Chapter 7

Multiple Zone Air Systems

Contents of Chapter 7

Instructions

Read the chapter. Re-read the parts of the chapter that are emphasized in the summary and memorize important definitions.

Objectives of Chapter 7

Chapter 7 shows the most common ways that a single-supply air system can be adapted to provide all-air air conditioning to many zones with differing loads. After studying the chapter, you should be able to:

Identify, describe, and diagrammatically sketch the most common all-air air-conditioning systems.
Understand the relative efficiency or inefficiency of each type of multiple zone air system.
Explain why systems that serve many zones, and that have a variable-supply air volume, are more energy-efficient than those with constant-supply volumes.

7.1 Introduction

In the last chapter, we considered two types of single zone direct expansion systems: the packaged rooftop system and the split system. The direct-expansion-refrigeration rooftop unit contained all the necessary components to condition a single air supply for air-conditioning purposes.

These same components can be manufactured in a wide range of type and size. As an alternative to a rooftop unit, they can be installed indoors, in a mechanical room, with the different components connected by sheet-metal ducting.

Both the packaged rooftop unit and the inside, single-zone unit produce the same output: a supply of treated air at a particular temperature.

The heating or cooling effect of this treated airflow, when it enters a zone, is dependent upon two factors:

The flow rate, (measured in liters per second, L/s).
The temperature difference between the supply air and the zone temperature, (measured in degrees Centigrade, °C).

When the unit is supplying one space, or zone, the temperature in the zone can be controlled by

Changing the air volume flow rate to the space.
Changing the supply air temperature.
Changing both air volume flow and supply air temperature.

In many buildings, the unit must serve several zones, and each zone has its own varying load. To maintain temperature control, each zone has an individual thermostat that controls the volume and/or temperature of the air coming into the zone.

Air-conditioning systems that use just air for air conditioning are called "all-air systems".

These all-air systems have a number of advantages:

- **Centrally located equipment**—operation and maintenance can be consolidated in unoccupied areas, which facilitates containment of noise.
- **Least infringement on conditioned floor space**—conditioned area is free of drains, electrical equipment, power wiring and filters (in most systems).
- **Greatest potential for the use of an economizer cycle**—as discussed in Chapter 2, this can reduce the mechanical refrigeration requirements by using outside air for cooling, and therefore reduce overall system operating costs.
- **Zoning flexibility and choice**—simultaneous availability of heating or cooling during seasonal fluctuations, like Spring and Fall. The system is adaptable to automatic seasonal changeover.
- **Full design freedom**—allows for optimum air distribution for air motion and draft control.
- **Generally good humidity control**—for both humidification and dehumidification.

All-air systems generally have the following disadvantages:

- **Increased space requirements**—significant additional duct space requirements for duct risers and ceiling distribution ducts.
- **Construction dust**—due to problems with construction-dust, all-air systems are generally available for heating later in the construction schedule than systems that use water to convey heat.
- **Closer coordination required**—all-air systems call for close cooperation between architectural, mechanical and structural designers.

In addition to these general disadvantages, constant-volume-reheat systems are particularly high energy consumers because they first cool the air, and then reheat it. Because the reheat coils are sometimes hot water coils, an additional potential disadvantage is a problem with leaking hot-water coils. We will discuss these systems in more detail in the next section.

To make these all-air systems work for many zones requires some form of zone control. In this chapter we will consider how zone control can be achieved with all-air air-conditioning systems.

The simplest, and one that we will start with, is the **constant-volume-reheat** system.

7.2 Single-Duct, Zoned-Reheat, Constant-Volume Systems

The **reheat system** is a modification of the single-zone system. The reheat system permits zone control by reheating the cool airflow to the temperature required for a particular zone. *Figure 7-1* shows a reheat system, with ceiling supply diffusers in the space.

A constant volume of conditioned air is supplied from a central unit at a normally, fixed temperature, (typically 13 °C). This fixed temperature is designed to offset the maximum cooling load in all zones of the space. If the actual cooling load is less than peak, then the reheat coil provides heat equal to the difference between the peak and actual loads. When heating is required, the heater heats the air above zone temperature to provide heating.

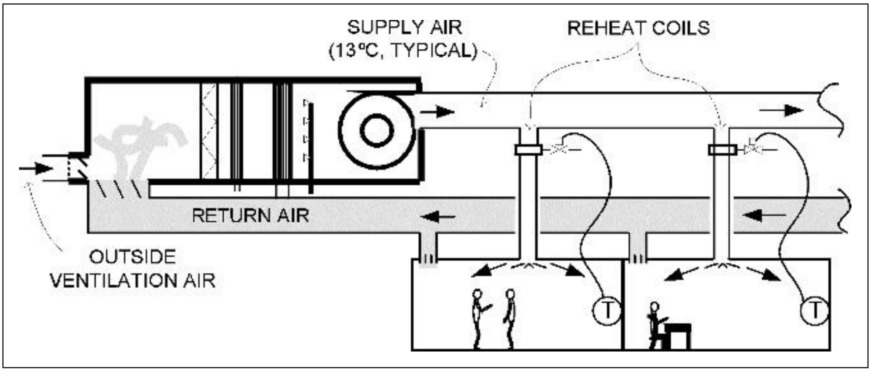

Figure 7-1 Reheat System

The reheat coil is located close to the zone and it is controlled by the zone thermostat. Reheat coils are usually hot water or electric coils. As noted above, if the reheat coils are hot water, then there can be a problem with leakage.

A reheat system is often used in hospitals, in laboratories, or other spaces where wide load-variations are expected.

When primary air passes quickly over a vent, it draws some room air into the vent. This process is called **induction**. There are two variations on the reheat system that both use **induced** room air: the **Induction Reheat Unit**, shown in *Figure 7-2*; and the **Low-Temperature Reheat Unit with Induced Air** shown in *Figure 7-3*.

The **Induction Reheat Unit** shown in *Figure 7-2* shows the primary supply of air, blown into the unit and directed through the induction nozzle. The reduced aperture of the nozzle forces the air to speed up and move quickly to the unit exit, into the room. As the primary air passes quickly past the reheat coil, it draws, or induces, air from the room into the unit. The room air passes across the reheat coil and mixes with the primary air.

Units like this are often mounted beneath windows, where they offset any downdraft in cold weather. In addition, even when the air supply is turned "off," hot water in the coil will still provide some heating.

The second type of induction reheat system, the **Low-Temperature Reheat Unit with Induced Air**, shown in *Figure 7-3*, is used where very cold supply air is provided. In some systems, the supply air can be as cold as 4°C. This could create intolerable drafts and serious condensation on the supply outlets. In this system, the primary air is preheated when necessary, but room air is

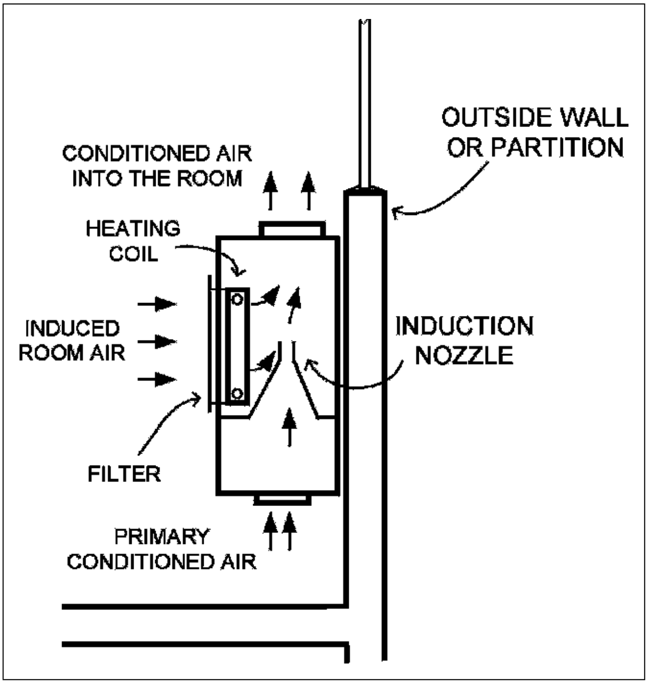

Figure 7-2 Induction Reheat Unit

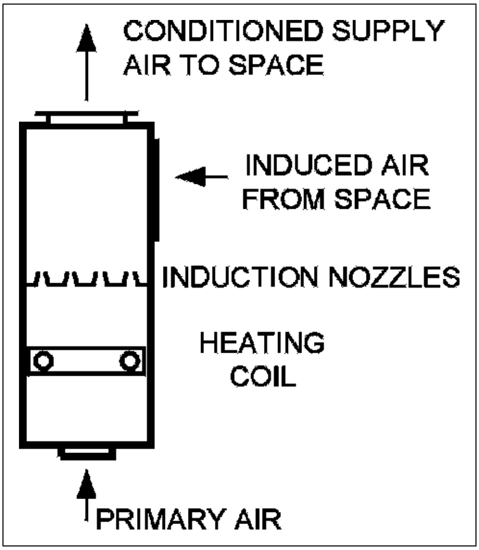

Figure 7-3 Low-Temperature Reheat Unit with Induced Air

always induced to mix with the primary air to ensure that the flow into the space is not excessively cold.

There are two primary advantages to this system:

- Duct sizing: When the system is designed to use 4 °C supply air, ducts can be sized for half the air volume, compared to the ducts required for a 13 °C supply-air temperature. This results in a lower installation cost, and a smaller requirement for duct space.
- The small volume of supply air may be exhausted from the room rather than returned to the main cooling system, possibly eliminating the need for return ductwork.

Overall, reheat systems are simple, and **initial costs**, the costs of design and construction, are reasonable. Reheat systems provide good humidity control, good temperature control, good air circulation, and good air quality.

The problem with all reheat systems is their energy inefficiency, so they are expensive systems to run. Generally, when the load is less than the peak cooling load, the cooling effect and the reheat are working against each other to neutralize their contributions. This means, in a no-load situation, the refrigeration is going at full blast and the reheat is just matching the cooling effect. There are two energy drains for no load! This is not quite as severe as it sounds because the no-load condition is the worst-case scenario, and it only occurs for a relatively small amount of the time.

Overall, though, reheat is energy expensive. As a result, these systems have fallen out of favor in recent times.

7.3 Single-Duct, Variable-Air-Volume Systems (VAV)

Buildings that are located in continuously warm climates, and interior spaces in any climate, require no heating, only cooling. For cooling-only situations, it would be ideal to supply only as much cooling and ventilation as the zone actually requires at the particular moment. A system that comes close to the ideal is the **variable-air-volume** system, "**VAV**."

The variable air volume system is designed with a volume control damper, controlled by the zone thermostat, in each zone. This damper acts as a throttle to allow more or less cool air into the zone. The VAV system adjusts for varying cooling loads in different zones by individually throttling the supply air volume to each zone. Regardless of the variations in the cooling load, a minimum flow of ventilation air is always provided and care must be taken to ensure that the required volume of ventilation air is provided.

In a VAV system, as the zone becomes cooler, the cooling load decreases and the cool airflow to the zone decreases. Eventually it reaches the minimum value necessary for adequate ventilation and air supply, *Figure 7-4*. When this minimum airflow is reached, if the zone is still too cool, heating is provided by a thermostatically controlled reheat coil or a baseboard heater.

This means there may be some energy wasted in the VAV system, due to heating and cooling at the same time. However, this energy waste is far less than in the terminal reheat system, since the cooling ventilation air is reduced to a minimum before the heating starts.

The total supply-airflow rate in a VAV system will vary as the zone dampers adjust the flow to each zone. Therefore, the supply fan must be capable of varying its flow rate. The variation in flow rate must be achieved without allowing the duct pressure to rise excessively or to drop below the pressure required by the VAV boxes for their proper operation. This pressure control is often achieved by using a pressure sensor in the duct to adjust a fan-speed control unit. Similarly, the return fan is controlled to meet the varying supply-air volume.

There are other methods that are discussed in the ASHRAE Course, *Fundamentals of Air System Design*.

In systems where the fan speed is reduced to reduce the volume flow, the fan power drops substantially as the flow reduces. This reduction in fan power is a major contribution to the economy of the VAV system.

VAV systems may have variable volume return air fans that are controlled by pressure in the building or are controlled to track the supply-fan volume flow.

In small systems, the variable-volume supply may be achieved by using a relief damper, called a "**bypass**," at the air-handling unit. The bypass allows air from the supply duct through a control damper into the return duct, as shown in *Figure 7-5*.

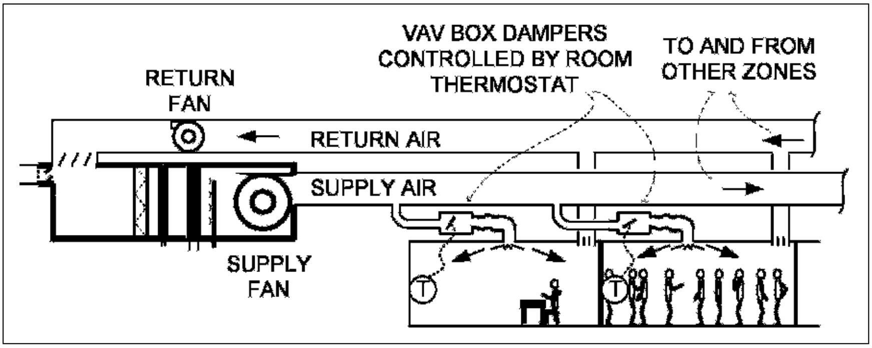

Figure 7-4 Variable Air Volume System

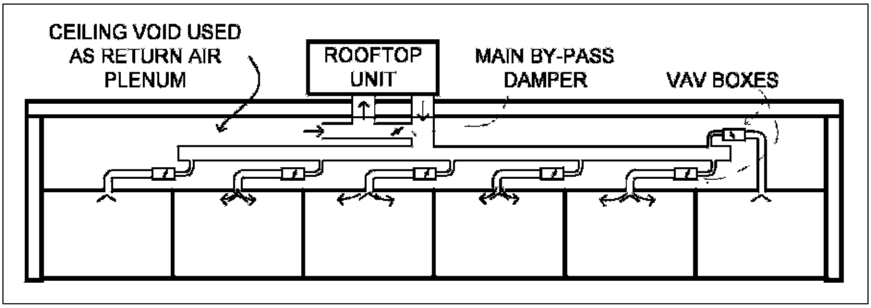

Figure 7-5 Variable-Air-Volume System with Bypass

As the zones reduce their air requirements, the bypass damper opens to maintain constant flow through the supply fan. This arrangement allows for the constant volume required by the refrigeration circuit. For smaller systems, this method can provide very effective zone control without creating problems that may occur when the airflow is varied across the direct expansion refrigeration coil. Unfortunately, this system keeps the fan working at near full load.

VAV Advantages

Advantages of the variable volume system are the low initial costs and low operating costs. Initial costs are low because the system only requires single runs of duct and a simple control at the end of the duct. Operating costs are low because the volume of air, and therefore the refrigeration and fan power, closely follow the actual load of the building. There is little of the cool-and-reheat inefficiency of the reheat system.

VAV Problems

There are potential problem areas with variable air volume systems. These include: poor air circulation in the conditioned space at lower flows; dumping of cold air into an occupied zone at low flows; and inadequate fresh air supplied to the zone. Improved diffusers have made it possible for the designer to avoid dumping and poor room circulation. However, the problem of inadequate outside air for ventilation needs additional care when the system is being designed.

For example, as we saw in the last chapter, in a constant volume system where all the zones require 20% outside air, setting the outside air to 20% on the main unit ensures that each zone receives 20% outside air. In the VAV system, one cannot set the outside air proportion. As the zone flows are reduced due to low thermal load, the proportion of outside-air-for-ventilation needs to increase. As a result, the outside-air volume must be maintained at all volume flows. This can be achieved in a number of ways, but the process requires a sophisticated, and potentially more expensive control system that is not required in constant volume systems.

7.4 Bypass Box Systems

Where the main supply unit must handle a constant volume of air, **bypass boxes** can provide a variable volume of air to the zones served. The bypass

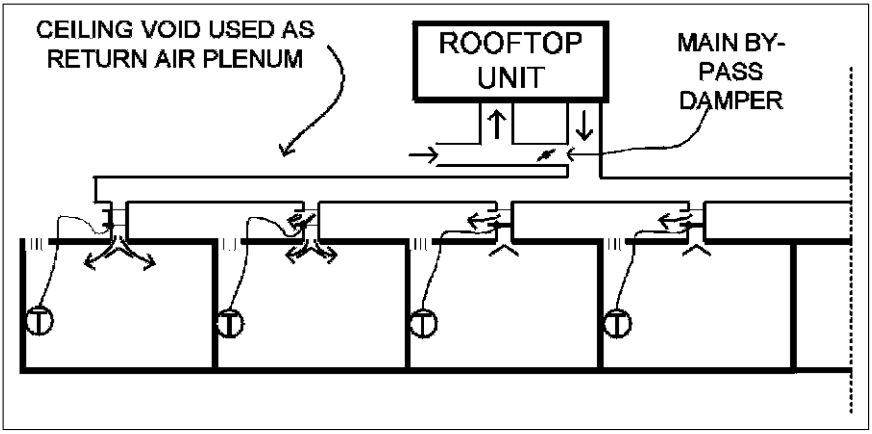

Figure 7-6 Bypass Boxes on Each Zone

boxes can be used on each zone, or as you saw in *Figure 7-4*, a single central bypass can be used with variable volume boxes serving each zone.

Figure 7-6 shows the use of the bypass box on each zone. A thermostat in each zone controls the damper in the bypass box serving the zone. The flow of air to each box is essentially constant. The bypass box, shown on the left, is set for full flow to the zone. The box in the center is passing some air to the zone and bypassing the balance. The zone on the right is unoccupied, and the box is set to bypass the full flow. The zone thermostat controls how much of the air is directed into the zone and how much is bypassed into the return-air system. In many buildings, the return can be via the space above the dropped ceiling, the **ceiling plenum**, and then, via a duct, back to the return of the air-handling unit.

With the bypass system, it is important to keep the ceiling plenum at a negative pressure, so that the excess cooling air does not leak into the zone. The danger of keeping the ceiling at negative pressure, though, is that this can cause infiltration of outside air through the walls and roof joints, resulting in moisture and load challenges.

7.5 Constant-Volume, Dual-Duct, All-Air Systems

A dual-duct system employs a different approach for establishing zone control. In a dual-duct system, cooling and heating coils are placed in separate ducts, and the hot and cold airflow streams are mixed, as needed, for temperature control within each zone.

In this system, the air from the supply fan is split into two parallel ducts, downstream of the fan. One duct is for heating and the other for cooling. A layout of three zones of a dual-duct system is shown in *Figure 7-7*.

The duct with the heating coil is known as the hot deck, and the duct with the cooling coil is the cold deck. These constant volume dual-duct systems usually use a single, constant-volume supply fan to supply the two ducts.

The dual-duct system can also be drawn diagrammatically as shown in *Figure 7-8*. Satisfy yourself that the two figures show the same system, although they look very different.

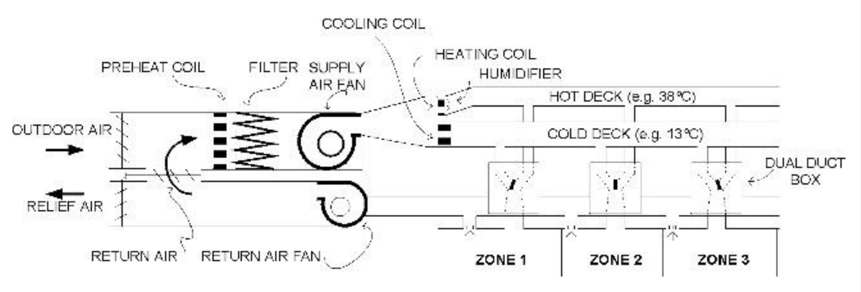

Figure 7-7 Dual-Duct System, Double Line Diagram

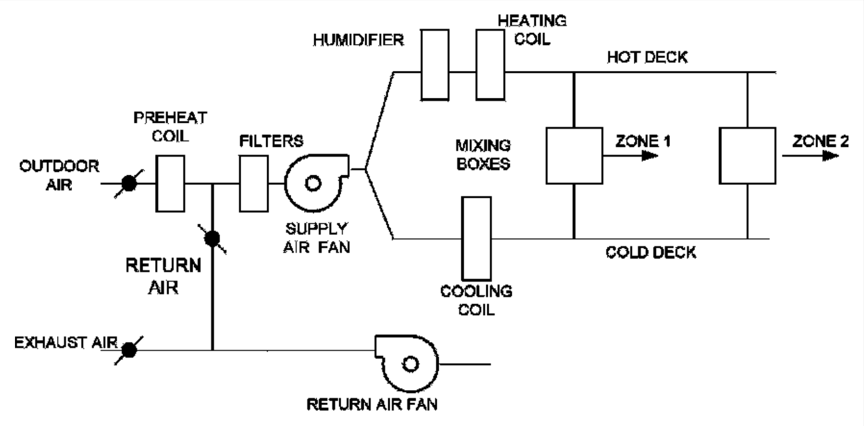

Figure 7-8 Dual-Duct System, Single Line Diagram

Dual-duct systems achieve the zoned temperature control by mixing the hot and cold air streams in a dual-duct box while maintaining a constant airflow. As in the reheat system described earlier, the heating and cooling effects are fighting against each other when the load is less than peak load. The combined energy use leads to energy inefficiency, which is the biggest disadvantage of dual-duct systems. The energy inefficiency may be reduced by these methods:

- Minimizing the temperature of the hot deck using control logic based on zone loads or outside temperature
- Raising the cold deck temperature when temperature and humidity conditions make it practical
- Using variable volume dual-duct mixing boxes.

The system also has a high first cost, since it requires two supply ducts. These two ducts need additional space above the ceiling for the second supply duct and connections.

Dual-duct systems were popular in the 1960s and 1970s and many are installed in hospitals, museums, universities, and laboratories. Due to the relatively high installation and operating costs, dual-duct systems have fallen

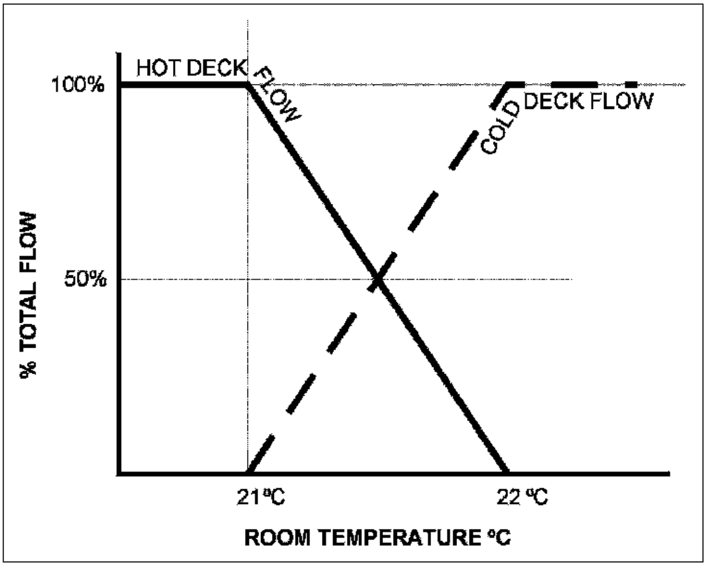

Figure 7-9 Airflow in a Dual-Duct System

out of favor except in hospitals and laboratories, where their ability to serve highly variable sensible-heat loads at constant airflow makes them attractive. Another advantage of dual-duct systems is that there are no reheat coils near the zones, so the problems of leaking hot water coils is avoided.

The dual-duct system delivers a constant volume of air, with varying percentages of hot and cold air, as shown in *Figure 7-9*.

In *Figure 7-9*, there are plots of percentage flow from the hot and cold air streams as a function of room temperature. The sum of the hot and cold airstream percentages always adds up to 100%. For the room temperature setpoint range, also known as the throttling range, of 21 °C to 22 °C, the thermostat will control the hot-air flow linearly, from 100% at 21 °C to 0% at 22 °C. Outside the throttling-temperature range, the flow is either all hot air or all cold air.

In *Figure 7-10*, there is a different view of the same process over the throttling range.

There are two plots. One plot, the solid line, shows how the delivered air temperature will vary as the thermostat controls the percentage mixture of hot and cold streams. The delivered air-temperature scale is on the right-hand side of the graph, and the room-temperature scale is on the horizontal axis.

At a room temperature of 21 °C and below, with 100% hot air, the delivery temperature is at 45 °C. At a room temperature of 22 °C and above, with 100% cold air, the delivery temperature is 13 °C. At room temperatures between 20 °C and 21 °C, the delivery temperature varies linearly with the room temperature.

The second plot in *Figure 7-10*, the dashed line, is that of the net cooling or heating power delivered to the zone to meet the load. The scale for the power variable is on the vertical axis, on the left-hand side of the graph. Zero power (or no net delivered heating or cooling) is at mid-height on the vertical axis. Above the mid-height there is net heating, and below mid-height there is net cooling.

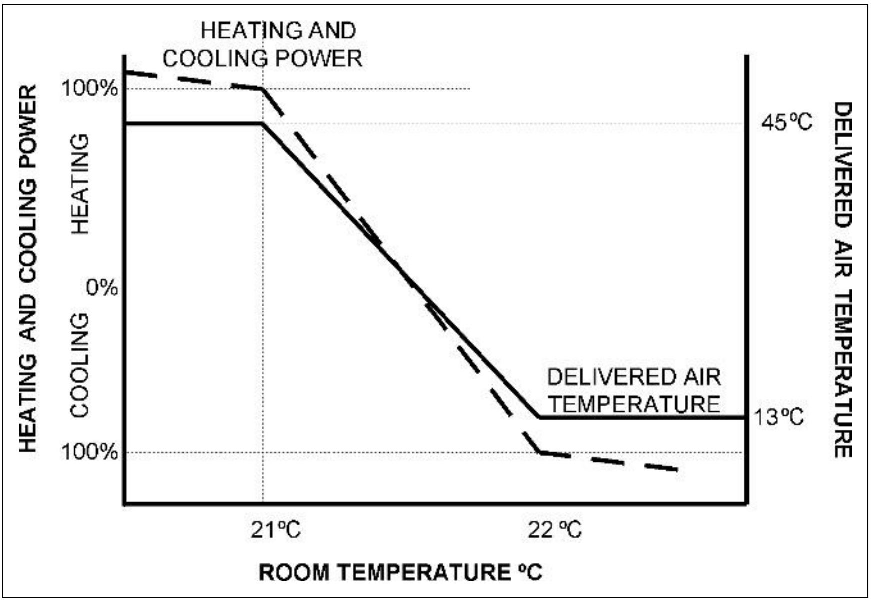

Figure 7-10 Delivered Air Temperature in a Dual-Duct System

It is important to observe that, because this is a constant volume system, *zero power* does **not** mean *zero energy use*. Zero power corresponds to an equal amount of heating and cooling, so that the heating and cooling effects cancel each other out, and give a neutral temperature effect on the zone.

As shown in *Figure 7-9*, below a room temperature of 21 °C, the flow is 100% heating at 45 °C; and above a room temperature of 22 °C, the flow is 100% cooling at 13 °C. Between 21 °C and 22 °C, the flow is a linear mixture of hot and cold air.

7.6 Multizone Systems

The multizone system is thermodynamically the same as the dual-duct system. They both involve mixing varying proportions of a hot-air stream with a cold-air stream to obtain the required supply temperature for that zone. In the dual-duct system, the mixing occurs close to the zone, in the dual-duct box. In the multizone system, as shown in *Figure 7-11*, the mixing occurs at the main air-handling unit

The basic multizone system has the fan blowing the mixed air over a heating coil and a cooling coil in parallel configuration. As you know, in the dual-duct system, the resulting hot and cold air is ducted through the building to dual-duct mixing boxes. In contrast, in the multizone system, the heating and cooling airflows are mixed in the air-handling unit at the coils using pairs of dampers.

The hot deck coil is arranged above the cold deck coil and they are sectioned off into zones; just two sections are shown in the figure. Each section has a two-section damper that opens to the cold deck as it closes to the hot deck. Each damper pair is driven by an actuator pushing the crank at the end of the damper shaft. The mixed air from each section is then ducted to a zone.

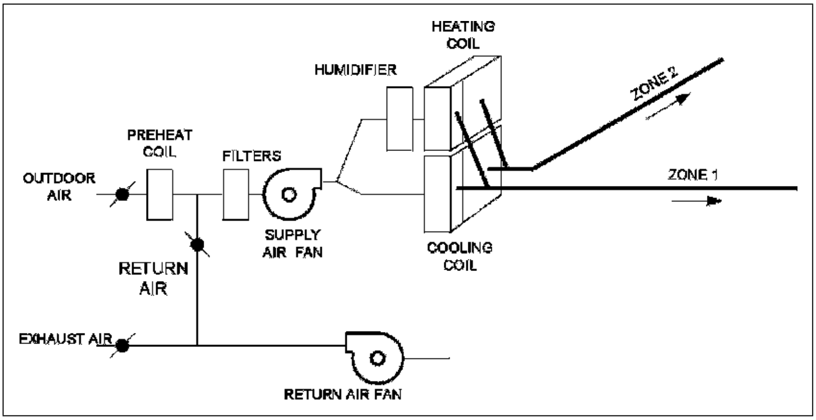

Figure 7-11 Mixing at the Air-Conditioning Unit in a Multizone System

As in the dual-duct system, a certain amount of energy inefficiency occurs because the air is being both heated and cooled at the same time.

7.7 Three-Deck Multizone Systems

The three-deck multizone system is a possible solution to overcome the energy inefficiency of the overlapping use of heating and cooling in a traditional multizone system.

The three-deck system is similar to the dual-duct and multizone systems, except that there is an additional (third) air stream that is neither heated nor cooled. Hot and cold air are never mixed in the three-deck system. Instead, thermal zones that require cooling receive a mixture of cold and neutral air, and thermal zones that require heating receive a mixture of hot and neutral air. The airflow control is shown in *Figure 7-12*. Thus, the three-deck system avoids the energy waste due to the mixing of hot and cold air streams.

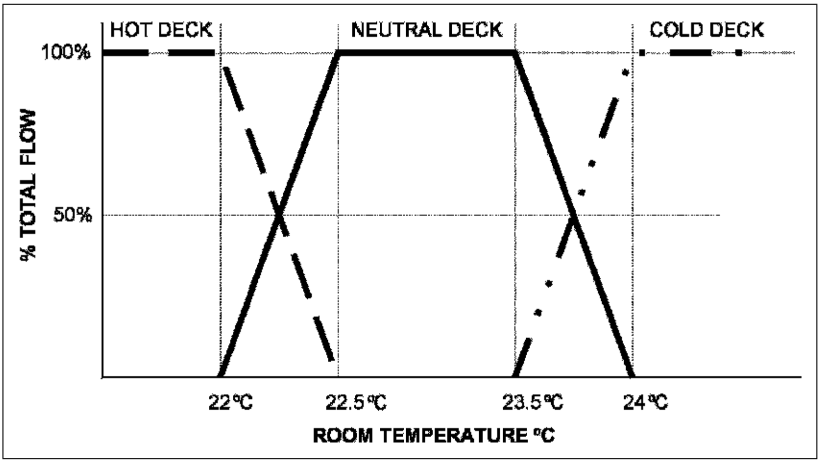

Figure 7-12 Airflow for Three-deck, Multizone System

The neutral air in the three-deck system is neither heated nor cooled and its temperature will change with the season. In summer, the neutral air will be warmer than the cold deck air. Consequently, the neutral air will take the place of the hot-deck air, eliminating the need for the heating coil in summer. In winter, the neutral air will be cooler than the hot deck, thus replacing the cold deck and the need for activating the cooling coil in winter. The net annual result is that there is no penalty for having heating and cooling coils operating simultaneously.

7.8 Dual-Duct, Variable-Air-Volume Systems

The dual-duct, variable-air-volume (VAV) system provides the thermal efficiency of the VAV system while generally maintaining higher airflows, and thus better circulation of air in the room, when heating is required. The difference is that the air is not drawn into the building by a constant volume fan, as it is in the usual dual-duct system, but it is split into two air streams that flow through two variable-volume fans. One air stream passes through a heating coil and one through a cooling coil. The two air streams are then ducted throughout the building.

The mixing of these two air streams is carried out in a mixing box serving each thermal zone. These mixing boxes can vary both the proportions of hot and cold air, and also the total flow rate of air to the zone. This is in contrast to the more conventional dual-duct system where the airflow delivered by the mixing box is constant.

The variation of flow in the dual-duct, variable-air-volume system is shown in *Figure 7-13*. This diagram indicates equal volume flows for both heating air and cooling air. Depending on the climate and resulting loads, the heating flow

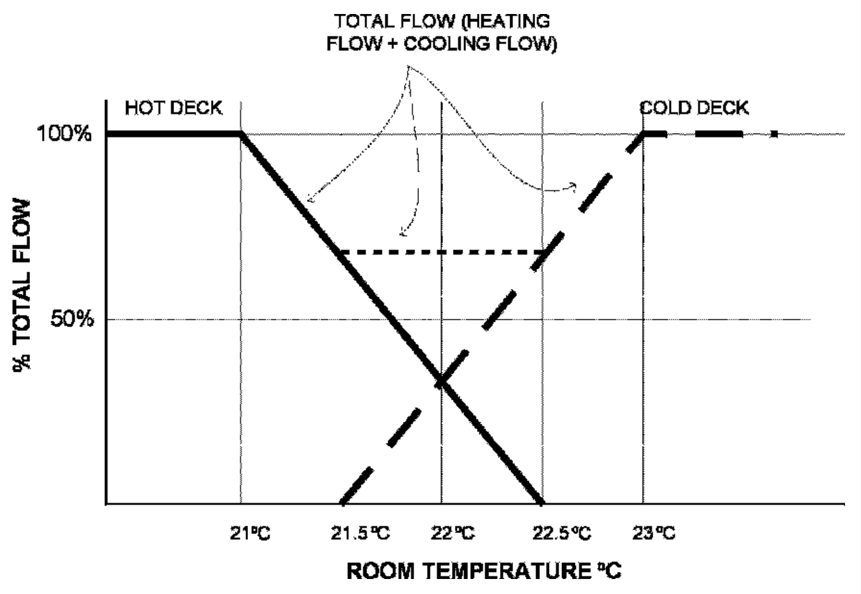

Figure 7-13 Airflow for a Dual-Duct, Variable-Air-Volume System

may be 50% less than the cooling airflow, but the control logic is the same. At maximum cooling load, the box provides sufficient cold air to meet the load. As the cooling load decreases, the volume of cold air is decreased, without addition of hot air to change the temperature. When the cooling load reaches the point where the cold airflow equals the minimum allowable flow, the cold flow continues to decrease, but the hot air is added to maintain sufficient total flow. As the heating load increases, the total flow remains constant while its temperature is increased above room temperature by increasing the proportion of air from the hot deck. When the cold deck flow reaches zero, the temperature of the delivered air will be the hot deck temperature. As the heating load increases further, the requirement for more heat is satisfied by increasing the volume flow rate of hot air.

7.9 Dual-Path Outside-Air Systems

Throughout this text, our examples have shown the outside ventilation air being mixed with return air before being processed and supplied to the building. This mixing method works well in cooler, dryer climates. This does not work as well in warm/hot, humid climates. The reason is very simple: the main cooling coil cannot remove enough moisture without overcooling the whole air stream. What is required is high moisture removal without full cooling.

An effective way around this problem is to use a dual path system. The outside air comes in through a separate, dedicated cooling coil before mixing with the return air. This dedicated outdoor air coil has two functions:

1. *Dehumidification*: The system is designed and operated to dehumidify the outside air to a little below the required space-moisture content.
2. *Cooling*: The system cools the outside air to about the same temperature as the main coil, when the main coil is at maximum cooling.

When the system is in operation, the fully cooled outside air, say 20%, mixes with 80% return air before it reaches the main cooling coil. The mixture is equivalent to the full airflow, substantially dehumidified and 20% cooled. The main cooling coil now provides the required extra cooling that the system needs, and a modest, achievable, requirement for dehumidification.

The challenge of providing adequate dehumidification at an acceptable cost is an ongoing challenge in moist climates. The dual path method described above is one of the many ways available to tackle the challenge of removing moisture without overcooling.

The Next Step

This chapter has been all about all-air systems that serve many zones. In many cases systems with separate water heating and/or cooling can be very effective. For instance, in a very cold climate, it is often more comfortable to provide a perimeter hot water heating system and use the air system for cooling, ventilation air supply, and fine temperature control. This also allows the air system to be turned off when the building is unoccupied, even though the heating system must remain on to prevent over-cooling or freezing.

In Chapter 8 we will consider water systems and how they coordinate with air systems we have discussed in this chapter and the previous one.

Summary

This chapter has introduced the various ways zoning can be achieved with all-air air-conditioning systems. They are all based on individually varying the air flow and/or temperature supplied to each zone.

7.2 The Reheat System

Reheat is the simplest system, known both for its reliability and its high energy wastage. Two induction variations were introduced: one that also provides some night time heating; and the other that accommodates very low supply-air temperatures.

7.3 Variable-Air-Volume (VAV) System

More energy efficient than reheat, VAV is a very flexible system with many virtues. When there is a low load, however, it does offer challenges for maintaining adequate ventilation air and good room air distribution.

7.4 The Bypass System

A variation on the VAV system, the bypass system, is suitable for providing good control in smaller systems, and for constant flow over a direct-expansion cooling coil. Designers must be cautious to ensure that bypassed air goes straight back to the air conditioning unit, but it is generally a simple system to design.

7.5 The Dual-Duct System

The system provides full airflow when the system is on, but, like the reheat system, suffers from the energy penalty of simultaneous heating and cooling. A very attractive feature of the dual-duct system is that there are no reheat coils near the zones, so the problems of leaking hot water coils is avoided.

7.6 The Multizone System

A system thermodynamically similar to the dual-duct system, the multizone system features a different layout. The multizone system is not as energy efficient as the VAV system, and requires a separate duct to each zone. However, the multizone system has the advantage of requiring no maintenance outside the mechanical room, except for the zone temperature-sensors and associated cable.

7.7 Three-Deck Multizone System

The more modern introduction of the third, neutral duct to the multizone system, avoids the conflict of concurrent heating and cooling.

7.8 Dual-Duct, Variable-Air-Volume System

A modification of the dual-duct system, this system uses variable volume dual-duct boxes to provide the thermal efficiency of the VAV system, while maintaining higher airflows, and thus better room air circulation when heating is required.

7.9 Dual-Path Outside-Air System

This system could be used to reduce the problem with excess moisture in the air that arises in warm/hot, humid climates.