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HVAC SYSTEMS IN THE CURRENT STOCK OF U.S. K-12 SCHOOLS

by

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ABSTRACT

Previous studies in school buildings have shown that radon levels can be reduced by depressurization and ventilation of soil under slabs, but that this method is not readily applicable on all buildings. The heating, ventilating and air-conditioning (HVAC) systems have also been shown to impact radon levels, either by depressurizing areas and increasing radon concentrations, or by pressurizing and ventilating to reduce radon concentrations.

This report summarizes information about types of HVAC systems commonly found in U.S. school buildings, their ability to pressurize and ventilate classroom spaces, and how they operate and are controlled. Some information is given to compare systems as to energy usage, cost and their ability to maintain stable levels of static pressure in classrooms and/or to adequately ventilate the spaces.

Not all HVAC systems are capable of providing pressurization since some have no provision for the outdoor air to replace the exfiltration losses always created by positive room pressure. The level of pressure attainable in a space depends upon the fan characteristics, the duct design, the room leakiness and the method of control of fans and dampers. Return fans and relief dampers play an important role in some systems, and exhaust fans always work against maintaining positive room pressures.

There appears to be no well defined trends in types of HVAC systems being installed in current school building construction and modifications. Some systems using reheat and/or mixing have been prohibited or their use discouraged by local codes and regulations because they waste energy. Capital costs appear to vary more with locale and quality of construction than with type of system installed.

The unit ventilator (UV) has been the most popular type of system in American schools but its noise and operating limitations have reduced its popularity in recent years relative to central systems. The UV system can provide limited pressurization and dilution through outdoor air intake but the fan must be operating for it to be effective.

The two-fan, dual-duct variable air volume (VAV) system appears to be considered as an excellent choice for relatively low operating costs in future construction and should be capable of pressurization and ventilation. All HVAC systems will have significantly increased utility costs if they are operated long hours during unoccupied periods and/or if they are modified to maintain higher static pressure levels in classrooms. This is particularly true for U. S. school buildings, many of which are not tightly constructed (i.e., they have high passive rates of outdoor air exchange through the building envelope).

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INTRODUCTION AND BACKGROUND

The United States Environmental Protection Agency (EPA) has studied ways to reduce radon levels in schools since 1987. A recent discussion of some of these studies is described in the proceedings of the 1991 International Symposium on Radon and Radon Reduction Technology, (1). Radon mitigation research to date has emphasized reduction of radon levels through the use of active subslab depressurization (ASD). Although ASD has proved successful in a number of schools, it is not reasonably applicable in all school buildings. As a result, reduction of radon levels with HVAC systems needs to be investigated as an alternative approach to radon mitigation, particularly in schools with moderately elevated radon levels (4 to 20 pCi/l). Leovic, Craig and Saum (2) concluded in their study that "One of the most significant factors contributing to elevated levels of radon in schools and influencing the mitigation approach is the design and operation of the HVAC system. The complexities of large building HVAC systems present problems not previously encountered in house mitigation."

Brennan (3) reported on the EPA School Evaluation Program (SEP), involving site studies in 26 schools in 8 regional locations in the United States. An HVAC system approach was the preferred radon reduction technique over soil depressurization in 23 of the 26 schools evaluated. The reason given was that many of the schools did not meet current standards for schoolroom ventilation, and that radon levels were low enough that meeting ventilation standards would likely solve the radon problem. A wide variety of ventilation systems were found in the SEP schools, and many of these systems were not designed or operated properly.

An update on radon mitigation research in schools by Leovic, Craig and Harris (4) describes efforts through 1991 to evaluate both ASD and HVAC methods in school buildings. One significant conclusion of the report was that many HVAC systems in schools were not supplying adequate outdoor air.

Researchers at EPA desired to better understand the various types of HVAC systems that exist in kindergarten through twelfth grade schools throughout the U.S. This report attempts to fill the need for a reference document that identifies the various HVAC systems that one should expect to find in U.S. schools, the ability of these systems to pressurize and ventilate, the strategies to control pressurization and ventilation, and to describe modifications that might have been made by owners to conserve energy, and how these might affect pressurization and ventilation.

THE PREVALENCE AND THE RADON ABATEMENT CHARACTERISTICS OF VARIOUS TYPES OF HVAC SYSTEMS

Early in the study it appeared that hard data regarding types and numbers of HVAC systems presently installed in U.S. schools was not readily available. Some 1979 data were found giving the distribution of U.S. school building heating and air- conditioning systems. These data are described and shown graphically in Appendix A. Most of the school buildings described by that data are likely still in use, some with modifications to their HVAC systems. Recent construction probably has led to trends different from those of the 1979 study, such as in the wider use of cooling, of forced air systems, and of rooftop units.

The 1991 paper by Leovic, Craig and Harris (4) reported the distribution of HVAC system types in the 47 AEERL research schools: 45% of the schools have central air handling systems, 43% have unit ventilators, 30% have radiant heat, and 11% have fan coil units. This distribution includes schools with combination HVAC systems. Actually only 83% of the schools were designed to provide conditioned outdoor air, the remaining 17 percent having only radiant heat (11%) or only fan coil units (6%). Most of the systems providing outdoor air were not designed or operated to meet the current guidelines recommended by ASHRAE.

Calls and inquiries to school administrators and staff and to consulting engineers revealed no newer quantitative data but did show clearly that there exists a very wide variety of HVAC systems in use in U.S. schools. While most school systems operate within guidelines of state and federal regulation they are generally free to select their own architects and engineers and the designs and policies followed in building construction are locally controlled. The types of systems might depend more upon age, size of plant and local economics and wage scales than upon geography or even climate, although cooling systems do appear to be more common in the southern, warmer states than in states with cooler or milder summer climates. They are also more common in schools used year-round.

With air-conditioning (cooling) very often there are more elaborate ventilation and control systems than where heating only is utilized. Some types of heating systems, such as radiant systems for example, have no controlled ventilation as part of the system and depend entirely upon radiation or free convection to transfer heat to the controlled space and depend on infiltration for ventilation.

School boards and administrators are becoming more concerned with indoor air quality problems and hopefully will benefit from the current attention being given to environmentally sound design. ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality (5) gives guidance for improving indoor air quality in buildings. It is useful in defining terms, setting minimum air requirements and in describing procedures for assuring that requirements are met. Since schools, like many types of buildings, are occupied intermittently, the procedures outlined in the standard for assuring air quality under such conditions is particularly useful. The impact of Standard 62-1989 on heating/cooling capacity and energy use in both new and retrofitted schools is discussed in a recent article by Wheeler (6). He states that few applications are likely to be affected more decidedly by ASHRAE Standard 62-1989 than the school classroom. This is so because the standard's recommended rate of outdoor air could be more than half the total air supply needed for cooling a classroom. Moreover says Wheeler this rate is also the minimum permissible total air flow as well as the outdoor air component.

The poor condition of many school buildings in the United States is described in a report of the Education Writers Association titled "Wolves at the Schoolhouse Door" (7). This report states that one fourth of all U.S. schools are in an inadequate condition and that there is an estimated backlog of $41 billion in maintenance and major repairs. It also states that maintenance funds are the first funds cut in a budget crisis and estimates that 85% of maintenance budgets are spent on emergency repairs rather than continued maintenance.

There is a boom in construction and refurbishing of school facilities in many parts of the country, with the national level being its highest since the 1950s. The estimate of the F. W. Dodge Group of McGraw-Hill for 1990 is that elementary and high school construction spending is at an all-time high of $10.7 billion and is expected to continue at near this level throughout the decade.

A very large part of the current construction projects involve overhauls of existing buildings, most of which were built during the 1950s and 1960s and which were of generally low-cost construction. Many school buildings have undergone modification, some with only quick fixes attempting to reduce energy consumption. Many school buildings have HVAC systems that need significant repairs (7). Concern over costs of heating and cooling school buildings and in meeting the new requirements of ASHRAE Standard 62-1989 are the main theme of the report by the American Association of School Administrators, "Schoolhouse in the Red - Cutting Our Losses" (8). Thus it is a good time to be promoting good design for improvement of indoor air quality (9).

Regarding future trends, the requirements of local building codes will be strongly influenced by ASHRAE Standard 90.1-1989, <u>Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings</u> (10). This standard and the desire of School Boards to have both low initial and operating costs in their buildings will probably cause certain types of systems (for example, reheat and dual-duct, constant flow) to no longer be built. No single type of system seems to be the obvious best choice for all schools. The following quote is taken from page 6.3 of the 1991 ASHRAE Handbook (11):

"No trends in educational facility design as related to heating, ventilating, and air-conditioning systems are evident. In smaller single-building facilities, centralized systems are often applied. These systems include unit ventilator, rooftop and single and multizone-type units. Central station equipment, especially variable volume systems, continues to have wide application in larger facilities; water-to-air heat pumps have also been used."

All of these systems have outdoor air capability that can be used to adequately pressurize and/or ventilate a building if equipment is sized properly.

The single most significant factor to be considered in this study is the air distribution system of a school building and whether that system has provision for outdoor air. Schools which have no air distribution systems, for example ones with only radiant heating or schools with exhaust only ventilation, cannot (without modification) pressurize the space for reduction of radon levels. Modification for radon abatement would require the addition of an air distribution system, properly designed to be compatible with the existing comfort system or to totally replace it.

Some existing school HVAC systems have air circulation but no controlled provision for outdoor air. Some systems with outdoor air have been modified to minimize (or eliminate) outdoor air to save on energy costs,and in some systems outdoor air damper units no longer operate properly due to poor maintenance. Brennan (3) reported that every one of the 26 schools in the EPA SEP study had at least one ventilation problem.

Pressurization of a building occurs when the amount of outdoor air introduced into the building exceeds the amount of air removed by exhaust systems. The excess air (air not exhausted by fans) is forced out of the building through leaks in the building shell (e.g., floor cracks, around windows and exterior doors). This leakage of air from inside the building to the outdoors is referred to as exfiltration. Air exfiltration always occurs under a positive pressure condition. Therefore any system without controlled outdoor air must be modified to provide that feature if room pressurization is to be ensured. It should be obvious that dilution of room air by ventilation cannot occur without the intake of outdoor air. Room pressurization is always accompanied by some dilution due to the required introduction of outdoor air.

After a brief introduction of pertinent HVAC terms the basic central air system will be described and used as the basis for comments on the different types of systems existing in schools.

DESCRIPTION OF TERMS

The term central system applied to an HVAC system implies that furnaces and chillers are located in a central area or areas in a building and energy is distributed by air (in ducts) or by water or steam (in piping) to and from the various zones served by that system. A very large percentage of the HVAC systems in school buildings are of the central system type. Where a campus, institution or facility has its chilled water, and/or hot water or steam generated in a single location the term central plant or central station is used. In contrast to central systems and plants, packaged terminal units and room air conditioners furnish heating and/or cooling to a single space, usually without the use of external ducting or piping.

Central units may be of the built-up type, being assembled on site from components selected by the designer to meet the specific application, or they may be unitary systems where the components are factory assembled into an integrated package or packages. Unitary systems can be split systems with an outdoor section (condenser) being separate from the indoor section or they can be packaged units as for example a rooftop unit. Both built-up and unitary systems may have external duct work and plumbing or tubing as well as some controls and electrical wiring installed on site. If heating needs are furnished by vapor compression or absorption cycles the term heat pump is often applied.

The system may consist of single or multi-zones. The term zone defines an area of one or more rooms that is under the control of a single thermostat. Central system may be further classified as to how the energy is distributed to the various zones. The three common types are all-air systems, air-water systems, and all-water systems.

An all-air system provides complete heating and cooling by supplying only air to the conditioned space. There may be some piping connecting the chillers or heaters to the air-handling devices. A simplified diagram of an all-air central system is shown in Figure 1. The system shown has both a return air and a supply air fan. Some systems have only a supply air fan. In systems having both fans the room pressurization level is determined by the characteristics and operating speeds of both fans as well as the positions of the exhaust air and the outdoor air dampers and the room tightness. Negative room pressures are possible if the return air fan overdrives the supply air fan and/or if the exhaust air exceeds the supply air rate. With a single (supply) fan the room pressure depends on the relative amounts of exhaust and makeup air. As emphasized before, for a positive (above atmospheric) pressure to exist in a zone there must be a higher rate of makeup air than exhaust air. In such cases the zone would be exfiltrating or losing air through cracks and openings to the exterior.

In an air-water system both air and water are distributed to each zone to perform the conditioning function. The bulk of the heating or cooling in the space occurs in a heat exchanger coil that may be part of an induction unit, a fan coil unit, or a radiant strip or panel. Individual zone control is obtained by controlling the rate of air flow across or rate of water flow into the coil. Air or water temperatures or both may be changed to permit control of space temperatures year around. Because the bulk of the energy required for maintaining comfort can be easily and compactly carried in pipes by the water, only enough air needs to be delivered to the zone to maintain pressure levels and/or comfort. This greatly reduces the duct size and fan power required resulting in many cases in both reduced installation and operating costs. Duct size can be further reduced by using high velocity air distribution. The air is usually supplied at constant rate from the central system and is referred to as primary air to distinguish it from room air that is recirculated over the room coil.

If the rate of primary air supply exactly balances that required for exhaust and/or exfiltration then the return system can be eliminated. This represents a significant cost reduction for installation and makes some types of air-water systems good candidates for future consideration when room pressurization is desired. With no air return the room would operate under positive static pressure, neglecting any wind or stack effects on the building. Some form of room pressure relief damper might be necessary if the required makeup air exceeds that which will naturally exfiltrate at the desired room static pressure.

All-water systems heat or cool a space by direct heat transfer between water and circulating air. Heating systems include baseboard radiation, free-standing radiators, wall or floor radiant, and even bare pipe. Cooling systems must provide for air flow including outside ventilation air, drain pans, and filters. The equipment designed for this purpose is referred to as a terminal unit. The all-water system has the advantages of requiring less building space for the delivery system, since pipes replace ductwork. Individual room control is easily maintained and there is little cross contamination of recirculated air from one space to another. Two disadvantages are that maintenance must be done in the occupied areas and condensate removal can be a problem.

THE BASIC CENTRAL SYSTEM

Because it is the air distribution system that plays the primary role in radon abatement by the HVAC system and because the central air system has characteristics somewhat in common with all systems it will be used at first to describe the basic problems and approaches to a solution. The discussion will deal first with constant volume air systems. The significant and unique characteristics of the more common types of HVAC systems will then be given, including systems that operate with variable air volume.

CONSTANT VOLUME CENTRAL SYSTEMS

The basic arrangement of an HVAC central air system shown in Figure 1 is taken from McQuiston and Parker (12). The characteristics of these components, along with those of the controls, the duct system and the space being conditioned and the operating schedule determine the HVAC effect on radon. In this report it is assumed that radon abatement by the HVAC system is entirely due to room pressurization relative to the subslab, dilution by outside makeup air, and the schedule of operation of the HVAC system. The effectiveness of radon removal by dilution is determined to some extent by the air distribution within the room itself. This room air distribution involves types and locations of air diffusers and return grills and the resulting entrainment, mixing and stagnation that might occur within the space being served. Any discussion of ventilation and room air dilution will also assume that outdoor makeup air is at typical ambient radon levels of 0.2 to 0.5 pCi/l.

The components shown in Figure 1 are not present in all central air systems. Systems designed to provide only ventilation air and not the basic heating or cooling (fan coil systems for example) may not have an air return. Systems without air returns provide positive pressurization to the space and are prime candidates for consideration where radon might be a problem.

In the smaller, basic central systems the fan cycles off when the thermostat is satisfied and more often than not the thermostat is setback during off hours. In this case there are long periods when the fan is not running and pressurization is lost. Most systems can be set to operate with the fan running continuously but these extra hours of fan time can add extra expense to the school's utility bills. A compromise would be to determine at what hour the fans could be turned on so that through dilution and pressurization the radon in a space could be reduced to an acceptable level before the space is occupied. This would depend on radon levels, source strength, etc.

The majority of central air systems used in residential or light commercial and in some school buildings have returns but do

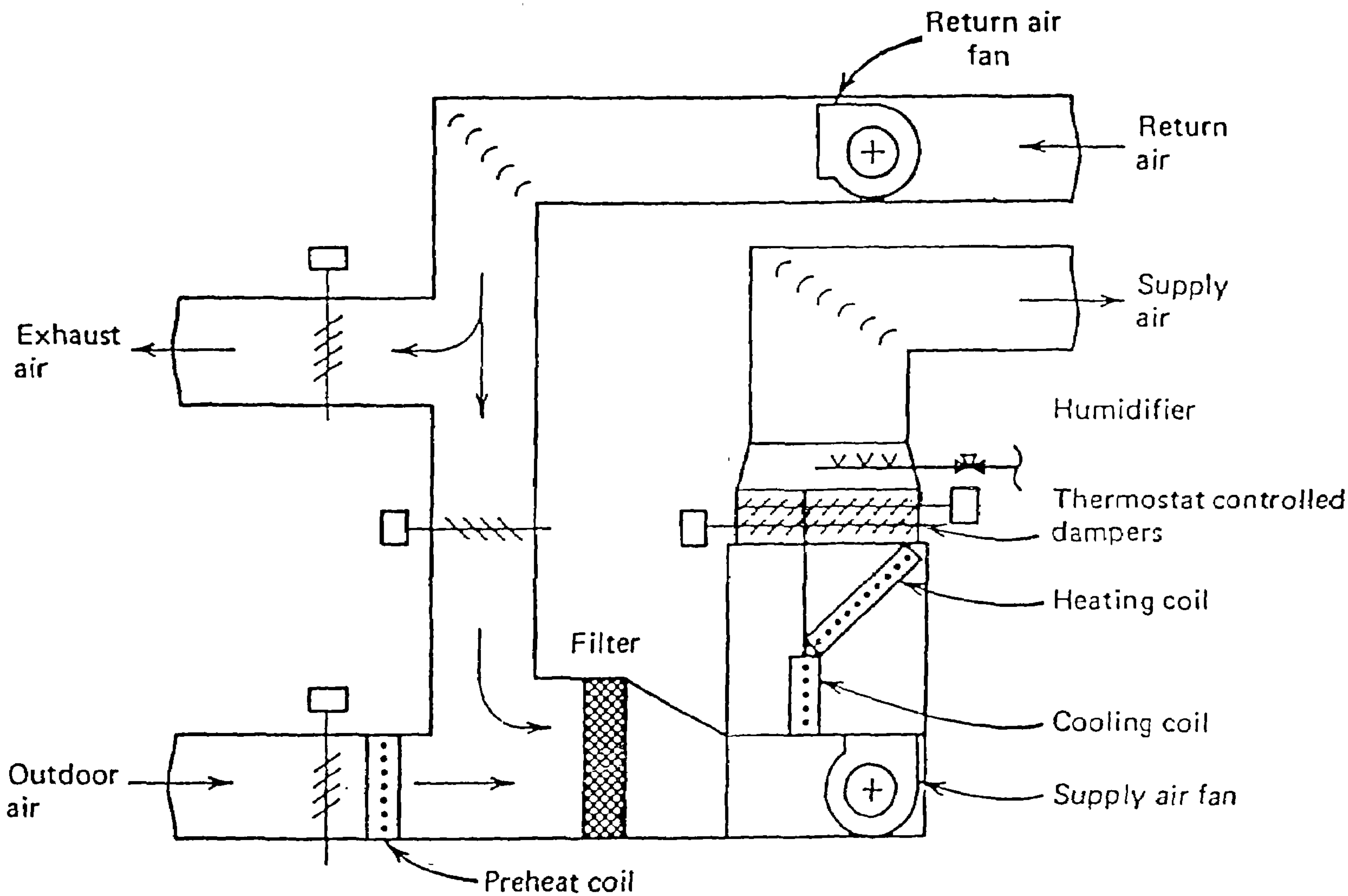

Figure 1 - The Basic HVAC Central System

not have provision for exhaust or outdoor air and the corresponding dampers, and would have no need for a preheat coil. Most small systems do not have a return air fan and many provide only heating or cooling and no humidification. In typical small systems the air flows sequentially (in series) through the heating unit and the cooling coil.

In most small air handling systems and in many large ones the air flow rate is constant regardless of the thermal load. The variable air volume system compensates for variations in heating or cooling load by regulating the volume of air supplied to each zone. These systems are sometimes simply called variable-volume systems and more often VAV systems. Energy conservation as well as improved controls and equipment have made VAV an increasingly popular option.

PRESSURIZATION WITH A CENTRAL SYSTEM

In these more simple systems, illustrated in Figure 2, the air flow can be assumed to start in the room, flow through the return ducts, through the air handler, then through the supply ducts and back to the room. Initially the room pressure might be assumed to be atmospheric and the pressure profile for the air might be assumed as shown. In this case the pressure drop through the return duct and filter and up to the fan is seen to be below atmospheric pressure and the pressure drop to be about one half the pressure drop from the fan to the room. The single fan furnishes exactly the pressure required to make up the losses in both the supply and the return systems, and the flow rate of air to the room is exactly equal to the return flow rate from the room. Any infiltration into the room through cracks and other openings will be exactly matched by exfiltration from the room through other cracks and openings.

The pressure variation shown in Figure 2 is the total pressure, the sum of the static pressure and the velocity pressure. The static pressure and the velocity pressure in a duct system may tradeoff, increasing or decreasing in the flow direction as the velocity of the air flow changes, but the total pressure can only increase when energy is added to the stream at the fan. In a room where the air velocity is relatively low the static pressure and the total pressure are for all practical purposes the same. Static pressure difference determines whether or not air flows in a particular direction through a crack or opening such as might exist in a duct or in a floor slab or wall.

It has already been emphasized that neither room pressurization nor air dilution can occur unless there is an intake of outdoor air somewhere in the system. With a single fan, such as shown in Figure 2, the intake must be at some point where the static pressure is below atmospheric, since that is only way that air can be induced into the system.

Element	Total pressure loss, in. H_2O	(Pascals)
Return grille	0.04	10.0
Return duct	0.08	20.0
Filter	0.08	20.0
Heat and cool coils	0.23	57.5
Supply ducts	0.14	35.0
Diffusers	0.03	7.5
Fan total pressure-in.H_2O	0.60	150.0

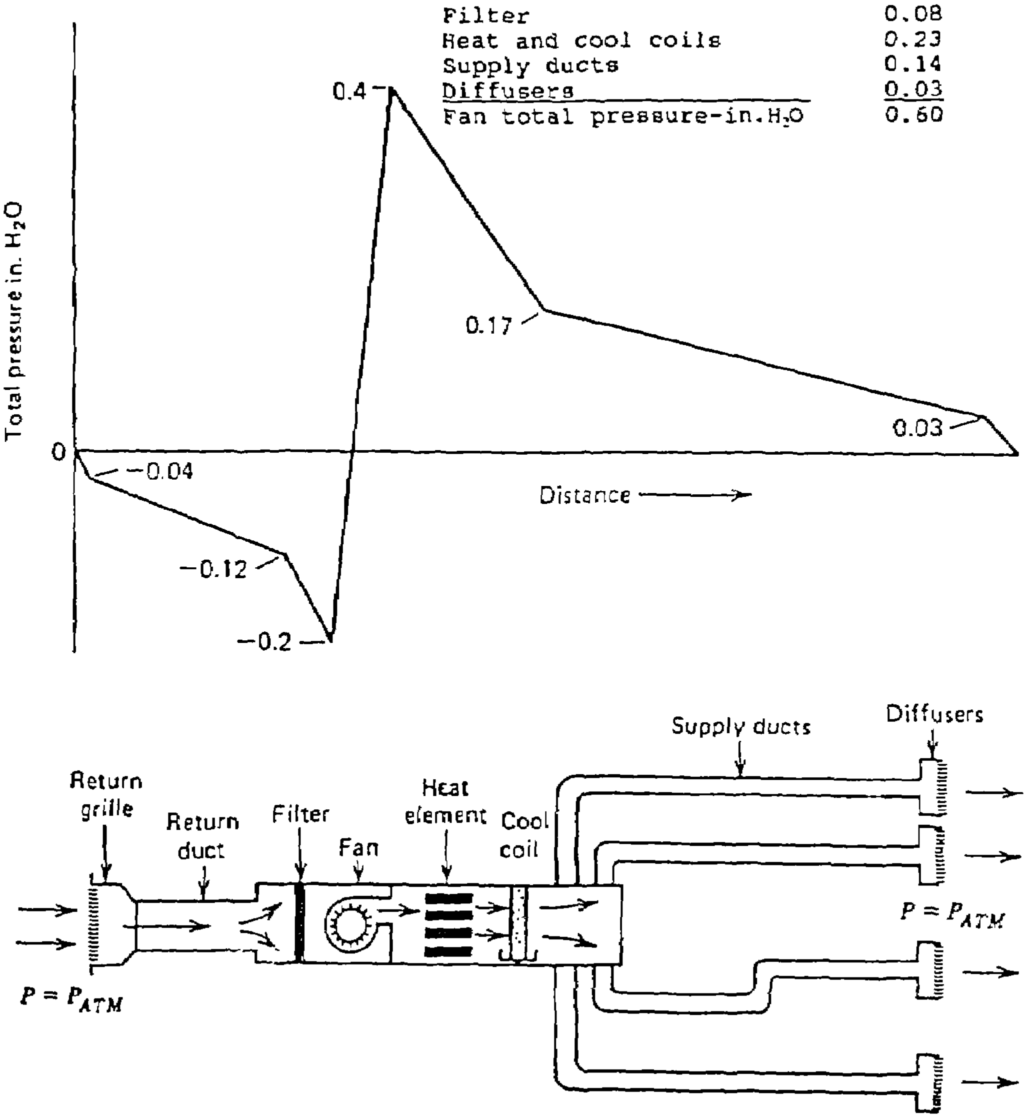

Figure 2 - Example of a Pressure Profile in a Simple HVAC System
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From Heating, Ventilating and Air Conditioning, Copyright © 1977, 1982, 1988 by John Wiley & Sons, Inc.

If there are leaks in the return duct of the system where the duct static pressure is below atmospheric, air will enter the system. If that part of the system is located in the subslab radon may be drawn in with that air. In many cases duct leakage works to the detriment of heating or cooling efficiency. Unless that air comes from the space being conditioned air must be exfiltrated at the same rate it enters and at some location where the static pressure is above atmospheric, either from the supply ducts or from the room being conditioned by the system. If the rate of air loss in the supply duct is less than that entering, then the space being served will rise slightly in pressure over what it would otherwise be and the excess air leaked into the air returns will be exfiltrated to the surroundings. Any system will always operate so as to be in balance, with the rate of air intake always equal to the rate at which air is lost from the entire system.

For the same reason, any system that is exhausting air to the outdoors must have outdoor air furnished to it at an equal rate. If there are no forced supply systems or fans providing that air then the space pressure will drop below atmospheric. The space pressure will be at a level so that leakage in is equal the rate at which air is being exhausted. If a space is to be pressurized relative to the surroundings then the rate of forced air supply must be greater than any rate of exhaust so as to provide the air that will be lost by leakage.

Deliberate, controlled pressurization of a space having a central air system and a single fan requires skill in duct design and a knowledge of the fan's characteristics and of the room leakiness. The control techniques required for zoned pressurization were presented by S.A. Anderson (13). The room leakage or room porosity, a term used in the predictive equations, is a function of room construction. It is probably intuitive that tight rooms are more easily pressurized than rooms with a great deal of leakage. It would be expected in most cases that a room operating at a positive pressure level relative to its surrounding could have its pressure level increased by simply making the room tighter, assuming no change in the HVAC system.

Modification of existing HVAC systems serving rooms which do not have any level of positive room pressurization would require the introduction of additional makeup air, most likely at some location in the air return system where the static pressure is below atmospheric. Even moderate levels of room pressurization are difficult to maintain where exhaust rates are fairly high This has been a continuing problem in operating clean rooms, for example, where makeup air requirements for pressurization might be 25 to 50 times that required for typical office space. For such applications Brown (14) presented a discussion of energy-saving opportunities for makeup air systems. The techniques discussed there have some general application to schoolrooms, especially where there might be an expenditure of significant energy in maintaining desired room pressures for radon reduction. In some cases excessive rates outdoor air needed to provide pressurization might freeze the heating coils in cold weather.

With regard to radon gas, which comes in primarily from the soil, the room pressurization required is relative to that in the subslab or walls in contact with the slab or soil. For rooms directly above unoccupied basements the pressurization of importance might be that of the room relative to that of the basement space. Upper floors may be relatively free of radon contamination. Pressurization levels needed to prevent radon entry into a space are not high, being in the range of .004 - .016 inches of water column (1-4 Pascals).

Outdoor air pressures are variable with changes in the barometer and, for a particular wall, with wind direction and velocity. Stack effects in a building may increase or decrease the indoor pressure relative to that outside and further complicate one's ability to predict with precision the room pressure levels that might be attained in a particular situation.

If one has poor control of the room pressurization, excessively high pressures may inadvertantly occur This can lead to such undesirable behavior as doors standing ajar or hard to open and slamming doors or whistling air through the space around a door. Static pressures greater than 0.2 inches of water column (50.0 Pascals) must be avoided at any time to prevent problems with opening doors. Dirkes (15) and Holness (16) have discussed the procedures and the difficulty of maintaining balanced air pressures in buildings of the large industrial type. These discussions may be pertinent to school shop areas and gymnasiums.

Raising the room pressure will increase the static discharge pressure on the supply fan and this will in turn reduce the air flow, assuming constant fan rpm. This reduced air supply from the fan combined with increased exfiltration losses may leave some systems short of necessary air flow to meet the comfort demands of the system. In some cases the fan may even be backed up to the point where it cannot operate at a stable condition. In some cases fans will need their rpm increased, in other cases fans may need to be replaced.

PRESSURIZATION CONTROL

Ideally the relative air pressure should be controlled by a pressure differential sensor that control fan speed or dampers to maintain the desired pressure differential under all operating conditions. A typical control block diagram for damper control only with fixed fan speed is shown in Figure 3. A schematic for pressure control using both damper and fan speed control for a typical VAV system from Haines (17) is also shown.

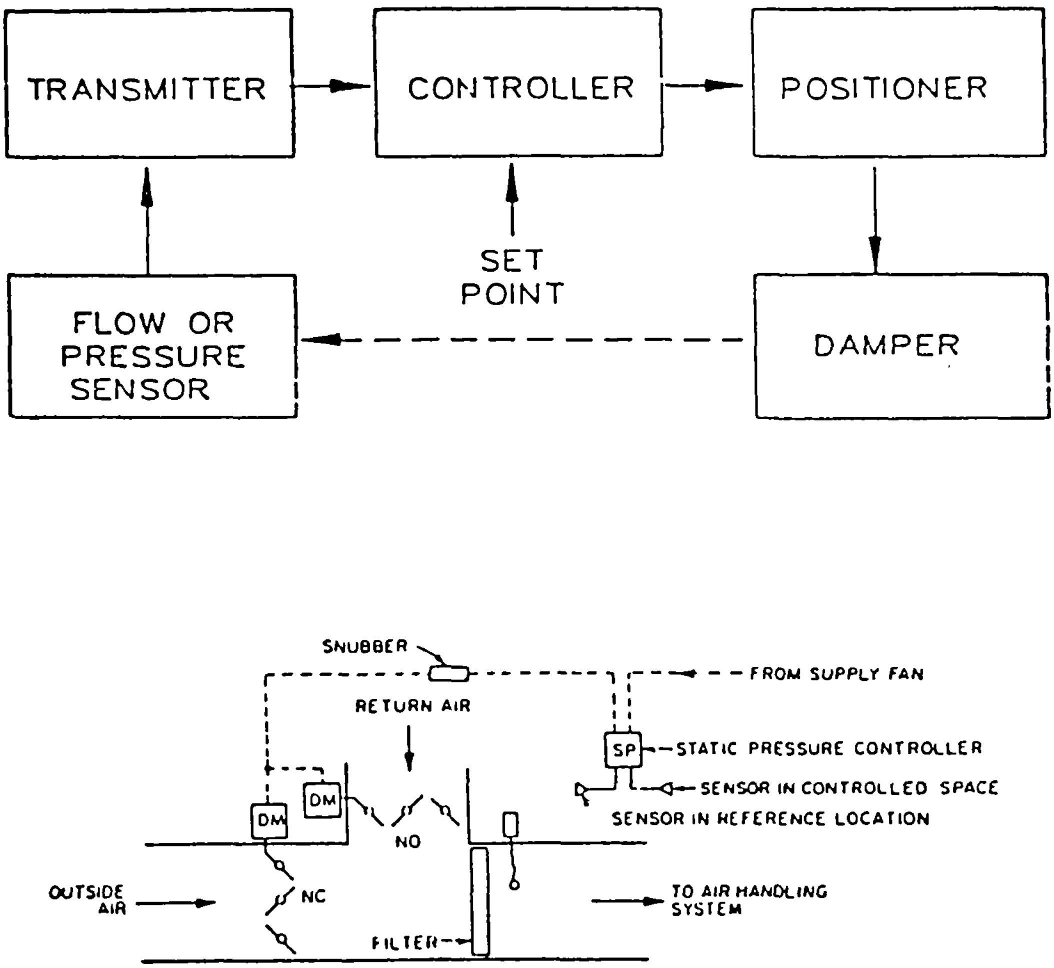

Figure 3 - Pressure Differential Fan Control
From Haines, Control Systems for Heating, Ventilating and Air Conditioning, Fourth Edition (17)
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The importance of the flow transmitter selection for return fan control in VAV systems is discussed by Smith (18). Location of both indoor and outdoor sensors is critical to satisfactory operation. Building pressurization control is discussed from a practical standpoint in the Trane Applications Engineering Manual, Trane (19). The difficulty seems not to be in just maintaining a suitable pressure level in a space but rather in doing this economically while maintaining thermal comfort within the space being pressurized.

In many schools there are separate buildings, connected by corridors which may become uncomfortable "wind tunnels" if the pressure differences between buildings is not controlled. It may be desirable in some cases, such as with laboratories, to maintain some reasonable pressure difference to control fumes and odors. The pressure control problem can be particularly critical for variable air volume (VAV) systems or where economizer cycles (with large changes in outdoor air) are utilized. Atkinson (20) discusses the control of such systems and the experience with a situation in a Western U.S. university laboratory and classroom building. He concluded that control could be accomplished in such cases if the duct pressure control system in each building can control accurately, laboratories are always controlled to remain at negative pressure relative to classrooms, and by fine tuning relatively balanced mechanical system airflows by measuring the differential pressure across the corridor and making up outdoor air or relieving the classroom building to maintain the building pressure relationships at an acceptable level.

The similar problem created in multizone buildings with variable thermal loads in each zone, a building stack effect and the need for odor and fume or smoke control for some zones is discussed by Bentsen (21). He concluded that flow tracking or control of air flow rates should be used in zones with high leakage and zones lacking containment, for example where there are large openings between zones. Static pressure control seemed to be best suited for tightly sealed, contained zones, for example where doors are always closed between zones.

A secondary benefit from introduction of outdoor air for pressurization is the dilution of the polluting gas in the conditioned space. In many practical situations rooms have a large number of cracks and openings to the outside and the exfiltration caused by pressurization requires the introduction of significant amounts of outdoor air. Thus pressurization would rarely occur independently of ventilation. On the other hand ventilation can occur in a space without room pressurization, depending upon the relative rates of outdoor, infiltration and exhaust air. There is a practical limit to what ventilation can accomplish, a limit which is dependent upon the source strength of the polluting source. This is illustrated in Figure 4, which shows the diminishing effect of increasing air ventilation rates. Piersol and Riley (23) in their

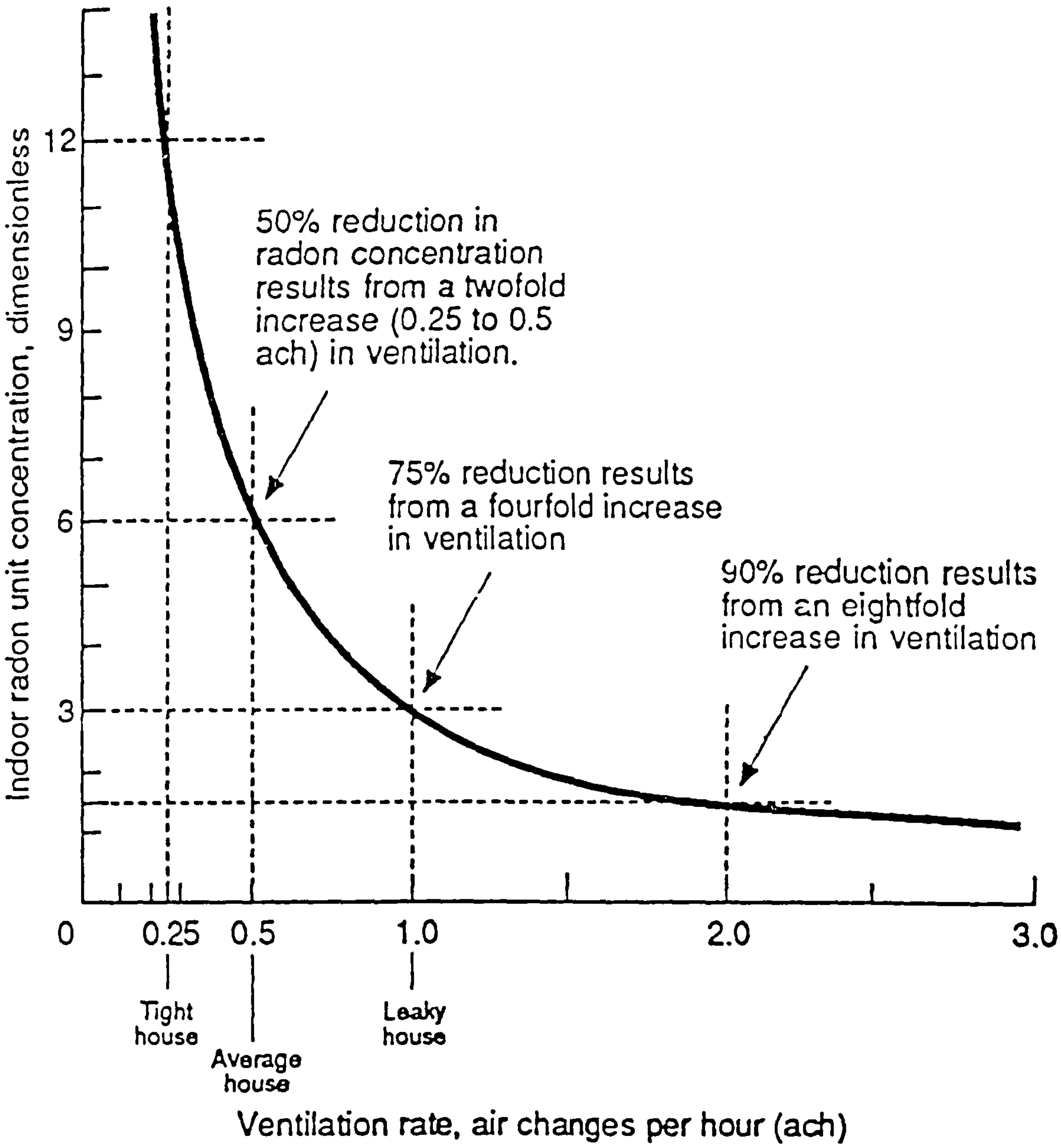


Figure 4 - The Diminishing Effect of Ventilation Rate (22)

study of ventilation and air quality state that "Pollutant source strength, not ventilation, is the predominant parameter in determining indoor pollutant levels." This study did not consider the effect of pressurization in reducing source strength, such as might occur with radon entering from the subslab.

AIR DISTRIBUTION; RETURN, RELIEF, AND EXHAUST COMPONENTS

Return fans, such as the one shown in Figure 1, are necessary when the pressure drops in the return ducts are excessively high due to long duct runs or inadequate space is available for a normally sized return duct. Simply removing the return fans from a system might result in increased room pressure levels but without controls the pressures might vary unacceptably. The removal of return fans might also reduce room outdoor air flow rates to unacceptable levels. Return fans are commonly used to permit the conditioned space to be held closer to atmospheric pressure, a goal which appears to be in opposition to what is desired in radon abatement.

Designers have widely varying opinions about the use of return fans, some never using them and others employing them frequently in their designs. Thus one might expect to find their use in one case and not see them in a very similar type of system designed by another firm. Compensation for this difference would be in the duct design, with larger return ducts used in the systems without return fans.

Care must be taken in the use of return fans since they can create negative pressures in the conditioned space and may create disturbing fluctuations in the flow. An additional complication occurs if the supply fan operates on a variable flow basis (as in VAV systems) since then the return fan must "track" the supply fan properly to maintain both the proper rate of makeup air and the desired space pressure. Kettler (24) discussed some of the field problems associated with return fans on VAV systems and suggested that major problems in surge and building pressurization difficulties could be solved by controlling the supply fan from duct static pressure and the return fan from the building pressurization. using low-limit control. In new designs relief fans should be used instead of return fans so that the problems created by return fans are eliminated.

Alcorn and Huber (25) state that many stability problems in control of supply and return fans in VAV systems are the result of the fans being coupled in the control scheme and due to deficiencies in the control algorithms being used. Their paper discusses how some of the problems may be corrected.

Care must be taken in both design and operation of new or modified systems to assure that no part of the duct system is damaged by the consequences of too high or too low a static pressure within the duct.

Relief fans are used to control the static pressure in return ducts. They differ from return fans in that they are not in series with the total air return flow and they remove some air from the duct. They are similar to return fans in that their operation tends to reduce the pressure in the room. Fans which remove air directly from the conditioned space are referred to as exhaust fans.

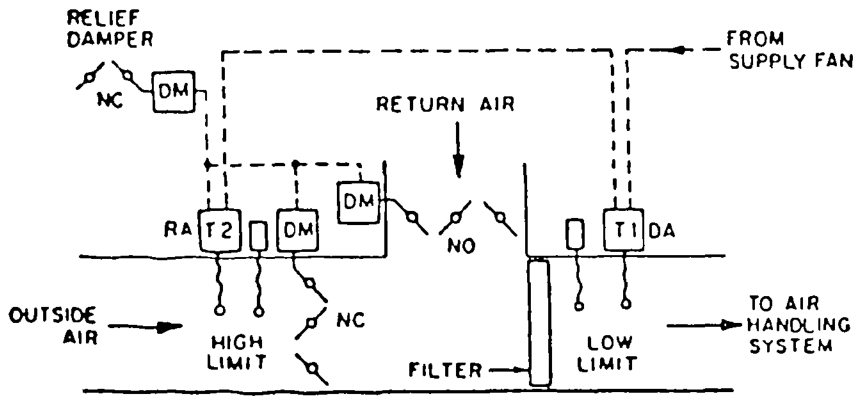
The operation of relief and exhaust fans in an existing system may be necessary in order to assure that there is adequate incoming outdoor air and to assure continuous thermal comfort and satisfactory air quality but they tend to lower room static pressure levels, and consequently will work against radon control.

THE ECONOMIZER CYCLE

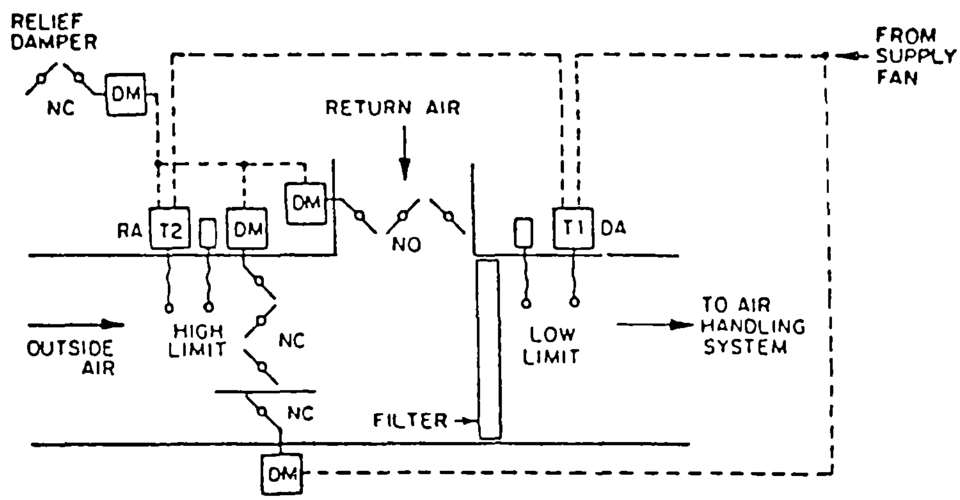
It is often possible to use cool outdoor air to either totally or partially meet the cooling load in one or more zones. This is especially the case during the spring and fall seasons and at night in northern latitudes and at high altitudes. Some buildings have interior zones that require cooling year around and the economizer can be used to meet that need during the cooler part of the year. This results in significant savings in many cases and the extra equipment required to do this is called an economizer. The economizer consists of the controls necessary to sense the outdoor and indoor (or return) air conditions and to operate the intake, return and relief dampers to provide the optimum amount of fresh air for the existing conditions.

Figure 5 shows two of the possible arrangements, using only temperature sensing to control the dampers. In (a) when the outdoor temperature is at the winter design condition the outside and relief dampers are set to provide the required minimum outside air to meet ventilation requirements, and the return dampers are at a maximum open position. For warmer outdoor temperatures the mixed air thermostat (T1) opens the outside air damper to provide the desired mixed air temperature and the return and relief dampers adjust accordingly. At some outdoor temperature, usually between 50 and 60 F (10 and 16 C) the damper system will provide 100% outside air. At some higher temperature, usually slightly above 70 F (21 C) the high limit thermostat will close the damper system back down to minimum outside air. An interlock with the supply fan assures that the outside air damper will close when the fan is off. Outdoor humidistats are widely used in place of thermostats to limit the use of outdoor air if the outdoor air enthalpies are too high for maintaining comfort.

The system shown in (b) operates in a manner similar to the system in (a) except that there is a separate damper to provide the minimum outside air whenever the fan is running and which is not



(a) No fixed minimum
outside air



(b) Fixed minimum
outside air

Figure 5 - The Control of An Economizer Using Temperature Sensing
From Haines, Control Systems for Heating, Ventilating and Air Conditioning, Fourth Edition (17)

affected by the air temperatures.

In both cases, where room pressurization control is desired, there must be sufficient outdoor air at minimum setting of the damper system to provide positive room pressure and there must not be too high a room pressure when the economizer damper system is providing high rates of outdoor air. Static pressure control of the relief system may need to be considered.

TYPES OF HVAC CENTRAL SYSTEMS

SINGLE ZONE

A single zone system can be used where all of the space or spaces have heating and cooling requirements sufficiently similar that comfort conditions can be maintained by a single controlling device or thermostat. Very large spaces and large or multi-story buildings usually require more than a single zone to maintain comfort in all spaces.

In a single zone constant-air volume (CAV) system the distribution of the air to the rooms is fixed by the design of the ductwork, and can be modified only to some degree by the adjustment of dampers within the duct system or at diffuser outlets. In a zone with multiple rooms and with limited air returns with restricted air flow between rooms a variation in pressure between rooms is highly probable with the possibility of one or more rooms being below while others are above atmospheric pressure. As with any system, pressurization of all rooms could only be attained with total rate of system intake of outdoor air exceeding that of the exhaust.

MULTIZONE

In all-air, multizone systems the discharge area of the air handler is divided so that several zones may be served, with separate temperature control in each zone. Hot and cold decks within the air handler provide heating or cooling as required in each zone. Dampers in the air handler are controlled by the zone thermostats to supply the proper air temperature and flow to each zone to meet that zones' individual load. A schematic of a typical multizone system is shown in Figure 6. The typical control system for a multizone system, shown in Figure 7, is the same as that for a constant volume dual-duct single fan system. Normally there is no provision for automatic control of either room or duct static pressure as these are set by system design and component adjustment.

If room pressurization and control is to be added to a constant volume multizone system it might be most easily accomplished by addition of controlled relief dampers in the return duct of each zone and a corresponding reduction in return and

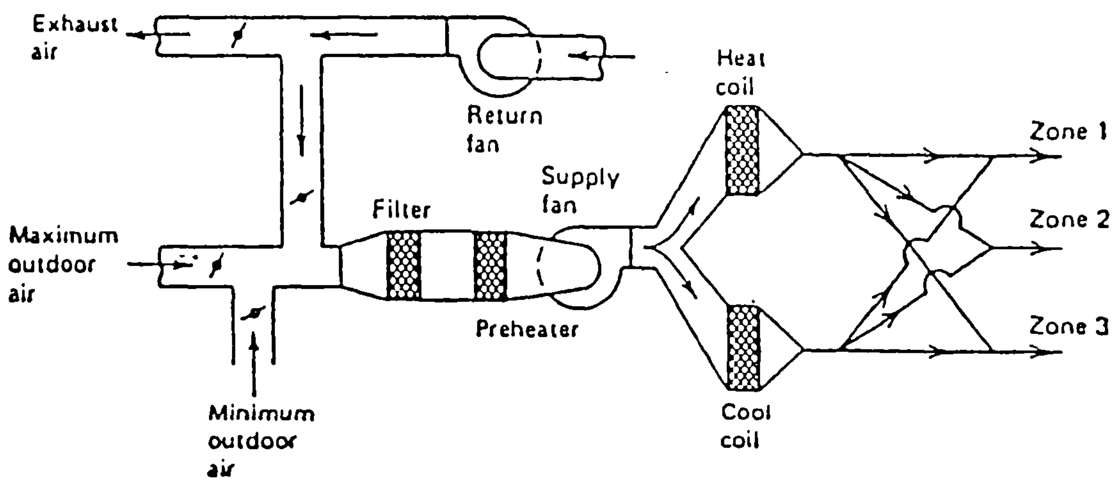


Figure 6 - Schematic of a Simple Multizone System (12)
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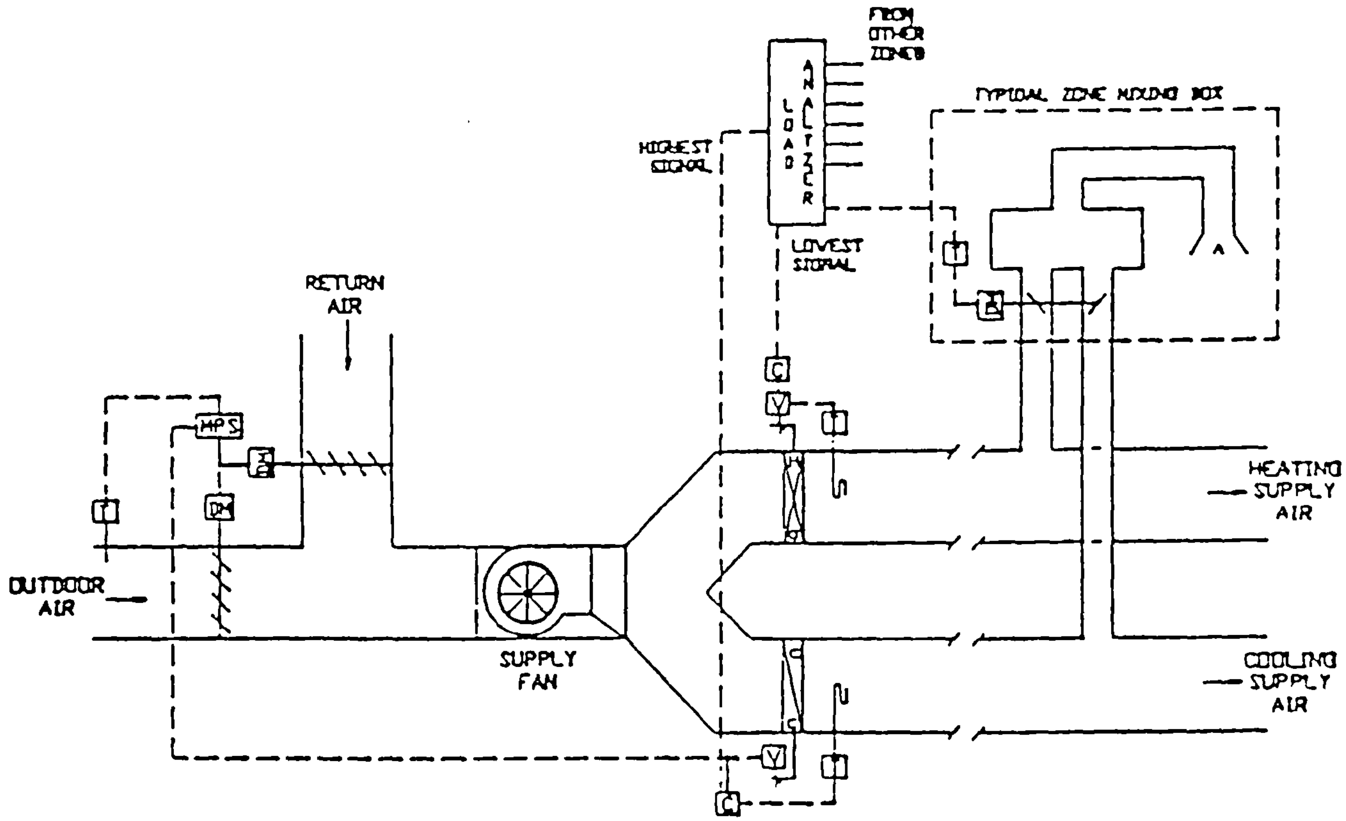

Figure 7 - A Typical Control Scheme for a Multizone System
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HVAC Applications Handbook (33)

central exhaust flow. With this modification for pressure control there would be concern that the existing fan and duct system could provide sufficient air flow to all zones to meet comfort demands. The second concern is that additional quantities of hot and cold air would be used to maintain comfort during both occupied and unoccupied periods and operating costs could be increased significantly. These concerns would be particularly valid if the building or parts of it have high leakage rates.

With supply and return ducts for each zone it is possible for the zones to operate at different static pressures although normally the engineer would attempt to design for each space to be near atmospheric pressure. In a multi-story building, where it might be necessary to pressurize only the ground floor rooms, careful duct design or modification might be necessary. For a positive pressure to exist in every zone the makeup air rate must exceed the overall exhaust air rate for the air handler.

For energy savings it is common practice to close outdoor air dampers during warm-up and unoccupied cycles. If room pressurization is considered to merit the additional operating cost involved, this control feature must be modified to allow the minimum makeup air rate required to obtain the desired level of pressurization.

Some multizone systems may have been modified to be VAV systems to conserve energy, particularly where cooling is the major load. These modifications could be carried out in several different ways. Wendes (26) discusses ways to accomplish this modification.

VARIABLE AIR VOLUME (VAV) SYSTEMS

The <u>variable air volume system</u> has been mentioned previously. These systems, which compensate for variations in heating or cooling load by regulating the volume of air supplied to each zone, are sometimes simply called <u>VAV systems</u>. Energy conservation as well as improved controls and equipment have made VAV an increasingly popular option.

In the VAV system each space supplied by a controlled outlet is a separate zone with its own thermostat. A VAV schematic is shown in Figure 8. Although some heating may be done with a variable volume system, it is primarily a cooling system and should be applied only where cooling is required a major part of the year. The best candidate buildings are those with large internal loads. A secondary heating system, such as baseboard heat, should be provided for boundary zones. During the heating cycle tempered fresh air is supplied to these boundary zones to maintain air quality. For zone pressurization a minimum rate of supply airflow would be required, depending upon zone leakiness and rate of return air flow.

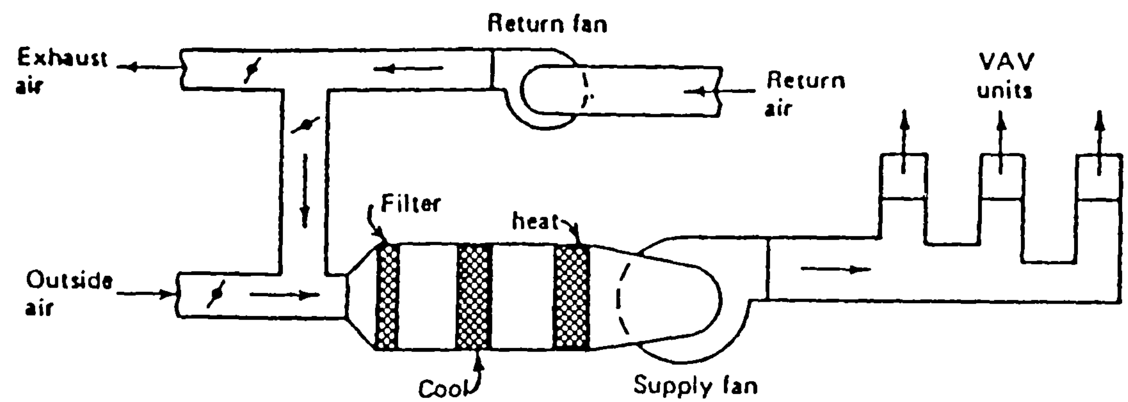

Figure 2-19. Variable air-volume system.

Figure 8 - A Simple VAV System
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The variable air volume concept has been applied to a variety of HVAC systems including both single and dual duct, with and without reheat, and with both all-air and air-water installations. It offers significant savings in operating costs, due primarily to reduced fan power costs at part load. In some cases it permits closer control and, especially where there is load diversity, reduced first costs. For cool weather conditions the economizer cycle is easily adapted to VAV systems. In addition the duct systems are virtually self-balancing. Haines (27), Wendes (26), and others have described the double-duct, double fan VAV system to be one of the most energy efficient HVAC systems available.

The main concern with using VAV systems to control radon levels is the maintenance of suitable static pressures and rates of dilution in each zone under all conditions of operation, especially at the very low air flow rates that normally occur when there are low cooling loads in one or more zones. It has been mentioned previously that Wheeler (6) expresses concern over the effect of ASHRAE Standard 62-1989 on school classroom ventilation rates. With VAV systems the new standard will require ventilation rates that will prevent large turndown ratios. IN such cases concern with reduction in the pressurization level will be lessened. However, this will tend to overcool the classroom space when cooling loads are low and will require reheat to maintain thermal comfort. Wheeler suggests that the number of occupants in a classroom be estimated realistically when computing required outdoor air. He also suggests the use of a fan powered VAV system to produce a continuous high rate of room air exchange and the employment of demand controlled ventilation (DCV) to save energy.

An additional concern arises in VAV systems when return or relief fans are used since they must successfully track the variable flow supply fan. These concerns have already been discussed in some of the previous sections. Alcorn and Huber (25) have discussed the need for taking special care in the design of the automatic control sequence. Their method involves decoupling the control of the supply and return fans and selecting suitable scan times in the direct digital control system.

Wendes (26) discusses the maintaining of building pressures when using VAV system with no fan controls (fan bypassing to obtain VAV). If no economizer is used, the outdoor air damper can be set to bring in sufficient air to cover losses and still maintain pressurization. The proper amount of bypass and return air must be maintained to prevent over or under pressurization. If an economizer is used there may be too much pressurization when additional outside air is brought in for free cooling. Relief air to the outside, equal to the additional outside air brought in, must be provided.

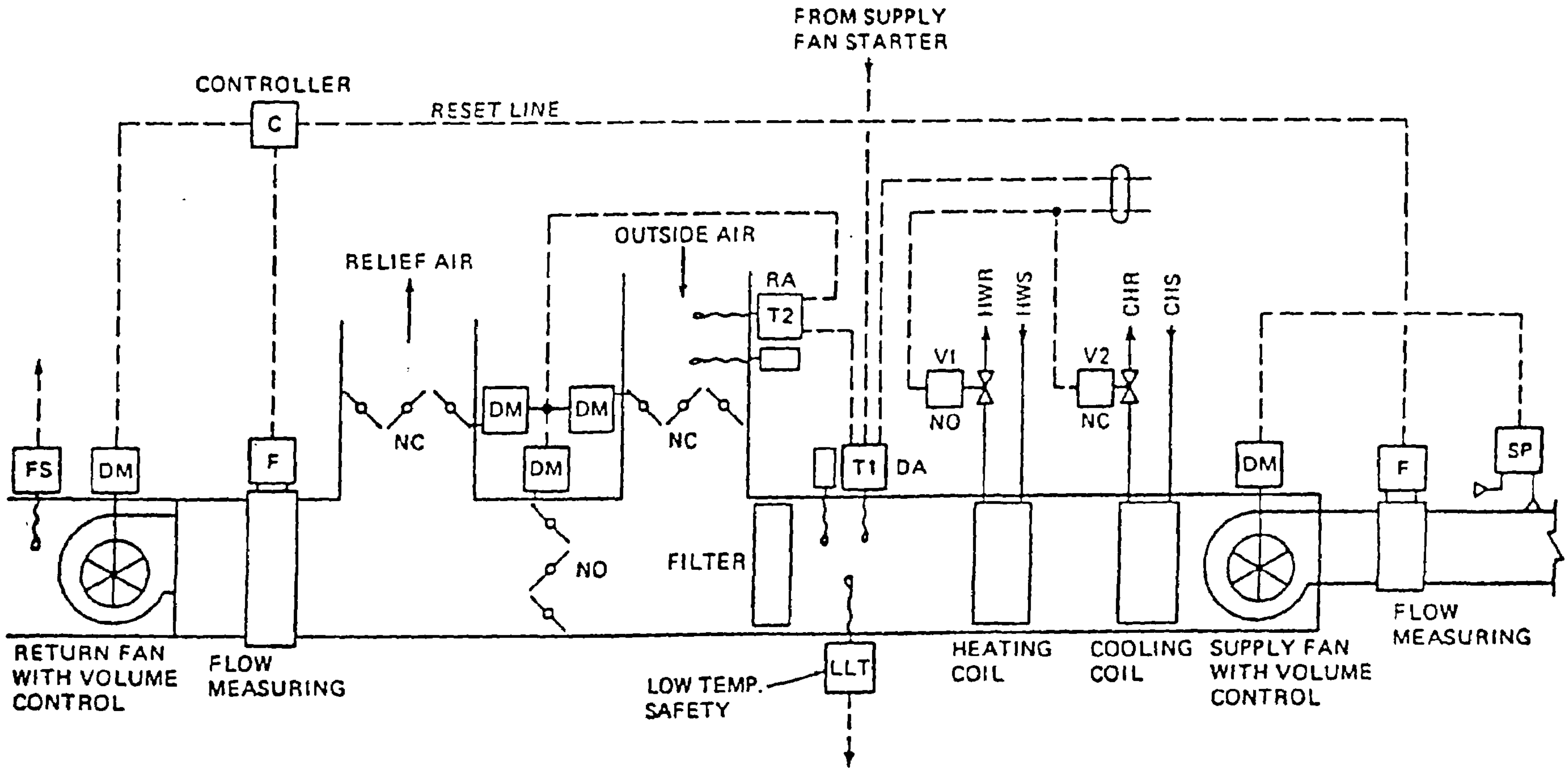

Figure 9 - Air Handling System for VAV with Return Fan Control Using Flow Measurement
From Haines, Control Systems for Heating, Ventilating and Air Conditioning, Fourth Edition (17)
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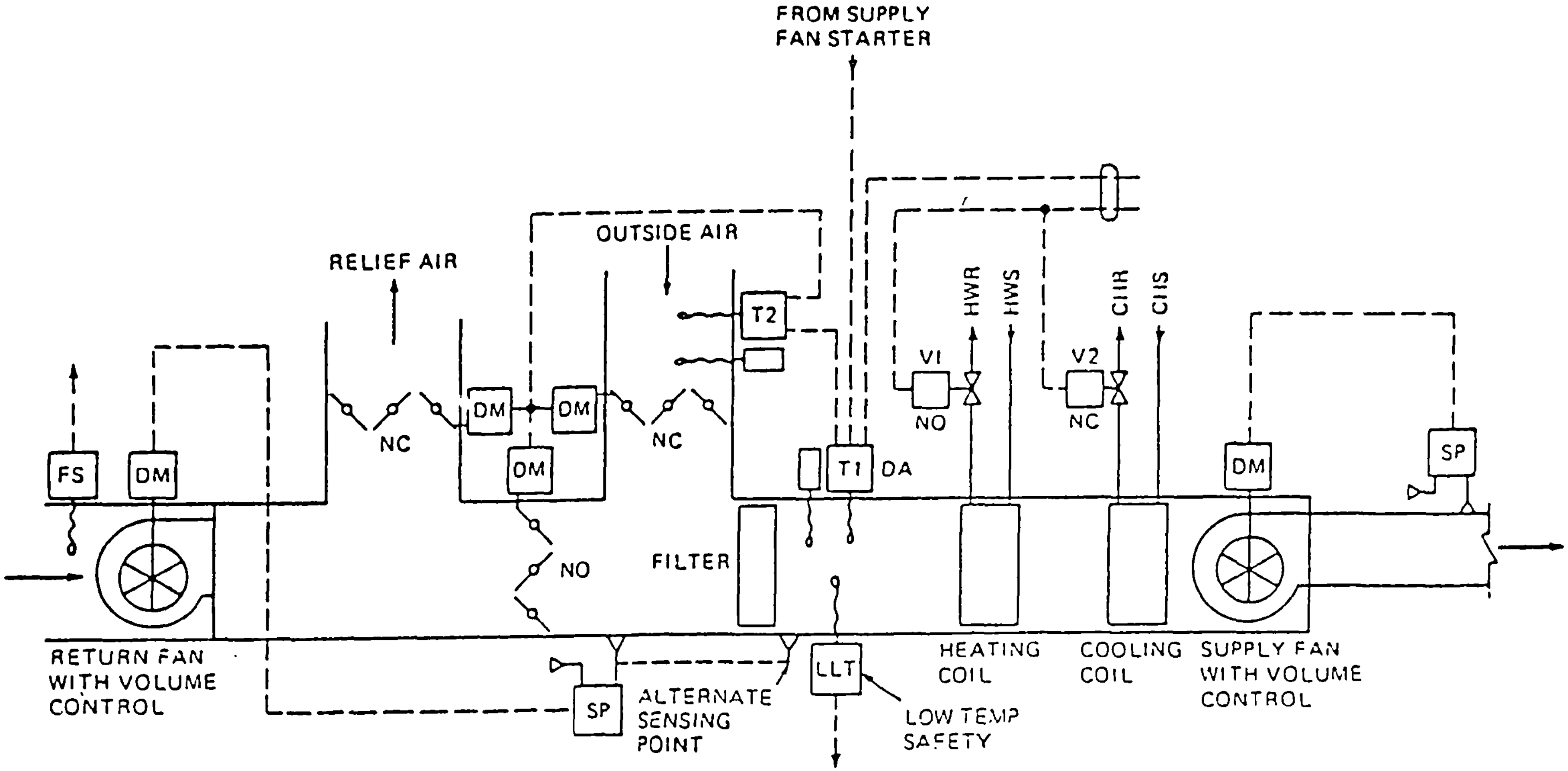

Figure 10 - Air Handling System for VAV With Return Fan Control Using Plenum Static Pressure
From Haines, Control Systems for Heating, Ventilating and Air Conditioning, Fourth Edition (17)
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Haines (17) describes the control of VAV systems having return fans. His schematic for control using flow measurement is shown in Figure 9 and for control using plenum pressure is shown in Figure 10. He states that flow measurement is more accurate but more expensive. Plenum pressure control is simpler and less expensive. Holding plenum pressure constant provides constant pressure across the outside air dampers and thus a constant flow of outside air, but at least 10 percent outside air is necessary to maintain control.

REHEAT

The reheat system, a variation of the single-zone system, permits close temperature control in several zones having unequal loading. A simple schematic of a reheat system is shown in Figure 11. A heating device (hot water or steam coil or electric resistors) is placed in the duct system leading to each zone and is controlled by the zone thermostat. Preconditioned air coming to the heater is heated to maintain comfort in that particular zone. The air flow to each zone may be constant or variable.

In the cooling season the central unit should provide cold air at a temperature just sufficient to meet the requirements of the zone with the largest cooling load. The other zones are furnished sufficient heat via their reheat coils to provide comfort in those zones. In the heating season the heat is added to the recirculated and makeup air which in some cases has been preheated at the central air handler. Reheat is often used where humidity control is desired since the air can be cooled to a very low, and therefore very dry, condition before being reheated to the desired level of temperature and low relative humidity. Reheat systems are not commonly found in classrooms in primary and secondary schools in the U.S. and their use in other situations has been limited by codes and general concern over energy conservation.

Reheat systems do not present any special features that distinguish them from the basic central system as regards room pressurization and air dilution. As with the basic central system these desired capabilities depend entirely upon the fan, duct and room characteristics. Modification of these components to accomplish the desired levels of radon reduction should generally create no new problems in maintaining comfort, providing that satisfactory air flow is maintained across coil and/or heater surfaces.

The zone heater is usually controlled by the thermostat to provide the necessary comfort regardless of the air flow rate to the zone. Since pressurization may require increasing the air flow rates to some or all zones there may not be sufficient fan power to provide the air flow rates necessary. Simply increasing air flow rate from the fan may not provide even pressurization to each zone. Fans may need to be replaced or their speed modified. In some cases

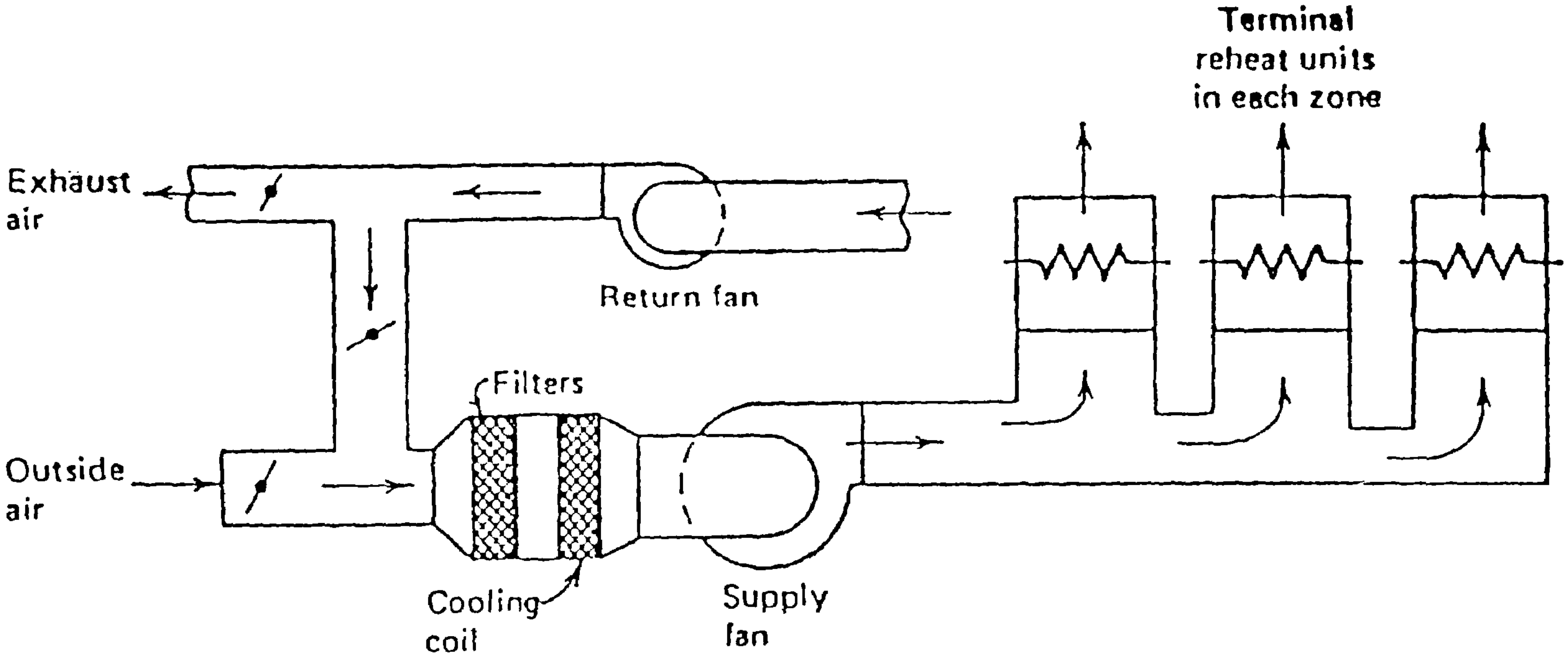

Figure 11 -A Simple Reheat System (12)
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adjustment of supply duct dampers or a combination of damper adjustment and addition of relief dampers might be required. Additional intake of outdoor air will be required in any case. As with any system the introduction of higher levels of outside air, except during economizer operation, will tend to lower the heating or cooling efficiency of the unit. Since reheat systems have not been considered energy efficient some of these systems have been or should be modified into VAV systems. Wendes (26) discusses some of the steps involved in such a modification.

The 1991 ASHRAE Applications Handbook (11) states, "For energy conservation, reheat systems have been restricted by ASHRAE Standards 90A-80 and 90.1-1989 and usually cannot be justified for schools, unless recovered energy is used for reheat.

"Dual-conduit and dual-duct systems are recommended if they are designed to minimize air quantities to those required and incorporate adequate energy conservation features to make them as economical as other systems."

The next section will discuss the dual-duct system and its special characteristics.

DUAL DUCT

Dual duct systems that are capable of meeting the energy conservation requirements of the latest ASHRAE standards have been recommended for use in some school systems (11). In the dual-duct system central equipment supplies warm air through one duct run and cold air through another. A simple schematic is shown in Figure 12. The temperature in a zone is controlled by a mixing box that mixes the warm and cold air to maintain the thermostat set-point. For dual-duct systems to work satisfactorily some form of control is required to maintain a constant overall flow rate of air as the thermal load changes. According to Int-Hout (28) the primary disadvantage with dual-duct systems has been the complexity of the necessary control systems and the lack of an affordable zone controller. The availability of affordable microprocessor-based controls has permitted dual-duct systems to now be considered a desirable alternative. Energy codes which prohibit the use of dual-duct systems unless energy savings can be proved in advance can now be more easily satisfied with the new controls technology.

This type of system can provide great flexibility in satisfying highly variable sensible heat loads between zones. It is capable of furnishing heat to one zone at the same time cooling is being furnished to another. An economizer with all outdoor air can be used when the outdoor temperature is low enough to handle the cooling load. Because of these features these systems are very common in office buildings, hotels, hospitals, and large laboratories. They are less common in school buildings.

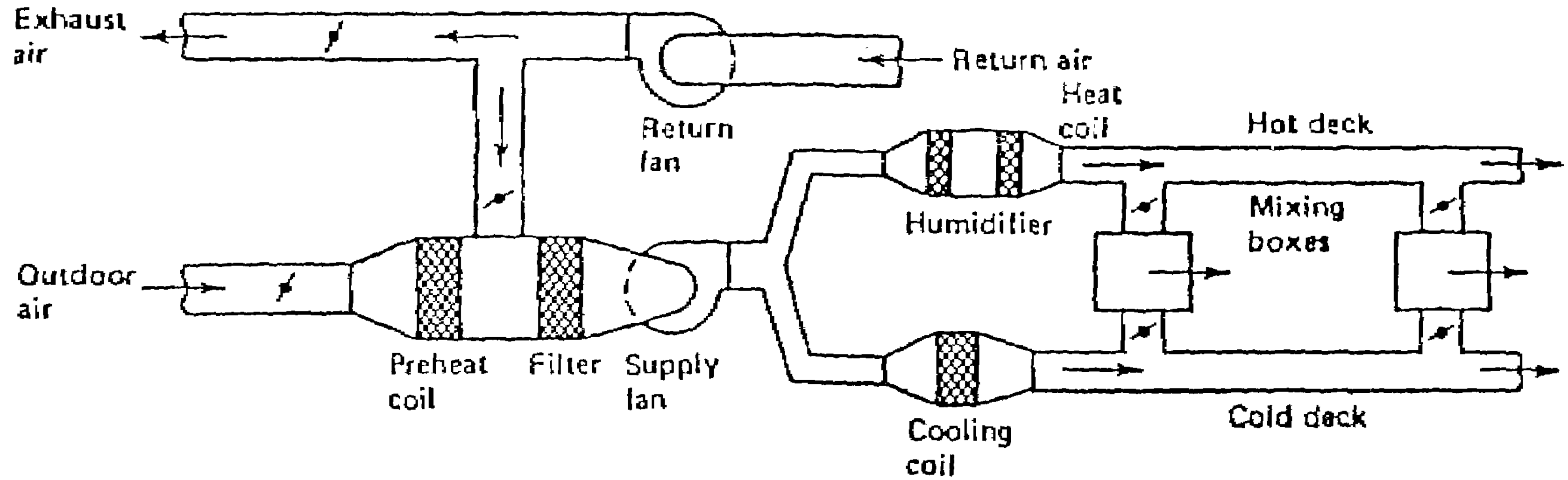

Figure 12 - Schematic of a Simple Dual Duct System (12)
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Many of these systems have been converted from constant volume to variable volume (VAV) to conserve energy and almost all new dual-duct systems proposed are of the VAV type. In VAV systems two supply fans are usually used, one for the hot duct and one for the cold, with each controlled by static pressure downstream in each duct. If a return fan is used, and it most often is, it is a single fan, controlled by room static pressure. Successful application and advantages of these systems in California is described by Linford (29), using 100 percent shutoff air valves (dampers), pressure-dependent controls, and 100 percent recirculation during heating. Outside air is furnished to perimeter zones by mixing returns with the interior zones on the economizer cycle. This system would require minimum outside air during heating in colder climates than experienced in Northern California.

The control of such a system is shown in Figure 13 from ASHRAE (11). The advantages of the properly designed dual-duct VAV system is further described by Kettler (30). Haines (27), a well-known writer in the controls area, states "It is not unreasonable to argue that two-fan double-duct with VAV may be the best possible solution to many air-conditioning problems, in terms of both energy conservation and quality of control." Wendes (26) makes a similar statement regarding the energy efficiency of these systems. A problem common to all VAV systems might occur in attempting to use dual duct VAV systems for room pressurization since there would have to be minimum flow rates established to maintain desired pressure levels. In the case of classrooms, new outdoor air requirements per occupant might give higher minimum flow rates than that necessary for pressurization however. Again the need for reheat at low cooling loads might cause excessive energy requirements and eliminate this type of system from consideration. Higher first costs may also be important in eliminating these systems from consideration.

AIR INDUCTION

Air induction systems are not common in school buildings but need mentioning as a possible consideration. A simple diagram of an air-water induction unit and a typical control schematic, Haines (17) are shown in Figure 14. Centrally conditioned primary air is supplied to the plenum at high pressure. The plenum may be acoustically treated to reduce noises generated in the duct system (often high velocity) and in the unit itself. A balancing damper can adjust the rate of primary air over some limited range. The primary air flows through the induction nozzles, drawing in secondary air from the room and over the coil. The coil either heats or cools the secondary air, which is mixed with the primary air and the mixed air is then discharged into the room. Induction units are usually installed under a window or overhead. In the heating mode floor mounted units can operate by free convection to provide heat with no primary air during unoccupied hours. In such cases the pressurization and dilution effect of the primary air is

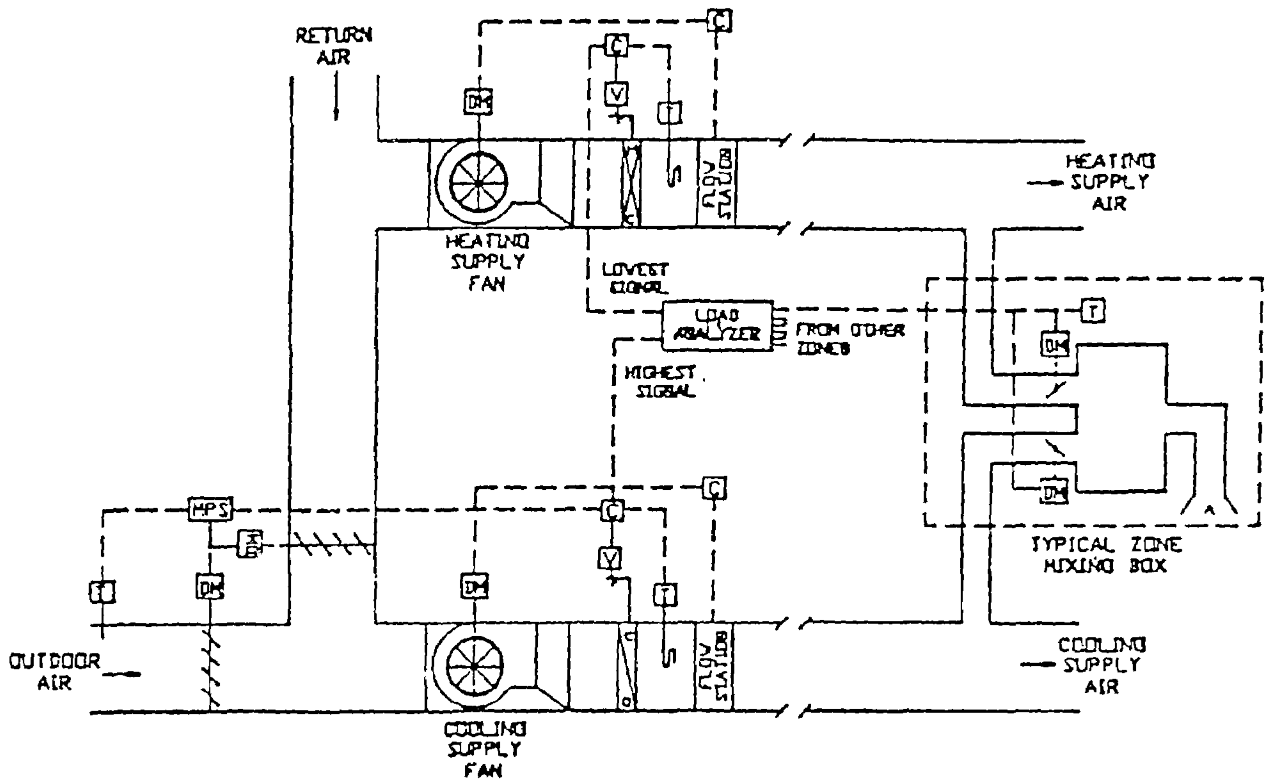

Figure 13 - Control of a 2-Fan Dual-Duct VAV System
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HVAC Applications Handbook (33)

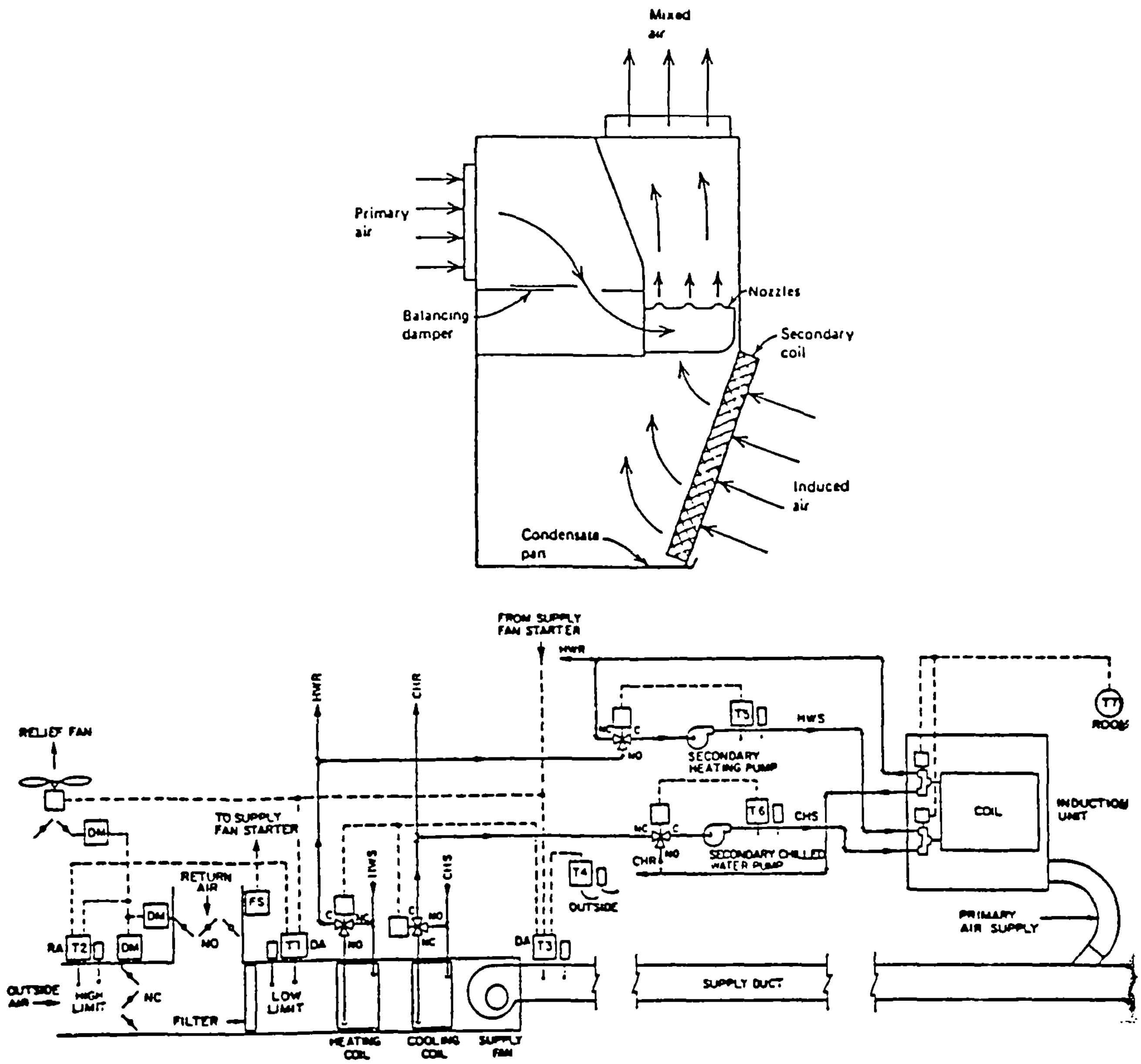


Figure 14 - Simple Diagram of an Induction Coil and Typical Schematic of an Induction System
From Haines, Control Systems for Heating, Ventilating and Air Conditioning, Fourth Edition (17)

not in effect.

Since induction units with no air returns give the room positive pressurization as well as dilution when operating with primary air a decision must be made with regard to their use for radon control is one of scheduling the hours of operation with primary air. With proper data one could determine a schedule that would permit the turning off of primary air for some periods, but which would still reduce levels prior to occupancy. For maximum effect when operating with primary air the unit should be set for highest primary air flow consistent with acceptable noise level and considering the effect of changing damper setting on the remaining units operating from the same central fan. As with most systems having a positive space pressure the tightening of the room itself will raise pressure levels. Assuming that the air delivery system has been properly designed and constructed it would normally not be productive to attempt to increase room pressurization levels by increasing fan speeds or sizes for moving additional primary air through the induction units.

UNITARY AND OTHER SYSTEMS

FAN COIL SYSTEMS

A typical fan-coil unit, a terminal unit used in both air-water and water-only systems, is shown in Figure 15. The fan section circulates room air continuously across a coil, which is furnished with either hot or cold water. In some fan-coils there is a separate heating unit which may be electric, steam or water heated. Primary (makeup) air may be furnished directly to the room by a separate central system. The primary air is normally only tempered to room temperature by the central system during the heating season but is cooled and dehumidified during the cooling season. During unoccupied periods of the heating season the primary air may be shut off to conserve energy. This conditioning of air in a central system does not appear to be common in school buildings.

As with the induction system there is normally no air return and the space operates with positive static pressure during the time that primary air is being furnished. The characteristics of the air delivery system is totally independent of the fan-coil unit and is not controlled by the zone thermostat. Room primary air delivery and static pressure must be controlled by central fan operation and any individual room dampers that might be present. Room pressurization levels can be increased by improving the tightness of the room.

Fan coil terminals or fan coil units have been described previously as devices used to provide heating or cooling in all-water systems as well as in the air-water systems. In all-water systems no primary air is provided from a central source. The <u>Type 1 fan coil unit</u> has no provision for outside air, recalculating 100

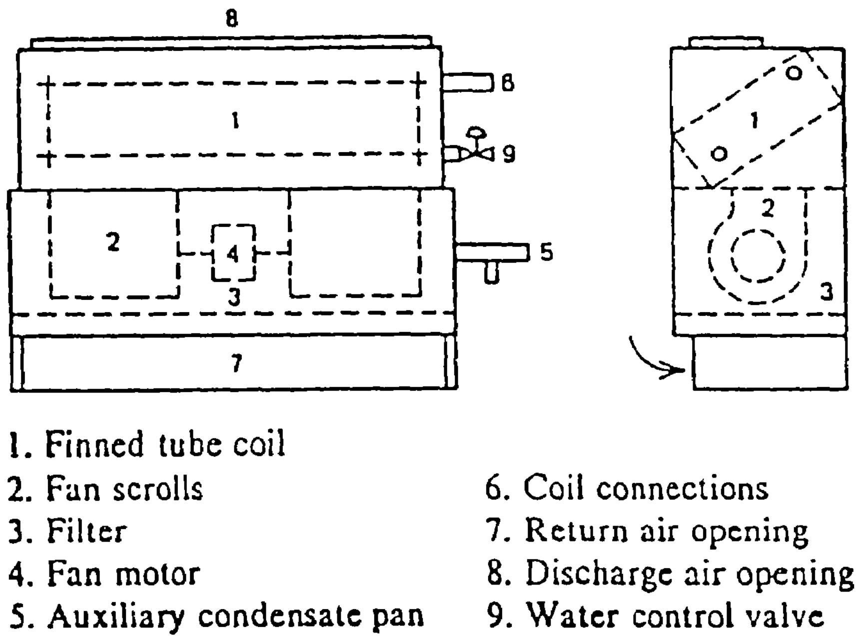


Figure 15 - A Simple Fan Coil Unit
Reprinted by permission of ASHRAE from the 1987
ASHRAE HVAC Systems and Applications Handbook (33)

percent room air, and is used for heating only in all-water systems. Type 2 fan coils are designed to introduce up to about 25 percent outside air to control air quality and may have cooling as well as heating coils. Type 1 units, with no provision for outside air, would be a poor choice for classrooms, which require ventilation, and would not be capable of providing room pressurization for radon abatement.

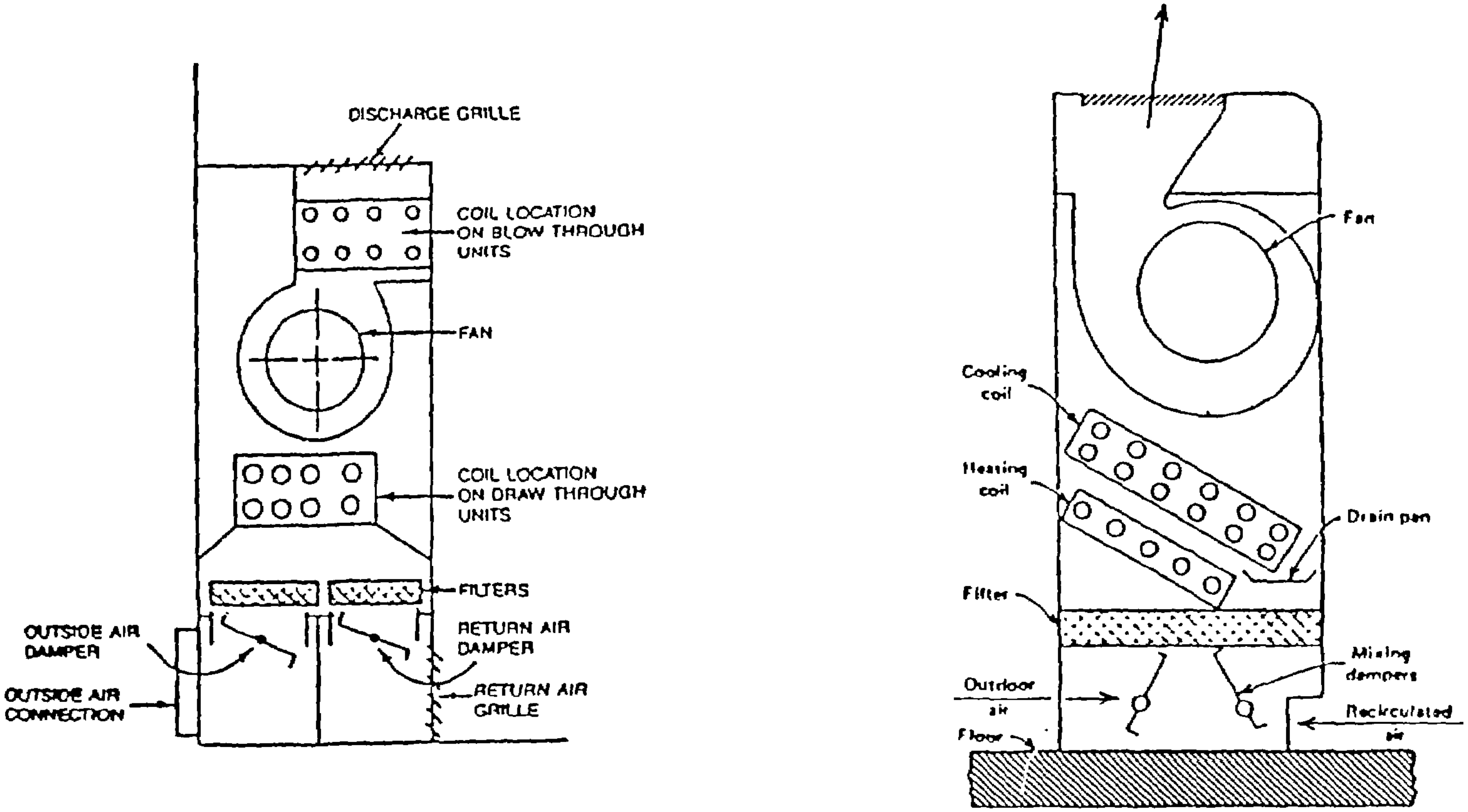
A type 3 fan coil unit has provision for 100 percent outside air and is usually referred to as a unit ventilator.

UNIT VENTILATORS

The unit ventilator is perhaps the most popular type of heating system in U.S. classrooms, and the classroom is its primary application. The heating unit ventilator heats, ventilates and cools a space by introducing outdoor air but has no refrigerated, cool water provided to its coil, depending entirely upon the outdoor air for any space cooling that might be required. An air-conditioning unit ventilator has refrigerated water provided to its coils to provide air cooling in addition to its ventilating and heating capabilities. The arrangements of components in typical floor-mounted unit ventilators are shown in Figure 16 (31). The units may be either blow through or draw through depending upon the location of the coil or coils relative to the fan.

The fan in a typical unit ventilator runs continuously, with the discharge air temperature being used to control the heating, cooling and ventilating functions. Whenever the outdoor air temperature is below the indoor temperature the heating unit ventilator increases the intake of outdoor air to provide space cooling. The air-conditioning unit ventilator can provide cooling even when outdoor temperatures are too high for ventilative cooling. A room thermostat controls the functions to provide the desired comfort level. During heating seasons the room thermostat is typically set down for unoccupied periods to save energy and during the warmer seasons the unit is turned off.

The unit ventilator can provide positive pressurization to the classroom since it brings makeup air into a space having no return system. Pressurization would not take place of course when the unit fan is turned off, during the warmup stage, or because the unit has been modified to turn the fan off when the indoor setpoint is reached. Pressurization would also not occur when the outdoor air dampers are closed, as they might typically be during the warmup stage or as a freeze protection measure when outdoor temperatures are below a setpoint. In the EPA SEP study of 26 schools Brennan (3) found that teachers frequently turned unit ventilators off because of the noise.



(a) coil-flow arrangement

(b) separate heating-cooling coils

Figure 16 - Typical Component Arrangement in a Unit Ventilator. Fig. 16 (a) reprinted by permission of ASHRAE from the 1988 ASHRAE Equipment Handbook (31) Fig. 16 (b) reprinted by permission of John Wiley & Sons, Inc. From Heating, Ventilating and Air Conditioning, Analysis and Design (12) by McQuiston and Parker, Copyright © 1977, 1982, 1988 by John Wiley & Sons, Inc.

Since the unit ventilator is providing air only to its classroom, pressurization of the room may be nullified if the classroom door is open and the hallway is not maintained at a positive pressure.

The most likely modifications of this type of system for energy savings would probably be in the lowering (or raising) of thermostats and reduced hours of operation. Control of the fan cycle and minimum outdoor air can be easily modified to provide room pressurization over any period of time deemed desirable for radon control. As with any system the cost of conditioning any quantity of outside air beyond that required for comfort may be significant. Pressure sensing and damper or fan control to maintain room pressure would likely be prohibitive since it would have to be applied to each classroom unit.

EXHAUST ONLY

Exhaust fans are frequently used in conjunction with HVAC systems to balance air flows in a zone and they are also used as the sole method of maintaining comfort in spaces with thermal gains (cooling load). Exhaust fans always tend to reduce the static pressure within a conditioned space. When used alone they always create a negative static pressure relative to atmospheric, and in most cases relative to subslab pressures. Where use would permit it (as regards noise levels and air turbulence and velocity and code requirements) exhaust only fans could be replaced with intake fans to reverse the direction of air flow to provide a positive internal pressure and exfiltration from instead of infiltration into the space. Filters are usually desirable in such situations to prevent the drawing in of dust and other even larger objects that might more easily be ingested by intake fans than by leaking cracks or openings with relative low air velocities. As with other HVAC systems the level of pressurization obtainable will depend upon the characteristic, number and location of the fans, the duct layout (if any) and the leakiness of the space. It is practically impossible to make reliable quantitative predictions of pressure levels in advance of installation.

Whereas exhaust increases depressurization of the interior space and thus the potential for radon entry, it also increases the entry of outdoor air which will dilute the radon that has entered the space. However exhaust and intake fans are almost never operated continuously, and are usually off during unoccupied periods and during periods of cool weather and in some cases where there is high outdoor humidity. Of course when the fans are off, the building internal static pressure will be approximately that of the outdoors, assuming there is no significant stack or wind effect. Some level of continuous pressurization could be accomplished by operating one variable speed fan or sequencing several small fans using static pressure difference control. In most cases some form of supplementary heat would be required to supply the load created whenever introduction of cold outside air would lower internal temperatures to an unacceptable level.

RADIANT AND FREE CONVECTIVE SYSTEMS

Some HVAC terminal units are natural (free) convective heating and/or cooling devices in which the heating or cooling is delivered without the use of fans or blowers. Thermal radiation provides an important fraction of the total heat furnished from the units.

The term radiator is usually applied to units made up of sectional cast-iron columns. The term convector describes a unit where the heating element is surrounded by an enclosure with an air inlet opening below and an air outlet opening above the heating element.The term baseboard heater refers to heat distribution units designed for installation along the bottom of walls, in place of the conventional baseboards. The term finned-tube heaters refers to heat-distributing units fabricated from metallic tubing with attached metallic fins. They may be bare or have an enclosure. In warm climates, where cooling is more significant than heating, natural convection downward is more desirable than the upward convection provided by these devices. Valance terminals consist of finned tubing housed in an insulated enclosure which is placed on the wall near the ceiling. Heating or cooling is accomplished by circulating a fluid such as water, a brine or a refrigerant through the tubing.

For these systems a supplementary system is necessary in order to provide fresh air for humidity or air quality control or to pressurize or depressurize the space. It is that supplementary air delivery system, which may or may not exist, that must be evaluated in the radon problem. Pressurization will require that the supplementary system introduce additional outside air compared to the conditions where no pressurization is required. One must be sure that the terminal heating-cooling system is capable of handling the additional thermal loads imposed by that makeup air. The extra cost of the fan power as well as the extra thermal loads will make careful scheduling of fan operation during unoccupied hours very important.

UNITARY SYSTEMS

With unitary systems the components are factory assembled into an integrated package or packages. Unitary systems can be split systems with an outdoor section being separate from the indoor section or they can be packaged units as for example a rooftop unit. Both built-up and unitary systems may have external duct work and plumbing or tubing installed on site. Where central units may be made up of an almost endless combination of components unitary systems come in a limited number of discrete sizes, optimized for a particular set of conditions. The advantage of unitary systems is in the quality control of manufacture and quite often in the fact that they tend to have lower first costs. In some cases, such as for rooftop units, the entire package sits outdoors and does not take up valuable indoor space. Maintenance may be more difficult in bad weather and performance may not be as good as carefully designed and built central systems which operate in a more comfortable indoor environment.

Rooftop Units

Because they usually have lower first costs than most indoor systems rooftop units are very popular in new construction and retrofits. They are usually ducted to distribute air throughout all or part of a building and they may be single or multizone. They do not create any special air flow situations not available or present in central systems and therefore their use in radon control is described in the appropriate section describing the particular airflow system. An interesting quote is taken from the 1991 ASHRAE Applications Handbook (11):

"Life expectancy may be less than for indoor equipment. However, some school districts have successfully operated rooftop units for over 15 years, with maintenance costs significantly less than schools with other systems."

Packaged Terminal Units

Packaged terminal units incorporate a complete heating and/or cooling system in one unit, usually to keep a relatively small area comfortable. They are usually mounted on the floor near the outside wall and are frequently seen in motels and hotels since they give good economics in such situations. There is no ducting or piping required, by fitting into the wall they take up little room space, and they can provide either heating or cooling independent of what any other unit in the complex is furnishing. They are also popular in some building renovation projects since their installation is less disruptive than in systems where there is extensive ducting and piping.

In a typical package terminal unit outside air can be introduced at the discretion of the operator, and since there is usually no return the unit pressurizes the space it serves. The level of pressurization depends upon the fan setting and characteristic and the leakiness of the room.

Most package terminal units with cooling have high compressor and fan noises which make them undesirable for use in classrooms. Like fan-coil units they also require the servicing of many filters and fans and the actual servicing must take place within the classroom itself. This same feature means that only a small fraction of the entire building would be without heating or cooling at any one time due to equipment failure.

Small size units, which usually only provide cooling, are considered to be appliances and are referred to as room air conditioners.

SPECIALIZED SYSTEMS

KITCHENS

Kitchens represent a unique situation because of the need to prevent kitchen odors, fumes and smoke from escaping to other parts of the school building. Kitchens are usually kept at a static pressure below that of the dining rooms but should not be at lower pressure than surrounding areas that might lead to contamination. Local makeup air is usually provided at a point near the range and other exhaust hoods to supply less conditioned air to be exhausted to reduce energy costs. Because the rate of air removal is so high in a properly designed kitchen, dilution by the forced makeup air and the air drawn in from other spaces probably keeps radon levels low. Maintaining kitchen static pressures consistently above subslab pressure is probably not practical. Generally the best abatement technique would likely be the sealing off of any cracks or other paths through which soil gases might enter the kitchen and operating the kitchen at a static pressure no lower than necessary to provide satisfactory odor control in the dining areas.

GYMNASIUMS

Gymnasiums are characterized by the large space and high ceiling in the playing area and for many cases by the anticipated large internal loads from crowds. In addition there are usually relatively large areas for dressing which include several shower stalls. Many gymnasiums are separate from the remainder of the school facilities and more often than not have their own heating/cooling/ventilating system. Often the heating system consists of fan type unit heaters or infrared heaters and/or perimeter heaters, none of which have the capability of introducing outside air. Most gymnasiums have either forced or natural exhaust systems for maintaining comfort in warm weather and for removal of crowd pollutants. The typical air change rate is four to six air changes per hour. Increasingly gymnasiums are placed in multipurpose use and the heating-cooling systems are designed with that in mind. Cooling of gymnasiums is becoming more common in all parts of the country.

Generally, significant pressure levels are difficult to maintain in gymnasiums because of the large building volume and extensive leakage of the typical type of construction.

Dressing rooms usually have significant levels of exhaust air, which may or may not come from the main room of the gym. This exhaust air which is primarily to remove humidity and odors will in most cases serve to dilute the levels of radon in these areas during the hours of operation. Pressurization of these dressing areas would not be desirable if the main playing (crowd) area were not also pressurized to a slightly higher level since the humidity and odors would otherwise flow into that playing area. For the typical gymnasium that means that dilution would likely be the best approach, assuming that reasonable steps have been taken to seal off any passages through which soil gas might enter the building. Controlled air intake systems, contrasted to the more common exhaust fan systems, would work more favorably toward increasing the static pressure level in the main gym arena.

LABORATORIES

Laboratories, particularly chemistry laboratories, are usually designed to minimize the likelihood of dangerous or poisonous gases being present in the laboratory or in adjoining spaces. Fume hoods are usually provided for the more critical situations and require the drawing in of makeup air either locally or from the laboratory space. As a result the laboratory would normally be at a pressure below that of the surrounding rooms at least during operation of the exhaust system or the fume hood. Any pressurization of the laboratory to keep its static pressure above subslab pressure would need to be additionally equipped with controls to assure that the laboratory pressure is always below the pressure in the adjoining spaces. This most likely would be an undesirable complexity and makes dilution the best HVAC candidate for maintaining safe radon levels in laboratories.

Location of laboratories on upper floors, where possible, will decrease or even eliminate concern about radon there. Since it is not desirable to have positive pressures in laboratoriesthey might be given priority in location on upper floors in future construction or renovation.

SWIMMING POOLS

Swimming pools create a very large source of humidity that must be continually removed from the space in which the pool is located. Good design practice attempts to create a flow of air from other spaces to the pool by maintaining a static pressure in the pool area that is below that of any of the surrounding spaces. This decreased pressure must be maintained constantly since the pool is evaporating constantly. This makes it impractical to try to operate the pool area at pressures less than might exist in the subfloor around the pool. Fortunately the pool itself usually covers a very large part to the floor space in the room where the pool is located. There should be no concern for radon gas leakage into the area occupied by the pool since a high hydrostatic head will exist beneath the pool. Large exhaust and consequent makeup rates for the pool area will tend to dilute radon level in that area. Care must be taken that surrounding room pressures are not dropped to below atmospheric as those spaces furnish some of the makeup air to the pool area. This balance can be obtained by a suitably controlled fresh air intake and exhaust fans.

RESTROOMS AND CUSTODIAL CLOSETS

All properly constructed and maintained restrooms and custodial closets have exhaust fans for odor removal. These fans are intended to maintain pressures in the rooms that are below the pressures in the surrounding spaces. It would be difficult to maintain positive (above atmospheric) pressures in these types of rooms and at the same time maintain them at pressures below that of the surrounding rooms. Some dilution takes place in restrooms and custodial closets. Because of this exhaust action, and since these rooms are not occupied for long periods of time by individuals, they are not a significant part of the radon abatement problem. Good sealing of the floors and walls to prevent gas leakage seems to be the most practical step.

APPENDIX A
1979 HVAC Survey Results

A 1979 survey, Nonresidential Building Energy Consumption (NBEC), conducted by DOE, provided Royal and Tsai (32) with information on the types of HVAC facilities in educational buildings in the U.S. This information has been reproduced graphically in Figures A-1 and A-2.

Among the heating systems at that time central radiators (C-RAD), central forced air (C-FA), and unitary forced air (U-FA) predominated in over 73 percent of the buildings. The forced air systems could be expected to already have some outdoor air and pressurization capability or can be modified to have that capability. Information on the central radiators does not show whether ventilation air is or is not furnished. If all or some of the central radiators have outdoor air ventilation capability the 73 percent total is still less than the 83 percent found to have that capability in the AEERL study (4). One would expect that most recent construction provides for outdoor air capability in keeping with building codes and/or standards and the percent of forced air systems probably continues to increase.

Among the air-conditioning systems, window units and packaged units together were more than double the number of central systems. Room pressurization and control of outdoor air quantities would likely be more readily carried out with the central systems. Air conditioning was found in less than 32 percent of the buildings. The present trend is probably fewer window units and an increase in the number of rooftops, a unitary type of system with outdoor air capability.

Although many of these buildings and their systems still exist, many have been modified and updated and recent construction probably has not followed the trends of previous years. It is doubtful that these data are applicable to existing schools as evidenced by the AEERL study (4).

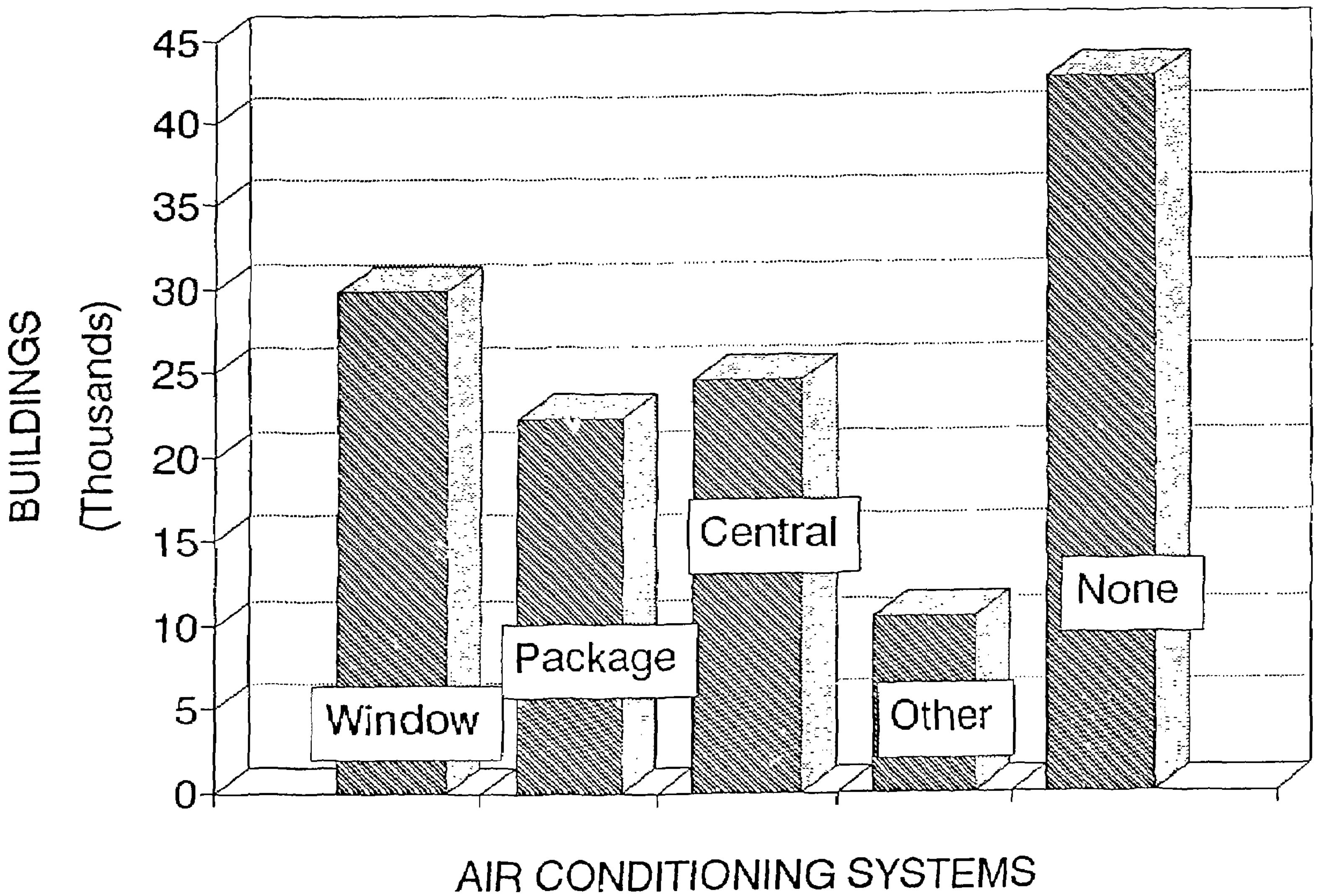
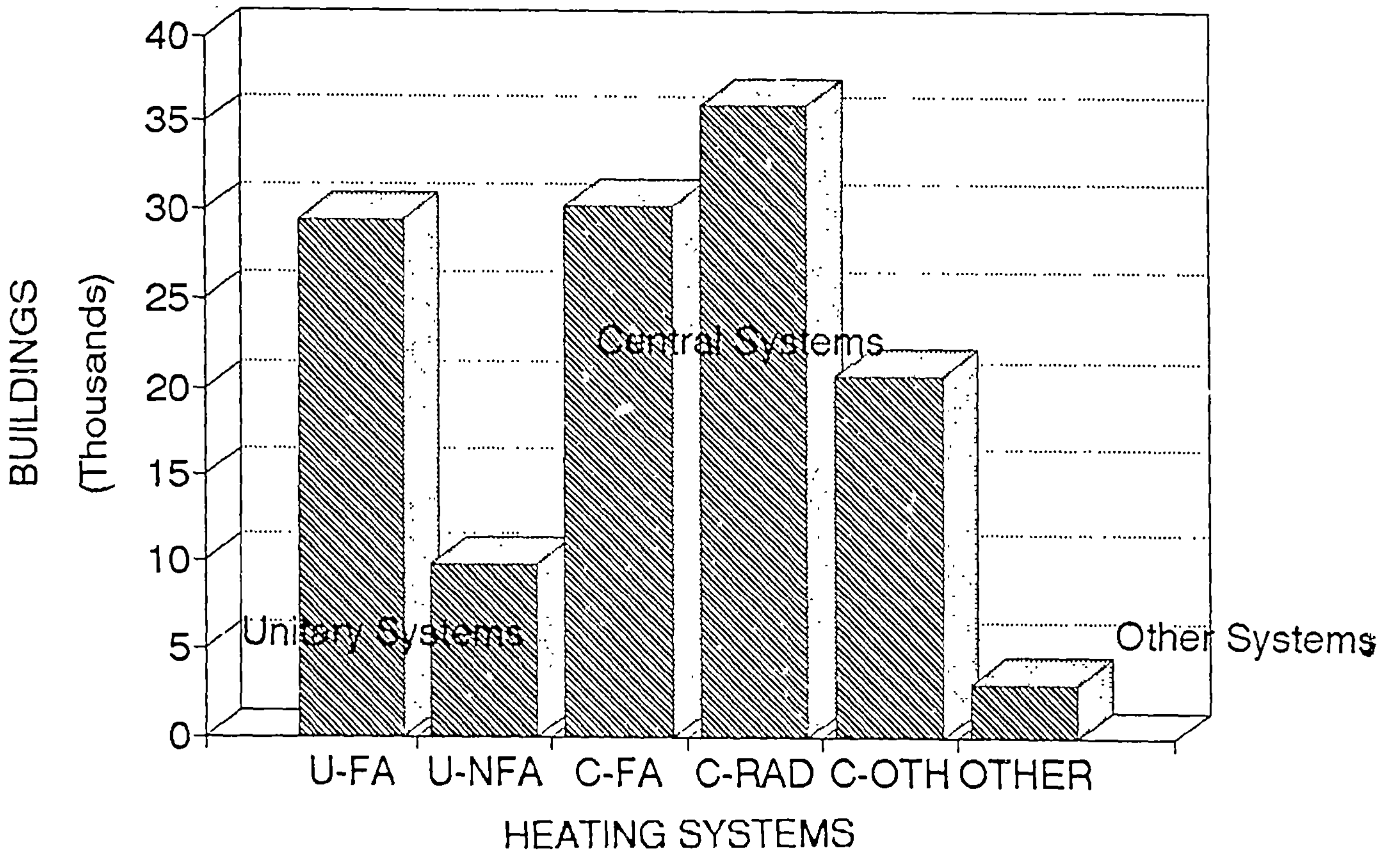


Figure A-1 - Distribution of U. S. School AC Systems in 1979. (32)



U-FA	UNITARY FORCED AIR
U-NFA	UNITARY NON-FORCED AIR
C-FA	CENTRAL FORCED AIR
C-RAD	CENTRAL RADIANT
C-OTH	CENTRAL OTHER

Figure A-2 - Distribution of U. S. School Heating Systems in 1979.

REFERENCES

1. EPA, "Session X, Radon in Schools and Large Buildings", In: Proceedings: The 1991 International Symposium on Radon and Radon Reduction Technology, Volume 4, EPA-600/9-91-037d (NTIS PB92-115369), pp. P10-3 thru P10-60, November 1991.

2. Leovic, K.W., A.B. Craig, and D. Saum, "Characteristics of Schools with Elevated Radon Levels", In: Proceedings: The 1988 Symposium on Radon and Radon Reduction Technology, Volume 1, EPA-600/9-89-006a (NTIS PB89-167498), pp. 10-37 thru 10-47, March 1989.

3. Brennan, T., "Radon Control and IAQ Concerns in Underventilated Buildings: School Studies", Fourth National Conference on Indoor Air Pollution, University of Tulsa, Tulsa, OK, 1991

4. Leovic, K.W., A.B. Craig, and D.B. Harris, "Update on Radon Mitigation Research in Schools", 1991 American Association of Radon Scientists and Technologists Meeting, Rockville, MD, October 9-12, 1991.

5. ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality, 1989

6. Wheeler, A.E., "Energy conservation and acceptable indoor air quality in the classroom", ASHRAE Journal, April 1992.

7. The Education Writers Association,"Wolves at the Schoolhouse Door", Washington, DC, 1989

8. Hansen Associates, "Schoolhouse in the Red - Cutting Our Losses", American Association of School Administrators, January 1992

9. Cutter Information Corp.,Indoor Air Quality Update, July 1991

10. ASHRAE Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, 1989

11. ASHRAE Applications Handbook, ASHRAE, Atlanta, GA, 1991

12. McQuiston, F.C. and J.D. Parker, Heating, Ventilating and Air Conditioning, Analysis and Design, Third Edition, Wiley, 1988

13. Anderson, S.A., "Control Techniques for Zoned Pressurization", ASHRAE paper NT-87-04-1, 1987

14. Brown, W.K., "Makeup Air Systems Energy-Saving Opportunities", ASHRAE paper SL-90-5-1, 1990

15. Dirkes, J., "Balancing Air Pressure: An Open Door Could Blow It", Air Conditioning, Heating & Refrigeration News, October 30, 1989

16. Holness, G.V.R., "Pressurization Control: Facts and Fallacies", Heating/Piping/Air Conditioning, February 1989

17. Haines, R.W., Control Systems for Heating, Ventilating and Air Conditioning, Van Nostrand-Reinhold, 4th Edition, 1987

18. Smith, R.B., "Importance of Flow Transmitter Selection for Return Fan Control in VAV Systems", ASHRAE paper AT-90-17-4, 1990

19. The Trane Company,"Building Pressurization Control", Trane Applications Engineering Manual AM-CON 17 (882), The Trane Company, LaCrosse, WI, 1982

20. Atkinson, G.V., "Controlling Space Static Pressure Between Connected Buildings", ASHRAE paper NT-87-04-3, 1987

21. Bentsen, L.J., "Zoned Airflow Control", ASHRAE paper NT-87-04-2, 1987

22. EPA, "Radon Reduction Techniques for Detached Houses", EPA-625/5-86/019, Research Triangle Park, NC, 1986

23. Piersol, P.G. and M.A. Riley, "Ventilation and Air Quality Monitoring in R-2000 Homes", ASHRAE paper NT-87-07-1, 1987

24. Kettler, J.P., "Field Problems Associated with Return Fans VAV Systems", ASHRAE paper DA-88-18-3, 1988

25. Alcorn, L.H. and P. J. Huber, "Decoupling Supply and Return Fans for Increased Stability of VAV Systems", ASHRAE paper DA-88-18-4, 1988

26. Wendes, H.C., Variable Air Volume Manual, Fairmont Press-Prentice Hall, 1991

27. Haines, R.W., "Double-Duct Systems", ASHRAE paper NT-87-16-1, 1987

28. Int-Hout, D.,"Stand-Alone Microprocessor Control of Dual-Duct Terminals", ASHRAE paper NT-87-16-2, 1987

29. Linford, R.G., "Dual-Duct Variable Air Volume - Design/Build Viewpoint", ASHRAE paper NT-87-16-4, 1987

30. Kettler, J.P. "Efficient Design and Control of Dual-Duct Variable Volume Systems", ASHRAE paper NT-87-16-3, 1987

31. ASHRAE Equipment Handbook, ASHRAE, Atlanta, GA, 1988

32. Royal, G.C. and S.S. Tsai, "Building Stock Energy Analysis: Elementary and Secondary Schools", DOE CE 30751-T2, E 1.99, DE86 004525, March 1985

33. ASHRAE HVAC Systems and Applications Handbook, ASHRAE, Atlanta, GA, 1987

BIBLIOGRAPHY

ASHRAE HVAC Systems and Applications Handbook, ASHRAE, Atlanta GA, 1987

Bogucz, E. A., "Valance Heating and Cooling", Handbook of HVAC Design edited by Nils R. Grimm and Robert C. Rosaler, McGraw-Hill, 1990

Khashab, A.M., Heating, Ventilating, and Air-Conditioning System Estimating Manual, McGraw-Hill, 1977

Leovic, K.W., A.B. Craig, and D. Saum, "The Influences of HVAC Design and Operation on Radon Mitigation of Existing School Buildings", ASHRAE IAQ Proceedings, The Human Equation: Health and Comfort, NTIS PB89-218-762, 1989

Leovic, K.W., D.B. Harris, T.M. Dyess, B.E. Pyle, T. Borak, and D. W. Saum, "HVAC System Complications and Controls for Radon Reduction in School Buildings", In: Proceedings: The 1991 International Symposium on Radon and Radon Reduction Technology, Volume 2, EPA-600/9-91-037b (NTIS PB92-115369), pp. 10-85 thru 10-104, November 1991

Turner, W.A., K.W. Leovic, and A. B. Craig, "The Effects of HVAC System Design and Operation on Radon Entry into School Buildings", In: Proceedings: The 1990 International Symposium on Radon and Radon Reduction Technology, Volume 2, EPA-600/9-91-026b (NTIS PB91-234450), pp. 9-35 thru 9-44, July 1991

Johnson Controls Corporation, "Building Pressure Control for Variable Air Volume Systems", Technical Support Group Engineering Report 4-47, Section II, July 1988