1981

Control of livestock environment by microcomputer

Fredrick Craig Vosper
Iowa State University

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Control of livestock environment
by microcomputer

by

Fredrick Craig Vosper

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
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DOCTOR OF PHILOSOPHY

Major: Agricultural Engineering

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<td>Alternating current</td>
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<td>ADC</td>
<td>Analog-to-digital converter</td>
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<tr>
<td>bit</td>
<td>Binary digit</td>
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<tr>
<td>byte</td>
<td>Eight bits</td>
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<tr>
<td>cfm</td>
<td>Airflow rate (ft³/min.)</td>
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<tr>
<td>CMOS</td>
<td>Complementary metal-oxide semiconductor</td>
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<tr>
<td>CSB</td>
<td>Complement speed byte</td>
</tr>
<tr>
<td>DAC</td>
<td>Digital-to-analog converter</td>
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<td>DSB</td>
<td>Dominant speed byte</td>
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<td>EMR</td>
<td>Electromagnetic relay</td>
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<tr>
<td>EPROM</td>
<td>Erasable programmable read-only memory</td>
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<tr>
<td>H</td>
<td>Hexadecimal code</td>
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<tr>
<td>I</td>
<td>Current output</td>
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<td>IC</td>
<td>Integrated circuit</td>
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<td>I/O</td>
<td>Input/output</td>
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<tr>
<td>LED</td>
<td>Light emitting diode</td>
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<td>LSB</td>
<td>Least significant bit</td>
</tr>
<tr>
<td>LSI</td>
<td>Large scale integration</td>
</tr>
<tr>
<td>MSB</td>
<td>Most significant bit</td>
</tr>
<tr>
<td>MSI</td>
<td>Medium scale integration</td>
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<tr>
<td>RH</td>
<td>Relative humidity</td>
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<tr>
<td>rpm</td>
<td>Revolutions/minute</td>
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<td>RST</td>
<td>Restart</td>
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<tr>
<td>RTD</td>
<td>Resistance thermometer detector</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>SAF</td>
<td>Speed adjustment factor</td>
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<tr>
<td>SSI</td>
<td>Small scale integration</td>
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<tr>
<td>SSR</td>
<td>Solid state relay</td>
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<tr>
<td>TI</td>
<td>Inside temperature</td>
</tr>
<tr>
<td>TO</td>
<td>Outside temperature</td>
</tr>
<tr>
<td>TS</td>
<td>Set temperature by operator</td>
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<tr>
<td>TTL</td>
<td>Transistor-transistor logic</td>
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<td>WR</td>
<td>Write (negative logic)</td>
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INTRODUCTION

Environmentally controlled livestock facilities are being utilized to improve animal performance and reduce labor requirements. The design of livestock facilities has been based on temperature extremes and relatively low energy costs. The level of management varies among confinement units and results in designs which conflict with energy conservation. Ventilation systems are installed that can not be lowered to the minimum ventilation rate for thermal energy conservation.

Optimizing energy expenditure or environmental control is not possible with conventional controls. An installation with several thermostats deters operator interaction. Sensitivity and inaccuracy of controls provides undesirable environmental fluctuation. A variable-speed fan control promotes thermal energy conservation but produces heat and utilizes a fan with low electrical efficiency. Ventilation above the minimum rate can be actuated by the supplemental heating system, therefore, increasing energy consumption.

An integrated logical controller is needed to improve environmental control, reduce energy consumption, provide operator convenience and increase productivity. Reference inputs should include temperature, moisture content of the air, static pressure, fan speed and the desired temperature from the operator. The device should have the ability to control the ventilation, supplemental heating, and the air distribution systems. The controller should have the flexibility to expand reference inputs and/or control forces.
OBJECTIVES

The overall objective of the research is to develop a logical controller which promotes energy conservation, improves environmental control, and simplifies management for a livestock confinement building. Specific objectives are:

1. Select an appropriate electronic device to be used for controlling a confinement environment.
2. Develop interface components for environmental controller.
3. Build and install controller in an existing livestock confinement building.
4. Develop an appropriate control scheme for optimization of overall objective.
5. Code, test and debug control scheme.
6. Evaluate logic controller's feasibility in a livestock building.
REVIEW OF LITERATURE

Environmental Control

A controlled livestock environment should not just provide for survival but also enhance good health, optimum growth, and high feed efficiency. Animals confined in a closed environment tend to alter air composition by reducing oxygen content; increasing carbon dioxide levels and water vapor content; and adding ruminant gases, ammonia from feces and urine, and microscopic particles of dust from feed and bedding. Experience has shown that, when operating an environment designed to elicit maximum productivity, the addition of sufficient fresh air to remove water vapor and ammonia will prevent any detectable effects of carbon dioxide buildup, lung respiratory irritation due to dust particles, or harmful effects from methane (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 1977). A young animal's homothermic mechanisms are not functioning at birth which increases its vulnerability to the environment. It is especially susceptible to respiratory diseases and digestive disturbances.

Ventilation, according to the American Society of Agricultural Engineers (ASAE) (1980), is a system of air exchange which provides the desired amounts of fresh air without drafts to all parts of the shelter while maintaining temperature¹ and relative humidity within desired limits. Ideally, there should be some continuous exchange of air through

¹Temperature denotes dry-bulb temperature and is ascribed so throughout the text.
a livestock building at all times.

The removal of moisture and odor places the greatest demand on the winter ventilation system (Midwest Plan Service (MWPS) 1980). Ventilation is, therefore, either a balance or a compromise between the minimum rate necessary to remove moisture and the maximum that can be permitted to control temperature. Temperature control is difficult during cold weather because of low ventilation rates that can cause inside temperatures to fluctuate beyond the desired range. The addition of supplemental heat may be needed to maintain a stable environment. The heating equipment can be a source of carbon monoxide production. Dilution of odors and uniform temperature during the winter are dependent on uniform air distribution.

Mechanical ventilation must be provided continuously during hot weather with systems that do not employ natural ventilation. If alternate cooling methods are not applied the ventilation system has limited temperature control. Air movement is utilized to provide cooling while attempting to maintain a maximum temperature of 2 to 3°F above ambient conditions in a properly designed ventilation system (MWPS 1980). A number of methods have been employed in the cooling of livestock shelters including room air conditioning, zone air conditioning, evaporative cooling, and spray cooling.

The design of the ventilation system is implemented for winter operation by the formulation of moisture and temperature balance curves as shown in Figures 1 and 2. A moisture balance presents the ventilation rate at which moisture production is equal to moisture
Figure 1. Ventilation curves for a livestock building with normal moisture production (MWPS 1980)
Figure 2. Ventilation curves for a livestock building with above normal moisture production.
removed by the ventilation system for a given outside temperature. The temperature balance indicates the ventilation rate at which the sources of sensible heat, with the exception of supplemental heat, are equal to sensible heat loss given an outside temperature.

Moisture balances are calculated by assuming a constant outside relative humidity and a maximum inside relative humidity. A colder outside temperature contains less moisture therefore reducing the ventilation rate required to remove moisture being produced by the animals. The decrease of inside temperature will cause an upward movement in the moisture balance curve because of the decreased capability of the air to hold moisture. The main sources of moisture production in a building are from the respiratory system of the animal, evaporation from surfaces, and moisture from the supplemental heating system. The amount of moisture from the animal's respiratory system and supplemental heating system are fairly constant but the amount of evaporation is highly variable. The amount of surface evaporation depends on management practices and the waste handling system. Current data on moisture production from livestock are variable (Esmay 1978).

Sensible heat production within the building is mainly from animals; machinery, including lights and motors; and the supplemental heating system. Heat losses are from air exchange including infiltration, evaporation of moisture, and building losses by conduction and convection.

Fan and control selection should be based on ventilation curves for a moisture and temperature balance. MWPS proposed ventilation curve and
the ideal ventilation curve for minimum energy consumption are shown in Figure 1. MWPS recommends their table value as the minimum and the ventilation rate to be increased once the temperature balance curve has been intersected. Supplemental heat is required whenever the actual ventilation rate is higher than the temperature balance curve. The amount of supplemental heat required is relative to the difference between the actual and temperature balance ventilation rates. MWPS recommended table values are based on conventional waste handling systems and do not take into consideration newer methods of odor and waste management. The ideal ventilation curve follows the higher of the two ventilation balance curves. Assuming a lower ventilation rate than recommended by MWPS would be adequate for odor control, the ideal ventilation curve would minimize thermal energy consumption for heating ventilation air.

Conventional controls are not available that could follow the ideal ventilation curve. The corrosive environment has prevented development of a reliable and practical humidistat control that would provide dependable control of fan operation. The single inside sensing thermostat for fan control will not achieve the desired results when the thermostatically controlled supplemental heater is providing a constant inside temperature.

Figure 2 depicts a system where the moisture balance is greater than the temperature balance for a wider range of outside temperatures relative to Figure 1. Selection of ventilation rate #2 would minimize energy consumption during periods of cold temperatures. A problem does
exist when outside temperature lies between the intersection of ventilation rate #2 and the temperature and moisture balances. At these outside temperatures the moisture content of the inside air would be above the maximum limit. It would be advantageous for the ventilation rate to increase as outside temperature increases before the moisture balance is intersected. This could be accomplished by a multistage thermostat measuring outside temperature. The ventilation rate would be increased to #1 at an outside temperature that would prevent a moisture buildup. An optimum solution would be the use of a variable-speed fan that gradually increased its ventilation rate as outside temperature increased. However, an outside temperature sensor would not sense increased moisture production as the animals increased in size or a change in management practices. Partial loading of the building with animals would require changing of the control settings.

Energy Conservation

Energy conservation requires the reduction of both thermal and electrical energy consumption for livestock housing. Thermal energy conservation can be most significant during the winter while electrical energy conservation can have its most meaningful reduction during the summer operation.

Smith (1976) reports that up to 90 percent of the total thermal energy requirements in a well insulated confinement building will be used for heating ventilation air. Figure 3 shows his data graphed for a portion of the winter of 1976. The actual data are compared to MWPS's (1980) recommendation of 20 cfm per sow and litter with a lower
Figure 3. Accumulated thermal energy consumption for a 20-crate farrowing building in 1976
environmental temperature which would result in a thermal energy reduction of approximately 75 percent. Bundy (1980) reports that with a superior system and management it is possible to lower the ventilation rate to 10 cfm per sow and litter. Muehling (1979) sites cases of actual ventilation rates of up to 250 cfm per sow and litter.

Ventilation systems require sufficient air distribution and precise control of winter ventilation rates to optimize design. Jordan et al. (1979) asserts the most cost effective way to conserve fossil fuel is to manage the ventilation system properly. He promotes the use of simplicity in control design to promote interaction between the operator and the control system. He states that a simplified control system will not optimize energy consumption but will result in increased conservation because of management input. Bloome (1980) reports that decreased inside design temperature does not automatically insure energy conservation. If a reduction in inside temperature increases the moisture balance requirements above that required for odor control then Figure 4 is applicable. Increases in ventilation account for a greater source of heat loss than a reduced temperature difference.

Electrical energy consumption is directly affected by the yearly duty factor of the fan system. The duty factor is a function of building characteristics, animal heat production, the fan control system, and the weather. Energy conservation can be optimized by delivering the minimum amount of ventilation required and providing it as efficiently as possible. Ventilation systems are designed with excess ventilation capacity to meet occasional extreme weather conditions.
Figure 4. Structural and ventilation heat loss versus indoor temperature for a 12-crate farrowing room (Bloome 1980)
in the summer. Using full capacity during average warm weather conditions is a waste of energy. Energy in modest amounts can be saved by raising thermostat set points to limit use of maximum ventilation to periods of real temperature stress (Albright 1976).

Conventional Control Systems

The objective of ventilation controls is to provide a range of ventilation rates which maintain an optimum environment with a minimum of energy expenditure. During the winter this requires a minimum ventilation rate to remove moisture and gases with emphasis on thermal energy conservation. Accurate and sensitive controls are required to accomplish this within the range of fan capacities available.

The design of a ventilation system requires the selection of fans and controls concurrently. Ideally, a ventilation system maintains temperature and relative humidity within the optimum range at all outside weather conditions. To achieve this, a ventilation system should have a broad representation of fan sizes. Small and medium size fans are used for winter ventilation while large fans are utilized during the summer.

Fan manufacturers distribute a limited selection of fan sizes. Normally, the smallest fan available provides between 780 and 3,720 cfm at design static pressure. Frequently, a single speed fan's ventilation rate will be greater than the desired minimum. One ventilation company has introduced fans in the 7 to 9-in. diameter range providing 139 to 218 cfm respectively at the anticipated static pressure. Adequate air distribution may necessitate more than one fan operating continuously,
which results in a ventilation rate above the desired minimum. The utilization of small fans does not typically reduce the number of fans required for summer ventilation; therefore, the purchase of small fans must be included as additional equipment cost. Single-speed fans do not have the flexibility of changing rates as the minimum ventilation changes.

A number of alternatives to continuous fan operation for attaining minimum ventilation rates are listed in ASAE (1980). A single-speed fan with intermittent operation controlled by a thermostat or timer is suggested. With a single thermostat control, the fan seldom runs during extremely cold weather, resulting in improper ventilation rates. A timer can provide a fluctuation of inside temperatures outside the desired range.

The use of throttling, where the fan is housed in a box-like mounting equipped with shutters on the intake side of the box behind the fan, is another possibility. The shutters are opened and closed by a damper motor controlled either manually or by a thermostat. Throttling will reduce the ventilation rate but may not save electrical energy. Shutters can also be applied in the partial recirculation of outside air which allows only a portion of the air in the building to be exhausted.

A fan with a variety of speeds in theory solves the problem of providing a small amount of ventilation with capabilities of increasing the airflow as the outside temperature rises. Multi-speed fans using mechanical components are limited in their speed selection and commonly attain a minimum of 67 percent capacity (ASAE 1980). A variable-speed
control consists of a thermistor heat sensor which provides a variable voltage signal to an electronic speed control which changes the alternating voltage to the fan motor. The permanent split capacitor motor has a high rate of slip which causes it to slow as the voltage is reduced. Newer variable-speed fans modulate airflow from a minimum of 20 percent capacity (MWPS 1980).

A significant number of problems have developed with the variable-speed controller. The ventilation rate may be reduced to zero by a slow speed or moderate winds. The units have had a high rate of failure due to inadequate protection from voltage surges. Radio frequency interference as reported by Soderholm and Andrew (1976) causes cross talk with other electronic devices. The controller has a fixed temperature range of 8 to 100°F between minimum and maximum speed. Each controller has its own individual nonlinear curve for temperature versus speed.

Corrosion of controls, contacts, and working parts is a serious problem in livestock housing. The sealing of the electrical system completely from the corrosive environment has not been attained. Connection boxes must be tight to exclude the entrance of dust and insects, while at the same time keeping the components ventilated to permit the dissipation of moisture and heat.

When a supplemental heater is large enough, and energy is available, it will maintain the inside temperature at the selected level regardless of weather conditions or the ventilation rate. The supplemental heater has conventionally been controlled with one thermostat and a multiple number of thermostats applied for the control of ventilation fans as
shown in Figure 5. A small continuously operated fan provides the minimum ventilation rate in Figure 5. A heater thermostat has approximately a 5°F range between the on and off points. If T1 and T2 are close, a cycling of fan #2 and the heater will result in waste of thermal energy. Fan #3 and #4 are large relative to fan #2 and are designed to operate at higher outside temperatures. A larger fan should not operate until the smaller fan is operating without intermittence. It is recommended by Jones et al. (1980) to set fan thermostats 3 to 5°F apart. This would result in a range from T1 to T4 of 11 to 15°F. If a large fluctuation of temperature is not acceptable, the thermostat settings would need to be changed with a variation in weather.

The operation of a supplemental heater, variable-speed fan, and single-speed fans is shown in Figure 6. The variable-speed fan begins to increase speed at 4 to 5°F below its set point of T3. To insure that it does not increase ventilation while the supplemental heater is on, AAA Associates (1980) recommends 9°F between settings. A single-speed fan could then be set 2°F above T3 at T4. The larger single-speed fan would be activated at T5 approximately 3°F above T3. The control scheme would result in a 12 to 14°F range between T1 and T5.

A desirable air distribution system has an adjustable baffle that regulates the velocity of the incoming air between 600 and 1000 fpm. Conventional methods of controlling air velocity have been with manual adjustments that are required each time a fan turns on or off. Automatic controls are available to regulate air inlet openings by monitoring static pressure. A reversible motor connected to the air
Figure 5. Operation of a supplemental heater and four single-speed fans
Figure 6. Operation of a supplemental heater, variable-speed fan, and two single-speed fans
Inlets maintains the static pressure, which is directly related to air velocity, between limits set by the operator.

Agricultural alarm systems utilizing electronics are available to prevent livestock losses. Experiences with electronic alarm systems have noted problems with dust, temperature extremes, gases and vapors, moisture extremes, power surges and transients. Clark (1980) states that the most damaging of all environmental problems is the potential energy from lightning strikes. He suggests that all electronic components be hermetically-sealed in an enclosure and that a controlled environment be provided for the electronic circuit boards.

A number of new control elements have been introduced utilizing mechanical components to improve environmental control. A composite of the desirable characteristics are:

-- Simultaneous control of heating and ventilation.
-- Single temperature adjustment for heating and ventilation.
-- Remote sensing of temperature.
-- Simplicity in system operation.
-- Increased diversity of ventilation rates.

Microcomputers in Agriculture

It has been proposed that for agriculture, a microcomputer offers relatively low cost, reliability, ease of use, and flexibility. Agricultural Engineers in Great Britian are presently developing real-time monitoring for control of milk, poultry and swine production (Cox, 1980). The use of microcomputers as an aid in record keeping is the most dominant application in the United States.
Experiments have shown that with correctly designed and controlled air inlets, combined with fan control, it is possible to maintain the intended air circulation patterns despite changing weather. An adjustable inlet is a critical part of the system which Cox (1980) notes is an appropriate application for a microcomputer. Cole et al. (1979) suggests that microprocessor units can do much to reduce the cost of mechanical ventilation. Ventilation systems are designed using the rough rules which have been proven over the years to be safe, in spite of inadequacies of air distribution, problems in building design, and poor construction practices (Cole et al. 1979). Examples and detailed studies can optimize a control system for a given situation.

Microcomputers in agriculture have reliability problems when electronic equipment is located in a harsh environment. Previous applications have required heated space outside the animal area for the location of the controller. An electrical enclosure with a gasket seal to prevent rodent, dust, moisture and corrosive gases from entering the microcomputer is suggested. Solid state devices operating in a field environment are in danger of lightning damage. Willits et al. (1980a) recommends a secondary lightning arrester, metal oxide varistors for solid state devices, surge suppression circuitry between the AC line and power supply, and grounding of sensors. Precautions should be taken to reduce electrical noise in the agricultural environment.
PROCEDURE AND RESULTS

Establishment of Design

The animal environmental control system is designed to control ventilation, supplemental heat, and air distribution. The flexibility of the microcomputer allows expansion beyond these objectives. However, reasonable goals were imposed to meet the time and financial framework of the project. A block diagram depicting the microcomputer control system is shown in Figure 7.

Environmental control of swine in confinement is an appropriate challenge for the controller. Swine are sensitive to their environment and benefit from improved environmental control. A controller designed for swine can be modified for use in other livestock environments.

Animal environmental control system

The ventilation system consists of single-speed and variable-speed fans. Input factors influencing ventilation rates include inside temperature, outside temperature, moisture content of the inside air, speed of the minimum ventilation fan, and management input. Air temperature versus the set temperature from management is the main factor affecting the ventilation rate. The outside temperature influences the quantity of change in airflow rates. Moisture content is examined by measuring dew-point temperature to maintain moisture levels below the maximum relative humidity. Fan speed is monitored to prevent the variable-speed fan from dropping below a minimum ventilation rate. A supplemental heater of a fixed output is incorporated to maintain a
Figure 7. Block diagram of control system
minimum inside temperature by comparing the desired versus the actual temperature. The supplemental heating system is not activated unless the ventilation system is at its minimum rate.

Air distribution is controlled by monitoring static pressure. The area of air inlet is adjusted to control air velocity to maintain a uniform air distribution.

Management input controls the minimum ventilation rate and sets the desired temperature. When the desired temperature changes the manager adjusts one setting. A teletype is provided for a hard copy of data.

Research site

The research is being conducted with an operator of a swine complex located approximately three miles north of Mingo, Iowa. The present manager has complained of the lack of ability to properly control the environment. The complex is a complete farrow-to-finish operation with a multiple number of confinement units. The microcomputer is designed to control one swine farrowing and one swine nursery room. The control of odor while minimizing energy consumption in the winter is a primary requirement in the farrowing room. High moisture levels with a relatively high temperature in the nursery room places different demands on the controller.

The 12-crate farrowing room is 24 ft by 32 ft by 8 ft with the length being on the east and west walls. Eight air inlets are placed symmetrically on the east and west walls at the ceiling. The air inlets are 6 in. doors that slide horizontally to a maximum opening width of 44 in. The exhaust ventilation system consists of a single-speed and a
variable-speed fan located on the south wall. The 14-in. diameter variable-speed fan is rated at 950 cfm at 0.10 in. water gage. The manufacturer's literature states that the fan's ventilation rate can be lowered to 112 cfm at 0.00 in. water gage. The 18-in. diameter single-speed fan is rated at 3,560 cfm at 0.10 in. water gage. A unit heater supplies 60,000 Btu/hr and ventilates its combustion gases in the room. Zone heating is used for the first week after birth in the individual crates. The waste management system consists of a shallow pit behind the sows which is emptied every four weeks by gravity flow. The crates are fully slatted with a solid portion provided for young pigs. Feeding is accomplished by moving a cart down the center alley. The door located on the north wall enters a common causeway joining the room to the complex.

The nursery room on the average contains 260 head in a 18 ft by 32 ft by 8½ ft space with the length on the north and south sides. The air inlets are located on the east and west with two on each wall. The inlet doors are 12 in. high and can be moved to a width of 44 in. Two ventilation fans, forming an exhaust ventilation system, are located on the west wall. The 18-in. diameter variable-speed fan is rated between 400 cfm at 0.00 in. water gage to 3,620 cfm at 0.10 in. water gage for the maximum ventilation rate. The 24-in. diameter single-speed fan provides 5,400 cfm at 0.10 in. water gage. A 60,000 Btu/hr non-vented unit heater supplies supplemental heat for the room. The waste management system is composed of a fully slotted floor above a shallow pit which is emptied between groups of pigs. Automated feeding
is accomplished by an auger system. The center alley in the room is entered through a door on the east wall.

The microcomputer is located in a metal container in the office. The container is grounded and sealed to protect the electronic components. The farrowing room is 190 ft and nursery room 20 ft from the office. A teletype is located next to the microcomputer.

Controller

Selection

The objectives require logical control to manipulate the environment. A number of methods to provide logic including a combination of SSI and MSI circuits and a programmable controller were investigated before selection of a microcomputer.

The use of less complex circuits of the SSI and MSI nature was applied by Kranzler (1977) for low-temperature grain drying. During the testing phase, the rationale of low-temperature grain drying was modified. Such changes require significant modifications in hardware design before the new concepts can be applied. A similar controller for livestock environments may require several different designs for various applications. Designer expertise is required in timing and noise reduction. The use of SSI and MSI provides the lowest initial hardware cost but overall developmental cost could be greater. Hardware modification requires retesting for reliability.

A programmable controller is a general purpose device which is programmed to control a variety of machines. Modifications may be
needed to adapt sensors required for the livestock environment. The designer is required to write software in the language of the individual machine. A major disadvantage of the programmable controller is its cost.

The microcomputer was selected for its relative cost and flexibility to provide logical control. Selection factors for a microcomputer are unique for agriculture applications where the speed of the microprocessor is not pertinent. The selection of a popular microprocessor augments the selection of a microcomputer. The future availability of a popular microprocessor enhances the prospects of software and hardware compatibility to the next generation of microprocessors.

Memory can be a considerable part of the cost of the microcomputer. A PROM or EPROM has significant costs which are increased if a convenient method of programming the IC is not available. Several options of programming language are available to the user. Assembly language is difficult to write but does optimize program memory size. Timing and I/O are facilitated by assembly language. The language consists of mnemonic abbreviations representing the machine instructions which can be structured into a recognizable program. A higher level language, located in ROM, provides programming ease but requires additional memory for the program.

Use of a commercial microcomputer requires development of transducers, interfacing, and software. Manufacturers of a proven microcomputer design will provide support and documentation. Support devices can aid development and be eliminated in the final design. The cost of a
microcomputer is substantial but the expense of transducers, interfacing and software is more significant. Reliability and protection of the microcomputer are critical for interfacing. A number of selection factors were considered including software support, I/O capabilities, and the number of supply voltages required.

Noise protection should be stressed in transducer and interfacing design. Transducer signals must be stable and provide accuracy with a minimum of maintenance. Interfacing should have a minimum number of chips for reliability. The isolation of all low-level signals from the AC power supply is critical. Transducers should be designed to use a minimum variety of supply voltages. A stable power supply designed for microcomputer applications is desired.

A single-board microcomputer utilizing assembly language was selected as the most cost effective controller for the livestock environment. The single-board microcomputer can provide the functions necessary and maintain hardware costs at a minimum.

**Development system**

An SDK-85 was selected as the development system to be employed for the project. The system, shown in Figure 8, is a complete single-board microcomputer containing a 6 digit LED readout, 24 pushbutton keyboard, and a system monitor program. A breadboard area for wire-wrapping is included on the left portion of the board. To the right of the breadboard are the I/O ports from the microcomputer. The left edge of the board contains jumper connections which couple off-the-board devices to the breadboard. Space is allocated for expansion drivers and
Figure 8. Physical representation of development system (Intel Corp.)
Physical representation of development system (Intel Corporation 1978c)
buffers for the address, data, and control buses.

The basic unit, whose schematics are shown in Figures 9-11, is composed of four LSI integrated circuits. The system utilizes an 8085A microprocessor as its central processing unit. The basic memory consists of an 8355 PROM and an 8155 RAM designated A14 and A16 respectively in Figure 10. The 8355 contains the resident monitor of 2K and two general purpose 8-bit I/O ports. The 8155 includes 256 bytes of RAM with two programmable 8-bit I/O ports, one programmable 6-bit I/O port, and a 14-bit timer. The timer for the basic RAM is dedicated to single-stepping with the monitor. An expansion RAM was added in the space designated A17 in Figure 10. The basic RAM beginning address is at $2000_H$ with the top 42 bytes reserved for the monitor and interrupt service routines. With the addition of the expansion RAM, located at $2800_H$, there are 470 bytes available to the user. An 8279, shown in Figure 9 as A13, is dedicated for the LED display and keyboard operation. The LED readout provides memory location and data in hexadecimal code. A 20 mA current loop is available for interfacing to a teletype.

The resident monitor, intended for general software utilities and system diagnostics, can be used for direct insertion and examination of a user's program. In addition, it has the capabilities of executing a program, single-stepping through a program, and servicing an interrupt via the keyboard. The software utilities of the monitor are available to the user's program. The monitor contains the software necessary to control data transfer between the microcomputer and a teletype.

Initially an 8755 EPROM was selected for direct placement in the
Figure 9. Schematic of keyboard and display (Intel Corporation)
Figure 9. Schematic of keyboard and display (Intel Corporation 1978c)
Figure 10. Schematic of processing area and TTY interface (Intel Corporation)
schematic of processing area and TTY interface (Intel Corporation 1978c)
Figure 11. Schematic of control, address, and data bus expansion (inte
tic of control, address, and data bus expansion (Intel Corporation 1978c)
space reserved on the board. The 40-pin integrated circuit could not be programmed locally. Experimentation led to the addition of the buffer and bus drivers as shown in Figure 11. A 2716 EPROM was substituted and connected as illustrated in Figure 12. The 2716 contains 2K of memory beginning at address $8000_{16}$ and can be programmed locally.

A commercial power supply from Elpac Power Systems was added with isolated outputs of 5, 15, and 15 volts. The supply, a μPS-35, was connected to provide +5, +15, and -15 volts with 3, 0.5, and 0.5 amps respectively. The power supply, designed for microcomputer applications, provides 0.3 percent line regulation and 0.5 percent load regulation. Overvoltage protection was added to the +5 volt supply. A second power supply providing a -10 volts was acquired to supply the 20 mA current loop for serial communication. A ISO-1, commercial surge protector and AC filter with three isolated sockets, was obtained from Electronic Specialists.

Modifications to the microcomputer were made to attain a real-time function. The TIMER IN line of the expansion RAM is connected to the system clock of the microprocessor. The TIMER OUT line of the expansion RAM is connected to the RST 7.5 line of the microprocessor. Intel's referenced designated capacitor C12 was removed to accommodate the modifications which disabled the interrupt pushbutton switch on the keyboard.

To facilitate trouble-shooting and program development, a pushbutton switch was added to the breadboard area. The depression of the pushbutton, shown in Figure 13, activates interrupt 6.5.
Figure 12. Schematic of memory expansion
Figure 13. Schematic of pushbutton interrupt
Reference Inputs

**Temperature**

A number of temperature sensing techniques were evaluated including thermocouples, thermistors, and semiconductors. The semiconductor sensor provides the best combination of cost, performance, and flexibility desired. It uses a fundamental property of the silicon transistor to realize its temperature proportional characteristics. The resulting voltage is converted to a current by a 51Ω metal film resistor with a low temperature coefficient located next to the sensor as depicted in Figure 14. The output current from the National Semiconductor LM334 is proportional to absolute temperature with the relationship:

\[ I = (8.01 \mu V/°R)(T) \]

The current signal is converted to a voltage at the ADC by a second resistor. The resistor is trimmed to provide a ratio of forty-to-one between the second and first resistors respectively. The resulting output is:

\[ V = (5.04 mV/°R)(T) \]

The LM334 has an operating range of 32 to 158°F with a operating voltage from 1 to 40. The output current does not have its accuracy affected because of series resistance in long wire runs. Trimming of the potentiometer at the ADC reduces error for the proportional relationship between temperature and voltage to less than one percent. Electrical interference is minimized by current sourcing. The sensor is located in a plastic tube and sealed in epoxy for protection from the environment. The sensors are placed approximately 3 ft above the floor.
<table>
<thead>
<tr>
<th>LOCATION</th>
<th>POTENTIOMETER&lt;sup&gt;a&lt;/sup&gt; DESIGNATION</th>
<th>JUMPER CONNECTION</th>
<th>IC CONNECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farrowing, South End</td>
<td>R18</td>
<td>J9-5</td>
<td>IC5, 3</td>
</tr>
<tr>
<td>Farrowing, Center</td>
<td>R17</td>
<td>J9-3</td>
<td>IC5, 4</td>
</tr>
<tr>
<td>Nursery, West End</td>
<td>R23</td>
<td>J11-1</td>
<td>IC5, 5</td>
</tr>
<tr>
<td>Nursery, East End</td>
<td>R24</td>
<td>J11-3</td>
<td>IC5, 6</td>
</tr>
<tr>
<td>Outside</td>
<td>R16</td>
<td>J11-21</td>
<td>IC5, 2</td>
</tr>
</tbody>
</table>

<sup>a</sup>All potentiometer values are 5kΩ.

Figure 14. Schematic example of temperature measurement with tabulation of sensors and connections.
beyond the reach of livestock and throw of the ventilation and heating systems.

**Moisture content**

Numerous methods, techniques, and parameters are used to measure moisture in the air. The selection of a sensor for livestock environment is dependent on the parameter to be measured, the degree of accuracy required, types of contaminants anticipated, and cost.

The two parameters that have the greatest potential in the livestock environment are wet-bulb and dew-point temperature. The use of wet-bulb thermocouples requires daily maintenance during the winter to supply distilled water. A saturated salt (lithium chloride) dew-point sensor was selected for its durability and simplicity. Contamination has little effect because the sensor operates saturated with lithium chloride, whereas relative humidity sensors operate starved of lithium chloride. The sensor has a relatively slow response time and a lower limit of 11 percent relative humidity. The dew-point temperature sensor is expensive and must be cleaned periodically in harsh environments.

The sensor selected for implementation was a General Eastern model 650/611A dew-point temperature sensor and temperature transmitter shown in Appendix A. The model uses an elemental winding of inert platinum wire over a glass wick on a teflon sheathed stainless steel bobbin. A linear platinum RTD monitors the bobbin temperature. The sensor provides a output of 0 to 5 volts between 0 and 200°F. The connection of the sensor to the ADC is shown in Figure 15. The sensor and transmitter located in the nursery room require a 120 VAC power supply.
Figure 15. Schematic of dew-point temperature sensor and transmitter
Static pressure

Two parameters, air velocity and static pressure, were considered as references for maintaining a uniform air distribution. Static pressure was selected as the parameter that could provide an analog signal with a minimum of maintenance. The equipment used to attain a static pressure signal is shown in Figure 16. A diaphragm within the metal container is located inside the controlled environment. A tube runs from the diaphragm to the attic of the building which is at outside pressure. The diaphragm's volume changes as the pressure difference between the room and the outside deviates. An increase in the ventilation rate for the exhaust system causes the bag to increase in size given a constant area of air inlet. A piece of sheet metal with a magnet attached is in direct contact with the diaphragm. A change in the volume of the diaphragm moves the sheet metal on a horizontal axis. A linear Hall effect sensor, located at a fixed location, monitors the movement of the magnet. The magnetic flux is amplified within the sensor to output a voltage representation of the distance from the sensor to the magnet. The signal from the sensor is then amplified as shown in Figures 17 and 18. Two different amplification circuits, one utilizing one operational amplifier and one employing two operational amplifiers, were constructed. A potentiometer in the amplification circuit provides an offset voltage for the output signal. Calibration of the signal is accomplished by referencing a liquid manometer with adjustments in the potentiometer or the location of the threaded Hall Effect sensor. The Hall Effect sensor is completely sealed with a aluminum exterior. The
Figure 16. Apparatus for monitoring static pressure
Figure 17. Schematic of static pressure sensor and amplification circuit for farrowing room
Figure 18. Schematic of static pressure sensor and amplification circuit for nursery room
amplification circuit is located in the metal container.

The amplified signal is nonlinear with the most significant changes occurring as the magnet approaches the sensor. The sensor requires a +5 volt supply and the operational amplifiers +15 and -15 volts.

**Fan speed**

There is a direct relationship between a fan's rpm and ventilation rate for a given static pressure. The circuits shown in Figure 19 and 20 were developed to measure fan speed. The sensor utilizes two magnets mounted with opposite polarity on a fan blade. A digital Hall effect sensor is mounted on the fan housing as shown in Figure 21. The signal changes when a different polarity is presented to the sensor. Utilizing current sinking logic, the sensor output is connected to a NAND gate located on the breadboard. The output from the NAND gate is connected to port 23_H of the microcomputer.

The major difference between the linear and digital Hall effect sensors is a trigger circuit that provides only two states. A bipolar device, requiring reversing polarities of a magnetic field, was selected because of improved noise margins with increased sensitivity. The 103SR17A-1 from Microswitch requires a +15 volt supply. The sensor is located in a sealed, threaded aluminum bushing. A calibration sensor was acquired to locate the appropriate distance between magnet and sensor.

**Management**

Management input for the desired temperature is located inside the controlled environment. The desired temperature is output to the ADC
Figure 19. Schematic of fan speed measurements for farrowing room.
Figure 20. Schematic of fan speed measurements for nursery room
Figure 21. Fan with rpm measurement apparatus
by the circuits shown in Figure 22. Adjustment of the potentiometer provides a voltage equivalent to the output of the temperature sensors. The value of the fixed resistors is a function of the expected range of temperatures. Temperature markings on the exterior of the container relate voltage to temperature for the operator. One management input is located in each room.

Interfacing

The I/O lines are dedicated as listed in Table 1. Ports \(00_H\) and \(01_H\) are connected to the ADC. Rpm pulses are interfaced to port \(21_H\). Ports \(22_H\) and \(23_H\) are employed for controlling the two DACs. Port \(2A_H\) is utilized to interface to control forces. The teletype is directly connected to the top right portion of the board with port \(29_H\) controlling its power.

Figure 23 is a physical layout of the breadboard area showing reference designations for components. Individual connections are shown in their respective figures. Capacitors not designated in the schematics are connected between ground and the adjacent IC's power supply or the board's power bus. \(R1\) is a 2.2KΩ pull-up resistor for \(\overline{WR}\) of the microprocessor. Connections made on the breadboard are wire-wrapped. Wire connections off the board are coupled with terminal strips. Reference inputs and control forces are interfaced to the board from terminal strips in the office to the jumper locations, designated with a \(J\) in the figures, on the left edge of the board.

Electrical noise is encountered in a livestock building. Design
Figure 22. Schematic of management input
Table 1. Dedication of microcomputer I/O ports

<table>
<thead>
<tr>
<th>Port</th>
<th>Bits</th>
<th>I/O</th>
<th>IC Reference</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>00_H</td>
<td>0-7</td>
<td>In</td>
<td>5</td>
<td>Data input from ADC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>Address input A for ADC</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Out</td>
<td>5</td>
<td>Address input B for ADC</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Out</td>
<td>5</td>
<td>Address input C for ADC</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Out</td>
<td>5</td>
<td>Address input D for ADC</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Out</td>
<td>5</td>
<td>Address logic enable for ADC</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Out</td>
<td>5</td>
<td>Voltage reference select for 4053</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Out</td>
<td>5</td>
<td>Start for ADC</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Out</td>
<td>5</td>
<td>End of conversion from ADC</td>
</tr>
<tr>
<td>21_H</td>
<td>0-7</td>
<td>Out</td>
<td>10</td>
<td>DAC for variable-speed fan in nursery</td>
</tr>
<tr>
<td>22_H</td>
<td>0-7</td>
<td>Out</td>
<td>8</td>
<td>DAC for variable-speed fan in farrowing</td>
</tr>
<tr>
<td>23_H</td>
<td>0</td>
<td>In</td>
<td>6</td>
<td>Rpm pulse from 14-in. fan in farrowing</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>In</td>
<td>6</td>
<td>Rpm pulse from 18-in. fan in farrowing</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>In</td>
<td>6</td>
<td>Rpm pulse from 18-in. fan in nursery</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>In</td>
<td>6</td>
<td>Rpm pulse from 24-in. fan in nursery</td>
</tr>
<tr>
<td>29_H</td>
<td>0</td>
<td>Out</td>
<td>1</td>
<td>Teletype power</td>
</tr>
<tr>
<td>2A_H</td>
<td>0</td>
<td>Out</td>
<td>11</td>
<td>Air inlet motor direction in farrowing</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Out</td>
<td>11</td>
<td>Air inlet motor power in farrowing</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Out</td>
<td>11</td>
<td>Air inlet motor direction in nursery</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Out</td>
<td>11</td>
<td>Air inlet motor power in nursery</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Out</td>
<td>11</td>
<td>18-in. fan power in farrowing</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Out</td>
<td>11</td>
<td>24-in. fan power in nursery</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Out</td>
<td>11</td>
<td>Supplemental heater solenoid in farrowing</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Out</td>
<td>11</td>
<td>Supplemental heater solenoid in nursery</td>
</tr>
</tbody>
</table>
Figure 23. Physical layout of development system breadboard with reference designations
considerations to eliminate noise coupling and reducing noise at the receiver were given primary consideration. Connections to the board are through shielded cable, grounded at one end, containing twisted pair #22 wire. A plastic conduit, utilized for physical protection of the cable, was installed between the rooms and the office. Common ground leads between high-level and low-level signals were avoided. Terminal strips are located in sealed and grounded metal containers.

The ADC0816 data acquisition component, shown in Figure 24, was selected to interface analog signals to the microcomputer. The successive approximation 8-bit converter can address sixteen different single-ended analog signals. The converter has long-term accuracy and repeatability with minimal temperature dependence. TTL Tri-state\textsuperscript{R} output provides for direct interfacing to the microcomputer. Using ratiometric conversion, it has an absolute accuracy of less than or equal to the least significant bit. The higher voltage reference should not be more positive than the supply of 5 volts and the lower voltage reference should be no lower than ground. The sensitivity of the converter can be increased by using a symmetrical reference system. A 7493 divide-by-eight counter was connected to the 3.072 MHz signal from the system clock to provide a 384 KHz signal to the ADC.

A full five volt range between voltage references for an 8-bit converter provides a sensitivity of 0.02 V/bit. The static pressure and dew-point temperature sensors are satisfied with this range. A full 0 to 5 volt output from a temperature sensor would provide a change of 5.04 mV/°F. The ADC would increment its digital value every 3.97°F.
Figure 24. Schematic of analog-to-digital conversion
The sensitivity for temperature conversion is not acceptable and several alternatives were tested.

A CMOS analog switch, as presented in Figure 24, was selected to provide two different voltage ranges to be utilized as references. Switches are connected in a single-pole double-throw configuration for both the lower and higher voltage references. A LM313 precision reference diode is used to provide a reliable voltage drop. The LM313 is a temperature compensated diode with low noise and long term stability. Each diode is inserted in series with a resistor of equal magnitude providing a symmetric signal of 1.9 and 3.1 volts. The increased sensitivity of the ADC is 0.93°F/Bit. A 0.3 volt drop was measured for the full voltage swing resulting in a full scale reference from 0.3 to 4.7 volts. All components shown in Figure 24 are located on the breadboard.

Control Forces

Relays

Solid state relays (SSR) were selected to control the fan motors, air inlet motors, supplemental heaters, and the teletype. A SSR is an electronic switching device which performs essentially the same function as an electromagnetic relay (EMR). They are single-pole single-throw switches whose ratings include current handling capability, voltage, and surge current. A SSR is more expensive than an EMR and does have small amounts of leakage along with electrical noise interference. Current handling capabilities can be lowered by high operating temperatures thus
requiring a heat sink.

A SSR with a zero-crossing switch is required to minimize electrical noise production and surges. An optically coupled relay isolates the power line from the microcomputer. A snubber network is designed to prevent the AC voltage surges from tripping the SSR. The SSR that is TTL compatible facilitates interfacing. Typical I/O ports are capable of producing enough current to drive two TTL loads but not an optically coupled relay. A standard 7400 gate provides the current capabilities required. The SSR is totally encapsulated and protected from the corrosive environment.

Connections between port 2A\textsubscript{H} and the relays are shown in Figures 25-27. Table 1 has presented the control forces that are manipulated by port 2A\textsubscript{H}. All SSRs are connected utilizing current sinking logic. The SSRs and EMRs are located in metal containers within the rooms.

Air distribution control is provided by adjusting the area of the air inlets. The inlets, located symmetrically within the rooms, are interconnected by a cable. A reversible motor is connected to each cable to regulate the opening size. The circuits controlling air distribution are presented in Figures 26 and 27. A universal motor with a double-pole double-throw EMR is utilized in the farrowing room. The EMR controls direction while the SSR activates the motor. The nursery room employs a single-pole double-throw EMR to control the direction of a permanent split capacitor motor. A SSR is utilized to energize the motor. Each EMR is controlled by a transistor which with the 74100 is located in the breadboard area. Limit switches are provided to prevent
Figure 25. Schematic of interfacing between port 2A_H and control forces
Figure 26. Schematic of air inlet motor control for farrowing room
REFERENCE DESIGNATION | COMPONENT VALUE OR TYPE
--- | ---
D4 | 1N457
Q2 | 2N1711
R20 | 470Ω

Figure 27. Schematic of air inlet motor control for nursery room.
the air inlet motor from operating after the doors are completely opened or closed.

Problems developed with transistor failure when operating the EMR. A diode was placed in parallel with the coils of the relays but did not protect the transistor in the nursery. A power transistor was acquired to facilitate the current requirements for the nursery's EMR.

A teletype was connected for serial communications to the board. It is not desirable to allow the motor on the teletype to run continuously therefore a SSR was installed as shown in Figure 28. The two NOR gates were connected to the I/O port as a driver for the optically coupled SSR located inside the casing of the teletype.

Variable-speed fans

A variety of ventilation rates in a confinement building enhances environmental control. A prototype variable-speed fan control from Chore-Time was acquired for the project. The speed controller consists of a General Electric triac SC265D with a 0.047μF capacitor in series with a 330Ω resistor. A General Electric varistor model V275LS(20A) is integrated into the design. Failure of the speed controller results in the fan's maximum ventilation rate.

The speed controller has a single-pole double-throw switch labeled automatic and manual. In the manual operating position, the speed is adjusted by the operator with speed not a function of temperature. The operator sets the minimum speed on automatic with the speed increasing with temperature. The thermistor employed for monitoring temperatures was disconnected and replaced by an analog voltage signal from the
Figure 28. Schematic of power to teletype motor
The variable-speed controller was tested in a chamber that maintained a constant static pressure of 0.10 in. water gage. The variable-speed controller was connected to a 18-in. diameter fan with a 1/3 horsepower permanent split capacitor motor rated at 1,680 rpm and 1.9 amps. Fan speeds were measured by the SDK-85 utilizing the previously discussed rpm sensors. The speed was read for eight seconds with the number of cycles displayed on the readout. A number of speed ranges, utilizing different minimum speeds, were tested with the results of three shown in Figures 29-31. Voltage applied to the variable-speed controller was in 0.02 volt increments. The manual and automatic settings do not provide the same minimum speed.

In the lower and higher voltage ranges, speed changes of less than 20 rpm were noted. In a narrow voltage range between 1.90 and 2.04 volts a significant portion of the speed change occurred. The rate of change was lower in this range with a higher minimum speed. The greatest speed change of 270 rpm for a 0.02 volt increment occurred with the lowest minimum speed. The minimum speed attained with the controller was 300 rpm. The fan stalled at lower speeds and did not function when the maximum voltage was applied to the variable-speed controller. An analog signal with 0.02 volt increments provides approximately ten speeds.

The speed controller, encased in plastic, generates electrical noise in the form of radiation. The cable running between the rpm sensor and the microcomputer was initially not shielded. Whenever the fan was
STATIC PRESSURE = 0.10" W.C.

Figure 29. Prototype variable-speed controller's rate of motion versus voltage to speed controller for a minimum speed of 420 rpm
Figure 30. Prototype variable-speed controller's rate of motion versus voltage to speed controller for a minimum speed of 610 rpm
Figure 31. Prototype variable-speed controller's rate of motion versus voltage to speed controller for a minimum speed of 950 rpm
below its maximum speed the rpm count would be equivalent to 120 Hz. Replacement with a shielded cable resulted in an accurate rpm count.

A DAC0808, shown in Figures 32 and 33, was selected to provide the analog voltage signal to the speed controller. The DAC0808 is an 8-bit converter with a full scale output current. The DAC is directly interfaced to the I/O ports of the microcomputer. Resistors were sized to provide a voltage range of 1.4 from the operational amplifier. The potentiometers, designated R21 and R22, are provided for a voltage offset. The voltage signal is trimmed to a minimum of 1.60 volts and then incremented in 5.5 mV steps to 3.00 volts. The trimming and narrow voltage range provides a broader range of speeds than employing 0 to 5 volts.

Software

The main segments of the program are as follows:

-- Initial setup of program.
-- Measurement of fan speed.
-- Conversion of analog signals.
-- Control of air distribution.
-- Control of the ventilation rate and supplemental heat.
-- Operation of the teletype.
-- Real-time interrupt service routine.
-- Operator originated interrupt service routine.

The flow of the main segments of the program is presented in Figure 34. The initial set-up programs ICs and standardizes memory. Once the
Figure 32. Schematic of variable-speed controllers with interfacing to variable-speed fan in farrowing room.
Figure 33. Schematic of variable-speed controllers with interfacing to variable-speed fan in nursery room.
Figure 34. Flow chart of main segments
initial segment is complete, the program begins to acquire data. Fan speeds are counted followed by the conversion of analog signals to digital form. The program then proceeds to control the static pressure for both rooms. The next segment contains the program flow control between the main sections. The program flow control provides a jump to measure fan speeds at the terminal count of one minute. The control portion allows a jump to the fan and heater subroutine only if fan speeds have been counted. After adjusting ventilation rates and supplemental heating, the program prints a hard copy of the data if desired. The display and alarm system are then serviced. The program then returns to the control portion used between the main sections. If the time delay is not complete and an air inlet motor is on, the program jumps to convert analog values and control static pressure. It then checks the time delay and continues to service the static pressure control sequence until terminal count. Memory locations used for data storage are listed in Table 2. The control program has 610 instructions which employ 1,187 bytes of memory.

The two interrupt service routines are a real-time clock using a timer pulse from the expansion 8155 and a pushbutton service routine that prints all pertinent information when depressed.

The control byte is defined as the eight bits used to control the supplemental heaters, single-speed fans, air inlet motors and their direction. A listing of the applications for the respective bits is located in the I/O port designations of Table 1.

The listing of the program is contained in Appendix B. The listing
### Table 2. Location of data in memory

<table>
<thead>
<tr>
<th>Memory Location</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>28E0_H</td>
<td>DSB for farrowing</td>
</tr>
<tr>
<td>28E1_H</td>
<td>CSB for farrowing</td>
</tr>
<tr>
<td>28E2_H</td>
<td>DSB for nursery</td>
</tr>
<tr>
<td>28E3_H</td>
<td>CSB for nursery</td>
</tr>
<tr>
<td>28E5_H</td>
<td>Teletype print command</td>
</tr>
<tr>
<td>28E6_H</td>
<td>Rpm for 14-in. diameter fan in farrowing</td>
</tr>
<tr>
<td>28E7_H</td>
<td>Rpm for 18-in. diameter fan in farrowing</td>
</tr>
<tr>
<td>28E8_H</td>
<td>Rpm for 18-in. diameter fan in nursery</td>
</tr>
<tr>
<td>28E9_H</td>
<td>Rpm for 24-in. diameter fan in nursery</td>
</tr>
<tr>
<td>28F0_H</td>
<td>Static pressure in farrowing</td>
</tr>
<tr>
<td>28F1_H</td>
<td>Static pressure in nursery</td>
</tr>
<tr>
<td>28F2_H</td>
<td>Dew-point temperature in farrowing</td>
</tr>
<tr>
<td>28F3_H</td>
<td>Dew-point temperature in nursery</td>
</tr>
<tr>
<td>28F4_H</td>
<td>Outside temperature</td>
</tr>
<tr>
<td>28F5_H</td>
<td>Temperature sensor #1 in farrowing</td>
</tr>
<tr>
<td>28F6_H</td>
<td>Temperature sensor #2 in farrowing</td>
</tr>
<tr>
<td>28F7_H</td>
<td>Temperature sensor #1 in nursery</td>
</tr>
<tr>
<td>28F8_H</td>
<td>Temperature sensor #2 in nursery</td>
</tr>
<tr>
<td>28F9_H</td>
<td>Desired temperature in farrowing from management</td>
</tr>
<tr>
<td>28FA_H</td>
<td>Desired temperature in nursery from management</td>
</tr>
<tr>
<td>28FB_H</td>
<td>Pulses from timer</td>
</tr>
<tr>
<td>28FC_H</td>
<td>Second count</td>
</tr>
<tr>
<td>28FD_H</td>
<td>Minute count</td>
</tr>
<tr>
<td>28FE_H</td>
<td>Control byte</td>
</tr>
<tr>
<td>28FF_H</td>
<td>Fan flags for ventilation and supplemental heat subroutines</td>
</tr>
</tbody>
</table>
provides a sequence number, source code, and a comment field. The source code consists of a label field, mnemonic field and an address field. The label field assigns a value to the label by its location in the program. The labels are used in jump and branch instructions. A complete listing of all labels, their assigned sequence number and where they are referenced is included at the end of the program listing. The instruction set utilized is for the 8080/8085 microprocessors from Intel Corporation (1978a). A cross-assembler was utilized in a PDP-8 which was accessed from a Commodore Pet microcomputer via a UNIX time-sharing system. Memory addresses and object code were omitted from the appendix for ease in duplication. The program is started at memory location 8000, which corresponds to sequence number one. All numbers are in decimal form unless followed by an H which signifies hexadecimal code. The alarm and display routine is not written in mnemonics nor included in the program listing.

The program is downloaded by the UNIX time-sharing system into a HP 64000. The HP 64000 programs the instructions into the 2716 EPROM.

Debugging of the program included:
-- Single-stepping through the program one instruction at a time.
-- Breakpointing where the program was automatically stopped in its normal routine.
-- Memory dumping where the contents of the memory were verified.

Initial testing was conducted with the RAM which did not have the capacity to store the complete program. Segments of the program were assembled and manually loaded into the microcomputer. When software
development was in its final stages, the complete program was loaded into the EPROM and tested.

**Initial set-up**

The execution of the program accomplishes the following steps between sequence numbers 1 to 49.

1. Sets the stack pointer to 20C2H.
2. Loads and starts the expansion RAM timer.
3. Programs the I/O ports.
4. Establishes a minimum ventilation rate in memory and outputs the data to the I/O ports.
5. Prepares for interrupts by masking and loading jump commands.
6. Sets timer count to zero.
7. Enables interrupt service routines.

**Real-time**

Real-time is acquired by using the programmable timer of the expansion RAM. The programmable timer, a down counter, is under direct control of the microprocessor. The system clock, connected to the TIMER IN line, is at 3.072 MHz. A count of 15,360 is loaded in the timer resulting in a terminal count frequency of 200 Hz. At terminal count a single positive pulse is output before the count is automatically reloaded. The single pulse is transmitted via the TIMER OUT line to RST 7.5 on the microprocessor. RST 7.5 is activated by a positive pulse which causes a jump to 20CEH. A jump to the service routine is located at the memory location. The service routine stores all registers and
replaces them with their original contents when the routine is completed. The segment counts pulses, seconds, and minutes employing the memory locations listed in Table 2. The second count is stored in two memory locations, one for the actual count and the other for the rpm segment of the program. The segment is located between sequence numbers 50 and 79 in the program listing with the flow chart in Figure 35.

Fan speed measurement

The measurement of a fan's rpm is from sequence number 80 to 113 in the program listing with the flowchart shown in Figure 36. The segment is accessed after the initial steps of the program or when the time delay for the main program is terminated. The segment sets the flag for the fan and heater subroutine which is accessed at its appropriate sequence. The rpm count is set to zero before determining a fan's speed. Counting is implemented after the second count is incremented, ensuring that the count begins at the start of a second. The signals from all RPM sensors are masked with register C to determine the status of an individual signal. The count continues for four seconds and is then stored in memory. The C register shifts to the left in preparation for masking the next signal. The process is repeated until all signals are read.

Analog-to-digital conversion

The conversion of an analog signal is accomplished from sequence number 114 to 134 in the program listing. The full voltage reference range is utilized for dew-point temperature and static pressure conversion with temperature and management inputs employing the narrower
REAL-TIME INTERRUPT

STORE REGISTERS

INCREMENT CLOCK COUNTER

HAS 1 SECOND ELAPSED?

YES

SET CLOCK COUNTER TO ZERO

INCREMENT SECOND COUNT

NO

HAS 1 MINUTE ELAPSED?

YES

SET SECOND COUNT TO ZERO

INCREMENT MINUTE COUNT

NO

HAS 1 HOUR ELAPSED?

YES

SET MINUTE COUNT TO ZERO

ENABLE INTERRUPT; RESTORE REGISTERS

RETURN

Figure 35. Flow chart of real-time interrupt
Figure 36. Flow chart of fan speed measurement
voltage reference range. The segment, as presented in Figure 37, selects the voltage references and the channel to be converted. The channel address is presented before the address latch enable observes a low to high transition. The converter starts when a high to low edge is detected. The address latch enable and start pulses are combined for an output instruction in the program. A time delay is accessed through the monitor software. At termination of the delay, the data are input through port $00^R$. The Tri-state$^R$ buffer of the ADC is permanently enabled. The segment again selects the proper voltage reference and initiates the conversion process which ends when all signals are read.

The ADC employs ratiometric conversion where the variable being measured is expressed as a percentage of full-scale which is not necessarily related to an absolute standard. The voltage input to the ADC0816 is expressed by the equation:

$$\frac{V_{in}}{V_{hs} - V_{ls}} = \frac{D_x}{D_{max} - D_{min}}$$

where

- $V_{in}$ = input voltage
- $V_{hs}$ = high-scale voltage
- $V_{ls}$ = low-scale voltage
- $D_x$ = data point being measured
- $D_{max}$ = maximum data limit
- $D_{min}$ = minimum data limit
Figure 37. Flow chart of analog-to-digital conversion
Air distribution control

The air inlet segment controls the static pressure in both the farrowing and nursery rooms. The constants used are set to maintain a static pressure between 0.04 and 0.06 in. water gage. The constants can be changed by reprogramming the EPROM. The segment starts the motor in the proper direction when the static pressure is outside the limit as depicted in Figure 38. The routine turns the motor off when the static pressure is within the limits. The figure does not show the duplication of the segment for the nursery room. The program is located between sequence number 135 and 150 for the farrowing room and 151 to 166 for the nursery room.

Ventilation and supplemental heat control

The fan and heater subroutine, as shown in Figure 39, is designed to control a supplemental heater, a variable-speed fan, and a single-speed fan. The subroutine can be modified for the addition of single-speed fans or supplemental heating units. The subroutine is written to control one room's environmental control system. Control of more than one system requires the movement of data prior to and following the subroutine. The subroutine is located in sequence numbers 183 to 368 for the farrowing room and 369 to 554 for the nursery room.

The design criteria require supplemental heat to be added when the system is at its minimum ventilation rate. Two terms related to the variable-speed control were developed, the dominant speed byte (DSB) and the compliment speed byte (CSB). The DSB is a function of inside temperature and is at its minimum value before the supplemental heat is
Figure 38. Flow chart of air distribution control for farrowing room
Figure 39. Flow chart of ventilation fans and supplemental heater control
actuated. The CSB is affected by the inside relative humidity and/or the rate of movement of the variable-speed fan when the single-speed fan is off.

The rate of change of speed for the variable-speed fan is designated the speed adjustment factor (SAF) and is primarily a function of outside temperature. During periods of cold weather the SAF is small, in mild weather moderate, and in warm weather large. The SAF is set to zero when the inside temperature is within the desired range determined by the constants, C1 and C2, as shown in Figure 39. The SAF is equal to zero when the supplemental heating system is on. When the inside temperature is significantly below the set temperature indicated by C4, the SAF is increased. Register D is utilized to store the SAF during the subroutine.

The CSB is adjusted at the label CHECK1 in the subroutine for the farrowing room. When the relative humidity is above 70 percent or the speed of the variable-speed fan supplying the minimum ventilation rate is below 400 rpm, the CSB is increased in value. If the CSB is less than the DSB, it is set equal to the DSB before being incremented. The utilization of the microcomputer makes the conversion of dew-point temperature to relative humidity convenient. In the region of expected temperatures there is a moderately linear relationship between dew-point temperature and relative humidity. The software utilizes this relationship which results in a maximum fluctuation of 3 percent between the calculated and actual relative humidity. Under extreme conditions, when the inside temperature is below the limit set by C6, the CSB is decreased substan-
After adjustment of the CSB the routine determines, beginning at label COOL1 for the farrowing room, the status of the supplemental heater. The heater is activated when the single-speed fan is off, the DSB at its minimum value, and the temperature is below the limit set by C5. If the supplemental heat is not to be engaged the SAF is subtracted from the DSB. A carry flag in the microprocessor indicates that the SAF is greater than the DSB. If a carry occurs and the single-speed fan is turned off, the DSB is set to zero after a carry. The larger of the DSB or CSB is output to the DAC.

Deactivation of the single-speed fan is accompanied by a rapid decrease in air velocity. The time period required to sense and raise the static pressure can be stressful to the livestock. The program starts closing the air inlet doors whenever the single-speed fan is deactivated.

The contingency segment of the subroutine starts at the label TEST1. When the single-speed fan is off, the variable-speed fan's rpm below 100, and the static pressure near zero the single-speed fan is activated. During the next cycles of the subroutine, the single-speed fan is deactivated. If the same conditions exist in the next cycle, the process is repeated. The subroutine is complete at the end of the contingency segment.

The portion of the subroutine starting at label WARM1 is employed whenever the inside temperature is above the range set by C2. When the supplemental heater is on and set temperature does not exceed the limit set by C3, the program sets the SAF to zero and jumps to check the
CSB. The flow of the program does not return to the warm segment of the subroutine after checking the CSB.

The supplemental heater is turned off when the range determined by C3 has been exceeded. The SAF is then added to the DSB. The testing of the variable-speed controller indicated that the lower range of voltages applied by the DAC did not substantially alter the fan's speed. The time delay required to increment the DAC to a significant voltage prevents airflow greater than the minimum ventilation rate during cold weather.

A carry flag appears in the microprocessor if the SAF plus the DSB is greater than FF. When the single-speed fan is off during a carry, the program compares inside temperature against C7. The single-speed fan is not activated until inside temperature indicates stressful conditions. Activation of the single-speed fan sets the DSB and CSB to zero. If the single-speed fan is not activated, the DSB is set to its highest value after a carry. The inlet door begins to open when the single-speed fan is activated to reduce excessive air velocities. The greater of the CSB or DSB is output to the DAC before exiting from the subroutine.

Figure 40 depicts the operation of the ventilation system. When the outside temperature increases to T1 the variable-speed fan begins to increase its ventilation rate. At T2 the variable-speed fan reaches its maximum ventilation rate. Electrical energy conservation prevents the single-speed fan from being activated until the temperature warms to T3. When the single-speed fan is activated, the variable-speed fan is reduced to its minimum rate which results in a smaller fluctuation in ventilation.
Figure 40. Operation of ventilation system
rates. Q3 minus Q1 represents the rating of the single-speed fan. At T3 the variable-speed fan begins to increase speed until T4 where the maximum ventilation rate for the system is attained. Q3 minus Q2 is the range of airflow rates for the variable-speed fan. T1 through T4 are functions of the sensible heat balance for the building.

**Teletype operation**

Serial communication for the teletype is controlled by a routine in the resident monitor. The routine is accessed by the flow diagram shown in Figure 41. Memory location 28E5H determines if data are to be printed. A 00H in the memory location has the segment bypassed, a 01H has data printed hourly, and a 2CH has data printed every minute. 28E5H is filled with the appropriate data prior to execution of the program. The teletype is activated followed by a time delay for the motor to prepare for operation. Data starting with 28E0H to 28FFH are printed as shown in Figure 42. A time delay from the resident monitor is provided after a line feed. At the end of the segment a jump occurs to the flow control segment of the main program.

Interrupt 6.5 is initiated by the pushbutton located in the breadboard area. The interrupt service routine employs the teletype segment of the program. Additional information including register contents and the program counter is printed as shown in Figure 42. At completion of the printout, the segment returns to the location of the program at which the interrupt occurred, returning all registers to their original values.
Figure 41. Flow chart of teletype operation
### Teletype routine printout

<table>
<thead>
<tr>
<th>STATUS</th>
<th>PROGRAM REGISTERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>COUNTER</td>
<td>XX-XX-XX-XX-XX-XX-XX-XX-SF- A- L- H- E- D- C- B-</td>
</tr>
<tr>
<td>INTERRUPT</td>
<td>PC-PC-PC-XX</td>
</tr>
</tbody>
</table>

### Interrupt 6.5 routine printout

<table>
<thead>
<tr>
<th>DATA FROM</th>
<th>EO-E1-E2-E3-E4-E5-E6-E7-E8-E9-EA-EB-EC-ED-EE-EF-</th>
</tr>
</thead>
<tbody>
<tr>
<td>28EO_H - 28FF_H</td>
<td>FO-F1-F2-F3-F4-F5-F6-F7-F8-F9-FA-FB-FC-FD-FE-FF-</td>
</tr>
</tbody>
</table>

---

**Figure 42.** Location on hard copy from teletype of memory contents from 28EO_H to 28FF_H and information for program debugging
Installation of System

Components designed for the system were constructed on a breadboard. Once the performance of the components was proven, they were permanently assembled. The circuit's operation was verified before removal to the research site. The assembled components were installed and evaluated at the research site. An oscilloscope was used for testing reference inputs. Acute low frequency noise was present on the static pressure signals. Capacitors of appropriate magnitude were added to resolve the problem. The combination of software and hardware was operational in June of 1981.

Conventional controls that previously existed are integrated into the system. A single-pole double-throw switch is connected to the conventional speed controller to operate the variable-speed fan when the microcomputer is not in operation. The safety thermostat for the conventional variable-speed control is in series with both units. The thermostat for the supplemental heater, utilized as a safety for low temperatures, is in parallel with a SSR. The thermostat for the single-speed fan is in parallel with a SSR which activates the fan for safety at high temperatures. Switches and fuses for the fans are in series with all controllers. The microcomputer regulates the variable-speed fan between its minimum and maximum ventilation rate but does not deactivate it. Manual switches are connected to control the air distribution system.

The physical layout for the static pressure sensor circuits are presented in Figures 43 and 44. The sensors were tested in the rooms with
Figure 43. Physical layout of static pressure amplification circuit in farrowing room
Figure 44. Physical layout of static pressure amplification circuit in nursery room
an adjacent liquid manometer as a reference. The results of the testing are presented in Table 3.

Table 3. Static pressure sensing data

<table>
<thead>
<tr>
<th>Static Pressure in. water gage</th>
<th>Farrowing room Volts</th>
<th>Nursery room Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td></td>
<td>2.65</td>
</tr>
<tr>
<td>0.03</td>
<td>1.71</td>
<td>2.68</td>
</tr>
<tr>
<td>0.04</td>
<td>2.20</td>
<td>2.79</td>
</tr>
<tr>
<td>0.05</td>
<td>2.91</td>
<td>2.99</td>
</tr>
<tr>
<td>0.06</td>
<td>4.00</td>
<td>3.23</td>
</tr>
<tr>
<td>0.07</td>
<td></td>
<td>3.62</td>
</tr>
</tbody>
</table>
DISCUSSION

The hardware costs of control components excluding labor to control the two rooms was approximately $1,500. The major expenditures were for the microcomputer, cables, and the dew-point temperature sensor and transmitter for the nursery. An environmental controller, capable of regulating a multiple number of environments, including a microcomputer and power supply costs approximately $180. The reference inputs, excluding the dew-point temperature apparatus, amount to approximately $80. The ability to control the single-speed fan, variable-speed fan, supplemental heater, and air distribution system cost approximately $150. The expense for containers, connectors, and cables to a room forty feet from the controller is approximately $170. The total hardware expenditure for a single room is approximately $580 when purchased in single quantities. The control of additional environments will reduce overall cost per room. Labor would substantially increase the cost of the system.

The microcomputer increases the possible parameters for moisture measurement in the animal environment. The dew-point temperature sensor and transmitter is expensive. The replacement of the RTD element and transmitter with a semiconductor sensor would significantly reduce cost. The testing of the sensor in a swine nursery indicates that maintenance once every four months should be adequate. The sensor is required for winter operation, therefore cleaning every fall would meet the maintenance requirements.

Microcomputer simulation of the moisture and temperature balance curves without moisture measurement is difficult. Reliable prediction
of moisture production values, given a waste management system, are arduous to obtain. Production values for different animals would require separate programs. The altering of moisture production during the growth of the animal or changing weather conditions reduces the feasibility of simulating the curves. Proper control of the minimum ventilation rate by the operator would eliminate the necessity of moisture measurement.

A general purpose 741 operational amplifier was employed in several reference input circuits. A more durable and stable operational amplifier or instrumentation amplifier would increase the quality of the circuit. A -15 and +15 volt supply is needed for offsetting and power to the operational amplifiers. If offsetting is not required, the use of a single-voltage supply operational amplifier is suggested.

The utilization of two ADC, one dedicated for temperature and management signals and the second employed for all other signals, can provide an improved design. Each ADC would have a fixed-voltage reference for their respective inputs thus excluding the analog switch used in the project. Two ADCs are a greater expense but the cost of the ADC0816 has been reduced from $30 to $18 for single quantities. If eight channels are sufficient, a similar ADC is available at a lower cost.

Analog signals cannot be greater than five volts or less than ground with the ADC. A signal greater than five volts results in all signals being read as high. The static pressure sensor's signal can result in above five volt readings. The insertion of a wooden block in the container provided a minimum distance between the sensor and magnet.
An improved method would be to install a voltage clipping circuit to all signals capable of exceeding five volts. A complement circuit is needed for signals capable of going below ground.

General purpose circuit modules that allow a microcomputer to control loads and sense reference inputs are available. The plastic encapsulated circuits are more expensive than custom designed interfaces but provide convenience and increased reliability. An increase in popularity may decrease their price making them feasible for control applications. The variety of I/O modules is increasing with motor control, temperature, and pressure sensing the most predominant.

Supplemental heaters are designed for extreme weather conditions and introduce undesirable temperature fluctuations when activated. Environmental control would be enhanced with a variable source of heat. The variable control of current for electrical resistance heating could be applied by a microcomputer to reduce temperature fluctuations that accompany supplemental heating.

A larger variable-speed fan relative to the single-speed fan would reduce ventilation rate fluctuations. The variable-speed fan at a low ventilation rate with rpm sensing can adapt to varying wind speeds.

Periodic maintenance of the controller and transducers may require a service agreement. The manufacturer could sell with the controller a service agreement in which the manufacturer supplies labor and replacement components.

The flexibility of the microcomputer allows for expansion of reference inputs and regulation of control forces. Particular appli-
cations may be suited for operator control. Heat lamps used for zone heating in a swine farrowing crate are an example.

As alternate energy sources are developed and the concepts of energy conservation enhanced, logical control from the microcomputer can be utilized. A solar collector for a livestock building produces heat during the daytime when ambient temperatures are the highest. When the heat is not required, the ventilation rate will increase and the solar energy is not utilized. The solar collector's productivity could be optimized with the addition of solar storage and logical control.

Heat exchangers, promoting energy conservation, are being employed in livestock buildings. The heat exchanger has limited airflow capacity and requires an alternate ventilation system for the summer. Logical control is a requirement to optimize the use of the heat exchanger with the conventional ventilation system.

Reliability of the system can be increased with appropriate software. The program is designed to sense a failure of the variable-speed fan when the single-speed fan is off, fan speed is reduced, and static pressure is low. A failure of the rpm sensor affects the variable-speed fan but not the single-speed fan. Temperature is monitored at three locations in the room and the average could be calculated and utilized by the microcomputer. The program could be loaded with the expected range of signals from a sensor. If an improper signal was sensed, it would be excluded from the calculation of the average. A temperature sensor with a reading of 00°F, indicating absolute zero, is an error and would be excluded before calculating the average.
A 00\textsubscript{H} could indicate an open connection between the ADC and sensor.

A routine can be included in which an operator would perform a periodic service check. The operator would monitor the service check and be able to identify malfunctions. An alarm system would be activated if the service check was not conducted periodically.

Design and formation of the alarm and display systems is not fulfilled. A two-stage alarm system can be incorporated into the design. One state, providing information from digital displays and LEDs, would be monitored by the operator. The value of the reference inputs and the control forces would be presented. The operator would locate malfunctions by comparing the information versus the actual conditions. Minor problems detected by the microcomputer would be presented to the operator.

A second state can be a commercial alarm system using solid state components with a FM-radio paging system. An alarm system would have sensors independent of the microcomputer. An alarm system, with battery backup, can activate the paging system when a power failure has occurred. The microcomputer would reset to the beginning of the program when power was restored. A battery backup for the microcomputer does not improve the system without a power backup for the control forces. The temperature limits of an alarm system must be changed with varying weather conditions. The microcomputer has the flexibility of changing limits and activating an alarm system.

An external counter, separate from the microcomputer, utilizing the alarm power supply would be an integral part of the system. The
counter would require a periodic reset or the alarm would be activated. Failure of the microcomputer or software would actuate the alarm system. Commercial alarm systems have additional capabilities of monitoring for fire, water pressure, and burglary.
SUMMARY

Cost, I/O capabilities, power supply requirements, and memory that can be readily programmed are critical factors in the selection of a microcomputer. The microcomputer should be supported with substantial documentation. If the system employed for software development is different from the controller, it should have the ability to transfer the program into the controller.

The feasibility of microcomputer control has increased since the conception of the project. The decision to employ a single-board microcomputer versus a larger microcomputer using a high level language was based on cost. The retail price of the development system in kit form was $250 with a larger system costing three to five times more in 1979. A manufacturer has recently lowered the price of a microcomputer with a limited high level language and ability to use machine language to $99. The microcomputer, in kit form, includes a full keyboard, power supply, and the ability to be interfaced to a CRT and cassette recorder. The cost of the microcomputer and its development system is becoming less significant relative to the cost of transducers, interfacing, and labor.

The hardware is compatible with changes in the microcomputer and control scheme. Reference inputs of air temperature, moisture content of the air, fan speed, static pressure, and management are input to the microcomputer. The interfacing integrates reference inputs and control forces to the microcomputer. The controller manipulates single-speed fans, variable-speed fans, supplemental heaters and the air distribution systems. All components are protected from the corrosive environment.
The control scheme presents a rational correlation between the ventilation, supplemental heating, and air distribution systems. The scheme utilizes two terms to control the variable-speed fan, one a function of temperature and the second a factor of fan speed and relative humidity. The supplemental heat is not activated unless the term for temperature is at its minimum. The greater of the DSB or CSB is output to the DAC manipulating the variable-speed control. The rate of change for the ventilation system is a function of outside temperature. The program provides for the air distribution and ventilation systems to interact at the potentially stressful condition when the single-speed fan's status changes. A change in the single-speed fan's state results in a contrary modification in the ventilation rate of the variable-speed fan to reduce ventilation rate fluctuations. Ventilation required for extreme warm weather is not utilized until needed to promote electrical energy conservation. The concept of a contingency segment for reliability design in software is advocated. Constants, to be determined in the testing phase, are presented to reduce environmental fluctuations within the limitations of the control forces. Interrupts are provided for a real-time reference and program development. Management input is less complicated than conventional systems and provides for interaction between the operator and microcomputer. The operator manipulates the desired temperature and minimum ventilation rate as weather conditions and animal densities dictate.

Software development accounts for a substantial portion of the total labor involved in the design and implementation of the microcomputer.
The verification of the hardware and software design was accomplished at the research site. The temperature, dew-point temperature, static pressure, and fan speed sensors were independently tested with acceptable results. The operation of fans, supplemental heaters, and air inlet motors was independently proven. The software combination of initialization, fan speed measurement, digital-to-analog conversion, and air distribution control provided satisfactory interaction with the hardware. The combined operation of the supplemental heaters, single-speed, and variable-speed fans was verified. The air distribution system was proven to interact properly with the ventilation system. The teletype was activated with the main program and interrupt service routines.

A microcomputer system and control scheme for environmental control were developed in the project. The software was developed for swine farrowing and nursery confinement buildings. The system was operational in June of 1981 and has entered the testing phase of the project. The system may be expected to:

-- Prove the suitability of the microcomputer and its economic benefits of controlling the environment.

-- Provide logical interaction between the ventilation, supplemental heating and air distribution systems.

-- Supply a variety of ventilation rates with a reduction in environmental fluctuations.

-- Simplify management interaction with environmental control.

-- Facilitate development of alternate sources of energy and new concepts in energy conservation.
SUGGESTIONS FOR FURTHER STUDY

1. Develop and test interfacing between microcomputer and an alarm system.
2. Increase the number of control forces for the microcomputer including spray cooling and feeding.
3. Develop cost effective method of moisture measurement in a confinement building.
4. Investigate direct control of variable-speed fan with a microcomputer.
5. Develop alternate energy systems with microcomputer control.
6. Develop a computer model that allows simulation of a microcomputer controlled livestock environment.
7. Research microcomputer analysis of stressful conditions for the livestock with reference inputs of temperature and relative humidity for energy conservation.
BIBLIOGRAPHY


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-- To my wife, Debra Karin, for her patience, understanding and love throughout my graduate program. To my son, Matthew Kent for reminding me of my family commitment.
APPENDIX A:

BLOCK DIAGRAM OF MODEL 650
DEW-POINT TEMPERATURE SENSOR
The three-wire passive bridge circuits independently and simultaneously measure temperature and dew point by means of platinum RTDs. Independent adjustments are provided for zero, span and electrical analog output. The panel meter is temperature compensated, and a load is switched into the circuit when the meter is switched out to avoid an offset in output voltages.

**Fig. 4**
APPENDIX B:

LISTING OF CONTROL PROGRAM
ORG 8000H
LXI SP, 20C2H; INITIALIZE STACK POINTER
SUB A; SET ACCUMULATOR TO ZERO
OUT 2CH; LOAD LOW ORDER TIMER COUNT=00 HEX
OUT 02; SET DDR PORT 0 MONITOR ROM
MVI A, 7CH
OUT 2DH; LOAD HIGH ORDER TIMER COUNT=3C HEX
MVI A, 0C3H; PREPARE TO START TIMER
OUT 28H; SET EXPANSION RAM CSR
MVI A, 0FFH
OUT 2AH; ENSURE THAT ALL SSR ARE OFF
OUT 29H; ENSURE THAT TELETYPE IF OFF
MVI A, 03H; PREPARE FOR BASIC RAM CSR
STA 20FFH; STORE FOR SINGLE STEP
OUT 20H; SET BASIC RAM CSR
MVI A, 7FH
OUT 03; SET DDR PORT 1 MONITOR ROM
MVI A, 0C3H; PREPARE FOR INTERRUPT
STA 20CEH; STORE JUMP COMMAND FOR RST 7.5
STA 20C8H; STORE JUMP COMMAND FOR RST 6.5
LXI H, TIME; JUMP LOCATION FOR RST 7.5
SHLD 20CFH; STORE JUMP LOCATION
LXI H, HARD; JUMP LOCATION FOR RST 6.5
SHLD 20C9H; STORE JUMP LOCATION
LXI H, 28FBH; LOCATE CLOCK COUNTER
SUB A; SET ACCUMULATOR TO ZERO
MOV M, A; SET CLOCK COUNTER TO ZERO
INX H; LOCATE SECOND COUNT
MOV M, A; SET SECOND COUNT TO ZERO
INX H; LOCATE MINUTE COUNT
MOV M, A; SET MINUTE COUNT TO ZERO
MVI A, 0FFH
INX H; LOCATE CONTROL BYTE
MOV M, A; STORE FF HEX FOR CONTROL BYTE
MVI A, 00H
INX H; LOCATE FAN FLAG
MOV M, A; SET FAN FLAG TO ZERO
MVI L, 0E8H; LOCATE FARROWING DBS
MOV M, A; SET FARROWING DBS TO ZERO
INX H; LOCATE FARROWING CSB
MOV M, A; SET FARROWING CSB TO ZERO
INX H; LOCATE NURSERY DBS
<table>
<thead>
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<th>SEQ</th>
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<th>COMMENT</th>
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<tr>
<td>43</td>
<td>MOV M, A;</td>
<td>SET NURSERY DS TO ZERO</td>
</tr>
<tr>
<td>44</td>
<td>INX H;</td>
<td>LOCATE NURSERY CSB</td>
</tr>
<tr>
<td>45</td>
<td>MOV M, A;</td>
<td>SET NURSERY CSB TO ZERO</td>
</tr>
<tr>
<td>46</td>
<td>MVI A, 09H;</td>
<td>PREPARE TO UNMASK INTERRUPTS</td>
</tr>
<tr>
<td>47</td>
<td>SIM;</td>
<td>UNMASK RST 6.5 AND RST 7.5</td>
</tr>
<tr>
<td>48</td>
<td>EI;</td>
<td>ENABLE INTERRUPTS</td>
</tr>
<tr>
<td>49</td>
<td>JMP FIRST;</td>
<td>INITIAL STEPS ARE COMPLETE</td>
</tr>
<tr>
<td>50</td>
<td>TIME: PUSH H;</td>
<td>STORE REGISTERS ON STACK</td>
</tr>
<tr>
<td>51</td>
<td>PUSH PSW;</td>
<td>STORE PROGRAM STATUS WORD ON STACK</td>
</tr>
<tr>
<td>52</td>
<td>PUSH B;</td>
<td>STORE REGISTERS ON STACK</td>
</tr>
<tr>
<td>53</td>
<td>PUSH D;</td>
<td>STORE REGISTERS ON STACK</td>
</tr>
<tr>
<td>54</td>
<td>LXI H, 28FBH;</td>
<td>LOCATE CLOCK COUNTER</td>
</tr>
<tr>
<td>55</td>
<td>INR M;</td>
<td>INCREMENT CLOCK COUNTER</td>
</tr>
<tr>
<td>56</td>
<td>MOV A, M</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>CPI 200;</td>
<td>COMPARE IF 200 PULSES HAVE OCCURED</td>
</tr>
<tr>
<td>58</td>
<td>JNZ DONE;</td>
<td>JUMP IF NOT</td>
</tr>
<tr>
<td>59</td>
<td>MVI M, 0;</td>
<td>IF YES THEN CLOCK COUNTER=ZERO</td>
</tr>
<tr>
<td>60</td>
<td>LXI H, 28EBH;</td>
<td>LOCATE TIME REFERENCE FOR RPM</td>
</tr>
<tr>
<td>61</td>
<td>INR M;</td>
<td>INCREMENT RPM TIME REFERENCE</td>
</tr>
<tr>
<td>62</td>
<td>MVI L, 0FCH;</td>
<td>LOCATE CLOCK COUNTER</td>
</tr>
<tr>
<td>63</td>
<td>INR M;</td>
<td>INCREMENT SECONDS</td>
</tr>
<tr>
<td>64</td>
<td>MOV A, M;</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>CPI 60;</td>
<td>COMPARE IF ONE MINUTE HAS ELAPSED</td>
</tr>
<tr>
<td>66</td>
<td>JNZ DONE;</td>
<td>IF NO THEN DONE</td>
</tr>
<tr>
<td>67</td>
<td>MVI M, 0;</td>
<td>IF YES THEN SECOND COUNT=ZERO</td>
</tr>
<tr>
<td>68</td>
<td>INX H;</td>
<td>INCREMENT TO MINUTE COUNT LOCATION</td>
</tr>
<tr>
<td>69</td>
<td>INR M;</td>
<td>INCREMENT MINUTES</td>
</tr>
<tr>
<td>70</td>
<td>MOV A, M;</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>CPI 60;</td>
<td>COMPARE IF ONE HOUR HAS ELAPSED</td>
</tr>
<tr>
<td>72</td>
<td>JNZ DONE;</td>
<td>IF NO THEN DONE</td>
</tr>
<tr>
<td>73</td>
<td>MVI M, 0;</td>
<td>IF YES THEN MINUTE COUNT=ZERO</td>
</tr>
<tr>
<td>74</td>
<td>DONE: POP D;</td>
<td>RESTORE REGISTER CONTENTS</td>
</tr>
<tr>
<td>75</td>
<td>POP B;</td>
<td>RESTORE REGISTER CONTENTS</td>
</tr>
<tr>
<td>76</td>
<td>POP PSW;</td>
<td>RESTORE PROGRAM STATUS WORD</td>
</tr>
<tr>
<td>77</td>
<td>POP H;</td>
<td>RESTORE REGISTER CONTENTS</td>
</tr>
<tr>
<td>78</td>
<td>EI;</td>
<td>ENABLE INTERRUPT</td>
</tr>
<tr>
<td>79</td>
<td>RET;</td>
<td>RETURN TO MAIN PROGRAM</td>
</tr>
<tr>
<td>80</td>
<td>FIRST: MVI E, 01H;</td>
<td>SET FAN AND HEATER FLAG IN REG E</td>
</tr>
<tr>
<td>81</td>
<td>MVI D, 0EBH;</td>
<td>LOCATION OF RPM COUNT MINUS ONE</td>
</tr>
<tr>
<td>82</td>
<td>MVI C, 01H;</td>
<td>START WITH LSB</td>
</tr>
<tr>
<td>83</td>
<td>COUNT: MVI B, 00H;</td>
<td>CLEAR COUNT REGISTER</td>
</tr>
<tr>
<td>84</td>
<td>LXI H, 28FBH;</td>
<td>LOCATE CLOCK COUNTER</td>
</tr>
</tbody>
</table>
SEQ | SOURCE | COMMENT
--- | --- | ---
85 | WAIT: SUB A; | SET ACCUMULATOR TO ZERO
86 | ADD M; | ADD CLOCK COUNTER CONTENTS
87 | JNZ WAIT; | IF NOT ZERO JUMP TO WAIT
88 | MVI L,0EBH; | LOCATE TIME REFERENCE
89 | MOV M,A; | SET TIME REFERENCE TO ZERO
90 | HIGH: IN 23H; | INPUT COUNT PULSES
91 | ANA C; | SELECT PULSE
92 | JZ NEXT; | JUMP IF SIGNAL LOW
93 | MOV A,M | 
94 | ANI 04H; | TIME CONSTANT OF 4 SECONDS
95 | JNZ STOP; | JUMP IF TIME DEPLETED
96 | JMP HIGH; | CONTINUE IF HIGH
97 | NEXT: INR B; | INCREMENT COUNT
98 | LOW: MOV A,M | 
99 | ANI 04H; | TIME CONSTANT OF 4 SECONDS
100 | JNZ STOP; | JUMP IF TIME DEPLETED
101 | IN 23H; | INPUT COUNT PULSES
102 | ANA C; | SELECT PULSE
103 | JNZ HIGH; | JUMP IF SIGNAL HIGH
104 | JMP LOW; | CONTINUE IF LOW
105 | STOP: INR D; | INCREMENT RPM STORAGE LOCATION
106 | MOV L,D | 
107 | MOV M,B; | STORE RPM COUNT IN MEMORY
108 | MVI L,0EBH | 
109 | MOV A,C; | PREPARE FOR NEXT SIGNAL
110 | RLC; | SELECT NEXT PULSE
111 | MOV C,A; | STORE IN REGISTER C
112 | ANI 0FH; | DETERMINE IF ALL PULSES COUNTED
113 | JNZ COUNT; | IF NOT JUMP TO NEXT COUNT
114 | MOV B,E; | MOVE FLAG TO REG B
115 | BEGIN: MVI C,00; | C DETERMINES ANALOG CHANNEL
116 | LXI H,28F0H; | SET MEMORY LOCATION FOR STORAGE
117 | MOV A,C | 
118 | START: OUT 01; | SELECT ANALOG CHANNEL
119 | ADI 50H | 
120 | OUT 01; | SET ADDRESS WITH ALE
121 | ANI 20H | 
122 | OUT 01; | START CONVERSION
123 | LXI D,0FFFFH; | SET UP TIME DELAY
124 | CALL 05F1H; | CALL TIME DELAY
125 | IN 00H; | INPUT CONVERTED VALUE
126 | MOV M,A; | STORE ANALOG VALUE
<table>
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<th>SEQ</th>
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<th>COMMENT</th>
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<tr>
<td>127</td>
<td>INX H;</td>
<td>MOVE TO NEXT MEMORY LOCATION</td>
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<tr>
<td>128</td>
<td>INR C;</td>
<td>INCREMENT TO NEXT SIGNAL</td>
</tr>
<tr>
<td>129</td>
<td>MOV A,C</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>CPI 04H;</td>
<td>IS TEMP SIGNAL TO BE READ</td>
</tr>
<tr>
<td>131</td>
<td>JC SAME;</td>
<td>IF NO JUMP</td>
</tr>
<tr>
<td>132</td>
<td>ORI 20H;</td>
<td>IF YES CHANGE VOLTAGE REFERENCES</td>
</tr>
<tr>
<td>133</td>
<td>CPI 2BH;</td>
<td>ARE ALL SIGNALS READ?</td>
</tr>
<tr>
<td>134</td>
<td>JNZ START;</td>
<td>IF NO RETURN TO START</td>
</tr>
<tr>
<td>135</td>
<td>LDA 28F0H;</td>
<td>LOAD FARROWING STATIC PRESSURE</td>
</tr>
<tr>
<td>136</td>
<td>MVI L.0FEH;</td>
<td>LOCATE CONTROL BYTE</td>
</tr>
<tr>
<td>137</td>
<td>CPI 0AH;</td>
<td>LOW CONSTANT FOR FARROWING</td>
</tr>
<tr>
<td>138</td>
<td>JC LESS1;</td>
<td>IF LOW THEN JUMP</td>
</tr>
<tr>
<td>139</td>
<td>CPI 0B1H;</td>
<td>HIGH CONSTANT FOR FARROWING</td>
</tr>
<tr>
<td>140</td>
<td>JNC MORE1;</td>
<td>IF HIGH THEN JUMP</td>
</tr>
<tr>
<td>141</td>
<td>MOV A,M;</td>
<td>RECALL CONTROL BYTE</td>
</tr>
<tr>
<td>142</td>
<td>ORI 02H;</td>
<td>SET FARROWING MOTOR OFF</td>
</tr>
<tr>
<td>143</td>
<td>JMP NEXT1;</td>
<td>JUMP TO NURSERY SECTION</td>
</tr>
<tr>
<td>144</td>
<td>MORE1: MOV A,M;</td>
<td>STATIC PRESSURE HIGH</td>
</tr>
<tr>
<td>145</td>
<td>ANI 0FCH;</td>
<td>SET FARROWING INLET TO OPEN</td>
</tr>
<tr>
<td>146</td>
<td>JMP NEXT1;</td>
<td>JUMP TO NURSERY SECTION</td>
</tr>
<tr>
<td>147</td>
<td>LESS1: MOV A,M;</td>
<td>STATIC PRESSURE LOW</td>
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<tr>
<td>148</td>
<td>ANI 0FDH;</td>
<td>SET FARROWING INLET MOTOR ON</td>
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<tr>
<td>149</td>
<td>ORI 01H;</td>
<td>SET FARROWING INLET TO CLOSE</td>
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<tr>
<td>150</td>
<td>NEXT1: MOV M,A;</td>
<td>STORE NEW CONTROL BYTE</td>
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<tr>
<td>151</td>
<td>LDA 28F1H;</td>
<td>LOAD NURSERY STATIC PRESSURE</td>
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<tr>
<td>152</td>
<td>CPI 37H;</td>
<td>LOW CONSTANT FOR NURSERY</td>
</tr>
<tr>
<td>153</td>
<td>JC LESS2;</td>
<td>IF LOW THEN JUMP</td>
</tr>
<tr>
<td>154</td>
<td>CPI 04CH;</td>
<td>HIGH CONSTANT FOR NURSERY</td>
</tr>
<tr>
<td>155</td>
<td>JNC MORE2;</td>
<td>IF HIGH THEN JUMP</td>
</tr>
<tr>
<td>156</td>
<td>MOV A,M;</td>
<td>RECALL CONTROL BYTE</td>
</tr>
<tr>
<td>157</td>
<td>ORI 08H;</td>
<td>SET NURSERY INLET MOTOR OFF</td>
</tr>
<tr>
<td>158</td>
<td>JMP NEXT2;</td>
<td>ROUTINE COMPLETE</td>
</tr>
<tr>
<td>159</td>
<td>MORE2: MOV A,M;</td>
<td>STATIC PRESSURE HIGH</td>
</tr>
<tr>
<td>160</td>
<td>ANI 0F3H;</td>
<td>SET NURSERY INLET TO OPEN</td>
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<tr>
<td>161</td>
<td>JMP NEXT2;</td>
<td>ROUTINE COMPLETE</td>
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<tr>
<td>162</td>
<td>LESS2: MOV A,M;</td>
<td>STATIC PRESSURE LOW</td>
</tr>
<tr>
<td>163</td>
<td>ANI 0F7H;</td>
<td>SET NURSERY INLET MOTOR ON</td>
</tr>
<tr>
<td>164</td>
<td>ORI 04H;</td>
<td>SET NURSERY INLET TO CLOSE</td>
</tr>
<tr>
<td>165</td>
<td>NEXT2: MOV M,A;</td>
<td>STORE NEW CONTROL BYTE</td>
</tr>
<tr>
<td>166</td>
<td>OUT 2AH;</td>
<td>OUTPUT CONTROL BYTE</td>
</tr>
<tr>
<td>167</td>
<td>MOV A,B;</td>
<td>MOVE FLAG REGISTER</td>
</tr>
<tr>
<td>168</td>
<td>ANA B;</td>
<td>AND FLAG TO ITSELF</td>
</tr>
</tbody>
</table>
JNZ FAN1; JUMP IF FLAG SET TO CHECK FANS

PAUSE: MVI B..00H; TURN FAN AND HEATER FLAG OFF

MVI L..0FCH; LOCATE COUNT REGISTER

MOV A.M

ANI 3CH; IS COUNT DURING FIRST FOUR SEC

JZ FIRST; JUMP IF YES

MVI L..0FEH; LOCATE CONTROL BYTE

MOV A.M

ANI 02H; IS FARROWING INLET MOTOR ON

JZ BEGIN; IF YES THEN JUMP

MOV A.M

ANI 08H; IS NURSERY INLET MOTOR ON

JZ BEGIN; IF YES THEN JUMP

JMP PAUSE; CONTINUE UNTIL START OF NEXT MINUTE

FAN1: MVI H..28H; ENSURES PROPER DATA IS LOCATED

LDA 28F4H; RECALL OUTSIDE TEMPERATURE

MVI D..10H; LOAD SPEED ADJUSTMENT FACTOR (SAF)

CPI 8EH; COMPARE AGAINST 70 DEGREES F

JNC SET1; JUMP IF WARM

MVI D..04H; ADJUST SAF FOR COOL TEMPERATURE

CPI 88H; COMPARE AGAINST 50 DEGREES F

JNC SET1; JUMP IF NOT COLD

MVI D..01H; ADJUST SAF FOR COLD TEMPERATURE

SET1: LDA 28F5H; LOAD ACCUMULATOR WITH INSIDE TEMP

INR A; ADD 0.9(C1) DEG F TO INSIDE TEMP

MVI L..0F9H; LOCATE DESIRED TEMP

CMP M; COMPARE IN PLUS 0.9(C1) VS. SET TEMP

JNC MILD1; JUMP IF NOT COOL

ADI 02H; ADD 1.8(C4-C1) DEG F TO INSIDE TEMP

CMP M; COMPARE IN PLUS 2.7(C4) VS. SET TEMP

JNC CHECK1; IF NOT COLD JUMP TO CHECK1

MVI D..04H; ADJUST SPEED ADJUSTMENT FACTOR

CHECK1: LDA 28F2H; LOAD ACCUMULATOR WITH DEW POINT TEMP

ADI 6EH; ADJUST DEW-POINT TEMP FOR COMPARISON

MVI L..0F5H; LOCATE INSIDE TEMP

CMP M; COMPARE TDP VS INSIDE TEMP

JNC MODIF1; JUMP IF RH ABOVE 70 PERCENT

LDA 28FEH; LOAD ACCUMULATOR WITH CONTROL BYTE

ANI 10H; MASK SINGLE-SPEED BIT

JZ LOWER1; JUMP IF ON

LDA 28EC; LOAD ACCUMULATOR WITH RPM

CPI 1BH; IS IT GREATER THAN 400RPM
SEQ   | SOURCE | COMMENT

211   | JC MODIF1; | JUMP IF RPM NOT OK
212   | LOWER1: MVI L,0E1H; | LOCATE CSB
213   | MOV A,M; | RECALL CSB
214   | SUI 02H; | DECREMENT CSB
215   | JNC ZERO1; | JUMP IF NO CARRY
216   | MVI A,00H; | SET CSB TO 00 HEX
217   | ZERO1: MOV M,A; | STORE CSB
218   | JMP COOL1; | JUMP TO ADJUST DSB
219   | MODIF1: MVI L,0E0H; | LOCATE DSB
220   | MOV A,M; | RECALL DSB
221   | INR L; | LOCATE CSB
222   | CMP M; | COMPARE DSB AND CSB
223   | JNC INCR1; | JUMP IF DSB GREATER THAN CSB
224   | MOV A,M; | LOAD REG A WITH CSB
225   | INCR1; ADI 02H; | INCREMENT CSB
226   | JNC NEXT3; | JUMP IF NO CARRY
227   | MVI A,0FFH; | SET CSB TO FF HEX
228   | NEXT3: MOV M,A; | STORE CSB
229   | COOL1: LDA 28F5H; | LOAD ACCUMULATOR WITH INSIDE TEMP
230   | ADI 03H; | ADD 2.7<C5> DEG F TO INSIDE TEMP
231   | MVI L,0F9H; | LOAD DESIRED TEMP
232   | CMP M; | COMPARE IN PLUS 2.7<C5> VS SET TEMP
233   | JNC ADJUS1; | JUMP IF NOT COLD
234   | LDA 28E0H; | LOAD ACCUMULATOR WITH DSB
235   | ANI 0FFH; | MASK DSB
236   | JNZ ADJUS1; | JUMP IF DSB NOT EQUAL TO ZERO
237   | MVI L,0FEH | LOCATE CONTROL BYTE
238   | MOV A,M; | RECALL CONTROL BYTE
239   | ANI 10H | MASK SINGLE SPEED
240   | JZ ADJUS1; | JUMP IF SINGLE SPEED ON
241   | MOV A,M; | RECALL CONTROL BYTE
242   | ANI 0BFH; | TURN SUPPLEMENTAL HEAT ON
243   | MOV M,A; | STORE NEW CONTROL BYTE
244   | OUT 2AH | OUTPUT CONTROL BYTE
245   | LDA 28F5H; | LOAD ACCUMULATOR WITH INSIDE TEMP
246   | ADI 09H; | ADD 8.1<C6> DEG F TO INSIDE TEMP
247   | MVI L,0F9H; | LOCATE DESIRED TEMP
248   | CMP M; | COMPARE IN PLUS 8.1<C6> VS SET TEMP
249   | JNC SPEED1; | IF NOT COLD CHECK FAN FLAG
250   | MVI L,0E1H; | LOCATE CSB
251   | MOV A,M; | RECALL CSB
252   | SUI 10H; | COLD THUS REDUCE CSB
SEQ | SOURCE | COMMENT
--- | --- | ---
253 | JNC SLOW1; | JUMP IF NO CARRY
254 | MVI A,00H; | SET CSB TO 00 HEX
255 | SLOW1: MOV M,A; | STORE CSB
256 | JMP SPEED1; | JUMP TO OUTPUT FAN SPEED
257 | ADJUST: MVI L,0E0H; | LOCATE DSB
258 | MOV A,M; | RECALL DSB
259 | SUB D; | SUBTRACT SAF FROM DSB
260 | MOV M,A ; | STORE NEW DSB
261 | JNC SPEED1; | JUMP IF NO CARRY
262 | LDA 28FEH; | LOAD CONTROL BYTE IN ACCUMULATOR
263 | ANI 10H; | CHECK IF FAN ON
264 | J2 TURN1; | JUMP IF YES
265 | NOT1: MVI L,0E0H; | NO, THEN LOCATE DSB
266 | MOV A,00H; | SET DSB TO ZERO
267 | MOV M,A; | STORE DSB
268 | JMP SPEED1; | JUMP TO OUTPUT FAN SPEED
269 | TURN1: MVI L,0FFH; | LOCATE FAN FLAG
270 | MOV A,M; | RECALL FAN FLAG
271 | ANI 0FH; | MASK FAN FLAG
272 | JNZ NOT1; | JUMP IF FAN FLAG ON
273 | ORI 0FH; | SET FAN FLAG ON
274 | MOV M,A; | STORE FAN FLAG
275 | MVI A,0FFH; | SET DSB EQUAL TO FF HEX
276 | STA 28E0H; | STORE DSB
277 | SPEED1: MVI L,0E0H; | LOCATE DSB
278 | MOV A,M; | RECALL DSB
279 | INR L; | INCREMENT MEMORY LOCATION
280 | CMP M; | COMPARE DSB VS CSB
281 | JNC CAT1; | JUMP IF DSB GREATER
282 | MOV A,M; | MOVE CSB TO ACCUMULATOR
283 | CAT1: OUT 22H; | OUTPUT GREATER OF DSB OR CSB
284 | LDA 28FFH; | LOAD ACCUMULATOR WITH FAN FLAG
285 | ANI 0FH; | IS FLAG ON
286 | JZ TEST1; | JUMP IF NOT ON
287 | MVI L,0FEH; | LOCATE CONTROL BYTE
288 | MOV A,M; | RECALL CONTROL BYTE
289 | ORI 10H; | TURN FAN OFF
290 | ORI 01H; | CLOSE AIR INLET
291 | ANI 0FDH; | TURN AIR INLET MOTOR ON
292 | MOV M,A; | STORE CONTROL BYTE
293 | OUT 2AH; | OUTPUT CONTROL BYTE
294 | INR L; | LOCATE FAN FLAG
SEQ | SOURCE | COMMENT
---|---|---
295 | MOV A,M; | RECALL FAN FLAG
296 | ANI 0F0H; | SET FAN FLAG OFF
297 | MOV M,A; | STORE FAN FLAG
298 | JMP FAN2; | SUBROUTINE COMPLETE
299 | TEST1: LDA 28E6H; | LOAD ACCUMULATOR WITH RPM
300 | CPI 09H; | COMPARE TO CHECK IF FAN TURNING
301 | JNC FAN2; | SUBROUTINE COMPLETE IF FAN TURNING
302 | MVI L,0FEH; | LOCATE MAIN CONTROL BYTE
303 | MOV A,M; | RECALL CONTROL BYTE
304 | ANI 10H; | MASK SINGLE SPEED
305 | JZ FAN2; | SUBROUTINE COMPLETE IF ON
306 | MVI L,0F0H; | LOCATE STATIC PRESSURE
307 | MOV A,M; | RECALL STATIC PRESSURE
308 | CPI 08H; | IS STATIC PRESSURE LOW
309 | JNC FAN2; | SUBROUTINE COMPLETE IF NOT LOW
310 | MVI L,0FEH; | LOCATE CONTROL BYTE
311 | MOV A,M; | RECALL CONTROL BYTE
312 | ANI 0E6H; | TURN FAN ON AND OPEN INLET DOOR
313 | MOV M,A; | STORE CONTROL BYTE
314 | OUT 2AH; | OUTPUT CONTROL BYTE
315 | INR L; | LOCATE FAN FLAG
316 | MOV A,M; | RECALL FAN FLAG
317 | ORI 0FH; | TURN FAN FLAG ON
318 | MOV M,A; | STORE FAN FLAG ON
319 | JMP FAN2; | SUBROUTINE COMPLETE
320 | MILD1: SUI 03H; | SUBTRACT 2.7(C2-C1) DEG F
321 | CMP M; | COMP IN TEMP LESS 1.8(C2) VS SET
322 | JNC WARM1; | JUMP IF WARM
323 | OK1: MVI D,00H; | SET SAF TO ZERO
324 | JMP CHECK1; | JUMP TO CHECK RPM AND TDP
325 | WARM1: SUI 02H; | SUBTRACT 1.8(C3-C2) DEG F
326 | CMP M; | COMP INSIDE LESS 3.6(C3) VS SET TEMP
327 | MVI L,0FEH; | LOCATE CONTROL BYTE
328 | JNC LIMIT1; | JUMP IF WARM
329 | MOV A,M; | RECALL CONTROL BYTE
330 | ANI 40H; | IS SUPPLEMENTAL HEAT ON
331 | JZ OK1; | JUMP IF HEATER ON
332 | JMP ADD1; | JUMP TO ADD SAF
333 | LIMIT1: MOV A,M; | RECALL CONTROL BYTE
334 | ORI 40H; | TURN SUPPLEMENTAL HEAT OFF
335 | MOV M,A; | STORE CONTROL BYTE
336 | OUT 2AH; | OUTPUT CONTROL BYTE
**SEQ** | **SOURCE** | **COMMENT**
--- | --- | ---
337 | ADD1: MVI L,0E0H; | LOCATE DOMINANT SPEED BYTE (DSB) LOCATE INSIDE TEMPERATURE
338 | MOV R,M; | MOVE DSB TO ACCUMULATOR
339 | ADD D; | INCREASE DSB
340 | MOV M,A; | STORE NEW DSB
341 | JNC SPEED2; | JUMP IF NO CARRY
342 | MVI L,0FEH; | LOCATE CONTROL BYTE
343 | MOV R,M; | RECALL CONTROL BYTE
344 | ANI 10H; | CHECK IF SINGLE SPEED ON
345 | JZ MAX1; | JUMP IF ON
346 | LDA 28F5H; | LOCATE INSIDE TEMPERATURE
347 | CPI 0AFH; | COMP TO 80 (C7) DEG F
348 | JC MAX1; | IF LESS THEN 80 (C7) THEN JUMP
349 | MVI L,0FEH; | LOCATE CONTROL BYTE
350 | MOV R,M; | RECALL CONTROL BYTE
351 | ANI 0ECH; | TURN FAN ON AND OPEN INLETS
352 | OUT 2AH; | OUTPUT FAN ON AND OPEN INLETS
353 | MOV M,A; | STORE CONTROL BYTE
354 | MVI L,0E0H; | LOCATE DSB
355 | MVI A,00H; | LOAD ACCUMULATOR WITH 00
356 | MOV M,A; | SET DSB TO ZERO
357 | INR L; | LOCATE CSB
358 | MOV M,A; | SET CSB TO ZERO
359 | JMP SPEED2; | JUMP TO OUTPUT FAN SPEED
360 | MAX1: MVI A,0FFH; | MOVE FF HEX TO ACCUMULATOR
361 | STA 28E0H; | LOAD DSB WITH FF HEX
362 | SPEED2: MVI L,0E0H; | LOCATE DSB
363 | MOV R,M; | RECALL DSB
364 | INR L; | LOCATE CSB
365 | CMP M; | COMPARE DSB VS CSB
366 | JNC CAT2; | JUMP IF DSB GREATER
367 | MOV R,M; | MOV CSB TO ACCUMULATOR
368 | CAT2: OUT 22H; | OUTPUT GREATER OF DSB AND CSB
369 | FAN2: MVI H,28H; | ENSURES PROPER DATA IS LOCATED
370 | LDA 28F4H; | RECALL OUTSIDE TEMPERATURE
371 | MVI D,10H; | LOAD SPEED ADJUSTMENT FACTOR (SAF)
372 | CPI 86H; | COMPARE AGAINST 70 DEGREES F
373 | JNC SET2; | JUMP IF WARM
374 | MVI D,04H; | ADJUST SAF FOR COOL TEMPERATURE
375 | CPI 68H; | COMPARE AGAINST 50 DEGREES F
376 | JNC SET2; | JUMP IF COOL
377 | MVI D,01H; | ADJUST SAF FOR COLD TEMP
378 | SET2: LDA 28F7H; | LOAD ACCUMULATOR WITH INSIDE TEMP

**RIAS UNIX 8080/8085 ASSEMBLY OF: FINAL PAGE 9**
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<th>SOURCE</th>
<th>COMMENT</th>
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<tbody>
<tr>
<td>379</td>
<td>INR A;</td>
<td>ADD 0.9(C1) DEG F TO INSIDE TEMP</td>
</tr>
<tr>
<td>380</td>
<td>MVI L.0FAH;</td>
<td>LOCATE DESIRED TEMP</td>
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<td>381</td>
<td>CMP M;</td>
<td>COMPARE IN PLUS 0.9(C1) VS. SET TEMP</td>
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<tr>
<td>382</td>
<td>JNC MILD2;</td>
<td>JUMP IF NOT COOL</td>
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<tr>
<td>383</td>
<td>ADI 02H;</td>
<td>ADD 1.8(C4-C1) DEG F TO INSIDE TEMP</td>
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<td>384</td>
<td>CMP M;</td>
<td>COMPARE IN PLUS 2.7(C4) VS. SET TEMP</td>
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<td>385</td>
<td>JNC CHECK2;</td>
<td>IF NOT COLD JUMP TO CHECK</td>
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<td>386</td>
<td>MVI D.04H;</td>
<td>ADJUST SPEED ADJUSTMENT FACTOR</td>
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<td>387</td>
<td>CHECK2:</td>
<td>LOAD ACCUMULATOR WITH DEW POINT TEMP</td>
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<td>388</td>
<td>ADI 6EH;</td>
<td>ADJUST DEW-POINT FOR COMPARISON</td>
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<td>389</td>
<td>MVI L.0F7H;</td>
<td>LOCATE INSIDE TEMP</td>
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<td>CMP M;</td>
<td>COMPARE TIP VS INSIDE TEMP</td>
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<td>391</td>
<td>JNC MODIFY2;</td>
<td>JUMP IF RH IS ABOVE 70 PERCENT</td>
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<td>392</td>
<td>LDA 28FEH;</td>
<td>LOAD ACCUMULATOR WITH CONTROL BYTE</td>
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<td>393</td>
<td>ANI 20H;</td>
<td>MASK SINGLE-SPEED BIT</td>
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<td>394</td>
<td>JZ LOWER2;</td>
<td>JUMP IF ON</td>
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<td>395</td>
<td>LDA 28E8H;</td>
<td>LOAD ACCUMULATOR WITH RPM</td>
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<td>396</td>
<td>CPI IBH;</td>
<td>IS IT GREATER THAN 400 RPM</td>
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<td>397</td>
<td>JC MODIFY2;</td>
<td>JUMP IF RPM NOT OK</td>
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<td>398</td>
<td>LOWER2:</td>
<td>LOAD COMPLEMENT SPEED BYTE (CSB)</td>
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<tr>
<td>399</td>
<td>MVI L.0E3H;</td>
<td>CALL CSB</td>
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<tr>
<td>400</td>
<td>MOV A.M;</td>
<td>RECALL CSB</td>
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<tr>
<td>401</td>
<td>JNC ZERO2;</td>
<td>JUMP IF NO CARRY</td>
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<tr>
<td>402</td>
<td>MVI A.00H;</td>
<td>SET CSB TO 00 HEX</td>
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<td>403</td>
<td>ZERO2:</td>
<td>MOVE M.A;</td>
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<td>404</td>
<td>JMP M.COOL2;</td>
<td>JUMP TO ADJUST DSB</td>
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<td>405</td>
<td>MODIFY2:</td>
<td>MVI L.0E2H;</td>
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<td>406</td>
<td>MOV A.M;</td>
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<td>407</td>
<td>INR L;</td>
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<td>CMP M;</td>
<td>COMPARE DSB AND CSB</td>
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<td>409</td>
<td>JNC INC2;</td>
<td>JUMP IF DSB GREATER THAN CSB</td>
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<td>410</td>
<td>MOV A.M;</td>
<td>LOAD REG A WITH CSB</td>
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<td>411</td>
<td>INC2:</td>
<td>ADDI 02H;</td>
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<td>412</td>
<td>JNC NEXT4;</td>
<td>JUMP IF NO CARRY</td>
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<td>MVI A.0FFH;</td>
<td>SET CSB EQUAL TO FF HEX</td>
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<td>414</td>
<td>NEXT4:</td>
<td>MOVE M.A;</td>
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<td>415</td>
<td>COOL2:</td>
<td>LOAD ACCUMULATOR WITH INSIDE TEMP</td>
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<tr>
<td>416</td>
<td>ADI 03H;</td>
<td>ADD 2.7(C5) DEG F TO INSIDE TEMP</td>
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<td>MVI L.0FAH;</td>
<td>LOCATE DESIRED TEMP</td>
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<td>CMP M;</td>
<td>COMPARE INSIDE PLUS 2.7 VS SET TEMP</td>
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<td>JNC ADJUST2;</td>
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<td>420</td>
<td>LDA 28E2H;</td>
<td>LOAD ACCUMULATOR WITH DSB</td>
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<tr>
<td>421</td>
<td>ANI 0FFH;</td>
<td>MASK DSB</td>
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<td>422</td>
<td>JNZ ADJUS2;</td>
<td>JUMP IF DSB NOT EQUAL TO ZERO</td>
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<td>423</td>
<td>MVI L,0FEH;</td>
<td>LOCATE CONTROL BYTE</td>
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<td>424</td>
<td>MOV A,M;</td>
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<td>425</td>
<td>ANI 20H;</td>
<td>MASK SINGLE SPEED</td>
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<td>426</td>
<td>JZ ADJUS2;</td>
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<td>MOV A,M;</td>
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<td>428</td>
<td>ANI 07FH;</td>
<td>TURN SUPPLEMENTAL HEAT ON</td>
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<td>MOV M,A;</td>
<td>STORE NEW CONTROL BYTE</td>
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<td>430</td>
<td>OUT 2AH;</td>
<td>OUTPUT CONTROL BYTE</td>
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<tr>
<td>431</td>
<td>LDA 28F7H;</td>
<td>LOAD ACCUMULATOR WITH INSIDE TEMP</td>
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<td>432</td>
<td>ADD 09H;</td>
<td>ADD 8.1(DEG F) TO INSIDE TEMP</td>
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<td>MVI L,0FAH;</td>
<td>LOCATE DESIRED TEMP</td>
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<td>CMP M;</td>
<td>COMPARE IN PLUS 8.1(DEG F) VS SET TEMP</td>
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<td>435</td>
<td>JNC SPEED3;</td>
<td>IF NOT COLD CHECK OVERRIDE FLAG</td>
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<td>MVI L,0E3H;</td>
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<td>MOV A,M;</td>
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<td>438</td>
<td>SUI 10H;</td>
<td>COLD THUS REDUCE CSB</td>
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<td>JNC SLOW2;</td>
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<td>440</td>
<td>MVI A,00H;</td>
<td>SET CSB TO 00 HEX</td>
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<td>SLOW2: MOV M,A;</td>
<td>STORE CSB</td>
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<td>JMP SPEED3;</td>
<td>JUMP TO OUTPUT FAN SPEED</td>
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<td>ADJUS2: MVI L,0E2H;</td>
<td>LOCATE DSB</td>
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<td>444</td>
<td>MOV A,M;</td>
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<tr>
<td>445</td>
<td>SUB D;</td>
<td>SUBTRACT SAF FROM DSB</td>
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<td>446</td>
<td>MOV M,A;</td>
<td>STORE NEW DSB</td>
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<td>447</td>
<td>JNC SPEED3;</td>
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<tr>
<td>448</td>
<td>LDA 28F4H;</td>
<td>LOAD CONTROL BYTE IN ACCUMULATOR</td>
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<td>449</td>
<td>ANI 20H;</td>
<td>CHECK IF FAN ON</td>
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<tr>
<td>450</td>
<td>JZ TURN2;</td>
<td>JUMP IF YES</td>
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<td>NOT2: MVI L,0E2H;</td>
<td>NO, THEN LOCATE DSB</td>
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<td>452</td>
<td>MOV M,A;</td>
<td>SET DSB TO 00</td>
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<td>MOV M,A;</td>
<td>STORE DSB</td>
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<td>454</td>
<td>JMP SPEED3;</td>
<td>JUMP TO OUTPUT FAN SPEED</td>
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<td>455</td>
<td>TURN2: MVI L,0FFH;</td>
<td>LOCATE FAN FLAG</td>
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<td>456</td>
<td>MOV A,M;</td>
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<td>ANI 0F0H;</td>
<td>MASK FAN FLAG</td>
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<td>458</td>
<td>JNZ NOT2;</td>
<td>JUMP IF FAN FLAG SET</td>
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<tr>
<td>459</td>
<td>ORI 00H;</td>
<td>SET FAN FLAG ON</td>
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<td>MOV M,A;</td>
<td>STORE FAN FLAG</td>
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<td>461</td>
<td>MVI A,0FFH;</td>
<td>SET DSB EQUAL TO FF HEX</td>
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<tr>
<td>462</td>
<td>STA 28E2H;</td>
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<td>SPEED3:</td>
<td>MVI L,0E2H; LOCATE DSB</td>
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<td>MOV A,M;</td>
<td>RECALL DSB</td>
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<tr>
<td>465</td>
<td>INR L;</td>
<td>INCREMENT MEMORY LOCATION</td>
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SEQ  SOURCE             COMMENT

505  JMP PRINT;          SUBROUTINE COMPLETE
506  MILD2: SUI 03H;     SUBTRACT 2.7(2-H-C1) DEG F
507  CMP M;              COMP IN LESS 1.8(C2) VS SET TEMP
508  JNC WARM2;          JUMP IF WARM
509  OK2: MVI D.00H;     SET SPEED ADJ FACTOR TO ZERO
510  JMP CHECK2;         JUMP TO CHECK RPM AND TDP
511  WARM2: SUI 02H;     SUBTRACT 1.8(C3-C2) DEG F
512  CMP M;              COMP INSIDE LESS 3.6(C3) VS SET TEMP
513  MVI L.0FEH;         LOCATE CONTROL BYTE
514  JNC LIMIT2;         JUMP IF WARM
515  MOV A,M;            RECALL CONTROL BYTE
516  ANI 80H;            IS SUPPLEMENTAL HEAT ON
517  JZ OK2;             JUMP IF HEATER ON
518  JMP ADD2;           JUMP TO ADD SAF
519  LIMIT2: MOV A,M;    RECALL CONTROL BYTE
520  ORI 80H;            TURN SUPPLEMENTAL HEAT OFF
521  MOV M,A;            STORE CONTROL BYTE
522  OUT 2AH;            OUTPUT CONTROL BYTE
523  ADD2: MVI L.0E2H;   LOCATE DOMINANT SPEED BYTE (DSB)
524  MOV A,M;            MOVE DSB TO ACCUMULATOR
525  ADD D;              INCREASE DOMINANT SPEED_BYTE
526  MOV M,A;            STORE NEW DSB
527  JNC SPEED4;         JUMP IF NO CARRY
528  MVI L.0FEH;         LOCATE CONTROL BYTE
529  MOV A,M;            RECALL CONTROL_BYTE
530  ANI 20H;            CHECK IF SINGLE SPEED ON
531  JZ MAX2;            JUMP IF ON
532  LDA 28F7H;          LOAD INSIDE TEMP
533  CPI 0B5H;           COMP TO 85(C7) DEG F
534  JC MAX2;            IF LESS THEN 85 (C7?) THEN JUMP
535  MVI L.0FEH;         LOCATE CONTROL BYTE
536  MOV A,M;            RECALL CONTROL BYTE
537  ANI 0D3H;           TURN FAN ON AND OPEN INLETS
538  OUT 2AH;            OUTPUT FAN ON AND OPEN INLETS
539  MOV M,A;            STORE CONTROL_BYTE
540  MVI L.0E2H;         LOCATE DSB
541  MVI A.00;           LOAD ACCUMULATOR WITH 00 HEX
542  MOV M,A;            SET DSB TO ZERO
543  INR L;              LOCATE CSB
544  MOV M,A;            SET CSB TO ZERO
545  JMP SPEED4;         JUMP TO OUTPUT FAN SPEED
546  MAX2: MVI A.0FFH;   MOVE FF HEX TO ACCUMULATOR
SEQ | SOURCE | COMMENT
--- | --- | ---
547 | STA 28E2H; | LOAD DSB WITH FF HEX
548 | SPEED4: MVI L,0E2H; | LOCATE DSB
549 | MOV A.M; | RECALL DSB
550 | INR L; | LOCATE CSB
551 | CMP M; | COMPARE DSB VS CSB
552 | JNC CAT4; | JUMP IF DSB GREATER
553 | MOV A.M; | MOV CSB TO ACCUMULATOR
554 | CAT4: | OUTPUT GREATER OF DSB AND CSB
555 | PRINT :LDA 28E5H; | LOCATE MINUTE COUNTER
556 | LXI H,28E5H; | TTY SELECT VARIABLE
557 | CMP M; | COMPARE IF TTV SHOULD PRINT
558 | JNC PAUSE; | RETURN TO MAIN PROGRAM
559 | PRINT1: LXI H,28E0H; | LOCATION FOR VALUE TO BE PRINTED
560 | PRINT2: MVI A,0FEH | 
561 | OUT 21H; | OUTPUT GREATER OF DSB AND CSB
562 | LXI D,0FE5H; | SET UP TIME DELAY
563 | CALL 05F1H; | CALL TIME DELAY
564 | TTY1: MOV A.M; | MOVE VALUE TO BE PRINTED
565 | CALL 06C7H; | PRINT COUNT VALUE
566 | MVI C,2DH | 
567 | CALL 07FAH; | PRINT SPACE
568 | INX H; | NEXT COUNT VALUE
569 | MOV A.L; | MOVE A.L TO ACCUMULATOR
570 | CPI 00H; | ARE ALL VALUES PRINTED
571 | JZ OFF; | JUMP IF YES
572 | CPI 0C3; | ARE ALL STACK VALUES PRINTED
573 | JNZ LINE; | CONTINUE TO LINE CHECK
574 | CALL 05EBH; | LINE FEED
575 | MVI C,05H; | EXTEND TIME DELAY
576 | DELAY1: LXI D,0FFFFFFH; | SET UP TIME DELAY
577 | CALL 05F1H; | CALL TIME DELAY
578 | DCR C | 
579 | JNZ DELAY1; | JUMP IF TIME DELAY TO CONTINUE
580 | JMP PRINT1 | 
581 | LINE: ANI 0FH; | END OF LINE
582 | JNZ TTY1; | JUMP IF NOT
583 | CALL 05EBH; | LINE FEED
584 | MVI C,05H; | EXTEND TIME DELAY
585 | DELAY2: LXI D,0FFFFFFH; | SET UP TIME DELAY
586 | CALL 05F1H; | CALL TIME DELAY
587 | DCR C | 
588 | JNZ DELAY2; | JUMP IF TIME DELAY NOT COMPLETE
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APPENDIX C:

SPECIALIZED LIST OF
COMPONENTS AND MANUFACTURERS
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