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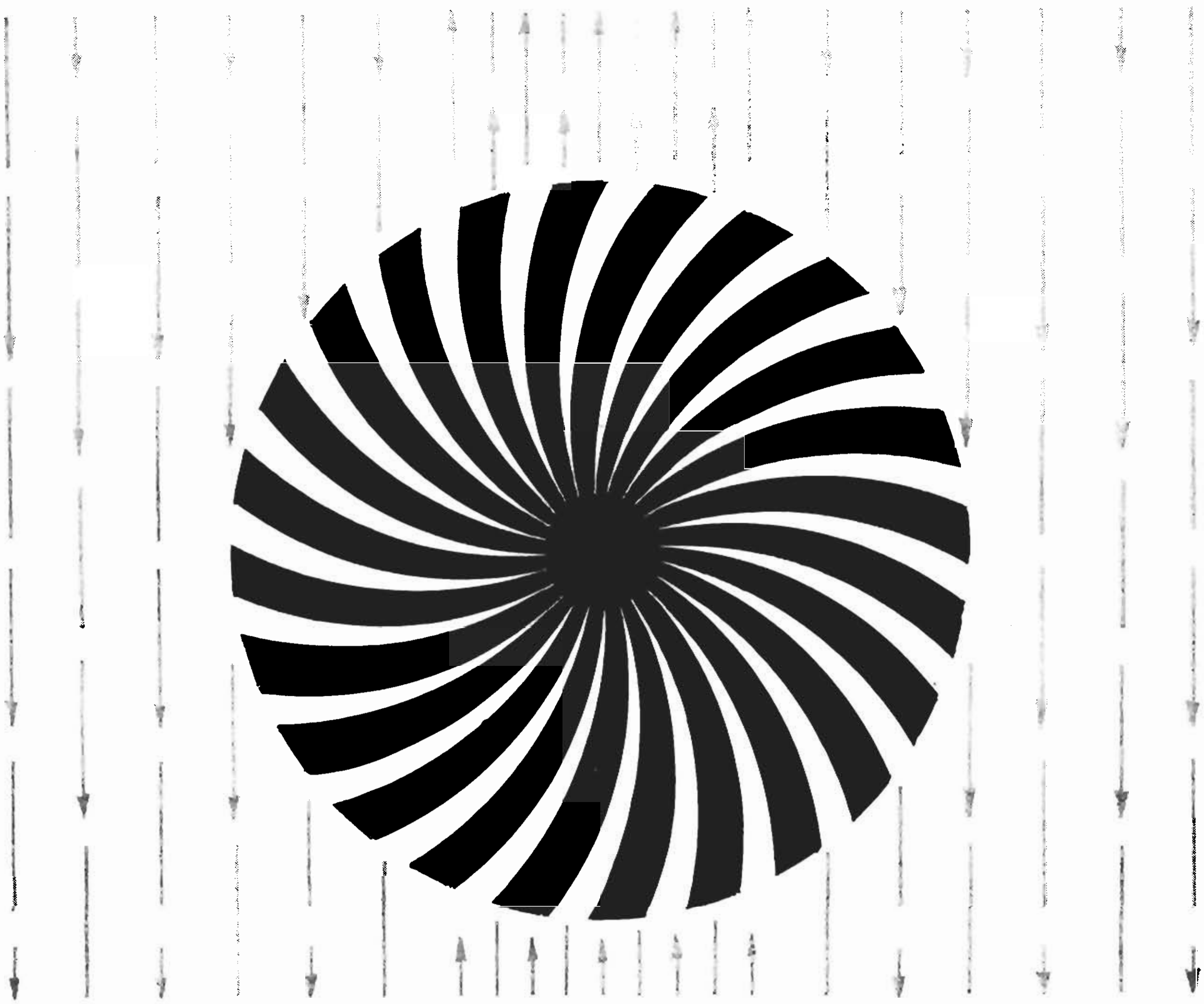

AERATION

FOR SAFE GRAIN STORAGE

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AERATION —

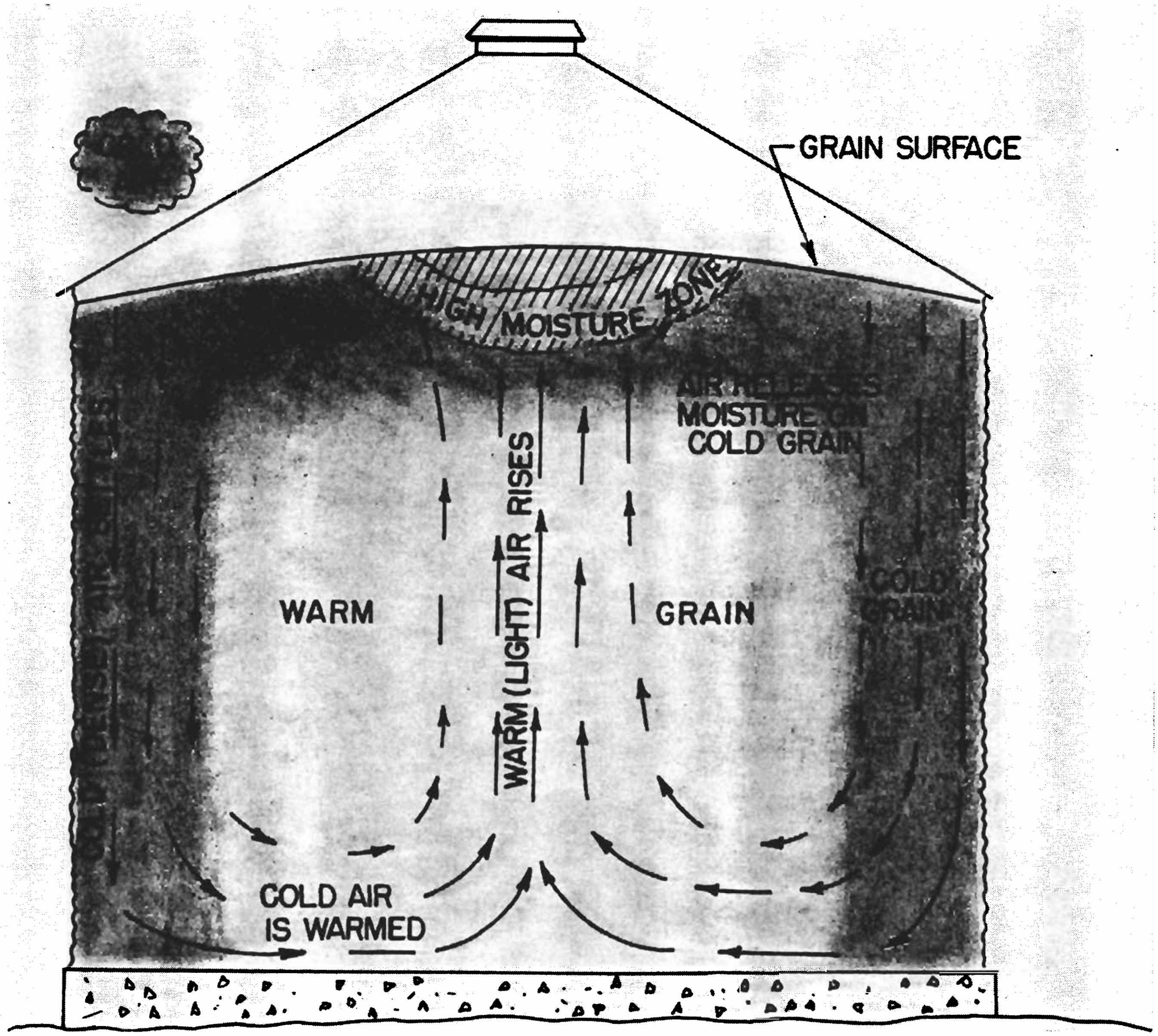


Figure 1. Example of moisture migration in grain stored several months without aeration.

FOR SAFE GRAIN STORAGE

Ronald T. Noyes, Extension Agricultural Engineer

Aeration is the practice of forcing air through bulk stored grain to maintain grain condition. It uses low airflow rates and replaces the practice of "turning" grain to equalize temperatures and remove "hot spots." With good aeration, shelled grain can be stored safely at 13.5 to 14.0 percent moisture if fines are *screened out* or *well distributed*. Grain quality can be maintained economically, and the risk of storage losses are greatly reduced by keeping grain cool and maintaining uniform temperatures and moisture contents.

Primary emphasis in this publication is placed on aeration in round storage bins, the most common type of farm grain storage in the central Corn Belt. Most of the principles discussed here can be applied to both flat and deep vertical storage. Aeration of flat and deep vertical bins, more common in commercial than farm storage, is discussed in two USDA publications, Marketing Research Report 178, "Aeration of Grain in Commercial Storages," and Marketing Research Report 337, "Operating Grain Aeration Systems in the Corn Belt." Both are published by the Agricultural Marketing Service, USDA.

Why Aerate?

Most spoilage in dry stored grain is caused by *moisture migration, mold growth,* or *insect infestations.* All three factors are closely related to temperature and moisture content of the grain, and relative humidity of air in the grain.

In the winter, cold, dense air in the outer grain settles while air between kernels at the bottom and center of the bin picks up heat from the warm grain, making it buoyant, Figure 1. The combination of dense outside air and buoyant center air causes the air to circulate. This air movement is called convection air currents. The warmed air, with increased moisture holding capacity, rises near the center and absorbs moisture. As it approaches the surface, moisture condenses on the cold grain, creating a high moisture zone called "top crusting." This moisture movement, called "moisture migration," can occur in corn with "safe" storage moisture contents of 12 to 13 percent.

Moisture migration affects both mold and insect activity by creating a favorable reproductive and growth environment—*warm,* moist areas. Mold growth is influenced by both humidity and temperature. Therefore, both grain moisture and temperature must be held uniform after grain is cooled. Winter storage temperatures of 35 to 40° F are recommended for control of mold and insect activity.

Some storage odors can be removed from grain by a few air changes; others require extended periods of aeration. Odors caused by soured or fermented grain can seldom be entirely removed by aeration.

Fumigation is often carried out by metering fumigants into the airstreams for uniform distribution in the grain. Many aeration systems do not provide uniform airflow rates in all parts of a bin. To obtain adequate fumigant distribution to all parts of a bin, recirculation of air may be necessary.

When Should You Aerate?

Begin cooling warm grain as soon as possible after placing it in storage. Operate fans when outside air temperatures are at least 10 to 15° F cooler than the warmest grain. During September and October, fans should be operated continually except in rainy or foggy weather. After October when air temperatures are lower and relative humidities higher, manually controlled aeration should be operated *during daylight on fair days* (relative humidity below 75%). Cool grain down to 35 to 40° F by late November and maintain this temperature through March.

After grain is cooled, check grain temperatures at representative locations in the bin once each week to 10 days when outside temperatures change radically and about every two to three weeks during periods when weather changes are slight. Grain should be aerated to equalize grain temperature throughout the bin when outdoor temperatures remain more than 20-30° F above or below average grain temperatures for one or two weeks. If hot spots or mold odors are detected, aerate as soon as weather is suitable. If no temperature or odor checks are made, aerate every two or three weeks when weather is suitable.

Do not operate fans below 30° F for long periods, or *grain may freeze!* Frozen grain may create problems during warm winter or spring weather. Warm, moist air contacting frozen grain condenses moisture on the grain when it is being warmed by aeration (or during bin unloading). This can result in a "chunk" of frozen grain, which is very difficult to thaw with airflow. When this "chunk" thaws, spoilage may occur. Unloading mechanisms may also be plugged by the frozen mass when the bin is emptied.

Grain stored until summer in bins of about 2000 bushels or less does not require warming. As weather warms in the spring, grain stored in larger bins should be warmed 5 to 10° F each month starting in April until grain temperatures reach about 70° F. Aerate on fair days with air 5 to 10° F warmer than grain. Air with less than 75 percent relative humidity should be used. (Note: Once a warming zone has started through the grain, it must be moved *completely through* since moisture tends to condense on the colder corn ahead of the warming zone. If the warm layer is stopped against the cool "wetted layer," corn in this zone may become musty and spoil.)

"Fines" Management

Mechanical damage in high moisture field shelled corn ranges from about 15 to 35 percent. Much of this damage is present in the form of "fines" or foreign material. Wind damaged or "down corn" that is field shelled usually contains a significant amount of dirt which adds to the amount of foreign material. Unless corn is properly distributed in storage, a column of foreign material forms under auger or gravity spout discharges; this dense core restricts aeration and may absorb moisture from surrounding air, causing it to cake or harden. If the column forms in the center of the bin, it is often drawn down into the auger hopper during grain unloading and blocks the grain flow.

Screening or cleaning to remove foreign materials before grain reaches storage is recommended. Mechanical distribution of grain as it goes into storage helps insure good airflow distribution and fewer problems with "hot spots." Stored grain may be probed for hard pockets of foreign material soon after filling. The size and location of hard spots should be recorded so that these specific areas can be checked periodically for moisture accumulation and heating.

If heating cannot be controlled by aerating, grain should be transferred or rotated to break up hot spots.

Aeration Requirements

Farm aeration systems normally consist of a fan and air duct arrangement which delivers a specific airflow rate through grain in a storage bin. An airflow rate of 1/10 cfm (cubic foot per minute) per bushel is recommended for both manually and semi-automatically controlled farm systems. This flow rate is sufficient for lowering grain temperatures 15 to 20° F in about 80 hours in the summer, 120 hours in the fall, and 160 hours in the winter. Thus, cooling corn from 80° F to 60° F in the fall would require about five days of continuous running or 10 days at 12 hours of fan time per day. Cooling times with other airflow rates would be proportional; cooling 15 to 20° F in the fall with 1/5 cfm/bu would be twice as fast as with 1/10 cfm/bu, or 2 1/2 days of continuous running. Automatic system airflow rates of 1/20 to 1/30 cfm/bu are adequate for farm storage.

Aeration rates in large commercial storages are usually lower, from 1/20 cfm/bu for flat storage to 1/40-1/50 cfm/bu for vertical (silo-type) storage. Flat storage needs higher airflow rates than vertical storage of equal volume because air distribution is less uniform.

The direction of airflow during aeration is normally downward. Warm, moist air is exhausted through warm grain at the bottom of the structure, not through cold grain under the bin roof where condensation can occur. Bins with high capacity fans can be aerated by pushing the air up through the grain; this high velocity air is exhausted rapidly and doesn't absorb or release much moisture while passing through the surface grain.

Grain volumes of less than 1000 bushels normally do not require aeration. Volumes up to 5000 bushels can be aerated satisfactorily with a vertical perforated duct, Figure 2. (Note: Vertical aerator sections should be soldered or brazed to keep sheet metal screws from pulling out, allowing sections to separate; use heavy chain to suspend the aerator from the bin fill ring.) Larger bins should have a horizontal floor duct system, Figure 3, to obtain more uniform air distribution. Figures 4 (a) through 4(d) show floor duct patterns which provide satisfactory air distribution. The system in Figure 4(b) provides the best air distribution pattern and gives a higher concentration of airflow at the center, often a trouble spot. This pattern would be desirable for bin diameters of 27 to 40 feet.

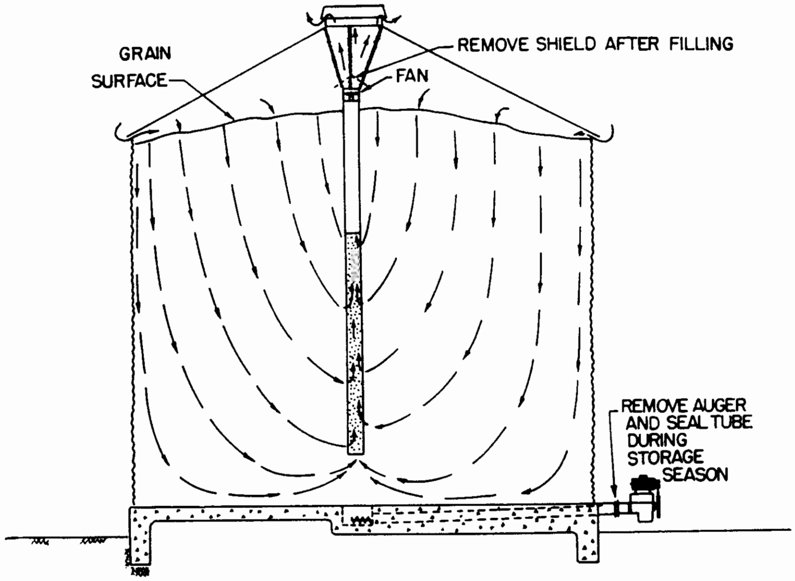


Figure 2. Vertical duct aerator for round bins.

Selecting Equipment

Fan and motor units are selected on the basis of air volume (cfm) at a certain static pressure (airflow resistance that fan operates against; inches of water). The volume of air is determined by multiplying the desired airflow rate per bushel (cfm/bu) by the number of bushels stored. Static pressure is

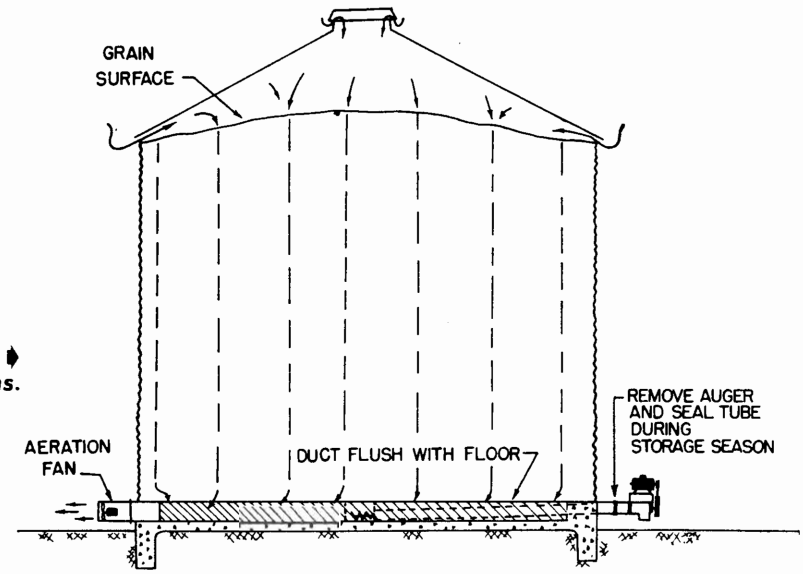
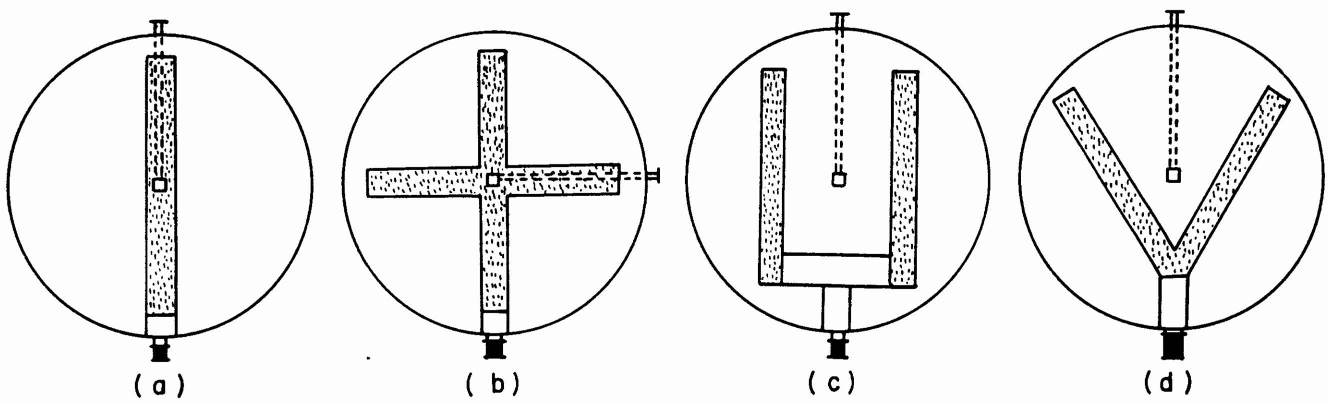
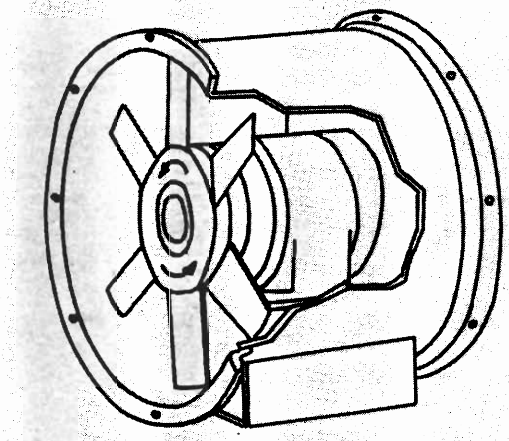


Figure 3 ➧ Horizontal duct aeration system for round bins.

Figure 4. Aeration duct patterns.





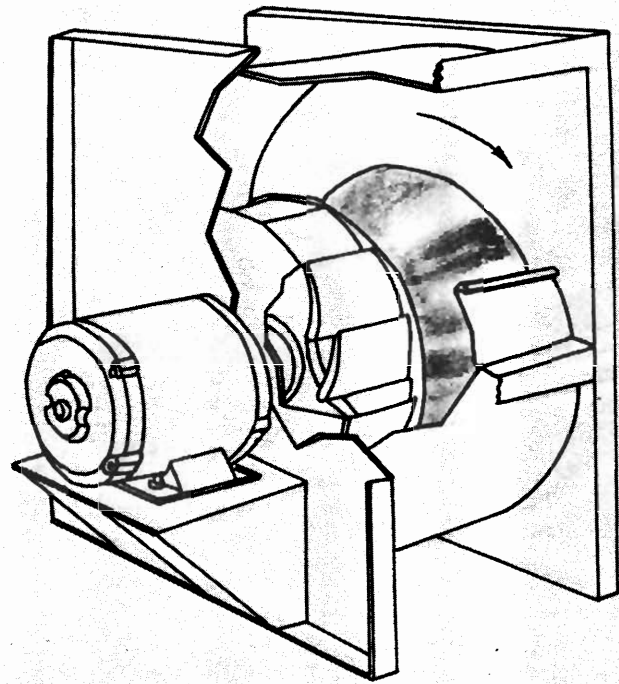


Figure 5. Common types of aeration fans.

estimated according to type and depth of grain, and duct losses. Other factors such as grain compaction and amount of foreign material also affect airflow. Table 1 lists approximate static pressures and horsepower requirements for five types of grain at depths used in farm storages.

Either propeller (axial flow) or centrifugal (radial flow) fans can be used in aeration systems where static pressures do not exceed 4 to 5 inches, Figure 5. Centrifugal fans with backward curved blades usually give more consistent delivery over a wide range of pressures than most propeller or axial flow fans. They are usually used when static pressures exceed 4 to 5 inches; however, special designs in axial flow fans, such as one using two fan wheels (two stage), are capable of developing high static pressures.

Air distribution systems for large round bins consist of flush-floor (top of duct even with floor surface) or on-floor ducts. Common on-floor duct cross-sections are circular, semicircular, arched, rectangular, or triangular. Flush-floor ducts are usually rectangular. Double corn crib bins can be aerated with on-floor ducts or by covering sheller trenches with reinforced perforated metal or closely spaced boards covered with hardware cloth. Flat storages usually use on-floor ducts, although flush-floor systems operate well.

The duct *cross-section area* is a *critical* factor in the overall system efficiency. For example, the pressure drop in a 15-inch diameter round duct will be more than twice the pressure drop of an 18-inch duct for the same airflow. The following equation is used to determine duct cross-section areas:

$$\text{Cross-section Area (square feet)} = \frac{\text{Total Air Volume (cfm)}}{\text{Max. Duct Air Velocity (fpm)}}$$

Recommended maximum duct velocities are 1500-2000 fpm for lengths up to 25 feet, and 1000-1500 fpm for 25 to 60 feet.

Duct surface area is another *critical* design factor. The necessary surface area, based on the velocity of air leaving the duct, is determined by the equation:

$$\text{Duct Surface Area (square feet)} = \frac{\text{Total Air Volume (cfm)}}{\text{Air Velocity Leaving Duct (fpm)}}$$

TABLE 1. MINIMUM AERATION DUCT CROSS-SECTION AND SURFACE AREAS AND LENGTHS

Bin diameter	Grain volume[1]	Air flow rate	Air volume	Minimum duct area: Cross-section[2]	Minimum duct area: Surface[3]	Perforated duct length in feet when effective surface area in square feet per foot is: 1.0	2.0	3.0
(feet)	(bushels)	(cfm/bu)	(cfm)	(square feet)	(square feet)	(feet)	(feet)	(feet)
		1/20	160	.11	6.4	......	......	......
18	3,200	1/10	320	.21	12.8	12.8	......	......
		1/5	640	.43	25.6	25.6	12.8	8.5
		1/20	220	.15	8.8	......	......	......
21	4,400	1/10	440	.29	17.6	17.6	8.8	......
		1/5	880	.59	35.2	35.2	17.6	11.7
		1/20	290	.19	11.6	......	......	......
24	5,800	1/10	580	.39	23.2	23.2	11.6	......
		1/5	1160	.77	46.4	46.4	23.2	15.5
		1/20	360	.24	14.4	......	......	......
27	7,200	1/10	720	.48	28.8	28.8	14.4	
		1/5	1440	.96	57.6	57.6	28.8	19.2
		1/20	450	.30	18.0	18.0	......	......
30	9,000	1/10	900	.60	36.0	36.0	18.0	......
		1/5	1800	1.20	72.0	72.0	36.0	24.0
		1/20	650	.43	26.0	26.0	......	......
36	13,000	1/10	1300	.87	52.0	52.0	26.0	......
		1/5	2600	1.73	104.0	104.0	52.0	24.7

[1] Grain depth = 16 feet.
[2] Maximum duct velocity = 1500 feet per minute.
[3] Maximum velocity of air leaving duct = 25 feet per minute.

Air velocities leaving the duct surface should not exceed 25 to 30 fpm. Perforated duct openings should be at least 7 to 10 percent of the total duct surface.

Aeration equipment specifications can be selected from Tables 1 through 4. For example, assume that a 27-foot diameter bin with a 16-foot sidewall is being built for corn storage. From Table 1, the level grain volume is 7,200 bushels. An air volume of 720 cfm is needed for an aeration rate of 1/10 cfm/bu. This calls for a *minimum* duct *cross-section* area of 0.48 sq. ft. $\left\{\frac{720 \text{ cfm}}{1500 \text{ fpm}}\right\}$ and a duct *surface* area of 28.8 sq. ft. $\left\{\frac{720 \text{ cfm}}{25 \text{ fpm}}\right\}$ This bin can be properly aerated with one single duct if there is adequate airflow space around the center unload box. Rectangular and circular duct areas are listed in Tables 2 and 3.

From Table 2, a 10-inch diameter round duct (0.54 sq. ft.), or a 14-inch diameter half-round duct can be selected for on-floor installation. However, a flush-floor installation is more practical for cleaning, especially with a sweep unloader. Table 3 shows that a rectangular duct 12 inches wide by 6 inches deep would give sufficent cross-section area, 0.50 sq. ft.; however, a check shows the surface area = 27 feet x 1 foot = 27.0 sq. ft. is slightly less than the 28.8 sq. ft. required. Therefore, a 15-inch by 6-inch duct would be selected. By dividing the required surface area by the duct width, the minimum length is found:

$$\frac{28.8 \text{ square feet}}{1.25 \text{ feet}} = 23 \text{ feet.}$$

(If a 6-inch augar is laid in the aeration duct, an additional 0.20 square feet will be required, or 0.68 square feet total. At least an 8-inch depth

TABLE 2. CIRCULAR DUCTS—EFFECTIVE CROSS-SECTION AND SURFACE AREAS

Diameter	Cross-section area: Round	Cross-section area: Half-round	Surface area: Round[1]	Surface area: Half-round
(inches)	(square feet)		(square feet/feet of length)	
6	0.20	0.10	1.26	0.79
8	0.35	0.18	1.67	1.05
10	0.54	0.27	2.09	1.31
12	0.78	0.39	2.52	1.57
14	1.07	0.54	2.94	1.83
16	1.40	0.70	3.34	2.10
18	1.77	0.88	3.78	2.36
20	2.18	1.09	4.18	2.62
22	2.64	1.32	4.60	2.88
24	2.14	1.57	5.02	3.14

[1] Round duct surfaces considered 80% effective.

TABLE 3. RECTANGULAR DUCTS[1,2,3] EFFECTIVE CROSS-SECTION AREAS

Depth (inches)	Duct area in square feet when top width in inches is: 9	12	15	18	21	24	27	30	33	36
	(square feet)									
4	0.25	.33	.41	.50	.59	.67	.75	.88	.90	1.00
6	0.38	.50	.62	.75	.88	1.00	1.12	1.24	1.36	1.50
8	0.50	.67	.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00
10	0.62	.83	1.04	1.25	1.46	1.67	1.88	2.08	2.29	2.50
12	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
14	0.88	1.16	1.46	1.75	2.04	2.33	2.62	2.92	3.20	3.50
16	1.00	1.33	1.67	2.00	2.33	2.67	3.00	3.33	3.66	4.00
18	1.12	1.50	1.88	2.25	2.62	3.00	3.38	3.75	4.12	4.50

[1] All surfaces exposed to grain should have 10% openings or more.
[2] Effect surface area of flush-floor duct = top width (ft.) × length (ft.).
[3] Effect surface area of on-floor duct = [top width + 2 (Depth)] (ft.) × length (ft.).

TABLE 4. APPROXIMATE STATIC PRESSURE AND HORSEPOWER FOR AERATION FANS[1]

Grain stored	Grain depth	Static presure when airflow rate in cfm/bu is: 1/5	1/10	1/20	Horsepower needed per 1,000 bu when airflow rate in cfm/bu is: 1/5	1/10	1/20
	(feet)	(inches of water)			(horsepower/1,000 bu)		
Corn	10	0.50	0.45	0.40	.035	.015	.006
and	15	0.60	0.55	0.50	.042	.020	.008
Soybeans	20	0.75	0.65	0.55	.052	.025	.010
	25	1.00	0.80	0.65	.070	.030	.012
Wheat,	10	1.15	1.00	0.95	.080	.030	.010
Oats	15	1.50	1.25	1.05	.120	.040	.015
and	20	2.15	1.60	1.20	.180	.050	.020
Sorghum	25	3.00	2.05	1.45	.250	.062	.025

[1] Approximate values from *Aeration of Grain in Commercial Storages,* MRR No. 178, Agricultural Marketing Service, U. S. Department of Agriculture.

would be needed to provide reinforcement clearance above the auger. A 15-inch by 8-inch duct would provide 0.83 square feet.)

The approximate static pressure from Table 4 for 1/10 cfm/bu, and 16 feet of grain is 0.57 inches. Two fan selection alternatives can be used: (1) A fan can be selected to deliver 720 cfm at about 0.60 inches static pressure from manufacturers' literature, or (2) power requirements can be estimated from Table 4. For 1/10 cfm/bu and 16 feet of corn, power per 1000 bushels is 0.021 horsepower. Total power is 7.2

$$(1000 \text{ bu.}) \times 0.021 \left[\frac{\text{hp}}{1000 \text{ bu.}}\right] = 0.15 \text{ hp.}$$

A 1/6 horsepower fan would be required. In either case, delivered airflow may deviate slightly from the required airflow rate. If the required fan size falls between two categories, such as between 1/4 hp and 1/3 hp, the larger size should be selected.

Fan Operation

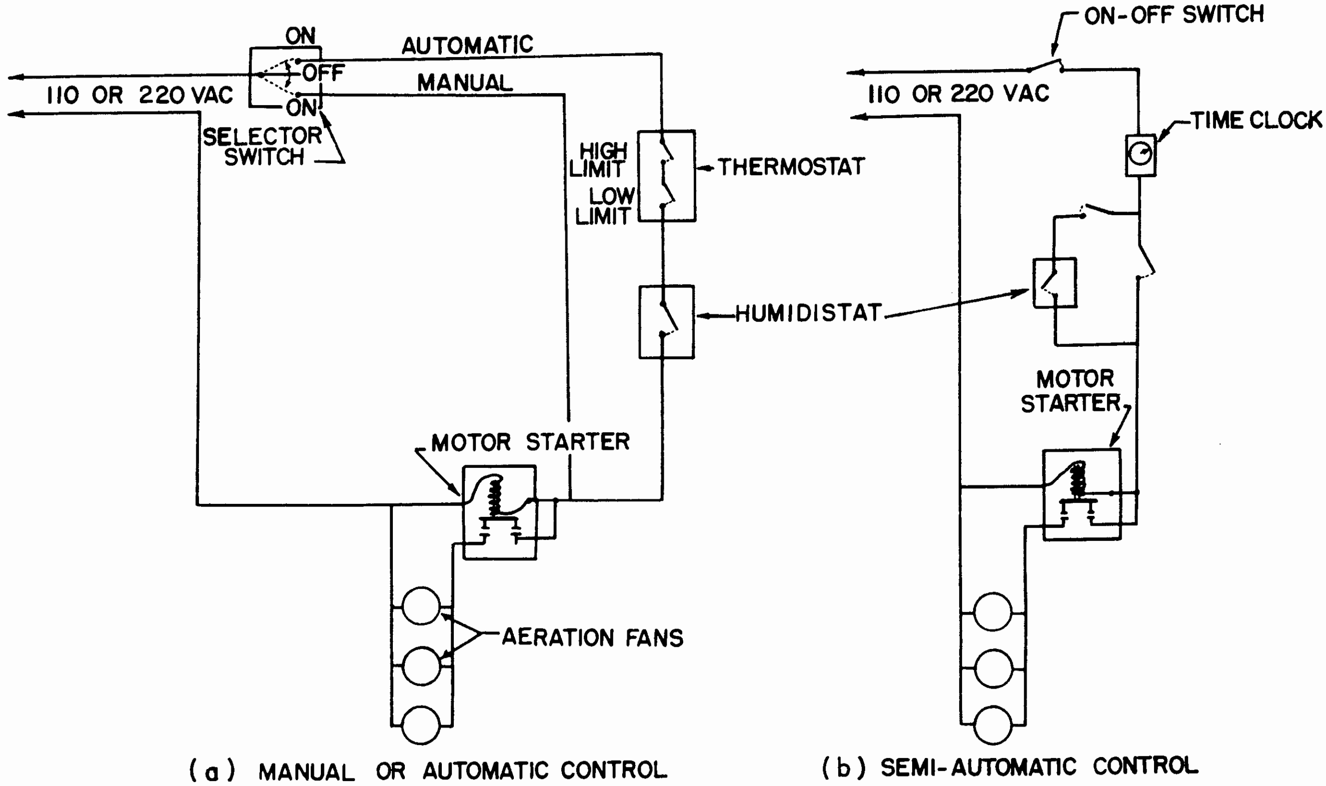
Figures 6(a) and 6(b) illustrate schematic wiring diagrams of three methods of fan control. Figure 6(a) shows manual and automatic control circuits combined.

Manually controlled systems consist of a simple on-off control operated during desirable weather conditions. This type of control is normally used with airflow rates of 1/10 cfm/bu or more where complete temperature changes of 15 to 20° F are made in one to two weeks.

Semiautomatic or scheduled control is recommended for airflow rates of 1/20 to 1/10 cfm/bu. This may consist of a time clock and on-off switch used individually, or connected in series with an outdoor humidistat control, Figure 6(b).

Automatic controls should be used with airflow rates of 1/30 to 1/20 cfm/bu. This will be an on-off switch and a high-and-low limit thermostat connected in series with a high-limit humidi-

Figure 6. Wiring diagrams for aeration fan control systems.



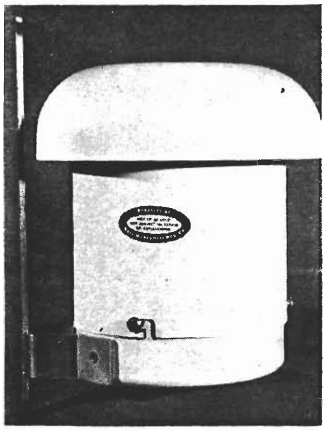
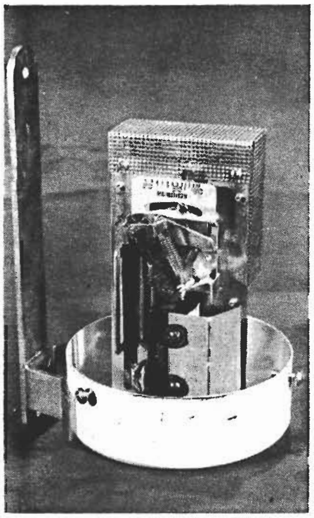
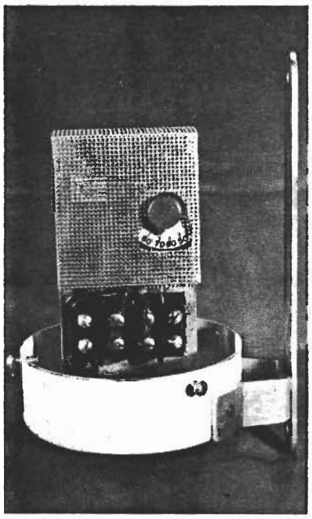
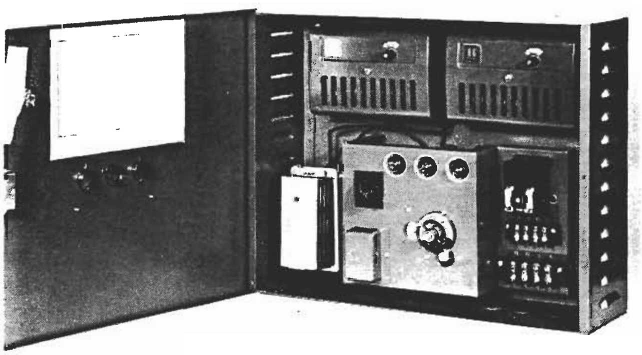
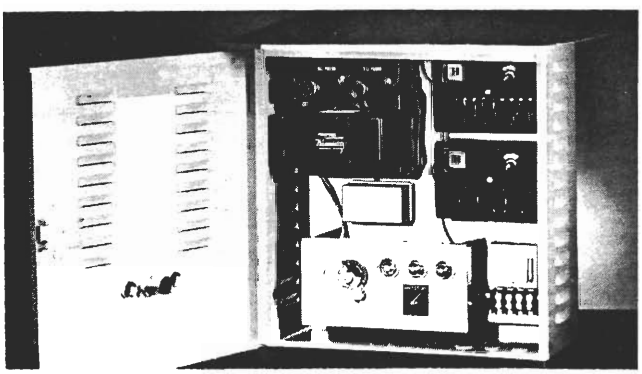


Figure 7. Typical temperature and humidity controls for farm use. The top three pictures show an inexpensive control unit for single bins. The bottom two pictures are more elaborate controls for multiple fan operation.









stat, Figure 6(a). Where several fans are operated from one set of controls, indicator lights can be installed on the control panel so the operator can easily tell which fans are operating. Control elements should be placed in the shade, should sense freely moving outside air, and be protected from weather. Both the thermostat and humidistat should be carefully adjusted and maintained according to manufacturer's recommendations. Humidistats should be cleaned with a *camel hair brush* at least once each year.

Units can be calibrated for accuracy by comparing the scale reading at which the contact points close against weather bureau humidity readings. Figure 7 shows temperature and humidity controls for farm aeration systems.

Magnetic motor starters should be used with automatic controls, especially for 1/2 horsepower or larger motors. Smaller motors can be started and stopped by temperature and humidity control switches if the switches are rated for those loads. Electrical advisors from local power companies can give assistance in selecting and installing control equipment.

In automatic control systems, after grain has been cooled to 40° F, the high limit thermostat is set to open when temperature rises to the upper limit (40-45° F for winter) and the low limit thermostat set to open as temperature falls to the lower limit (25-30° F for winter), so that the fan operates only between the preset limits. The humidistat connected in series with the thermostats should be set to open when the relative humidity rises to the set point. Summer and early fall relative humidities of 80 percent or below and winter relative humidities of 70 to 75 percent are satisfactory if air temperatures are at least

10° F lower than the grain. For spring warming, a setting of 70-75 percent with air temperatures 10° F higher than the grain should be used.

Agricultural weather report information must be closely followed in using either the manual or semi-automatic control systems. Weather data from instruments on the farm can be used, but long-range forecast data are also desirable. Time clocks can be set to operate the system during periods of the day when the humidity and temperature are desirable (normally daylight on sunny days). Grain temperature probes or cables can be used to spot check or monitor grain temperatures in specific locations. A general idea of grain temperature can be obtained by holding a thermometer in the exhaust air stream.

Aeration Costs

Aeration system costs are comprised of ownership and operating costs. Ownership costs are governed by the type of storage, size and type of duct installation, method of control, plus size and type of fan or blower used. The installed cost of farm aeration systems will range from about three to eight cents per bushel of capacity, depending on the degree of complexity. Based on 13 percent of original cost per year, annual ownership costs would range from about 4/10 to one cent per bushel.

Operating costs depend on rate of airflow required, grain type and depth, total fan and management time, and costs of labor and power. Operating costs (power and labor) range from 1/20 to 1 cent per bushel per year depending mainly on *labor*. As an illustration, assume that a 1/4 horsepower fan on a 7500-bushel bin of corn is operated 400 hours in 30 weeks to cool to 40° F, hold, then warm. The fan will consume about 250 watts per hour for 400 hours, or 100 KWH. At 2.5 cents per KWH, this cost would be $2.50 per year for electricity. If management time requires an average of 1/2 hour per week for 30 weeks with labor at $3.00 per hour, the labor cost would be $45.00, more than 18 times the cost of electric power. Thus, total operating cost would be $47.50 or about 5/8 cent per bushel.

The more complex (controlled) system will have higher ownership costs but probably lower operating costs because of lower management time. Ownership costs for automatic controls can be spread over several bins by connecting fans in parallel with one set of controls designed for the total motor load. Cutoff switches can be placed on each fan for individual control.

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