# Dr. Norbert Cheung's Series
# in
# Electrical Engineering

## Level 4 Topic no: 06

# Direct Digital Control

**Contents**



**Reference:**

"Direct Digital Control of Building Systems," H Michael Newman, John Wiley & Sons. Chapters 1 & 8.

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## 1. Introduction

Distributed processing is clearly the wave of the future in computerized heating, ventilating, and air conditioning (HVAC) control, primarily because it offers the promise of both improved reliability and accuracy of regulation.

On what areas of theory and practice does the existence of DDC depend? Here are some of them: automatic feedback control theory, electronics, mathematics, solid-state physics—particularly semiconductors, sensors, actuators, data communications, and, of course, computer technology in all its facets. Obviously not all of these areas are independent of each other and that is exactly the point. Major advances in technology usually involve the interdependence of many disciplines and advances in one area often spur advances in other areas. DDC applied to building automation and control is a perfect example!

## 2. A Case Study

In this chapter we will design a complete direct digital control system using a methodology that both simplifies the design task and results in high quality documentation, an aspect of DDC jobs that has often been inadequate. In fact, the lack of documentation standards has been one of the main impediments to the universal acceptance of DDC as the control technique of choice for building HVAC systems.

The technique we will use was first proposed by my colleague Clay G. Nesler, currently Manager of Advanced Systems Development at Johnson Controls, in conjunction with the ASHRAE Professional Development Seminar on DDC that we have been teaching together since the spring of 1990. We have been trying jointly to refine and streamline it since its introduction.

For our case study we will design the controls for a single-zone, constant-volume air handler. As we work through the example, it should become clear how straightforward it would be to design and document a more complicated system, perhaps involving humidity control and variable air volume. The components of our "top-down" design method are shown schematically in Fig. 8.1.

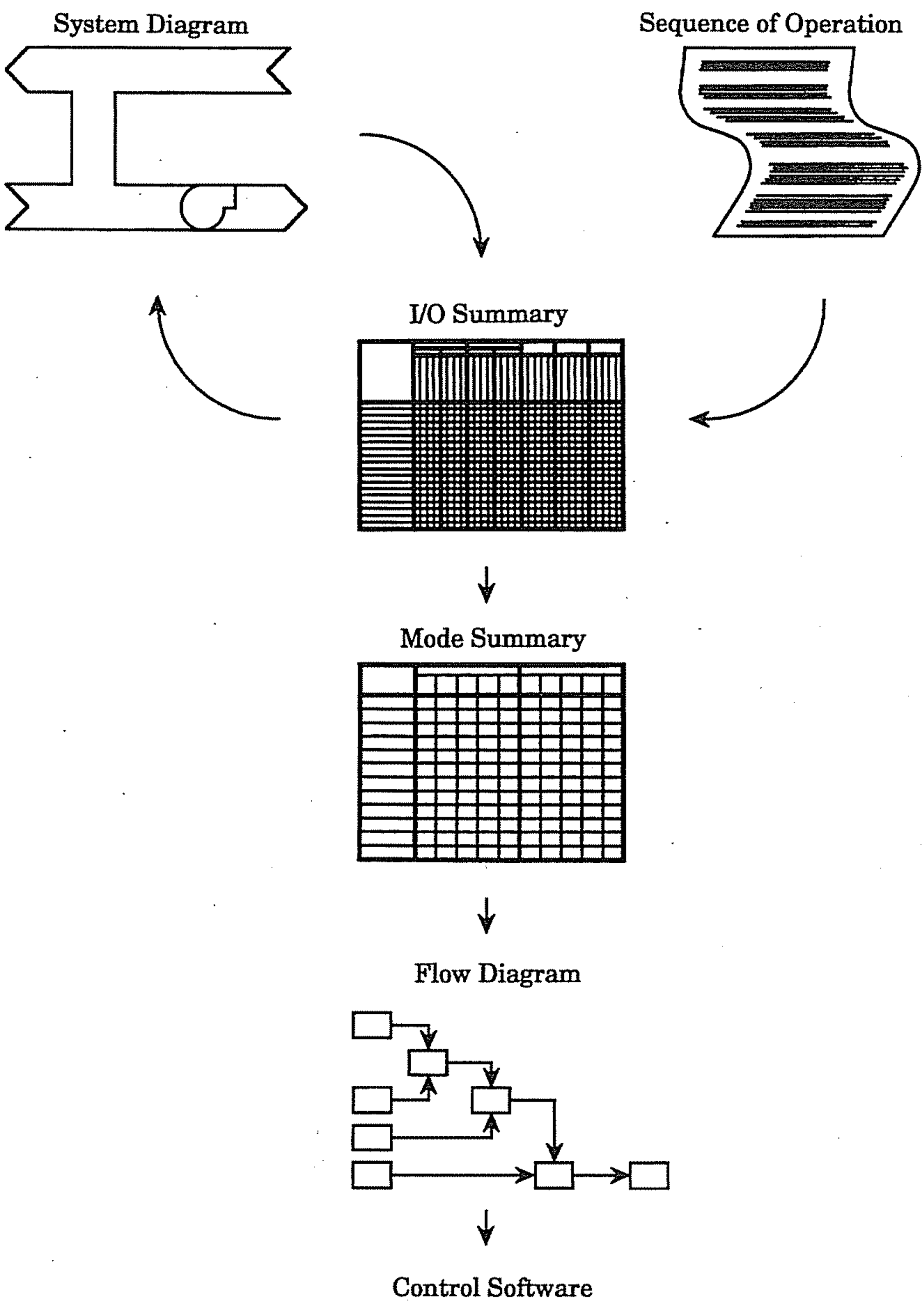


***FIGURE 8.1.*** The components of the top-down DDC design methodology described in the text. The technique both simplifies the design task and produces documentation suitable for both hardware and software implementation.

## 8.1 SYSTEM DIAGRAM

For the purposes of this example, let's assume that the HVAC engineer has already designed the air handler in terms of laying out the ductwork, appropriately sizing the fan and heating and cooling coils, and selecting the proper dampers, damper actuators, and motor contactor. From this design we can construct a system diagram as shown in Fig. 8.2A. The designations DA and VA stand for damper and valve actuator, respectively, C is for electrical contactor, and H/C and C/C represent the heating and cooling coils. We will return to the diagram to add sensors and interface components after we study the sequence of operation and begin to construct the I/O

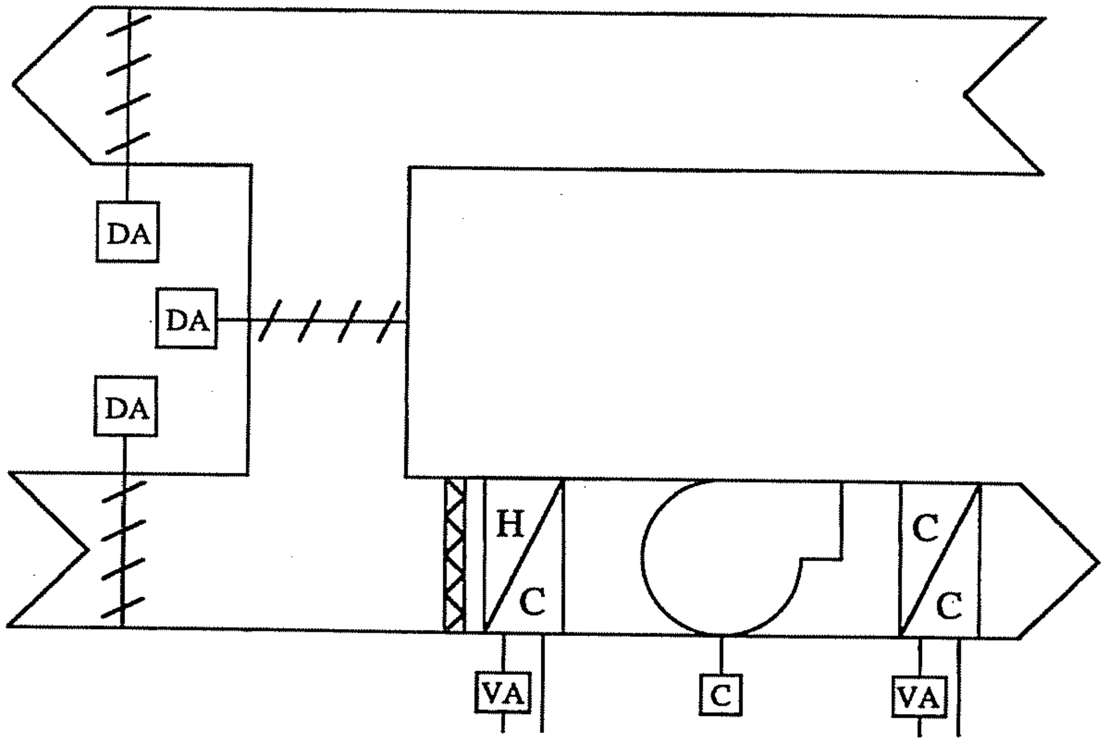


***FIGURE 8.2A.*** A schematic of the basic single-zone, constant-volume air handler used in our example.

| | |
|---|---|
| DA | Damper Actuator |
| VA | Valve Actuator |
| C | Electrical Contactor |
| H/C | Heating Coil |
| C/C | Cooling Coil |

After that, we should add appropriate sensors and actuators for DCC control. The modified diagram is shown in Fig 8.2B in the next page.

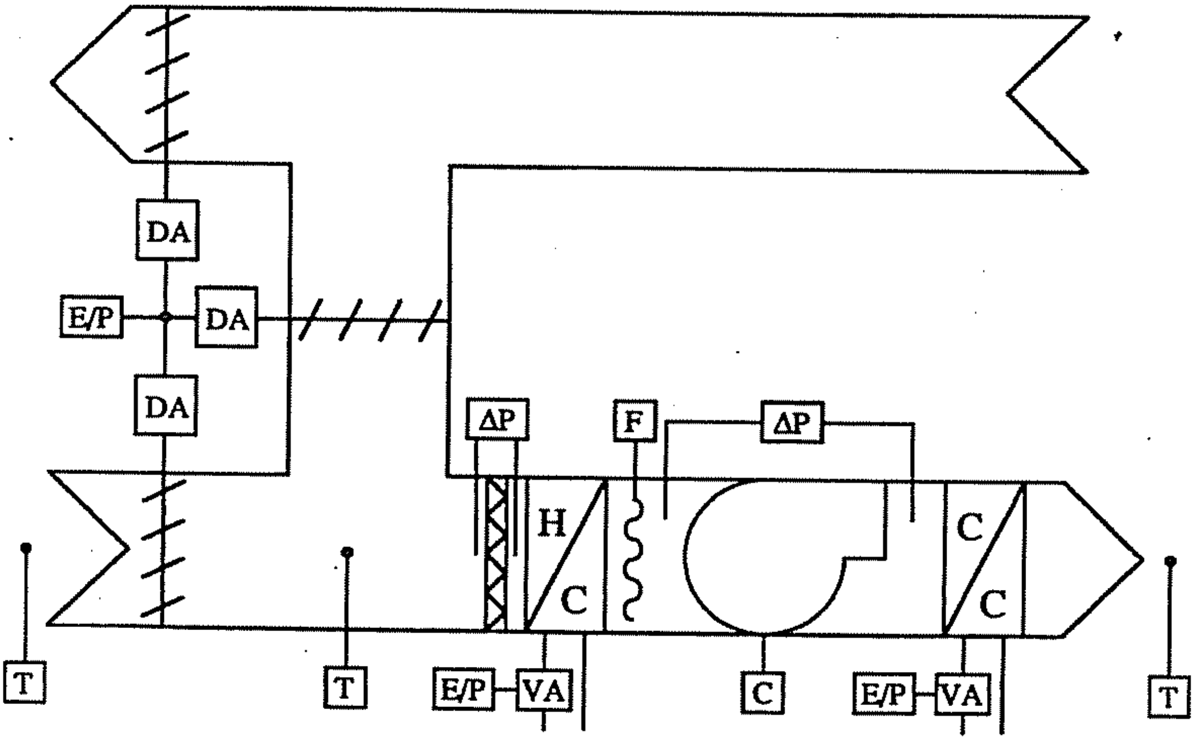


***FIGURE 8.2B.*** The same air handler with the addition of the sensors and actuators needed for DDC control.

| | |
|---|---|
| E/P | Electrical to Pneumatic Transducer (Analogue Output) |
| T | Temperature Probe (RTD – resistor temperature detector) |
| ΔP | Pressure probe (measure pressure difference) |
| F | Freeze stat (measure freezing point) |

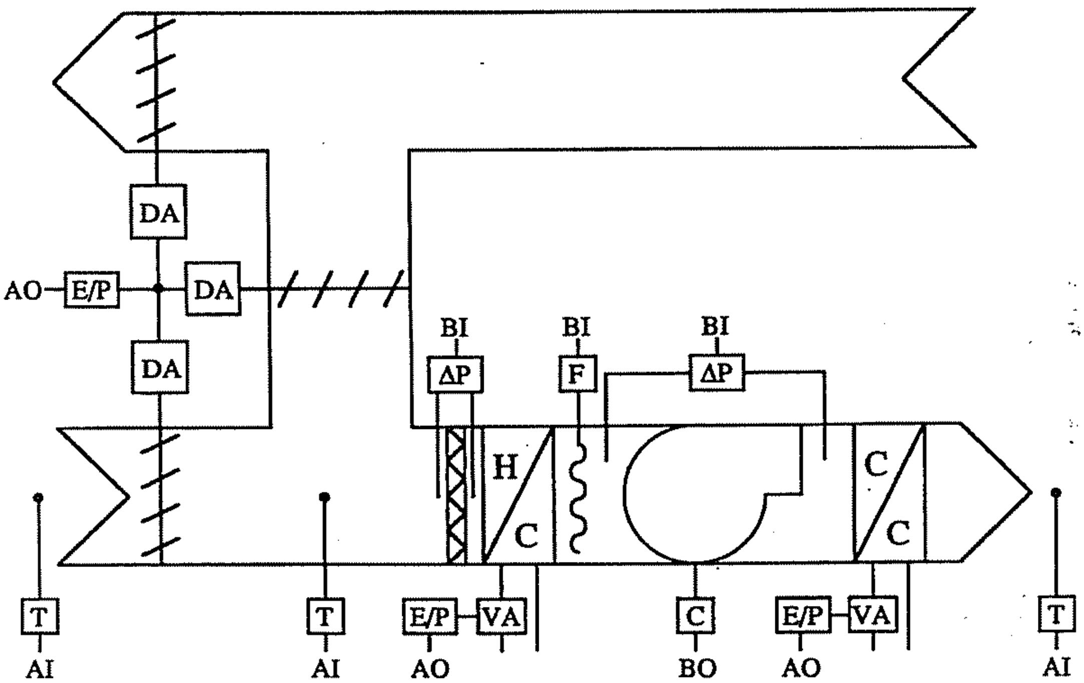


***FIGURE 8.2C.*** The final installation showing the connections to the DDC input and output circuits.

## *SEQUENCE OF OPERATION*

The sequence of operation verbally describes how the air handler is to be operated and controlled. It contains detailed descriptions of each mode of operation, control strategy, and alarm condition, including setpoints, limit values, temperature setback schedules, and any other relevant operating parameters.

1. *Occupied Mode.* When the date and time fall within the specified schedule, the system shall enter the occupied mode. The supply fan shall be turned on; the normally open heating and normally closed cooling valves and air dampers shall be controlled by a sequenced proportional plus integral (PI) controller to maintain the room air temperature setpoint of 70°F.
2. *Unoccupied Mode.* When the date and time fall outside of the specified schedule and the room air temperature exceeds 55°F (or 60°F if the room air temperature has previously been less than 55°F), the system shall enter the unoccupied mode. The supply fan shall be turned off; the heating valve shall be set to fully open and the cooling valve and outside air dampers shall be set to fully closed.
3. *Setback Mode.* When the date and time fall outside of the specified schedule and the room air temperature is less than or equal to 55°F, the system shall enter setback mode. The supply fan shall be turned on; the heating valve shall be set to fully open and the cooling valve and outside air dampers shall be set to fully closed. Once in this mode, the system shall not leave it until the room air temperature exceeds 60°F.
4. *Fan Alarm Mode.* If the supply fan has been commanded to start and the supply fan status, after a delay of 30 s, indicates that the fan is not operating, the system shall enter fan alarm mode (ON). A stop command shall be sent to the supply fan; the heating valve shall be set to fully open and the cooling valve and outside air dampers shall be set to fully closed.

   If the supply fan has been commanded to stop and the supply fan status, after a delay of 30 s, indicates that the fan is continuing to run, the system shall enter fan alarm mode (OFF). A stop command shall be sent to the supply fan and the heating valve, cooling valve, and outside air dampers shall continue to be controlled normally as in the occupied mode.

5. *Room Temperature Control.* During the occupied mode, room temperature will be maintained by a PI control algorithm which will sequentially modulate the heating valve, outside and return air dampers, and cooling valve. As the PI controller output goes from 0 to 33%, the heating valve shall go from fully open to fully closed. As the PI controller output ranges from 34 to 66%, the outside air dampers shall go from a minimum position of 20% to fully open. As the PI controller output goes from 67 to 100%, the cooling valve shall go from fully closed to fully open.
6. *Dry Bulb Economizer Control.* When the system is in occupied mode and the outside air temperature rises above 65°F, the dry bulb economizer setpoint, the outside air damper will be set to a constant position of 20%, subject only to mixed air low control. Dry bulb economizer control shall have priority over room temperature control.
7. *Mixed Air Low Limit Control.* When the system is in the occupied mode, a proportional (P) control algorithm shall modulate the outside air dampers from 100 to 0% as the mixed air temperature drops from 40 to 35°F. The output of the controller shall be passed to a low select control block, which will adjust the outside air dampers to the lesser of the positions called for by this controller and the room temperature local loop controller. Mixed air low-limit control shall have priority over both room temperature and dry bulb economizer control.
8. *Fan Alarm.* Whenever the system is in fan alarm mode, the fan alarm shall be initiated.
9. *Filter Alarm.* If the differential pressure across the air filter should exceed 0.2 in. WC, the filter alarm shall be initiated.
10. *Freeze Alarm.* If the heating coil discharge temperature should fall below 35°F, the freezestat contacts shall close and the freeze alarm shall be initiated.

*I/O SUMMARY*

Table 8.1 shows the completed I/O summary. Across the top are column labels that divide the table into five main sections: inputs, outputs, modes, strategies, and alarms. The modes, strategies, and alarms can be filled in just by going down through the sequence of operation and recording the paragraph titles. The sequence is divided into 10 paragraphs and there are the same number of labeled columns in the right half of the table. The list of inputs and outputs is compiled and entered in the rows of the table by going through each paragraph in turn and figuring out what sensors and actuators are needed to actually carry out each of the specified functions.

**TABLE 8.1 I/O Summary**

| | Input Type | | | Output Type | | Modes of Operation | | | | | Control Strategies | | | Alarms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analog | Binary | | Analog | Binary | | | | | | | | | | | |
| Inputs/Outputs | RTD | Freezestat | ΔP Switch | E/P Transducer | Start/Stop Contactor | Occupied | Unoccupied | Setback | Fan Alarm | | Room Temperature (PI) | Dry Bulb Economizer | Mixed Air Low Limit (P) | Fan | Filter | Freeze |
| Supply Fan | | | | | X | X | X | X | X | | | | | | | |
| Room Air Temperature | X | | | | | X | X | X | | X | | | | | | |
| Heating Valve | | | | X | | X | X | X | X | | X | | | | | |
| Cooling Valve | | | | X | | X | X | X | X | | X | | | | | |
| Dampers | | | | X | | X | X | X | X | | X | X | X | | | |
| Outside Air Temperature | X | | | | | | | | X | | | | | | | |
| Mixed Air Temperature | X | | | | | | | | | X | | | | | | |
| Fan Status | | | X | | | | | | X | | | | | X | | |
| Filter Status | | | X | | | | | | X | | | | | | X | |
| Freeze Lockout | | | X | | | | | | | X | | | | | | X |

**TABLE 8.2 Mode Summary**

| | Input Condition | | | | Output Action | | | |
|---|---|---|---|---|---|---|---|---|
| Mode of Operation | Schedule | Room Air Temp. | Supply Fan S/S | Supply Fan Status | Supply Fan | Heating Valve | Cooling Valve | Outdoor Air Dampers |
| Occupied | Occupied | | | | On | Normal | Normal | Normal |
| Unoccupied | Unoccupied | >55°F | | | Off | Fully open | Fully closed | Fully closed |
| Setback | Unoccupied | ≤55°F | | | On | Fully open | Fully closed | Fully closed |
| Fan alarm (ON) | | | On | Off | Off | Fully open | Fully closed | Fully closed |
| Fan alarm (OFF) | | | Off | On | Off | Normal | Normal | Normal |

*MODE SUMMARY*

Now let's build a mode summary table. See Table 8.2. Across the top are column labels for each input condition and output action. In the first column we list each of the modes of operation. Note that the fan alarm mode requires two rows in the table

since we want to take a different action if we are trying to start the fan and the status feedback tells us that the fan failed to start as opposed to the case where we are trying to stop the fan and the feedback tells us that the fan is continuing to run. The value of this table is that it summarizes very compactly how each mode is entered and what is then supposed to happen.

*FLOW DIAGRAM*

The next to last step in the design process is to put together a flow diagram. A flow diagram is a graphical, schematic representation of the entire control system that depicts each sensor and output device and the logic, to be implemented in software in the DDC, that interconnects them. See Fig. 8.3.

Here are the general rules for creating the diagram. Start by arranging the inputs on the left and the outputs on the right. Analog logic signals are shown using solid lines while binary signals are dashed lines. In any given logic chain, the priority of the function blocks increases to the right. Thus, in the logic chain that determines the signal to be sent to the damper actuators, the override logic takes precedence over the mixed air low limit logic, which in turn takes precedence over the economizer switchover, which supercedes the minimum ventilation logic, which is in series with the output of the PI controller.

*CONTROL SOFTWARE*

The final step in the process is to develop the actual control software that will execute in the DDC. The configuration method will depend on the equipment to be used as has been described in Chapter 4. Now is the time to go back to the system diagram and add the AI, BI, AO, and BO blocks that show the actual connection to the DDC panel. See Fig. 8.2C. In a real job, these blocks would indicate the wiring termination to be used, e.g., DDC Panel 1, AI-2, and possibly the symbolic variable name to be used in the software to refer to the input or output such as AHU1.MAT.

If the system to be programmed happens to use graphical programming, the flow diagram can essentially be used "as is," assuming you have had the foresight to use the same logic symbols as employed by the DDC vendor's graphical programming language. If the DDC is to be programmed using a text-based language, having the flow diagram, along with the verbal sequence of operation makes the coding process relatively easy, if not trivial.

## 3. Implementation

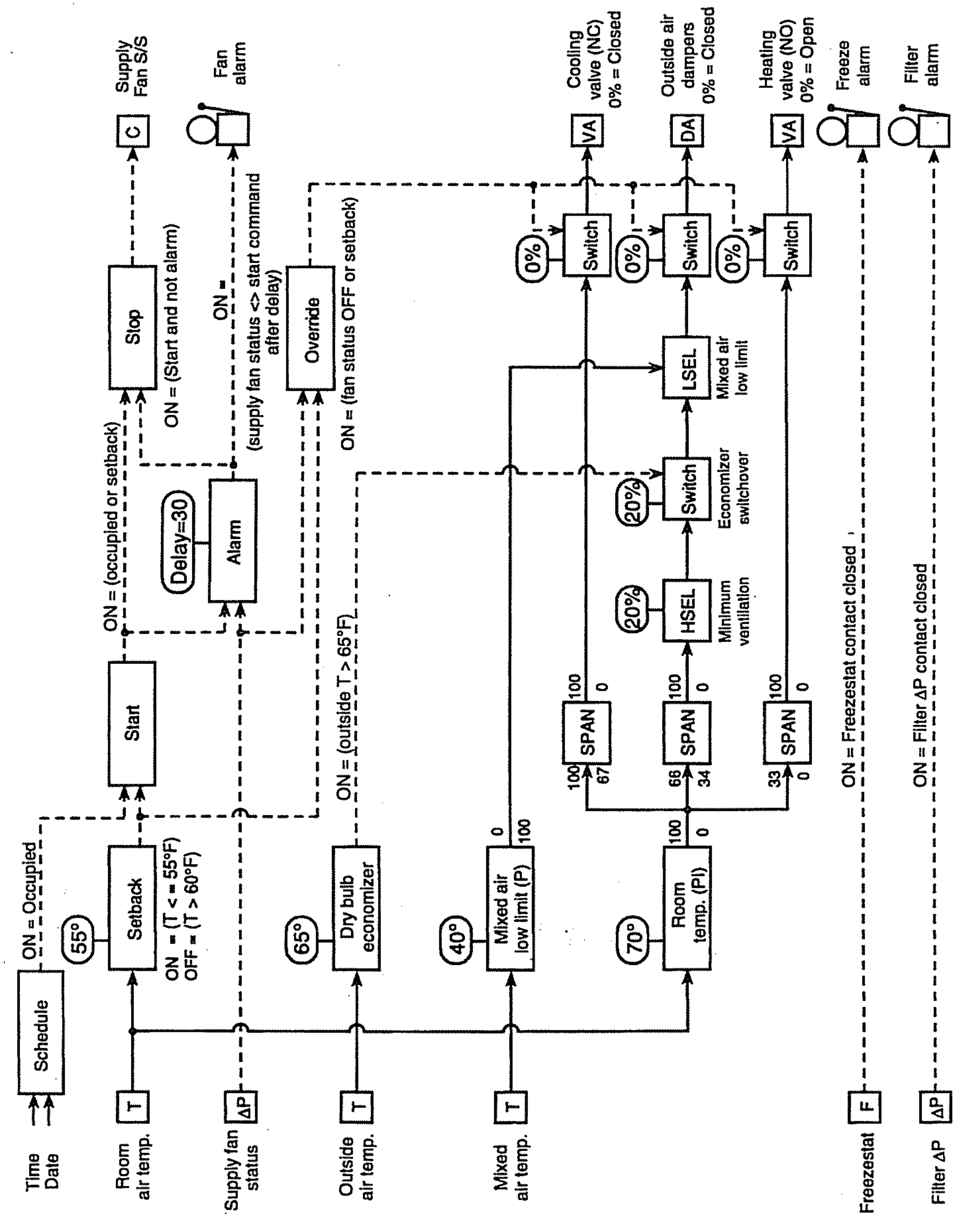


***FIGURE 8.3.*** The completed flow diagram depicting a schematic representation of each sensor, actuator, and logic sequence.

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