



# 1987 ASHRAE HANDBOOK

## Heating, Ventilating, and Air-Conditioning Systems and Applications

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.  
1791 Tullie Circle, N.E., Atlanta, GA 30329

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**DEDICATED**  
**TO THE ADVANCEMENT OF**  
**THE PROFESSION**  
**AND ITS ALLIED INDUSTRIES**

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Comments, criticisms, and suggestions regarding the subject matter are invited. Any errors or omissions in the data should be brought to the attention of the Editor. If required, an errata sheet will be issued at approximately the same time as the next Handbook. Notice of any significant errors found after that time will be published in the ASHRAE JOURNAL.

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# CONTRIBUTORS

In addition to the text, the following individuals contributed significantly to this volume. Their names are listed in the following order:

## PREFACE

This Handbook completes the reorganization of the ASHRAE Handbook series. Last year's 1986 REFRIGERATION Volume included the refrigeration-related chapters from both the 1982 APPLICATIONS and the 1984 SYSTEMS volumes. The remaining chapters, which are primarily related to heating, ventilating, and air conditioning systems and applications, have been revised and included in this volume.

The 61 chapters are divided into four major sections. The first of these sections describes various heating and air-conditioning systems. These chapters help the engineer in evaluating the systems and learning how they operate.

The second and third sections cover specific applications and describe the air conditioning of public and private buildings, various forms of transportation and their facilities, and several industrial and manufacturing applications. Both the practicing engineer and those looking for information about the heating, ventilating, and air conditioning of a wide variety of applications will find this section a valuable reference.

The last section includes several chapters principally for the design engineer, although building owners and operating engineers will also find several chapters of interest.

Three chapters in this volume (40, 42, and 46) are new to the handbook series. They include information on the heating, ventilating, and air conditioning of nuclear facilities; ventilating and air conditioning for underground mines; and thermal storage.

Over half of the chapters have been extensively revised by volunteers who work with ASHRAE'S Technical Committees. The Handbook Committee appreciates their efforts, for it is the expertise of these volunteers that makes the Handbook a respected and authoritative reference. The major contributors are listed in the front of the handbook.

In addition to the new and revised chapters, the following changes have been made to the format:

- Both Inch-Pound (I-P) and International System (SI) units of measurement are used in this volume. This decision to publish only one edition, instead of separate I-P and SI editions, required revising most chapters to clarify the tables, figures, and equations.
- References are now shown in the chapter by author and date of publication rather than as superscript numbers. Many people find this method of referencing easier to follow and it has the added advantage of being easier to revise.
- Major section headings for each chapter are now located in the Table of Contents instead of at the beginning of each chapter, which should make information easier to find.

Changes in technology have also helped in producing this year's Handbook. The word processor has given the editorial staff increased flexibility, as well as new challenges. The text from about a quarter of the chapters was received from authors on a microcomputer floppy disk.

Errata for the 1983, 1985, and 1986 volumes precede the Index. Errata for this volume will be included in the 1988 EQUIPMENT Volume.

The Handbook Committee welcomes reader input. If you have suggestions and comments on improving a chapter or would like more information on helping review a chapter, please write to Handbook Editor, ASHRAE, 1791 Tullie Circle, Atlanta, GA 30329.

Robert A. Parsons  
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# AIR-CONDITIONING SYSTEM SELECTION AND DESIGN

**A**N air-conditioning system maintains desired environmental conditions within a space. In almost every application, there are several ways these conditions may be maintained. Ideally, air-conditioning systems permit people or products to function within the structures at optimum level. Different systems approach this ideal with varying degrees of success.

Air-conditioning systems are categorized by how they control cooling in the conditioned area. They are also segregated to accomplish specific purposes by special equipment arrangement. This chapter considers procedures for selecting the appropriate system for a given application. It also describes and defines the design concepts and characteristics of the basic air-conditioning systems. Chapters 2 through 5 describe various systems and their attributes, based on their terminal cooling medium and their common variations.

## SELECTING A SYSTEM

The designer has responsibility for considering various systems and recommending the one or two that will perform as desired, fit into the available space, and give the owner the best combination of first cost, operating cost, and reliability.

Those five factors are interrelated, so the owner and building designer must consider how each affects the other. The relative importance of these five factors differs with different owners and often changes from one project to another for the same owner.

## SELECTION GOALS

An owner invests in air conditioning to achieve goals other than providing a desired environment. Goals may be: (1) to complete a process such as the operation of computer equipment, the infection-free implant of an artificial hip, the manufacture of semi-conductors, or any other task; (2) to provide a desirable environment for employees to reduce fatigue and errors and make the location a desirable place to work; (3) to increase the sale of goods or services; (4) to increase net rental income; or (5) to enhance the sale of the property soon after project completion.

The relative importance of first cost as compared to operating cost, the extent and frequency of maintenance and whether that maintenance requires entering the occupied space, how often a system may be expected to fail, how much of the project would be affected by a failure, and how long before the failure can be corrected are typical concerns of owners. Each of these concerns has a different priority, depending on the owner's goals.

The owner can only make appropriate value judgments if the designer provides complete information on the advantages and disadvantages of each option. Just as the owner does not usually

The preparation of this chapter is assigned to TC 9.1, Large Building Air-Conditioning Systems.

have the knowledge of the relative advantages and disadvantages of different systems, the designer rarely knows all the owner's financial and functional goals. Hence, it is important to involve the owner in selecting the system.

## SYSTEM CONSTRAINTS

The first step in selecting a system is to determine and document constraints dictated by performance, capacity, available space, and any other factors important to the project.

Few projects allow detailed quantitative evaluation of all alternatives, and common sense and subjective experience narrow choices to two or three potential systems.

## Cooling Loads

Establishing the cooling load often narrows the choice to systems that will fit within the available space and are compatible with the building architecture. The FUNDAMENTALS Volume covers how to determine the magnitude and characteristics of the cooling load and how it varies with time and operating conditions. By establishing the capacity requirement, the size of equipment can be estimated. Then, the number of options may be narrowed to those systems that work well on projects of certain broad size ranges.

## Zoning Requirements

Loads vary over time in the various areas due to changes in weather, occupancy, activities, and solar exposure. Each space with a different exposure requires a different control zone to maintain constant temperature. Some areas with special requirements may need individual control, or individual systems, independent of the rest of the building. Variations in indoor conditions, which are acceptable in one space, may be unacceptable in other areas of the same building. The extent of zoning, the degree of control required in each zone, and the space required for individual zones will also narrow the system choices.

No matter how efficiently a particular system operates, or how economical it may be to install, it cannot be considered if it: (1) does not maintain the desired interior environment within an acceptable tolerance through all conditions and occupant activity, and (2) does not physically fit into the building without being objectionable.

## Heating and Ventilation

Cooling and humidity control are often the basis of sizing air-conditioning components and subsystems, but the system may also provide other functions such as heating and ventilation. For example, if the system provides large quantities of outside air for ventilation or replaces air exhausted from the



building, only systems that transport large air volumes need to be considered. In that situation, the ventilation system will require a large air-handling and duct-distribution system, so other means can be discarded.

Effectively delivering heat to an area may be an equally strong factor in system selection. A distribution system that offers high efficiency and high comfort for cooling may be a poor compromise for heating. That performance compromise may be small for one application and in one climate and be unacceptable in another that has more stringent heating requirements.

### Architectural Constraints

Air-conditioning systems and the associated distribution systems often take substantial space. Major components may also require special support from the structure. The size and appearance of terminal devices, whether they are diffusers, fan coil units, or radiant panels, have an impact on the architectural design because they are visible from the occupied space.

Other factors that limit the selection of a system include (1) acceptable noise levels, (2) space available to house equipment and its location relative to the occupied space, (3) space available for distribution pipes and ducts, and (4) the acceptability of components protruding into the occupied space—both physically and visually.

### NARROWING THE CHOICE

Each of the succeeding system chapters includes an *Evaluation* section, which briefly summarizes the good and bad features of various systems. Comparing the features against the list of design factors and their relative importance will usually identify two or three approaches that most nearly meet the project criteria. In making subjective choices, it is helpful to keep notes on all systems considered and the reason for eliminating those that are unacceptable.

In most cases, two system selections will evolve: the *secondary* (or distribution) system delivers heating or cooling to the occupied space from a *primary* system, which converts energy from fuel or electricity. The two systems are, to a great extent, independent, so several secondary systems will work with different primary systems. In some cases, however, only one particular secondary system will work with a specific primary system.

Once subjective analysis has identified two or three systems—and sometimes only one choice may remain—detailed quantitative evaluations of each system must be made. All systems considered should provide satisfactory performance to meet the owner's essential goals. The owner then needs specific data on each system to make an informed choice. Chapter 28 in the 1985 FUNDAMENTALS Handbook, "Energy Estimating," outlines how to estimate annual energy costs. In this volume, Chapter 59 deals with mechanical maintenance, and Chapter 49 describes life-cycle costing, a method that compares overall economics of systems.

### SELECTION REPORT

As the last step of system selection, the designer prepares a memorandum or report that summarizes the selection criteria, briefly outlines the systems considered inappropriate, and compares the systems selected for detailed study by answering the following questions.

1. Does the system fit in the available space, or does it require some architectural modification? Does the system use more floor space than others considered, or does it require construction of additional space for mechanical rooms or shafts?
2. Will the system deliver the desired uniform temperature under

varying weather and solar conditions? If compromises are made from the ideal control zoning, how much variation may be expected between spaces?

3. How much will the system cost to own compared to others considered? What is the recovery time of the initial investment, interest on investment, and the future cost of replacement equipment?
4. What are the operating costs of this system compared to others, including energy costs, maintenance, operating labor, and supplies?
5. What reliability can the owner expect compared to other systems? What component failures might affect the entire building, and which would affect only limited areas? How easily may the system be serviced? How quickly can the system be restored to operation after various equipment failures?
6. Is the system flexible enough to meet changes in the owner's needs? What is required to add a control zone? Can it meet the increased capacity requirements of a space when equipment is added? How will changes in the interior layout and arrangement affect performance?

The System Selection Report should conclude with a recommended system choice, along with reasons for the choice. The report should be discussed with the owner long enough to be sure the owner's goals have been recognized and the owner understands the reasons for the designer's recommendations.

## THE BASIC CENTRAL AIR-CONDITIONING AND DISTRIBUTION SYSTEM

The basic secondary system is an all-air, single-zone, air-conditioning system. It may be designed to supply a constant air volume or a variable air volume and for low, medium, and high pressure air distribution. Normally, the equipment is located outside the conditioned area, in a basement, penthouse, or service area. It can, however, be installed within the conditioned area if conditions permit. The equipment can be adjacent to the primary heating and refrigeration equipment or at considerable distance from it by circulating refrigerant, chilled water, hot water, electricity, or steam for energy transfer.

### APPLICATIONS

Some central system applications are: (1) spaces with uniform loads, (2) small spaces requiring precision control, (3) multiple systems for large areas, (4) systems for complete environmental control, and (5) a primary source of conditioned air for other subsystems.

#### Spaces with Uniform Loads

Spaces with uniform loads are generally those with relatively large open areas and small external loads, such as theaters, auditoriums, department stores, and the public spaces of many buildings. Here, the air-conditioning loads are fairly uniform, and adjustment for minor variations can be made by supplying more or less air in the original design and balance of the system.

In office buildings, the interior areas generally meet these criteria as long as local areas of relatively intense and variable heat sources, such as computers, are treated separately. In these applications, non-ceiling partitions allow wider diffusion of the conditioned air and equalization of temperatures. These areas usually require year-round cooling, and any isolated spaces with

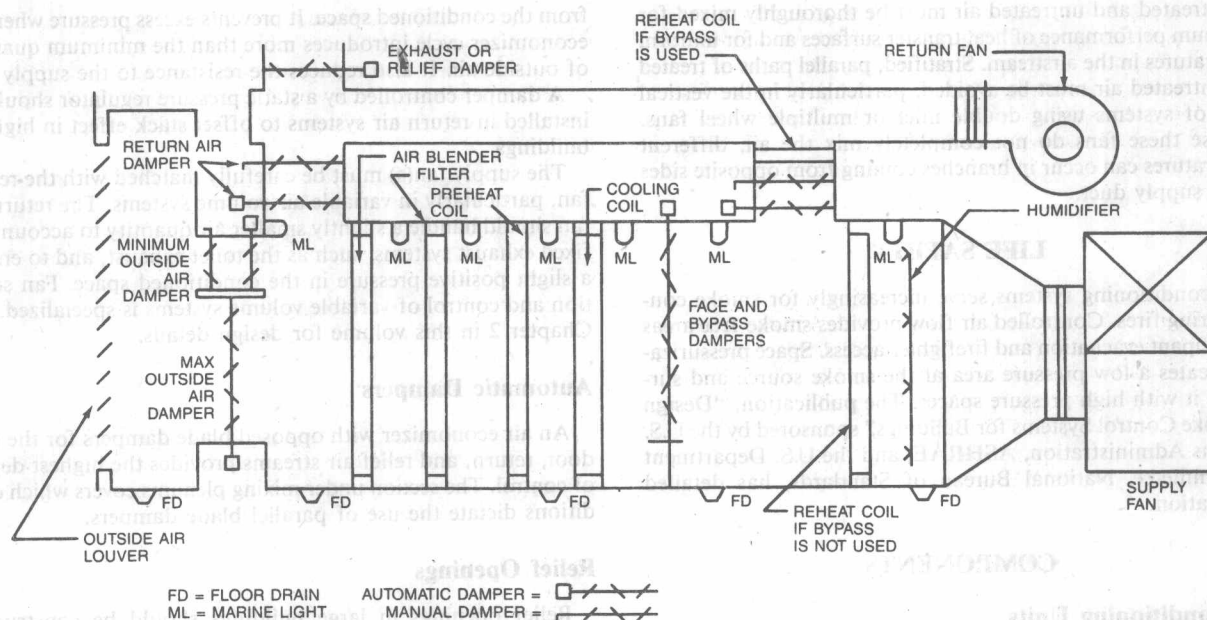


Fig. 1 Equipment Arrangement for Central Systems

limited occupancy may require special evaluation, as discussed in Chapter 19 in this volume.

The central system can also adapt to one-story buildings and top floors of single-occupancy spaces, if the exterior walls are part of the main conditioned areas and if the space has a uniform roof load.

In most single-room commercial applications, temperature variations of up to 4°F (2°C) at outside walls are usually considered acceptable for tenancy requirements. However, these variations should be carefully determined and limited during design. If people sit or work near the outside walls or if they are isolated by partitions, supplementary heating equipment may be required at the walls, depending on the outdoor design temperature in the winter.

### Spaces Requiring Precision Control

These spaces are usually isolated rooms within a larger building and have stringent requirements for cleanliness, humidity, temperature control, and air distribution. Central system components can be selected and assembled to meet the exact requirements of the area.

### Multiple Systems for Large Buildings

In large buildings such as hangers, factories, large stores, office buildings, and hospitals, practical considerations require installation of multiple central systems. The size of the individual system is usually limited only by the building's structural limitations.

### Primary Source for Other Systems

Systems for controlling conditions in individual zones are described in the following chapters of this volume. These systems move a constant supply of conditioned air for ventilation and control some of the air-conditioning load. This air supply often reduces the amount of conditioned air handled by the central system and, consequently, the space required for ductwork. Ductwork size can be reduced further by moving air at high velocities.

However, high velocity system design must consider the resultant high pressure, sound levels, and energy requirements. Chapters 7 and 33 of the 1985 FUNDAMENTALS Volume, Chapter 3 of the 1983 EQUIPMENT Volume, and Chapter 52 of this volume give design procedures.

### Environmental Control

All-air systems generally provide the necessary air supply to dilute the controlled space in applications requiring close aseptic or contamination control. These applications usually are combinations of supply systems and scavenging exhaust systems that circulate the diluting air through the space. Since establishing adequate dilution volumes is related to space configuration, occupancy type, air delivery, and scavenging methods, the designer must consider the terminal systems used.

The cleanliness of the air supply also relates directly to the level of environmental control desired. Suitable air filtration should be incorporated in the central system upstream from the air moving and tempering equipment. Some applications, such as hospitals, require downstream filtration as well.

These systems usually incorporate some form of energy recovery. Chapter 10 of the 1983 EQUIPMENT Volume has information on air cleaners, and Chapters 8, 11, and 12 of the 1985 FUNDAMENTALS Volume include data on physiological factors, contaminants, and odors.

### CENTRAL SYSTEM PERFORMANCE

Figure 1 shows a typical draw-through central system that supplies conditioned air to a single zone or to another system. A blow-through configuration may also be used if space or other conditions dictate. The quantity and quality of this air is fixed by space requirements and determined, as described in Chapter 26 of the 1985 FUNDAMENTALS Volume. Air gains and loses heat by contacting the heat transfer surfaces and by mixing with air of another condition. Some of these mixtures are intentional, as at the outdoor air intake. Others are the result of the physical characteristics of a particular component, as when untreated air passes without contacting the fins of a coil.

All treated and untreated air must be thoroughly mixed for maximum performance of heat transfer surfaces and for uniform temperatures in the airstream. Stratified, parallel paths of treated and untreated air must be avoided, particularly in the vertical plane of systems using double inlet or multiple wheel fans. Because these fans do not completely mix the air, different temperatures can occur in branches coming from opposite sides of the supply duct.

### LIFE SAFETY

Air-conditioning systems serve increasingly for smoke control during fires. Controlled air flow provides smoke-free areas for occupant evacuation and firefighter access. Space pressurization creates a low pressure area at the smoke source and surrounds it with high pressure spaces. The publication, "Design of Smoke Control Systems for Buildings," sponsored by the U.S. Veterans Administration, ASHRAE, and the U.S. Department of Commerce, National Bureau of Standards, has detailed information.

### COMPONENTS

#### Air Conditioning Units

The designer considers the function and physical characteristics of the space to be conditioned and the air volume and thermal exchange capacities required to determine the system's air-handling requirement. Then, the various components may be selected and arranged by keeping the fundamental requirements of the central system in mind. These requirements are: equipment must be adequate, accessible for easy maintenance, and not too complex in arrangement and control to produce the required conditions.

Further, the designer considers economics in component selection. Both initial cost and operating costs bear on design decisions. The designer should not arbitrarily design for a 500 fpm (2.5 m/s) face velocity, which has been common for selection of cooling coils and other components. A 1977 study showed that filter and coil selection at 300 to 400 fpm (1.5 to 2.0 m/s), with its lower pressure loss, could pay back on constant volume systems. Chapter 49 in this volume has further energy and life-cycle cost details.

Figure 1 shows a general arrangement of the components of a single zone, all air, central system suitable for year-round air conditioning with close control of temperature and humidity. Seldom would all these components be used in a comfort application. Although Figure 1 indicates a built-up system, most of the components are available completely assembled by the manufacturer or in sub-assembled sections that can be bolted together in the field.

Factors to be considered when selecting central system components include evaluation of specific design parameters to balance cost, controllability, operating expense, maintenance, noise, and space. The sizing and selection of primary air-handling units substantially affect the results obtained in the conditioned space. See the 1983 EQUIPMENT Volume for a detailed discussion of each of the unit components.

#### Return Air Fan

A return air fan is optional on small systems but usually essential for the proper operation of large systems. It functions to provide a positive return and exhaust from the conditioned area, particularly when mixing dampers permit cooling with outdoor air in intermediate seasons.

The return air fan ensures that the proper volume of air returns

from the conditioned space. It prevents excess pressure when the economizer cycle introduces more than the minimum quantity of outside air. It also reduces the resistance to the supply fan.

A damper controlled by a static pressure regulator should be installed in return air systems to offset stack effect in highrise buildings.

The supply fan(s) must be carefully matched with the return fan, particularly in variable air volume systems. The return air fan should handle a slightly smaller air quantity to account for fixed exhaust systems, such as the toilet exhaust, and to ensure a slight positive pressure in the conditioned space. Fan selection and control of variable volume systems is specialized. See Chapter 2 in this volume for design details.

#### Automatic Dampers

An air economizer with opposed blade dampers for the outdoor, return, and relief air streams provides the highest degree of control. The section under mixing plenums covers which conditions dictate the use of parallel blade dampers.

#### Relief Openings

Relief openings in large buildings should be constructed similarly to outdoor air intakes, but they should have motorized or self-acting backdraft dampers to prevent high wind pressures or stack action from causing the air flow to reverse when the automatic dampers are open. The pressure loss through relief openings should be 0.10 in. of water (25 Pa) or less. Low leakage dampers, like those for outdoor intakes, prevent rattling and minimize leakage.

Relief dampers sized for the same air velocity as the maximum outdoor air dampers facilitate control when an air economizer cycle is used. Power relief fans that are interconnected with outside air dampers can exhaust the area, especially when an economizer cycle is part of the system. The relief air opening should be located so that the exhaust air does not short-circuit to the outdoor air intake.

#### Return Air Dampers

The negative pressure in the outdoor air intake plenum is a function of the resistance or static pressure loss through the outside air louvers, damper, and duct. The positive pressure in the relief air plenum is, likewise, a function of the static pressure loss through the exhaust or relief damper, the exhaust duct between the plenum and outside, and the relief louver. The pressure drop through the return air damper must accommodate the pressure difference between the positive pressure-relief air plenum and the negative pressure outside air plenum. Proper sizing of this damper facilitates both air balancing and mixing. An additional manual damper may be required for proper air balancing.

#### Outdoor Air Intakes

Resistance through outdoor intakes varies widely, depending on construction. Frequently, architectural considerations dictate the type and style of louver. The HVAC engineer must see that the louvers selected offer a minimum pressure loss, preferably not to exceed in 0.10 in. of water (25 Pa). High efficiency, low pressure loss louvers that effectively limit carry-over of rain are available. Flashing installed at the outside wall and weep holes or a floor drain will carry away rain and melted snow entering the intake. Cold regions may require a snow baffle to direct fine snow particles to a low velocity area below the dampers. Outdoor dampers should be low leakage types with special gasketed edges and special end treatment. Separate damper sections for