percent. Therefore, the area of flue required is 1525 × 0.945 = 1441 sq in.

Inlets. Inlet flues, each approximately 60 sq in. in area, have given good results. One such flue should be provided for each 3500 lb animal weight. They should deliver air from points 12 to 18 in. below the ceiling.

Sheep Barns

Shelters used for breeding and feeding stock usually have enough openings, so that no special provision for ventilation is required. Barns for winter lambing flocks, however, require ventilation systems. Fermentation in the floor pack of manure produces heat, vapor, and odor. These must be added to the ventilation load regularly produced by the animals.

Outlets. In practice, results obtained by the basic formula, Equation 7, when modified by the use of the chart, Fig. 6, have given good results:

$$A_o = \frac{4A_f}{\sqrt{h}} \qquad (7)$$

where

A_o = area of the outlet, square inches.
A_f = floor area, square feet.
h = vertical height from top of inlet openings to top of outlet flue, feet.

The bottom of the outlet flue should be 15 to 24 in. above the surface of the manure pack.

Inlets. Provide one inlet, 60 sq in. in area, for each 150 sq ft of floor area. Inlets should be well distributed around the side walls, and designed to deliver air near the ceiling (see section on Dairy Stables).

Swine Barns

Community swine barns, because of the extent of slop feeding and the absence of daily cleaning of the pens, are the most difficult farm buildings to ventilate satisfactorily. Farrowing pens, to which supplemental heat is supplied, present less of a problem. In all cases, good floor drainage to remove urine and excess spilled water is important.

Temperatures of from 50 to 55 F are usually recommended for farrowing pens. It is desirable to maintain temperatures above freezing in all other pens in community houses. For barns that are well stocked and adequately ventilated, this requires walls with an overall thermal resistance of from 3 to 6, and ceilings with 40 to 50 percent greater resistance.

Outlets. The outlet flue should draw air from a level of 15 to 18 in. above the floor. Equation 8 is the basic formula for flue area, and gives reasonably good results when modified according to the chart, Fig. 6.

$$A_o = \frac{5 \times A_f}{\sqrt{h}} \qquad (8)$$

Inlets. At least one inlet flue should be used for each pen. Swine are given or select definite nesting places, and care must be exercised to avoid having inlets located over them.

Total inlet area should be approximately 70 percent of outlet area. The area of individual inlets is best determined from the total area required, and the number that can be so installed as to meet previous specifications. Inlets should deliver air from points 12 to 15 in. below the ceiling, or from a level deflector on a sloping ceiling.

Poultry Laying Houses

From the standpoint of ventilation, poultry laying houses may be divided into cold houses and warm houses. The former are uninsulated, except in the ceiling. The indoor-outdoor temperature difference is seldom more that 5 F deg. In the warm house, because of insulation or supplemental heat, the temperature seldom falls below 32 F, and is usually above 45 F.

Outlets. The outlet flue is best placed near the middle of the pen. It is advisable to limit the length of pens to 80 ft.

The area of the outlet flue may be determined from Equation 9, and modified according to the chart, Fig. 6.

$$A_o = \frac{2.5 \times A_f}{\sqrt{h}} \qquad (9)$$

For a cold house, the bottom of the flue should be at the level of the insulated ceiling. In warm houses, the bottom of the flue should be 12 to 15 in. above the level of the floor litter.

Inlets. Inlets may be approximately 60 sq in. in area. The total inlet area may be equal to 70 percent of the outlet area. Inlets in cold and in warm houses should deliver air from points 12 to 24 in. above the floor. In cold houses which normally do not have storm sash, windows may be raised enough to give the desired area, and be fitted with baffle boards to direct the air straight and upward.

In houses less than 20 ft in width, all inlets may be on one side. In wider houses, a rather uniform distribution of inlets is essential.

GARAGE VENTILATION

Because of hazards resulting from carbon monoxide and other physiologically harmful or combustible gases or vapors in garages, the importance of proper ventilation of these buildings cannot be over-emphasized. During the warm months of the year, garages are usually ventilated adequately because the doors and windows are kept open. The ASHAE Code of Minimum Requirements for Heating and Ventilating Garages,[14] adopted in 1935, specifies that openings for natural ventilation shall be distributed as uniformly as possible in at least two outside walls, and that the total area of such openings shall be equivalent to at least 5 percent of the floor area. The code further states that where it is impracticable to operate such a system of natural ventilation, a mechanical system shall be used, and shall provide for either the supply of 1 cfm of outdoor air for each square foot of floor area, or for exhaust of the same amount of air, discharging it to the outdoors as a means of flushing the garage.

Cooperative research[14] on garage ventilation, undertaken by the ASHAE Committee on Research at Washington University, St. Louis, Mo., and at the University of Kansas, and tests conducted at the ASHAE Research Laboratory, have resulted in authoritative papers on the subject.

Some of the conclusions based on work at these laboratories are:

1. Upward ventilation results in a lower concentration of carbon monoxide at the breathing line and a lower temperature above the breathing line, than does downward ventilation for the same rate of carbon monoxide production, air change, and the same temperature at the 30-in. level.

2. A lower rate of air change and a smaller heating load are required with upward than with downward ventilation.

3. In the average case, upward ventilation results in a lower concentration of carbon monoxide in the occupied portion of a garage, than that obtained with mixing of the exhaust gases and the air supplied. However, the variations in concentration from point to point, together with the possible failure of the advantages of upward ventilation to accrue, suggest the basing of garage ventilation on complete mixing, and an air change sufficient to dilute the exhaust gases to the allowable concentration of carbon monoxide.

4. The rate of carbon monoxide production by an idling car is shown to vary from 25 to 50 cfh, with an average rate of 35 cfh.

5. An air change of 350,000 cfh per idling car is required to keep the carbon monoxide concentration down to one part in 10,000 parts of air.

Individual Exhaust Ducts

Motor vehicle servicing areas may be provided with underground or overhead exhaust systems discharging outdoors. Each service location should be provided with a flexible branch duct, the inlet end of which is sized to slip over the tail pipe of the engine, or over any deflector attached to the tail pipe. The minimum branch size and ventilation rate for the largest class of vehicle regularly serviced at each location are shown in Table 5.

Table 5 . . . . Minimum Tail Pipe Connection Size and Ventilation Rate per Vehicle

Vehicle	Ventilation Rate, cfm	Flexible Pipe, Dia, in.	Diameter of Rigid Branch Connection to Flexible Pipe, in.
Auto up to 200 hp	100	3	4
Auto or truck above 200 hp	200	4	4½
Diesel truck or bus	400	4½	5½

Where each tail pipe exhaust branch is provided with an automatic device to close the branch inlet when it is not in use, the capacity of the fan for the system should be based on the maximum number of branches in simultaneous use. Where the branch inlets are open when not in use, the system capacity should be based on the total number of branches connected to the main.

Individual straight lengths of gas tight duct, not over 20 ft in length, terminating outdoors, may be provided where exhaust systems are not installed. The duct should fit tightly over the tail pipe and be of a diameter not less than the diameter of the tail pipe.

REFERENCES

[1] D. R. Bahnfleth, T. D. Moseley, and W. S. Harris: ASHAE Research Report No. 1614—Measurement of infiltration in two residences, Part I—Technique and measured infiltration (ASHAE Transactions, Vol. 63, 1957, p. 439).

[2] D. R. Bahnfleth, T. D. Moseley, and W. S. Harris: ASHAE Research Report No. 1615—Measurement of infiltration in two residences, Part II—Comparison of variables affecting infiltration (ASHAE Transactions, Vol. 63, 1957, p. 453).

[3] T. C. Min: Winter infiltration through swinging-door entrances in multi-story buildings (ASHAE Journal Section, *Heating, Piping and Air Conditioning*, February 1958, p. 121).

[4] F. C. Houghten and Margaret Ingels: ASHVE Research Report No. 786—Infiltration through plastered and unplastered brick walls (ASHVE Transactions, Vol. 33, 1927, p. 377). G. L. Larson, D. W. Nelson, and C. Braatz: ASHVE Research Report No. 826—Air infiltration through various types of brick wall construction (ASHVE Transactions, Vol. 35, 1929, p. 183). G. L. Larson, D. W. Nelson, and C. Braatz: ASHVE Research Report No. 851—Air infiltration through various types of brick wall construction (ASHVE Transactions, Vol. 36, 1930, p. 99). G. L. Larson, D. W. Nelson, and C. Braatz: ASHVE Research Report No. 868—Air infiltration through various types of wood frame construction (ASHVE Transactions, Vol. 36, 1930, p. 397).

[5] F. C. Houghten and C. C. Schrader: ASHVE Research Report No. 686—Air leakage through the openings in buildings (ASHVE Transactions, Vol. 30, 1924, p. 105). C. C. Schrader: ASHVE Research Report No. 704—Air leakage around window openings (ASHVE Transactions, Vol. 30, 1924, p. 313). F. C. Houghten and M. E. O'Connell: ASHVE Research Report No. 803—Air leakage studies on metal windows in a modern office building (ASHVE Transactions, Vol. 34, 1928, p. 321). F. C. Houghten and M. E. O'Connell: ASHVE Research Report No. 815—Air leakage through a pivoted metal window (ASHVE Transactions, Vol. 34, 1928, p. 519). W. M. Richtmann and C. Braatz: ASHVE Research Report No. 817—Effect of frame calking and storm windows on infiltration around and through windows (ASHVE Transactions, Vol. 34, 1928, p. 547). G. L. Larson, D. W. Nelson, and R. W. Kubasta: ASHVE Research Report No. 909—Air infiltration through double-hung wood windows (ASHVE Transactions, Vol. 37, 1931, p. 571). J. E. Emswiler and W. C. Randall: The weathertightness of rolled section steel windows (ASHVE Transactions, Vol. 34, 1928, p. 527). J. E. Emswiler and W. C. Randall: Pressure differences across windows in relation to wind velocity (ASHVE Transactions, Vol. 36, 1930, p. 83). D. O. Rusk, V. H. Cherry, and L. Boelter: Air infiltration through steel framed windows (ASHVE Transactions, Vol. 39, 1933, p. 169).

[6] A. P. Kratz and S. Konzo: Fuel saving resulting from the use of storm windows and doors (ASHVE Transactions, Vol. 42, 1936, p. 87).

[7] A. M. Simpson and K. B. Atkinson: The infiltration problem of multiple entrances (ASHVE Journal Section, *Heating, Piping and Air Conditioning*, June 1936, p. 345). A. M. Simpson: Infiltration characteristics of entrance doors (*Refrigerating Engineering*, June 1936).

[8] F. C. Houghten and J. L. Blackshaw: Indices of air change and air distribution (ASHVE Transactions, Vol. 39, 1933, p. 261).

[9] F. C. Houghten, J. L. Blackshaw, and Carl Gutberlet: ASHVE Research Report No. 994—Wind velocities near a building and their effect on heat loss (ASHVE Transactions, Vol. 40, 1934, p. 387). F. C. Houghten and Carl Gutberlet: ASHVE Research Report No. 1069—Heating requirements of an office building as influenced by the stack effect. (ASHVE Transactions, Vol. 43, 1937, p. 437). H. L. Alt: Flue action in high buildings (ASHVE Journal Section, *Heating, Piping and Air Conditioning*, May 1932, p. 376). Axel Marin: Influence of stack effect on the heat loss in tall buildings (ASHVE Transactions, Vol. 40, 1934, p. 377).

[10] J. E. Emswiler: Neutral zone in ventilation (ASHVE Transactions, Vol. 32, 1926, p. 59).

[11] *State Building Construction Code Applicable to One- and Two-Family Dwellings* (New York State Building Code Commission).

[12] W. C. Randall and E. W. Conover: Predetermining airation of industrial buildings (ASHVE Transactions, Vol. 37, 1931, p. 605).

[13] F. L. Fairbanks: Dairy stable ventilation (ASHVE Transactions, Vol. 34, 1928, p. 181). A. J. Offner: Cow barn ventilation (ASHVE Transactions, Vol. 39, 1933, p. 149). For additional information on this subject see: M. A. R. Kelley: *Technical Bulletin* (U. S. Department of Agriculture, 1930). F. L. Fairbanks: Air conditioning of farm buildings (*Agricultural Engineering*, November 1937, p. 485). F. L. Fairbanks and A. M. Goodman: *Dairy Stable Ventilation* (Cornell University, *Cornell Extension Bulletin* No. 151, revised 1949). F. L. Fairbanks and A. M. Goodman: *The Ventilation of Poultry Laying Houses* (Cornell University, *Cornell Extension Bulletin* No. 315, revised 1950).

[14] Code of minimum requirements for heating and ventilating garages (ASHVE Transactions, Vol. 41, 1935, p. 30). W. C. Randall and L. W. Leonhard: Airation study of garages (ASHVE Transactions, Vol. 36, 1930, p. 233). A. S. Langsdorf