ciency over a wide range is more desirable than one which reaches an even higher maximum efficiency, but decreases more rapidly on either side of a narrow range. A self-limiting horsepower curve may permit more accurate selection of motor size.

The selection of size of fan usually involves balancing cost and space against sound and efficiency. Unless the pressure involved is so high that a smaller fan running at greater speed requires a higher class[2] of construction, the smallest fan is the cheapest in first cost of the fan only. However, as the cost of the driving equipment is also involved in the total installation cost, fan efficiency must be considered for that reason as well as its bearing on the cost of operation. In some cases where large fans operate long hours per year, selection at absolute maximum efficiency is indicated. Generally, however, the power saving by selecting for optimum efficiency does not justify the extra cost, and a slightly smaller fan gives the best balance of cost and efficiency. Reference to Figs. 2 to 4 shows that all types tend to have a minimum sound near maximum efficiency. When noise is a consideration, therefore, selection approaching maximum efficiency is indicated. Too large a fan may not only cause an unnecessary investment and an increased power consumption and sound, but may also give faulty performance if it is of a type having an unstable pressure characteristic at low capacity.

Table 1 shows the outlet velocities and impeller tip speeds recognized as good practice for various static pressures for centrifugal, tubeaxial, and vaneaxial fans applied to average heating, ventilating, and air-conditioning applications. Fans for churches, schools, residences, and other buildings having a low prevailing noise level should be selected for lower than average outlet velocities.

FAN INSTALLATION

In designing heating, ventilating, and air-conditioning systems, the characteristics of the fans available for use therewith should not be ignored. If double inlet fans or multiple fans in parallel are used, care must be taken that both inlets have the same free area and general approach conditions.

The dimensions of the ductwork and the size of the various devices whose individual resistances determine the static pressure, dictate the fan selection. Often a minor modification of the system may permit use of a smaller motor, and even a lower class[2] of fan, with considerable saving of cost. Invariably, the sound generated is affected, as fans operating at high pressure produce more noise than at lower pressure (see Chapter 25). Minimizing the resistance may be the best insurance against noise. On the other hand, sometimes the lowest overall cost results from selecting the minimum size of system equipment, and then installing adequate acoustical and vibration treatment.

All ducts should be connected to fan outlets and inlets by means of unpainted canvas or other flexible material. Access should be provided in the connections for periodic removal of any accumulations tending to unbalance the rotor. When operating against high resistance, or when ambient noise levels are low, it is preferable to locate the fan in a room removed from occupied areas or acoustically treated to prevent sound transmission. The lighter building constructions which are common today, make it desirable to mount fans and driving motors on resilient bases designed to prevent transmission of vibrations through floors to the building structure. Conduits, pipes, and other rigid members should not be attached to fans. Noises due to high velocities, abrupt turns, grilles, and other items not connected with the fan, may be present. Treatment of such problems, as well as the design of sound and vibration absorbents, are covered in Chapter 25.

FAN APPLICATIONS

Many fan applications and the corresponding types of fan commonly used are listed in the following paragraphs. Reference is also made to the chapters where the applications are discussed.

Central-system supply fans (Chapter 19) are usually of the centrifugal type, since this application requires a wide range of satisfactory and quiet operation against high pressures. They can readily be connected to apparatus of large cross-section on the inlet side, and to relatively small ducts on the outlet side.

Comparative sizes have been standardized among manufacturers,[3] and most rating tables cover a range of 700 to 500,000 cfm, and static pressures from ¼ to 15 in. of water.

Central-system exhaust fans are predominately centrifugal, but the space conservation of the axial is being increasingly utilized. Tubeaxial and vaneaxial fan sizes are not yet standardized, but several manufacturers list capacities from 2000 to 125,000 cfm, and static pressures up to 3 in. of water.

Exhaust fans are found in all types. *Wall fans* are predominantly of the propeller type, since they operate against little or no resistance. They are listed in capacities from 1000 to 75,000 cfm. They are sometimes incorporated in factory-built penthouses or roof caps, or are provided with matching automatic louvers. *Hood-exhaust fans* (Chapter 52) involving ductwork, are predominantly centrifugal, especially if handling hot, corrosive, or erosive fumes, where it is best to keep the bearings and drive remote from the air stream. Otherwise, axial fans are applicable, and where little or no ductwork is involved, propeller fans are suitable. *Spraybooth-exhaust fans* (Chapter 52) are frequently centrifugal, especially if built into self-contained booths. Tubeaxial fans lend themselves particularly well to this application, where ease of cleaning and of suspension in a section of ductwork are advantageous. For such application built-in cleanout doors are desirable. *Material handling fans* (Chapter 52) are always straight radial (or modified) blade centrifugal type. They are of heavier construction, and have fewer blades and greater clearances than ventilating fans. Many characteristics are compromised to provide wear resistance and ease of maintenance. They are commonly listed in capacities from 600 to 125,000 cfm, and static pressures up to 18 in. water.

Mine-fan applications[11] vary greatly and require fans ranging from small portable units for local ventilation, to immense slow speed centrifugal fans, often steam-engine-driven, for general or emergency ventilation. Vaneaxial fans are well suited to mine ventilation. For underground location, their compactness saves on cost of excavations, and above ground, their ready reversibility is valuable in emergencies, even if reversal causes a reduction in capacity.

Marine fans (Chapter 48) are both centrifugal and vaneaxial types. The latter are particularly well adapted to both combatant and noncombatant ships, where compactness and light weight are invaluable.

Unitary systems, i.e., unit heaters, unit ventilators, unit humidifiers, unit air conditioners, unit air coolers, and unit evaporative condensers are equipped with centrifugal or propeller fans, the latter usually being limited to the relatively small suspended type where no ductwork is involved. Fans for units having considerable internal or possible external resistance, are mostly of the forward-curved blade, or so-called mixed-flow centrifugal type. The latter is really a centrifugal type with axial inlets, having a pressure curve resembling a backward-curved-blade centrifugal fan. Both of these types have the high capacities (in relation to displacement) requisite for a compact unit. Ratings are frequently given for these units as separate fans, as well as in conjunction with the various internal resistances. In multiple units on a common shaft they are listed up to 40,000 cfm capacities.

Cooling tower fans (Chapter 40) are predominantly of the propeller type, but axial types are also used for packed towers, and occasionally a centrifugal fan is used to supply forced draft.

Circulating fans are invariably of propeller or disk type, and are made in a vast variety of blade shapes and arrangements. They are designed for pleasing appearance, as well as utility.

General purpose fans are centrifugal fans of conventional design, built for service in the lower capacity ranges. They are built with the fan wheel mounted on the motor shaft, or connected to a self-contained belt-driven arrangement. They are listed in capacities from 100 to 20,000 cfm, and static pressures up to 1½ in. water.

Kitchen fans for domestic use are small propeller fans arranged for window or wall mounting, and with various useful fixtures. Their capacities range from 300 to 1200 cfm.

Attic fans are used during the warm seasons to draw large volumes of outdoor air through a house or other building whenever the indoor temperature exceeds the outdoor, and thereby utilize the cooling effect of the relatively cool evening or night air. Research by the ASHAE[12] indicates that a two to three-minute air change is desirable in the North while in the South, a one-minute change is recommended to provide the additional cooling effect of air motion.

Fans may be centrally located in an attic or other unused space, or in a hallway, and arranged to draw proportionately from several rooms; or local window units may be installed in a single room. Central units draw from the living quarters and discharge into the attic, whence the air escapes through windows or grilles; or the air may be drawn through grilles into the attic with the fan discharging directly outdoors. Discharge openings on the lee side are preferred.

Attic fans are usually of propeller type, and should be selected to operate at low velocities to minimize noise. Noise is more of a problem on local units, but care should be taken to prevent transmission of noise or vibration on all installations, because they operate during sleeping hours. Central units are available in sizes from 3,000 to 30,000 cfm, and window units up to 8,000 cfm.

Fans For Special Applications

Fans are used to handle many gases other than air at normal temperature. These range from heated air to many types of fumes, vapors, and industrial gases which may be corrosive, explosive, toxic, radio active, or merely noxious.

For handling corrosive gases fans should be constructed of a material suitable for the particular gas being handled, although at times it is economical to plan on replacing a unit of standard material at more frequent intervals. Explosive combinations usually dictate a non-sparking fan in which either the fan, or only those parts which might strike together if not adjusted, are built of non-sparking materials. Noxious, toxic, radio-active, or pure or valuable gases call for special construction to prevent leakage. This usually consists of a welded gas-tight housing, using flanged inlet and outlet, and some form of shaft seal.

In most of these special applications, since it is desirable to keep all bearings, drives and motors outside the gas stream, centrifugal fans are usually used and in arrangements 1, 2, 4, or 8 (Fig. 6). The exception is in the case of fans handling explosive mixtures, where propeller or axial fans are permissible when built with explosion-proof motors and non-ferrous wheels.

Fans handling hot air or gas are generally of the centrifugal types and follow arrangements 1 or 8 so that bearings, drives and motors are remote from the heat. If of double-inlet type, they have inlet boxes and long shafts to keep the bearings outside the stream. Propeller or axial types are rare when the temperature exceeds 150 F. With temperatures above 600 F special heat-resistant materials may be required for the rotors. In addition to a remote location for the bearings, external cooling is frequently required when the temperature exceeds 200 to 250 F. This is often obtained by use of air-cooled or water-cooled jackets. With anti-friction bearings a head-radiating disc or a small circulating impeller between the fan and the nearest bearing is sometimes sufficient. Oil lubrication rather than grease lubrication is commonly recommended.

REFERENCES

[1] ASME *Test Code for Fans* (American Society of Mechanical Engineers, PTC 11-1946).

[2] Standards, Definitions and terms in use by the fan and blower industry (*National Association of Fan Manufacturers Bulletin* No. 110, 1952, p. 2).

[3] Standard test code for centrifugal and axial fans (ASHVE and the National Association of Fan Manufacturers, *NAFM Bulletin* No. 110, 1952, p. 18).

[4] Sound measurement test code for centrifugal and axial fans (*NAFM Bulletin* No. 110, 1952, p. 33). W. H. Hoppmann II and Fred Lager: Noise ratings of ventilating fans (ASHVE TRANSACTIONS, Vol. 51, 1945, p. 271).

[5] R. D. Moyer: Fan laws simplify performance calculations (*Power*, August 1946).

[6] F. L. Busey: The centrifugal fan (ASHVE TRANSACTIONS, Vol. 21, 1915, p. 43).

[7] S. A. Moss, C. W. Smith, and W. R. Foote: Energy transfer between a fluid and a rotor for pump and turbine machinery (*ASME Transactions*, 1941).

[8] E. N. Jacobs, K. E. Ward, and R. M. Pinkerton: *The Characteristics of 78 Related Airfoil Sections from Tests in the Variable Density Wind Tunnel* (*National Advisory Committee for Aviation Report* No. 460). R. M. Pinkerton and Harry Greenberg: *Aerodynamic Characteristics of a Large Number of Airfoils Tested in the Variable Density Wind Tunnel* (*National Advisory Committee for Aeronautics Report* No. 678).

[9] M. C. Stuart and J. B. Lusk: The specific characteristics of fans (ASHVE TRANSACTIONS, Vol. 43, 1937, p. 57).

[10] W. R. Heath and A. E. Criqui: The axial flow fan and its place in ventilation (ASHVE TRANSACTIONS, Vol. 50, 1944).

[11] J. J. Walsh: Mine ventilation (ASHVE TRANSACTIONS, Vol. 23, 1917, p 659). D. Harrington: Mine ventilation and its relation to health and safety (ASHVE TRANSACTIONS, Vol. 51, 1945, p. 243).

[12] G. B. Helmrich and G. H. Tuttle: Comfort cooling with