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The Basic Air-Conditioning Problem

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Please note

A building may be regarded as an assemblage of spaces, each providing a particular environment appropriate to its intended use. Correspondingly, much of the design of a modern building must be concerned directly with the means for ensuring that the desired conditions will be obtained. Air conditioning is now a common requirement and poses special problems for the building designer. He must, of necessity, delegate some responsibility for the design of the system to be employed, but he cannot do so completely. Some decisions may influence the design of other parts of the building, and decisions concerning the design of the building can have a marked influence on the cost and performance of the system.

An understanding of the interaction between the building and the air-conditioning system is essential if good design is to be achieved. The effects of some features of the building on heating and cooling requirements were discussed in **CBD 105**. These were considered primarily in relation to the cost of air conditioning. The quality of the environment produced by air conditioning is also important and depends in large measure on what happens in individual spaces. The creation of acceptable conditions by the manipulation of heated and cooled air within a space is called here the basic air-conditioning problem and is the principal subject of this Digest. Discussion will be carried on primarily in the context of air conditioning for human comfort.

Design for a comfortable thermal environment must begin with a recognition of the reactions of people to the pertinent physical conditions of a space. These matters were discussed in **CBD 102** and reference was made to the ranges of conditions within which people will probably be comfortable. It was noted that thermal radiation levels are a factor in body heat balance and that they are not directly under the control of air conditioning. As these levels are determined mainly by the pattern of temperatures of surrounding objects, including wall, floor, ceiling and window surfaces, they are variable with location in the space. They cannot readily be offset, except in a general way, by an adjustment in the over-all level of air temperature.

Thermal radiation levels result from conditions and decisions not normally within the control of the air-conditioning engineer, yet they may affect markedly the extent to which a uniform thermal environment can he provided. When close control over conditions becomes of prime importance, limitations may have to be imposed on the design of the enclosure and perhaps also on the nature of the occupancy. This is a common occurrence in the design of research laboratories, for example, where windows have to be omitted to make possible close temperature and humidity control.

The essential operation in controlling temperature and humidity involves supplying or extracting heat and moisture within a space so as to offset the effects of the losses and gains of the space as a whole. The nature of these losses and gains is discussed in **CBD 105**, in which it becomes evident that the thermal characteristics of the space and its occupancy can lead to storage effects that modify the amount of heating or cooling required at any given time. The basic air-conditioning problem consists of making adjustments to balance the heating and cooling loads for the space as a whole so that conditions will be maintained everywhere within the occupied space within acceptable limits.

A common way of arranging for the supply or removal of heat and moisture is to draw a definite amount of air from the space and replace it with an equal amount of conditioned air. The conditioning of the air, which may include filtering to remove dust and blending with a certain proportion of fresh air for ventilation, is often carried out outside the conditioned space. (The means by which this can be accomplished are not important at this stage in the discussion.)

Some thought about the situation depicted in Figure 1 will lead to the conclusion that the air exhausted from the room is substantially at room condition. The entering air stream must therefore be at a higher or a lower temperature and moisture content, to the degree required to balance the heat and moisture loads. Several most significant features of this basic relation become apparent only when they can be examined quantitatively.

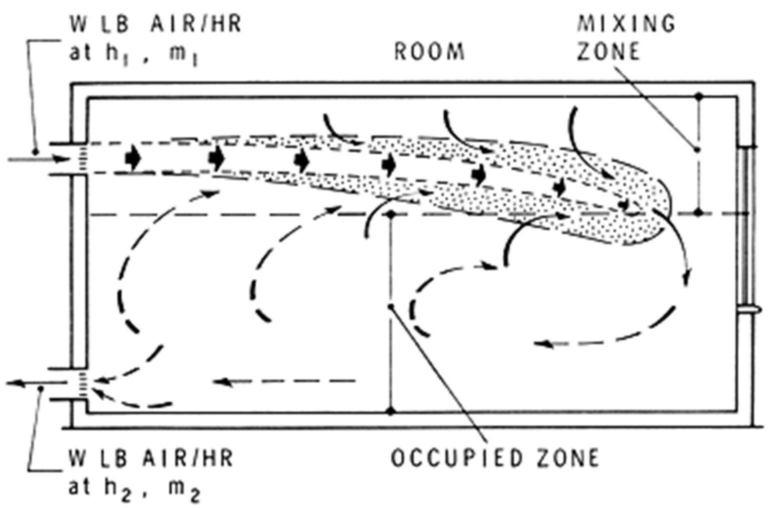

Figure 1. The basic air distribution problem.

Consider that the room in question has a cooling load, H, and a moisture load, M, in unit time. If the mass flow of air in and out is W lb/hr and h and m are the heat and moisture contents of the air, respectively, for 1 lb of air, the simple mass and energy balance equations for the room are as follows:

$H = W (h_2 - h_1)$ (1)
$M = W (m_2 - m_1)$ (2)
These equations indicate that the cooling load, H, of the space must be balanced by the difference in the heat content of W lb of leaving and entering air. When the cooling and moisture loads result from heat and moisture gains to the room, the entering air must be cooler and contain less water vapour than the exhaust air. If under winter conditions there are heat and moisture losses to be made up, the entering air must be warmer and contain more moisture than that in the room.

The amount by which the condition of the entering air differs from that of the room air is shown to be dependent on the magnitude of the heat and moisture loads (H and M) and on the rate of air circulation (W). Under winter conditions, which involve mainly heating, it is not uncommon to employ air stream temperatures up to 150°F. Rooms with average heat requirements will have a rate of air circulation, W, corresponding to a volume change of three air changes per hour. The heating of the air to this level presents no problem and warm air will not usually create uncomfortable drafts. Air supplied for cooling can more easily create sensations of draft and must usually be kept above 40°F to avoid frosting of the cooling coil. In practice, air for cooling is generally supplied at from 15 to 30F deg below room temperature. Thus it is more common to employ ten air changes or even more per hour with the loads that usually occur.

It will be recognized at once that if an air stream is to be projected into a room at 15F deg below room temperature, those parts of the space it affects directly will deviate by as much as 15F deg from room temperature. A similar situation could occur with moisture content. It might be proposed, therefore, that the primary air stream should not deviate from the desired room condition by more than the accepted tolerance. For example, if room air temperature is to be 75°F ± 2°F one might require that the primary air stream for cooling be no lower than 73°F and for heating no more than 77°F. The required air changes with a limit of 2F deg would be 110 to 150 air changes per hour (ach) for heating and 75 ach for cooling.

An air change rate approaching 100 ach must be considered very high indeed for any ordinary occupancy, requiring very large fans, ducts and grilles, and leading to the possibility of high local room air velocities. When such rates are required a complete pierced ceiling and floor or two opposite walls may be used as supply and return grilles. Under such conditions a uniform sweep of air in one direction, with little turbulence and low velocity (laminar flow), can be obtained. Such arrangements are justified only in special cases, usually in clean rooms or where there is a requirement for very high air rates to reduce temperature differences throughout the whole room.

In normal air conditioning practice great advantage is taken of the fact that of a whole space only the part that is to be occupied need be held within acceptable limits for occupancy. That part of the room volume above the 6-ft level may be used to advantage as a distribution and mixing zone (see Figure 1). This requires that the primary air be projected with sufficient velocity to entrain room air by induced secondary circulation in amounts up to three to five times its own volume before it enters the occupied zone; and at the same time provide the best possible distribution and movement of air throughout the occupied zone. This is not easy to accomplish and it constitutes one of the great challenges to the designer of the air-conditioning system. Clearly the extent to which uniform air temperature, air movement, and relative humidity can be achieved throughout the occupied zone is greatly dependent on it.

Distribution of the air is accomplished by three factors: velocity energy of the primary stream, gravity effects due to differences in temperature, and displacement resulting from the general movement caused by the continuous over-all introduction and withdrawal of air. It becomes necessary to take account of all three in designing for adequate room air distribution. The supply registers must also be designed to assist in the scheme of air distribution selected. Their size, location, spacing, amount of air handled, and the direction given to the air are all important factors.

If the "throw" of a register is too great the primary air stream may be projected directly into the occupied zone or may "splash" on a wall and be deflected downward. Heated air streams rise when projected horizontally; cooled streams fall and must be given an appropriate initial deflection.

It is hardly necessary to point out that a cooled primary stream striking anyone will give rise to a very objectionable draft. The secondary circulation (Figure 1) induced by the primary stream, however. can also produce drafts if room conditions are generally on the cool side. Note that the induced flow making up the secondary air circulation is in the same direction as the primary stream when it is near it, but in the opposite direction when it is further away. Examples of such "reverse flow" accompanied by marked drafts can be produced by the hot primary streams of car heaters or warm air heating registers in low sidewall locations where the air temperature is generally below the comfort level, even though the primary stream itself is quite warm.

Various locations are used for supply registers and exhaust grilles. The arrangement shown in Figure 1 is reasonably well-suited for both summer and winter conditions provided the heating load is not large. When the width of the room permits, the cooled primary air can he projected well over toward the opposite wall to mix with the rising warm air at wall and window surfaces. The low sidewall location for the return grille provides some advantage for summer cooling, but during the heating season a location beneath the window would tend to remove some of the cold air flowing down from the cold surface. Warmed air projected overhead tends to remain there, so that no great compensation is provided for the cooling effects of the exterior wall and window.

Ceiling diffusers are also common. The primary air supply is projected generally downward from a central location in a flat cone. Such an arrangement can be quite acceptable for cooling, but when used for heating it is difficult to project the heated air downward through the occupied zone with sufficient velocity for it to mix with or displace the cooled air at the floor. Like the system shown in Figure 1 this arrangement is more satisfactory in a split system of heating and ventilating in which convectors located at the window carry the winter heating load, and the air system is operated to provide tempered air at room temperature only. The rising warm air stream from the convectors is in the proper location to counter the tendency for cold air to fall and collect at the floor. When the same air system is to be used for both heating and cooling, it is difficult to ensure good performance in both seasons.

When, as is often the case, windows are a major source of both heat and cold, it is common to discharge air vertically upwards from either continuous or cabinet-type units located below the windows. When this is done the vertical zone close to the windows becomes, in part, a mixing zone. This location is often satisfactory for heating with only natural upward convection, but for cooling forced convection must be used. In one arrangement the energy of the primary air, supplied to the unit under pressure, is used to induct large volumes of room air from the floor for mixing before it is discharged vertically upward. Thus displacement is used along with discharge velocity to provide vertical circulation in the room, counteracting the natural tendency for a cold zone at the floor in winter and a hot zone at the ceiling in summer due to gravity effects.

Thus far the problem has been discussed mainly in the context of temperature variations as affected by the distribution of the conditioned air and the heating and cooling effects of exterior walls and windows. The lighting system, when in use, also enters in an important way into the problem, since it contributes markedly to the heating of the space. The thermal interaction with the space varies with the arrangement. Suspended fixtures give off their energy by radiation and by convection through heating of the air adjacent to them. Recessed ceiling systems give off part of their energy to the space above the ceiling, and this warms floors and ceilings and ultimately returns to the conditioned spaces.

Various elements associated with the occupancy of a space such as lamps and stoves, as well as people, can contribute energy to the space by radiation exchange with surrounding surfaces and by convection involving the air in contact with them. Air that is warmed in contact with a hot object will rise as a plume to the extent permitted by the overriding influence of local air movement. Cool objects will produce falling streams. The resulting air streams may depart markedly in temperature from the surrounding air, but this may not be objectionable if they do not come in contact with occupants before becoming well mixed with the air in the space.

Temperature is not the only factor of interest. The plumes of air rising from human bodies will contain added water vapour and will produce deviations from the general level of moisture content in the space. Additional heat and moisture is projected into the space in respiratory air, which is also deficient in oxygen and carries a high level of carbon dioxide. Odours are also given off, and smoke may be an additional contaminant. Any or all of these factors, and others arising from a particular occupancy, lead to variations in conditions. Their extent can be controlled by the simple process of dilution, or mixing. This can usually be produced satisfactorily by promoting turbulence and general circulation of the air in the space.

Contamination by dust, smoke, carbon dioxide and odours, and depleting effects such as reduction of oxygen through respiration, are normally not required to be held within close limits but only to be kept below some limiting value. They are normally controlled by filtering and by dilution with fresh air. The amount of fresh air required is often only 10 to 20 per cent of the air capacity required for conditioning the space.

This discussion of air conditioning from the viewpoint of the conditions in the space has been presented in the hope that it will lead to a better appreciation of what is involved. It is highly desirable, when deciding upon the environmental conditions for a space, that the ease or difficulty, and thus the cost, of providing what is proposed should at least be recognized in a general way. There is a similar need to recognize the influence of various other decisions that may be made in the course of developing a design. It has only been possible to indicate briefly and somewhat indirectly how an enclosure and the nature and requirements of the occupancy affect the conditioning of the space. It has been assumed that means exist for sensing the needs of the space and for producing the conditioning air streams as required. The many considerations involved in the choice of systems and equipment will be the subject of a later Digest.