shown that good results may be expected when the radius to the center of the elbow is 1.5 times the pipe diameter or duct width parallel to the radius. Examination of the curve will indicate that little advantage is to be gained by selecting elbows having a centerline radius of more than two diameters[5]. Elbows having a radius of more than three diameters show a slightly increased resistance due to the increased length of pipe but, when used, they reduce the overall resistance of the system and therefore should not be avoided.

Where space conditions necessitate the use of short radius or miter

TABLE 2. EFFECT OF VANES ON PRESSURE LOSS OF 7-INCH SQUARE VENTILATING DUCT[a]
Expressed in feet of total equivalent length of duct (ELD)

SQUARE MITER ELBOW								STANDARD ELBOWS WITH VARIOUS RADII							
	Radius Ratio R_1/W	0	.2	.4	.6	.8	1.0		Radius Ratio R_1/W	0	.2	.4	.6	.8	1.0
	ELD, ft	41.1	30.5	27.5	30.1	37.7	38.5		ELD, ft	39.7	23.3	22.0	25.7	28.9	39.7
	Radius Ratio R_1/W	0	.2	.3					Radius Ratio R_1/W	0	.2	.3	.4	.5	.6
	Radius Ratio R_2/W	0	.4	.5					Radius Ratio R_2/W	0	.4	.5	.6	.7	.8
	ELD, ft	41.1	23.5	23.3					ELD, ft	39.7	20.0	22.0	23.0	23.8	25.7
	Radius Ratio R_1/W	0	.2	.3					Radius Ratio R_1/W	0	.4	.6	.8	1.0	1.2
	Radius Ratio R_2/W	0	.4	.5											
	Radius Ratio R_3/W	0	.6	.7											
	ELD, ft	41.1	20.7	22.2					ELD, ft	25.3	17.7	16.5	18.7	23.5	25.6
									Radius Ratio R_1/W	0	.7	.8	.9	1.0	1.2
VANE A	B		C		D										
ELD, ft 21.8	17.0		17.9		17.8				ELD, ft	14.2	13.3	13.0	12.7	12.5	12.7

[a]For more complete data see A.S.H.V.E. RESEARCH PAPER—Effect of Vanes in Reducing Pressure Loss in Elbows in 7-Inch Square Ventilating Duct, by M. C. Stuart, C. F. Warner and W. C. Roberts (A.S.H.V.E. JOURNAL SECTION, *Heating, Piping and Air Conditioning*, September, 1942, p. 566).

Note A: Vane *A* made up of a large number of small splitters; *B* made up of a small number of large splitters bent on a large radius; *C* hollow vanes having different outside and inside curvature; and *D* four splitters with $R/W = 0.4$. Elbow same as *D* except 2 in. trailing edge on the end of each splitter. ELD in feet = 17.0.

Note B: The air velocity has no effect on the loss of elbows when the loss is expressed as equivalent length of duct.

elbows in square or rectangular duct work, turning vanes should be used to reduce the pressure losses. Rough or raw edges on the vanes should be avoided to prevent objectionable noise. Typical types of vanes are shown in Table 2 with the total equivalent length of duct that may be used in estimating the resistance of each type.

The pressure loss through elbows of less than 90 deg may be assumed to be directly proportional to the ratio of the angle through which the turn is made. The resistance will vary widely for the large degree turns

[5]Pressure Losses in Rectangular Elbows, by R. D. Madison and J. R. Parker (*Heating, Piping and Air Conditioning*, July, p. 365, August, p. 427, September, p. 483, 1936).

depending upon the aspect ratio and the length of straight pipe between the elbows, but for practical purposes, it may be assumed that the ratio remains proportional to the angle through which the turn is made. Reverse 90 deg elbow turns should be avoided wherever possible but, where used, the friction of the elbows indicated in Fig. 5 should be doubled for the second elbow.

PROPORTIONING THE LOSSES

The entrance loss through the outside air intake louvers will vary with the design of the louvers and method of connection to the system. The louvers and connecting duct will have a friction resistance of from 0.25 to 1.00 times the velocity pressure. Therefore, the total entrance loss will vary from 1.25 to 2.00 h_v. Common practice is to use 1.5 h_v for a 75 per cent free area louver with connecting duct having 15 deg tapered sides. Wherever air passes through a plenum space having a negligible velocity, allowance must be made for the loss in velocity head. This may be taken as the velocity head corresponding to the difference in velocities in the plenum and the duct. Where the ducts are very smooth with long transformation fittings, a regain in static pressure is sometimes allowed, but generally ordinary construction does not warrant a consideration of this factor, and it is customary to neglect it. When it is allowed, the regain is estimated at one-half the difference between the velocity pressure at the fan outlet and at the last run of pipe.

Other losses of pressure occur through the heating units, at the air washer and at air filters. In ordinary practice in ventilation work it is usual to keep the sum of the duct losses one-third to one-half and the loss through the other units at less than one-half of the static pressure. The remainder is then available for producing velocity. In the design of an ideal duct system, all factors should be taken into consideration and the air velocities proportioned so that the resistance will be practically equal in all ducts regardless of length.

DUCT SIZES

Ducts and flues for gravity circulation must be sized so that the friction loss will not exceed 50 per cent of the available aspirating effect due to the temperature and height of the column of heated air. Duct systems for mechanical circulation may be sized so as to have much higher pressure losses than gravity systems. The total pressure of these systems is limited to the available pressure from the fan used.

The general rules to be followed in the design of a duct system are enumerated herewith:

1. The air should be conveyed as directly as possible at reasonable velocities to obtain the results desired with greatest economy of power, material and space.
2. Sharp elbows and bends should be avoided unless turning vanes are used.
3. Transformation pieces should be made as long as possible. The angle between the sides and axis of the duct should never exceed 30 deg and where possible, 15 deg should be made the maximum.
4. Especial care should be taken to maintain a true cross-section and not to restrict the air flow either in transformation pieces or in elbows.
5. Rectangular ducts or flues should be made as nearly square as possible. Good