MECHANICAL VENTILATION AND EQUIPMENT

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Keywords: Air diffusion, All-air systems, CAV, Coils, Controls, Diffusers, Ducts, Economizer, Energy recovery, Filter, HVAC, Mechanical ventilation, Stratification, VAV

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Summary

Mechanical ventilation systems for controlling conditions in individual zones can move a constant or variable supply of conditioned air to handle all or some of the heating and cooling loads. They are classified as all-air, air-water, and all-water systems. All-air systems include single-duct, dual-duct and multizone. The systems can be designed to operate at Constant Air Volume (CAV) or Variable Air Volume (VAV). Air-water and all-water systems are categorized as two-, three- and four-pipe. The Air Handling Unit (AHU) is the main air conditioning and treatment equipment. A typical AHU consists of a single volume unit with a supply fan, heating coil, cooling coil, humidifier where necessary, filters, mixed air economizer dampers, and sound attenuator. The air distribution is a key element for the successful operation of central systems to deliver the air to the conditioned spaces in an efficient way, satisfying the indoor environmental conditions as economically as possible. The air is then distributed by the ductwork and is delivered by the air-diffusion outlets. Proper circulation and exhaust must satisfy the indoor environmental quality. Mechanical ventilation systems provide great flexibility for controlling the indoor conditions, if properly designed, installed, commissioned, operated, and maintained. Proper controls can optimize their use, enhance flexibility, and improve energy efficiency. On the other hand, poor design, installation, and performance can lead to serious Indoor Air Quality (IAQ) problems, and cause thermal and acoustical discomfort, with a high energy cost.

1. Introduction

Heating, Ventilating, and Air-Conditioning (HVAC) central systems are becoming an ever more common amenity in most non-domestic buildings. The majority of older buildings were poorly heated and ventilated, while central HVAC systems were rather rare. This picture is rapidly changing worldwide. Building occupant comfort expectations are growing, indoor environmental quality standards are becoming more stringent, and new problems in terms of indoor and outdoor adverse conditions introduce complex new demands on HVAC systems.

Natural ventilation (see chapter *Natural Ventilation*), although in some countries still the dominant ventilation technique, is fast being pushed aside by mechanical ventilation systems as part of a greater shift towards HVAC in buildings. This shift is not without a price though, since considerable investment is required for mechanical installations, and there is a significant increase in operating and maintenance costs. For example, a building with a central HVAC system has increased energy consumption by up to 40%, depending on the system's operating conditions.

Ventilation rates and outdoor air requirements vary significantly, depending on the architecture and function of the building, the occupancy, and whether smoking is permitted or not. Typical minimum ventilation rates per person range between 8 to 30 L/s. Increased ventilation rates are necessary to handle indoor pollutants and maintain acceptable air quality levels (see chapter *Indoor Air Quality*). For example, smoking is a common indoor air pollutant and in most cases it doubles the necessary ventilation rates and thus results in significantly higher energy consumption. Air filtration can be used to solve problems in relation to outdoor and indoor air pollution and enable mixing of return and outdoor air in most kind of applications (see chapter *Filters and Maintenance* for more information on filters).

2. Systems

Mechanical ventilation systems for controlling conditions in individual zones can move a constant or variable supply of conditioned air to handle all or some of the heating and cooling loads. Other secondary systems can be combined with mechanical ventilation to reduce the amount of conditioned air required. Accordingly, the systems are classified as:

- All-air systems. These supply only air to the conditioned space to meet the sensible and latent loads. Since all the conditioned air is delivered by the central system, these need to be a large size and require a lot of space for ductwork. In some applications, the system can provide cooling, preheating, and humidification, while combined with separate heating systems (i.e., a separate air, water, steam, or electric heating or reheat system) can reduce ductwork size.
- Air-Water systems. These supply air and water to meet the cooling loads, by changing the fluid temperature to control the indoor temperature. Water pipes take much less space than the ductwork for air, and the pumping power required for the water is much lower than the fan power required for air supply and return circulation in an all-air system. Savings are significant especially in large buildings. In the case that the air supply is sufficient to meet the outdoor air requirements for zone ventilation and/or to balance the exhaust air, the return air system (ductwork and accessories) can be eliminated all-together.

- All-Water systems. These supply cold or hot water to fan coil and unit ventilators, while unconditioned ventilation air is supplied by an opening through the wall, natural ventilation, and infiltration. Cooling and humidification is supplied by circulating chilled water or a refrigerant through a coil in the unit. Heating is supplied by hot water pumped through the same or a different coil, or by an electric resistance.

All-air systems include the following categories:

- **Single-duct systems**. These involve one common duct distribution system that supplies the ventilation air at all local terminal units that is distributed to all zones. The air handling unit (AHU) contains the main heating and cooling coils in a series flow air path, so they either heat or cool the ventilation air using a common duct distribution system at a common air temperature to feed all terminal units. The system may be modified for reheat, an application with a secondary heating coil inserted in the duct system, to heat either preconditioned primary supply air or recirculated air, before it enters the space. This makes possible zone and space control with different loads (i.e., provide heating and cooling with a single-duct system) but it is a high energy consuming process.
- **Dual-duct systems**. These involve two ducts to supply a cold and a warm air stream that is mixed at the local terminal units to reach the desirable conditions (according to the zone thermostat) before the air is supplied indoors. Alternatively the two air streams are mixed at the main supply fan and then use a single supply duct to each zone. The AHU contains the main heating and cooling coils in a parallel flow or series-parallel flow air path, so they heat and cool air at the same time. This system provides great flexibility for handling variable loads and satisfy concurrent needs for warm and cool temperature air supply, but at high energy cost (a similar disadvantage as in the case of reheat).
- **Multizone systems**. In these, a central unit provides a single duct for each zone and meets the load by mixing warm and cold air at the central unit (controlled by the zone thermostat). They can serve several zones with different indoor space requirements. They are similar to the dual-duct system, in the sense that the supply air for meeting the different zone loads is prepared by mixing cold and warm air, but then single-zone ducts distribute the air. They are common in applications with high sensible heat loads and limited ventilation requirements, but with a high initial cost.

The systems can be designed to operate as:

- **Constant Air Volume (CAV) systems**. Varying loads are handled by regulating the temperature of the supply air, while maintaining a constant air volume. Single-duct CAV systems change the temperature of the air supply in response to the indoor load. The systems can be single zone (spaces with the same temperature requirements) or multiple-zones with reheat (spaces with different load requirements). A bypass system can be used in place of the reheat. In this case, the main system operates under CAV conditions, but if the space load is reduced then a portion of the supply air is bypassed before it is supplied indoors. The volume of the space-supplied air varies with time, but the AHU operates with a constant air volume. Energy consumption for conditioning the air at the AHU is reduced since the return air is maintained at more favorable conditions. Dual-duct CAV systems are similar but with a bypass for the mixture of outdoor and return air as indoor conditions change.

- **Variable Air Volume (VAV) systems**. Varying loads are handled by regulating the volume of the supply air. Single-duct VAV systems control indoor space conditions by varying the volume of the supply air, thus decreasing the air supply with space load. Precise humidity control is problematic with this kind of a system. Secondary heating systems are usually necessary during winter. Terminal units can be designed in several configurations, like reheat, induction and fan-powered. Dual-duct VAV systems mix cold and warm air at different volume rates. The available types include a single supply fan for both airflows (located upstream of the reheat and cooling coils) or a dual supply fan that utilizes two independently controlled fans for each air stream.

CAV systems are commonly used in facilities with high internal loads (i.e., occupancy, equipment, and lighting loads) and require a large air supply and primarily cooling. Spaces with large load diversity are better served with a VAV system in order to optimize energy use at low levels. VAV systems have a low initial cost and low operating costs since there are significant fan power savings from reduced fan speed in relation to the supply air volume. Designs of VAV systems with improved volume-throttling devices and better-designed outlets have resolved the problems previously encountered for applications with significantly varying loads (that is, loss of control of indoor air movement and drafts, and noise from throttling dampers) and have extended their use. Large volume spaces and large buildings that need considerable amounts of ventilation air supply are usually served by single zone or variable volume all-air systems. Separate air-handling units can serve different zones (spaces), although multizone, dual-duct, or reheat types can also be applied with lower operating efficiency. In large buildings with high loads it is common to use several air handling systems that serve a single space, because of the limits in equipment size and for better control of energy consumption.

Air-Water systems include central air-conditioning equipment to treat the air that is then distributed through the ductwork to the zone terminal units. The air is supplied at constant volume. The water is pumped to a heat exchanger coil in the terminal unit (i.e. induction unit), or independent components in the zone (i.e. radiant panel), or a fan coil unit.

Air-Water systems are categorized as:

- two-pipe systems, one water supply and one return pipe
- three-pipe systems, one cold water supply, one hot water supply, and one common return
- four-pipe systems, one hot water supply with one return and one cold water supply with one return.

Regulation of indoor conditions can be obtained by either water flow control through the heat exchange surface or airflow control over it. The same coil can be used for cooling or heating, or two coils used (one cooling coil and one heating coil), or an independent device for heating used.

Air-Water induction systems receive the conditioned air supply at medium to high pressure and a balancing damper adjusts the amount of supply air to be mixed with the return air from the zone. The return air is conditioned as it flows over water coil, mixed with the main supply air and then delivered indoors. A fan coil unit can also be used, but this is more common with all-water systems.

All-Water systems are categorized again as two-pipe, three-pipe, or four-pipe systems for the water distribution from the central equipment. A fan coil can be used to draw outdoor air through a wall opening. Local unit ventilators are supplied with outdoor and indoor air, properly mixed with adjusting dampers. The air is then filtered and flows through a cooling/heating coil (used with a two pipe system) or two separate coils (used with a four pipe system). Additional heating may also be provided through a local electric resistance.

In 1989 the European Committee for Standardisation (CEN) established a technical committee, CEN TC 156 “Ventilation for buildings”. The committee has produced standards and other reference documents for ventilation products and systems, and for the terminology (CR 12792—Symbols, Units and Terminology). TC 156 collaborates with other technical committees (TC 89 and 228) in a joint effort to produce information on applicable calculation procedures.

A European Pre-standard was published in 1997 on the requirements for ductwork components to facilitate the maintenance of ventilation systems (ENV 12097—Ductwork: Requirements for components to facilitate maintenance of systems) and other dimensional standards for ductwork (i.e. dimensional standards on rectangular sheet metal ducts (EN 1505—Ductwork: Rectangular sheet metal air ducts: Dimensions), circular sheet metal ducts (EN 1506—Ductwork: Circular sheet metal ducts - Dimensions), circular flanges for ventilation ductwork (EN 12220—Ductwork: Circular flanges for general ventilation - Dimensions) and other in progress) and for dampers and valves (EN 1751—Terminals: Aerodynamic testing of dampers and valves), and air handling units (EN 1886—Air handling units: Mechanical performance). Other drafts include duct covering, performance testing for air terminal devices, constant and variable rate terminal units, louvres, chilled ceilings, and beams and air handling units.

The item that caused the most controversy was an attempt to standardize design criteria for the indoor environment. The criteria developed have been published as a CEN Technical Report CR 1752—Design criteria for the indoor environment. It specifies the levels of temperature, air velocity, noise, and ventilation for occupied spaces. Values are given for three categories of environmental quality: A—a high level of expectation, B—a medium level and C—a moderate level. Supporting information is given on the derivations of the specified values of the parameters as well as to enable alternatives, such as different clothing levels, to be accommodated in the design assumptions. Practical examples of the derivation of appropriate criteria are also included.

3. Equipment

Typical Air Handling Units (AHU) consist of a single volume unit with a supply fan, heating coil, cooling coil, humidifier where necessary, filters, mixed air economizer dampers, and sound attenuator. A typical system layout is illustrated in Figure 1. The layout and configuration can include different kind of methods for any stage of the air conditioning and treatment (i.e. for heating, cooling, humidification, filtering). The fan is located downstream of the coil and is referred to as a draw-through configuration. The AHU can be centrally located in a mechanical room or distributed at various locations in the building (local AHU minimize the required distribution ductwork and the size of the units).

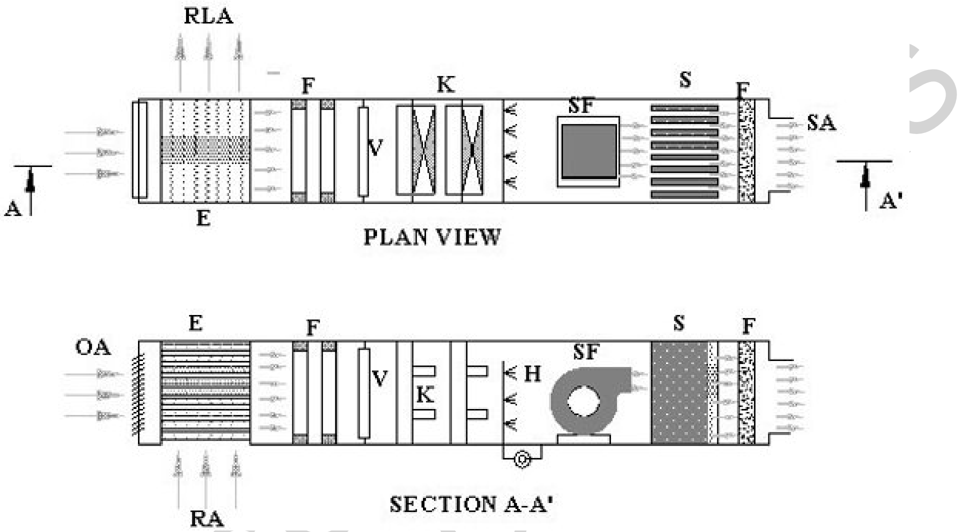

Figure 1. Typical plan view and cross section of a single stage draw-through AHU. OA: Outdoor Air, RA: Return Air, RLA: Relief Air, SA: Supply Air, V: Heating coil, K: Cooling coil, F: Filters, H: Humidifier, SF: Fan, S: Sound attenuator, E: Economizer

Economizers offer an attractive alternative for reducing energy costs. The economizer is a heat exchanger used to retrieve heat from the return air for the outdoor air (i.e. using a plate heat exchanger), but without mixing by using 100% outdoor air (see chapter *Space Loads and Energy Conservation* for more information).

The system may use a simple mixing-damper instead, for mixing some return with outdoor air. A minimum outdoor air damper specifies the amount of necessary outdoor (fresh) air. The amount of the return air that is not used is exhausted as relief air. Depending on the application and the outdoor air quality, the air may need to be properly treated at different levels, using filters with the appropriate efficiency. For example, the first filter is usually a prefilter (30% efficiency), followed by a chemical filter, and then a final filter before the air is supplied to the indoors (65–85% efficiency). (For more details on filters, see chapter *Filters and Maintenance*)

Indoor humidity levels must be controlled at a relative humidity of 30-60% in order to minimize microbial growth, so AHU must provide, if necessary, air humidification and dehumidification (preferably without reheat). Humidifiers add moisture to the supply air in order to ensure that the air is not too dry, which may occur during winter. The amount of moisture should not be excessive for the given conditions, so that the supply air can absorb it without condensing. Nearly saturated supply air can lead to condensation inside the system (i.e. ductwork or diffusers) that may create IAQ problems by supporting the growth of pathogenic and allergic organisms.

Cooling and heating coils are supplied by cold and warm water from conventional chillers and heating systems. Cooling coils are heat exchangers for removing sensible and latent heat from the ventilation air. Operating conditions determine the size of the heat exchanger. Some air can bypass the finned coils, that is, the airflows without contacting the heat exchange surface, depending on the number of coil rows.

Heating coils can be located upstream in the outdoor air stream (preheating) or in the mixed air stream. Preheating coils operate when the temperature of the outdoor air is below 10^{o}C. A heating coil can be used at the terminal units to bring the ventilation air to the desirable indoor temperature in the event that no other means for space heating is provided. In some applications where internal gains are high, very little heating of the ventilation air is required. The system can also be combined with other conventional modes of heating.

Some systems are also equipped with a reheat coil in order to ensure proper supply air temperature when dehumidification takes place. Reheat should not be used unless there is an energy recovery system. A less expensive alternative is a coil runaround loop that recovers some heat from the exhaust air and is used to reheat the subcooled, dehumidified air leaving the air handler (see chapter *Space Loads and Energy Conservation* for more information).

All together, the AHU needs to have easy access for thorough inspection and cleaning of the system components, according to a regular maintenance program and during problematic operation. Usually, outside air is measured and balanced during the start-up of the system. However, after some time of operation, the amount of outside air volume can change and as a result this may have a direct impact on the indoor air quality of the ventilated spaces.

To maintain the correct amount of ventilation air and verify proper operation it is necessary to install control systems for monitoring the operating conditions, in order to properly calibrate the system or perform periodic measurements and implement necessary adjustments during regular maintenance. Properly controlled dampers of the AHU along with airflow data can be used to accurately control the operating conditions and assure conformance with regulations and standards.

Periodically it is necessary to measure the actual airflow rates in the AHUs, to ensure that there are no serious deviations from manufacturer data or design. Data from on-site measurements indicate that AHUs rarely maintain their design characteristics and with time there is a significant decrease in the ventilation efficiency.

Measured deviations that have been reported range between 64% and 154%. The airflow rates in the AHU can be measured using tracer gas. This can provide useful insights for detecting shortfalls in the AHU and for assessing the ventilation efficiency. However, these measurements must be performed with great scrutiny, following a detailed testing protocol to ensure the proper selection of tracer gas injection and air sampling locations, and properly process the results using the appropriate interpretation algorithms.

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Biographical Sketch

Constantinos A. Balaras, Ph.D. Born in Athens, 1962. Married, one son. Mechanical engineer, researcher at the National Observatory of Athens, IERSD, Group Energy Conservation. Ph.D. and M.S.M.E. from Georgia Tech., B.S.M.E. from Michigan Tech. Active in the areas of energy conservation, thermal and solar building applications, renewable energy sources, analysis and numerical modeling of thermal energy systems, and HVAC systems. Previous affiliations with the University of Athens, Central Institute for Energy Efficiency Education, Protechna Ltd, Technological Educational Institute of Pireaus, British-Hellenic College, American Standards Testing Bureau Inc., American Combustion Inc., Georgia Institute of Technology, Hellenic Shipyards Co., Georgia Power Co. Participated in various European and national research projects, as a project manager and scientist in charge, including projects on energy renovation of office and apartment buildings, HVAC systems in hospital operating rooms, solar absorption heat pump, solar control, passive cooling, and regional development of renewable energy sources. Private practice includes electromechanical design and installation projects for new constructions and renovations of residential and office buildings, and a small size industrial building. Member of the Hellenic Technical Chamber (Chartered Mechanical Engineer), EUR ING, Hellenic Society of Mechanical—Electrical Engineers, Hellenic Society of Heat and Power Cogeneration, Hellenic Forum for the Dissemination of Renewable Energy Sources (ELFORES), ASHRAE (Inititating representative and president of Hellenic Chapter 1999-2000), and ASME (Member of the Governing Board ASME Greek Section), ISES. Author and co-author of over 35 papers in international Journals and 50 papers at conferences, chapter contributions in 9 scientific books and numerous technical project reports. Guest editor for a special issue of the Journal *Energy and Buildings*; Invited Reviewer of papers for the *Journal of Solar Energy*; Invited Technical Assessor for the European Architectural Competition Living in the City and Working in the City (under the auspices of the European Commission); Member of The Scientific Research Society; Pi-Tau-Sigma, Honorary Mechanical Engineering Fraternity.