AIR CONDITIONING APPLICATION OF FLUIDIC CONTROLS

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ABSTRACT

AIR CONDITIONING APPLICATION OF FLUIDIC CONTROLS

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The application of fluidic controls in air conditioning dates back less than ten years, while the development of the fluidic controls in general started some 15 years ago. There have been only a few noteworthy applications of fluidics in the field of air conditioning, such as:

(a) The "controlling receiver" based on the impact modulation principle and used to control temperature, humidity or pressure,

(b) the "air motion relay" based on the wall attachment principle and used to interlock various control functions to air motion, and

(c) two types of variable air volume terminals, both self-contained and self-powered, not requiring any power supply or external control circuitry.

It appears therefore that the basic advantages of fluidics, i.e. operation under severe environmental conditions, accuracy and versatility, have not yet been appreciated in the air conditioning field. In general, however, the presence of air as an inherent part of the system indicates that in future, more fluidic control devices will be developed.

ACKNOWLEDGEMENTS

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A. INTRODUCTION

This report intends to present an up-to-date survey of the application of fluidics in air conditioning control.

In the first chapter, a brief presentation of air conditioning systems' objectives is given, followed by the analysis of all control functions required to attain those objectives, such as: flow and temperature measurement and regulation, on-off and proportional control, balancing of systems.

In the second chapter, the principles of fluidics are briefly presented, with reference to the existing fluidic components and the control functions obtainable by using these components, individually or in combinations. Further on, some important aspects of fluidic controls are examined, such as power requirements, reliability, manufacturing methods and costs, advantages and disadvantages over other methods of control, namely pneumatic, electric and electronic controls.

The third and fourth chapters deal specifically with the application of fluidic controls in air conditioning. In Chapter 3, following a brief presentation of the historical evolution of fluidic control applications in air conditioning, the description of various devices now in production is given in some detail.

In Chapter 4, the present status of the application of fluidics in the air conditioning field is reviewed and some reasons are given for the slow progress in that direction, followed by an assessment of possible future developments.

CHAPTER 1

AIR CONDITIONING SYSTEMS AND THEIR CONTROL FUNCTIONS

1.1 Air Conditioning System Objectives

Air conditioning means the maintenance of those atmospheric factors affecting comfort. Specifically, it is the maintenance of the following variables within well defined limits:

a. The desired temperature.

b. An acceptable humidity.

c. Minimal atmospheric particulates, including pollens and bacteria.

d. An acceptable odor level.

e. A uniform air pattern and air motion.

Eliminating "thermal stress", results in a more comfortable environment which is conducive to efficient production. This "thermal stress" elimination is achieved by maintaining some of the factors mentioned above within such limits that will ensure a rate of heat dissipation from the human body equal to the rate of heat generation by that same body.

The human body is a rather inefficient machine producing a lot of surplus heat energy which must be dissipated by conduction, convection and/or radiation, otherwise the body temperature will rise, with resulting discomfort. The heat generation rate is a function of the activity and varies from a base rate of about 300BTU/H when sleeping, to 400BTU/H for clerical tasks, to about 1000BTU/H when bowling.

The ambient relative humidity or "wet bulb temperature" affects the rate of heat dissipating by evaporation from the body in the form of latent heat. Both the ambient temperature or "dry bulb temperature" and the ambient air motion affect the convection rate and the evaporation rate. The surface temperature of the surrounding partitions, walls, floors, etc., affects the rate of heat dissipated by radiation.

1.2 Classification of Air Conditioning Systems Based on the Controllable Fluid

All air conditioning systems fall into one of four major categories according to the controllable fluid:

1. All-Air Systems
2. Air-Water Systems
3. All-Water Systems
4. Refrigerant Systems

These are described separately in the following sections.

1.2.1 All-Air Systems

In this type of system, the cooling-heating medium is air. It is brought into the conditioned space through ducts and distributed within the space through outlets or mixing terminal units. The air has to be cleansed, heated or cooled, and humidified or dehumidified at some central arrangement which may be located at some distance from the conditioned space.

The common variations of all-air systems are the following:

a. Dual Duct-Constant Volume Rate System (Fig.1)

Treated cold and hot air is brought through a pair

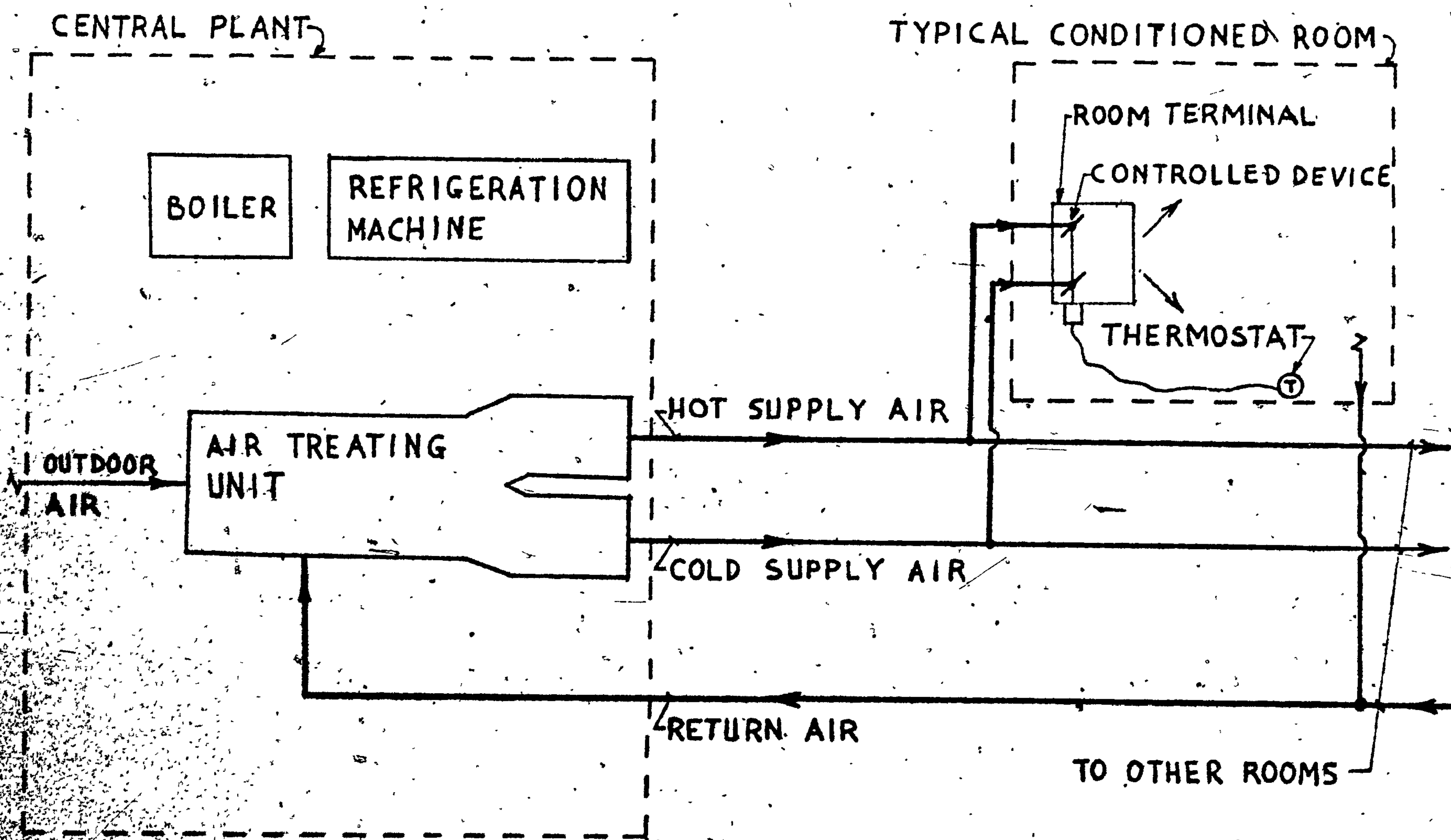

FIG. 1.-- DUAL DUCT-CONSTANT VOLUME SYSTEM SCHEMATIC

of ducts to room terminals that mix cold air with hot air automatically to maintain proper temperatures as well as proper volumes and air patterns.

b. Single Duct-Variable Volume Rate System (Fig.2)
A single stream of either hot or cold air is brought through a duct to the room where its volume is automatically adjusted to match the heat load of the space.

c. Dual Duct Reheat System (Fig.3)
Two air streams are supplied to each room from the central air treating plant. The primary stream (constant volume-variable temperature) is supplied through room perimeter units to offset the transmission heat gains or losses, and its temperature is controlled at the central plant. The secondary stream (variable volume-constant temperature) is supplied through ceiling units to offset the heat gains or losses from people, lights, etc., and its volume is controlled by the room thermostat. Usually, both streams are treated by one central unit, with reheat applied to the primary stream.

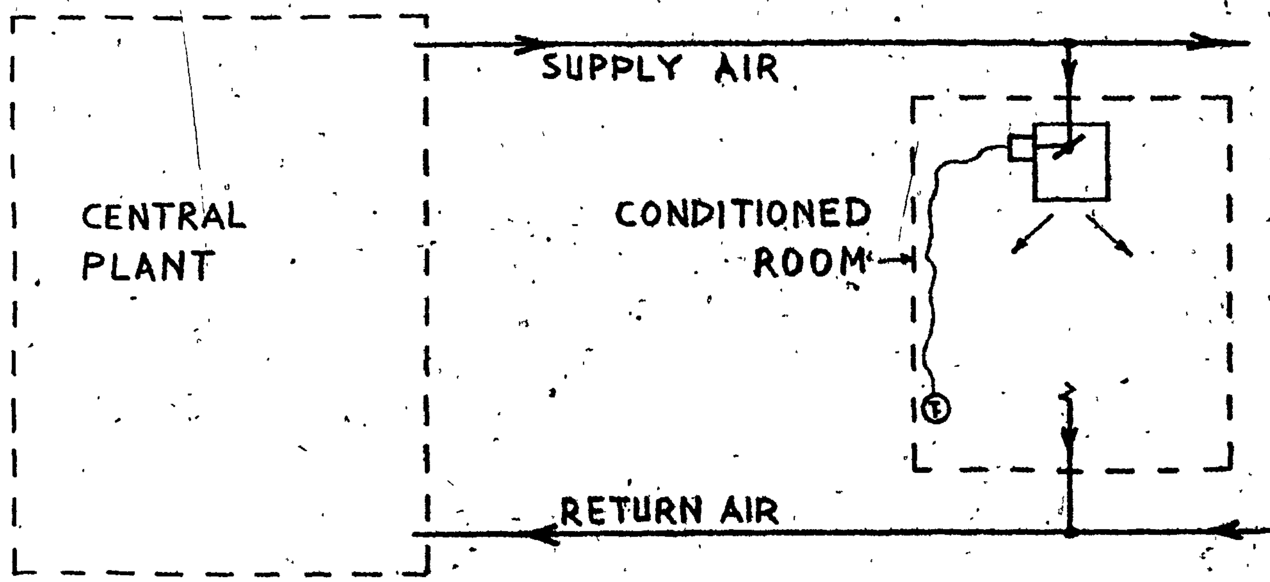

FIG. 2.-- SINGLE DUCT—VARIABLE VOLUME SCHEMATIC

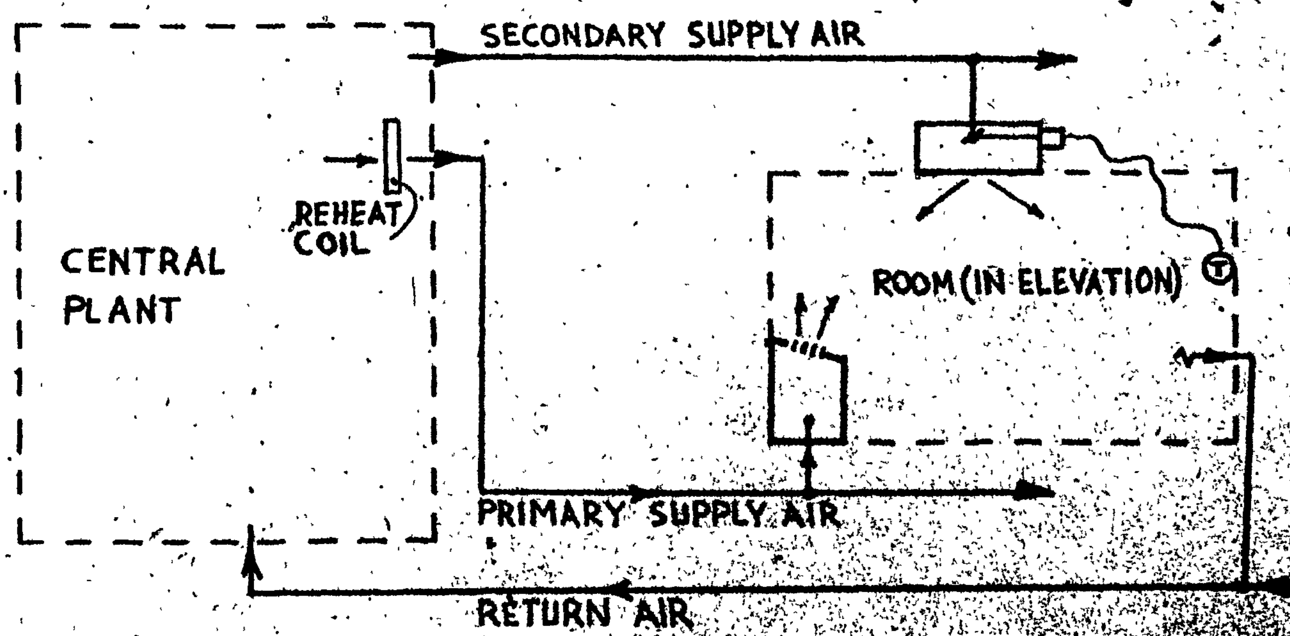

FIG. 3.-- DUAL DUCT REHEAT SYSTEM SCHEMATIC

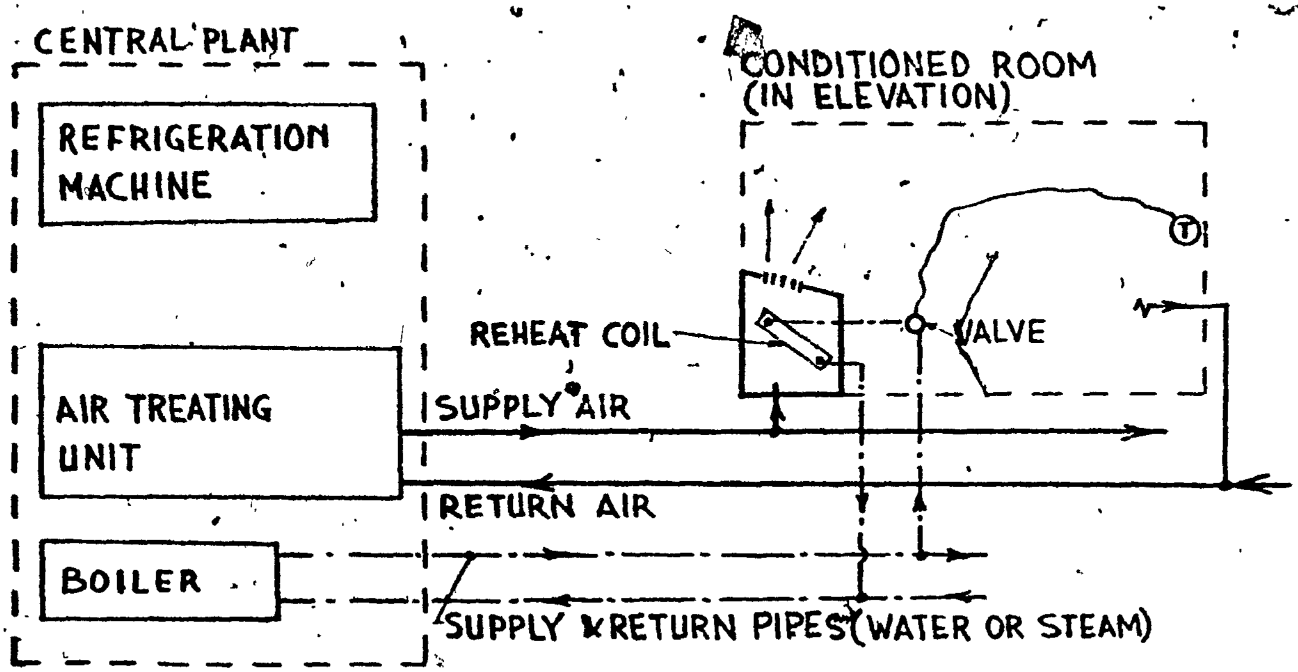

FIG.4.--SINGLE DUCT WITH REHEAT, SYSTEM SCHEMATIC

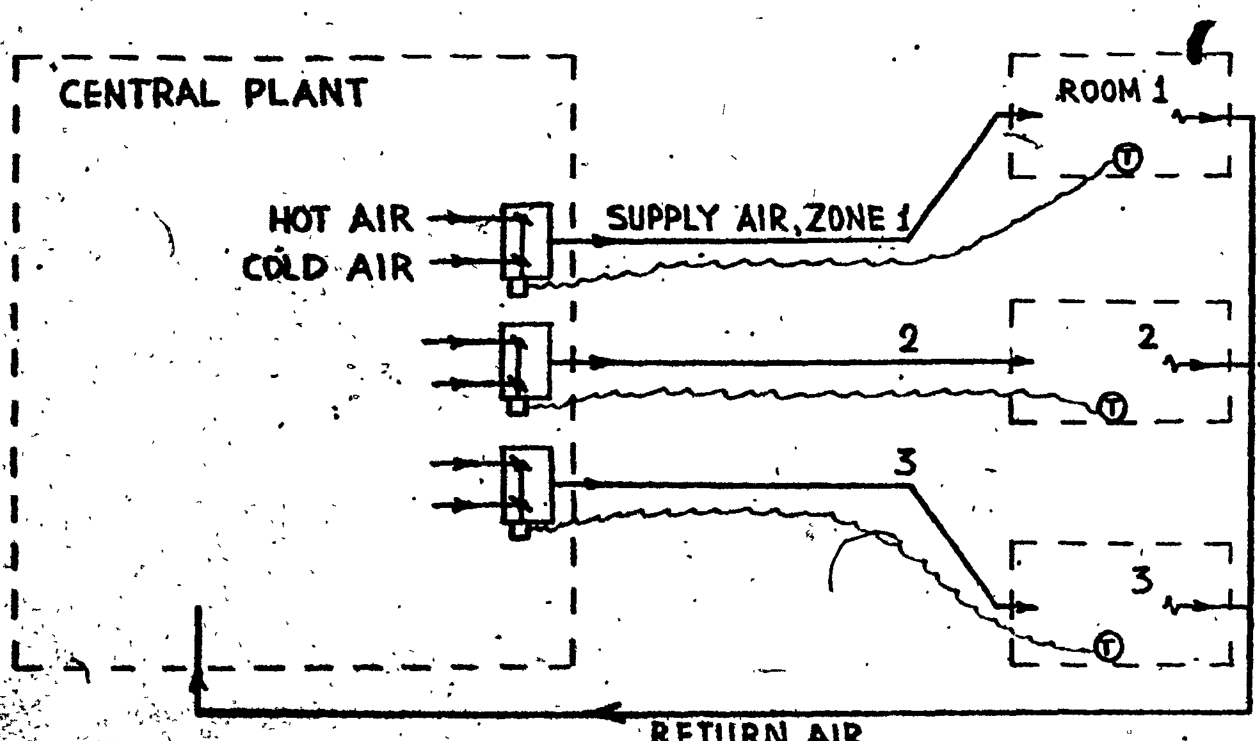

FIG.5.-- MULTI-ZONE SYSTEM SCHEMATIC

d. Single Duct Reheat System

Centrally treated air is supplied at constant volume through a single duct to room units, each of which is equipped with a reheat coil which is controlled from the room or zone thermostat. A schematic showing steam or hot water reheat is given in Fig. 4.

e. Multi-Zone System

A single stream of air is distributed through individual ducts to each room. The central air treating plant includes dampers (controlled by room thermostats) that mix the cold and warm air before being supplied to each zone. A 3-zone schematic is shown in Fig. 5.

1.2.2 Air-Water Systems

In this type of system, air is treated centrally and locally. The centrally treated air stream is a small portion of the total air circulating in the conditioned room and is not returned back to the central apparatus. The locally treated air is the room air which circulates through local units equipped with heating-cooling coils. These coils are supplied with centrally heated or cooled water.

The common variations of air-water systems are the following:

a. Induction

High velocity, high pressure, constant volume air is brought to an induction type terminal. Air induced from the room is either heated or cooled within the terminal by going over a coil. The capacity is adjusted to meet room requirements by controlling the water flow or the air by-pass. This system may use one water circuit (two pipes) or two water circuits (four pipes) for heating and cooling. A schematic of one circuit system is shown in Fig. 6.

b. Fan-Coil with Supplementary Air

The fan-coil terminal provides direct heating or cooling of the room air. The supplementary constant volume air supply provides the necessary ventilation. A schematic of one water circuit system is shown in Fig. 7.

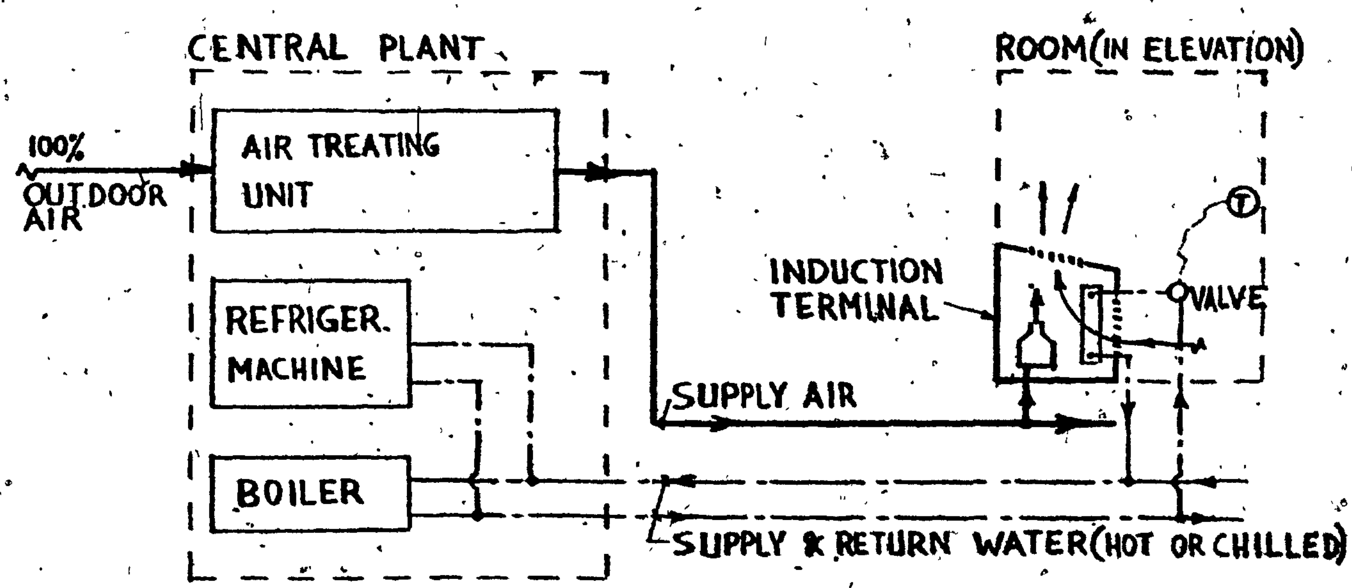

FIG. 6.--INDUCTION SYSTEM SCHEMATIC

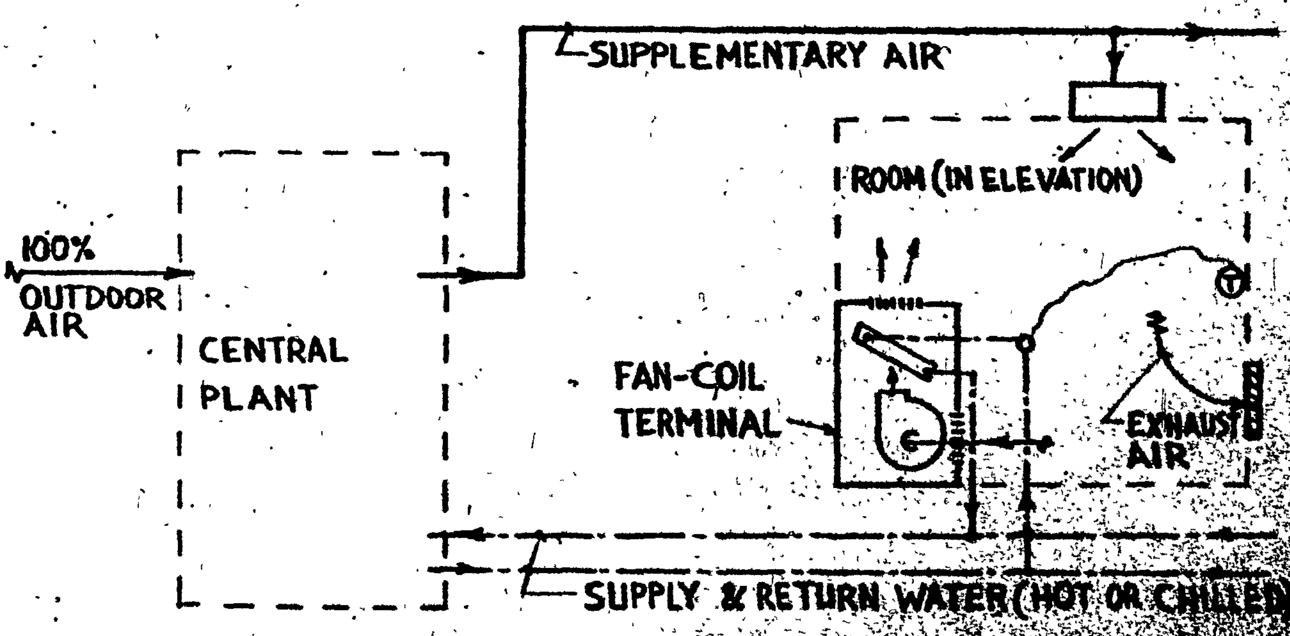

FIG. 7--FAN-COIL WITH SUPPLEMENTARY AIR, SYSTEM SCHEMATIC

c. Radiant Panels with Supplementary Air

The radiant panel terminal (ceiling or wall mounted) provides either radiant heating or radiant cooling. The supplementary constant volume air supply provides for dehumidification and ventilation. A schematic of the system with one water circuit is given in Fig. 8.

1.2.3 All-Water Systems

These systems have fan-coil room terminals. The terminals are connected to one or two water circuits. The central plant includes only the boiler and the refrigeration machine. All the air is treated locally. Ventilation is obtained through an opening in the wall or from bleed-off from the interior zone system, if there is one, or by infiltration, or using a unit ventilator.

The water circuits in all-water systems can be as follows:

a. 2-Pipe

Either hot or chilled water can flow to the fan-coil units. Cooling operation is illustrated in Fig. 9.

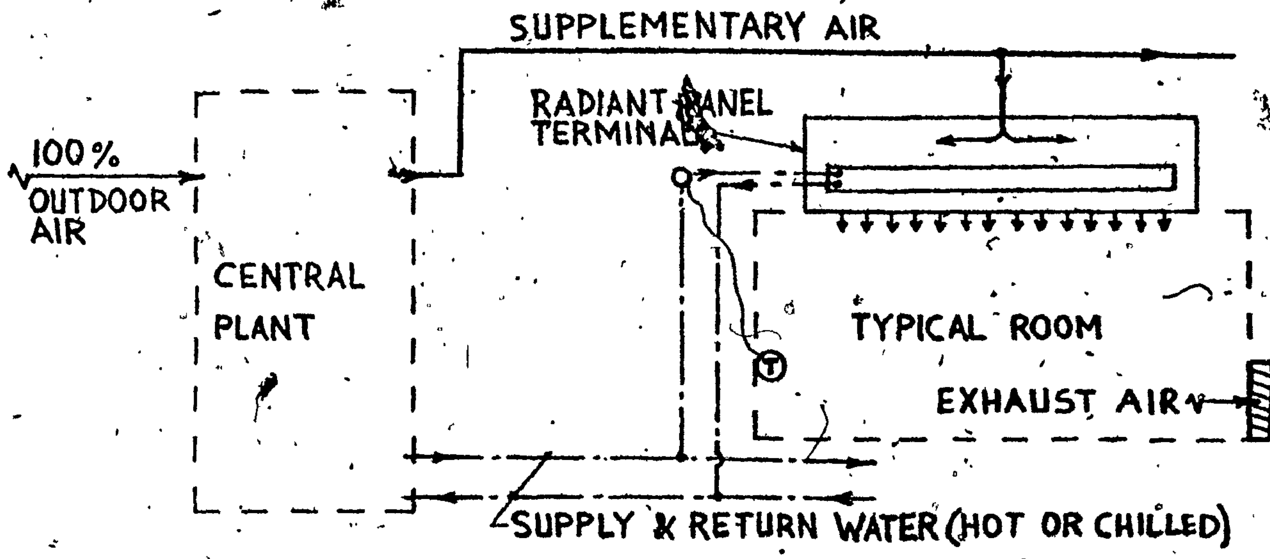

FIG.8.--RADIANT PANELS WITH SUPPLEMENTARY AIR, SYSTEM SCHEMATIC

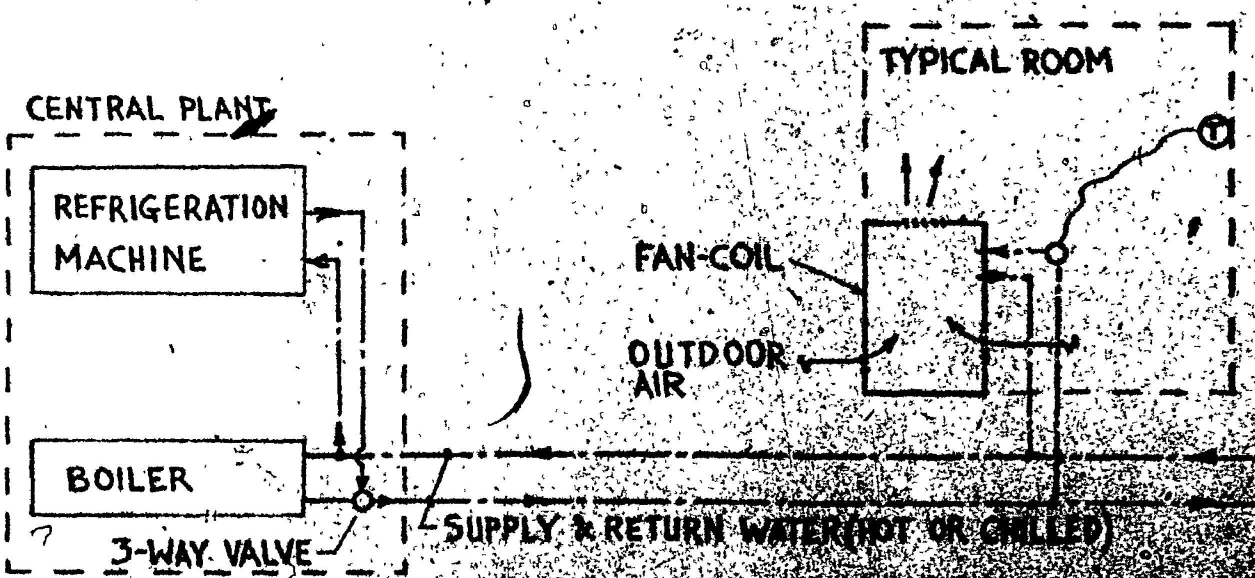

FIG.9.-- ALL-WATER 2-PIPE SYSTEM SCHEMATIC

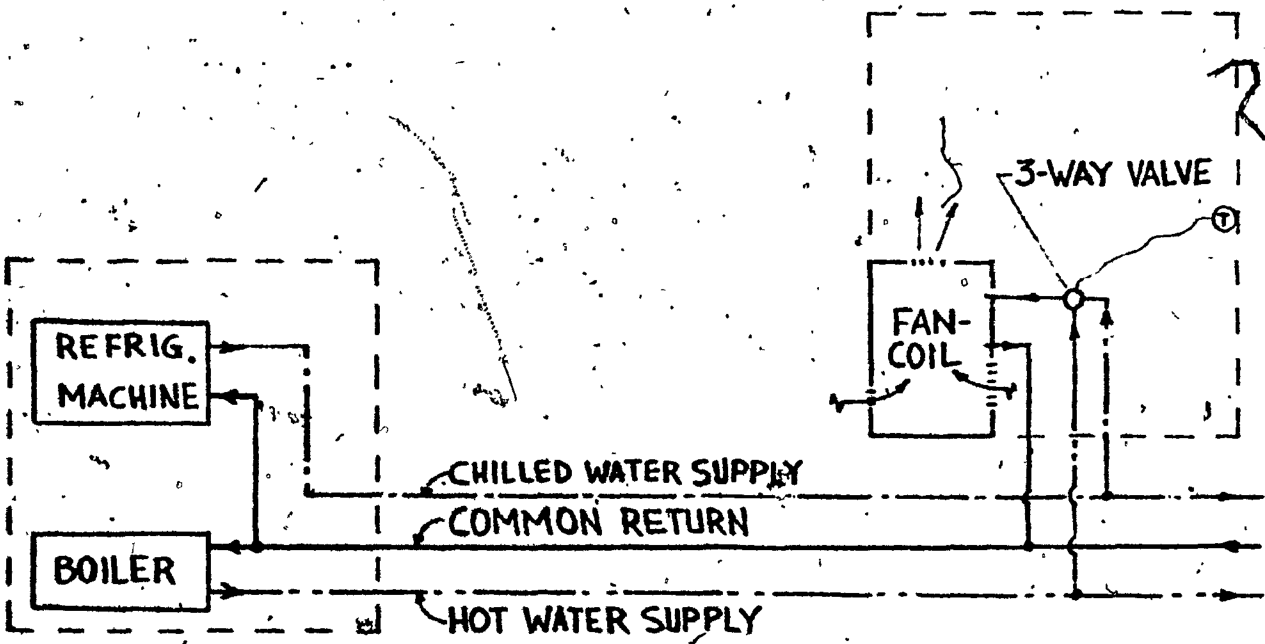

FIG. 10.-- ALL-WATER 3-PIPE SYSTEM SCHEMATIC

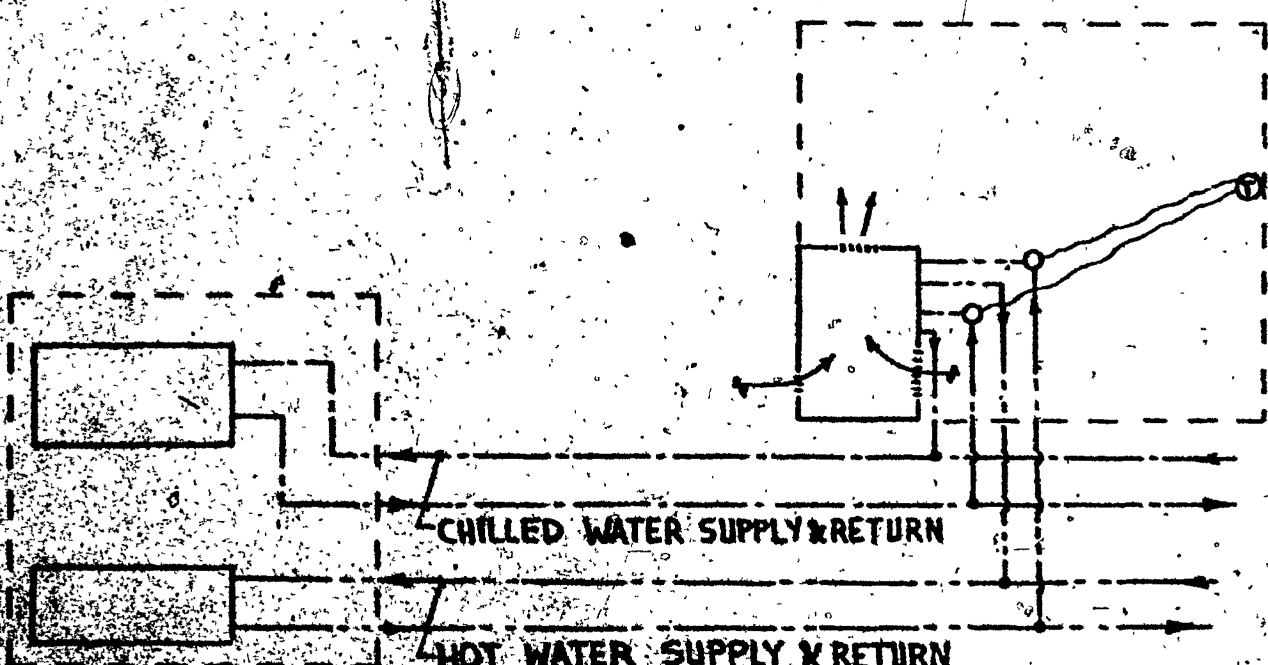

FIG. 11.-- ALL-WATER 4-PIPE SYSTEM SCHEMATIC

b. <u>3-Pipe</u>

Two supply pipes, as shown in Fig. 10, one for hot and the other for chilled water, make both heating and cooling available at any time needed. The return pipe is common for both hot and chilled water.

c. <u>4-Pipe</u>

Two separate piping circuits are used here, as shown in Fig. 11, one for hot and one for chilled water. The fan-coil unit has a double or split coil - one part of the coil heats only, the other cools only. Thus, both heating and cooling are available at any time.

1.2.4 Refrigerant Systems

These systems utilize refrigerant to directly cool or heat (by reversing the refrigeration cycle) the room air. Heating can also be provided by supplementary heating elements. Self-contained units are normally located within or adjacent to the air conditioned space as follows:

a. <u>Through-the-Wall or Window Unit</u>

A typical installation is shown in Fig. 12:

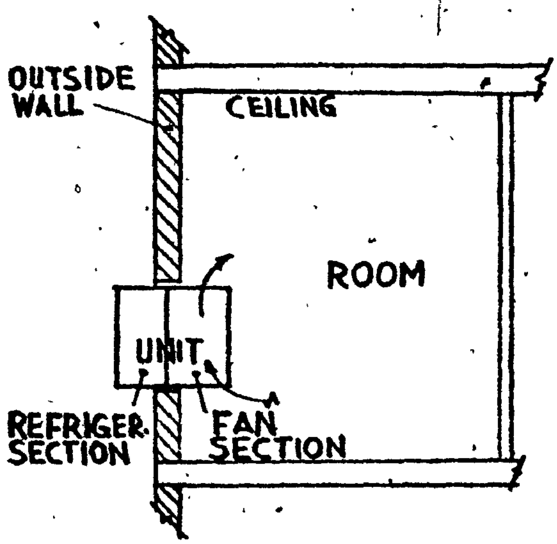

FIG. 12.-- THROUGH-THE-WALL UNIT

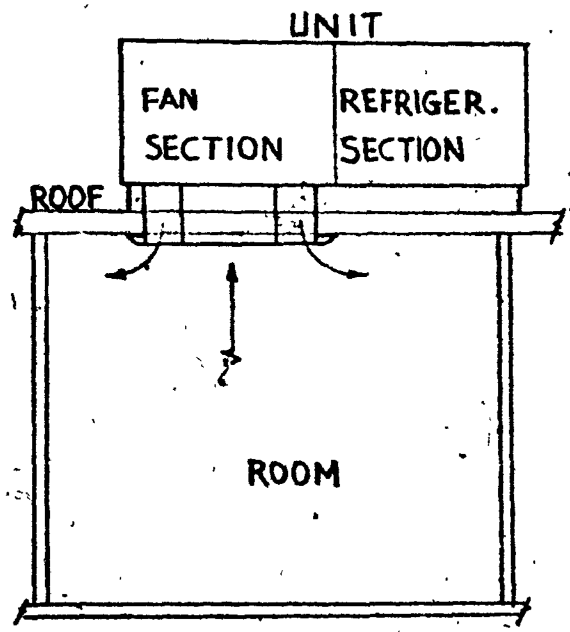

FIG. 14.-- ROOF-TOP UNIT

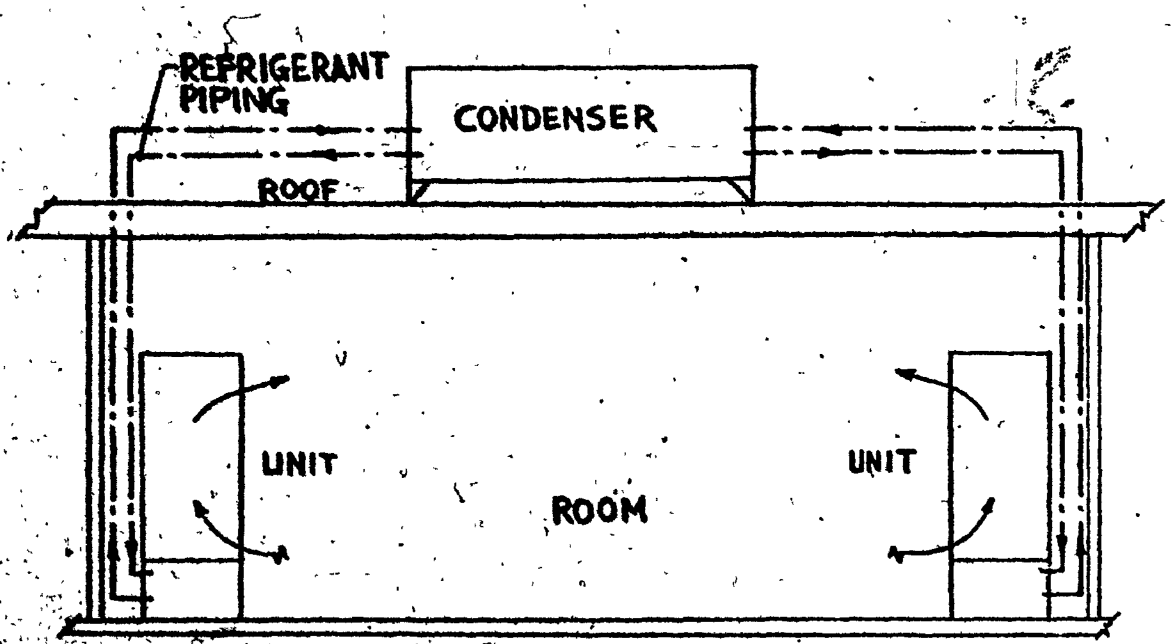

FIG. 13.-- PACKAGED UNITS WITH REMOTE CONDENSER

Heating is provided by reversing the refrigeration cycle and/or by electric, central hot water or gas heating elements installed within the same unit.

b. Packaged Unit

Shown in Fig. 13 are floor-mounted units with air-cooled roof-mounted condensers. Supplementary heating is required for year-round operation.

c. Roof-Top Unit

Usually serves larger areas than the through-the-wall unit and the air is distributed through ductwork or directly by combination supply/return diffusers. The latter is shown in Fig. 14. Heating is produced by electric, gas or oil heating elements installed within the unit.

1.3 Air Conditioning Control Systems

1.3.1 Elements of Air Conditioning Control Systems

In the air conditioning system schematics of Figs. 1 through 14, only a part of the control system is shown - the room thermostat commanding a valve, damper or on-off switch. However, to provide control for most air conditioning systems, comprehensive control set-ups are required with several control devices arranged in closed and/or open loops. All control systems may be reduced to three fundamental elements:

1. Sensor - to measure the "controlled variable".
2. Controller - to compare the measured variable with a "set point" and adjust the controlled device.
3. Controlled Device - to regulate the output of the "process plant".

For example, in the case of the control system for a room reheat unit, we can identify the above elements as follows: (See Fig. 15)

- Controlled Variable = The room temperature.
- Set Point = The desirable room temperature.
- Process Plant = The reheat unit.

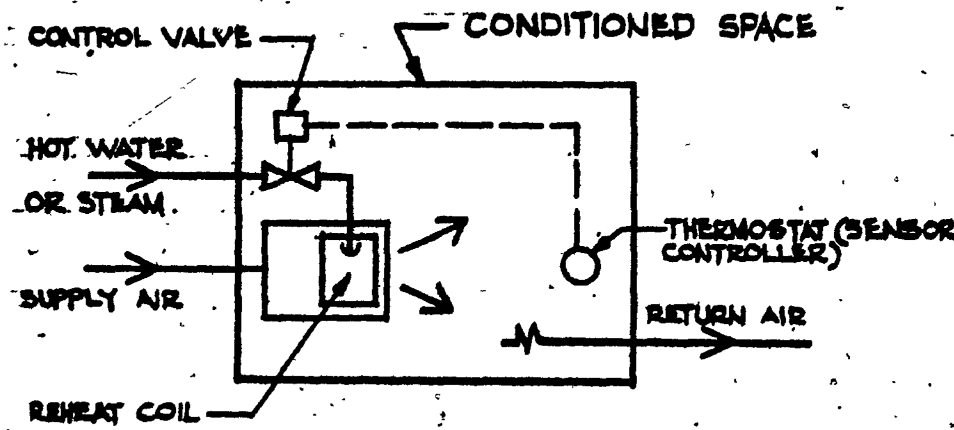

FIG. 15 – CONTROL SYSTEM FOR A REHEAT UNIT

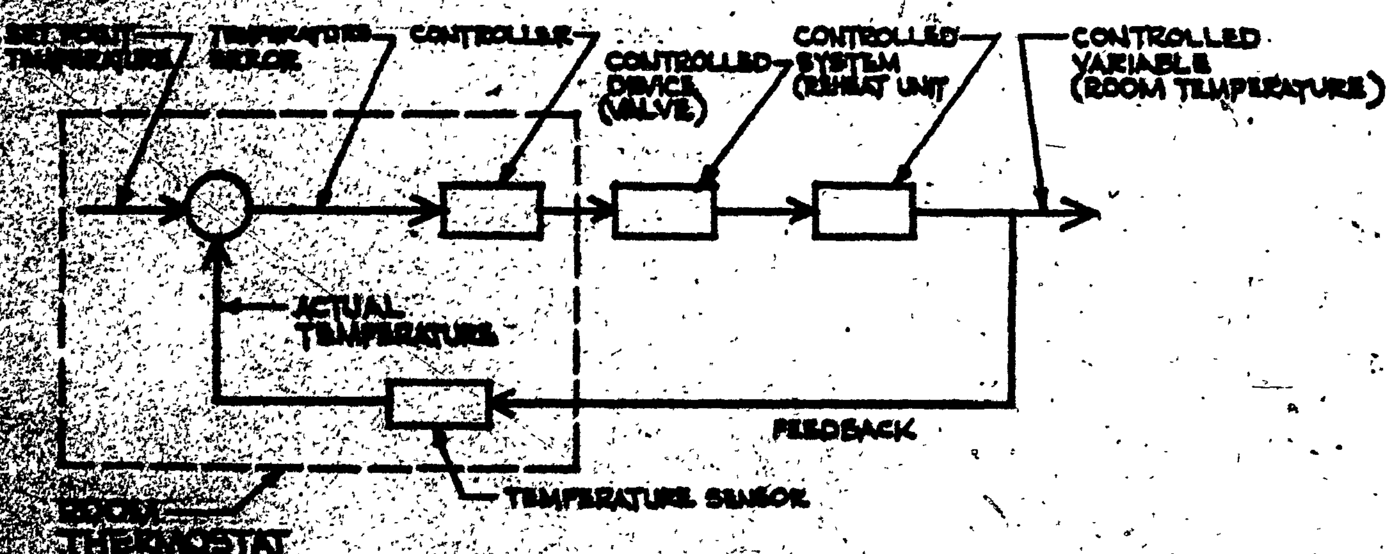

FIG. 16 – BLOCK DIAGRAM FOR THE CONTROL SYSTEM IN FIG. 15 (CLOSED LOOP)

- Sensor and Controller = The room thermostat.
- Controlled Device = The valve on the line to the reheat coil.

1.3.2 Closed-Loop and Open-Loop Systems

The block diagram of the Fig. 15 control system is shown in Fig. 16. It is a closed-loop control system.

In this type of system, a correspondence is maintained between the controlled variable (room temperature) and the set-point; a change in temperature caused by a change in valve position and/or room heat load will be sensed and additional adjustments in valve position will be made as necessary.

In the open-loop system, the sensor is not directly affected by the action of the controlled device. An example of an open-loop control system is shown in Figs. 17 and 18, which represent a simple arrangement for preventing freezing of coils in air conditioning systems. The set-point is about 35°F, so that when the outside air temperature reaches below that point, the valve will open and the heating coil will pre-heat the incoming air before it is allowed to reach the rest of the air-handling unit.

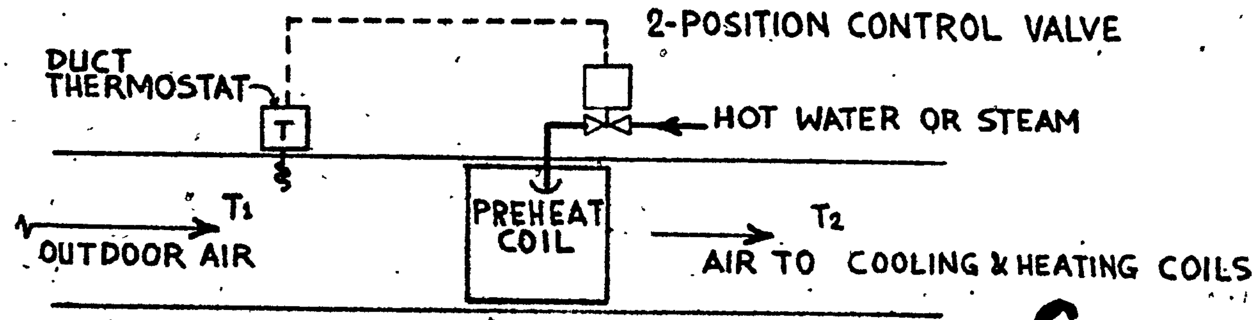

FIG. 17.-- CONTROL SYSTEM FOR PREHEATING

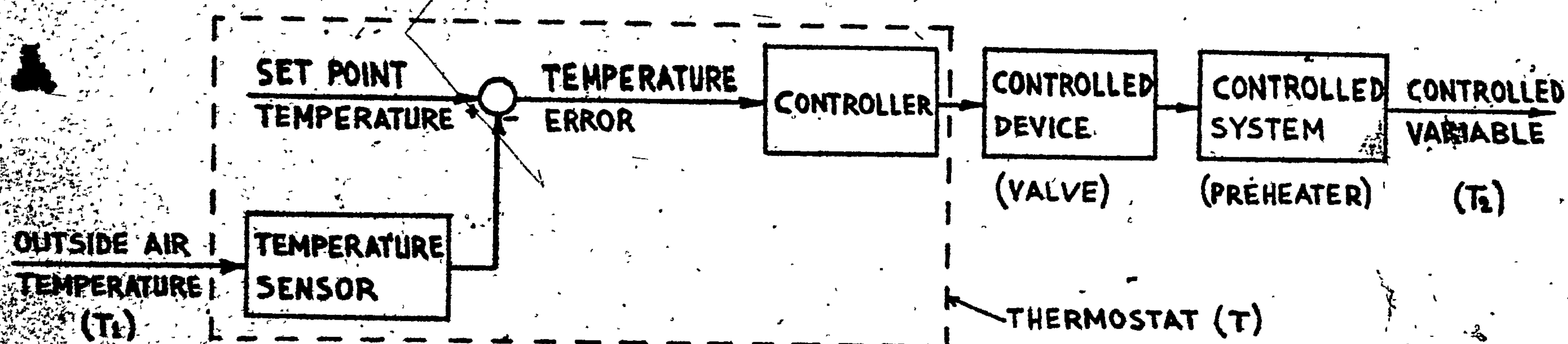

FIG. 18.-- BLOCK DIAGRAM FOR THE CONTROL SYSTEM IN FIG.17 (OPEN LOOP)

The thermostat senses the outside air temperature and not the temperature of the air leaving the preheat coil.

1.3.3 Control System Functions

It could possibly be deduced from Section 1.1 - Air Conditioning System Objectives, that the automatic control system to meet those objectives is designed just to provide control of the temperature and/or humidity in the space (the air filtration and the achievement of proper air patterns is incorporated into the initial design of the air conditioning system and its hardware). But controlling the room temperature and humidity are not the only functions performed by an automatic air conditioning control system. The following functions could also be included in the system:

a. Controlling the relative pressure between two spaces, to prevent, for instance, the spread of contamination.

b. Controlling the temperature of incoming fresh air, to prevent freezing of coils.

c. Safety controls to prevent the operation of equipment when in an unsafe condition.

d. Controls to trigger visual or audible alarms for unsafe conditions.

e. Controlling equipment capacity to closely match the load. This way the most economical operation of the air conditioning system is achieved.

f. Change-over controls, interlocks and internal monitoring and compensating controls to minimize human intervention and the chance of human error.

1.3.4 Types of Control Action

To perform all the previously mentioned control system functions, the following types of control actions are available:

a. Two-Position (On-Off) Action

An example of this action, which is the simplest control action, is shown in Fig. 19 for a cooling application (upper limit). On-Off action can be achieved, for instance, by a thermostat starting and stopping (through a relay) the motor of a

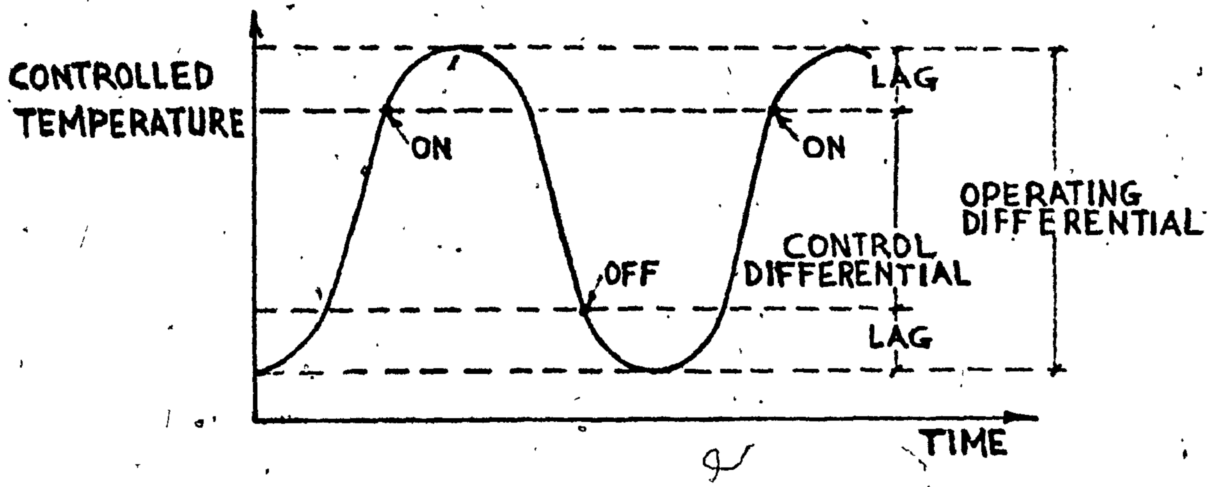

FIG. 19.-- ON-OFF CONTROL ACTION FOR COOLING (UPPER LIMIT)

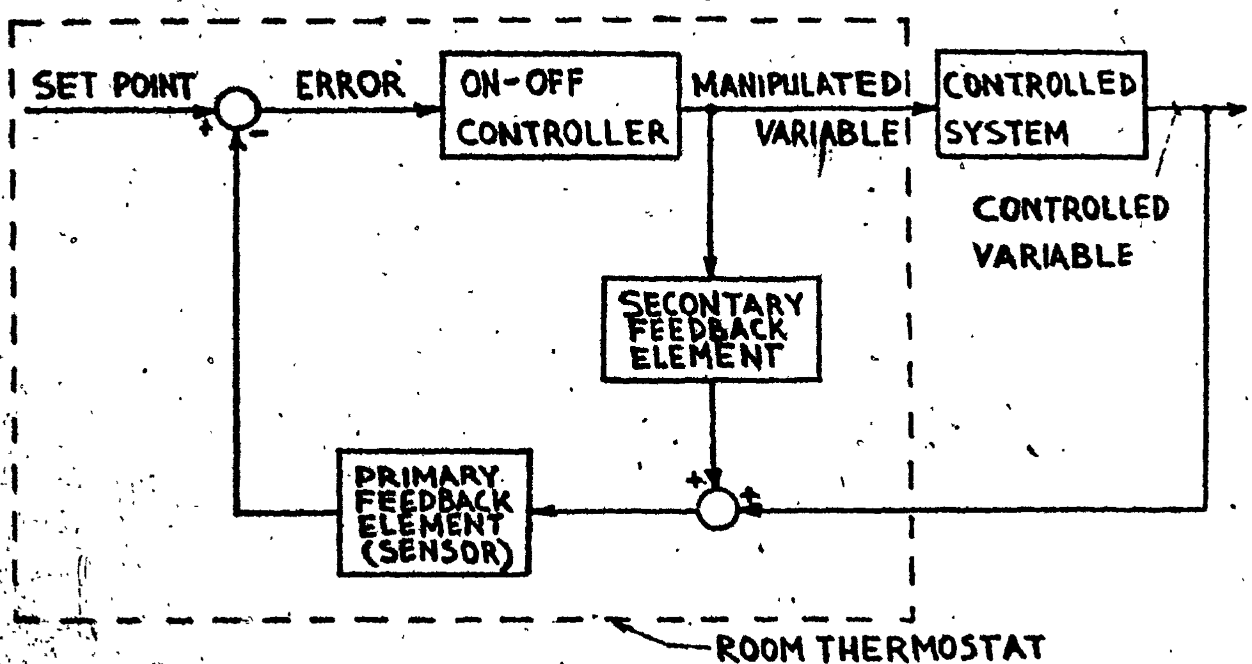

FIG. 20.-- BLOCK DIAGRAM FOR COMPENSATED ON-OFF ACTION (HEATING)

refrigerating compressor.

Any two-position controller needs a "control differential" to prevent too rapid cycling ("hunting"); this is the difference (in units of the controlled variable) between the set point at which the controller operates to one position (On) and the setting at which it changes to the other (Off). The "control differential" setting of any controller is usually somewhat less than the actual "operating differential" of the air conditioning system due to the response lag of the instrument and the air conditioning system.

b. <u>Compensated Two-Position Action</u>

If the lag of the two-position action is excessive, lead can be built into the control elements to compensate and thus reduce the operating differential by artificially shortening ON or OFF time in anticipation of system response. If, for instance, a mechanical heating thermostat, acting as a combined sensor (feedback), comparator, and controller, is too far away from the controlled source of heating (main heater), a small internal heater wired in parallel with the main heater is affixed to the thermostat to provide lead compensation. This heater is energized during ON periods, thereby giving a false signal to the thermostat in anticipation of system response. The size of this compensating (or anticipating) heater controls the amount of lead provided. The block diagram for this system is shown in Fig. 20 where the compensation appears as a secondary feedback.

c. <u>Proportional Action</u>

In this type of control action (Fig. 21) the amount of control power expended is proportional to the amount of deviation of the measured value of the controlled variable from the set point.

The terms shown on Fig. 21 have the following meaning:

- Throttling range: the amount of change in the controlled variable required to run the actuator of the controlled device from one end of its stroke to the other.

- Control point: the actual value of the controlled variable. When the control point lies within the throttling range, the controller is "in-control",

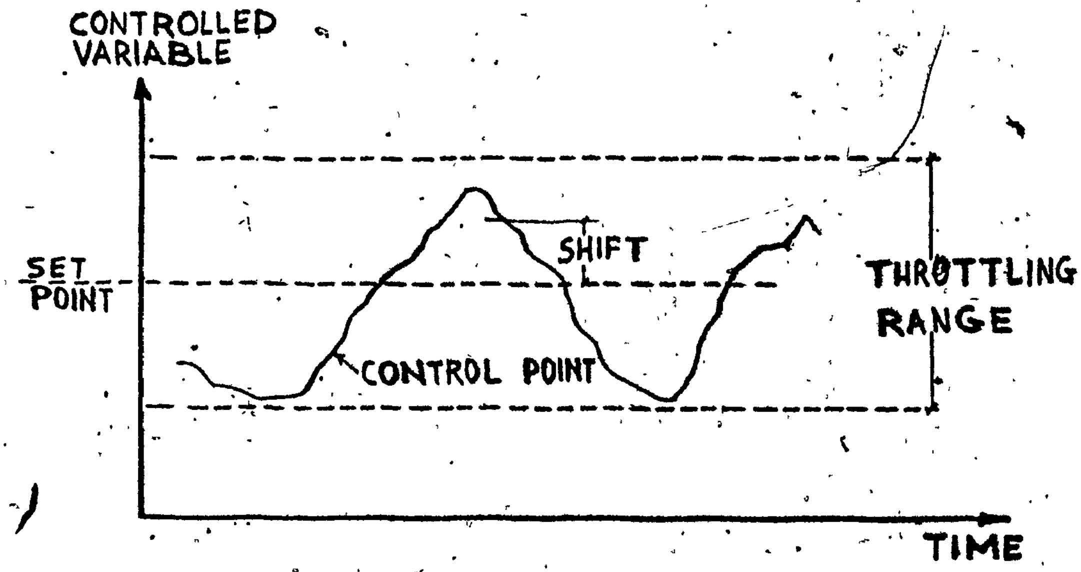

FIG. 21.- PROPORTIONAL ACTION

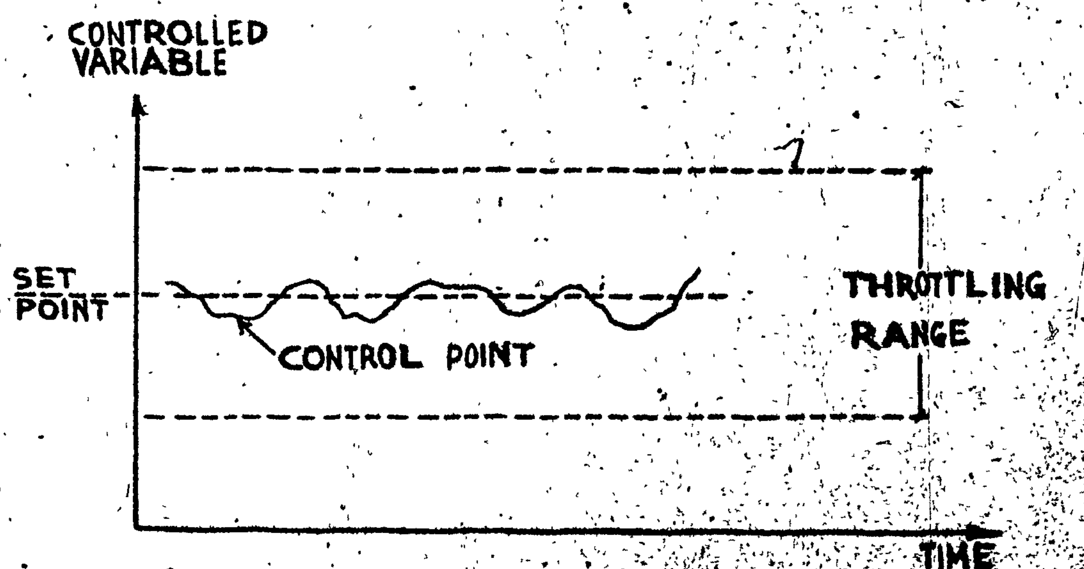

FIG. 22.- PROPORTIONAL ACTION WITH AUTOMATIC RESET

otherwise it is "out-of-control".

- Control point shift, or offset, or drift, or deviation is the difference between the set point and the control point. Only in "out-of-control" situations the amount of shift will exceed half the value of the throttling range.

d. <u>Proportional Action with Automatic Reset</u>

The consequence of the automatic reset (Fig. 22) is to increase the magnitude of the change in the controlled variable as the rate of shift (move of the control point in Fig. 21) increases; thus the control point is automatically returned to the original set point. This apparently provides more accurate control of the controlled variable.

The stability of the system (ability to maintain the control point very close or at the set point) depends, (1) on the speed of response by the total system (the building environment and the air conditioning system itself) to changes in the controlled variable, and (2) on the magnitude of the throttling range. This means that if the total system has a slow response, then a wide throttling range is required to obtain stability while when the response is faster a narrower throttling range could be established.

e. Discontinuous Control Action

This action is obtained with a multiposition switch and tends toward proportional action as the number of switching points increases.

1.3.5 Measurements and Sensors

It can be seen from the previous section that measurement of a controlled variable is essential to every control action, in either closed-loop or open-loop arrangements.

The degree of accuracy of a measurement, i.e. the difference between the actual value of the controlled variable and the reading obtained by the sensor, is a very important aspect in the study of a control system and depends basically on the construction of the sensor, its location and its relationship to the rest of the system. The accuracy of a thermostat, for instance, will be affected by the mass of the sensing element, the temperature of the surface on which the thermostat is mounted, the presence of radiant effects from windows, the velocity and direction of air motion in the space, the distance over which the signal must be transmitted; the latter will affect electric signals which may become greatly attenuated by the electrical resistance of long lines, or pneumatic signals which again may become seriously attenuated by fluid friction losses and can travel only at sonic speeds. On the other hand, a pressure sensor located at the turn of a duct or pipe, or where there is a sudden change in size, will never provide accurate and consistent measurement due to the fluid turbulence in those locations.

However, accuracy of a measurement has a relative meaning and depends on the application. Thus, when the controlled variable is changing, or fluctuating rapidly, it is very difficult to obtain accurate instantaneous readings, while at the same time the designer should ask himself what the desirable accuracy is for his particular application.

CHAPTER 2

PRINCIPLES AND BASIC COMPONENTS OF FLUIDIC CONTROLS

2.1 Development and Principles of Fluidic Controls

The concept of fluidics and fluid amplifiers as a control device was developed in the late 1950's. Much of the initial work was done by or for the military and cost was not a prime consideration. Today, considerable research is being done also by corporations and universities. There has been a steady increase in the use of fluidic devices and this trend should continue.

Pure fluidic devices are those which do not have any moving part, other than the fluid. Fluidic devices mostly work on differential pressures or flows and thus offer some flexibility over conventional pneumatic controls. Disadvantages over pneumatics are higher air consumption and quality (need of clean air with a very low moisture content.)

The air (or some other gas) used in pure fluidic devices is at low pressure, often 4 psig to a fraction of a pound, and must flow continuously. Here is the difference of fluidics from pneumatics, that is they utilize the dynamic rather than the static properties of the fluid. In terms of control logic, fluidic controls are closer to electronic controls than to pneumatics and they use much of the electronics terminology. Proportional or two-position control action is also possible with fluidic elements.

Most fluidic devices operate on one of three basic principles: wall attachment, turbulence amplification and vortex amplification. Many other devices are available, but the devices employing the above principles comprise the most commonly used hardware.

2.2 Components

2.2.1 Wall Attachment Devices

The Coanda effect, i.e. the property of a jet to attach itself to the surface of an adjacent wall, is the basis for the function of these devices. The most common of them are the following:

a. Bistable Amplifier

This is a logic relay-amplifier with memory (Fig.23). If a control jet (signal) is applied at port C1 the supply jet will be deflected away from the port and attach itself to the opposite wall, providing an output signal at O2, which will stay even if we remove the control signal. If, after the removal of C1, we apply a signal at C2 the supply jet will switch to the opposite wall and an output signal will be provided at O1. Amplifications (output to control signal) in the order of 4 to 1 are obtainable. Interruption of airflow when the output ports are blocked is undesirable, therefore the dump ports D1 and D2 are provided to allow continuous air-flow. On-Off control action can be accomplished by using this device, which also could be connected as an oscillator (Fig. 23(a)).

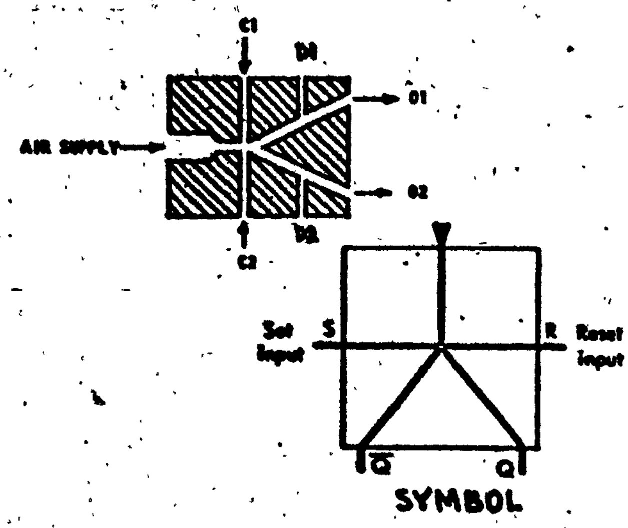

FIG.23.-- BISTABLE AMPLIFIER

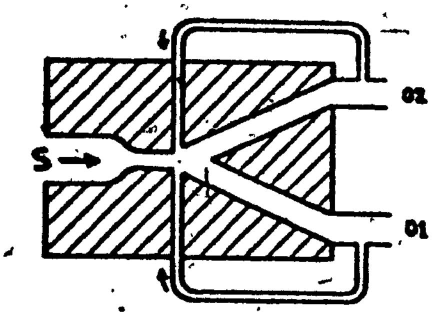

FIG.23(a).--OSCILLATOR

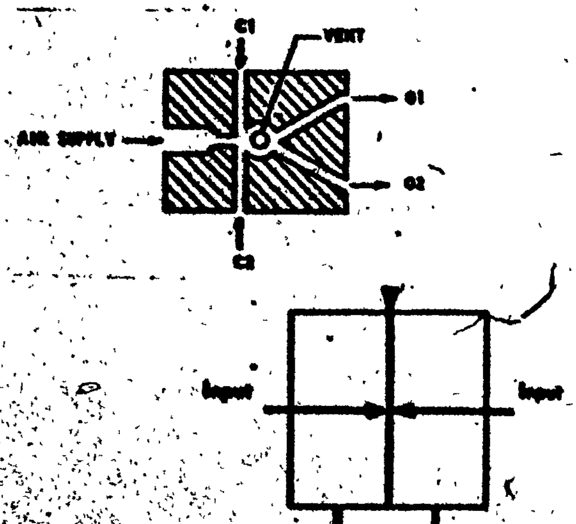

FIG.24.--BEAM DIFLECTON AMPLIFIER

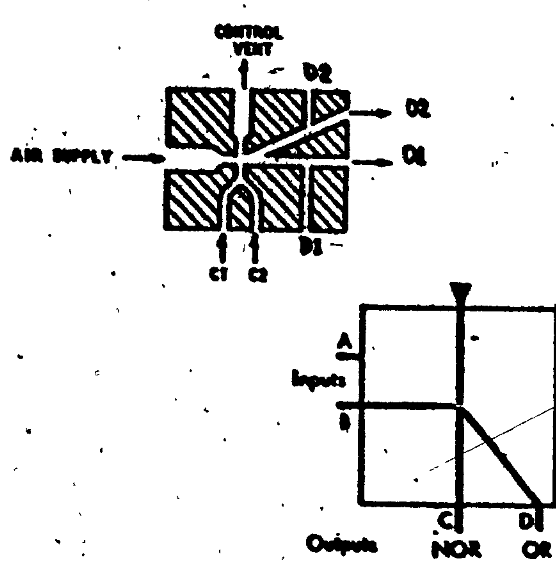

FIG.25.-- MONOSTABLE AMPLIFIER

We should note that the supply jet could be switched to the wall attached to one control port by applying negative pressure (suction) through that port.

b. Monostable Amplifier (OR-NOR Element)

By varying the geometry of the bistable amplifier as shown in Fig. 25 we obtain an OR-NOR element. With no signals at the control ports C1 and C2, there is an output only at 01. If a control signal is applied to C1 and/or C2 the output switches to 02. When the control signals are removed, the jet returns to 01 (no memory). If output 01 is obtained the element is a NOR element because neither control C1 nor C2 is present. If output 02 is obtained, it is an OR element because either control C1 or control C2 or both are present.

c. Beam Deflection Amplifier

A slight structural deviation in the configuration of the bistable-amplifier results to a proportional control device shown in Fig. 24, which is not actually based on the wall attachment effect, since the walls just beyond the control ports are cut away. With no control signal the supply jet goes straight out and produces two equal outputs at 01 and 02; if a control signal is applied at C1 or C2 the supply jet is deflected in proportion to the strength of the signal and the output signals at 01 and 02 become unequal. When the control signal is removed or when C1 equals C2, the device returns to its initial position of equal outputs (no memory). Thus, the difference between the two outputs is usually compared to the difference between the two inputs.

Wall attachment devices are not limited to low pressures (as those required by turbulence amplifiers). They can operate at very high pressures. Most available amplifiers, however, work best with supply pressures of 1 to 5 psig, recovering usually at the output less than 1 psig, and control pressures of 0.1 psig or less. Most proportional amplifiers are designed to work with power supplies of approximately 0.01 to 5 psig, recovering about 0.04 to 0.2 psig at the output, and control pressures of approximately 0.01 to 0.03 psig.

2.2.2 Turbulence Amplifiers

Gas jets issuing freely from nozzles can be adjusted to provide fairly long (in the order of 1 in. or more), narrow laminar flow patterns. These laminar jets are easily disturbed into turbulence by small control jets.

In Fig. 26, a receiving nozzle in alignment with the laminar jet receives some flow and pressure when the issuing jet is laminar. When the jet is turbulent, as in the case of applying a small control jet directed at the laminar jet, output flow and pressure drop off drastically. The turbulence amplifier can have more than one control port, as shown in Fig. 26. The device uses very low pressures, at the level of 10 in. water for supply and 0.4 in. water for control. The output then would be approximately 4 in. water (amplification 10:1). Because of these low operating pressures, the turbulence amplifier is generally used for low level logic work, i.e. to operate some other device to provide an output capable of operating standard equipment. It can drive up to 10 or more secondary units.

The device is primarily used as a two-position element and classified as a logic NOR element (output is on when there is no input). These NOR elements are basic building blocks of logic circuits and theoretically could be the only elements used in the construction of any logic circuit, however, that circuit may contain more logic elements than desired.

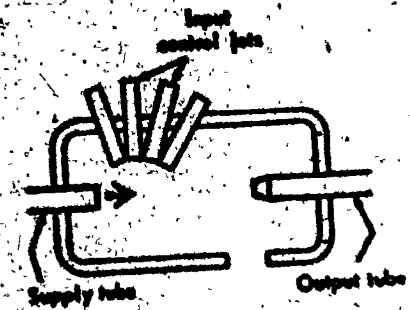

FIG. 26.-- TURBULENCE AMPLIFIER

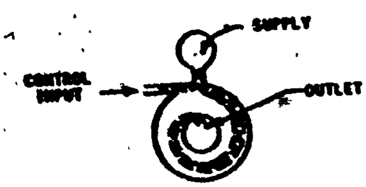

FIG. 27. -- VORTEX AMPLIFIER

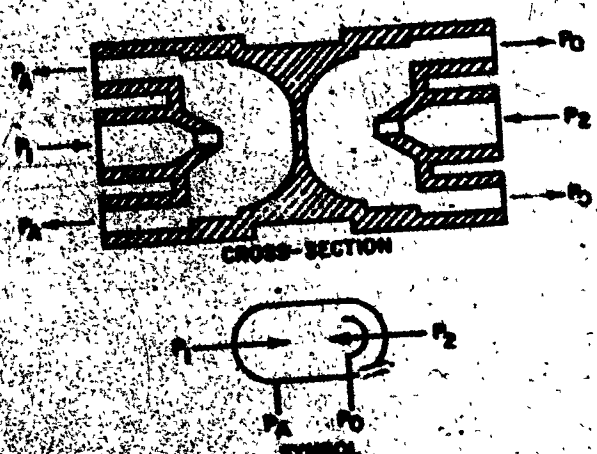

FIG. 28. -- SUMMING IMPACT MODULATOR (SIM)

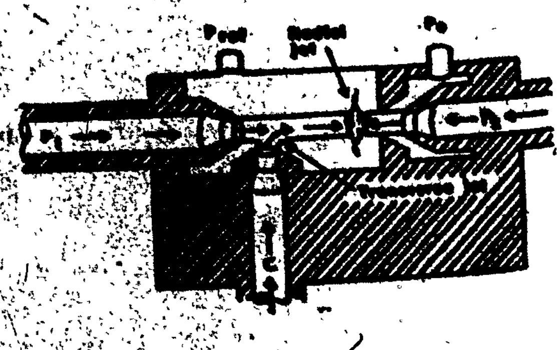

FIG. 29. -- TRANSVERSE IMPACT MODULATOR (TIM)

2.2.3 Vortex Amplifiers

A vortex amplifier (Fig. 27) has a cylindrical body with supply air introduced at the side and output at one end of the cylinder. The control signal is introduced at a tangent to the cylinder and at right angle to the supply flow. With no control jet there, the supply air flow is straight through to the outlet with minimum resistance. A control jet causes the main stream to swirl, creating a vortex; greater swirling causes more resistance and reduces output flow.

The control pressure must be higher than the main stream pressure and supply output can be reduced, proportionally, to as little as 10% of supply flow, but never to zero flow. Vortex devices are most often used as valves or variable restrictors and can be designed to operate over a wide range of supply flows and pressures. The requirement though of higher control pressures limits their application.

2.2.4 Impact Modulators (Radial Jet Amplifiers)

These amplifiers utilize two impacting fluid jets, as shown in Fig. 28. At the point where the two jets meet a radial jet is created which, when confined in a chamber, will produce an output signal or be vented, depending on the relative strength of the two impacting jets. The reference jet B is adjusted to a desired pressure (set point). When the signal from the sensor (jet A) is greater than B, then the radial jet forms in the right-hand chamber and the pressure developed in that chamber generates an output signal which can power an actuator or reset a relay. When A is less than B, the radial jet forms in the left-hand chamber and is vented to atmosphere.

The operating range of Summing Impact Modulator (SIM) takes place when the pressures P_1 and P_2 are very near the same value. This makes SIM a highly sensitive "pressure comparator". The amount of change of output P_0 for a given change in P_1 (P_2 is held constant) is called the gain of the device; this gain, as shown by the graph (Fig. 28) of the relative characteristics of the device, is in the neighbourhood of 500. This ability of the device to subtract one pressure from another, and amplify the difference without deadband or hysterisis, makes the SIM a very accurate "pressure detector". Because it can detect changes in the controlled variable, and amplify them with only small amounts of distortion and phase shift, higher loop gains are achievable, resulting in systems with less offset; then, tighter control loops are possible which produce controllers with higher total frequency response (up to 1000 cycles/sec with negligible output of SIM).

Another arrangement for an impact modulator could be the one shown in Fig. 29. This is called Transverse Impact Modulator (TIM). Very small signals from the control jet can move the radial jet producing large changes in the output signal.

2.2.5 <u>Diaphragm Type Devices Used in Fluidic Circuits</u>

These devices (Fig. 30) are used in fluidic logic circuits to compare and select pressures. No amplification is performed here, as it is with the fluidic-pneumatic transducers. Their advantage over pure fluidic circuit elements is that they do not need continuous fluid flow, therefore they have less energy dissipation; they are also capable of delivering large amounts of flow upon demand, and still can be throttled to near shut-off when steady-state conditions result.

In Fig. 30(a), a diaphragm controlled bleed is shown, consisting of two chambers separated by a thin diaphragm which when pushed downward restricts or shuts off the flow through the nozzle projection. Pressures applied in the upper and lower chambers, control the position of the

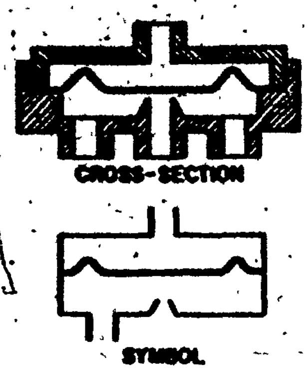

FIG. 30(a).--DIAPHRAGM CONTROLLED BLEED

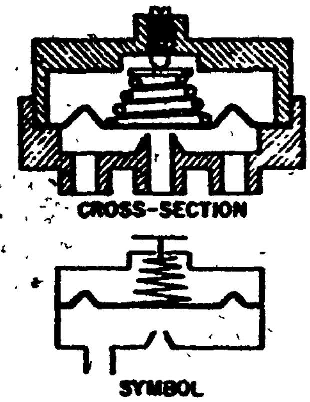

FIG. 30(b).--SPRING LOADED DIAPHRAGM CONTROLLED BLEED

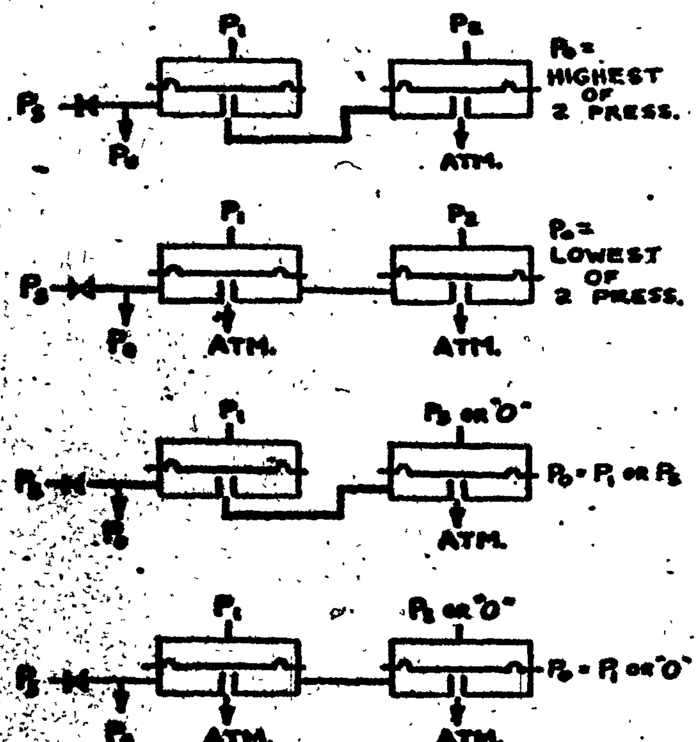

FIG. 31.--DIAPHRAGM LOGIC COMBINATIONS

FIG. 32.--PRESSURE REGULATOR

diaphragm relative to the bleed. There are various circuits that can be made from this device, some of which are shown in Fig. 31.

In Fig. 31(a) two diaphragm type devices are used to compare two pressures and provide an output signal equal to the higher of the two. In Fig. 31(b) the same two devices on a different piping arrangement provide an output equal to the lower of the two pressures. In Figs. 31(c) and 31(d) there are applications of the same circuits for comparing an input signal P_1 to a set-point pressure. This principle can be expanded and used to compare more than two input signals and provide outputs equal to the highest and lowest of these inputs.

A deviation from the diaphragm controlled bleed is the spring-loaded diaphragm controlled bleed shown in Fig. 30(b). The adjustable spring preloads the diaphragm with respect to the bleed nozzle which opens only when a certain pressure is applied to the lower side of the diaphragm. This device can be utilized in several different circuits, one of which, a pressure regulator, is shown in Fig. 32.

2.2.6 Passive Fluidic Devices

These devices have no moving parts and are used as flow control components. Unlike the devices described in earlier sections, these do not have separate power supplies for themselves. Some of the passive fluidic devices are briefly described in the following paragraphs.

The orifice (Fig. 33) transforms pressure into flow. This is accomplished by converting the potential energy (pressure) to kinetic energy (flow) through the small aperture. This transformation is not linear.

The capillary (Fig. 34) is very similar in function to the orifice; however, the transformation of pressure to flow is linear, due to the fact that it is based primarily on the viscous effects of the fluid. These effects are neglected in the case of the orifice.

The needle valve (Fig. 35) is a variable (adjustable) restrictor and its flow-pressure (transformation) characteristics depend on the position of the needle with respect to the orifice. When it is adjusted to high resistance, curves are more capillary-like than they are orifice-like; when it is adjusted to low resistance, the device performs closer like an orifice. This device is very

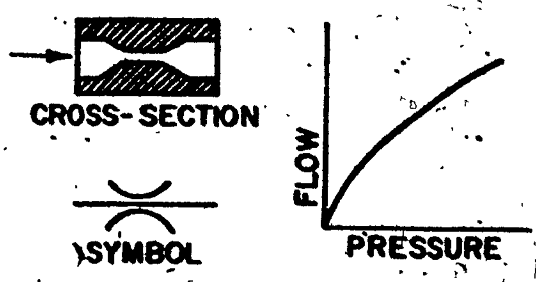

FIG. 33.--ORIFICE

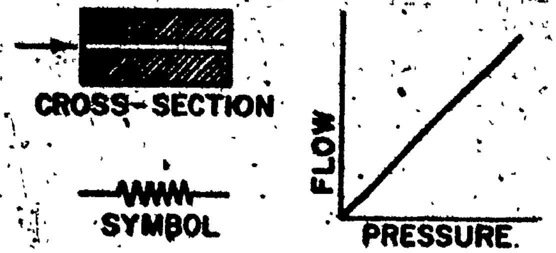

FIG. 34.--CAPILLARY

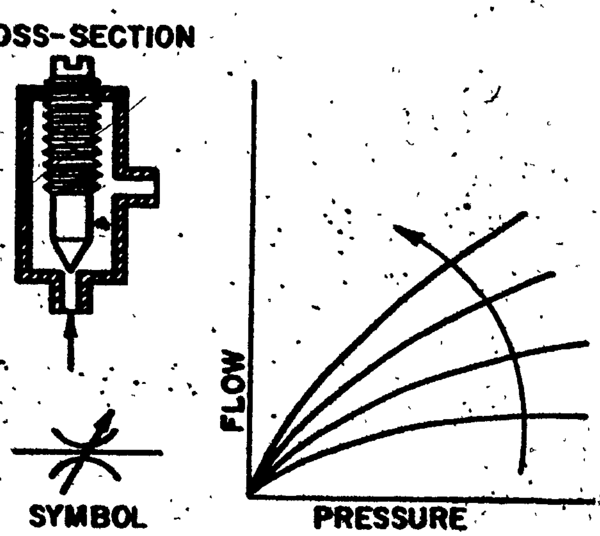

FIG. 35.--VALVE

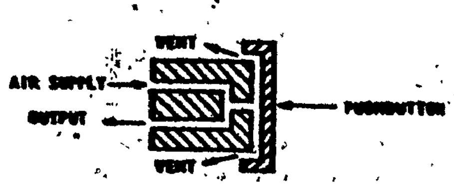

FIG. 36.--FLUIDIC PUSHBUTTON

FIG. 37.--SELECTOR SWITCH

useful to a circuit, since it can balance or correct for manufacturing tolerances of the circuit. It also allows for adjustments on the circuit such as set point and/or gain.

2.2.7 Manual Switches

Manual intervention is sometimes necessary in fluidics, as with any other type of control action. Manual controls include push buttons, selector switches and proportioning switches.

The fluidic push button switch (Fig. 36) operates on the bleed principle. Normally the air supply vents out through an orifice and chamber under the button. When the button is depressed, the vent orifice is blocked and a momentary output signal is generated. This may trigger, for example, a bistable amplifier.

The fluidic selector switch of Fig. 37 provides a choice of two outputs in a sliding arrangement; it can be built in a rotary arrangement as well. The device is used as 3-way or multiport valve in fluidic circuits.

Proportioning switches are the same type as used in pneumatic control circuits, but designed for the lower fluidic pressures.

In general, any of the manual (or automatic) air valves commonly used for pneumatic controls can also be used with fluidic circuits.

2.2.8 Fluidic Interface Devices

Most of the fluidic devices, as noted in previous sections, operate most efficiently at very small pressures. To operate controlled devices such as valves and dampers or even electric switches, higher pressures are required. Fluidic interface devices serve this purpose, amplifying or converting low pressure fluidic signals to higher levels or other forms of outputs. The basic interface devices, or transducers in process control terminology, are the direct force transducer and the assisted force transducer.

a. Direct Force Transducers

In Fig. 38, the output signal from the fluidic controller is applied directly on the one side of the diaphragm. The movement of the diaphragm may close or open an electrical switch or move a pilot valve in a pneumatic relay. The device can handle only small loads, even with a large diaphragm.

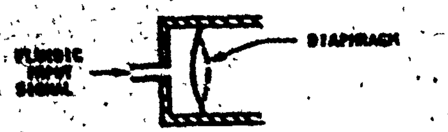

FIG.38.--DIRECT FORCE TRANSDUCER

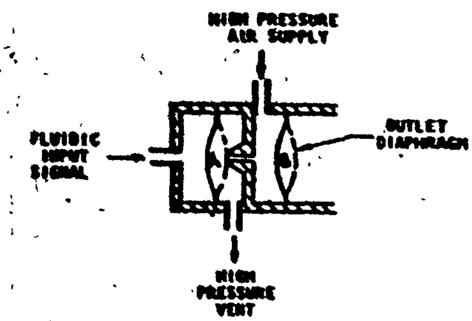

FIG.39.--ASSISTED FORCE TRANSDUCER

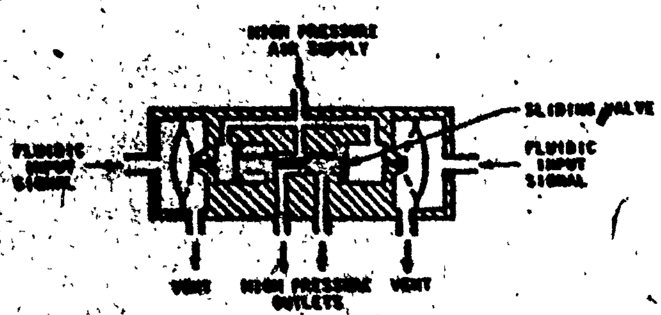

FIG.40.--THREE-WAY VALVE (WITH ASSISTED FORCE OPERATION)

b. Assisted Force Transducers

A high pressure air supply is provided, as shown in Fig. 39, to assist or amplify the low pressure fluidic signal. The low level input signal and diaphragm of the previous device are used to control the higher pressure supply which, in turn, operates the controlled device; with no (or low) fluidic signal the high pressure supply is vented; when the fluidic signal is increased the diaphragm A moves to restrict or completely block the nozzle to the vent chamber; consequently the pressure in the supply chamber increases and moves diaphragm B. The force on B is adequate for positioning valves or dampers directly. The action can be on-off or proportional, depending on the construction of the diaphragm.

An application of the assisted force transducer is the three-way two-position valve shown in Fig. 40. This pneumatic valve is driven both ways by two assisted force transducers operating on the two opposite sides of a piston. The valve could also be constructed with a spring return piston, thus being able to operate with only one fluidic signal and use only one transducer; these valves have very fast response time.

Fluidic-electronic transducers are also available, but generally are not yet used in air conditioning systems. They use pressure-sensitive transistors or strain gages to modify the low-power fluidic signals.

2.3 Manufacturing and Cost of Fluidic Devices

Turbulence amplifiers were the first fluidic amplifiers commercially available, primarily because of their simplicity and ease of manufacture. They are made from small diameter tubing inside cylindrical metal shells. An injection molded plastic turbulence amplifier has been developed, improving substantially manifolding and interconnections, which initially presented a major problem; greatly reduced manufacturing costs are also achieved by the injection molding method.

Wall attachment amplifiers lend themselves to low cost, injection molding, however, this method did not produce reliable and repeatable devices initially. Modifications in design, processes, and sealing have now resulted in reliable amplifiers of injection molded plastic. Costs are coming down as more applications develop. Other methods of manufacture include compression molding of thermosetting plastic, which produces units of greater stability than the injection molded plastic amplifiers, and at a cost which also drops with time. However, the process which appears to be the best of all available processes for the manufacture of wall attachment devices, is the etching of one or more amplifiers and associated interconnections and restrictions into one piece of glass (in effect producing an integrated circuit). In addition, layers of integrated circuits can be bonded together to produce even more complex circuits; so while this may be an expensive way to manufacture a single amplifier, it is very economical for an entire circuit. Metal etching also has been used successfully.

Vortex amplifiers, because of their configuration, lend themselves to conventional machining techniques and can be fabricated from a wide variety of metals and plastics.

CHAPTER 3

FLUIDIC DEVICES AND CONTROLS USED IN AIR CONDITIONING

3.1 History

The use of fluidic devices in air conditioning control is a quite recent development, starting in the second half of the 1960's. However, the application of fluidics is becoming increasingly important in the rapidly growing environmental control industry.

In around 1966, Johnson Control introduced their fluidic "controlling-receiver", based on the impact modulation principle. This device can control temperature, humidity or pressure by operating valves and dampers.

Around 1969, Honeywell Inc. developed their fluidic "air motion relay", based on the "wall attachment" principle. This relay can be used as interlock on both central fan systems and terminal units such as fan-coil units and unit ventilators.

The most economical and simple applications appear to be in the switching or regulation of air conditioning air streams.

and the reason is obvious: the presense of the air stream which could be used to amplify the low fluidic signals to achieve its own control. In the late 1960's, Fluidtech Corporation utilized the same principle as Honeywell (wall attachment amplification) in developing a fluidic "terminal air distribution unit" requiring no control power supply and having no moving parts. In 1973, Anemostat Products announced their fluidic "variable volume terminals" which also are self-powered and have no moving parts.

To the best of the writer's knowledge, the applications mentioned briefly above represent the only devices commercially available to-date. The descriptions presented in the next section were made possible with the help of literature and sample devices offered to the writer by the companies involved in the manufacturing of those devices or systems. In many cases, however, performance data was only made available without details of the fluidic components involved in the systems. Other applications are possibly in the stage of research by the same or other companies, however, no information on those projects has been made available.

3.2 Commercially Available Devices

As noted in the previous section, the commercially available devices make use of two of the basic fluidic principles, the wall attachment and the impact modulation. They also combine many of the techniques described in previous sections. Operational description and application of these devices are given in the following paragraphs.

3.2.1 Air Motion Relay (Ref. No.14)

This fluidic relay uses basic fluidic techniques to boost low level static pressure signals high enough to switch pneumatic circuits. Therefore, it can be used for control functions interlocking with air flow, for example, for the freeze-up protection of an air handling unit. Until now, such functions have been provided by electric-pneumatic relays with the necessary interfaces. Consequently, installation costs are high and performance problems are many. Alternatively, these functions are provided by mechanical air motion relays which eliminate the above disadvantages. However, they present their own significant problems, since they are not particularly sensitive to low static pressures in small unit ventilators and fan-coil units. They are also cumbersome and have limited switching

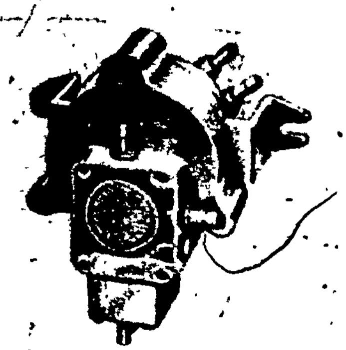

FIG. 41.- AIR MOTION RELAY

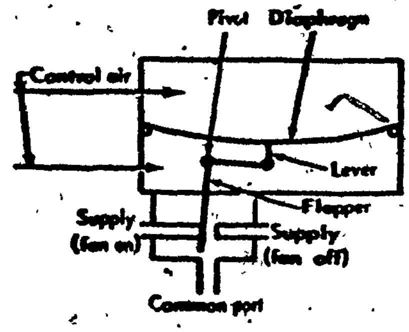

FIG. 43.-- FLUIDIC TO PNEUMATIC TRANSDUCER & PNEUMATIC SWITCH

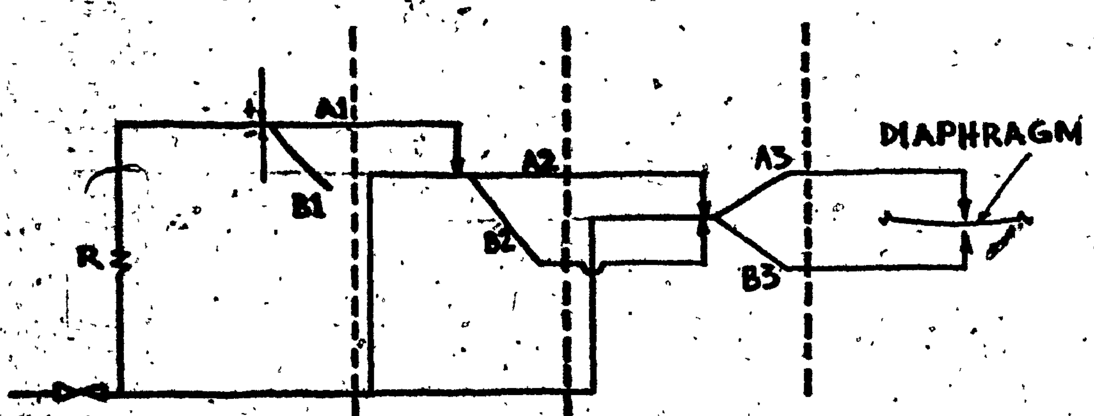

FIG. 42.-- 3-STAGE AMPLIFIER OF AIR MOTION RELAY

capability.

The above disadvantages presented by the conventional air motion relays are overcome with the fluidic air motion relay (Fig. 41) which amplifies small static pressures to levels high enough to provide both interlock and control functions. This relay is a two-position fluidic-pneumatic device consisting of a three-stage fluidic amplifier (Fig. 42), a fluidic to pneumatic transducer (Fig. 43) and a pneumatic switch (Fig. 43). A seal isolates the high pressure switch section from the low pressure diaphragm section. The three-stage amplifier circuit is etched on a shell-shaped glass plate some 2¼ in. across, and operates a small neoprene power diaphragm. The body is of injection molded, corrosion resistant thermoplastic.

The operation of the relay can be followed on Figs. 42 and 43. With no signal to the amplifier, restricted air supply flows through leg A1 of the 1st stage to the control port of the 2nd stage, thus switching the flow through that stage to leg B2 which leads to the lower control port of stage 3, thus switching the flow through that stage to leg A3; the latter leads to the upper side of the diaphragm which will be pushed downwards shutting off the pneumatic switch, as shown in Fig. 43. With a very small signal (0.04 in. water) to either the positive or the negative control port of the

1st stage, air-flow will be switche[illegible] leg B1 and vented; thus, there will be no signal to stage 2 and flow will come back to leg A2 switching the supply flow of stage 3 to leg B3, which boosts pressure against the lower side of the diaphragm causing the flapper in the pneumatic switch to unseal the fan-on port.

The restriction on the supply line of the 1st stage is to match the flow out of the stage to the input requirements of the 2nd stage.

The above described fluidic air motion relays can be used as interlocks on both central air-handling systems and terminal units such as unit ventilators and fan-coil units. High pressure models are used on central fans and low pressure models are used on terminal units. Modular construction permits various sub-assemblies to be combined for specific applications. Supply air could be from main or branch pressure, the latter requiring the addition of a pressure regulator valve to maintain a constant low pressure for powering the fluidic amplifier.

The two specific applications of the air motion relay are discussed below:

Air motion relays for central fan systems: They can be used individually or in combinations to handle specific job requirements such as:

- Closing the outside air dampers on fan shutdown to prevent drafts or freeze-up. As shown in Fig. 44, the relay is powered by main control air (M) and has its input (HI) connected to a static pressure probe located in the discharge side of the fan. The probe senses air motion in the duct (positive pressure). When the fan is operating, the air motion relay amplifies the positive pressure signal, as described earlier, and directs the main pressure through the "common" port to the damper operator (MD) holding the damper open. When the fan stops, no signal comes from the static pressure probe, thus the relay lets the flapper seal the fan-on port and stop the flow of main air into the switch, allowing the damper operator to close the damper. The same function can be obtained with the arrangement of Fig. 45 where the relay is powered by branch control air and is mounted on the damper motor sensing negative static pressure (suction side of the fan).
- The above function plus closing the humidifier valve on fan shut down to prevent overhumidification and downstream condensation. In this case, as

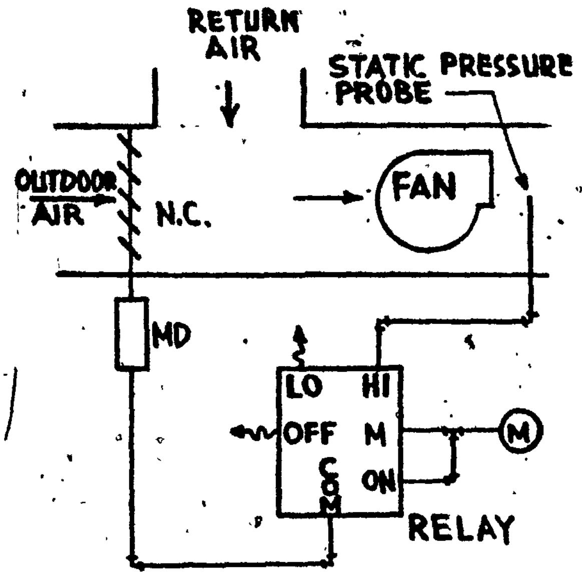

FIG.44.--FREEZE-UP PROTECTION (USING MAIN CONTROL AIR)

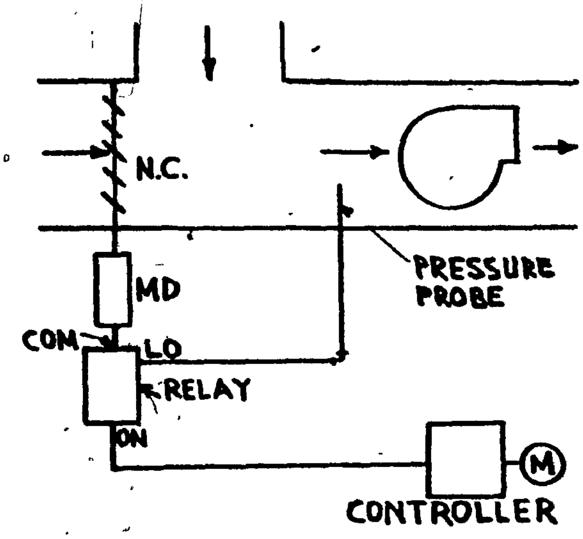

FIG.45.--FREEZE-UP PROTECTION (USING BRANCH CONTROL AIR)

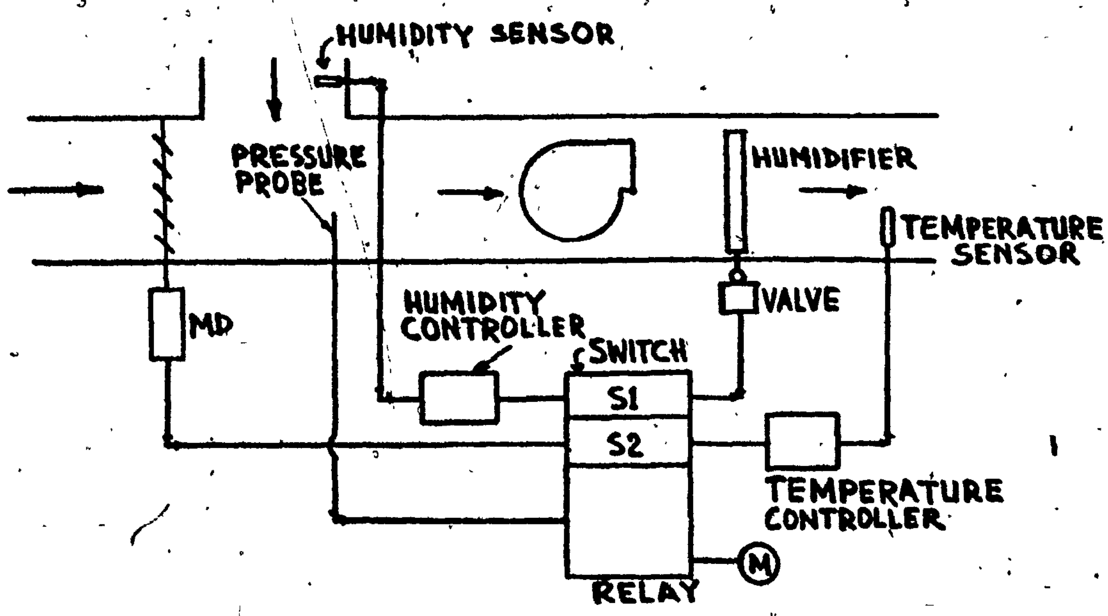

FIG.46.-- FREEZE-UP & CONDENSATION PROTECTION

shown in Fig. 46, the relay is assisted by a double pole switch, so that when the fan goes off, the relay closes the dampers and humidifier valve while, when the fan is running, turns their modulation over to the temperature and humidity controllers respectively. Here, the relay is powered by main control pressure air and is sensing negative static pressure. The same circuit could be used to close a heating valve when the fan shuts down to prevent wasteful or dangerous overheating, or to interlock the operation of the refrigeration system. When more than two of the above functions are required in the same control system, more than one relay could be used.

Fluidic air motion relays for central fan systems are available in a number of models to work with static pressure differentials ranging from 0.25 to 12 in. WG and handle control pressures up to 25 psi. The manufacturer claims that they are sufficiently sensitive that they can be located up to 100 ft. from the static pressure pick-up point. The relays can use either positive or negative static probes or both, depending on the application; generally, supply fan discharge pressure (positive) would be the most convenient signal, however, where ducts could be pressurized under shut-down conditions, using both positive and negative probes will avoid false signals.

Air motion relays for terminal units: Due to its high sensitivity, the air motion relay is particularily suitable in applications comprising fan-coil units, unit ventilators, and branch ducts. With a minimum static pressure differential of 0.04 in. WG, as stated by the manufacturer, the relay is sensitive enough to measure air flow of even small fans running at low speed. Various control functions of the terminal units can be handled by the fluidic relay, including:

- Closing a chilled water valve on fan shutdown to prevent condensation during summer (Fig. 47). The same circuit can be used also to close a heating valve to prevent overheating during shutdown or to open a heating valve on fan shutdown to provide night convection heating during winter. The relay can operate on either main pressure (Fig. 47) or branch pressure (Fig. 48). When the fan goes off, valve is closed (or opened); when the fan is on, thermostat modulates valve.

- Performing similar functions as above on a terminal unit with summer-winter changeover control (Fig. 49). During summer operation (13 psi main)

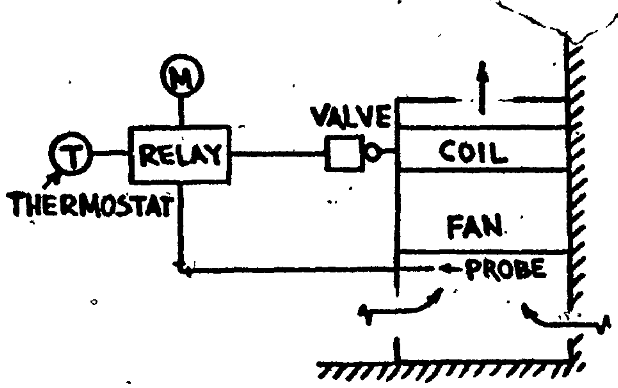

FIG.47.-- CONDENSATION PROTECTION (SUMMER) OF TERMINAL UNIT (MAIN PRESSURE)

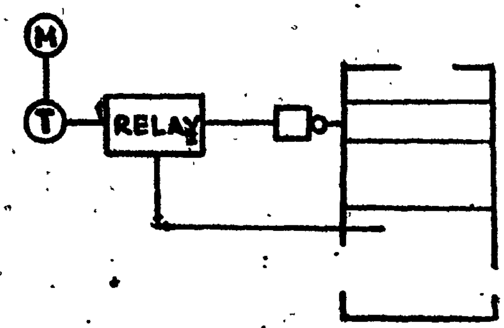

FIG.48.--CONDENSATION PROTECTION (SUMMER) OF TERMINAL UNIT (BRANCH PRESSURE)

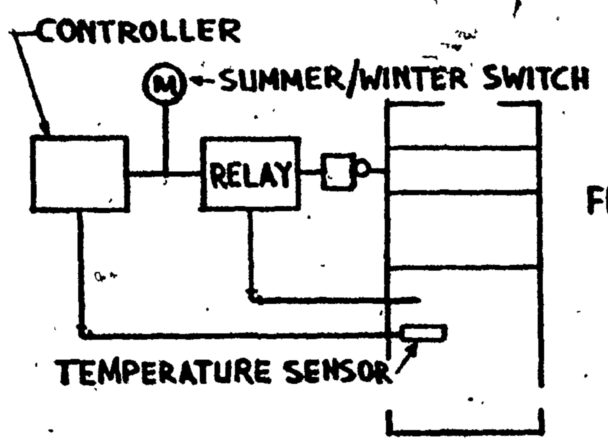

FIG.49.--CONDENSATION PROTECTION (SUMMER-WINTER CHANGEOVER) OF TERMINAL UNIT

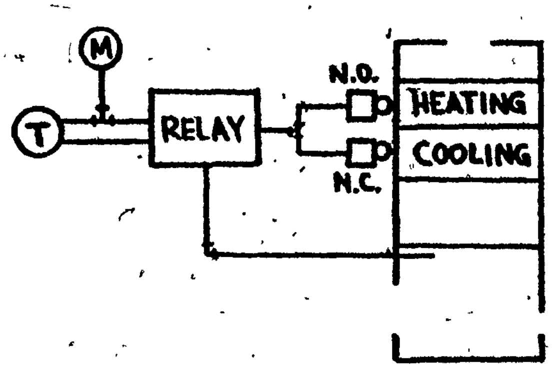

FIG.50.--OVERHEATING AND CONDENSATION PROTECTION OF 4-PIPE TERMINAL UNIT.

the unit thermostat modulates the valve when the fan is running; when the fan is shutdown, the relay closes the valve to prevent condensation. During winter operation (18 psi main) the controller is direct acting for hot water: the valve is regulated by the controller (on thermostat signals) continuously regardless of fan operation, i.e. there is no action by the air motion relay (fluidic amplifier is locked-out by the 18 psi pressure acting on a pressure regulator valve).

- Closing the valves on both heating and cooling coils of a 4-pipe terminal unit (Fig. 50). When the fan goes off, the output port of the relay will always be at 8 psi "neutral" pressure to maintain both valves in a closed position. When the fan is running, the heating and cooling valves will modulate in sequence to satisfy the thermostat (sensor/controller) demands.

- Shutting off electric reheat coils, when the air flow has stopped, to prevent overheating.

As shown in Figs. 47 to 50, negative pressure signal is used to trigger the relay. If positive signal had been used, any pressurization due to wind and outside air damper leakage could cause a false signal to the relay even during fan shutdowns. If necessary however, both negative and positive signals can be used simultaneously to provide a pressure differential signal.

In concluding, the fluidic air motion relay appears to have significant advantages over its conventional electric-pneumatic and mechanical counterparts. It can detect stopping of air flow due to a fan belt breakage or a fan motor burnout, without being fooled (as would be the case with electrical interlock) by the fact that the electric power circuit to the motor may still be energized, though the motor has been shut-off by its built-in overload protection. The fluidic relay also eliminates the problems of logical interconnections between electrics and pneumatics, offering very broad switching capabilities and simplicity of installation. No special installation tools are required and the units are equipped for surface mounting on an air duct or wall, or for attaching directly to a valve or damper operator. No field adjustment or calibration is required, since the units are factory-calibrated and sealed. Air pressures can be up to 25 psi, and ambient temperatures should be within the range of 40 to 140F.

3.2.2 Controlling-Receiver (Ref. No.15)

This instrument is called by the manufacturer "controlling-receiver" as opposed to the other controllers (e.g. thermostats) they manufacture which have the sensing element incorporated to the device. In the controlling-receiver, the sensing element is remote.

The controlling-receiver (Fig. 51) is a fluidic-pneumatic instrument based on the impact modulation principle. It is used for controlling temperature, humidity or pressure. The set point can be either remote or integral and can be adjusted either at a certain desired value or at a certain desired range of values. In the latter case, the set point is automatically adjusted to a value (within its range) corresponding to a control input related to a variable other than the controlled variable. The above possibilities in set point location and adjustment give the following four control combinations, corresponding to the four models of the controlling-receiver:

- Single input, remote set point.
- Single input, integral set point.
- Dual input, remote set point.
- Dual input, integral set point.

Information on the structure of the components of the

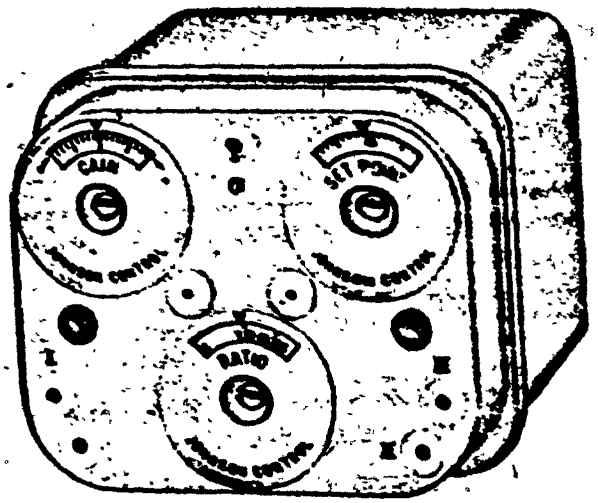

FIG. 51.-- CONTROLLING-RECEIVER (PHOTO)

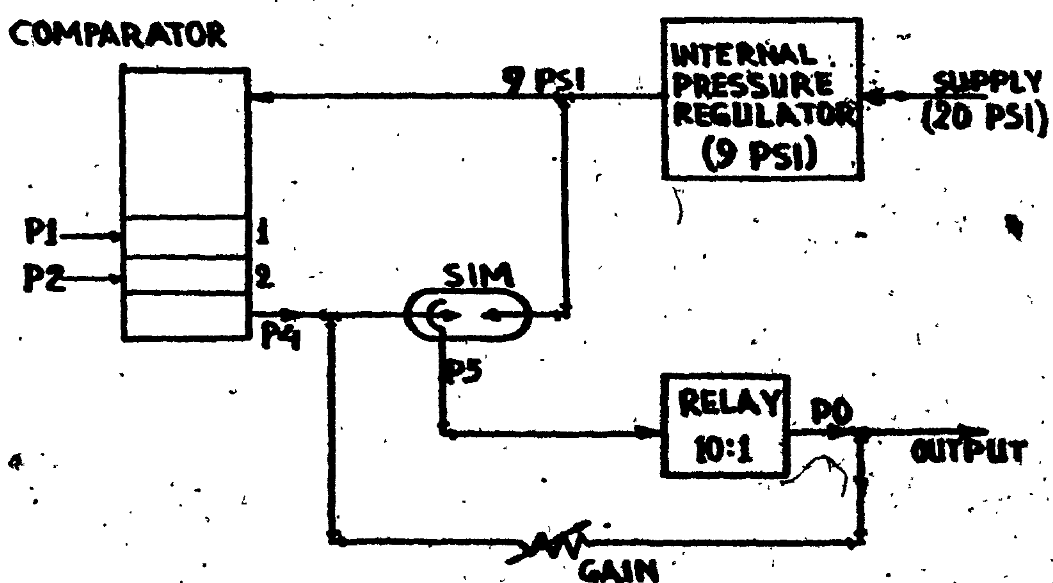

FIG. 52.-- CONTROLLING-RECEIVER CIRCUIT SCHEMATIC

controlling-receiver has been classified by the manufacturer for proprietary reasons, however, the basic circuitry of the single input, remote set point model can be illustrated as in Fig. 52. There are three fundamental parts with the following operating sequence:

a. <u>Input Comparator</u>: It is a diaphragm type component and accepts 3 to 15 psig pneumatic signal from a temperature, relative humidity or pressure transmitter and compares it with a set point signal to produce an output signal to the Summing Impact Modulator. Input 1 is used for the remote set point signal and input 2 is used for the control signal. The comparator is factory adjusted so that when inputs 1 and 2 are of the same value (e.g. 5 psi) the output is 9 psi. Then, if the control signal P2 increases 1 psi, the output signal P4 increases 1 psi and if P2 decreases 1 psi, P4 decreases 1 psi. If the device was of the dual input type, then a third input port would be needed for the "master" input signal, which, as mentioned earlier, would regulate the set point within a predetermined range of values.

b. <u>The Summing Impact Modulator (SIM)</u>: One of the two impacting jets is from the output of the comparator.

The other jet is a constant pressure, 9 psi. This pressure is closely regulated by the "internal supply pressure regulator". As output signal P4 from the comparator decreases, the SIM output pressure P5 increases.

c. <u>The Output Relay</u>: The output of the SIM is fed into a 10:1 direct acting relay. The reason for using a relay is two-fold, (1) it reduces air consumption and (2) it provides the air capacity required to operate controlled devices (valves, damper operators, etc.). A portion of the output signal Po is fed back through the gain (sensitivity) adjustment to the SIM.

All three basic components described above, and the related circuitry, are contained in an acetal thermoplastic enclosure. All adjustments, including calibration, internal supply pressure, integral set point, ratio and gain adjustments are made on the face of the device. Controller gain is the output change in psi per control transmitter input change in psi and it is adjustable from 3 to 50 psi/psi (preset at 10). Ratio, used for those instruments with dual inputs, is the controller set point change in psi per psi change in the master signal.

A typical application of the single input, remote set point model is the controlling of constant air mixture temperature (Fig. 53). The controlling-receiver is shown connected to the operators of two dampers (D1 & D2) regulating the air mixing from two air streams of different temperature. Say, for instance, that the desired mixture temperature is 55F. Then the remote set point (input 1) is set at 55F and when the control transmitter (T) reaches this value, the output of the controlling-receiver is calibrated to be in the midpoint of the controlled devices operating range. When the mixture temperature is less than 55F, the output will be less than the midpoint and this will cause the cold air damper to move to more close position and the hot air damper to move to more open position. When the mixture temperature is higher than 55F, the control action caused will be opposite to the one described above.

Typical applications of the other three models of the controlling-receiver include the following:

- Controlling a heating coil valve and dampers in an air distribution system. Fig. 54 shows a controller with single input and integral set point (input 1 port is capped). The control input comes from the discharge air temperature transmitter.

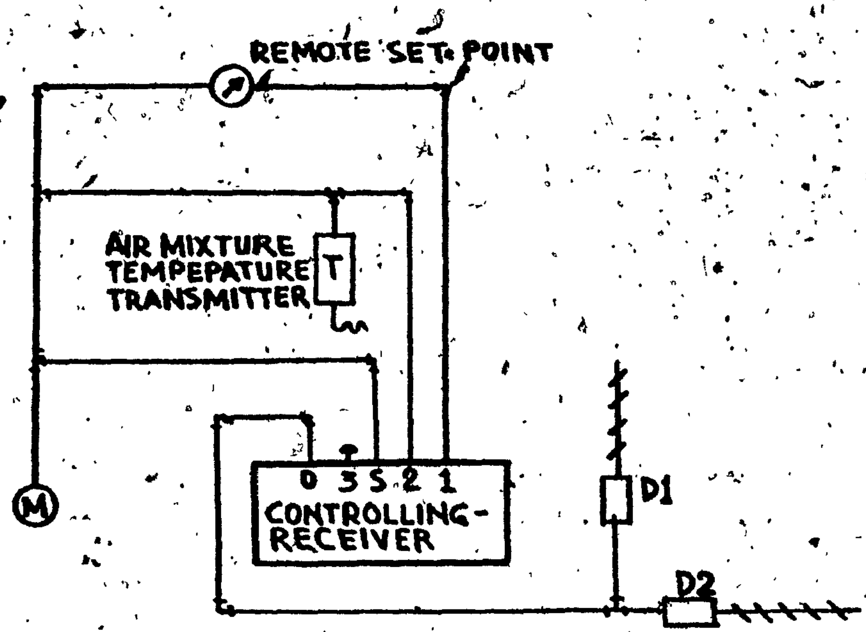

FIG. 53.-- CONTROLLING-RECEIVER WITH ONE INPUT AND REMOTE SET POINT ADJUSTMENT

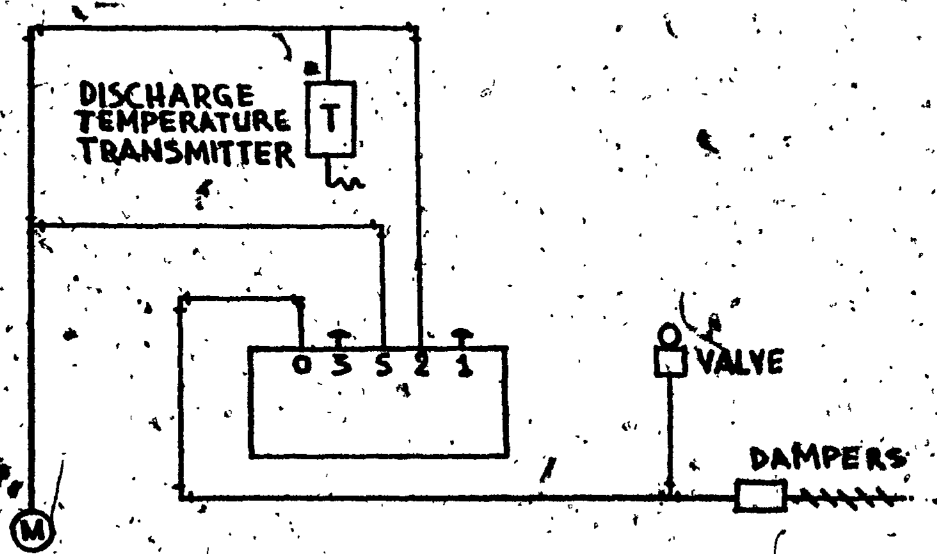

FIG. 54.-- CONTROLLING-RECEIVER WITH ONE INPUT AND INTEGRAL SET POINT ADJUSTMENT

- Operating as a heat exchanger reset control. As shown in Fig. 55, a controller with dual input and remote set point is used. "Master" control is provided by MT, which is an outdoor air temperature transmitter. The signal from this transmitter goes to the comparator (input 3) causing a change in the set point which then is compared to input signal from "submaster" transmitter SMT sensing the hot water supply temperature. The output of the controller will close or open the heat exchanger valve.

- Operating as reheat control for an air distribution system. In Fig. 56, a controller with dual input and integral set point is used to control the reheat valve. The room temperature transmitter MT acts as "master" control, while the controlled variable is the reheat temperature, sensed by SMT.

The air consumption of these instruments, since they are continuous flow devices, is higher than that of the conventional pneumatic devices, being (at maximum) 90 cim for the remote set point models and 100 cim for the integral set point models. Moreover, the air consumption of the transmitters and remote gradual switches must be included to arrive at a total system air consumption figure. To prevent

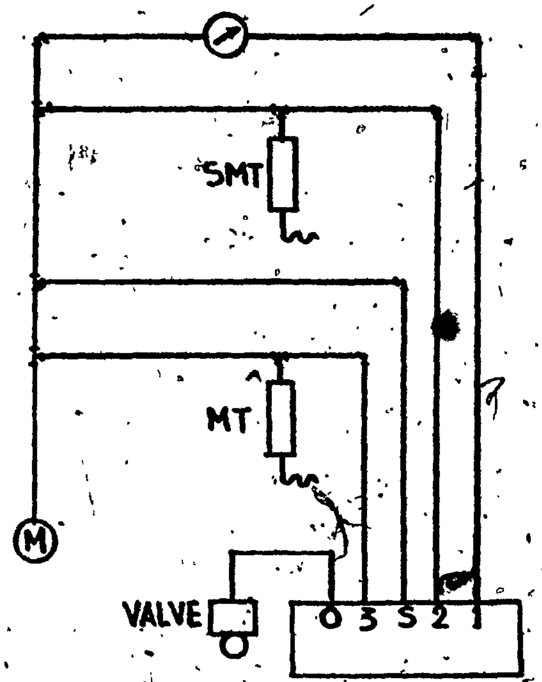

FIG. 55.-- CONTROLLING-RECEIVER WITH DUAL INPUT AND REMOTE SET POINT

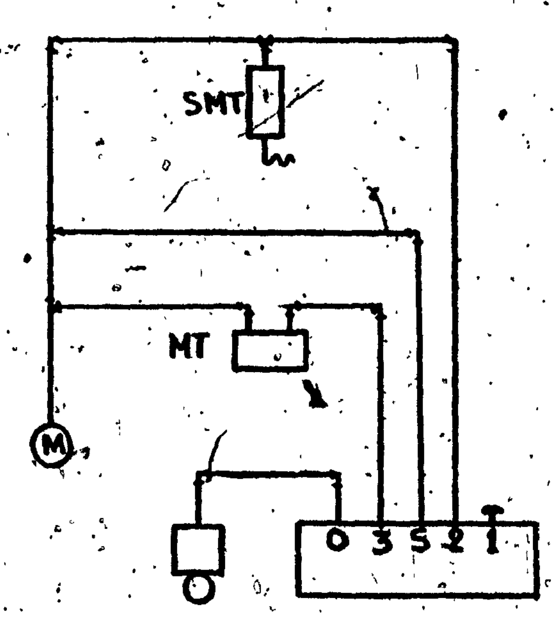

FIG. 56.-- CONTROLLING-RECEIVER WITH DUAL INPUT AND INTEGRAL SET POINT

internal supply air fluctuations, which would result in a change of the set point or loss of control, initial 20 psi main air is reduced internally to 9 psi.

3.2.3 Terminal Air Distribution Unit (Ref. No.16)

The great advantage in this fluidic control unit (Fig. 57) is that it does not require any control air supply. The control unit is self-powered from the air conditioning air stream. The manufacturer claims lower first cost versus all other terminal unit systems, while temperature control at ±3/4F is attainable.

The system achieves variable volume control at the terminal unit by switching the main supply air stream (Fig. 58) from room supply to room by-pass (return) to the central air handling unit which, thus, operates at constant volume rate. Thus, complex and expensive controls usually required with the conventional variable volume central units are eliminated. The switching occurs at a modulated rate depending upon the heating or cooling demands of the space. Basically the system works like this: there are two fluidic switches (bistable amplifiers), one a "Y" shaped duct at A and one a much smaller device at B. The main air stream flows through fluidic switch A, while there is a bleed-off of air from the

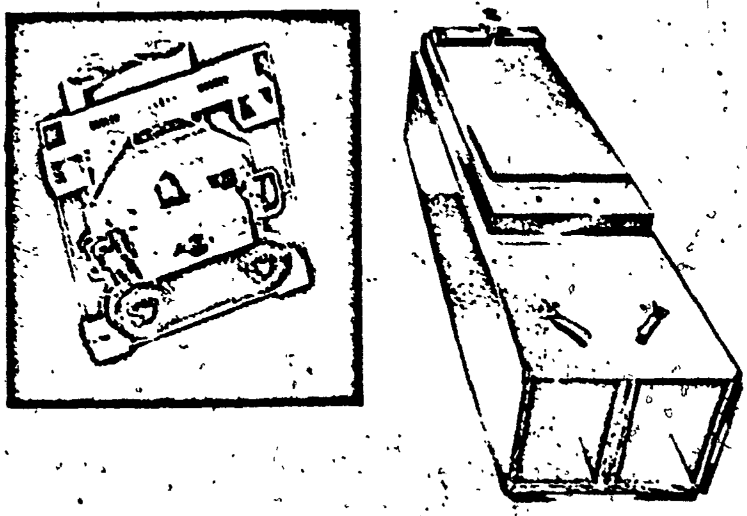

FIG. 57.--TERMINAL AIR DISTRIBUTION UNIT AND THERMOSTAT (PHOTO)

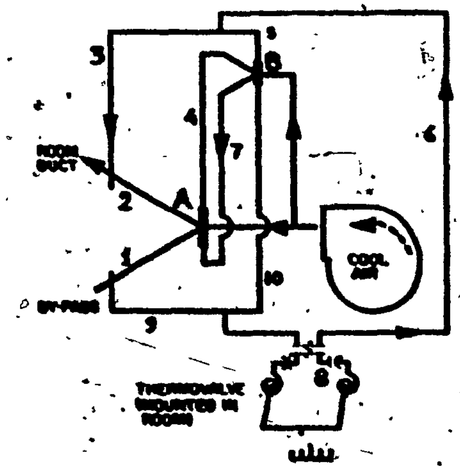

FIG. 58.--UNIT (FIG. 57) CONTROL SCHEMATIC-COOLING

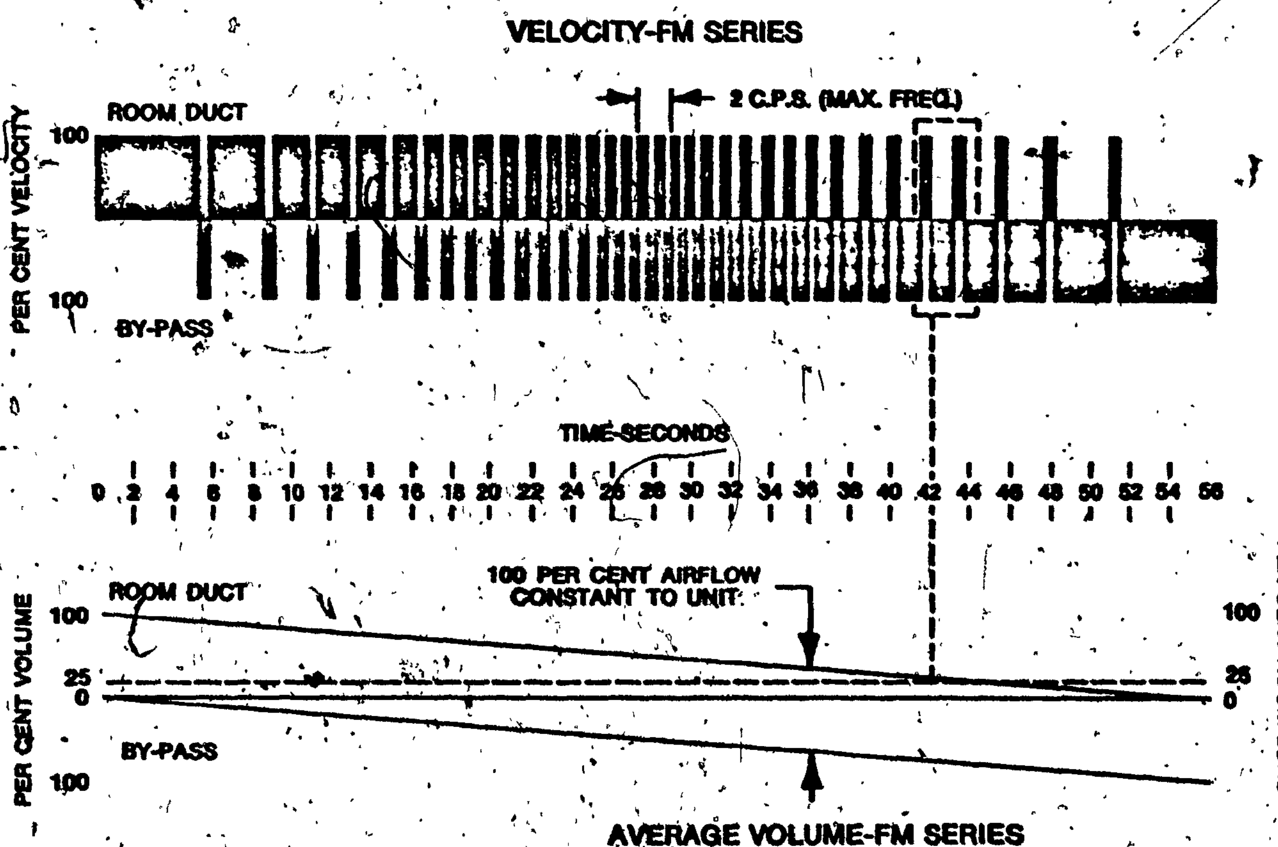

FIG. 58(a).--TIME VS. VELOCITY & VOLUME FOR UNIT IN FIG. 57.

main air stream to fluidic switch B. Assume that the main air stream is first flowing through leg (1). This results in a negative pressure in the signal tube (9)-(10). This negative signal, assuming that the thermostat is not yet connected to the circuit, causes the air stream which is bled off from the fan to flow through leg (7) at B, causing the main air stream at A to switch to leg (2). Now there is negative pressure in signal tube (3)-(5) which causes the main stream to switch back to leg (1). In this situation, the main air stream would switch alternatively between legs (1) and (2), allowing equal air flow. However, if we add the thermostat which consists of a bimetal blade that causes opening and closing of aspirating ports, the situation will change. Assume that main air flows initially through (2). Air is drawn from the signal tube (3) which draws its air from the thermostat (8) through tube (6). Because the port of the thermostat is fully open (8), the fluidic switch B cannot switch the main stream to the bypass because of no draw at tube (5). As the room becomes satisfied, the port at (8) will begin to close and fluidic switch A will move the main airstream back and forth from room duct to bypass. Thus the unit is called Frequency Modulation Terminal Unit and achieves control of room temperature by varying the length of time (Fig. 58(a)) it lets the supply air from the central unit flow through the supply leg of the "Y" duct and through the bypass side. When maximum heating or cooling is called for, all air flows through the supply side of the "Y". If the demand is completely satisfied, it all flows through the return side. When, however, there is an intermediate demand for a certain rate of heating or cooling effect, the main air stream switches back and forth at a rate and total time for cycle depended upon the rate of supply of heating or cooling effect needed to satisfy the demand.

When the frequency modulation unit is applied to a heating and cooling air system, a bimetal actuated changeover valve is added to the basic unit (Fig. 59) with its bimetal projecting into the main air stream. Thus, when the unit is supplied with warm air, and the thermostat calls for full heat, the bimetal senses this change and reverses operation of the thermostat so that warm air is supplied to the room (as required), and not to the bypass.

Because there are no moving parts, motors, damper blades to wear and to generate noise, the unit is quieter than unit ventilators and most other terminal units. Also, the basic venturi design of the terminal unit tends to break up central system sound waves as supply air enters the unit. Tests conducted in a certified laboratory of the Air Diffuser Council have shown this unit to operate at NC levels between 34-37, proof of quiet operation for the occupants of the space.

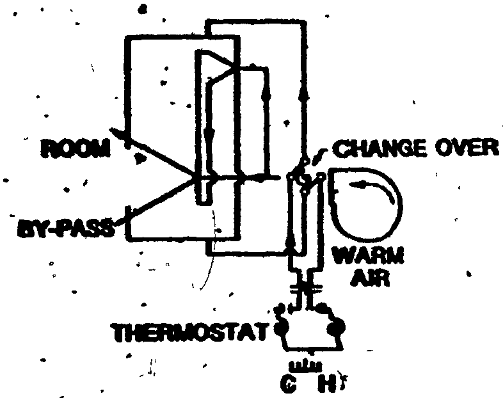

FIG. 59.-- UNIT (FIG.57) CONTROL SCHEMATIC - HEATING & COOLING

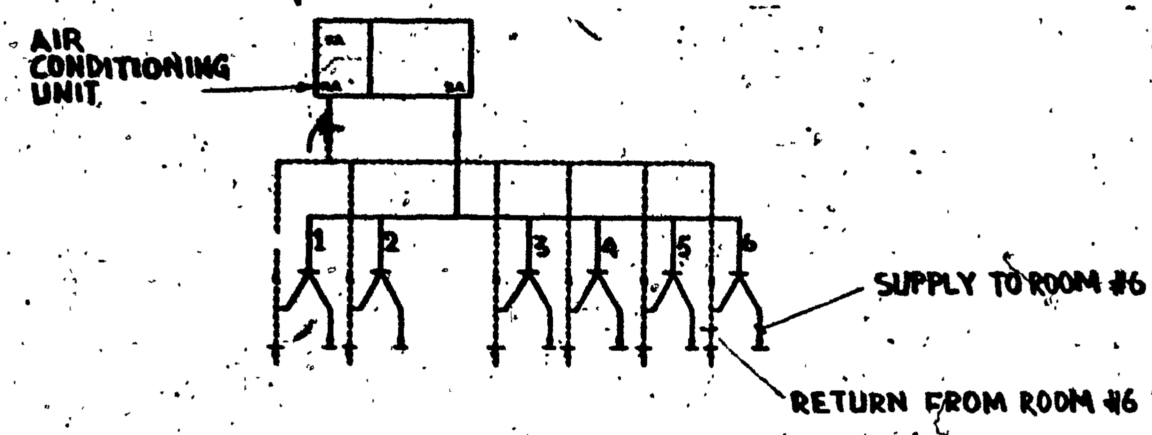

FIG. 60.-- TYPICAL ARRANGEMENT WITH SIX UNITS

In terms of air distribution pattern in the conditioned space, the unit is advantageous over the conventional variable air volume units because it can maintain those patterns very closely, due to the fact that during supply cycles air is supplied at constant volume.

Numerous variable air volume system arrangements can be accomplished using the unit described in this section in its cooling, heating or automatic changeover version. A typical arrangement is shown in Fig. 60, where six terminal units have been connected to the main supply duct (solid line). The bypass lines have been connected to the room return ducts (dotted lines).

3.2.4 <u>High Velocity Variable Volume Terminal</u> (Ref. No.17)

This unit is also used to supply variable volume air to air conditioned zone areas. It is also a self-contained, self-powered unit consisting of the following parts:

- High velocity attenuator box (Figs. 61(a) & 61(b)) internally lined with accoustical insulation. This box encases the whole assembly.
- Fluidic control package consisting of an integrated fluidic circuit amplifier (Fig.62(a)), a fluidic

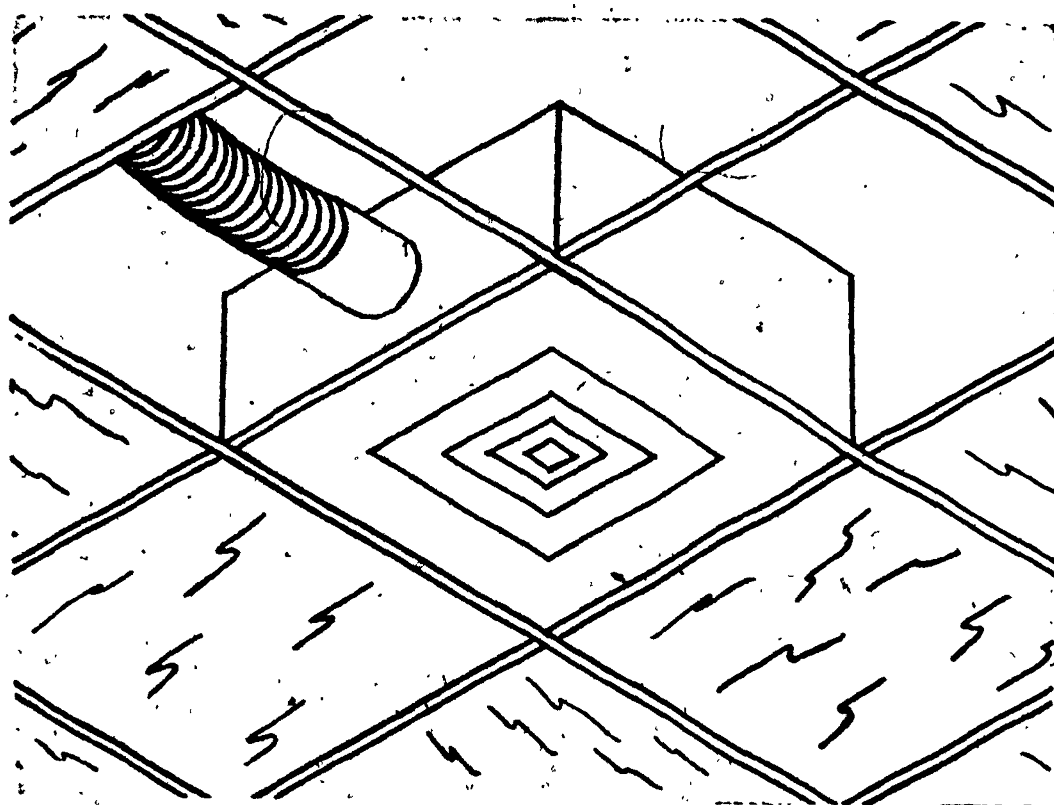

FIG.61(a).-- HIGH VELOCITY VARIABLE VOLUME TERMINAL-SQUARE DIFFUSER

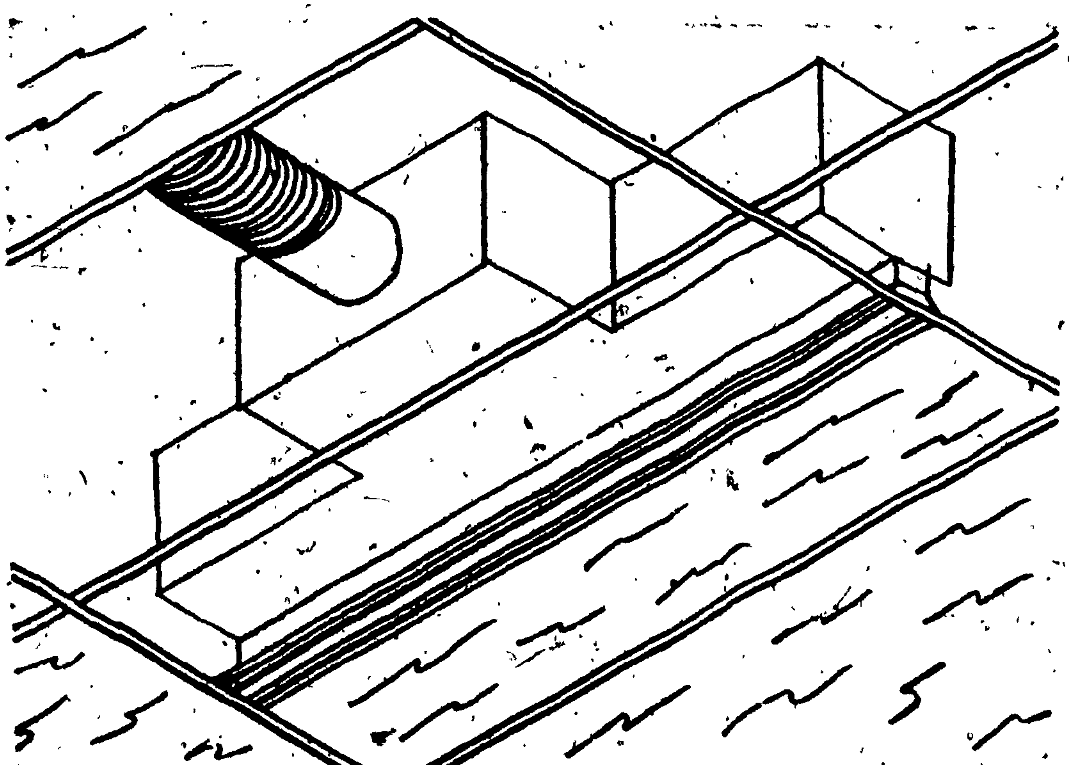

FIG.61(b).--HIGH VELOCITY VARIABLE VOLUME TERMINAL-LINEAR DIFFUSER

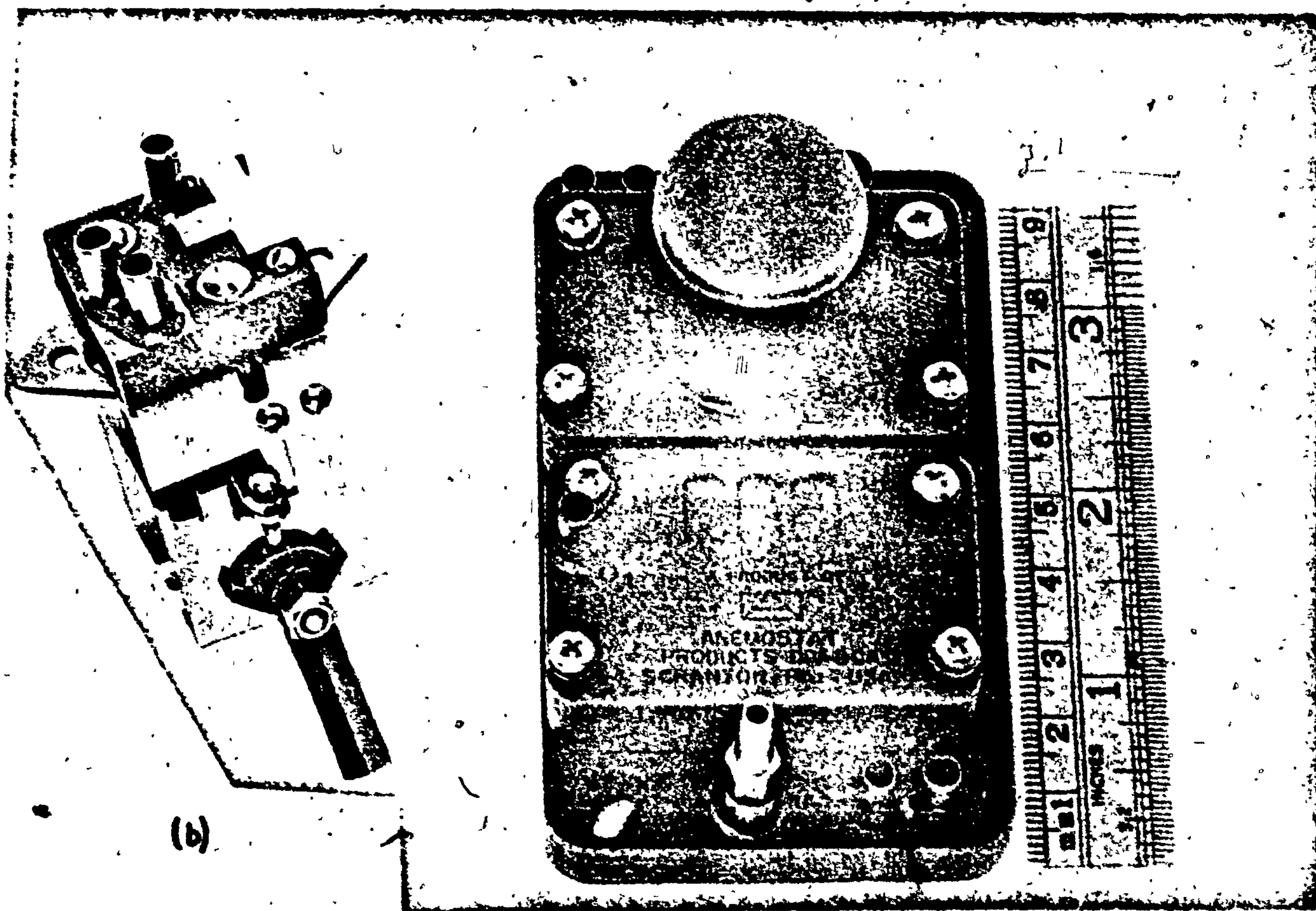

FIG. 62.-- FLUIDIC CONTROL BLOCK (a) AND FLUIDIC THERMOSTAT (b) FOR UNIT IN FIG. 61 (PHOTO)

adjustable thermostat (Fig. 62(b)) variable volume valve, capacity reset and connection to sub-master terminals.

- Square or linear air diffuser.

<u>Operating Principle of the Terminal</u> (Fig. 63): The terminal controls zone temperature by varying the conditioned air volume to the zone. Design maximum and minimum volumes are factory calibrated and set to meet space cooling requirements. These limits can be reset in the field when necessary.

The fluidic circuit consists of a wall attachment amplifier assembly etched on photosensitive glass plates permanently fused into a single ceramic element. The circuit is powered from the unit inlet duct (3/4 in. WG to 6 in. WG required). It senses a volume indicating signal from the terminal and compares it against the factory set volume signal. On a call for full cooling, from the thermostat the fluidic circuit sends an amplified signal to the variable volume damper which positions itself so as to pass design volume, regardless of inlet static pressure. At all times during operation, room air is induced through an aspirator across the terminal integral thermostat (a remote wall thermostat could also be used if necessary).

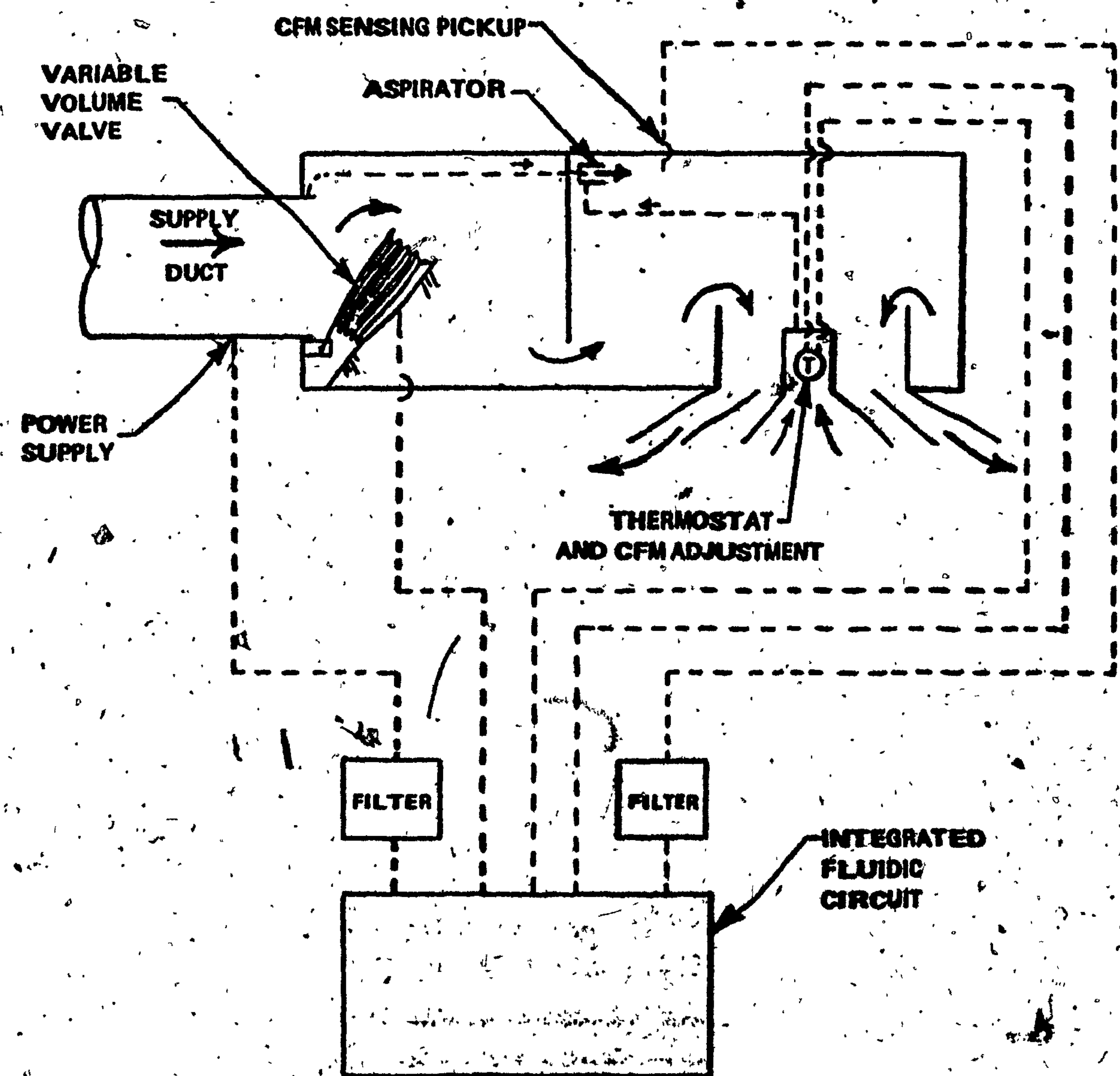

FIG. 63.-- CONTROL SCHEMATIC FOR UNIT IN FIG. 61.

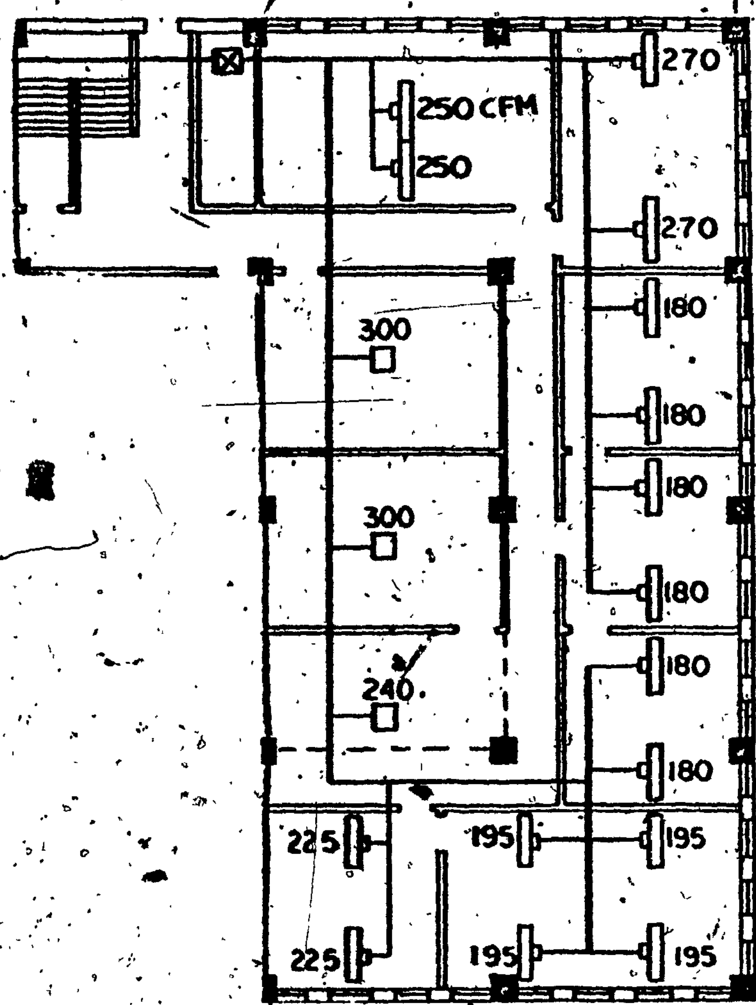

FIG. 64.-- TYPICAL ARRANGEMENT WITH 3 SQUARE & 16 LINEAR DIFFUSER UNITS.

<u>System Arrangements</u>: Terminals are of various sizes and can operate on a wide range of zone sizes. When, however, the design of a zone exceeds the maximum air quantity for a terminal, up to four sub-master terminals can be added on; each sub-master terminal is identical in construction and performance to the master terminal, but does not include the fluidic control circuit and the thermostat; instead, the master terminal provides the control signals for the sub-master terminal.

The units can be used in similar air conditioning system arrangements as the terminal unit described earlier. A typical layout is shown in Fig. 64, where three square and 16 linear diffuser units are connected on the supply duct.

3.2.5 <u>Flow Diverting Valve</u> (Ref. No.4, pg.487-488)

The flow diverting valve is one of the simplest industrial applications of fluidic devices in diverting flows of either very hot or corrosive fluids by using a gas to switch the stream of liquid flowing through a turbulent reattachment amplifier. This valve can also be used in water heating systems as shown in Fig. 65, where the hot water itself is used to divert its flow(self-powered control) without the use of any secondary gas. The response of such systems is

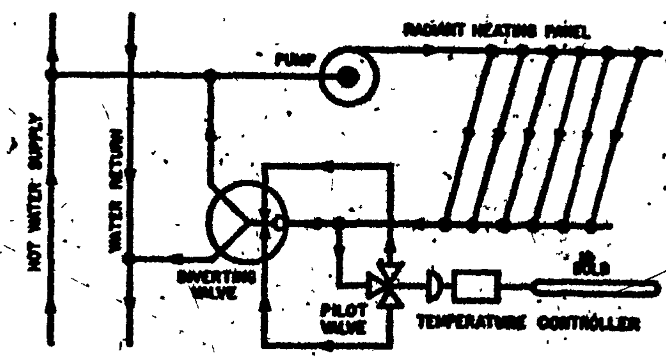

FIG.65.-- RADIANT HEAT CONTROL

very fast, e.g. a 4 in. valve will switch from full flow to one direction to full flow in the other within 0.02 sec. This principle is similar to the Frequency Modulation Terminal Unit principle and extends the diverting techniques to both air and water flows in air conditioning systems.

CHAPTER 4

CONCLUSIONS ON PRESENT APPLICATIONS AND PROSPECTS FOR NEW DEVELOPMENTS

4.1 Conclusions

It appears that generally, fluidic controls are not threatening at present the conventional types of control (electric, electronic and pneumatic) for air conditioning applications. The reasons could be summarized as follows:

a. There are not enough qualified people in the air conditioning field that understand the principles of fluidics.

b. For the most part, fluidic amplifiers do not do anything that is new, and thus compete with long-established control devices. Some controls manufacturers, therefore, have been understandably slow to develop or promote a new family of relatively unknown devices to replace their present lines of well understood characteristics.

c. Installators and owners of air conditioning systems are sceptical in deciding on the investment on training mechanics and operators in the handling of the new fluidic technology, though they may probably be convinced on the economic merits in the installation and operation of a particular system or category of systems.

d. Most of the advantages resulting from a major characteristic of the fluidic controls, the absence of moving parts, are not so important for conventional air conditioning applications. Temperatures, objectionable vibrations, mechanical shocks, magnetic fields or nuclear radiation are usually not very extreme. The relatively quiet operation of the fluidic controls, resulting also from the absence of moving parts, is not of any serious importance for the conventional air conditioning systems where the noise problem lies with the fans, the undersized ducts, the dampers, the boilers and the refrigeration machinery.

e. Accuracy of control and ability of obtaining complex logic functions by using fluidics are again not a major consideration for most air conditioning systems which generally require simple control functions and allow wide fluctuations for their controlled variables.

f. Production difficulties which exist with all fluidic devices, due to increased requirements for accuracy and treatment of surfaces, dimensions to be maintained exactly, uniform couplings, high degree of quality control and repeatability of assembly, materials and workmanship. The problems have not been all solved, although progress has been made in many cases.

Owing basically to these reasons, only a few devices have been developed for air conditioning applications. These devices however, cover all basic parts of an air conditioning control (sensing, comparing, controlling), with emphasis on applications where advantage of the moving conditioned air could be taken for powering all control operations. Thus the two package terminal units can be hooked up to the ductwork of the air conditioning system without any control power connections; the units will power their own control. Many installations are reported by the manufacturers, particularly of the frequency modulation terminal unit which uses even the main air stream as a bistable amplifier. All control piping or wiring beyond the central air conditioning plant is eliminated, with the exception of the connections between the terminal unit and the room thermostat. Even those connections could be eliminated, however, in the case of the Anemostat terminal unit where the thermostat can be incorporated into the unit package.

In addition to the reasons mentioned in paragraphs a. to f. above, the air conditioning design engineer faces another obstacle in specifying fluidic controls when he is designing a system: he is forced to consult with more than one controls manufacturer, since no fluidic manufacturer covers the entire area of air conditioning systems. This exercise is time consuming and could result in coordination difficulties at the time of installation. However, this comment does not hold for the case of the two terminal units which can be specified regardless of the type of controls used in the rest of the air conditioning system.

4.2 Prospects for New Developments and Applications

Special air conditioning applications could make use of the advantages of fluidic controls mentioned in d. and e. of Section 4.1 above, for instance:

a. Air conditioning systems in transportation (spacecrafts, planes, ships, buses, etc.) are subject to severe working conditions and fluidic environmental controls would possibly be the answer, for example, in spacecrafts where already life support systems are making use of fluidic control principles.

b. Air conditioning systems for computer rooms, laboratories and other critical applications, where accuracy and sophistication of controls are of great importance, fluidics could replace electronics or other conventional controls, in consideration of lower costs and/or compactness of control equipment and systems.

In terms of instrument developments, the measurement/sensing area presents some encouraging prospects. Two possible applications could be the following:

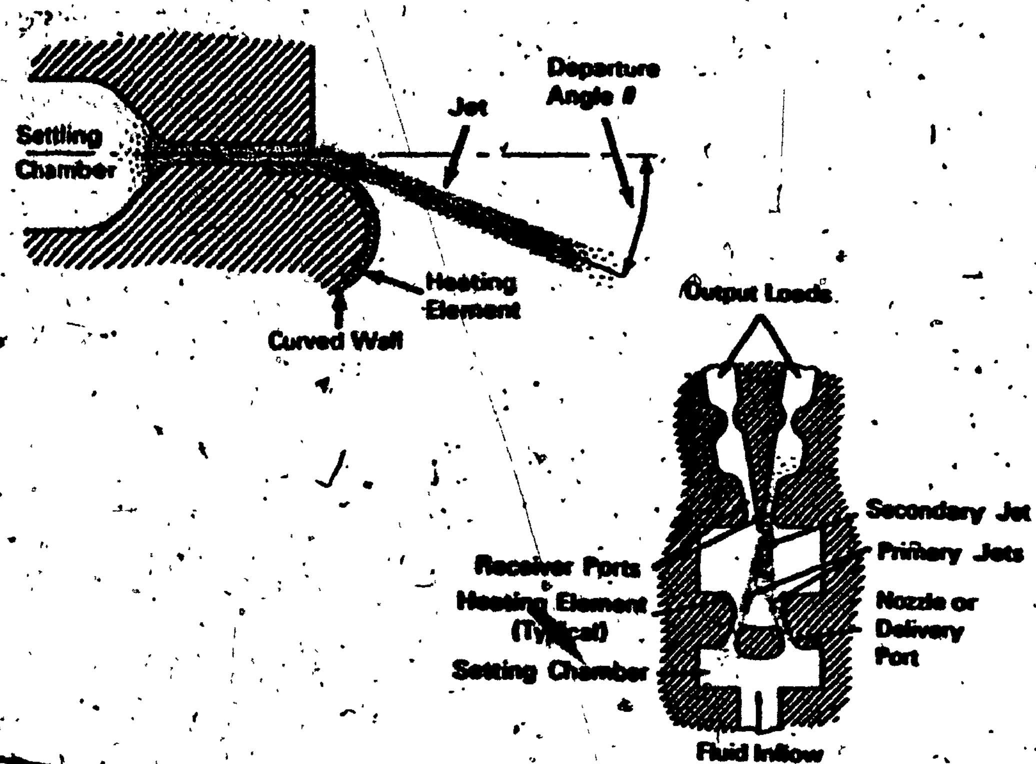

FIG. 66.--TEMPERATURE-CONTROLLED FLUIDIC DEVICE

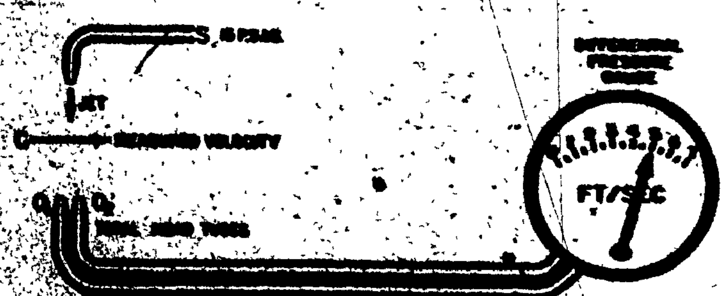

FIG. 67.--SINGLE AXIS FLUID JET ANEMOMETER (LOW VELOCITIES)

a. Temperature Sensing (Thermostats)

A concept presented by NASA (Fig. 66) suggests using the temperature difference to deflect the jet in a wall attachment device which then could be used as a thermostat if the heating element location in relation to the jet could be made adjustable to provide for set point adjustment.

b. Air Flow Measuring (System Balancing)

The anemoneter for measuring low velocities (Fig. 67) developed by National Research Council of Canada, could be used at the stage of balancing the air distribution system, when many reliable and quick air flow measurements in air outlets are required.

Finally, it could be noted that the area of fluidic controls where the main air conditioning stream is used as a control power source, could develop more instruments of the fluidic-pneumatic type, which eventually would overcome most of the obstacles preventing the extensive use of fluidics in air conditioning system control.

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