANEL is energized, possibly through an interlock with a fan motor starter as described in VAV SYSTEM - SEQUENCE OF OPERATION. This interlock energizes relay coil R1 which in turn provides power to the HOT WATER TEMPERATURE CONTROL PANEL. If heating is required, the OFF TEMP relay contact C2-1 will be in its normally closed position and the pump motor starter M1 will be energized. Auxiliary contact M1-1 on the pump motor starter closes and two-position solenoid valve SV1 is energized. When SV1 is energized, steam is supplied to the convertor. If heating is not required, the OFF TEMP relay contact will open, de-energizing M1 and opening M1-1. Thus the pump is off and SV1 is closed. If the H-O-A switch is switched from "AUTO" to "OFF", auxiliary contact M2-1 will close, causing the steam valve to close.

B. TEMPERATURE CONTROL

1. The HW supply temperature is controlled by electronic PI CONTROLLER C1 using the sensed water temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position the three-way mixing valve V1, maintaining the required hot water supply temperature. The set point of CONTROLLER C1 is determined by the output of electronic proportional CONTROLLER C2 using the sensed outside air temperature from temperature sensor T2 -- the hot water temperature controller is reset on the basis of outside air temperature as shown in the Temperature Control Profile.

2. The control panel is equipped with manual control features which are enabled by turning the timer on and pushing the "SET" button. The valve may then be adjusted by turning the VALVE MANUAL ADJUST knob. The valve returns to automatic control when "RESET" is pushed or the timer times out.

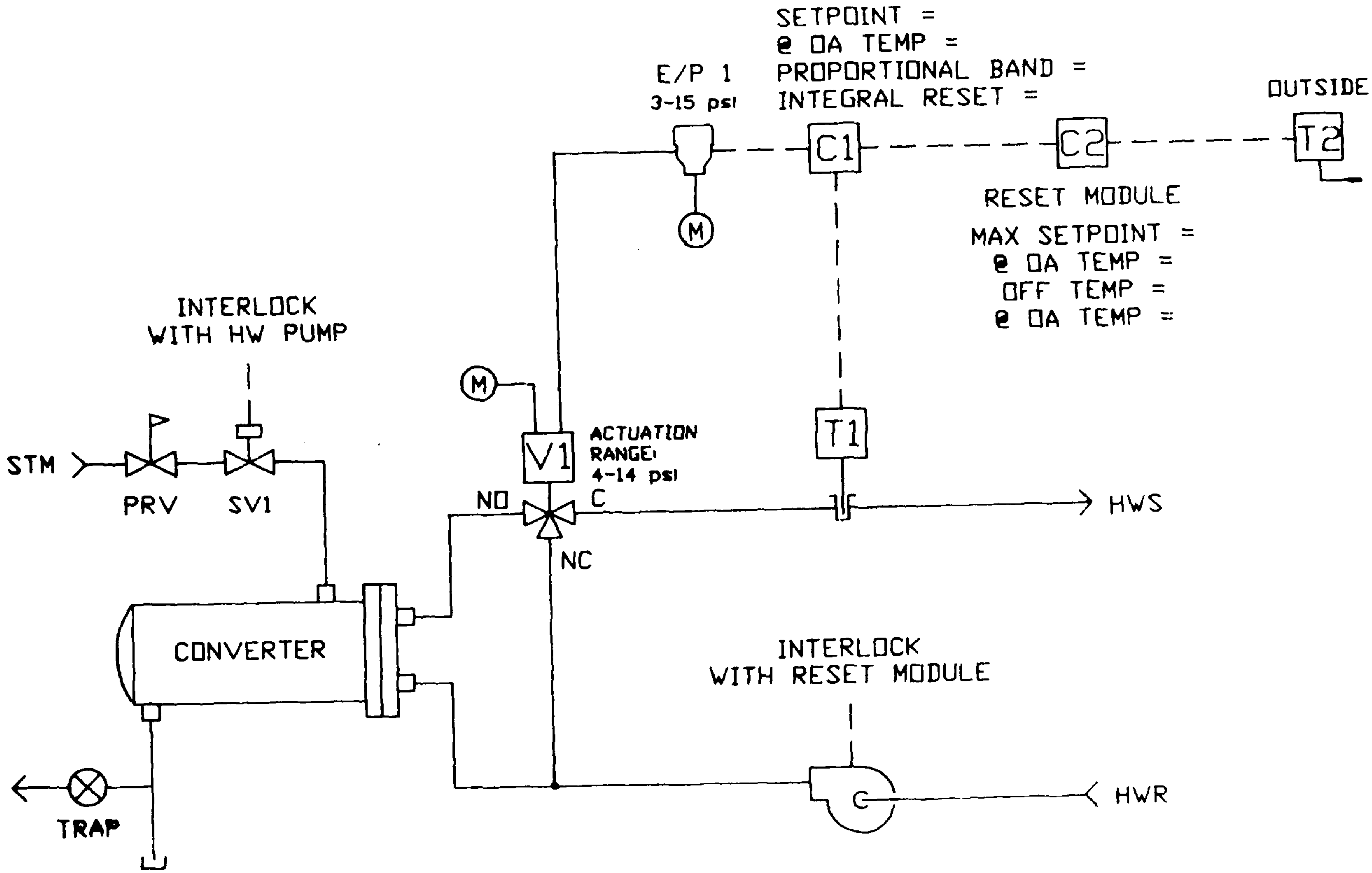


Figure A2-2. Steam to Hot Water Convertor, Mixing Valve Control

HTW/HOT WATER CONVERTOR

SEQUENCE OF OPERATION

A. START-UP

1. Pump may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the pump motor starter can be set in the "HAND" (or "ON") position to start the pump and in the "OFF" position to stop the pump.

1.2 Automatically: with the pump motor starter switch in the "AUTO" position, the hot water temperature control system has two modes of operation - off and normal.

2. Normal operation begins when the HOT WATER TEMPERATURE CONTROL PANEL is energized, possibly through an interlock with a fan motor starter as described in VAV SYSTEM - SEQUENCE OF OPERATION. This interlock energizes relay coil R1 which in turn provides power to the HOT WATER TEMPERATURE CONTROL PANEL. If heating is required, the OFF TEMP relay contact C2-1 will be in its normally closed position and the pump motor starter M1 will be energized. Auxiliary contact M1-1 on the pump motor starter closes and the three-way electrically actuated pneumatic switch EPS1 is energized. With EPS1 energized, the pneumatic control signal from electronic to pneumatic transducer E/P-1 is sent to the valve actuator V1 and the valve is controlled. If heating is not required, the OFF TEMP relay contact will open, de-energizing M1 and EPS1. Thus the pump is off and, when EPS1 is de-energized, the pneumatic switch returns to its normal state and supply air is sent to V1 causing the valve to close. If the H-O-A switch is switched from "AUTO" to "OFF", auxiliary contact M1-1 will open and the valve will be closed.

B. TEMPERATURE CONTROL

1. The HW supply temperature is controlled by electronic PI CONTROLLER C1 using the sensed water temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position the throttling valve V1, maintaining the required hot water supply temperature. The set point of CONTROLLER C1 is determined by the output of electronic proportional CONTROLLER C2 using the sensed outside air temperature from temperature sensor T2 -- the hot water temperature controller is reset on the basis of outside air temperature as shown in the Temperature Control Profile.

2. The control panel is equipped with manual control features which are enabled by turning the timer on and pushing the "SET" button. The valve may then be adjusted by turning the VALVE MANUAL ADJUST knob. The valve returns to automatic control when "RESET" is pushed or the timer times out.

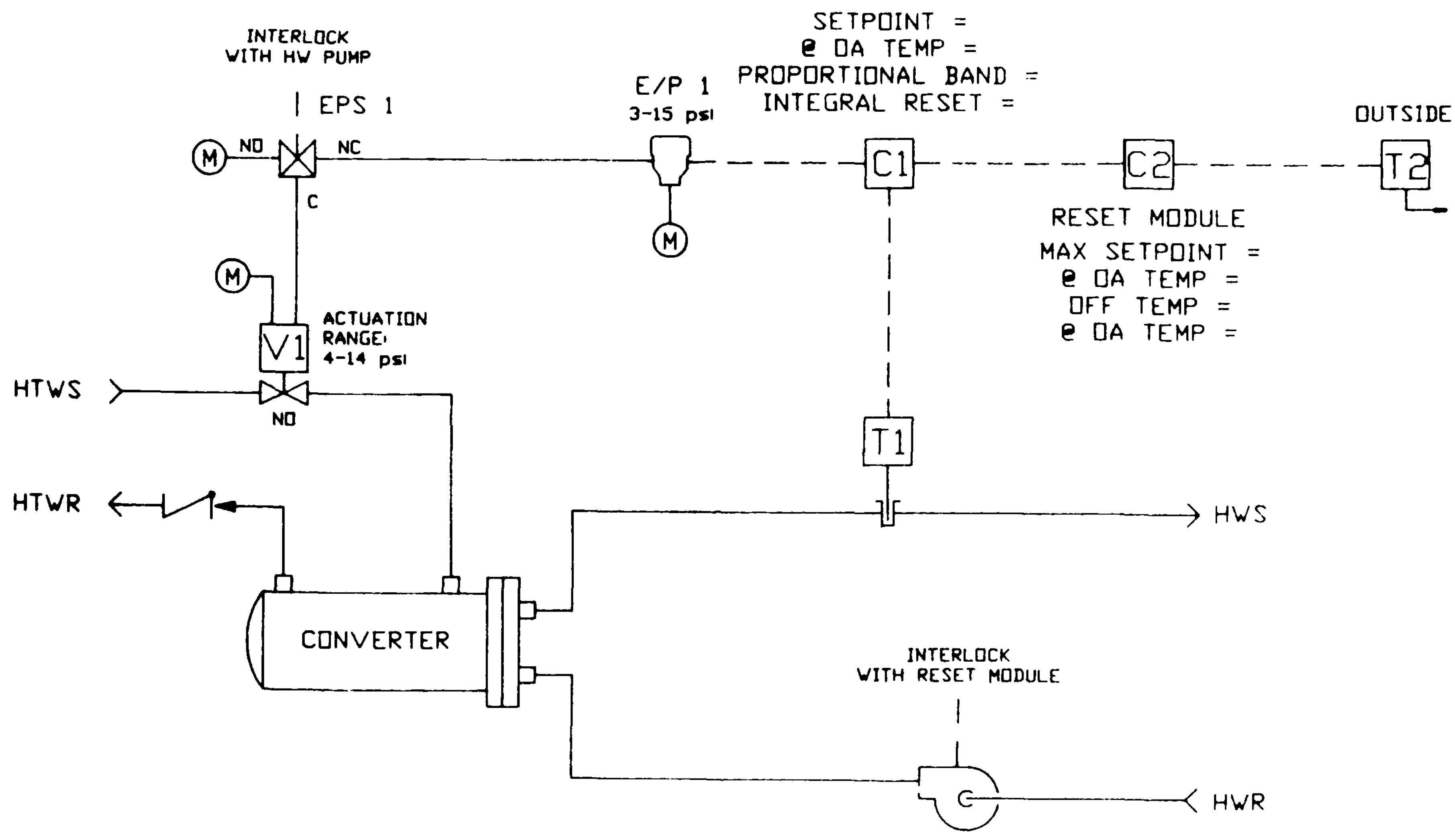


Figure A2-3. High Temperature Hot Water Convertor

HOT WATER SUPPLY, BOILERS

SEQUENCE OF OPERATION

A. START-UP

1. Pump may be started and stopped in one of two ways:

1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the pump motor starter can be set in the "HAND" (or "ON") position to start the pump and in the "OFF" position to stop the pump.

1.2 Automatically: with the pump motor starter switch in the "AUTO" position, the hot water temperature control system has two modes of operation - off and normal.

2. Normal operation begins when the HOT WATER TEMPERATURE CONTROL PANEL is energized, possibly through an interlock with a fan motor starter as described in VAV SYSTEM - SEQUENCE OF OPERATION. This interlock energizes relay coil R1 which in turn provides power to the HOT WATER TEMPERATURE CONTROL PANEL. If heating is required, the OFF TEMP relay contact C2-1 will be in its normally closed position and the pump motor starter M1 will be energized. Auxiliary contact M1-1 on the pump motor starter closes and the three-way electrically actuated pneumatic switch EPS1 is energized. With EPS1 energized, the pneumatic control signal from electronic to pneumatic transducer E/P-1 is sent to the valve actuator V1 and the valve is controlled. If heating is not required, the OFF TEMP relay contact will open, de-energizing M1 and EPS1. Thus the pump is off and, when EPS1 is de-energized, the pneumatic switch returns to its normal state and supply air is sent to V1 causing the valve to close. If the H-O-A switch is switched from "AUTO" to "OFF", auxiliary contact M1-1 will open and the valve will be closed.

B. TEMPERATURE CONTROL

1. The HW supply temperature is controlled by electronic PI CONTROLLER C1 using the sensed water temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position the three-way mixing valve V1, maintaining the required hot water supply temperature. The set point of CONTROLLER C1 is determined by the output of electronic proportional CONTROLLER C2 using the sensed outside air temperature from temperature sensor T2 -- the hot water temperature controller is reset on the basis of outside air temperature as shown in the Temperature Control Profile.

2. The control panel is equipped with manual control features which are enabled by turning the timer on and pushing the "SET" button. The valve may then be adjusted by turning the VALVE MANUAL ADJUST knob. The valve returns to automatic control when "RESET" is pushed or the timer times out.

3. Boiler water temperature is controlled by control systems furnished with the boilers.

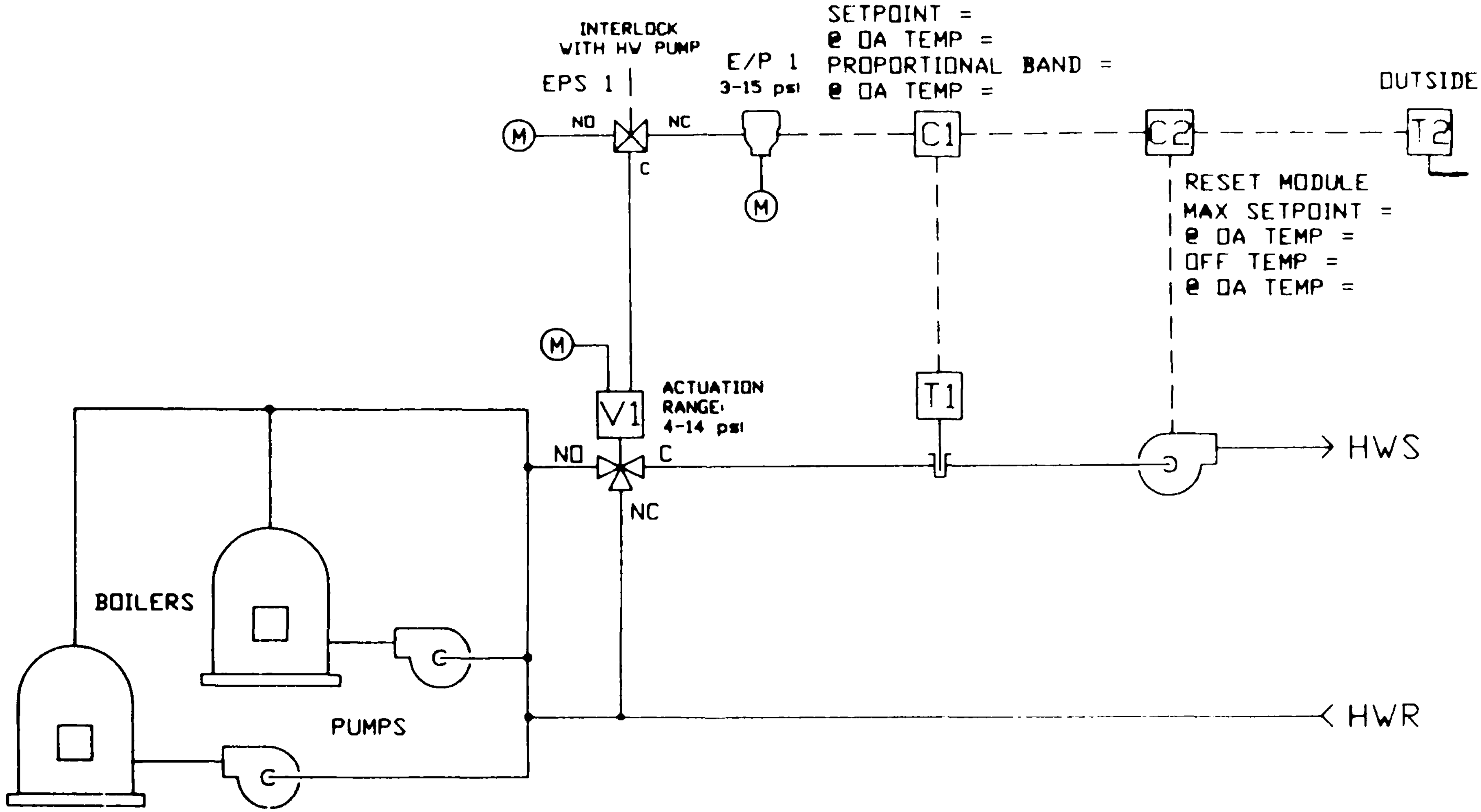


Figure A2-4. Hot Water Supply, Boiler Control

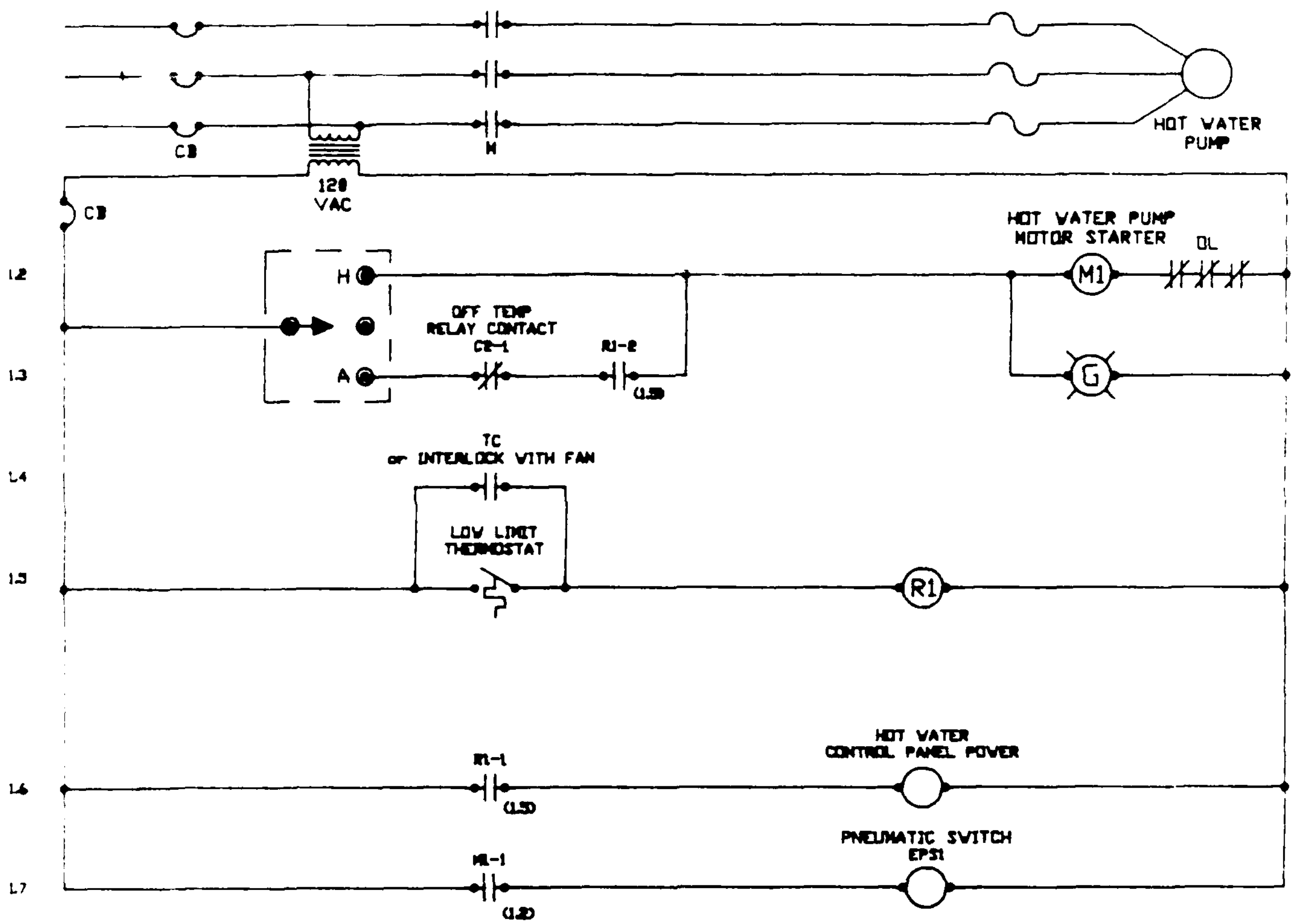


Figure A2-5. Ladder Diagram for Hot Water Systems

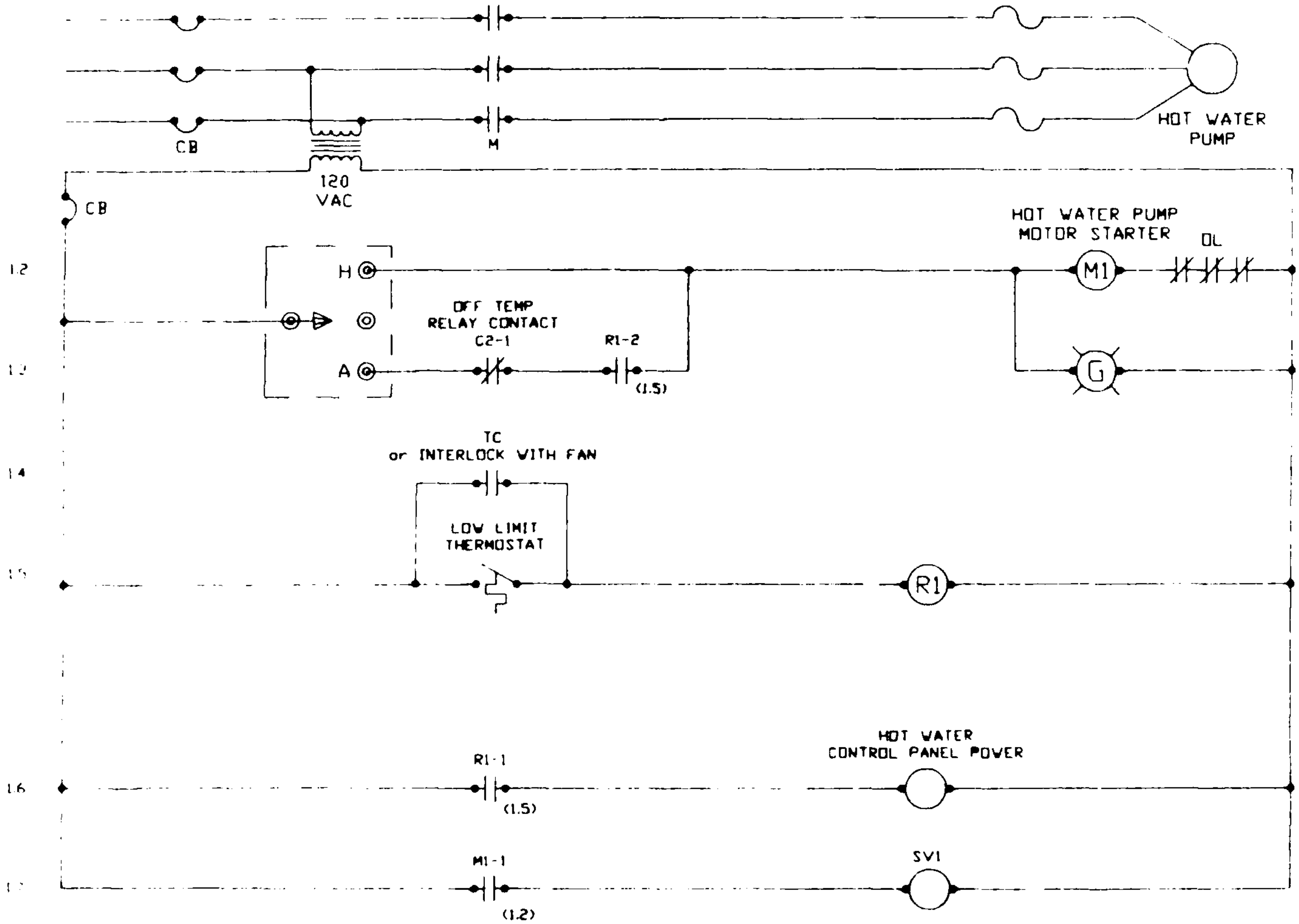


Figure A2-6. Ladder Diagram for Steam Convertor with Mixing Valve Control

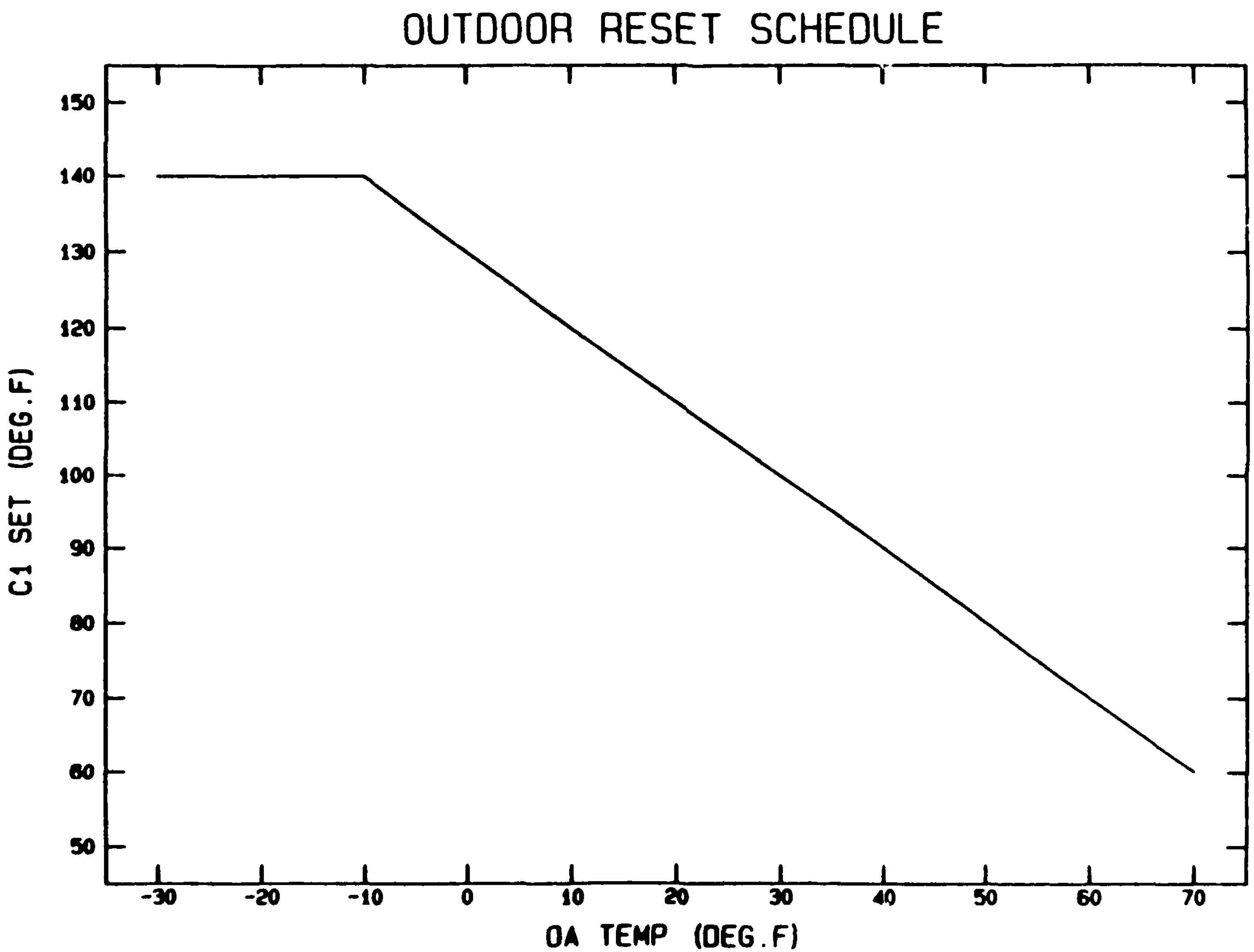


Figure A2-7. Reset Schedule for Hot Water Temperature Controller.

SINGLE ZONE SYSTEM, SMALL SYSTEM - ONE CONTROLLER

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the Single Zone heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan motor starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T3) are located as shown in Fig A3-1. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the fan motor starter, and the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL are energized (through auxiliary contacts M1-1 and M1-2). Auxiliary contact R1-2 (normally closed) opens and de-energizes electrically actuated pneumatic switch EPS1, returning it to its normal position. Thus EPS1 disconnects the damper actuators from their pneumatic control signal and allows the dampers to return to their normal states, preventing outside air from entering the system. Heat is provided through heating coil valve V1 which is regulated by CONTROLLER C1. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. SUPPLY AND MIXED AIR TEMPERATURE CONTROL

1. The mixed air temperature and the supply air temperature are controlled by electronic proportional controller C1 located in the SINGLE ZONE TEMPERATURE CONTROL PANEL.

2. The heating coil hot water valve V1 and the cooling coil chilled water valve V2 are modulated by CONTROLLER C1 using the sensed air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valves V1 and V2 accordingly, maintaining a constant supply air temperature. The set point of controller C1 is the desired room temperature (72 to 74 F).

3. The outside, relief, and return air dampers are also modulated by CONTROLLER C1 using the sensed air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C1 will be higher than the signal from SW1 and its value will be passed to E/P-2, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly.

4. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

5. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

6. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

C. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the heating coil is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

D. INTERLOCKS

Smoke detectors (SD1 and SD2) and low temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures. The ladder schematic on the drawings shows how equipment is to be interlocked.

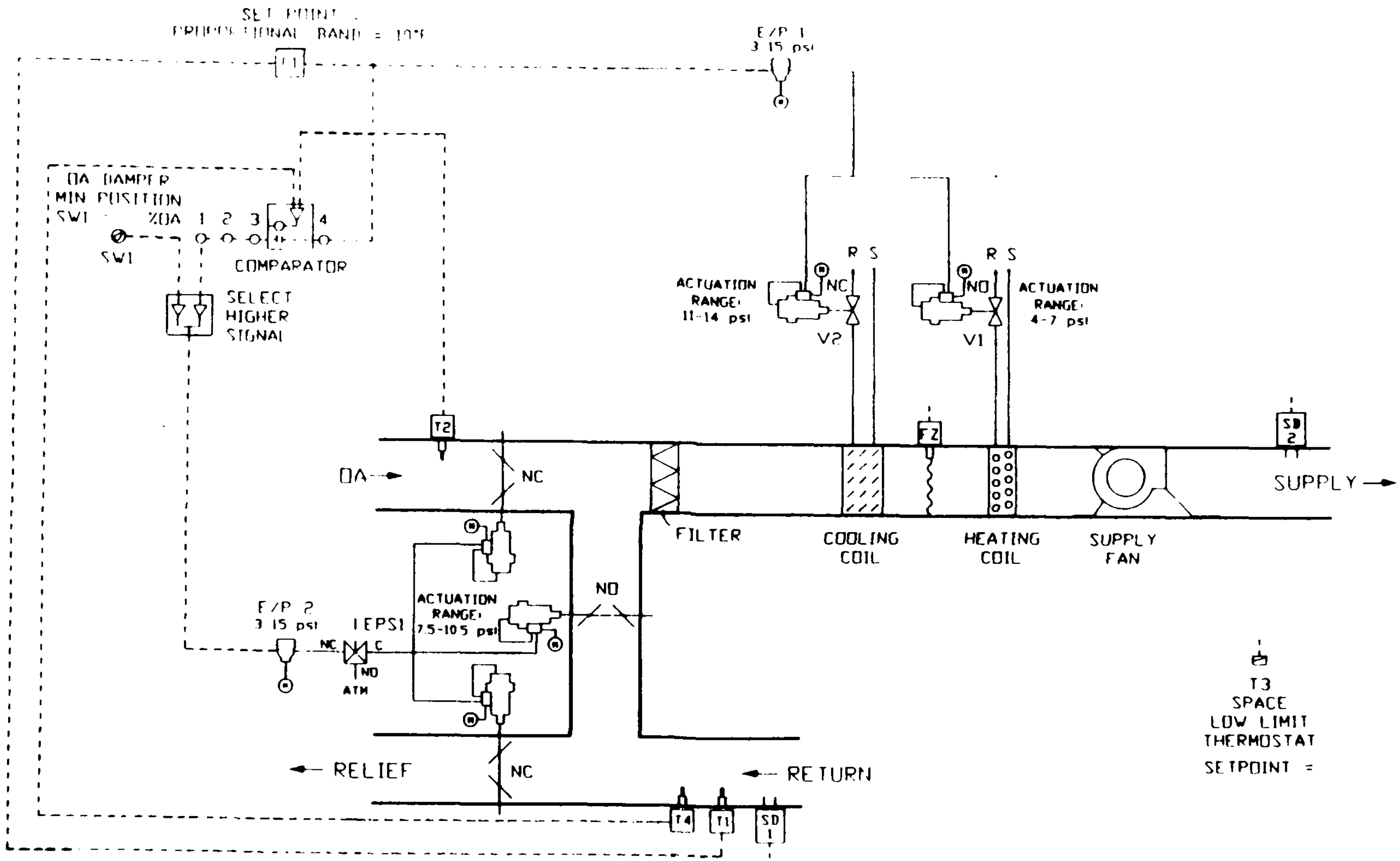


Figure A3-1. Single Zone System with Simple Control

SINGLE ZONE SYSTEM, SEPERATE HEATING AND COOLING CONTROLLERS

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
   1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the Single Zone heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan motor starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T6) are located as shown in Fig. A3-2. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the fan motor starter, and the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL are energized (through auxiliary contacts M1-1 and M1-2). Auxiliary contact R1-2 (normally closed) opens and de-energizes electrically actuated pneumatic switch EPS1, returning it to its normal position. Thus EPS1 disconnects the damper actuators from their pneumatic control signal and allows the dampers to return to their normal states, preventing outside air from entering the system. Heat is provided through heating coil valve V2 which is regulated by CONTROLLER C2. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. MIXED AIR TEMPERATURE CONTROL

1. The mixed air temperature is controlled by electronic PI CONTROLLER C3 located in the SINGLE ZONE TEMPERATURE CONTROL PANEL.

2. The outside, relief, and return air dampers are modulated by CONTROLLER C3 using the sensed mixed air temperature from temperature sensor T3. The output from CONTROLLER C3 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-3, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from CONTROLLER C3 will be higher than the signal from SW1 and its value will be passed to E/P-3, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of CONTROLLER C3 is determined by the output of electronic proportional CONTROLLER C4 using the sensed return air temperature from temperature sensor T4 -- the mixed air temperature controller is reset on the basis of return air temperature.

3. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

4. Hysterisis is required in the comparator relay circuit. if the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

5. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

C. SUPPLY AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by the SINGLE ZONE TEMPERATURE CONTROL PANEL.

2. The heating coil hot water valve V2 is modulated by electronic PI CONTROLLER C2 using the sensed air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to position valve V2, maintaining a constant air temperature leaving the heating coil. The set point of CONTROLLER C2 is determined by the output of electronic proportional CONTROLLER C4 using the sensed return air temperature from temperature sensor T4 -- the heating coil controller is reset on the basis of return air temperature.

3. The cooling coil chilled water valve V1 is modulated by electronic PI CONTROLLER C1 using the sensed supply air temperature from temperature sensor T1. The output from CONTROLLER C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant supply air temperature. The set point of CONTROLLER C1 is determined by the output of electronic proportional CONTROLLER C4 using the sensed return air temperature from temperature sensor T4 -- the cooling coil controller is reset on the basis of return air temperature.

D. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the heating coil is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

E. INTERLOCKS

Smoke detectors (SD1 and SD2) and low temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures The ladder schematic on the drawings shows how equipment is to be interlocked.

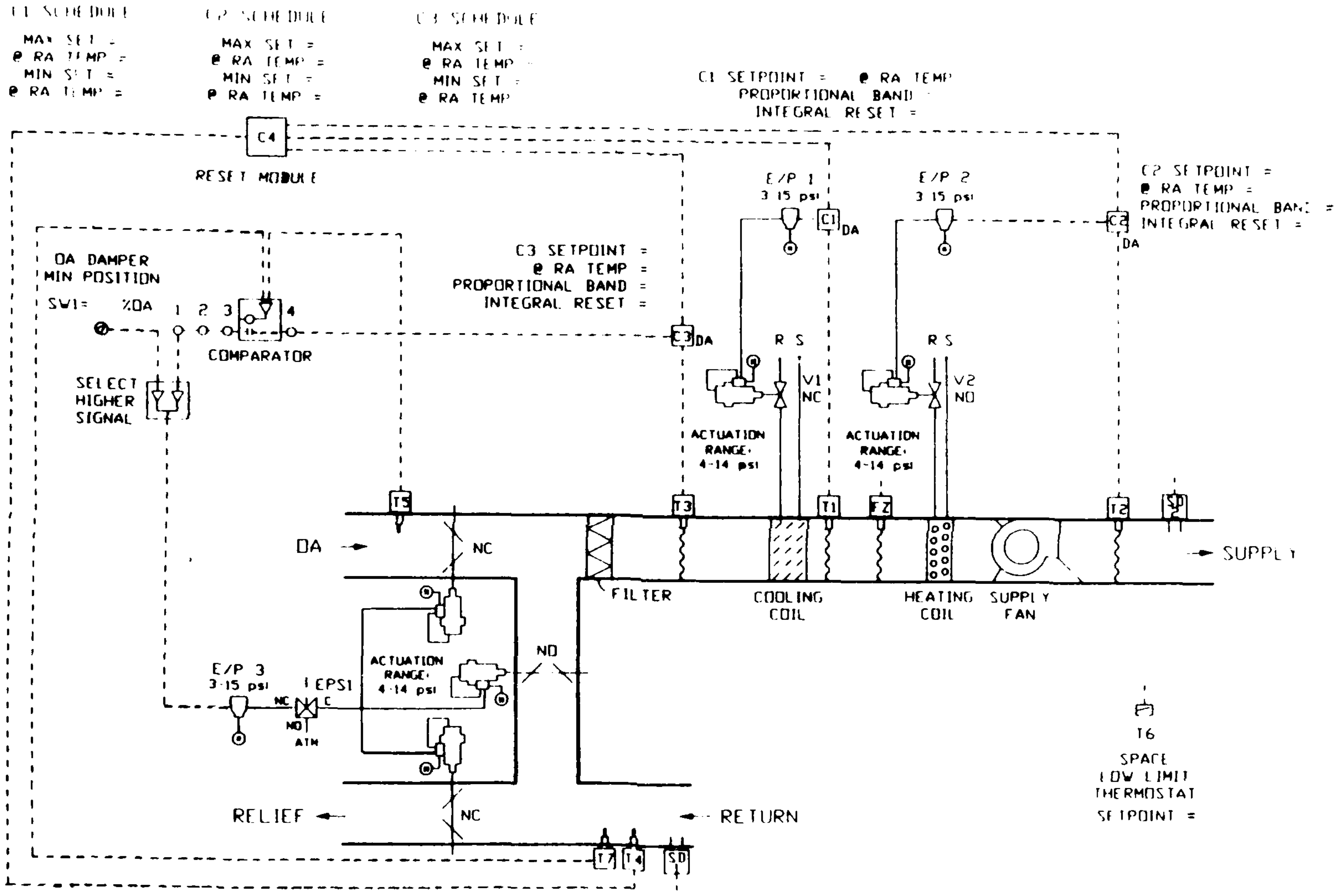


Figure A3-2. Single Zone System with Cascade Control

SINGLE ZONE SYSTEM WITH HUMIDITY CONTROL

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
   1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the Single Zone heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan motor starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T5) are located as shown in Fig A3-3 . If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the fan motor starter, and the SINGLE ZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL are energized (through auxiliary contacts M1-1 and M1-2). Auxiliary contact R1-2 (normally closed) opens and de-energizes electrically actuated pneumatic switch EPS1, return it to its normal position. The switch disconnects the damper actuators from their pneumatic control signal and allow the dampers to return to their normal states, preventing outside air from entering the system. Heat is provided through heating coil valve V2 which is regulated by CONTROLLER C2. On a rise in room temperature, the contacts on the freeze protection thermostats open, returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. MIXED AIR TEMPERATURE CONTROL

1. The mixed air temperature is controlled by electronic PI controller C1 located in the SINGLE ZONE TEMPERATURE CONTROL PANEL.

2. The outside, relief, and return air dampers are modulated by controller C1 using the sensed mixed air temperature from air temperature sensor T1. The output from controller C1 is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by the minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from controller C1 will be higher than the signal from SW1 and its value will be passed to E/P-1, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of controller C1 is 60 F minus the temperature rise across the fan (under full air flow conditions).

3. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

4. Hysterisis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

5. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

C. SUPPLY AIR TEMPERATURE AND HUMIDITY CONTROL

1. The supply air temperature and humidity are controlled by the SINGLE ZONE TEMPERATURE CONTROL PANEL.

2. The heating coil hot water valve V2 is modulated by electronic PI CONTROLLER C2 using the sensed return air temperature from temperature sensor T2. The output from CONTROLLER C2 is connected

to electronic to pneumatic transducer E/P-2, which produces a pneumatic signal to position valve V2, maintaining a constant supply air temperature. The set point of controller C2 is 68 F.

3. The cooling coil face and bypass dampers are modulated by electronic PI CONTROLLER C3 using the sensed air temperature from temperature sensor T3. The output from CONTROLLER C3 is connected to electronic to pneumatic transducer E/P-3, which produces a pneumatic signal to position face and bypass dampers accordingly, maintaining a constant supply air temperature. The set point of CONTROLLER C3 is 60 F.

4. The humidifier valve V1 is modulated by electronic proportional CONTROLLER C4 using the signal from supply air humidity sensor H2. The output of CONTROLLER C4 goes to electronic to pnuematic transducer E/P-4, which produces a pneumatic signal to position valve V1. The set point of CONTROLLER C4 is reset from electronic PI CONTROLLER C5 which uses the signal from return air humidity sensor H1.

D. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the heating coil is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

E. INTERLOCKS

Smoke detectors (SD1 and SD2) and low temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures The ladder schematic on the drawings shows how equipment is to be interlocked.

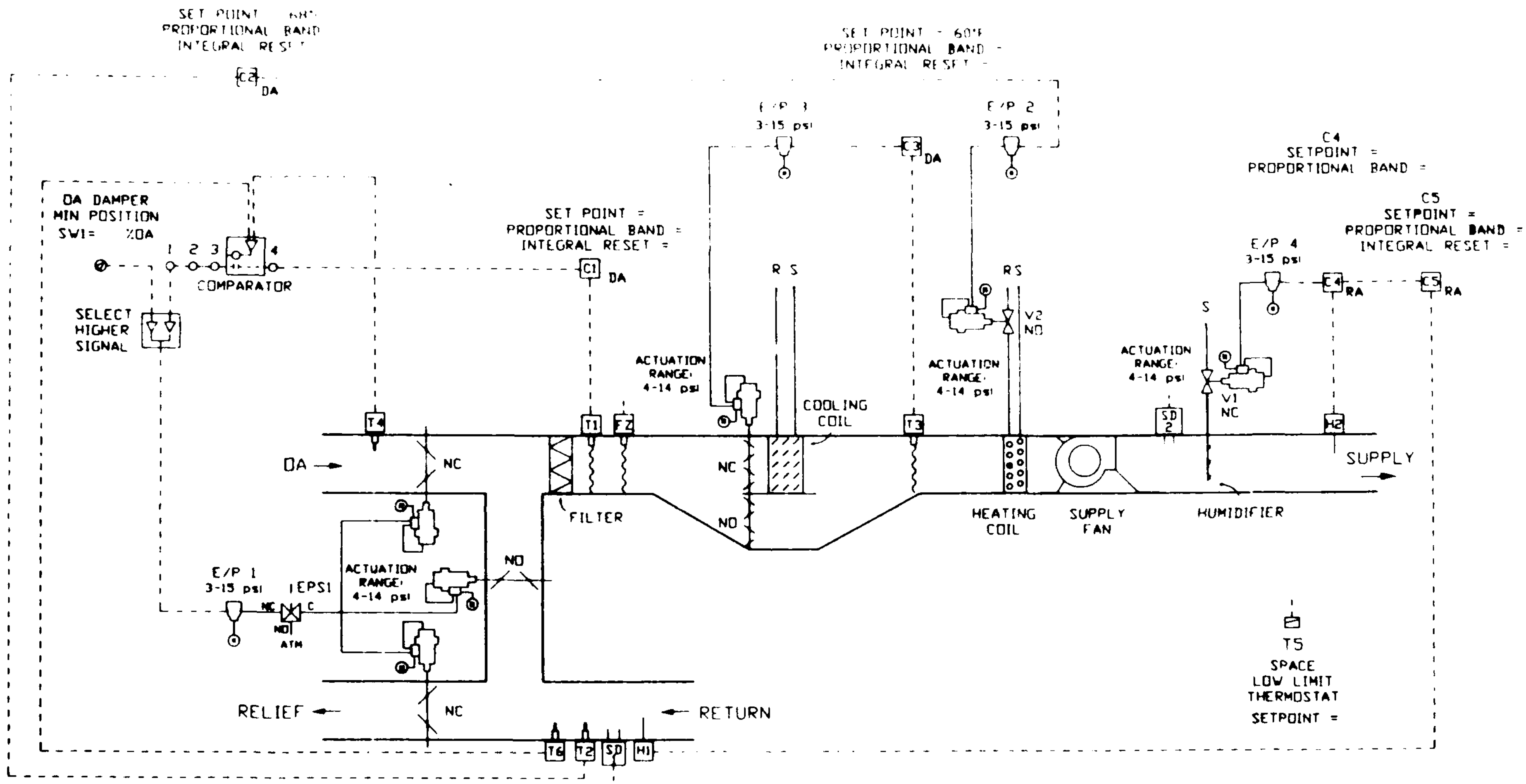


Figure A3-3. Single Zone System with Humidity Control

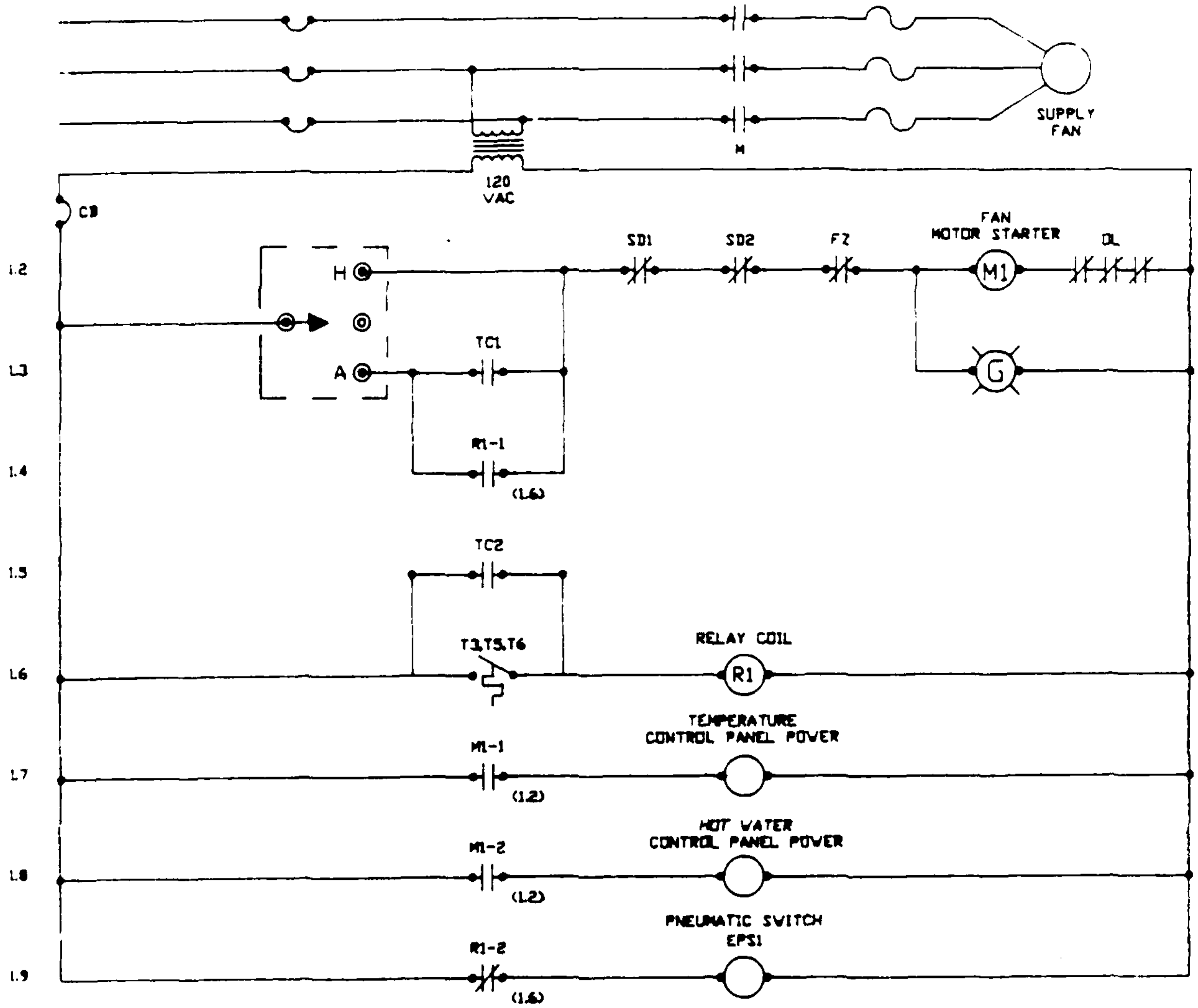


Figure A3-4. Ladder Diagram for Single Zone Systems

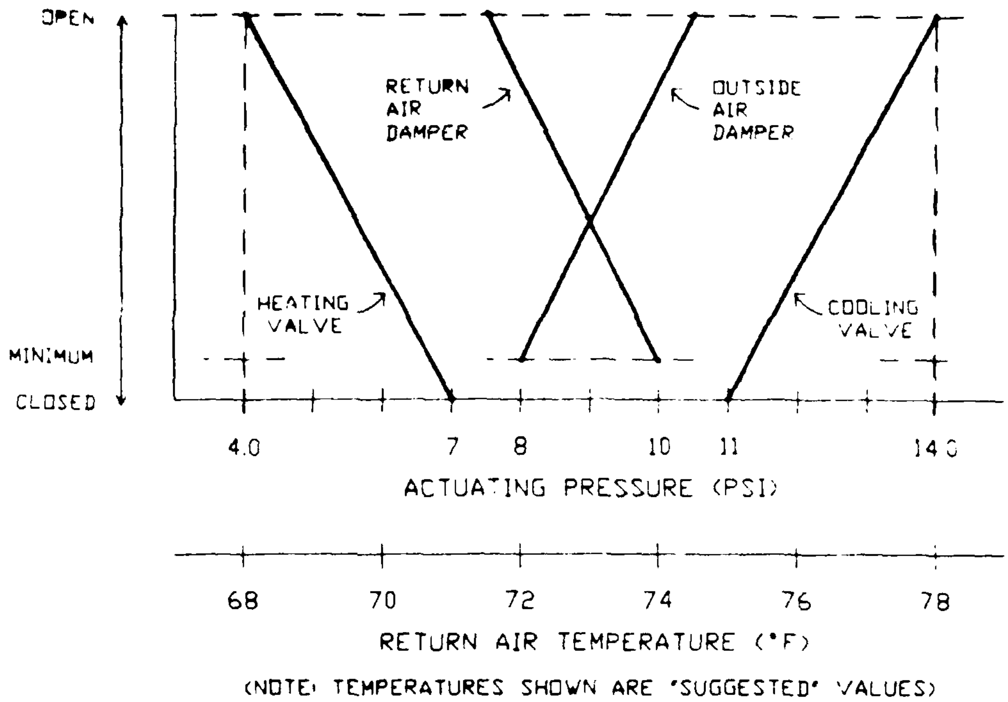


Figure A3-5. Temperature Control Profile for Single Zone System with Simple Control

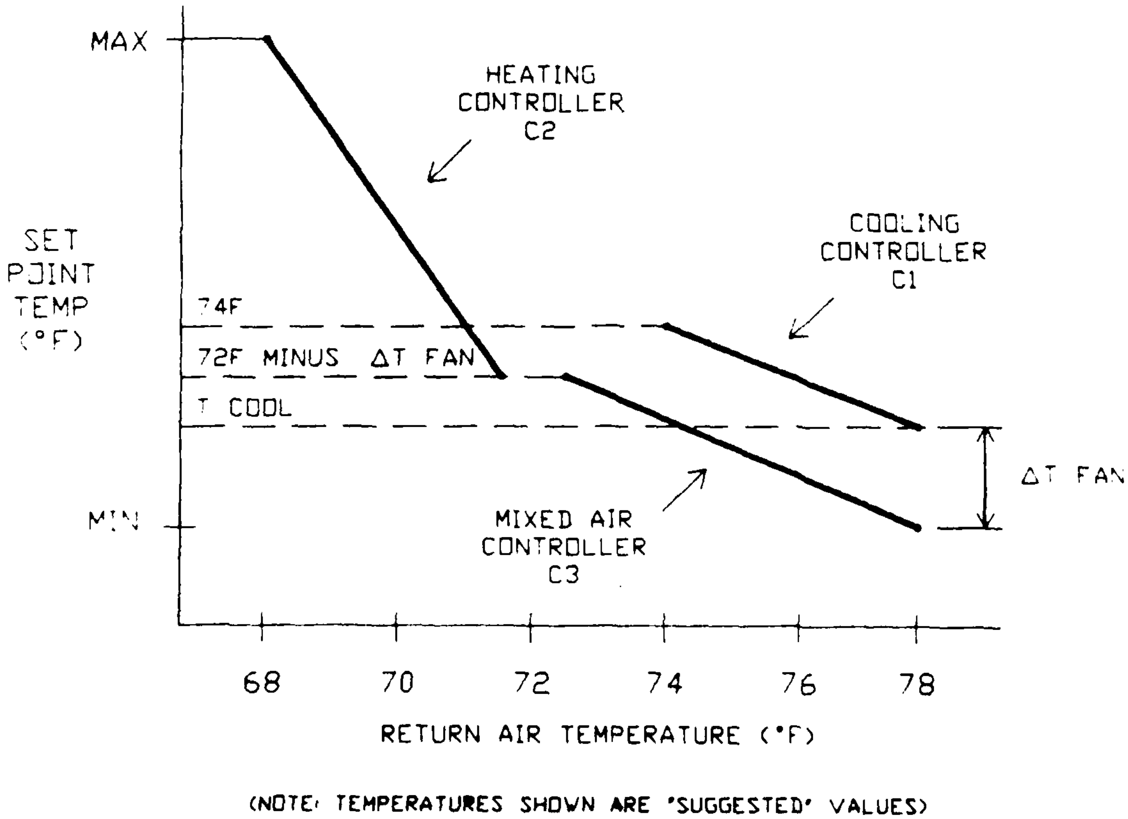


Figure A3-6. Controller Reset Schedule for Single Zone System with Cascade Control

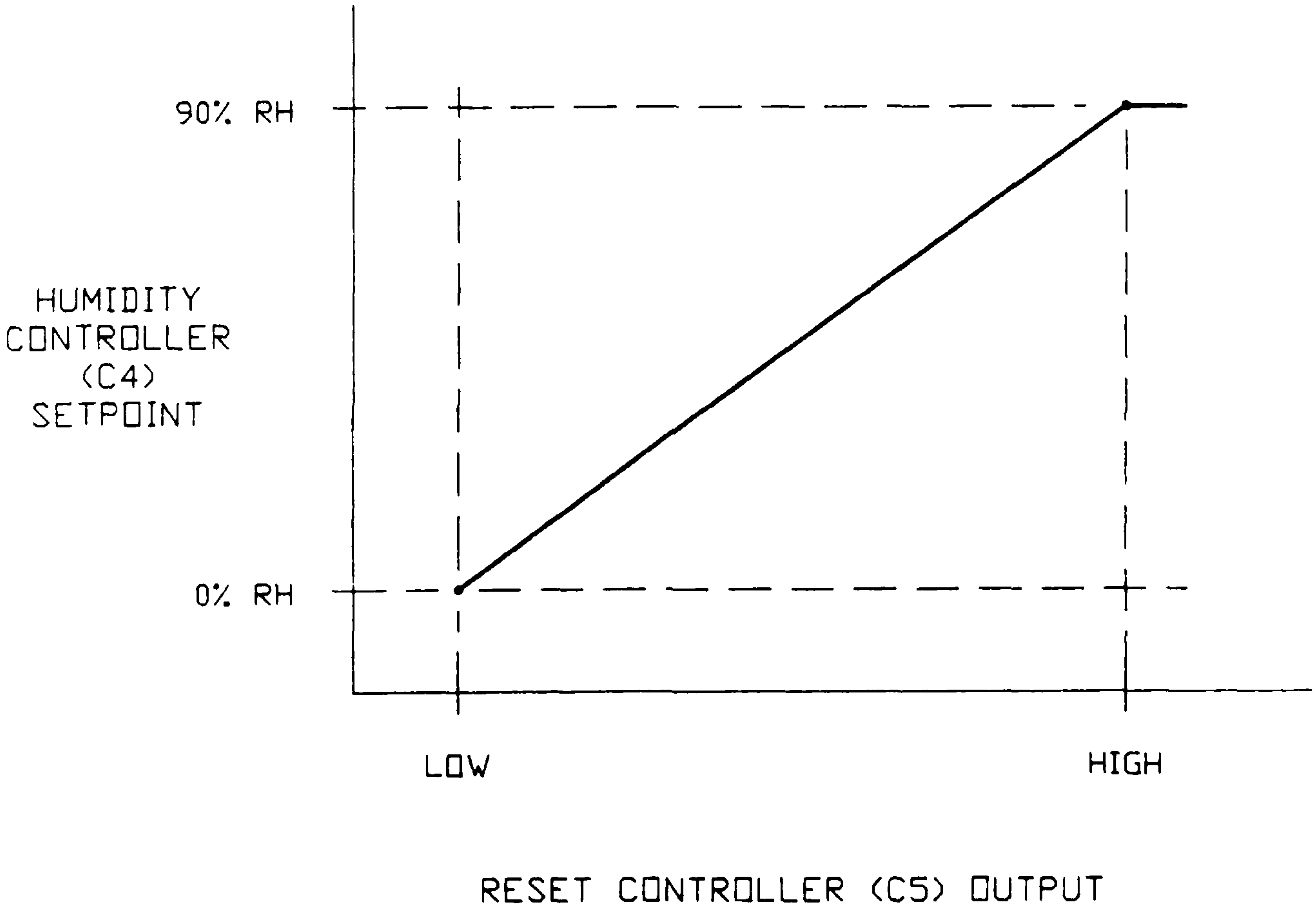


Figure A3-7. Humidity Reset Schedule for Single Zone System with Humidity Control

MULTIZONE SYSTEM

SEQUENCE OF OPERATION

A. START-UP

1. The supply fan may be started and stopped in one of two ways:
   1.1 Manually: the "HAND, OFF, AUTO" (H-O-A) switch on the fan motor starter can be set in the "HAND" (or "ON") position to start the fan and in the "OFF" position to stop the fan.
   1.2 Automatically: with the fan motor starter switch in the "AUTO" position, the Multizone heating and air conditioning system has three modes of operation - off, normal, and warm-up.

2. Normal operation is initiated (usually at the beginning of the working day) by a contact closure from local time clock switch TC1, or in some applications, a remote energy monitoring and control system (EMCS) may be used. This contact closure provides power to the fan motor starter. Power to the MULTIZONE TEMPERATURE CONTROL PANEL and the HOT WATER TEMPERATURE CONTROL PANEL is supplied through auxiliary contacts M1-1 and M1-2 on the supply fan motor starter.

3. At the end of the occupied period, time clock switch TC1, or the remote EMCS, de-energizes the fan motor starter relay, consequently interrupting power to all the control panels.

4. To guard against freezing in the building, two-position low-limit electric freeze protection thermostat(s) (T7) are located as shown in Fig A4-1. If the temperature drops below the set point of any of the freeze protection thermostat(s), relay R1 is energized. Through auxiliary contact R1-1, power is supplied to the fan motor starter. Auxiliary contact R1-2 (normally closed) opens and the MULTIZONE TEMPERATURE CONTROL PANEL remains de-energized. Through auxiliary contact M1-2, the HOT WATER TEMPERATURE CONTROL PANEL is energized and, through an electric-to-pneumatic switch (not shown), pressure is supplied to the room thermostats. With no power to the MULTIZONE TEMPERATURE CONTROL PANEL, the outdoor air dampers and the cooling coil valve remain closed. The heating coil valve remains in its normally open state and the fan delivers warm air to the zones. On a rise in room temperature, the contacts on the freeze protection thermostats open returning the system to the off state.

5. To provide a preoccupancy warm-up cycle, an auxiliary contact on time clock switch TC2, or in some applications, remotely energized contacts from an EMCS system, are energized for a period before occupancy. Closure of these contacts has exactly the same effect as the closure of contacts on one of the freeze protection thermostats. At the end of the warm-up period, the system begins normal operation.

B. MIXED AIR TEMPERATURE CONTROL

1. The mixed air temperature is controlled by electronic PI CONTROLLER C3 located in the MULTIZONE TEMPERATURE CONTROL PANEL.

2. The outside, relief, and return air dampers are modulated by CONTROLLER C3 using the sensed mixed air temperature from temperature sensor T3. The output from CONTROLLER C3 passes through OFF TEMP relay contact which disables economizer operation during cold periods. The OFF TEMP relay is connected to the comparator relay which will pass the controller signal only if the outdoor air temperature is less than the return air temperature. The electronic high signal selector compares the signal from the comparator with the voltage produced by minimum positioning adjustment knob SW1. If the output from the comparator is less than the output from SW1, the minimum positioning signal will be passed to electronic to pneumatic transducer E/P-3, which produces a pneumatic signal to hold the outside and relief air dampers at their minimum position. When more than minimum outdoor air is economical, the signal from controller C3 will be higher than the signal from SW1 and its value will be passed to E/P-3, which will produce a pneumatic signal to position the outside, relief, and return air dampers accordingly. The set point of controller C3 is 60 F.

3. Remote EMCS economizer control is possible through the use of economizer contacts 1, 2, 3, and 4. With contacts 3 and 4 open, and 1 and 2 shorted, the economizer works as described above. With 3 and 4 shorted, and 1 and 2 shorted, the comparator is bypassed and the control signal sent directly to the high signal selector. With 1 and 2 open, the minimum position signal holds the dampers in their minimum position.

4. Hysterisis is required in the comparator relay circuit. If the comparator relay is open, the outdoor air temperature must fall to approximately 2.0 F below the return air temperature before the relay closes and if the relay is closed, the outdoor air temperature must rise to equal the return air temperature before the relay opens.

5. When the system is off (no power to the control panels) ,the outdoor air dampers return to their normally closed position.

C. SUPPLY AIR TEMPERATURE CONTROL

1. The supply air temperature is controlled by the MULTIZONE TEMPERATURE CONTROL PANEL.

2. The heating coil hot water valve V2 is modulated by electronic PI controller C2 using the sensed hot deck air temperature from temperature sensor T2. The output from controller C2 is connected to electronic to pneumatic transducer E/P-2, which produces a

pneumatic signal to position valve V2, maintaining a constant hot deck air temperature. The set point of controller C2 is determined by the output of electronic proportional controller C4 using the sensed outdoor air temperature from temperature sensor T4 -- the heating coil controller is reset on the basis of outdoor air temperature.

3. The cooling coil chilled water valve V1 is modulated by electronic PI controller C1 using the sensed cold deck air temperature from temperature sensor T1. The output from controller C1 is connected to electronic to pneumatic transducer E/P-1, which produces a pneumatic signal to position valve V1, maintaining a constant cold deck air temperature. The set point of controller C1 is 58 F.

D. ROOM AIR TEMPERATURE CONTROL

Room air temperature control is achieved by pneumatic room thermostats modulating individual mixing dampers.

E. HOT WATER TEMPERATURE CONTROL

The temperature of hot water supplied to the heating coil is controlled by the HOT WATER TEMPERATURE CONTROL PANEL as described in the section on "HOT WATER CONTROL SYSTEM".

F. INTERLOCKS

Smoke detectors (SD1 and SD2) and low temperature safety switch (FZ) are wired in series with fan motor starter relay M1 to stop the fan in the event of smoke or extremely low temperatures The ladder schematic on the drawings shows how equipment is to be interlocked.

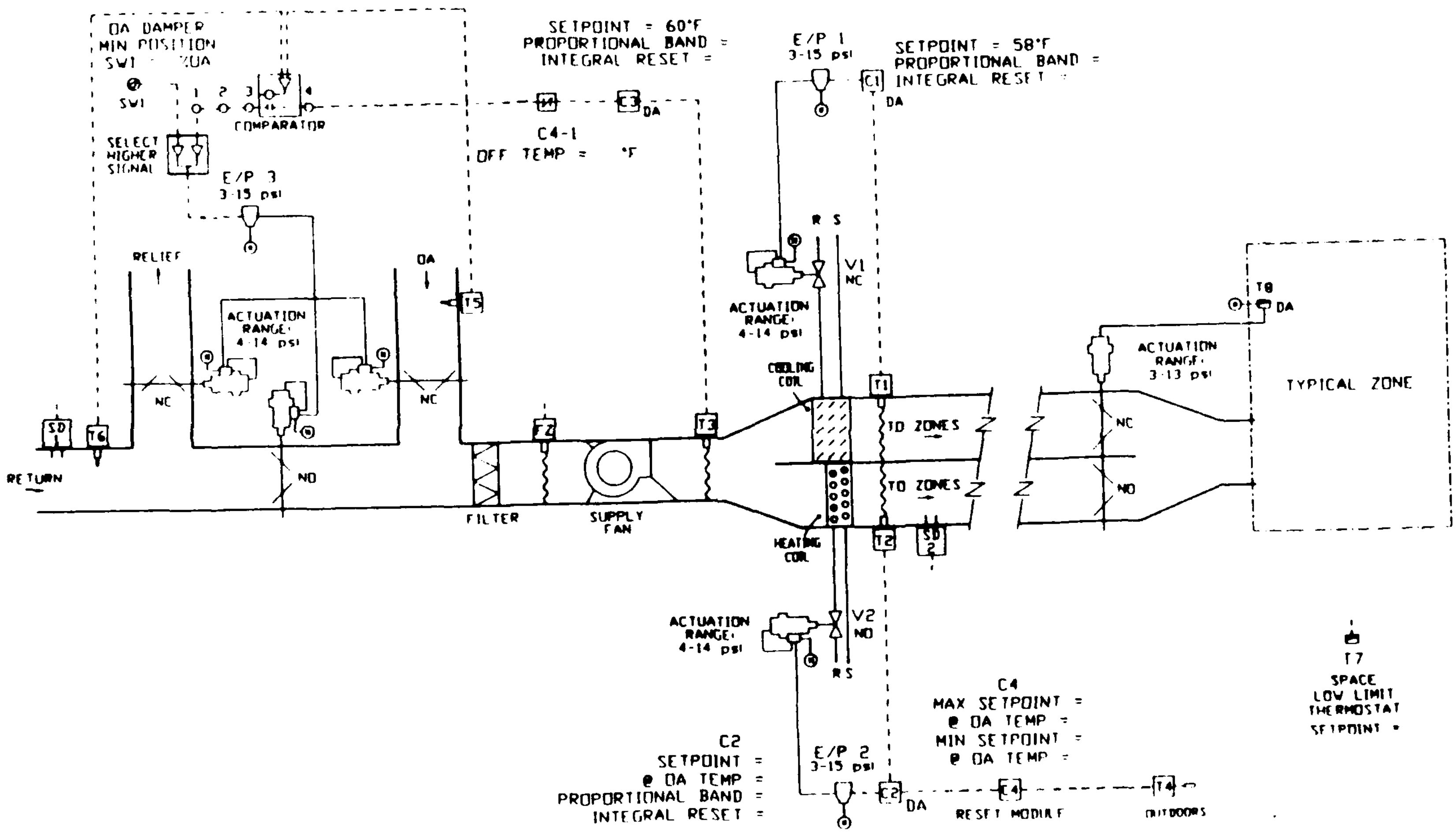


Figure A4-1. Multizone System Temperature Control Diagram

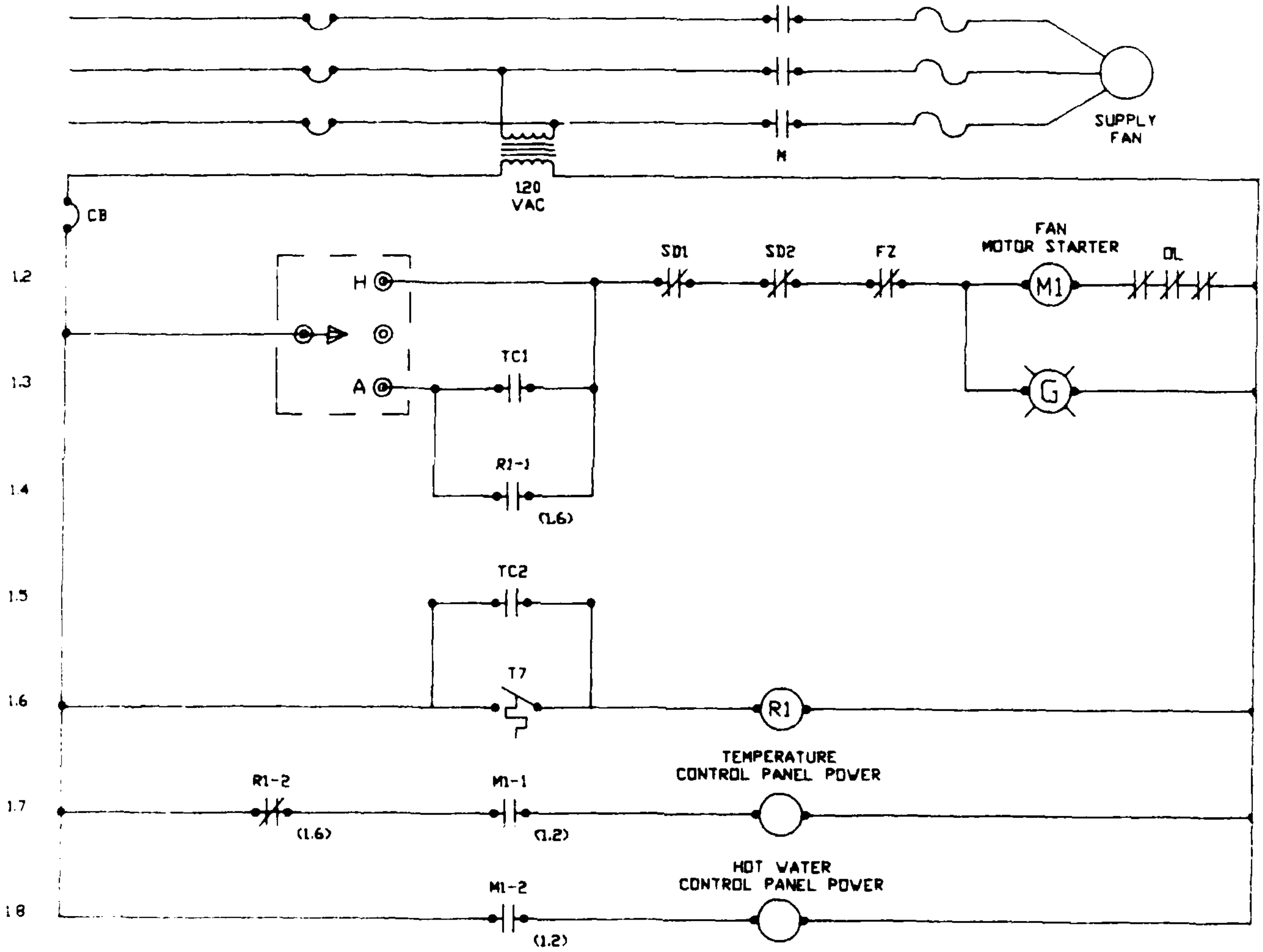


Figure A4-2. Ladder Diagram for Multizone System

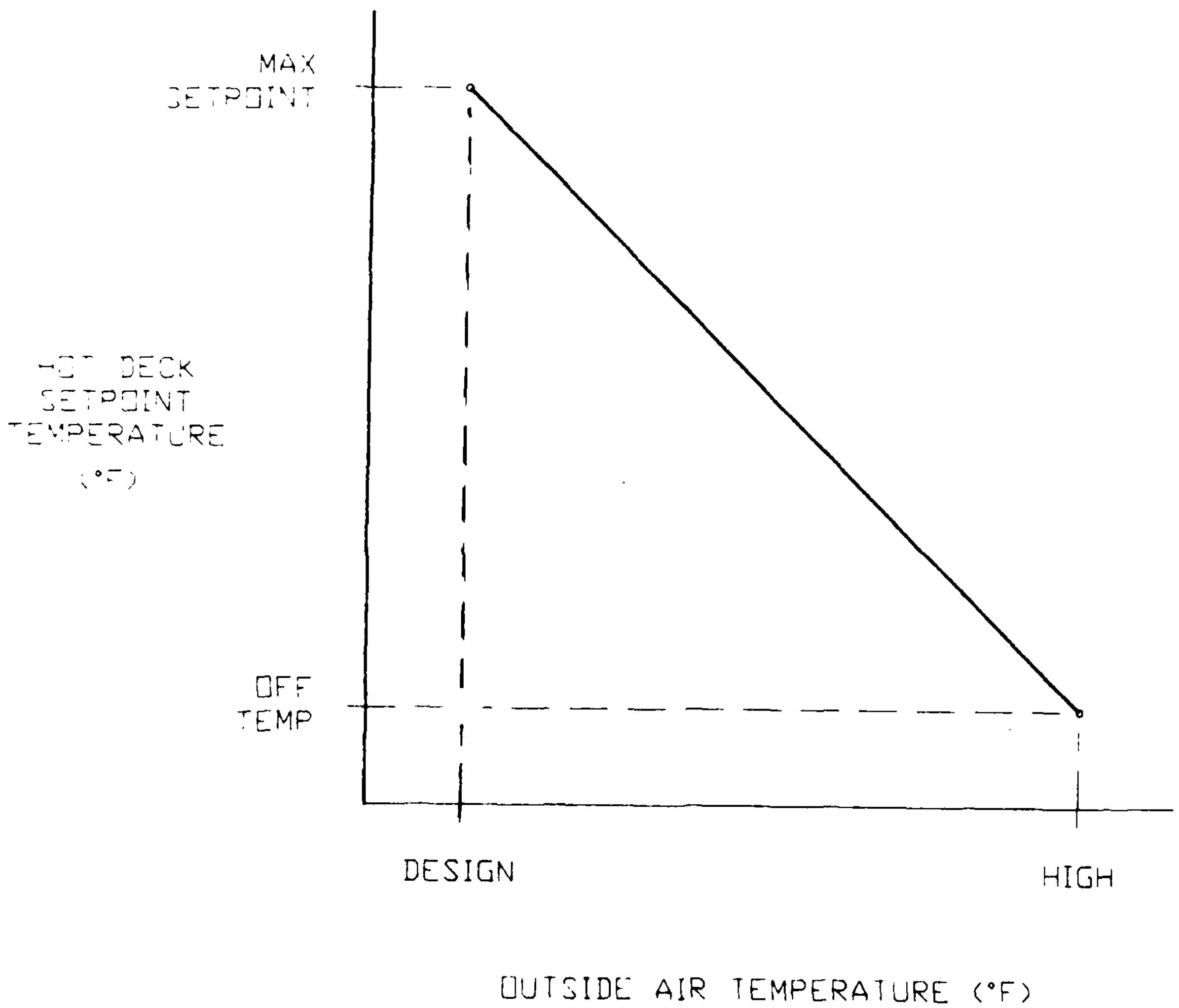


Figure A4-3. Hot Deck Controller Reset Schedule for Multizone System

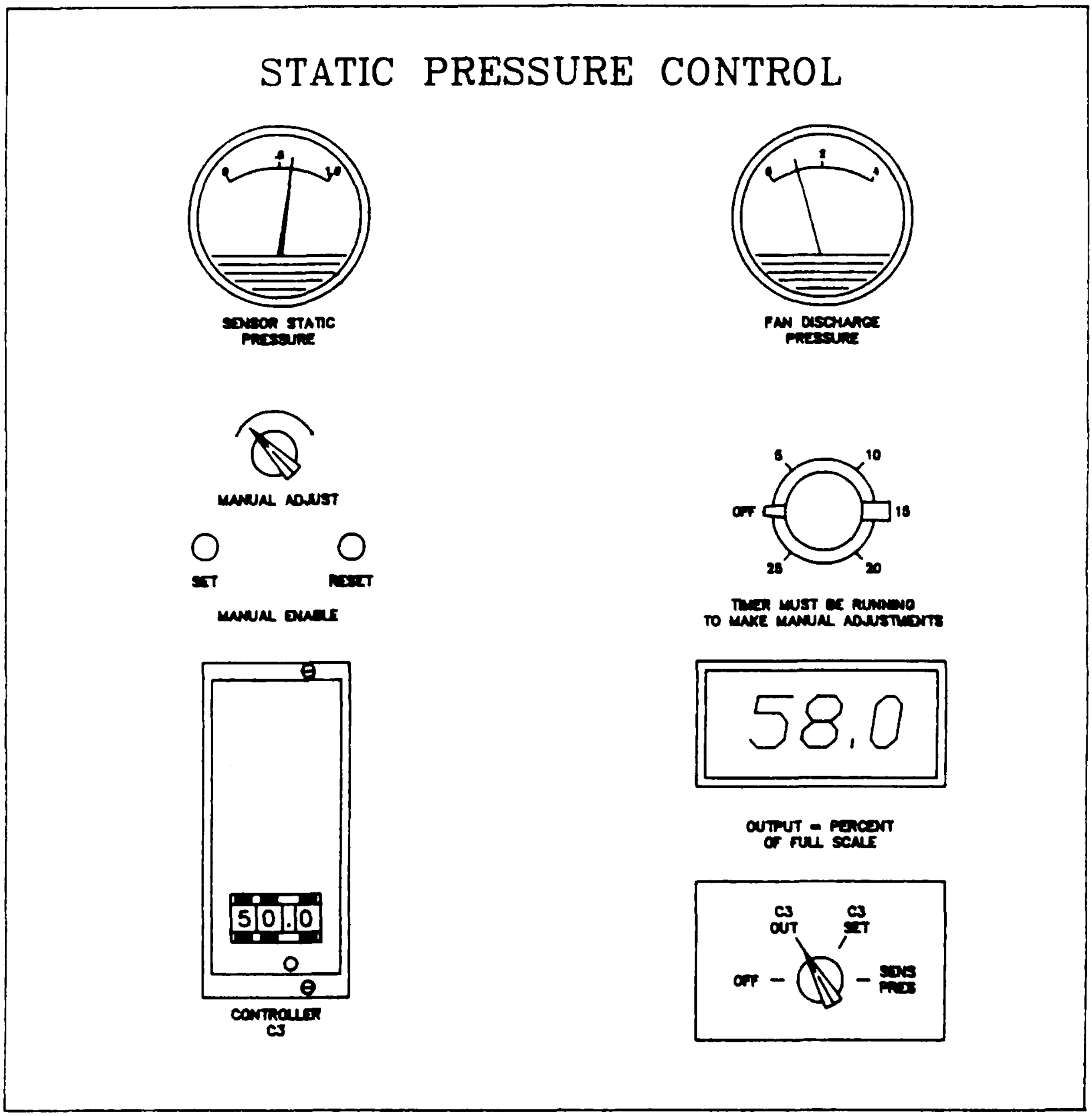


Figure A5-1. Static Pressure Control Panel for FSC System.

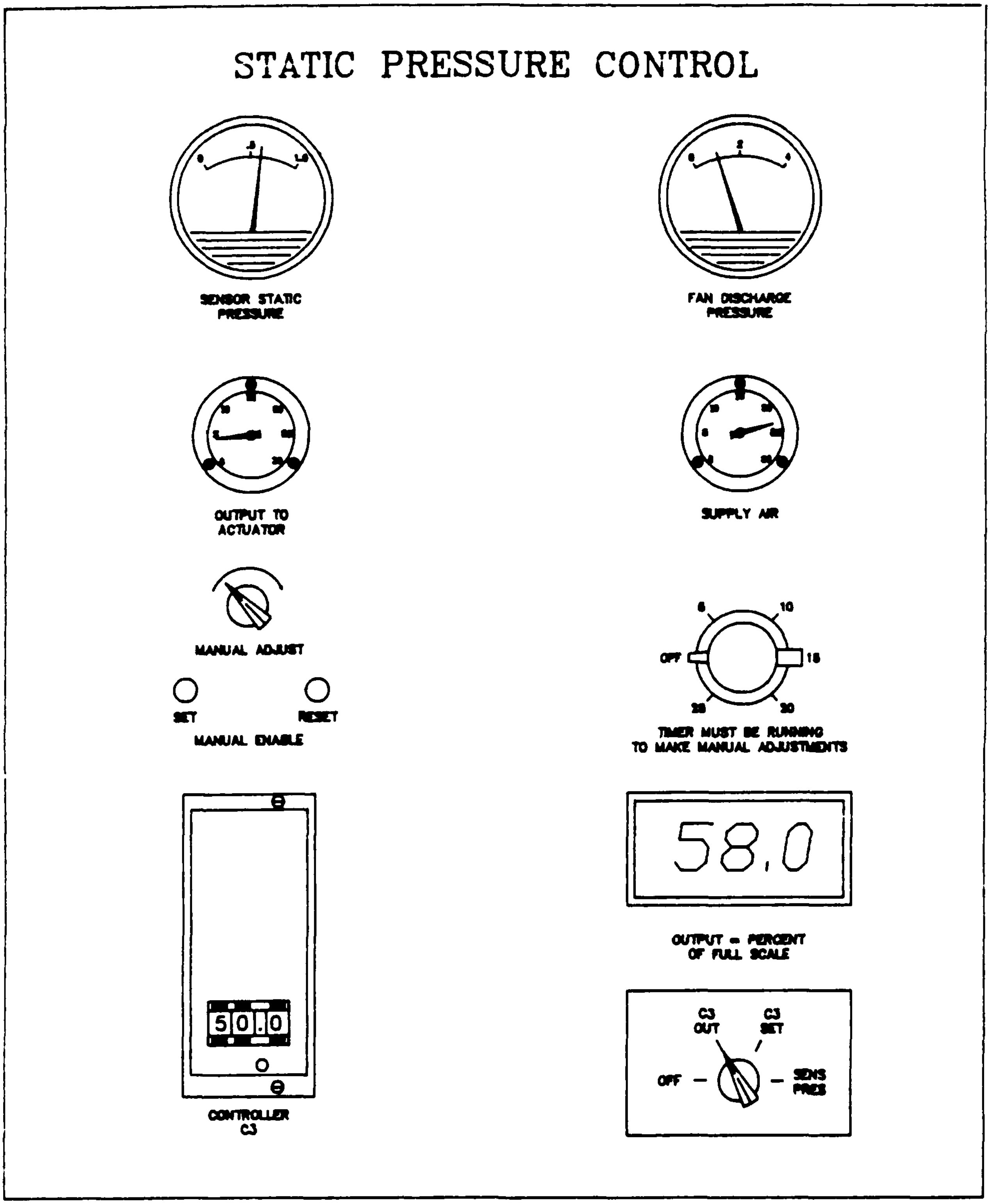


Figure A5-2. Static Pressure Control Panel for IVD System.

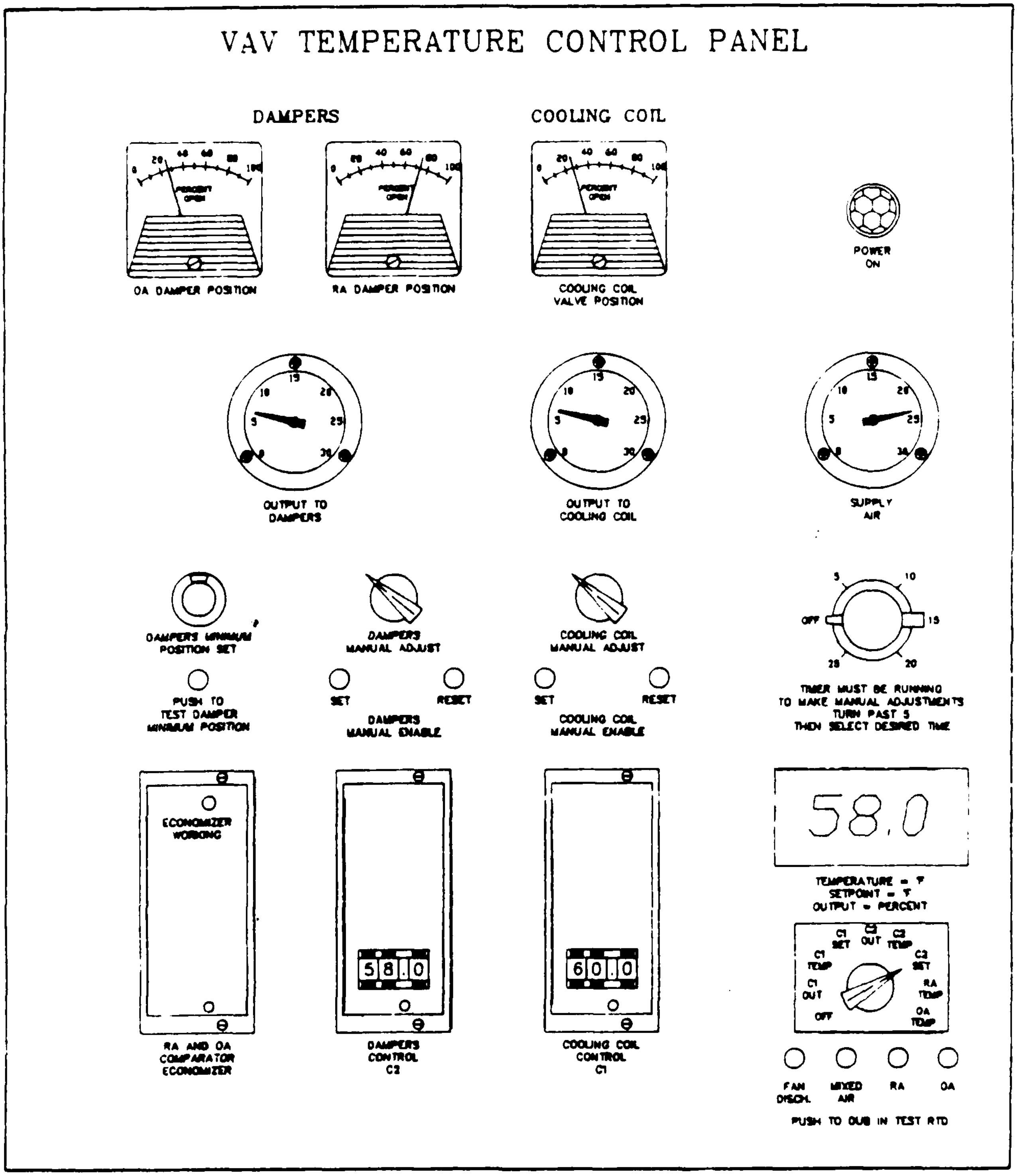


Figure A5-3. VAV Temperature Control Panel.

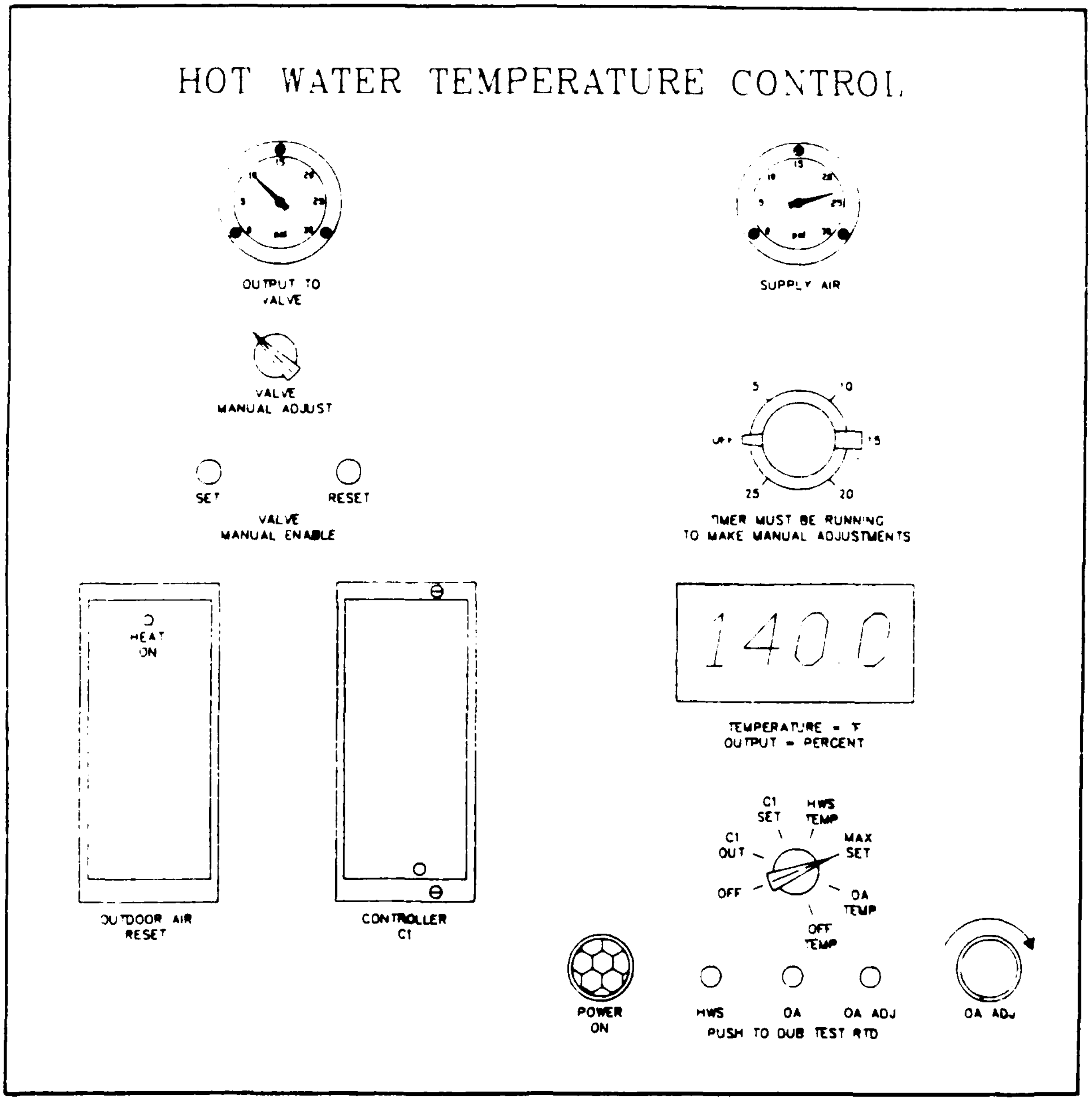


Figure A5-4. Hot Water Temperature Control Panel.

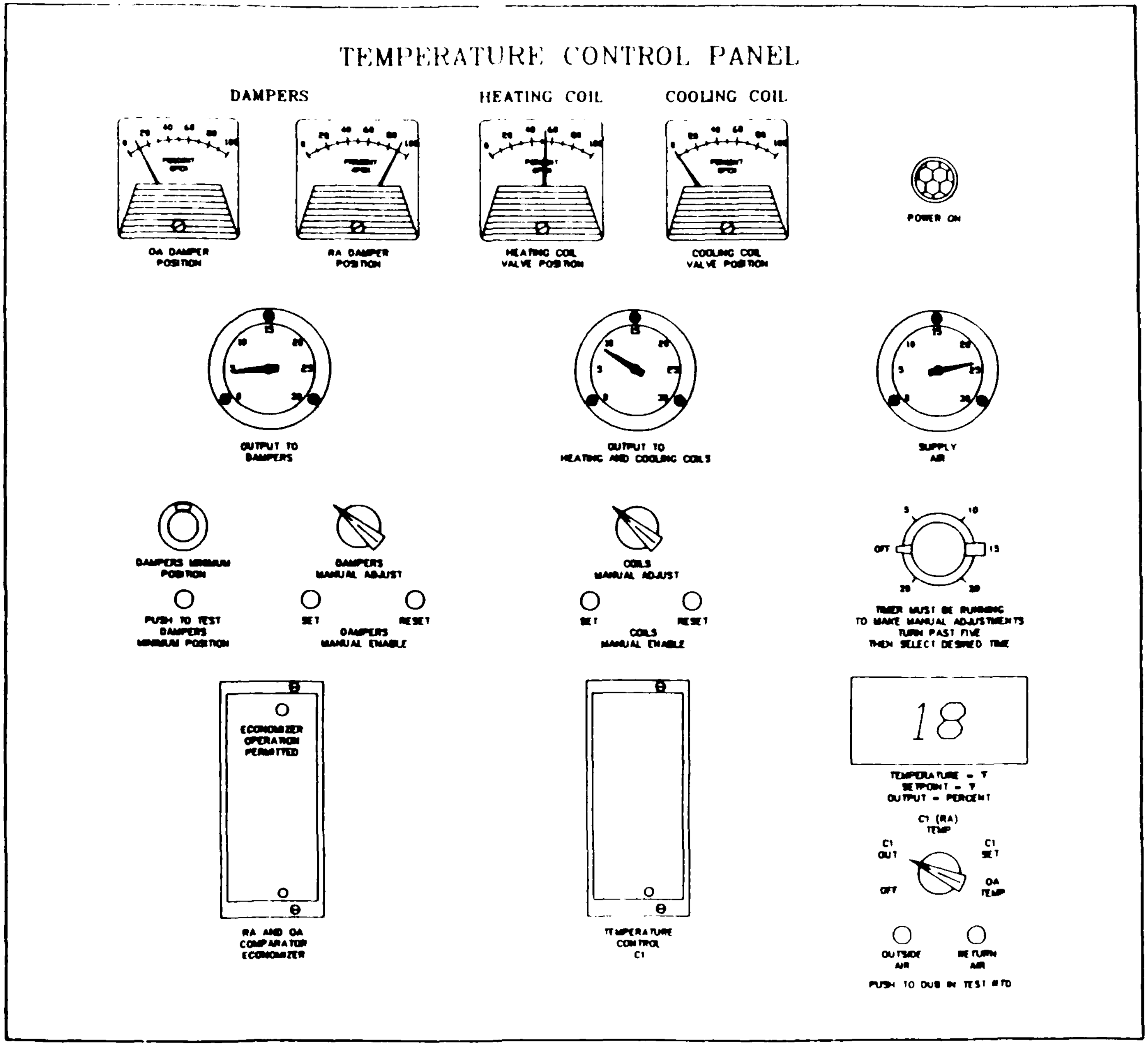


Figure A5-5. **Temperature Control Panel for Single Zone System with One Controller.**

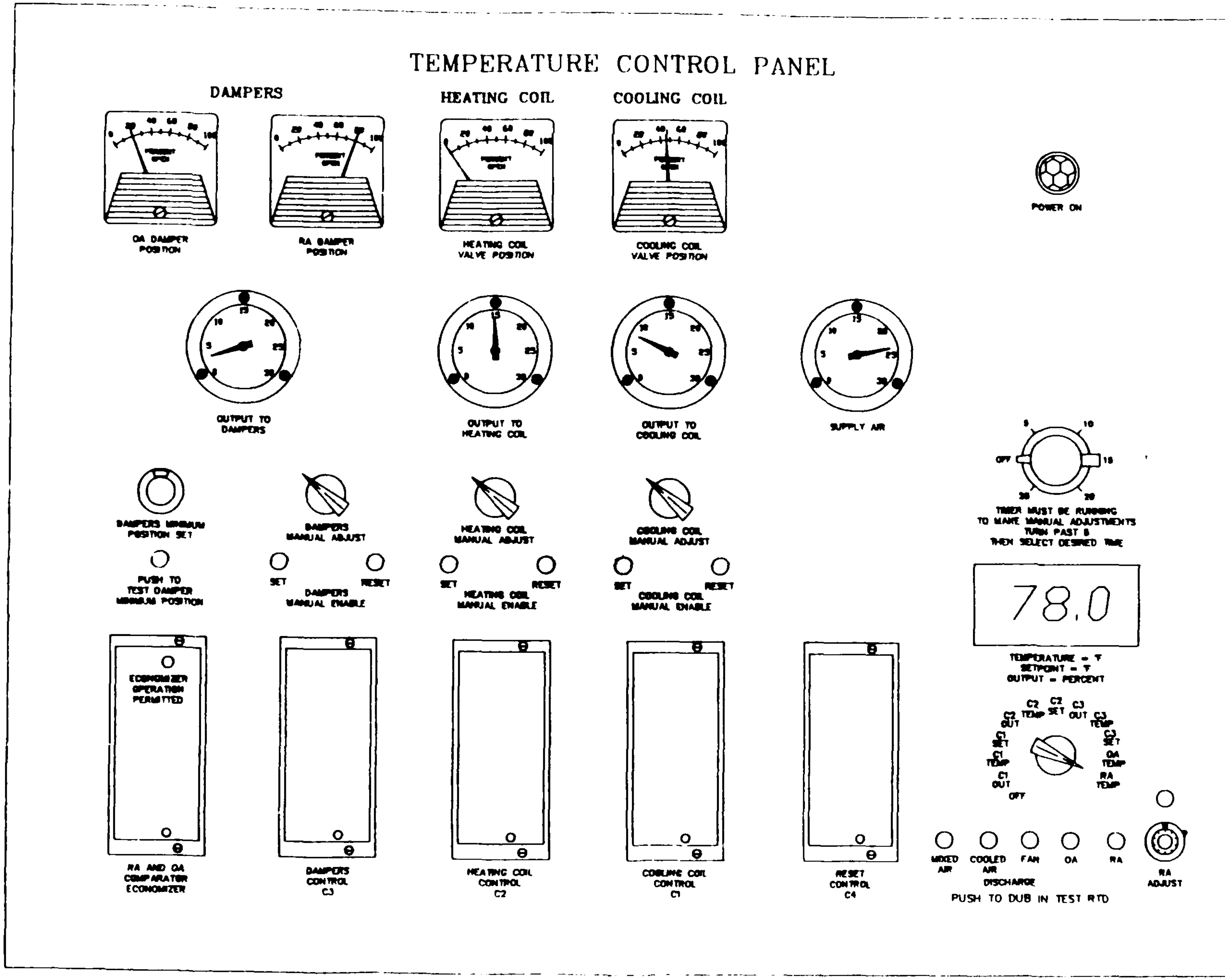


Figure A5-6. **Temperature Control Panel for Single Zone System with Cascade Control.**

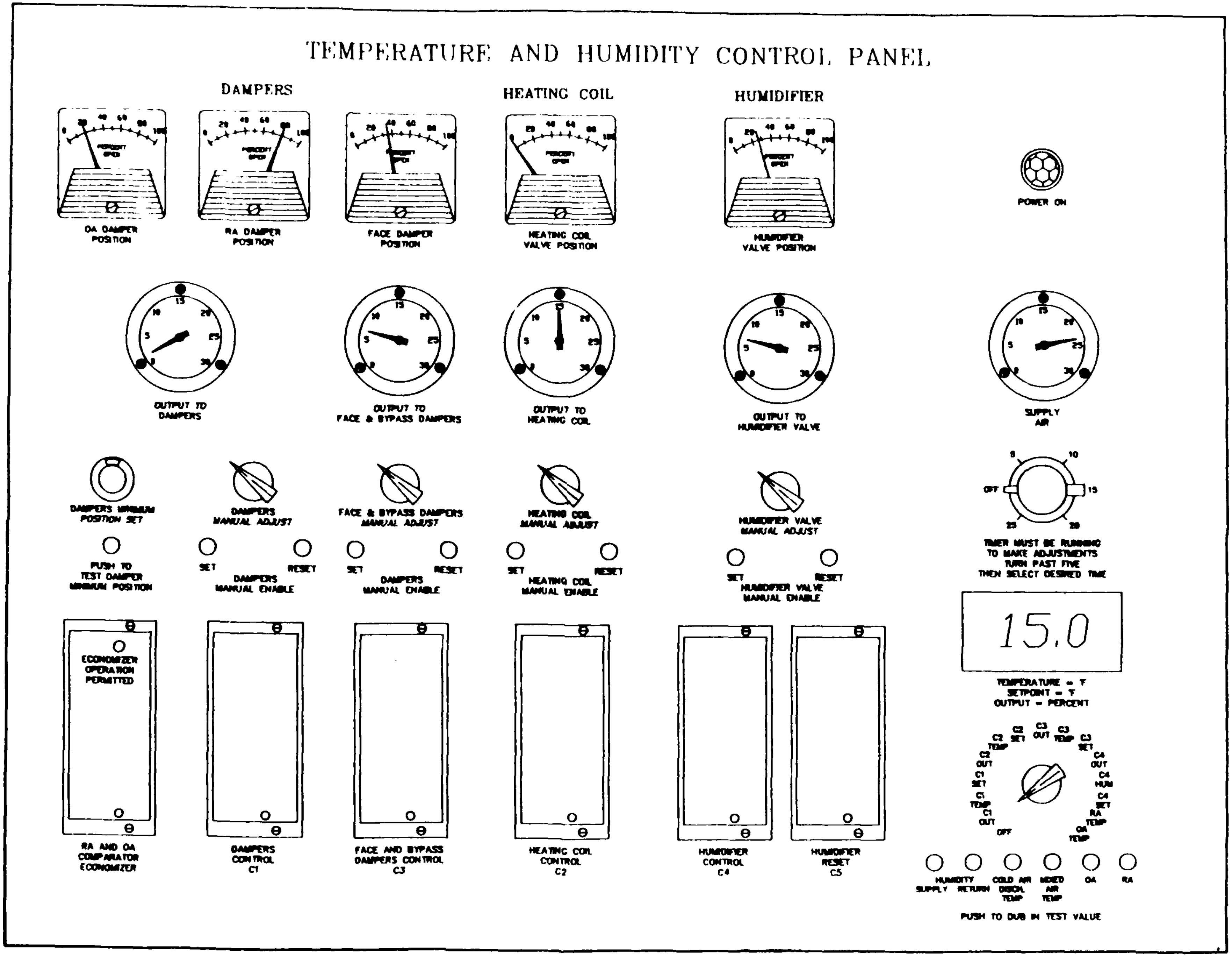


Figure A5-7. **Temperature and Humidity Control Panel for Single Zone System.**

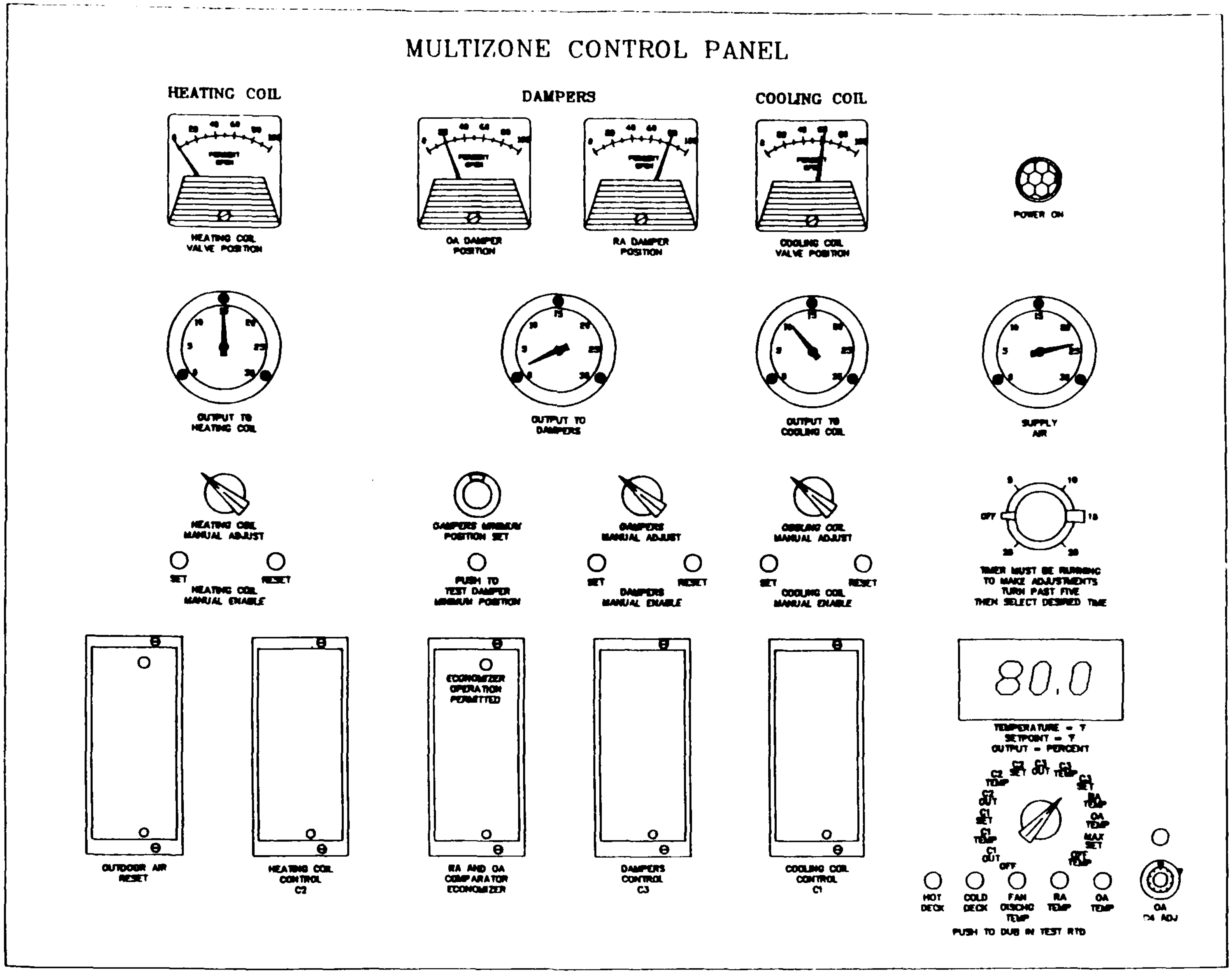


Figure A5-8. Multizone Control Panel.

APPENDIX B:

INSTRUCTION AND TEST PLAN: ENERGY SAVINGS OF RETROFIT CONTROLS, APPLIED INSTRUCTION BUILDING, FORT LEONARD WOOD, MO

I INTRODUCTION

In this report, we have first discussed a general conceptual framework for field testing when time and cost resources are limited. We have then developed Fort Leonardwood installation as an example of a field test using the approach discussed in the conceptual framework.

The U.S. Army Construction Engineering Research laboratory (USA-CERL) has installed three HVAC control panels as retrofits to existing HVAC control panels in the Applied Instruction Building at Fort Leonard-wood, Missouri. The three panels are:

- Hot Water Reset Control Panel
- VAV Temperature Control Panel
- Static Pressure Control Panel

The new control panels are installed in parallel to the existing control panels. This allows the systems to be controlled by either the new panel or the old panel as desired.

The primary objective of this instrumentation and test plan is to specify the tests, procedures and instrumentation for testing the new control panels and the old control panels with the intent of estimating energy savings attributable to the new control panels.

The test plans will focus of tests where some variables are held constant to study the effect of specific parameters on energy use and energy savings between the old and new panels. The test plans next go into operation of the control panels under field operating conditions where none of the parameters are controlled but data is collected on all parameters.

In order to accomplish the goal of estimated energy savings, the accuracy of data gathered is critically important. We have, therefore, specified instrumentation and pre-installation procedures to be followed in obtaining the data.

II CONCEPTUAL FRAMEWORK FOR FIELD TESTING

A. GENERAL CONCEPTS

Field testing of specific heating, ventilating, air condition equipment and associated controls entails data gathering over substantially long timeframes in order to make fairly accurate assessments of the technologies, equipment, operating strategies involved in field testing. The majority of the time such long timeframes are too expensive in terms of the cost and time resources necessary. In order to reduce the resource requirements and at the same time, maintain sufficient accuracy, we have developed a field testing approach and an instrumentation plan in this document.

The conceptual framework within which such field tests should be carried out consists of controlled tests and field conditions tests.

The controlled tests are performed with specific parameters held constant or eliminated from impacting the dependent variables. For example, to study the impact of out door conditions on energy consumption, we might eliminate or hold constant the internal loads in a building. Next, we may study the impact of internal loads on energy consumption in the absence of weather dependent loads. This may be done by imposing known internal loads in an internal zone and studying the impacts of known internal loads on energy consumption.

Using controlled test such as the ones described above, we can determine relationships between each major independent variable on a specific dependent variable.

Next step is to conduct the field tests under usual operating conditions of the building. Many interactions between the independent variables will now come into play and their combined impacts on the dependent variable (e.g., energy consumption) will be measured. These field tests under real field conditions can be carried out for a shorter period of time with values of the independent variables such as weather parameters measured at each point in time.

The final step is to use the relationships obtained from controlled tests to extrapolate the field conditions tests to an entire season. In order to do this, the profile of the independent variables such as weather data, occupancy schedules, etc. have to be obtained from other sources or assumptions made based on historical data.

B. FORT LEONARDWOOD EXAMPLE

The tests described in Section VI "Test Plans and Procedures" apply to the field testing of 2 types of control panels. The first set of 3 control panels are pneumatic controls as found in the existing buildings and the second set of 3 control panels are electronic controls developed by CERL and installed by them in the same building.

For the hot water reset panels, two controlled tests and one field conditions test are described. The first controlled test is performed with internal loads kept almost negligible. This is achieved by performing the test from 7 p.m. on a Friday to 6 a.m. on a Monday morning during a weekend when building is totally unoccupied. The expected outputs from this test will be the profile for energy usage over the unoccupied time period for both the pneumatic controls and the electronic controls. The pneumatic control panel profile is likely to show greater swings than the electronic control panel. The mean energy consumption at any give time is likely to be higher for the pneumatic controller as compared to the electronic controller.

Controlled test #2 for the hot water reset would be conducted with the ventilation and all lights on. This would impose a known internal load. Energy use profiles will be developed as in test #1.

The differences in energy use profiles between tests 1 and 2 will show how changes in internal load affects energy consumption for each of the two panels - pneumatic and electronic.

This information would be used in analysis to project energy consumption over the season using historical or typical occupancy schedules provided by Fort Leonardwood personnel.

Comparison of data from the two tests for the daylight hours will show impacts of solar and transmission loads on energy use profiles. This information would be used to project the seasonal energy use based on historical weather data for a typical year.

The test conducted under field test conditions forms the basis for projecting energy use for the season.

III SYSTEM DESCRIPTION

A. HOT WATER HEATING SYSTEM

District high temperature hot water is supplied from a central plant to the Applied Instructions Building. A high temperature hot water to hot water for space heating, converter, of the tube and shell type is used to heat water for space heating in the building. Space heating is delivered by unit heaters and convectors located in the conditioned spaces.

A valve on the high temperature hot water return from the converter is controlled by the space heating hot water supply temperature which can be reset on a fixed schedule with outdoor air temperature.

B. VAV AIR HANDLING SYSTEM

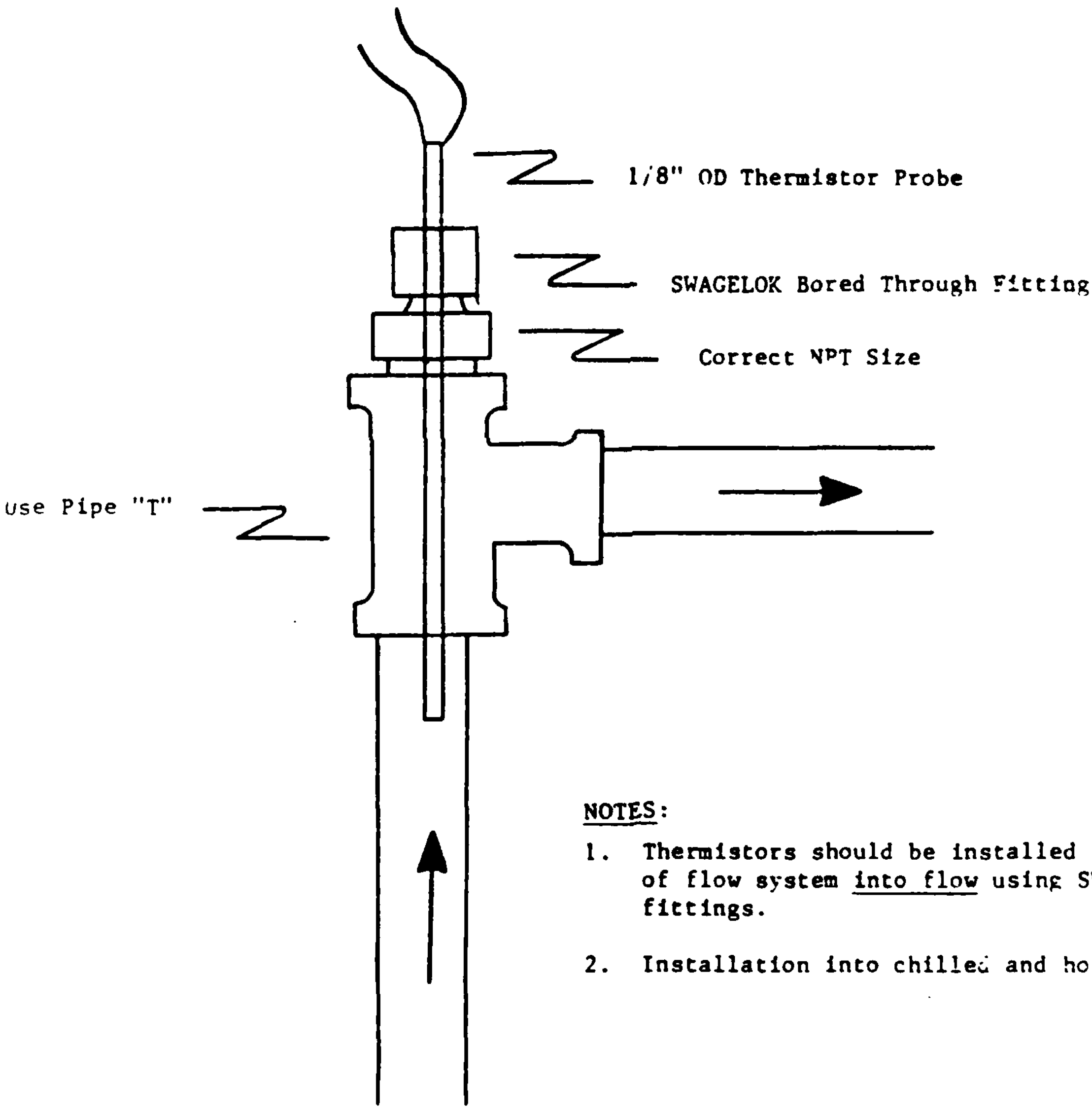
Two Variable Air Volume Air Handling units provide air conditioning to the Applied Instruction Building. The VAV units are equipped with an economizer cycle so that outdoor air is used for cooling whenever the outdoor air enthalpy is lower than the return air enthalpy.

A three way chilled water valve controls the temperature of the chilled water supply to the cooling coil. The supply air fan is controlled by static pressure sensors in the supply ductwork. Whenever the VAV boxes cut down on the amount of supply air, the static pressure in the duct rises and the inlet vanes on the supply air fan reduce the air flow and thereby reduce electrical energy use.

Table IV-1

INSTRUMENTATION SPECIFICATIONS

ITEM	MAKE AND MODEL	SIZE	DWG. DESIGNATION	CONTACT & TEL. NO.	PRICE PER UNIT ($)	LEAD TIME (WEEKS)
Flowmeters	Foxboro Vortex Shedder - E83W-03 with Power Supply	3" ϕ	FT 101, 202	Neil Cassidy Boston, MA (617) 361-7600	$1800 each	4 weeks
Thermistors	YSI Instrument Co. 033/44036/5.5/FP/12/ST		TT 101,102,103, 206, 207, Outdoor Temp, 4 extras	Borderweick Eng. 427 Washington St., Norwell, MA (617) 843-0845	$83.46 each	3 to 4 weeks
Flow Computer	D.K. Enterprises, Inc. Model 83 Series Computer #83A2C3-1-13-SX		1 for hot water system and 1 for AHU. FT & TT inputs, Btu output to Accurex Recorder	Dave Keegan 7361 Ethel Ave. #1, No. Hollywood, CA 91605 (818) 764-0820 (800) 451-2012	$846 each	4 weeks
Electric Meter	General Electric Polyphase VW62 TA15CL100 480V 5 Terminals 15 amps.	Correct Sized Meter for each AHU	JT 201,202 Pulsed output to Accurex for KWH count	Lloyd Jordan G.E. Meter Div. Somersworth, NH (603) 692-2100	$400 (Approx)	4 weeks
Pressure Transducer	Setra Engineering Model C261-1 Power Supply #204970 120 VAC 60Hz Input	4-20 mA	PT 201	Dick Pansire Setra Eng. Acton, MA (617) 263-1400	$235 (for P.T.) $25 each (Power Supply)	2 to 3 weeks



NOTES:

1. Thermistors should be installed in elbow of flow system into flow using SWAGELOK fittings.

2. Installation into chilled and hot systems.

Figure IV-1. Typical thermistor installation

V PRE-INSTALLATION PROCEDURES AND CALIBRATION REQUIREMENTS

Based on past experience, we strongly recommend that the following pre-installation procedures and calibration requirements be strictly adhered to during the conduct of this testing.

The instrumentation as specified in this plan will be purchased by CERL. For the flowmeters, CERL should request Foxboro, the manufacturer, to calibrate the flowmeters at the test conditions. The hot water flowmeter shall be calibrated at 240 gpm and 140°F. The chilled water flowmeter shall be calibrated at 250 gpm and 48°F. Arthur D. Little's representative will be present during the calibration of flowmeters at Foxboro facilities where the test rig is located.

Our staff member will witness the calibration and characterize the pulsed output signal.

We will then have the flowmeter hooked to the Btu meter electronics (DK Enterprises), to be purchased by CERL as specified in this instrumentation plan. We will check the gallons readout to make sure the flowmeter works properly and the output can be correctly handled by the Btu meter.

Temperature sensors acceptance tests will be performed by us, but the sensors will be bought by CERL as per our specifications. Using standard resistors having the same resistance as the sensors at test temperatures, we will prepare twelve (12) sensors, although only six (6) are required. The redundant sensors are for later use in case the sensors drift. Since the thermistors specified are relatively low cost items, we are recommending CERL to buy twice as many as are actually required.

Prior to installation, we will integrate the flowmeter, temperature sensors and the Btu meter to check and make sure the Btu board is working properly.

A flowmeter simulator should be ordered along with the Btu board from DK Enterprises. This simulator will simulate heat input to the board. We will check to make sure that the number of counts for a 15 minute interval is correct.

The above testing and calibration is a very important step in the field tests, since the flowmeter, once installed, cannot be recalibrated. The Btu board should be checked from time to time if the testing is continued for more than a month. Temperature sensors should be changed halfway through a season if testing is continued for the whole season.

1.1 Test Number 1: No Air Movement and No Lights

The test shall be performed for the pneumatic controls and for the electronic controls. All tests related to hot water reset control should be performed to cover as wide a range of outdoor winter temperatures as possible.

1.1.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Air Handling Units - air handling uits (AHU-1 and AHU-2) de-energized.
- Building lighting - off.
- Space temperature - space heating thermostats set at 68°F.
- Blinds or draperies - closed.
- Occupancy - building not occupied.
- Exhaust fans - exhaust fans (EF-1 and EF-2) de-energized.

1.1.2 Measured Parameters

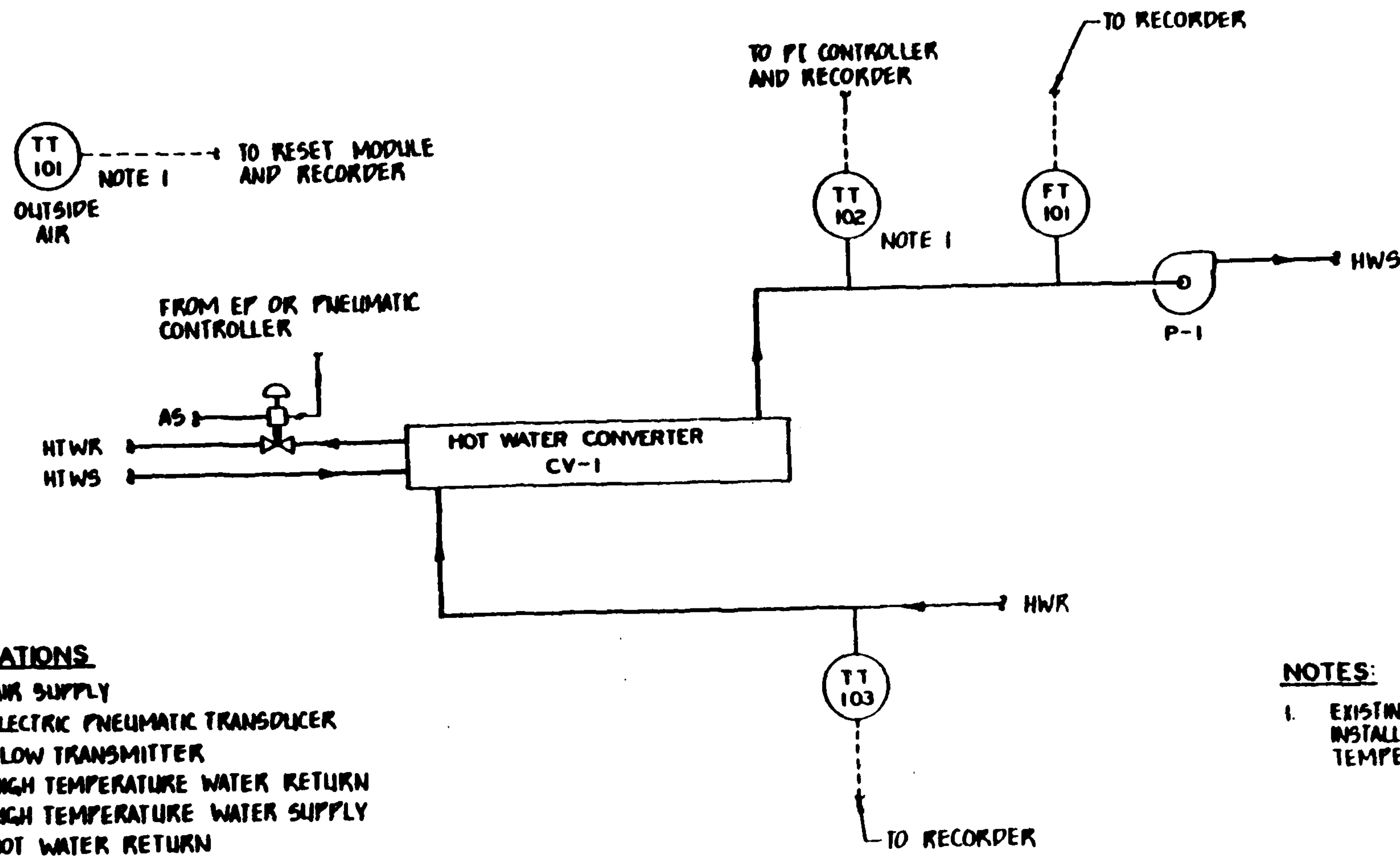
Measured parameters shall be as follows (device locations are shown on Figure VI-1):

- Outside air temperature (TT-101).
- Supply water temperature (TT-102).
- Return water temperature (TT-103).
- Total converter output (FT-101, TT-102, TT-103) (totalized value).
- Instantaneous converter output (FT-101, TT-102, TT-103).

1.1.3 Duration and Scheduling of Tests

To eliminate the effect of building occupancy and usage on the test results, the test shall be performed during an unoccupied period.

The time and duration of the test shall be from 7:00 p.m. on a Friday to 6:00 a.m. on the following Monday. This will be repeated on at least 2 weekends. It may, at CERL's option, be repeated during nighttime hours.



ABBREVIATIONS

AS – AIR SUPPLY
EP – ELECTRIC PNEUMATIC TRANSDUCER
FT – FLOW TRANSMITTER
HTWR – HIGH TEMPERATURE WATER RETURN
HTWS – HIGH TEMPERATURE WATER SUPPLY
HWR – HOT WATER RETURN
HWS – HOT WATER SUPPLY
P – PUMP
TT – TEMPERATURE TRANSMITTER

NOTES:

1. EXISTING TRANSMITTER INSTALLED FOR HOT WATER TEMPERATURE CONTROL

INSTRUMENT DIAGRAM
HOT WATER RESET CONTROL
FIGURE VI-1

1.1.4 Test Conditions

Tests shall be conducted under the following conditions:

- During a period when outside temperature is changing to allow reset control action of system to function.
- Outside temperature range is fairly cold (0 to 30°F) to allow for a fairly large heating load.

1.1.5 Anticipated Problems and Their Solutions

- Building Occupied - schedule with building user weekends when the building is not intended to be used.
- Persistent high outside air temperature - review weather forecast before starting test.

1.1.6 Data Logging Format

Table VI-1 lists the data item and the frequency of measurement.

1.1.7 Testing Procedures

- The instruments should not be calibrated directly before the test. Calibrate the pneumatic controls and the electronic controls a minimum of one month before tests are to be conducted.
- Test and log data for each control system (pneumatic and electronic) with approximately the same outside temperature conditions.
- Change from Proportional Only Control Panel to Proportional-Integral Control at every 2 hour interval during the controlled tests.

VI TEST PLANS AND PROCEDURES

A. GENERAL

The testing of the two sets of panels (proportional only panels and proportional integral panels) will be performed at two different operating conditions. Firstly, the tests will be performed under controlled conditions as specified in this plan and secondly the tests will be performed under field operating conditions. The purpose of the controlled tests is to find correlations between loads and energy use for each of the two sets of panels. The controlled tests results will provide a database for extrapolation of data taken over a relatively short period of time (2 weeks per season), to the entire season.

The field operating conditions will provide the actual energy use and savings achieved by the PI control panels over the proportional only control panels for the period during which data is obtained. This data will include the effects of variables such as:

- Human activities and occupancy;
- Opening and closing of doors and windows;
- Operation of lights, exhaust fans, motors, etc.;
- Space temperature setpoints;
- Opening and closing of draperies; and
- Weath.. effects - temperature, humidity, solar insolation and wind velocity and direction.

In the following text, we will first discuss the controlled tests followed by field tests.

B. CONTROLLED TESTS

1. HOT WATER RESET CONTROL PANELS

The hot water reset control system resets, on a predetermined schedule, th hot water supply (HWS) temperature from the hot water converter (CVI-1) based on outside air temperature.

Two test conditions will be used to compare the pneumatic proportional controls to the electronic proportional-plus-integral controls.

1.2 Test Number 2: Ventilation and Lights Turned On

Same as for paragraph 1.1.

1.2.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Air Handling Units - air handling units (AHU-1 and AHU-2) energized.
- Building lighting - all lights in building on.
- Space temperature - space heating thermostats set at 68°F.
- Blinds or draperies - closed.
- Occupancy - building not occupied.
- Exhaust fans - exhaust fan EF-1 energized, exhaust fan EF-2 de-energized.
- Ventilation - outside air (AHU-1 and AHU-2) fixed at minimum.
- Building cooling - chilled water pump (P-3) de-energized.

1.2.2 Measured Parameters

Same as paragraph 1.1.2.

1.2.3 Duration and Scheduling of Tests

Same as paragraph 1.1.3.

1.2.4 Test Conditions

Same as paragraph 1.1.4.

1.2.5 Anticipated Problems and Their Solutions

Same as paragraph 1.1.5.

1.2.6 Data Logging Format

Same as paragraph 1.1.6.

1.2.7 Testing Procedure

Same as paragraph 1.1.7.

Table VI-1

DATA LOGGING FREQUENCY
HOT WATER RESET CONTROL

DEVICE	DESCRIPTION	UNITS	FREQUENCY BETWEEN MEASUREMENT (MINUTES)
TT-101	Outside Air Temperature	°F	15
TT-102	Supply Temperature - Hot Water	°F	15
TT-103	Return Temperature - Hot Water	°F	15
FT-101, TT-102, TT-103	Convertor Output (Totalized)	Btu	15
FT-101, TT-102, TT-103	Instantaneous Convertor Output	Btu/hr	15

2. VAV TEMPERATURE CONTROL PANELS

The VAV temperature control system controls the cooling coil discharge temperature and the operation of the economizer.

2.1 Test 1: Economizer System Test

This test will determine the energy usage of the economizer system. It should be noted that the existing economizer system consists of an electric enthalpy economizer located in the outside air duct. Test shall be performed on Air Handling Unit 2 only both for the pneumatic controls and for the electronic controls. The test should cover as wide a range of outdoor conditions as possible, that affect the operation of economizer from minimum to maximum setting.

2.1.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Building lighting - on in areas served by AHU-2.
- Building cooling - chilled water available, chilled water pump energized.
- Air Handling Units - air handling unit (AHU-1) de-energized, air handling unit (AHU-2) energized.
- Space temperature - space cooling thermostats set at 78°F.
- Occupancy - building not occupied.
- Exhaust fans - exhaust fan EF-1 energized, exhaust fan EF-2 de-energized.
- Blinds or draperies - closed.

2.1.2 Measured Parameters

Measured parameters shall be as follows (device locations are shown on Figure VI-2):

- Outside air temperature (TT-201)
- CHW return temperature (TT-206)
- CHW supply temperature (TT-207)
- CHW cooling energy (totalized) (TT-206, TT-207, FT-202)
- Supply fan power input (totalized) (JT201)
- Return fan power input (totalized) (JT202)

2.1.3 Duration and Scheduling of Tests

To eliminate the effect of building occupancy and usage on the test results, the test shall be performed during an unoccupied period.

The time and duration of the test shall be from 7:00 p.m. on a Friday to 6:00 a.m. on the following Monday.

2.1.4 Test Conditions

The test shall be conducted under the following conditions:

- Change from P only panel to PI panel every 2 hours.
- During a period when the outside air dry bulb temperature is less than the inside air dry bulb temperature, and varies over the range for economizer operation (55°F to 65°F at a minimum).

2.1.5 Anticipated Problems and Their Solutions

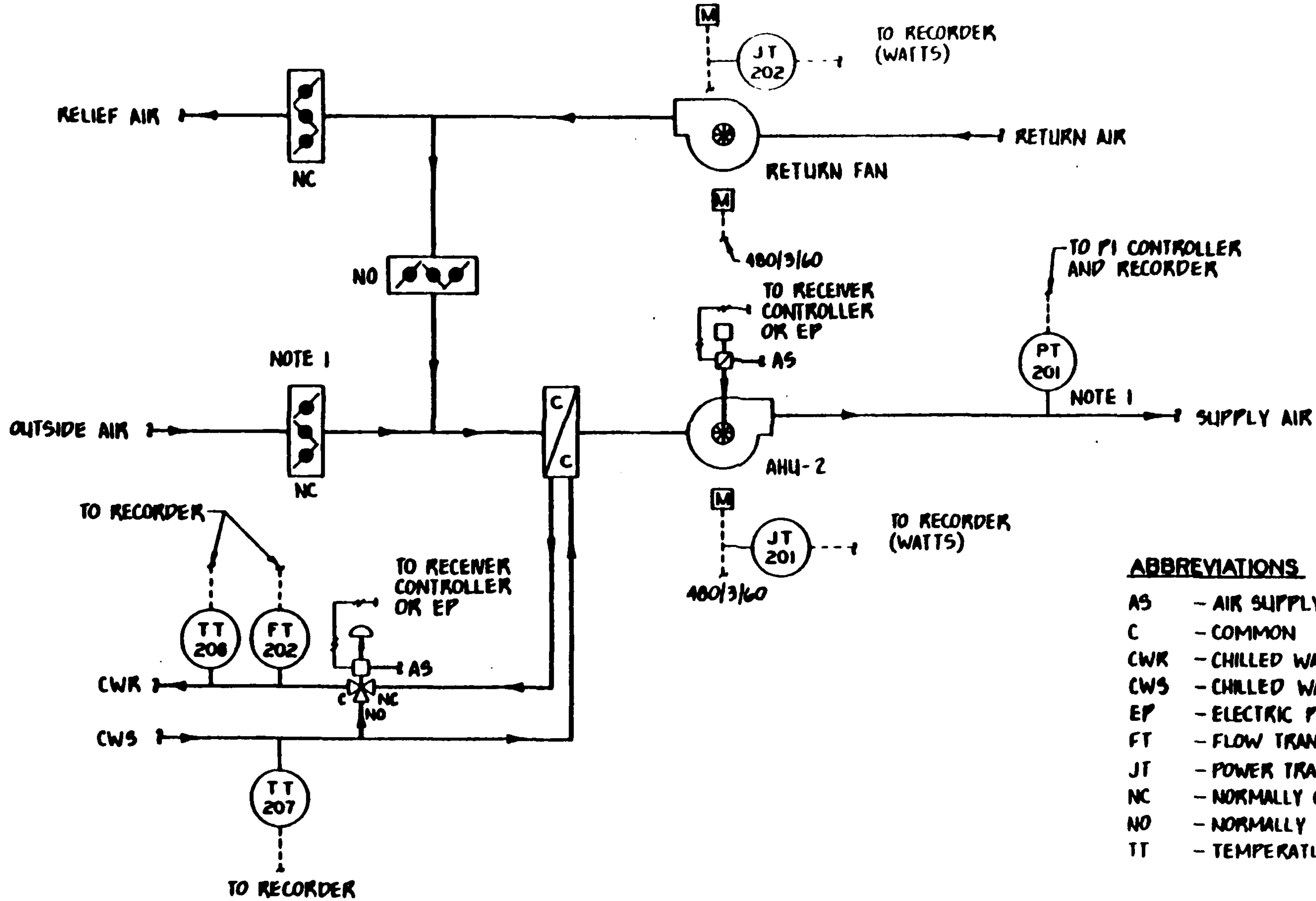
- Building occupied - schedule with building user weekends when the building is not intended to be occupied.
- High outside air temperature - if outside air temperature is above return air temperature, economizer will not function. Review weather forecast before starting test.

2.1.6 Data Logging Format

Table VI-2 lists the data item and the frequency of measurement.

2.1.7 Testing Procedures

- Calibrate the pneumatic controls and the electronic controls a minimum of 30 days before the tests are to be conducted. Do not calibrate the controls directly before the test.
- Test and log data for each control system (pneumatic and electronic) with approximately the same outside air temperature.
- Change from Proportional Only Control Panel to PI control panel at every 2 hour interval during the tests.



ABBREVIATIONS

AS	– AIR SUPPLY
C	– COMMON
CWR	– CHILLED WATER RETURN
CWS	– CHILLED WATER SUPPLY
EP	– ELECTRIC PNEUMATIC TRANSDUCER
FT	– FLOW TRANSMITTER
JT	– POWER TRANSMITTER
NC	– NORMALLY CLOSED
NO	– NORMALLY OPEN
TT	– TEMPERATURE TRANSMITTER

INSTRUMENT DIAGRAM
VAV TEMPERATURE CONTROL
FIGURE VI-2

2.2 Test 2: VAV Temperature Control System

This test will determine the energy usage of the chilled water system. Tests shall be performed on Air Handling Unit 2 only. The test shall be performed for the pneumatic controls and for the electronic controls. The test shall be performed to cover a wide range of outdoor conditions, as well as measured load inputs to the space using an electric heater.

2.2.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Building lighting - on in areas served by AHU-2.
- Building cooling - chilled water available, chilled water pump energized.
- Air Handling Units - air handling unit (AHU-1) de-energized, air handling unit (AHU-2) energized.
- Ventilation - air handling unit (AHU-2) outside air fixed at minimum position.
- Space temperature - space cooling thermostats set at 78°F.
- Blinds or draperies - closed.
- Occupancy - building not occupied.
- Exhaust fans - exhaust fan EF-1 de-energized, exhaust fan EF-2 de-energized.

2.2.2 Measured Parameters

Same as paragraph 2.1.2.

2.2.3 Duration and Scheduling of Tests

Same as paragraph 2.1.3.

2.2.4 Test Conditions

The test shall be conducted when the outside air dry bulb temperature is sufficiently high to produce; a fairly large cooling load. Test shall be repeated with measured increases in load using an electric heater in space.

2.2.5 Anticipated Problems and Their Solutions

- Building occupied - schedule with building user weekends when the building is not intended to be occupied.

- Low outside dry bulb temperature - review weather forecast to determine that temperature during test will be sufficiently high to produce a fairly large cooling load.

2.2.6 Data Logging Format

Table VI-2 lists the data item and the frequency of measurement.

2.2.7 Testing Procedure

Same as paragraph 2.1.7.

Table VI-2

DATA LOGGING FREQUENCY
VAV TEMPERATURE CONTROL

DEVICE	DESCRIPTION	UNITS	FREQUENCY BETWEEN MEASUREMENT (MINUTES)
TT-201	Outside Air Temperature	°F	15
JT-201	Supply Fan Power Input (Totalized)	kWh	15
JT-202	Return Fan Power Input (Totalized)	kWh	15
TT-206	Return Chilled Water Temperature	°F	15
TT-207	Supply Chilled Water Temperature	°F	15
TT-206, TT-207, TT-202	Waterside Cooling Energy Used from Beginning of Test (Totalized)	Btu	15

3. FAN STATIC PRESSURE CONTROL PANELS

The fan static pressure control system controls the duct static pressure by positioning the supply fan inlet vanes.

Two test conditions will be used to compare the pneumatic proportional controls to the electronic proportional-plus-integral controls.

3.1 Test 1: Space Temperature at 78°F

The test shall be performed for the pneumatic and for the electronic controls, and shall cover a wide range of simulated load conditions using a measured heat input to space with electric space heater.

3.1.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Building lighting - on in areas served by AHU-2.
- Blinds or draperies - closed.
- Occupancy - building not occupied.
- Ventilation - outside air damper on AHU-2 closed.
- Air Handling Units - AHU-1 de-energized. AHU-2 energized.
- Space temperature - cooling space thermostats in areas served by AHU-2 set at 78°F.
- Exhaust fans - exhaust fan EF-1 and EF-2 de-energized.

3.1.2 Measured Parameters

Measured parameters shall be as follows. (Device locations are shown on Figure VI-3).

- Outside Air Temperature (TT-201).
- Supply Fan Power Input (Totalized) (JT-201).
- Return Fan Power Input (Totalized) (JT-202).

- Return Chilled Water Temperature (TT-206).

- Supply Chilled Water Temperature (TT-207).

- Supply Duct Static Pressure (PT-201).

- Waterside Cooling Energy (Totalized) (TT-206, TT-207, FT-202).

3.1.3 Duration and Scheduling of Tests

To eliminate the effect of building occupancy and usage on the test results, the test shall be performed during an unoccupied period.

The time and duration of the test shall be from 7:00 p.m. on a Friday to 6:00 a.m. on the following Monday.

3.1.4 Test Conditions

Both control systems shall be tested when the weather conditions are approximately the same.

3.1.5 Anticipated Problems and Their Solutions

- Building occupied - schedule with building user weekends when the building is not intended to be occupied.

- Weather conditions - weather conditions are substantially different between test weekends. Schedule tests on adjacent weekends when weather pattern is fairly stable. Review weather forecast before starting tests.

3.1.6 Data Logging Format

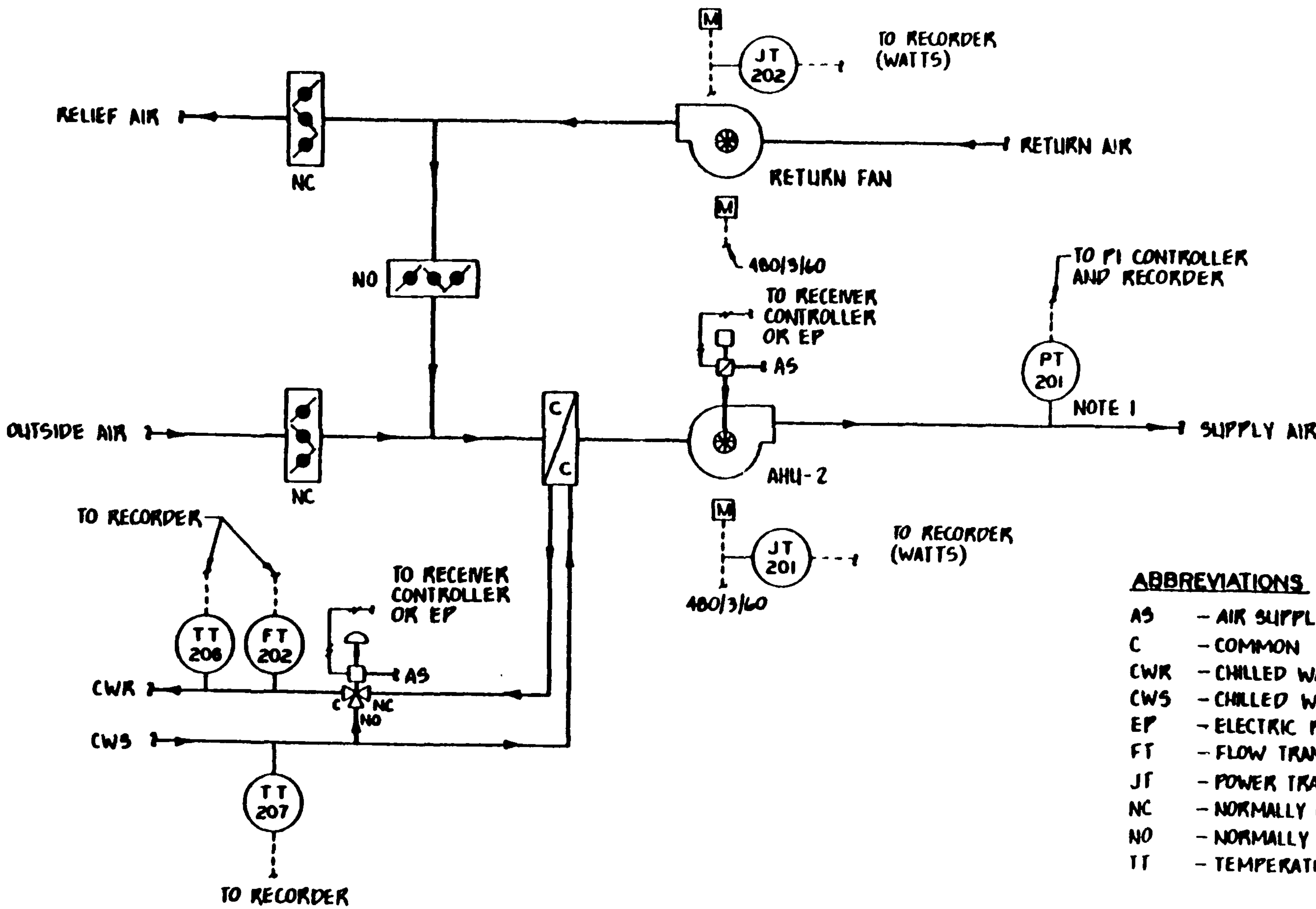
Table VI-3 lists the data item to be measured and the frequency of measurement.

3.1.7 Testing Procedures

- Calibrate the pneumatic controls and the electronic controls a minimum of 30 days before the tests are to be conducted. Do not calibrate the controls directly before the test.

- Test and log data for each control system (pneumatic and electronic) with approximately the same outside air temperature.

- Change from Proprotional Only to PI controls and vice versa every 2 hours.



ABBREVIATIONS

AS - AIR SUPPLY
C - COMMON
CWR - CHILLED WATER RETURN
CWS - CHILLED WATER SUPPLY
EP - ELECTRIC PNEUMATIC TRANSDUCER
FT - FLOW TRANSMITTER
JT - POWER TRANSMITTER
NC - NORMALLY CLOSED
NO - NORMALLY OPEN
TT - TEMPERATURE TRANSMITTER

INSTRUMENT DIAGRAM
STATIC PRESSURE CONTROL

FIGURE VI-2

3.2 Test 2: Space Temperature at 70°F

Same as for paragraph 3.1.

3.2.1 Controlled Parameters

The controlled parameters shall be as follows:

- Infiltration - no exterior doors opened.
- Building lighting - on in areas served by AHU-2.
- Blinds or draperies - closed.
- Occupancy - building not occupied.
- Ventilation - outside air damper on AHU-2 closed.
- Air Handling Units - AHU-1 de-energized, AHU-2 energized.
- Space temperature - cooling space thermostats in areas served by AHU-2 set at 70°F.
- Exhaust fans - exhaust fan EF-1 and EF-2 de-energized.

3.2.2 Measured Parameters

Same as paragraph 3.1.2.

3.2.3 Duration and Scheduling of Tests

Same as paragraph 3.1.3.

3.2.4 Test Conditions

Same as paragraph 3.1.4.

3.2.5 Anticipated Problems and Their Solutions

Same as paragraph 3.1.5.

3.2.6 Data Logging Format

Table VI-3 lists the data item and the frequency of measurement.

3.2.7 Test Procedure

Same as paragraph 3.1.7.

Table VI-3

DATA LOGGING FREQUENCY
STATIC PRESSURE CONTROL

DEVICE	DESCRIPTION	UNITS	FREQUENCY BETWEEN MEASUREMENT (MINUTES)
TT-201	Outside Air Temperature	°F	15
JT-201	Supply Fan Power Input (Totalized)	kWh	15
JT-202	Return Fan Power Input (Totalized)	kWh	15
TT-206	Return Chilled Water Temperature	°F	15
TT-207	Supply Chilled Water Temperature	°F	15
TT-206, TT-207, TT-202	Waterside Cooling Energy Used from Beginning of Test (Totalized)	Btu	15
PT-201	Supply Duct Static Pressure	Inches Water	15

C. FIELD CONDITIONS TESTS

Tests shall be performed under normal operating conditions to collect acceptable quality data for a minimum of 1 full week in winter and 1 full week in summer. During the winter testing period, the hot water reset panels will be compared and during the summer testing period, the VAV temperature control and static pressure control panels will be tested. In each case, the "P" control will be tested against the new PI control panel.

Measured Parameters and Data Collection

Though none of the variables will be controlled in any way, measurements and data on the various independent variables shall be collected. Aside from the measured parameters discussed under controlled tests, the following parameters and data elements will also be included in the data collection process:

- Occupancy level by zone by 4 hour intervals to match the flip-flop data gathering on the "P" and PI control panels; (The 4 hour intervals are discussed later in the text.)

- Status of the AHU and return air fans;

- Status of Exhaust fans in the building;

- Any process related heat generation in the building;

- Any exterior doors or windows left open for more than a few minutes; and

- Any problems with the HVAC equipment during that period of time.

All of the building's energy-using systems will be operational in their normal mode, without any interference or control, for these tests.

For the hot water reset panels, the measured and recorded parameters shall include:

- Outside air temperature (TT-101)

- Hot water supply temperature (TT-102)

- Hot water return temperature (TT-103)

- Total high temperature hot water/hot water converter output (FT-101, TT-102, TT-103) (Totalized)

- Instantaneous converter output (FT-101, TT-102, and TT-103).

For the VAV temperature control panels, the measured parameters shall include:

- Outside air temperature (TT-201)
- CHW return temperature (TT-206)
- CHW supply temperature (TT-207)
- CHW Cooling Energy (Totalized) (TT-206, TT-207, FT-202)
- Supply fan power input (Totalized) (JT-201)
- Return fan power input (Totalized) (JT-202)

For the static pressure control panels, the measured parameters shall include:

- Supply duct static pressure (PT-201)
- In addition all of the parameters to be measured under the VAV temperature control panels tests as shown above.

Duration and Scheduling of Field Conditions Tests

The data is to be collected for a continuous interval of at least one week during a winter heating period and at least one week during a summer cooling period. It may be necessary to collect data for a period of time which is greater than the stated interval of one week in order to obtain useable data for seven continuous days.

The purpose of the tests will be to compare the efficiencies of two different types of controllers. The new panels will provide proportional plus integral (PI) control. Existing panels are proportional only (P) controllers.

During the test procedure, these controllers will be operated in a 4 hour on, followed by a 4 hour off sequence in which the system will be switched between the controllers so that one of the controllers is always in operation (only one controller can be in operation at any given time). In order to effectively evaluate the efficiency of the two controllers, it will be necessary to operate them on a similar daily time schedule. Since a 4 hour flip-flop sequence will always have the same controller in operation during any particular 4 hour interval (ex. 12 p.m. to 4 p.m.) throughout the entire week of testing, it will be necessary to run one controller through two 4 hour segments for each day of testing. This will allow for a controller to operate on an identical schedule every day. Thus, the operational sequence for the proportional plus integral (PI) controller, and the proportional only (P) controller, is as follows:

Day	Time Interval	Controller in Operation
1	12 a.m. - 8 a.m.	PI
	8 a.m. - 12 p.m.	P
	12 p.m. - 4 p.m.	PI
	4 p.m. - 8 p.m.	P
	8 p.m. - 12 a.m.	PI
2	12 a.m. - 8 a.m.	P
	8 a.m. - 12 p.m.	PI
	etc.	etc.

Anticipated Problems and Suggested Solutions

Problems in logging of data could arise as shown by history of the Accurex Autograph machine used by CERL in the past. In order to minimize this problem, checks for reasonableness of data should be made at least twice in any 4 hour period. If unexplained values occur for parameters, the cause should be determined and noted. The cause could be malfunctioning of the data recorder or an unusual situation such as a receiving door left wide open. While no attempts should be made by the data collection personnel to change operating conditions such as closing doors, they should determine the length of time for which operating conditions are out of the ordinary.

In case of problems with instrumentation or data logging equipment, date and time at which failure occurs and the date and time when problem is corrected should be logged in a log book.

The log book should be kept on site and detailed notes maintained on all occurrences that are out of the normal course of events. This log book can then be used during analyses to account for data outside of reasonable control limits. For example, an indoor temperature level of 45°F may indicate a door or window that is open.

Data Logging Frequency

Data should be logged at 15 minute intervals. The units for each parameter should be clearly specified (Btu, °F, kWh, etc.). Totalized values should be for the entire 15 minute period.

The collected data shall be rechecked and transmitted on diskettes to Arthur D. Little, Inc. for analysis.

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