Shell Ventilation Systems for

POTATO STORAGES

in the Fall Crop Area

Marketing Research Report No. 579

Agricultural Marketing Service
Transportation and Facilities Research Division
U.S. DEPARTMENT OF AGRICULTURE

PREFACE

This report is based on research conducted at the Red River Valley Potato Research Center, East Grand Forks, Minn. The study is part of a marketing research project to develop more efficient work methods, equipment, and facilities for the off-farm handling, storage, and preparation for market of fall-crop potatoes. The report covers ventilation systems for providing optimum storage conditions for potatoes, and presents guides for the design, selection of equipment, and operation of shell ventilation systems.

Improved efficiency in marketing farm products is the objective of a broad program of marketing research by the Agricultural Marketing Service, and this study is part of that program. This research was begun under the direction of Wallace Ashby, formerly of the Agricultural Research Service, and is now under the direction of Joseph F. Herrick, Jr., marketing research analyst, Handling and Facilities Research Branch, Transportation and Facilities Research Division, Agricultural Marketing Service.

Work on ventilation and air circulation, including the design and operation of ventilation systems in commercial potato storages, was conducted over a 12-year period with the help of many individuals and organizations in Maine, Michigan, Nebraska, Colorado, Idaho, Alaska, Minnesota, and North Dakota. The broad project of which this research is a part is carried on with the cooperation of the North Dakota and Minnesota Agricultural Experiment Stations. This report is an attempt to present concisely the results of this research relating to shell ventilation.

A. H. Bennett, agricultural engineer, AMS, contributed immeasurably to the content and organization of this report.

Previous publications covering improved methods, equipment, and facilities for handling, storing, and packing potatoes are:

From the Office of Information, U. S. Department of Agriculture, Washington 25, D. C., these Marketing Research Reports:

Storage of Fall-Harvested Potatoes in the Northeastern Late Summer Crop Area. MRR No. 370, January 1960.

Handling Potatoes into Red River Valley Storages--Methods and Equipment. MRR No. 471, September 1961.

Handling and Shipping Potatoes to Processing Plants in Pallet Boxes and Burlap Bags. MRR No. 495, September 1961.

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.:

White Potato Storages for New Jersey, Long Island, and Southeastern Pennsylvania. MRR No. 70, June 1954. (20 cents)

Flume Systems for Handling Bulk Stored Potatoes. MRR No. 177, June 1957. (15 cents)

Out of print, but may be consulted at principal libraries:

An Improved Elevator for Deep Bin Potato Storages. MRR No. 131, August 1956.

An Evaluation of Methods for Cooling Potatoes in Long Island Storages. MRR No. 494, June 1961.

From the Maine Agricultural Experiment Station, Orono, Maine:

Methods of Receiving Potatoes in Barrels at Maine Trackside Storages. Maine Agr. Expt. Sta. Bul. 560, June 1957.

Mechanized Methods of Receiving Potatoes at Maine Trackside Storages. Maine Agr. Expt. Sta. Bul. No. 585, September 1959.

From the Marketing Information Division, Agricultural Marketing Service, U. S. Department of Agriculture, Washington 25, D. C.:

A Light-Weight Conveyor for Filling Deep Bin Potato Storages. AMS-362, February 1960.

Pressures on Walls of Potato Storage Bins. AMS-401, August 1960.

Washington, D. C.   January 1963

CONTENTS

SUMMARY

This report and research which preceded it provide some answers to increasing demands for help in designing systems for controlling temperature, humidity, and other conditions in potato storages. The demands arose from the growing size of production units and the practice of storage and packing for specific markets. Attention has been given to improved circulation of air in large storages where potatoes must be held at about 50° to 55° F. for the processing market.

Potato storages are used, in the fall-crop area, to protect potatoes from light, water, and temperature extremes. With good equipment and management, they can maintain a small temperature differential and prevent free water from accumulating on the potatoes, with low vapor pressure around them at the same time. With circulation and ventilation systems, outdoor air is used to regulate humidity and storage temperature. Without adequate insulation and without the heat of respiration from the potatoes and artificial heat, winter temperatures in potato storages would drop well below freezing. With proper use of insulation, heating, ventilation, and air circulation, it is possible to maintain potato temperatures within a range of 4° to 6° F., at any level between 30° and 60° F.

Forced air circulation and ventilation systems provide better control of storage conditions than gravity ventilation systems. Forced "shell" circulation (air circulation around and over the bins of potatoes), which includes gravity circulation between the bin atmosphere and the air above, is usually practical for regulating temperatures within the bin, although "forced-through" circulation (air circulation through the bins of potatoes) can be utilized for special control measures. With gravity circulation, the rate of air movement drops when the temperature differential in different parts of the bin decreases. With forced circulation, care must be exercised so that the rate of air movement is not continued beyond needs. Over-ventilation causes extra shrinkage.

As used in this report, <u>ventilation</u> means exchanging inside air for outside air by introducing outside air and exhausting inside air. <u>Circulation</u> means moving or distributing air within a storage, even between the free air in work alleys or above bins and the air within bins.

Forced circulation and ventilation systems are controlled by thermostats and motor dampers, but an equally good job can be done manually, if enough continuing attention is given to setting and adjusting dampers.

Guides are presented, in this report, for layout, design, and choice of equipment for several forced circulation and ventilation systems. First cost of a system was found to be between 11 cents and 16 cents per hundredweight of potato storage capacity, while costs of owning and operating were from 2 cents to 3 cents per hundredweight per storage season at the time this study was made.

SHELL VENTILATION SYSTEMS FOR POTATO STORAGES IN THE FALL CROP AREA

by Alfred D. Edgar, agricultural engineer 1/
Handling and Facilities Research Branch,
Transportation and Facilities Research Division
Agricultural Marketing Service

BACKGROUND AND PURPOSE OF STUDY

The fall potato crop represents over two-thirds of the annual potato production in the United States. Most of the crop is stored from 2 to 8 months before it is marketed. During the storage period, the potatoes must be protected as well as possible from light, decay, sprouting, freezing, and shrinkage (loss of weight).

The climate in many fall-crop areas is such that outdoor air can be used to provide the needed storage environment. By ventilating with outdoor air and by circulating the air within the storage, operators can maintain the temperature and humidity that will prevent appreciable deterioration.

An increasing number of potato growers and shippers are asking for assistance in the design of ventilating systems. This increasing need for assistance is directly related to the fact that more large storages are being built now than formerly. Larger and more efficient storages are required because of such changes in the potato industry as these:

1. More potatoes are grown per farm. Between 1934 and 1959, the number of farms reporting potato crops in the United States dropped from 3,100,000 to 685,000, total production remaining about the same (9). 2/

2. There has been a shift from portable packing lines, which require relatively little space, to large-capacity stationary packing lines, which require a special room within the storage for practical and economical operation.

3. The shift from movement of potatoes in containers from field to storage, toward handling them in bulk in trucks, requires larger capacity storage bins for efficient operation.

4. There is increased use of potatoes by processors, who must have a steady supply of suitable potatoes for long periods (8).

Ventilation in large, commercial storages is supplied by forced-air systems. Air may be distributed through the bins in which potatoes are stored--"through circulation"--or around and over the bins--"shell circulation."

1/ Richard S. Claycomb, formerly an agricultural engineer with the AMS Transportation and Facilities Research Division, collaborated with the author in some of the earlier research which served as a basis for this report.

2/ Figures underscored in parenthesis refer to items in Literature Cited, p. 35.

Through-circulation systems have been described in Marketing Research Report No. 370, "Storage of Fall-Harvested Potatoes in the Northeastern Late Summer Crop Area," issued by the U. S. Department of Agriculture.

This publication discusses shell-circulation systems for potato storages ranging in capacity from 4,000 to 100,000 hundredweight (cwt.). Its purpose is to present guides for the design, selection of equipment, and operation of shell-ventilation systems, and examples of installations in typical storages. Storage operators should consult qualified engineers for the actual designing and installation of ventilation systems.

POTATO STORAGE REQUIREMENTS

Potatoes placed in storage in the fall may be held for short periods of 10 to 14 weeks, or varying amounts may be marketed from time to time during a longer period up to 8 months, in accordance with the storage operator's marketing practices and the climate in his area. Some of the potatoes may be sold for table or seed stock, and some may be sold to processors for chipping, French frying, or flake processing.

Storage requirements differ for short and long holding periods, and between potatoes marketed for processing and those for table and seed stock, but some general requirements are applicable to all. These are removing excess heat, maintaining high humidity, and equalizing the temperature of the potatoes within the storage.

The temperature of fall-crop potatoes when they are moved into storage may range from 55° to 70° F. or higher. Adding to this temperature is the heat evolved by respiration. As living plant material, potatoes convert carbohydrates to heat, water, and carbon dioxide. Heat evolved by respiration is useful in preventing the temperature of potatoes from dropping too low during cold weather storage, but it must be removed during early or short-term storage to prevent potato temperatures from going too high.

Besides increasing temperatures, respiration is responsible for some loss in potato weight. The principal cause of shrinkage, however, is evaporation of water. Potatoes are about 80 percent water and their skins are relatively porous. Whenever air with less than 100 percent relative humidity comes in contact with potatoes, water evaporates from the saturated potatoes into the dryer air because of the difference between the vapor pressures in the potatoes and in the air, called the vapor pressure difference (fig. 1). As the relative humidity of the air decreases, the rate of shrinkage of the potatoes increases. Vapor pressure difference also depends on the temperature of the air and the potatoes; 75 percent relative humidity at 40° F. of the air, for example, results in nearly the same vapor pressure difference, with potato temperature unchanged, as 90 percent relative humidity at 65° F.

Figure 1 illustrates the relation of relative humidity to storage air temperature and vapor pressure difference. From these curves, it is seen that, by maintaining a high relative humidity within the range of storage temperatures encountered, the vapor pressure difference is held to a minimum.

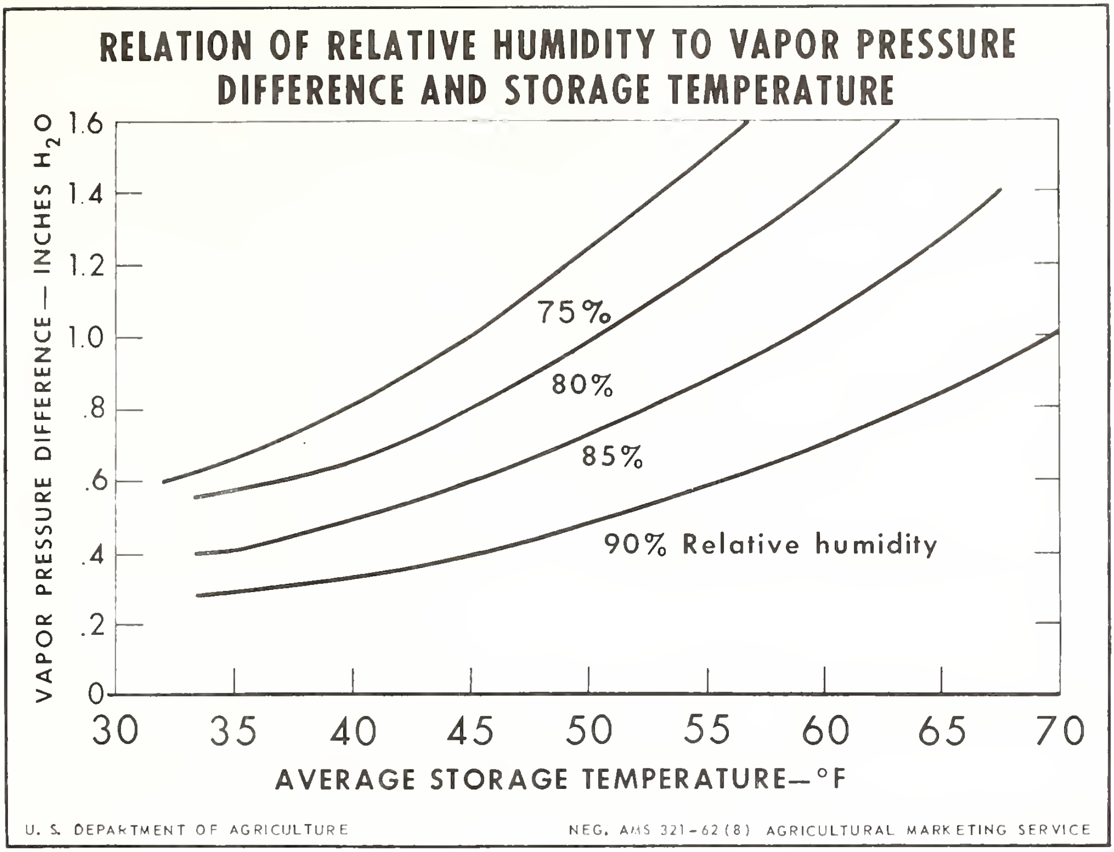


Figure 1

Vapor pressure difference, however, has less effect on the rate of shrinkage as the storage period increases (7). Loss of moisture from potatoes is restricted by the potato skin, which with time, becomes less permeable to the passage of water vapor. 3/ Figure 2 illustrates the rate of shrinkage of potatoes at various vapor pressure differences during 6 months of storage.

During cold weather, the highest humidity that can be achieved in a storage is limited by wall and ceiling temperatures. Because of outdoor temperatures, wall and ceiling temperatures are lower than that of the air in the storage. Colder air can hold less moisture than warmer air, and when the walls and ceiling reach dewpoint temperature (the point at which water vapor condenses), the condensation reduces the relative humidity in the storage and around the potatoes. Wetting of potatoes facilitates the spread of certain diseases. A balance between high humidity and condensation must be maintained throughout the storage period.

3/ Loss of moisture from potatoes, early in storage, is highest partly because of skinned, abraded, or otherwise damaged areas caused by mechanical damage during harvest (5). After damaged areas are suberized or healed, they have about the same moisture permeability as the unbroken skin.

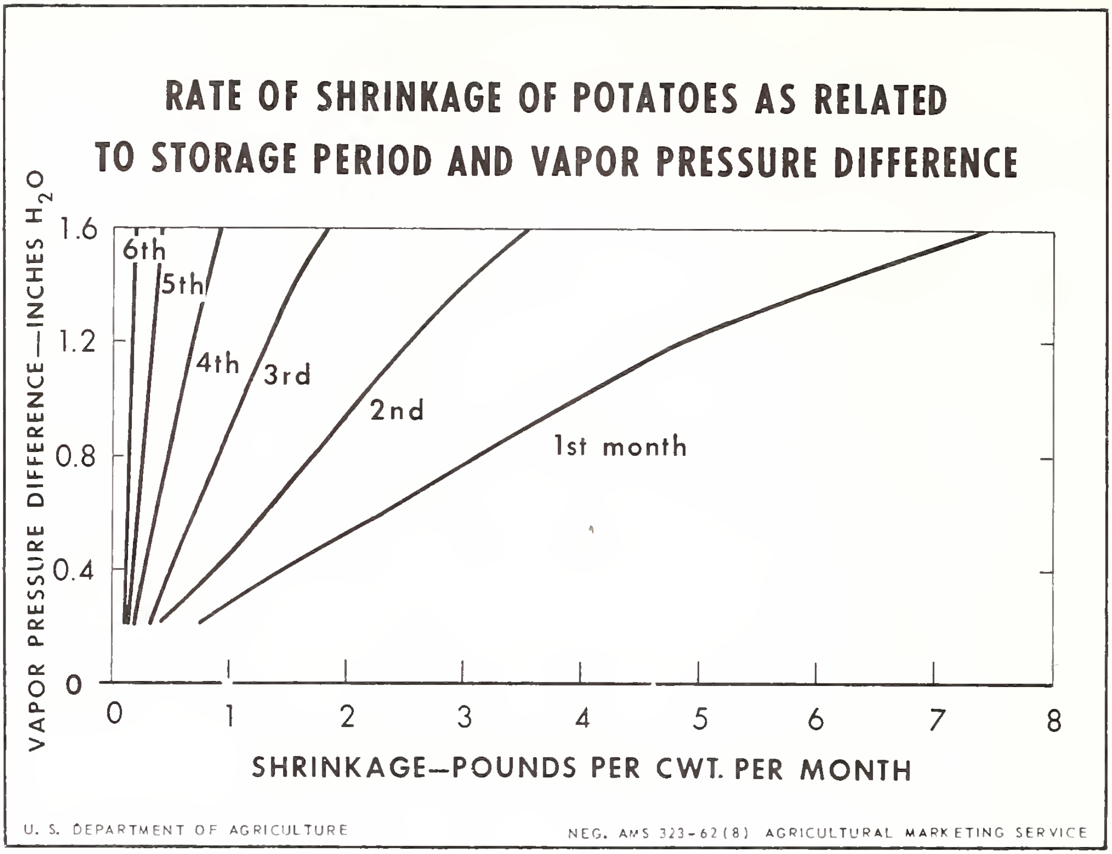


Figure 2

Condensation may occur on the potatoes themselves because of temperature variations among potatoes in the storage bins. It is important, therefore, to keep this variation as small as possible. Temperature variation is widest at the time the potatoes are stored, because of different temperatures prevailing at the time the potatoes are harvested. Throughout storage, the temperature of the potatoes varies, depending on their location in the bin. Potatoes at the outer edges of the storage bin generally are cooler than those in the middle, and water vapor may condense on the cooler potatoes. 4/

For the initial storage period, holding conditions are the same for all lengths of storage and end uses of the potatoes. At this time, storage conditions must provide for rapid healing (suberization) of skinned or cut surfaces of potatoes, to prevent spread of disease through the broken areas and to reduce water loss. Evaporation of water from skinned areas is much greater than that from unbroken areas (10).

4/ In warmer parts of the fall-crop area, so much ventilation may be required to hold potato temperature below 60° F. that humidity is understandably low. In this case humidifiers are sometimes used (2).

The Suberization Period

A minimum temperature of 55° F. and a relative humidity of 90 percent are required for the first week to 10 days of storage. Maximum temperature should be 60° F.

Short-Term Storage

For potatoes that will be marketed for processing or for table or seed stock within 10 to 14 weeks after harvest, the minimum and maximum temperatures may remain at 55° F. and 60° F.

Long-Term Storage

Mature potatoes begin to sprout after a dormant period, which varies from 60 to 90 days, depending on the variety. Sprouts will not grow, however, when the temperature of the potato is below 40° F. Some potatoes may have already gone through part of the dormant period at the time they are harvested and may be ready to sprout early in the storage period. For long-term storage, the temperature of the potatoes, after the suberization period, should be gradually reduced and maintained at a maximum of 40° F. and a minimum of 36° F. (a minimum of 38° F. is preferred but hard to maintain). These temperatures can usually be attained by the end of the third month of storage.

After potatoes have been stored at 40° F., a warming or conditioning period is required. The warming period needed to improve eating quality of table potatoes is usually provided during the time potatoes are in normal marketing channels. The storage operator, however, must provide the conditioning for potatoes for processing, because they require a longer period and higher temperatures to reach acceptable quality.

Figure 3 shows the recommended average temperatures of stored potatoes used for table, seed stock, and processing, for 1 to 8 months of storage. It also shows the temperature and length of time required for conditioning potatoes for processing.

Potatoes for processing may be held for long periods at 50° to 55° F. if they are treated with sprout inhibitors (4). At this temperature, however, shrinkage and decay losses may be high.

REGULATING STORAGE ENVIRONMENT

In shell-ventilation systems, the total volume of air used to regulate the environment in the potato storage may be classified as: (1) Ventilating air from the outside only; (2) a mixture of ventilating air and air within the storage; and (3) air within the storage that is recirculated. Some systems do not provide for mixing the ventilating and recirculating air.

Ventilating air is admitted to the storage to remove excess heat and moisture. Ventilating and recirculating air are mixed to obtain air of the desired temperature when the outside air is too cold to use alone (potatoes

RECOMMENDED AVERAGE TEMPERATURES OF STORED POTATOES FOR TABLE, SEED STOCK & PROCESSING USE

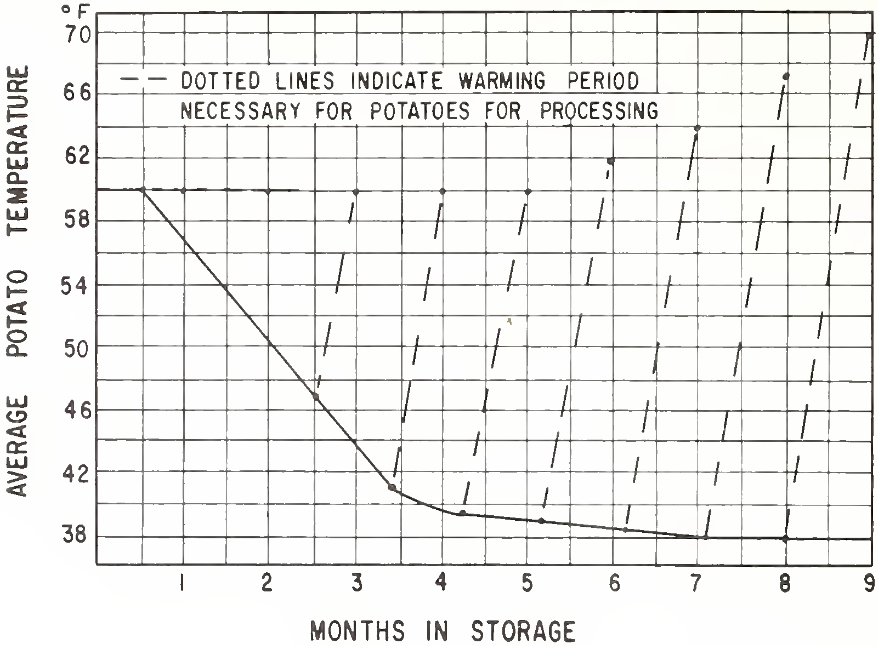


Figure 3

freeze at 29° F.). Air is recirculated within the storage to maintain a uniform temperature distribution when the outside air is too cold or too warm to use for ventilation. Air movement within the potato storage is almost continuous during the storage period.

Effective regulation of storage environment also depends on effective insulation. Insulation is particularly important in helping to maintain high humidity by preventing condensation on the ceiling and walls. It also helps to moderate temperature fluctuations within a storage by reducing the gain in heat in the storage on warm days and the loss of heat from the storage in cold weather. Even though the storage is well insulated, however, it may be necessary to make some provision for heating during the winter, particularly if the storage is not full.

Ventilating Air

The degree of cooling (or heat removal) obtained by ventilation depends on the volume of air admitted and on the differences in temperature and humidity of the air admitted and those of the air within the storage. The less difference there is between indoor and outdoor temperatures and the greater the amount of heat the system must remove, the greater the volume of air required.

In most fall-crop areas, potatoes are harvested and placed in storage when the average outdoor temperature is 50° F. or below; the temperature of the potatoes then averages about 60° F. In some fall-crop areas, storage takes place when the outdoor temperature averages 60° F. or lower, and potato temperature averages about 70° F. 5/

Table 1 shows the average monthly temperatures from September to May in the major fall-crop States. The least difference in temperatures of the potatoes and of the outdoor air occurs during the early months of storage. Cooling capacity of ventilating air is limited, at that time, not only by the small temperature difference but also because air cooler than that in the storage may be available only 8 to 12 hours out of a 24-hour period. Moreover, it is during the warmer periods that the system must meet its peak cooling load.

Table 1.--Approximate average monthly temperatures in certain fall-crop potato States

State groups	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Minnesota, North Dakota, Wisconsin	50	40	30	20	10	0	20	30	50
Maine, Michigan, Nebraska, Washington	--	50	40	30	20	10	20	40	50
Colorado, Idaho, New York, Pennsylvania 1/	--	50	40	30	25	20	30	40	50
California, Long Island, Oregon 1/ 2/	--	--	50	40	30	30	40	45	50

1/ In this table, New York is divided into Upstate New York and Long Island.
2/ Only the late-crop area in California is included.

During the first 5 days of storage, the rate of heat evolution by respiration (table 2) and the rate of water loss from potatoes are about double the normal rates. Field heat (the heat retained by potatoes when they go into storage) also must be removed to lower the temperature of the potatoes to the recommended average.

The maximum volume of air, therefore, is required the first month or two of storage.

5/ Occasionally at harvest, potato temperatures may be as high as 80° F. Practically all decay organisms affecting the potato are more active at high temperatures. For this reason, it is important to reduce the potato temperatures immediately after harvest, or decay will spread rapidly from cuts or bruises before they get a chance to heal (6).

Table 2.--Heat evolved per hour per cwt. of potatoes at different temperatures after about 3 weeks of storage 1/

Temperature--$^{\circ}$F.	32	40	50	60	70
Heat evolved--B.t.u./cwt./hr.	2/ 2	1	2	4	6

1/ Maximum heat evolved during first few days of storage is about three times that shown at the lower temperatures and twice that at higher temperatures.
2/ Increase in heat evolved at 32° F. is apparently due to more available reducing sugars at this lower temperature.

Ventilation requirements decline as the storage season advances. The amount of heat evolved and moisture given up by the potatoes becomes less as the temperature of the potatoes is reduced, and the cooling capacity and availability of ventilating air are high during the winter. Once the temperature of the potatoes has been reduced to about 36° to 40° F., the airflow rate can be reduced to the lowest level sufficient to maintain this temperature. This rate varies, depending on the climate of the area.

In those areas where potatoes are placed in storage at an average temperature of 60° F., when the outside temperature averages 50° F. or lower, an airflow rate of .65 cubic foot per minute (c.f.m.) per cwt. is recommended. The recommended rate for potatoes stored at an average temperature of 70° F., when the outside temperature is 60° F., is .85 c.f.m. per cwt.

Recirculating Air

Recirculating air, when ventilation either is not needed or is impossible, aids in preventing condensation on cooler potatoes, in keeping the potatoes near the outer edges from freezing during prolonged cold spells, and in preventing excessive differences in the temperatures of the potatoes at different places in the bin.

Insulation

Insulation is essential during the winter to maintain both proper temperatures and high humidity in the storage. During the colder months of storage, differences in temperatures inside and outside the storage may range up to 80° F. The minimum insulation requirements to prevent condensation on the ceiling of the storage, in various conditions of relative humidity in the storage and temperature difference between air inside and outside, are shown in figure 4. A minimum of 4 inches of rock wool or equivalent insulation should be provided to maintain a minimum relative humidity of 85 percent when the temperature difference is 80° F.

A vapor barrier should be placed on the warm side of the insulation. This is to prevent the flow of water vapor from the storage atmosphere into insulation where it may condense and saturate the insulation or form frost, greatly reducing the insulation's value.

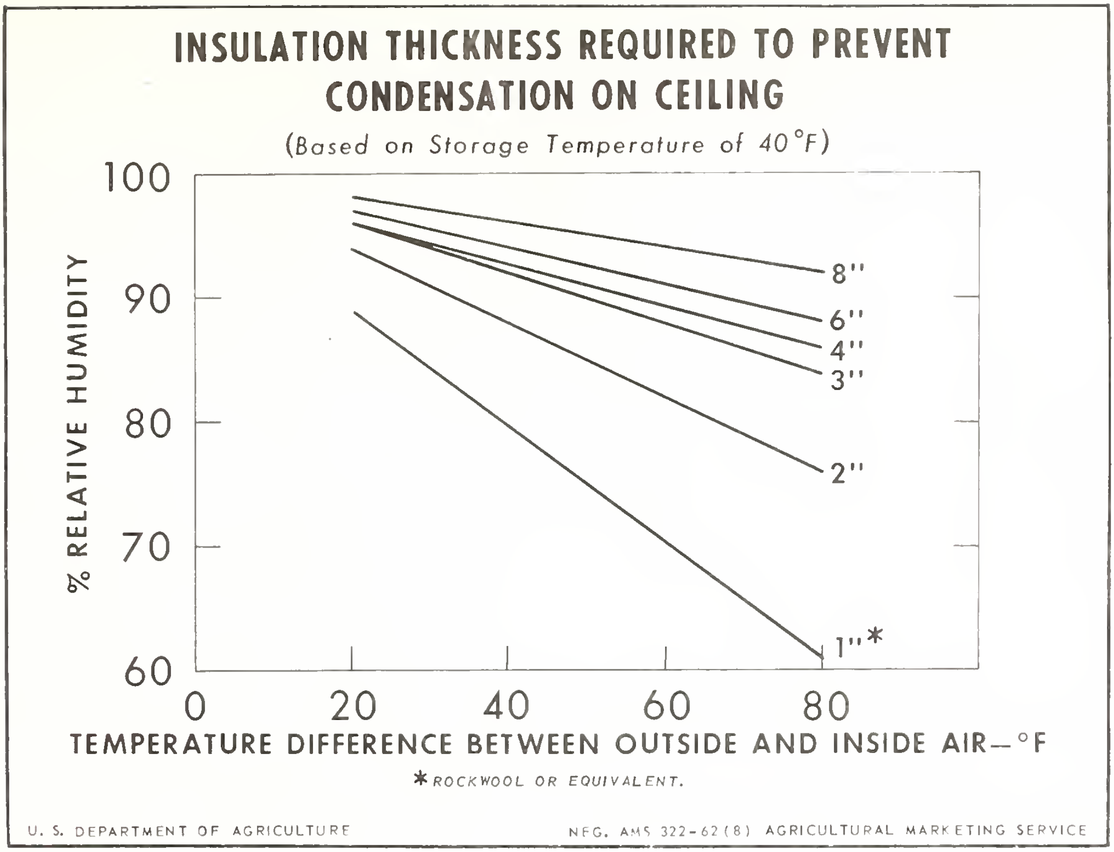


Figure 4.--Minimum insulation thickness required to prevent condensation on the ceiling, for various values of relative humidity in the storage and of outside-to-inside temperature differences. Storage at 40° F. Insulation based on rock wool or equivalent.

Materials such as sheet metal, aluminum foil, or polyethylene, which have a perm (permeability) rating of zero, will stop vapor flow entirely unless there is leakage through uncaulked joints or holes.

DESIGN OF SHELL-VENTILATION SYSTEMS

The principal parts of a shell-ventilation system and their functions are: (1) Ducts to distribute the air within the storage; (2) one or more fans to supply the necessary volume of air at the required static pressure; (3) one or more dampers to admit, exhaust, and circulate air; and (4) controls to operate the system.

Control of the ventilation system may be manual or automatic. For manual control, only two or three inside-outside thermometers are needed. For automatic control, a motor for the dampers is required, with thermostats and manual switches wired to the damper motor.

Ventilation systems must be designed by qualified engineers. Any of several designs and types of equipment may be suitable for one storage. This discussion is presented to give the storage operator information on how the ventilation system is put together and on the effectiveness or economy of use of various types of fans, dampers, and types of control. Some guides for use of design engineers also are given.

The Duct System

In shell ventilation, the duct system consists of air passages between the walls of the storage bins and those of the building. The system usually extends entirely around the interior walls of the building and consists of main, branch, and riser ducts (riser ducts are vertical air passages within the wall sections) (fig. 5). Air enters through the main duct, is distributed around the bins at or below floor level through branch ducts, and up the sides of the wall through the riser ducts. The riser ducts open over the bins.

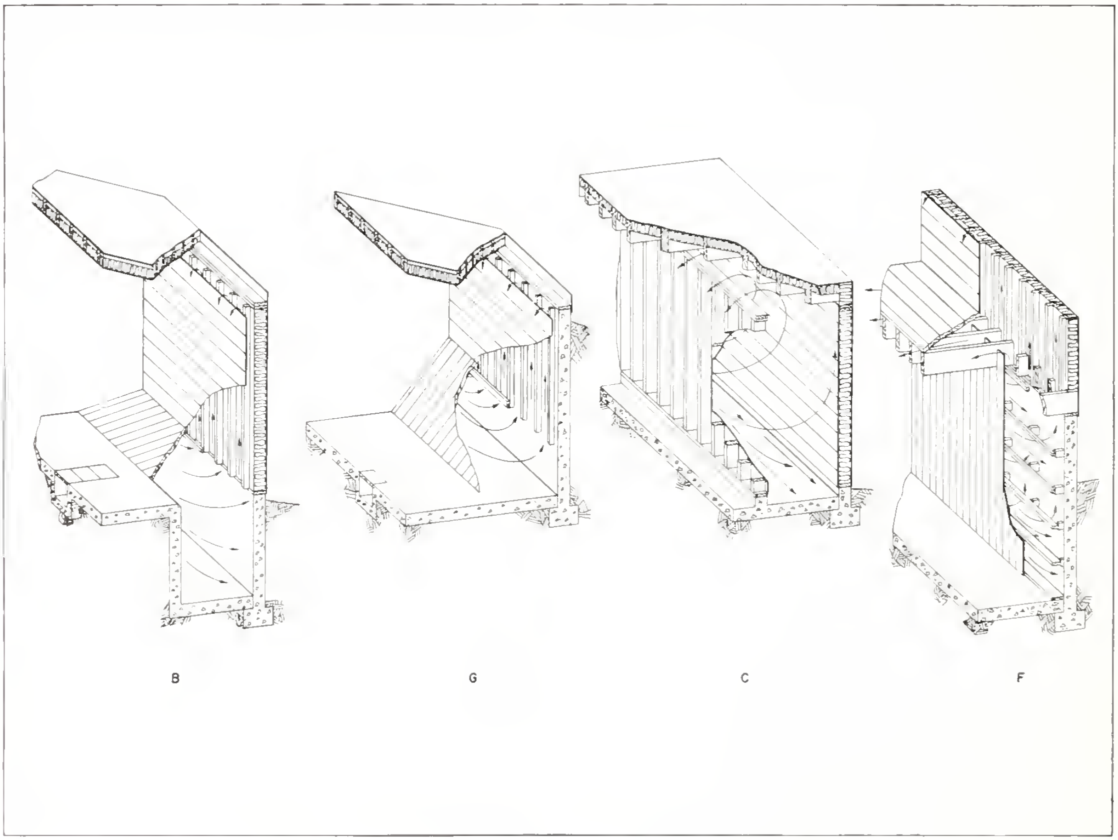


Figure 5.--Four shell-ventilation systems. Letters refer to storage examples given in the appendix.

A duct system for a potato storage is designed by:

1. Determining the total volume of air to be delivered to the storage (capacity of the storage x the maximum airflow required per hundredweight).

2. Studying the plan of the building and sketching a layout of the most convenient duct system.

3. Calculating the sizes of all main ducts, branch ducts, and risers. If duct sizes are unreasonably large, it may be more economical to design two or more separate systems.

4. Calculating the losses or total pressure drop (decline in air pressure along the length of a duct) in the system. Selection of fan and motor sizes is based on total pressure drop and total volume of air delivered.

Total Volume of Air Required

In areas where potatoes are harvested when the outdoor temperature averages 50° F. or lower, the volume of outside air required is .65 c.f.m. per cwt. When the outdoor temperature averages 60° F. or above, the airflow rate required is .85 c.f.m. per cwt.

Convenient Duct Systems

For small to moderate-size storages (from 4,000 to 95,000 cwt. capacity), it is usually simpler and more economical to design a single duct system to deliver the volume of air required. If the storage length is divided by a cross alley, however, it may be more practical to provide one complete ventilation system for each end of the building than to construct ducts under the cross alley.

In very large storages (over 100,000 cwt. capacity), it may be most economical to have two or more complete ventilation systems. In these cases, it is less expensive to use a number of standard-size fans, dampers, and damper motors than to use special sizes required for large single units.

Size of Main, Branch, and Riser Ducts

The size of the main duct is determined by the following formula:

$$\frac{\text{Total volume of air to be delivered (c.f.m.)}}{\text{Velocity of the air (feet per minute)}} = \text{area of duct (square feet)}$$

A maximum velocity of 1,000 feet per minute is generally recommended. During the first month of storage, however, when ventilation requirements are greatest, higher velocities of up to 2,000 feet per minute in the main duct may be justified when balanced against the cost of constructing larger ducts.

The branch and riser ducts must be designed to deliver equal volumes of air throughout the storage.

There are three ways to determine duct sizes in any ventilation system. A technique based on the equal friction method, as illustrated in the following example, is recommended for shell-ventilation potato storages.

As a hypothetical case, assume a storage requires 4,000 c.f.m. for ventilation. If the recommended air velocity of 1,000 feet per minute is not exceeded, a square main duct 2 feet on each side is needed. Assuming that there are two branch ducts, each carrying 50 percent of the total air volume (2,000 c.f.m.) and 40 risers, each carrying 2.5 percent (100 c.f.m.) of the total, the respective dimensions of the branch ducts and risers can be determined by referring to figure 6 as follows:

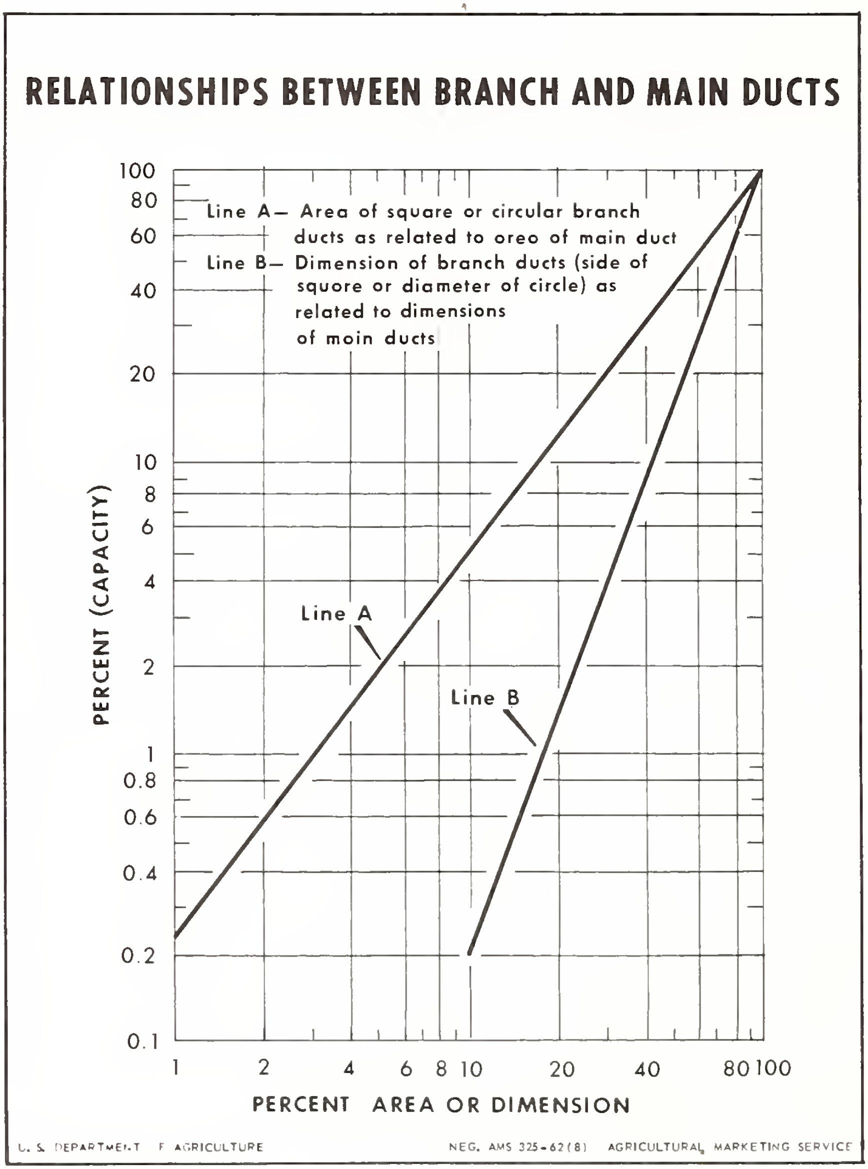


Figure 6

At the point of intersection of the line corresponding to 50 percent on the horizontal scale with curve B, it is seen that each side of a square branch duct should be 77 percent of that of the main duct. Or,

2 feet x .77 = 1.54 feet

Similarly, the cross-sectional area of the branch ducts can also be found by locating the point of intersection of the 50 percent line and curve A. At this point, it is seen from the vertical scale that the branch duct area is 60 percent of that of the main duct. Or,

2 x 2 feet x .60 = 2.40 square feet

The cross-sectional area of the risers is found in the same manner. In this example, where one riser carries 2.5 percent of the total volume, the point of intersection with curve A occurs at 6.3 percent. Thus,

2 feet x 2 feet x 0.063 = 0.25 square foot

The dimensions and areas given are computed for square ducts. Rectangular ducts that are not square have less capacity than square ducts of equal area. Figure 7 is used to convert dimensions of square ducts to those of equivalent rectangular ducts carrying equal volumes of air. As an illustration, normal riser width is 1.85 feet (fixed by framing at 24 inches on centers). Hence, to obtain a total area of 0.25 square foot, thickness must be 0.136 foot. The ratio of short side to long side of this rectangle is therefore 7.4 percent. At the point of intersection of the vertical scale at 7.4 percent with the curve, it is seen that the rectangular riser has 65 percent of the capacity of an equivalent square riser. Therefore, the thickness of the riser must be increased to 0.136/0.65 = 0.21 foot, or 2.5 inches, to provide the capacity needed.

The foregoing illustration is a simplified means of employing the equal friction method for determining duct sizes in a ventilation system. It can be used for square, rectangular, or circular ducts; where two or more ducts branch off the main; and for any number of risers, so long as the percent of total volume of airflow is specified for each duct.

The most effective design for equal friction throughout the branch duct is obtained by reducing the duct dimension by the appropriate amount at each riser. This can best be accomplished by tapering the duct from the maximum cross-sectional area at the main duct to a minimum cross-sectional area, at the end, equal to that of the risers. An alternate solution is to reduce branch duct size by steps at several points along the duct. Still another method of regulating the amount of air that flows through the risers is to install a regulating damper at the top of each riser.

Proper branch duct design is essential for uniform air distribution throughout the wall section.

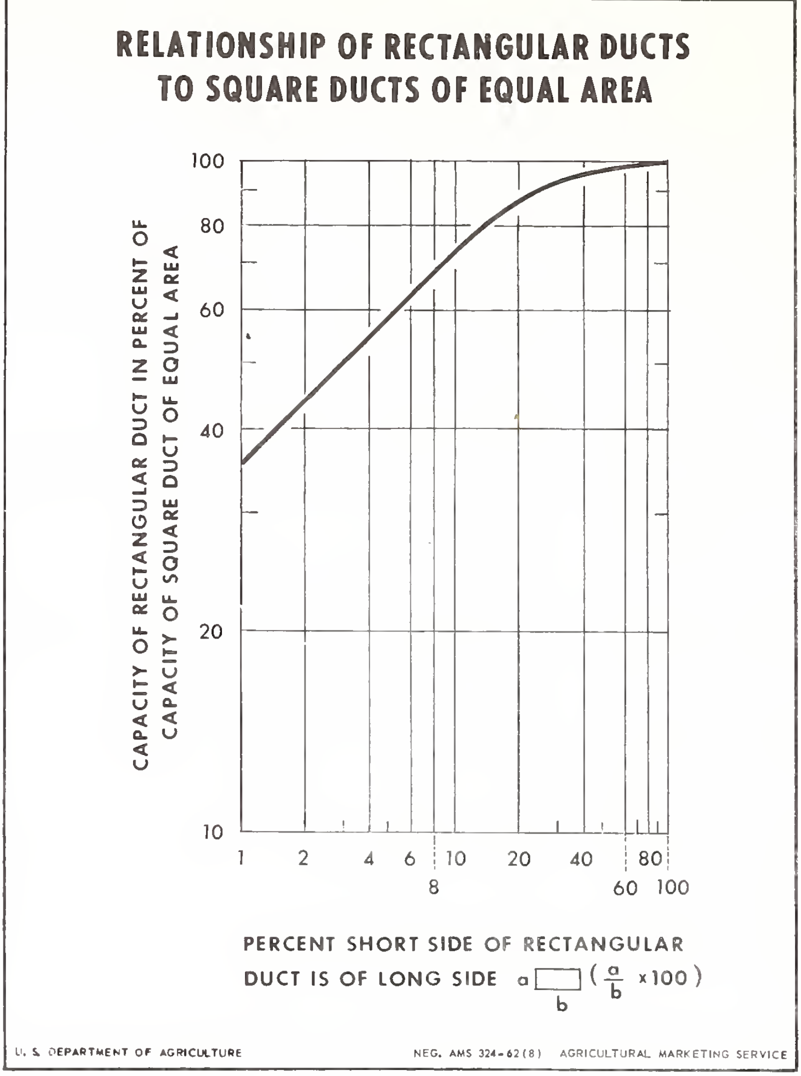


Figure 7

Determining Static Pressure

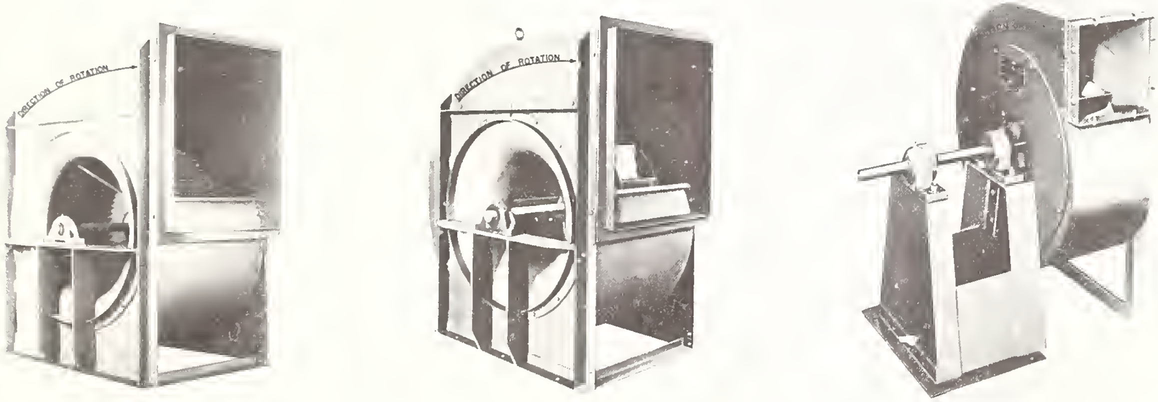
The amount of power required to move a given quantity of air through a duct system depends upon the amount of resistance the air encounters in its path of flow. This resistance is measured in terms of static pressure or pressure drop. In a straight duct, the pressure drop is a function of the duct length and cross-sectional area, a roughness coefficient, and the velocity of air. In addition, there is a pressure drop caused by turns or bends and by small openings or passages such as intake, exhaust, or circulating ports. These pressure drops are additive and combine to form the total pressure drop against which the fan must work. In a duct system, the pressure drop varies directly with the square of the velocity of air moving through the ducts. Therefore, it is imperative to design the system to facilitate distribution of the required amount of air at velocities as low as may be economically feasible.

In shell-ventilation systems, the static pressure should range between .25 and 1 inch of water.

Fans

There are two general types of fans, the centrifugal and the axial flow.

Centrifugal fans are divided into three types: Forward curve tip blade, backward curve tip blade, and straight tip blade (fig. 8). The first two are sometimes used for potato storage circulation systems. The forward-curve tip blade fan is gaining in favor in storage systems because of its high capacity at the low pressures of perimeter circulation systems. The straight tip blade fan is particularly adapted for exhausting refuse from grinders, saws, etc., and for working at relatively high pressures, and is seldom used in potato storage circulation (3).



(A) FORWARD CURVE

(B) BACKWARD CURVE

(C) RADIAL

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Figure 8.--Three types of centrifugal fans.

An axial-flow fan is shown in figure 9. In the past, axial-flow fans were seldom used in duct air distribution systems. Now this type is most practical for potato storage air-distribution systems where static pressures are relatively low. The change from the free-delivery propeller type, like a general-purpose fan that stirs air in a room, to disk, vane, axial, and tube-axial types has put the axial fans in a competitive position for all potato storage applications. They are generally cheaper than the centrifugal fans because there is no expensive housing.

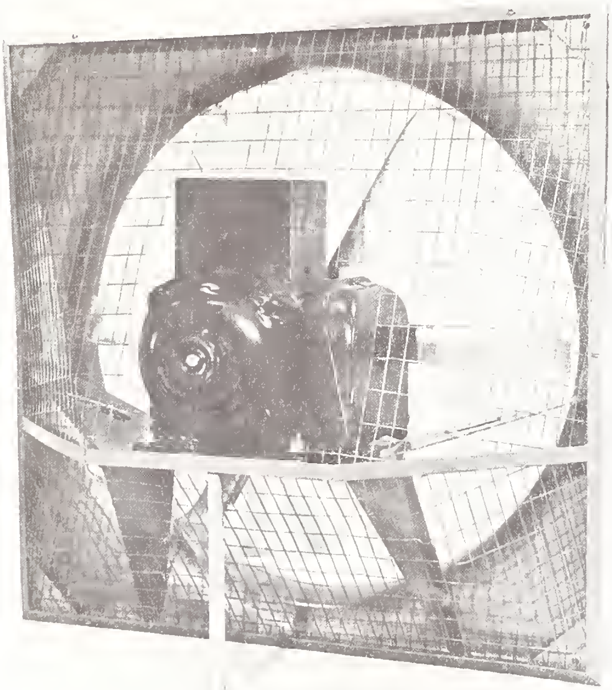

Figure 9.--Axial-flow fan of the propeller type.

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Fan and motor sizes for a circulation system may be selected from a manufacturer's catalog after capacity and pressure drop are determined. Usually, a fan is selected with outlet velocity from 1,000 to 1,600 f.p.m. Lower velocities than this save power, but require relatively large, expensive fans and fan houses. Smaller fans, operating at higher outlet velocities, mean lower first cost, but operating costs are greater. Table 3 gives examples of fans of two different sizes for various air volume requirements (1, 3).

Table 3.--Comparison of power requirements and velocities of two sizes of fans

Fan output	Static pressure	Fan	Larger fan			Smaller fan		
c.f.m.	Inch	Type	Size 1/	f.p.m.	hp.	Size 1/	f.p.m.	hp.
20,000	.75	Axial	48	1,600	4.5	42	2,080	4.8
27,500	.50	Centrifugal	10sw	1,350	3.67	9sw	1,620	4.38
60,000	.50	Centrifugal	11dw	1,350	7.62	10dw	1,620	8.7
21,500	.38	Axial	54	1,390	2.0	48	1,460	2.82
12,000	.25	Axial	42	1,250	1.00	36	1,700	1.30
6,000	.25	Axial	32	1,000	.40	27	1,500	.54
6,000	.38	Axial	27	1,500	.54	24	1,900	.70
3,000	.50	Axial	21	1,250	.49	18	1,700	.52

1/ Sw = single inlet, single width; dw = double inlet, double width.

Fans must be sized to meet peak-load conditions in the fall. Variable-speed pulleys on belted fans permit regulation of the volume of airflow as required.

Sometimes it may be more economical to buy a smaller fan and pay a higher power cost for the peak-load month in the fall than to make the initial investment for a larger fan, sized on the basis of maximum airflow required. Later in the season, the fan can be run at half speed. At half speed, the capacity is halved, pressure drop is quartered, and power requirement is cut to one-eighth of that at full speed.

Where large fans are used together, as in storage A (appendix), the simpler direct drive rather than the belted drive is often used. This permits using one fan for a half load. However, except for the first-cost economy, this is not necessarily an economical arrangement: Two belted fans running at full speed against a static pressure of .75 inch of water (P_s) deliver 40,000 c.f.m. for 9.0 horsepower (hp.), and two belted fans at half speed running against .2 P_s deliver 20,000 c.f.m. for 1.25 hp.; but one running at full speed requires almost 3 hp. to deliver 20,000 c.f.m. against the .2 P_s.

Because economy, from the standpoint of both initial and operating costs, and effectiveness of the ventilating system depend upon proper fan selection, it is recommended that a competent engineer be consulted to assist in selecting the best sizes of fan and motor for a job.

Dampers

Dampers are a type of valve used to reduce, proportion, or stop airflow in ducts. Dampers may be set by hand or by special motors.

Single-vane dampers can be used in very large sizes with manual operation, but for motor operation, multiple-vane dampers are commonly used to reduce torque requirements. In the same opening, torque for turning one damper is twice as great as for turning two dampers and four times as great as for turning four dampers. Multiple-vane dampers are more expensive than single-vane dampers, however, so the cost of a damper requiring less torque must be balanced against the cost of a motor with greater capacity.

A simple method of damper construction is shown in figure 10 and more complex, multiple-vaned dampers in figure 11.

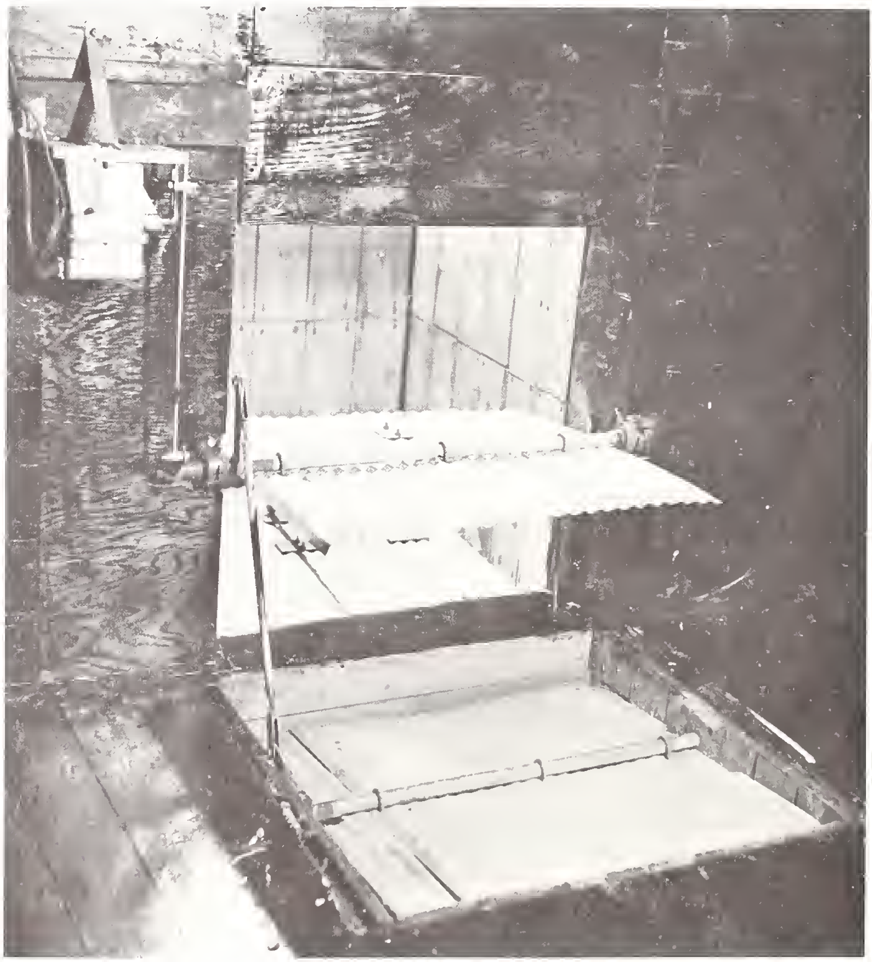

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Figure 10.--Small single-blade dampers made of corrugated sheet metal in 3- by 3-foot ducts.

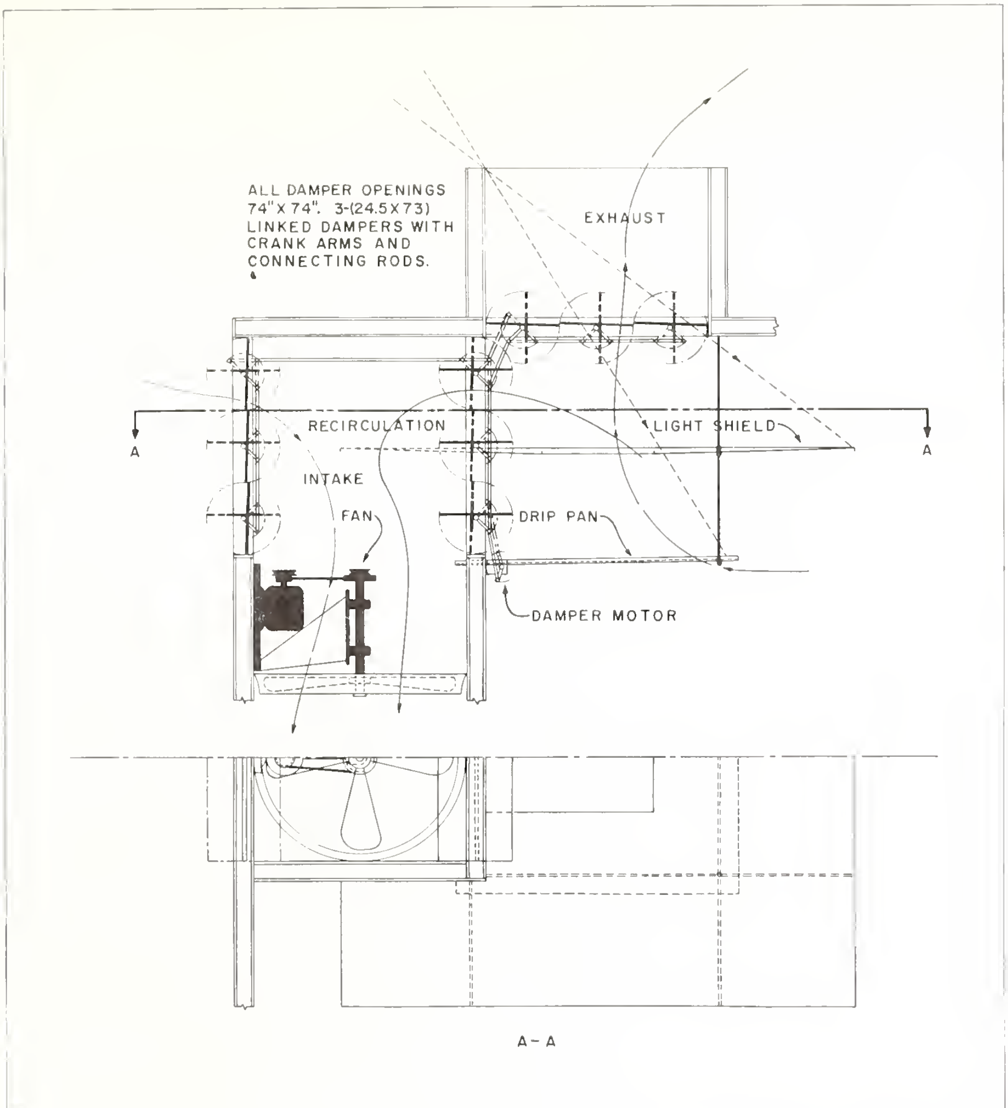

Figure 11.--Balance vanes, crank-arm, and connecting-rod linked damper units.

When more than one damper is used to regulate the intake, mixing, recirculation, and exhaust of air, the dampers are linked together so that the recirculation dampers open as the intake and exhaust dampers close, and vice versa. Figure 12 shows one large single-vane damper and figure 13 shows three small single-vane dampers arranged to regulate ventilation and recirculation.

Generally, dampers need not fit tightly in ducts in potato storage systems--a little ventilation is always needed to dissipate moisture from the storage (except during warm weather) and some air circulation leakage does little harm during ventilation. A loose-fitting damper that will always function is better for storage regulation than a tight-fitting one that may stick and freeze in the ventilating position during cold weather or swell and stick in the recirculating position when ventilation is needed.

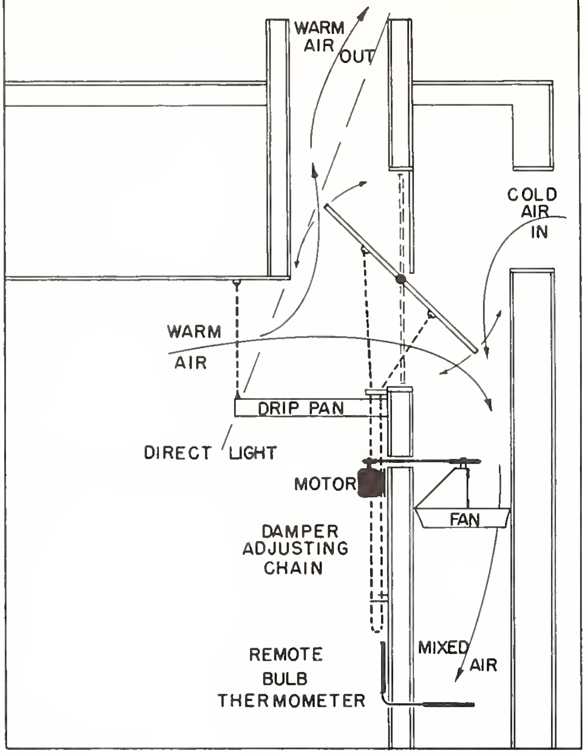

Figure 12.--Large single-vane damper that controls ventilation and recirculation.

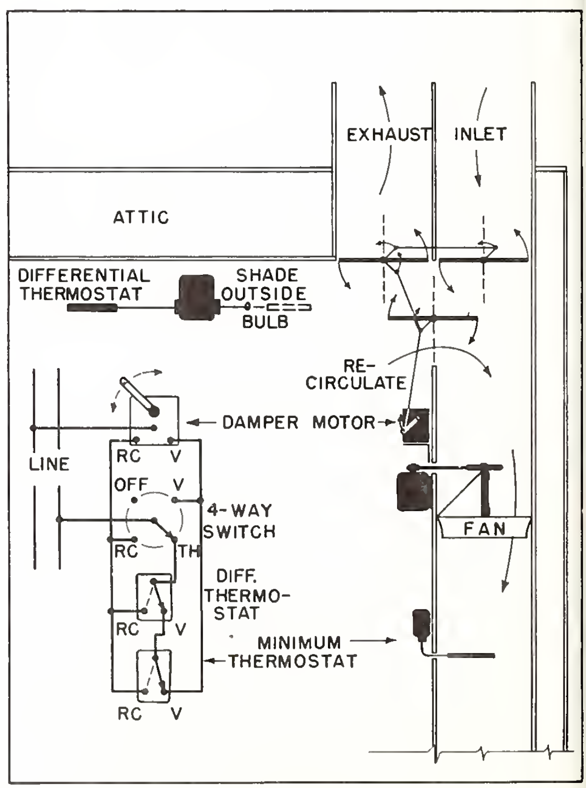

Figure 13.--Three small single-vane dampers arranged to regulate ventilation and recirculation.

Control Equipment

Manual

Manual regulation of a ventilation system gives satisfactory results if the operator is guided by good reference thermometers and gives enough attention to the storage.

Three inside-outside thermometers are required. These instruments should be of the type having an ordinary thermometer for the inside reading, and a remote temperature capsule and a 6-foot capillary tube for the outside reading.

Two of the units are placed in an accessible location near the damper. One of the remote bulbs is placed where the circulating air first comes in contact with the potatoes after it leaves the fan. The second remote bulb is placed outside, in the shade, preferably on the north side of the building. The third unit is located on a partition above the height of the potatoes in bins, near the center of the building if possible. The remote bulb of this unit is buried in the center of a bin, 2 feet beneath the surface of the potatoes.

These locations give the storage operator temperature readings of the outside air; of the air as it reaches the first potatoes, or about the coolest part of the storage; and of the air above and among the potatoes in about the warmest part of the storage.

Automatic

Automatic control of the ventilation system requires a motor for the damper, and two thermostats wired in series to the motor.

Damper motors.--Both line-voltage (110V and 220V) and low-voltage (25V) damper motors are manufactured. The low-voltage motor is probably more durable, but requires a transformer. The line-voltage motor is simpler, but does require code wiring. Torque limits for damper motors are between 20 inch-lb. for small sizes and about 400 inch-lb. for large sizes.

Thermostats.--Thermostats may be classified by type of sensing element and by type of temperature control given by the instrument.

In the most common type of sensing element, temperature changes at the sensing bulb change pressure in the bulb, capillary, and bellows system. This pressure variation actuates an electrical switch to energize the damper motor. In thermistor-equipped thermostats, the sensing element is electrical. The thermistor is a very high electrical-resistance unit. Its resistance varies inversely with the temperature, and actuates switches through relays to the damper motor. The advantage of the resistance type over the pressure type is that the resistance sensing elements, connected to the thermostat with an extension cord, may be placed much farther from the thermostat than the pressure-sensing bulb, which is connected by capillary tubes. The resistance-sensing element is often 100 feet from the thermostat, compared with 6 to 10 feet from the pressure bulb. Pressure-type thermostats, however, are usually cheaper than the resistance or thermistor type. Capillary tubes in 30-foot lengths are available at extra cost.

The simplest type of automatic temperature control is obtained with minimum and maximum thermostats. The operator sets the thermostat controls at the minimum and maximum temperatures of air desired in the storage.

When the temperature outside is below that set on the maximum thermostat and air at the first affected potatoes is above that set on the minimum thermostat, the damper is opened for ventilation. Each thermostat can change the system from ventilation to recirculation--the minimum thermostat, when the temperature of the incoming air at the first affected potatoes drops below the set minimum; and the maximum thermostat, when the temperature of the outside air rises above the set maximum.

The instruments should be mounted in an accessible location in the storage. The sensing element of the minimum thermostat should be placed on the exhaust side of the fan in the main duct. The sensing element of the maximum thermostat should be located in the shade, preferably on the north side of the building.

A differential thermostat, which automatically adjusts the maximum air temperature admitted to the storage according to the maximum air temperature in the storage, may be used in place of the maximum thermostat. The differential instrument has both inside and outside remote temperature-sensing elements. The inside element is located over the center of a bin, or as near the maximum storage temperature as possible. The outside element is placed in the shade. The instrument is located so that both sensing elements can be placed at the same level. The operating differential between the two elements should be set at 1 or 2 degrees, so ventilating air is 1 or 2 degrees cooler than the maximum air temperature in the storage. Like the maximum thermostat, the differential thermostat is wired in series with the minimum thermostat.

The differential thermostat has been recommended in preference to the maximum thermostat for many years. Because the differential thermostat requires little attention, however, some operators give it none, and the instruments are often found in nonoperating condition.

A proportioning thermostat, which provides ventilating air of constant temperature, may be used in place of the minimum thermostat.

With the proportioning thermostat and a proportioning damper motor, ventilating air is mixed with air in the storage to obtain air of the desired temperature. The storage operator sets the minimum temperature desired on this thermostat. A differential or maximum thermostat is used with the proportioning instrument to recirculate storage air when outside air would warm the storage.

Three dampers are required for proportioning control (fig. 14): (1) To admit some cold outside air; (2) to mix outside air with storage air; and (3) to let some storage air escape from the building. When the proportioning thermostat senses a temperature change, the damper motor adjusts the dampers accordingly to bring the ventilating air back to the right temperature.

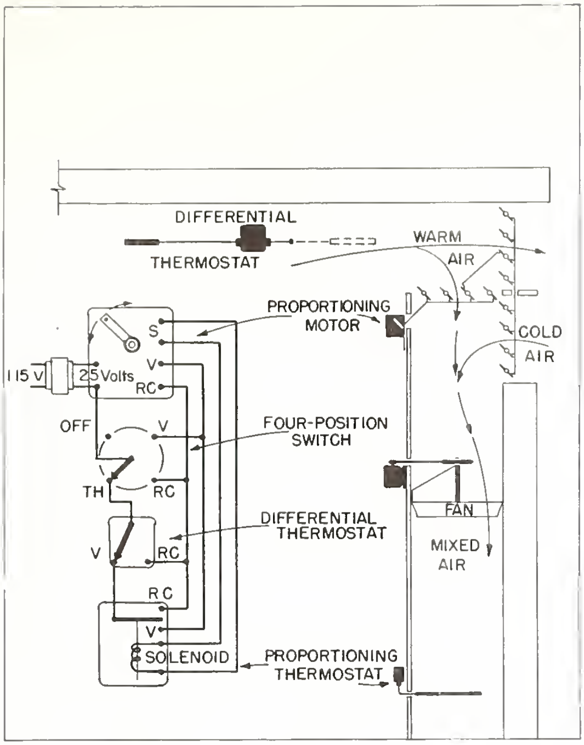

Figure 14.--Control circuit for proportioning dampers.

Continual cycling is prevented by the proportioning control built into the damper motor to work with the minimum control in the proportioning thermostat. The motor can adjust the dampers only in proportion to the temperature change demanded by the thermostats. It will stop itself after a slight adjustment without waiting for an order from the thermostat. The result is continuous, but with very slight damper readjustment.

When in good working order, the proportioning system does a good job. But in potato storage practice, considerable difficulty is experienced in keeping the controls in good order, because the controller potentiometer seems vulnerable to dust and moisture. Much of this problem can be eliminated by housing the controls in a dust-tight control room.

Wiring of control systems.--Proportioning control requires a special three-wire system designed to hold the dampers at part-ventilation and part-recirculation positions.

The minimum and maximum or differential thermostatic controls may use either: (1) A two-wire system, with single-throw thermostat switches and a one-direction spring (or weight) return damper motor; or (2) a three-wire system with double-throw switches in the thermostats, and reversing motors with limit switches.

The two-wire system is relatively simple (fig. 15). When the controls call for ventilation, the power circuit is completed through them, and the motor turns to the end of the power stroke, or to a stall position, and holds the damper as long as the power is on. When power to the motor goes off for any reason (because of action of the thermostat or manual switch, or of power failure), a weight or spring rotates the motor in the opposite direction and the damper returns to the recirculating position. Since this motor must have power both to turn the damper and wind the spring (or lift the weight), more torque is needed than for the three-wire reversing motor system.

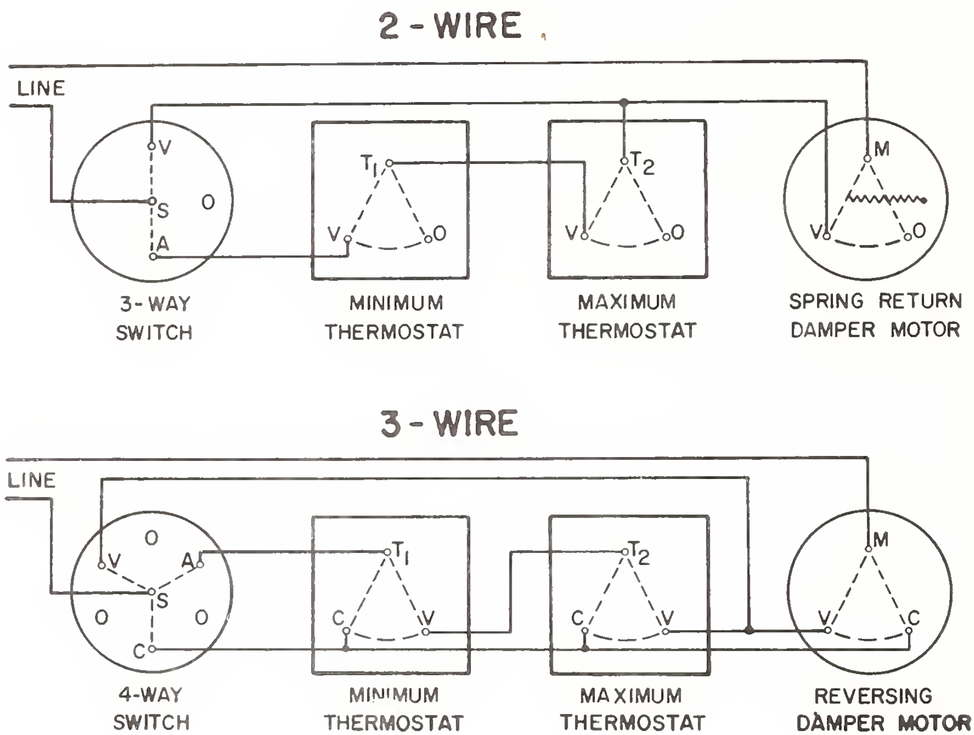

Figure 15.--Two-wire and three-wire damper control circuits.

The three-wire system is somewhat more complex, but smaller, and reversing damper motors are used. When controls call for ventilation, the power circuit is completed and turns the motor in one direction to open the damper. When the damper is open, the limit switch cuts off the power and the motor stops, leaving the damper in the ventilating position. When ventilation is not required and the controls call for recirculation, the power circuit is completed to reverse the motor, driving the damper to the recirculation position, at which point the limit switch stops the motor, leaving the damper in the recirculation position.

During the first week to 10 days of storage, air between 55° and 60° F. should be used for ventilation. For short-term storage or for longer storage of processing potatoes treated with sprout inhibitors, these minimum-maximum temperatures remain the same.

For long-term storage of table or seed stock and for untreated processing stock, circulation of air as cool as 32° F., where it first affects the potatoes, is permissible after the suberization period. The maximum temperature of air admitted to the storage should be gradually lowered during the first 2 or 3 months, depending on the rate of cooling of the potatoes. For best results, the maximum temperature of ventilating air should equal the temperature of the potatoes at the top of the bin. (With minimum-maximum thermostats, an indoor-outdoor thermometer must be used to obtain this temperature reading.) By the end of the third month of storage, the temperature of the potatoes at the top of the bin has usually dropped to 40° F. Even some subzero outside air may be used for ventilating for the rest of the winter; this, mixed with the storage atmosphere, is used to keep circulating air between 32° and 40° F. Winter ventilation is needed mainly to lower humidity so as to reduce ceiling condensation, and is used usually with artificial heat.

In manually controlled systems, the operator may open the damper for full ventilation when the outside air is at the desired temperature, or he may adjust the damper to mix outside and inside air to the desired temperature.

In automatically controlled systems, the proportioning thermostat and damper motor provide for continuous mixing of outside and inside air. The two- and three-wire systems, with on-and-off or reversing-motor damper regulation, provide outside and inside air mixing as the cycle changes from ventilation to recirculation and back.

One advantage of thermostatic control of the ventilation system may be peace of mind for the operator during cold snaps. These controls may eliminate extra trips to the storage at night and on holidays to regulate dampers. Storage ventilation thermostats require occasional checking and setting, as do heating thermostats. Often the differential thermostat mechanism, which moves only in the fall and spring in cold climates, becomes inoperative due to mechanical damage or corrosion. The minimum control should always be carefully set. Thermostats must be checked periodically to insure good operation.

During extremely cold weather, the little ventilation needed to regulate relative humidity can be done in a short time. In such weather, to prevent freezing, artificial heat is often needed during ventilation whether control is manual or automatic. During such ventilation, operators should be on hand, because ice can block a damper on either the ventilation or recirculation cycle.

Fans should be cut to half-speed or lower after the second month of storage.

If an oil, gas, or coal heater is used to heat the storage, it should be installed on the pressure side of the fan circulating system. This will insure good draft and circulation of the warmed air. A heater that is not connected with the circulation system may not be efficient because of short circuiting out the exhaust opening.

OWNERSHIP AND OPERATING COSTS

It is difficult to separate the cost of owning and operating a ventilation system, or the overhead chargeable to ventilation, from the total potato storage cost. Protection from the weather by walls, roof, and insulation is hardly complete without an air-circulation space between the potatoes and the exterior walls. However, in this report, the wall air-circulation space is considered as a part of the cost of the ventilation and air-circulation system. On the other hand, the cost of the work and drive alleys and the space above the bins (helpful in the air-circulation system) are not charged to the ventilating system. Ownership and operating costs of the eight storages studied, per 10,000 cwt. capacity, are shown in table 4, as of the time of this study.

Ownership

A rough approximation indicates that the storage shell, with the walls and roof insulated, sheathed inside and out, roofed, and sided, often costs half as much as the completed storage. Partitions, potato handling, and ventilation and air-circulation provisions account for the other half of the completed storage costs.

Storages A to H, represented in previous figures and tables, are actual storages, one or more of them being in Maine, Michigan, Minnesota, Nebraska, New Mexico, North Dakota, or Utah. Total costs of construction varied from 50 cents to $1.20 per cwt. of capacity. In general, there has been a gradual rise in prices, although unit costs were lowered because of increased size of plants. For 1962, average costs are estimated at $1.00 per cwt., of which 11 cents represents the extra cost of the ventilation and air-circulation facilities listed in table 5.

Initial Costs

Table 5 shows the first cost of air-circulation and ventilation equipment required for the storages previously discussed. These are based on 1957 costs or assumed costs, as noted in the table, which are believed still to be approximately valid in 1962.

Dampers are estimated at $5.00 per square foot, but most of the dampers were built locally at lower cost. Damper motors and controls include costs of one or two large or small motors at $140 and $60 each, respectively, and electric-type thermostats at $175. Wiring includes the cost of motor starters and other wiring costs for the control system. This cost is based upon 25 percent of equipment cost for storages B and C, and 40 percent for the others. Electrical outlets should be grouped to reduce the cost of wiring.

For the eight storages, total cost of the ventilation system averaged 16 cents per cwt. The wall air space, which is needed in any storage, averaged 5 cents per cwt. The added cost of an automatic ventilation system therefore averaged 11 cents per cwt.

Table 4.--Estimated ownership and operating costs of ventilation systems per 10,000 cwt. capacity of potato storage

Item	Initial cost	Expected life	Costs						
			Ownership			Operation			
			Depreciation	Interest 1/	Insurance and taxes 2/	Power and maintenance 3/	Labor 4/	Total	Per cwt.
	Dollars	Years	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Ducts and air walls..	1,000	30	33.33	25.00	20.00	--	--	78.33	0.008
Fans and motors......	340	20	17.00	8.50	6.80	67.80	67.60	167.70	.017
Wiring, damper, controls...........	290	10	29.00	7.25	6.20	2.70	--	45.15	.005
Total..........	1,630		79.33	40.75	33.00	70.50	67.60	291.18	.030

1/ Interest at 5 percent of average value.
2/ Insurance and taxes at 4 percent of average value.
3/ Power consumption based on a 1.5-horsepower motor running at full power 1,440 hours during 2 months and at one-fifth power or 0.3 horsepower for 2,880 hours. Power and maintenance costs computed at 3 cents per kw-hr. and 0.746 kw-hr. per hp.
4/ Labor costs are based on 26 weekly 1-hour visits for inspection and checking, at $2.60 per hour.

Table 5.--Comparative estimated costs of ventilation systems for eight selected storages

Storage	Capacity of storage	Airflow	Motor power required 1/	Cost by item					System	
				Fan and motors	Dampers 2/	Damper motor and controls 3/	Wiring 4/	Construction, ducts, air walls, etc.	Total	Per cwt.
	Cwt.	Cfm.	Hp.	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
A	62,000	40,000	9	1,500	640	455	790	5,680	9,065	0.146
B	85,000	55,000	10	5/ 4,000	665	315	1,080	5,980	12,040	.142
C	93,500	60,000	7.5	5/ 4,000	675	315	1,080	5,226	11,296	.121
D	66,500	43,000	6	1,500	640	455	790	6,838	10,223	.154
E	36,000	24,000	6	860	370	235	518	7,170	9,153	.254
F	17,200	12,000	2	540	190	295	334	4,350	5,709	.332
G	9,500	6,000	1	270	95	235	202	1,536	2,338	.246
H	4,600	3,000	1	155	45	235	156	838	1,429	.311

1/ Based on 1.5 hp. per 10,000 cwt.
2/ Dampers priced at $5.00 per sq. ft.
3/ Large motors $140, small $60, thermostatic controls $175.
4/ Twenty-five percent of equipment cost for wiring and starters used for storages B and C; for others, 40 percent was assumed.
5/ Centrifugal fans used for these storages, axial fans for others.

Depreciation

Experience indicates that a well constructed and maintained structure has a 30-year useful life; fans and motors, a 20-year useful life; and dampers, damper motors, and thermostat controls with wiring and motor starters, a 10-year life. A well installed and operated ventilation system, with insulation and vapor proofing, will extend the useful life of the main structure and the components of the ventilation system beyond these periods.

Obsolescence is not considered in these cost analyses, but it could make a storage useless long before it would fail structurally.

Interest, Taxes, and Insurance

In determining annual costs, interest is estimated at 5 percent, taxes 2 percent, and insurance 2 percent.

Operation

Operating costs of ventilation systems include light, power, maintenance, repair, and labor.

Fan operating cost is based on the assumption that the motor supplied with the fan by the manufacturer is adequate for good operating efficiency. Power consumption for fall operation is based upon hp. x 0.746 = kw., running full time. Half-speed power requirement during the winter is theoretically one-eighth of that for full-speed power. To compensate for less efficient operation, this one-eighth is increased to one-fifth. Full power is needed approximately 2 months, and one-fifth power for approximately 4 months in a 6-month storage period. Power costs are based on 3 cents per kw-hr., including a cost of 1 cent per kw-hr. to maintain and repair electrical equipment. This value is grouped with power cost in table 4 and includes electricians' services to adjust thermostats and check wiring when required, to replace fuses, repair switches, and perform other maintenance.

Labor Required

The labor required to operate the system varies greatly with individual storage situations. A daily check of operations may take 5 minutes when the operator is in the storage for other purposes, or checking operations may require an hour or more if a special trip is needed. Once the controls are set and the system is operating satisfactorily, weekly inspection and adjustment may be enough during periods of uniform weather. Attention is required at least daily to check controls and possibly add supplemental heat when the weather is changeable, cold, or windy.

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APPENDIX

The eight storages studied were:

Storage A--Envelope Circulation (With Supplementary Shell Circulation)

This 180- by 360- by 18-foot storage (the third number is the height) is made up of four units, each with a capacity of 62,000 cwt. Each of the four units requires a 40,000-c.f.m. ventilation and air-circulation system. To handle the envelope (closed circuit) recirculation and ventilation, two fans, each of 20,000-c.f.m. capacity, are used. In addition, a separate fan of 20,000-c.f.m. capacity, which serves each storage unit, is wired in series with the two fan systems of each unit to provide shell circulation. This shell circulation system will handle one-half as much air as the main envelope system, but will operate only when needed to remove excess water vapor. The layouts of these storage and circulation systems are shown in figure 16.

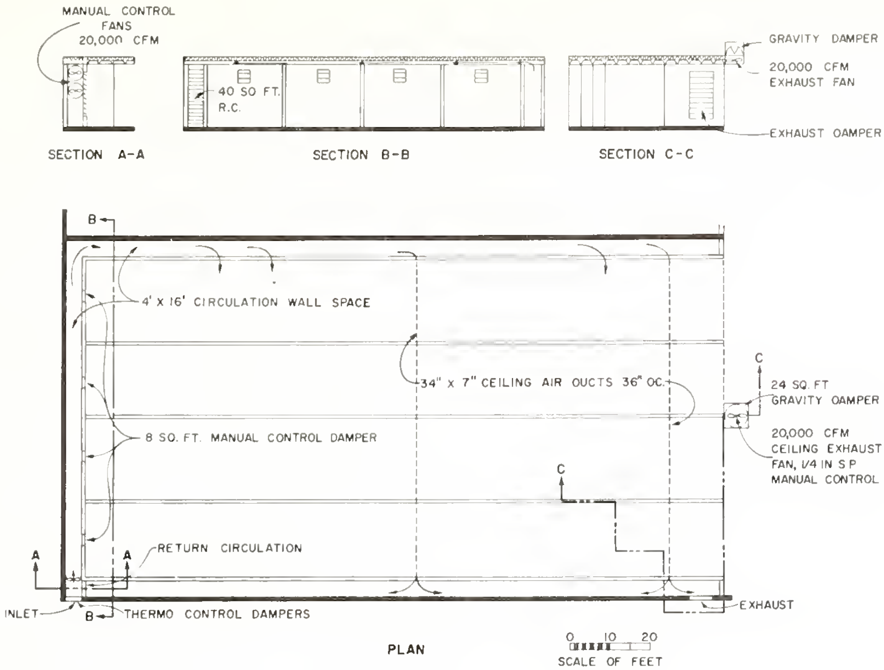

Figure 16.--Storage A.

Wall ducts are 4 feet wide and 16 feet high on three sides of each storage space, and sixty-four 0.3- by 2.3-foot ceiling spaces open to the wall spaces. The fans force the air along two sides, and along one side it is forced over the top of the storage space to the wall space on the third side where it returns to the fan for further circulation.

Storage B--Shell Circulation

This single-room storage is 96 by 180 by 10 feet, and has a capacity of 85,000 cwt. (fig. 17). Two 27,500-c.f.m. single-width, bottom-horizontal-discharge, centrifugal fans provide the 55,000 c.f.m. of air needed. The fans are lined up to deliver air into 4- by 5.5-foot below-floor mains which extend out to the two sidewalls of the storage and then along the two sidewalls. The ducts along the sidewalls are tapered from 4 by 5.5 feet to 4 by 3.7 feet to provide equal air distribution along their length to the 110 wall risers which are 0.5 by 1.83 inches and set on 2-foot centers. In this storage, the air is moved by the fans out to the two main wall ducts and then up the risers, which discharge the air over the top of the potatoes piled in the storage. The air returns to the fans when recirculating, or is discharged at the damper when ventilating.

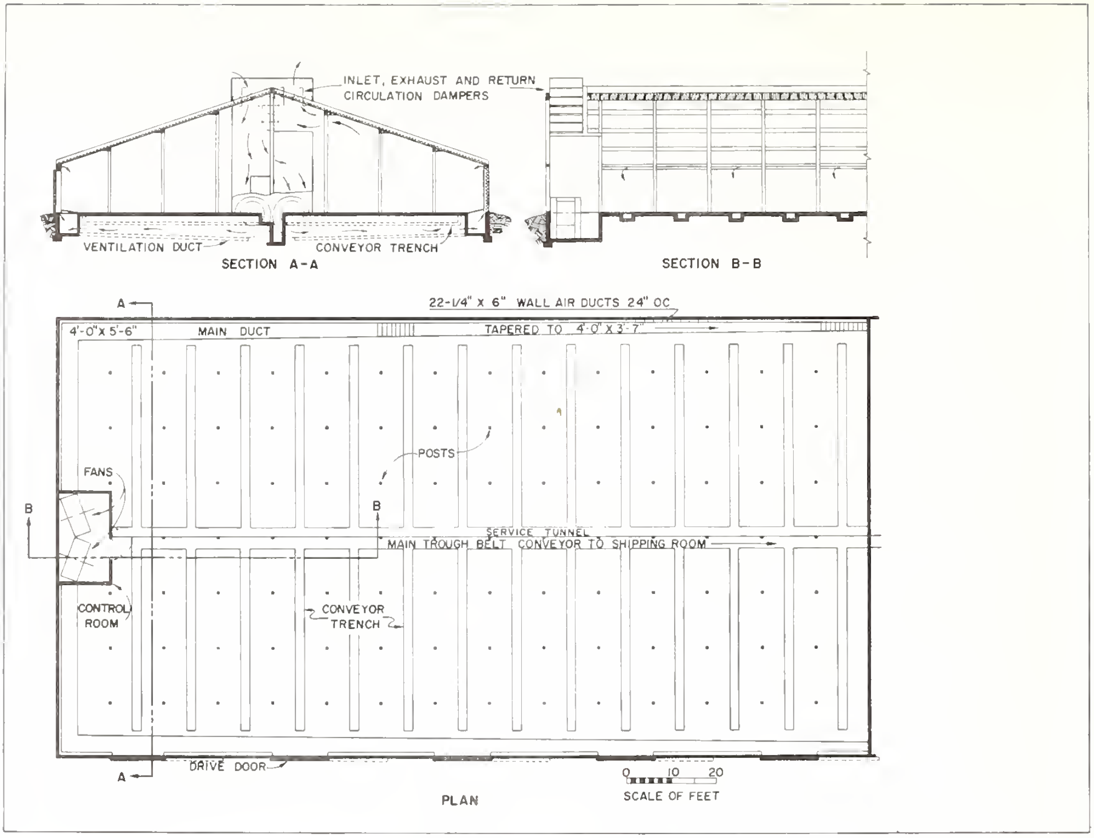

Figure 17.--Storage B.

Storage C--Door Per Bin

This "door-per-bin" 80- by 250- by 14-foot storage has a capacity of 93,500 cwt. and requires a 60,000-c.f.m. ventilation and air circulation system (fig. 18). Similar to storage A, this storage employs a service alley or wall space, but with air-circulation space on only two sides of the storage. This wall space runs from the fan to the one sidewall opposite the doors and along the wall the length of the storage. It is 3 by 14 feet and is not tapered for equal friction along its length. To equalize or proportion the airflow, a series of exhaust slot openings or orifices are installed at the top of the wall space. The openings are located every 2 feet. Along the sides, they are 0.76 by 1.83 feet, and on the end, 1.1 by 1.83 feet.

In this storage, the air moves from the fan along the wall air space and is exhausted from the wall air space through the slot openings over the piles of potatoes in each of the bins. The air is then drawn back toward the fan when recirculated, or exhausted to the outside when the storage is ventilated.

Storage D--Long Bin, Cross Alley

This 72- by 220- by 10-foot storage has a capacity of 66,500 cwt. and requires a 43,000-c.f.m. ventilation and air-circulation system (fig. 19). This storage has two axial-flow fans, one at each end wall of the storage.

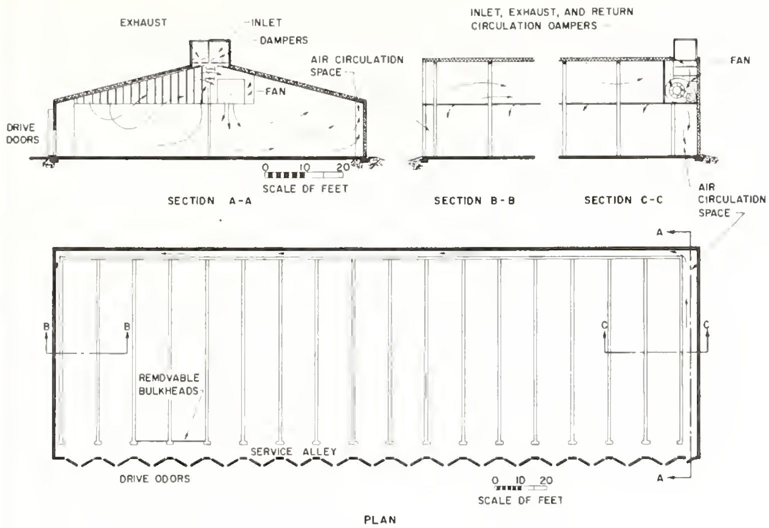

Figure 18.--Storage C.

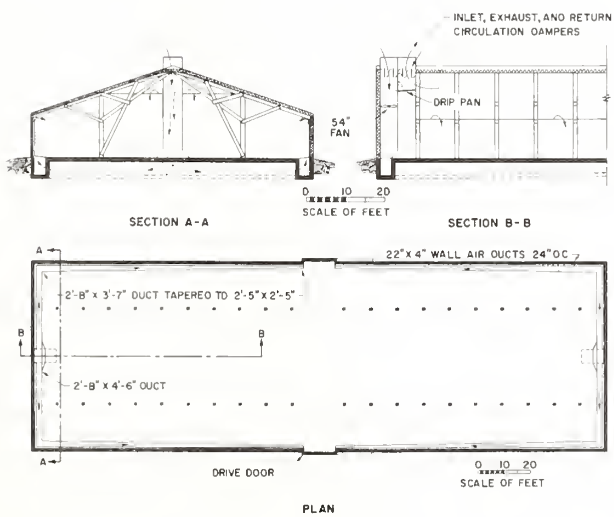

Figure 19.--Storage D.

The fans are mounted high and blow the air downward into ducts below the floor, which divide and move the air halfway along two sides of the storage. The ducts are tapered for equal friction as they deliver air to the 0.34- by 1.83-inch wall risers along the end and sidewall. These risers are on 2-foot centers.

In this storage, the air moves from the fan through the tapered duct space and up through the risers. Here the air is exhausted over the pile of potatoes and returns to the fan, if recirculating, or is exhausted through the damper above the fan, if ventilation is called for.

Storage E--Deep-Bin Storage on Level Site

This 60- by 96- by 14-foot deep-bin storage, designed for a level site, has a capacity of 36,000 cwt. and requires a 24,000-c.f.m. ventilation and air-circulation system (fig. 20). This storage has a gable roof with two identical control centers. Each center has a 12,000-c.f.m. belted axial-flow fan mounted in the attic space at the angle of the roof, midway of the length of the storage. From each fan, a 3.5- by 3.5-foot main tapered duct delivers air to horizontal ducts that move the air around the wall at about ground level and to the risers under the roof and at the gable ends.

The air is delivered by the horizontal ducts to the risers, which exhaust the air over the piles of potatoes. The air then returns to the fan, when recirculated, or is exhausted through the damper, when ventilation is used.

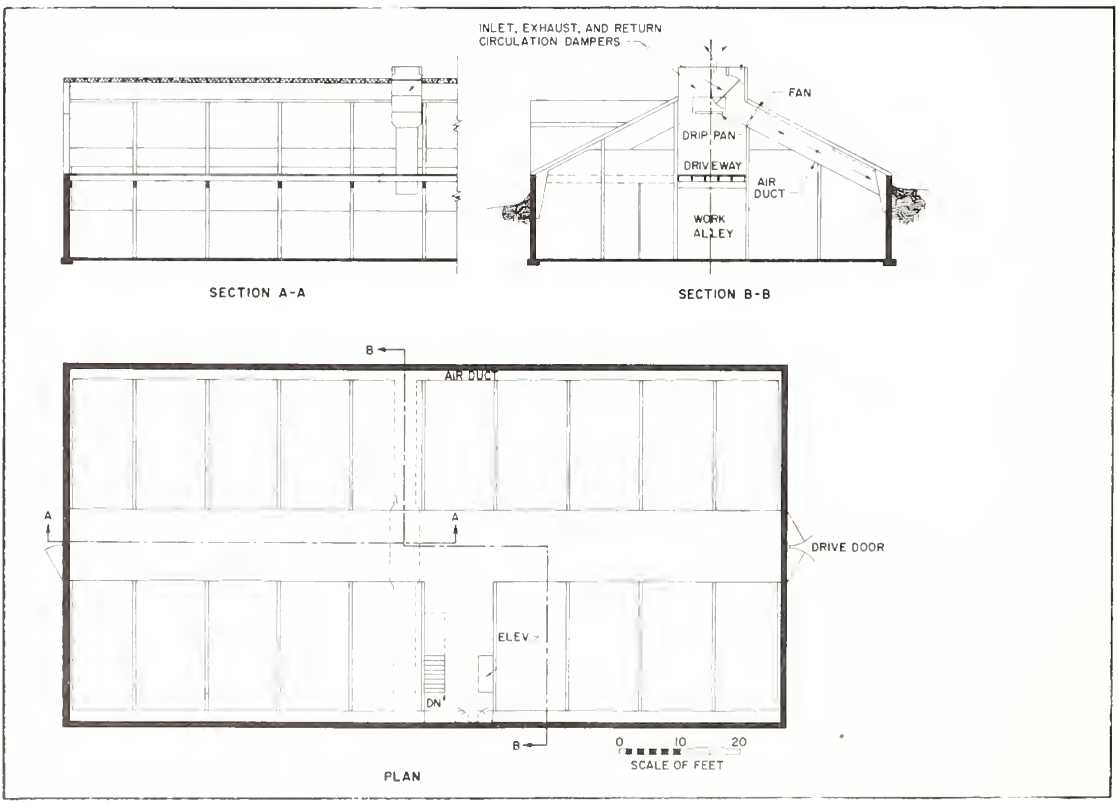

Figure 20.--Storage E: **Deep bin, level site.**

Storage F--Two-Floor Storage

This two-floor 40- by 60- by 24-foot storage has a capacity of 17,200 cwt. and requires a 12,000-c.f.m. ventilation and air-circulation system (fig. 21). Two 6,000-c.f.m. fans are used, one at each end of the storage, and are mounted in the attic space. The main 2.5- by 2.5-foot ducts are tapered the last 12 feet to 2.5 by 1.83 feet at the lower horizontal duct. The horizontal ducts are blocked out from the wall, permitting the air to move either horizontally or vertically to supply air to the risers. The air moves up the risers and is exhausted over the piles of potatoes on the lower and upper floors. The air then returns to the fan for recirculation or is exhausted for ventilation.

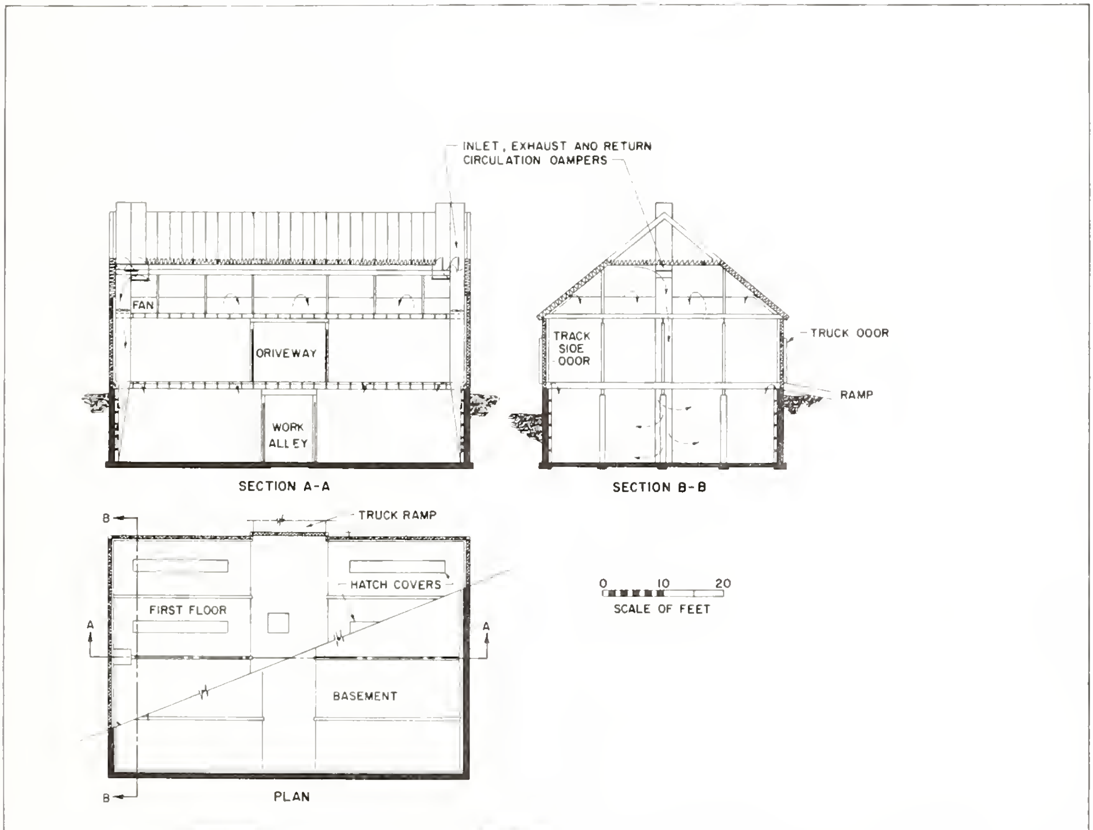

Figure 21.--Storage F: Two-floor storage.

Storage G--Below Ground, Single Floor

This 40- by 72- by 8-foot below-ground storage has a capacity of 9,500 cwt. and requires a 6,000-c.f.m. ventilation and air-circulation system (fig. 22). A single fan of 6,000-c.f.m. capacity is used, and is mounted in the attic space at one end of the storage. A 2.5- by 2.5-foot main duct is used to move the air from the fan into triangular wall-floor ducts tapered for equal friction and extending from the main duct around the walls of the storage to the driveway opening. The air moves up the wall space, is discharged over the potatoes, and returns toward the fan for recirculation or exhaust.

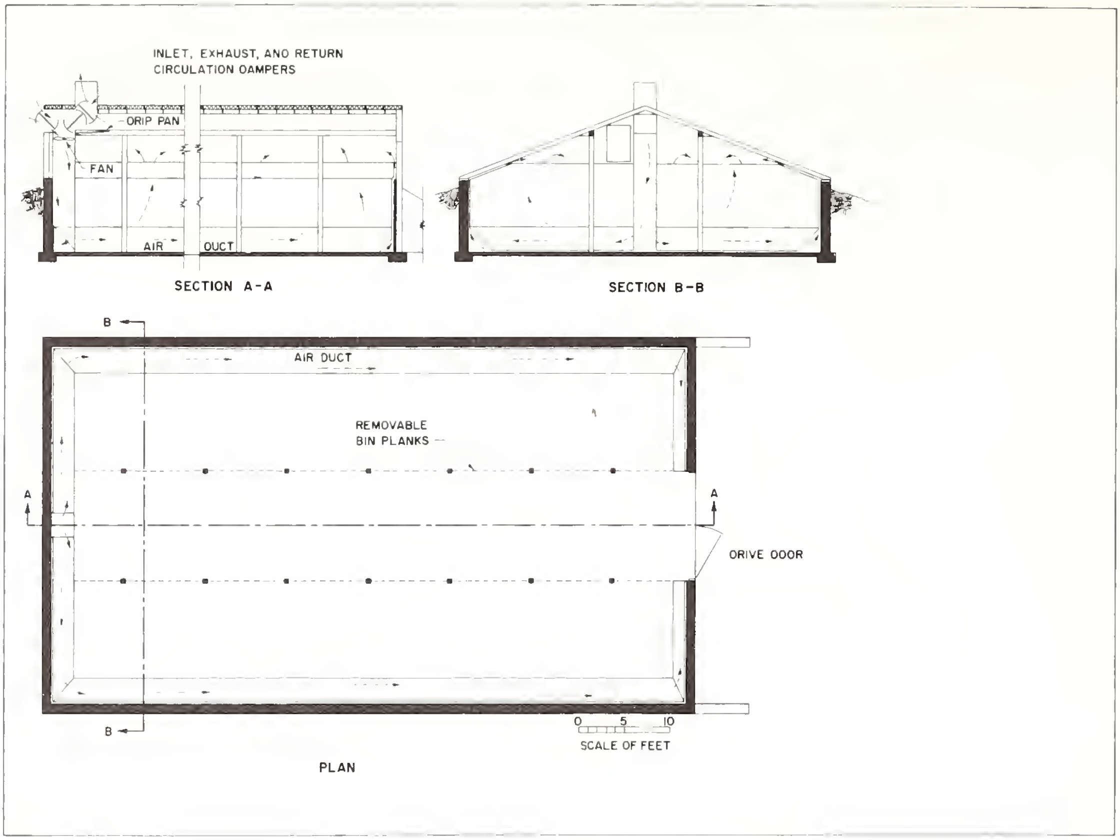

Figure 22.--Storage G: Below ground, single floor.

Storage H--Below Ground, Two Floors, Deep Bin

This 30- by 42- by 12-foot two-floor storage is the smallest of those discussed in this report (fig. 23). This storage has a center driveway on the first and second floors running the length of the storage. It has a capacity of 4,600 cwt. and uses a single-damper air ventilation and circulation system of 3,000-c.f.m. capacity. One 21-inch fan mounted near the ceiling of the upper floor is used to move the air down a main duct, from which the air moves through triangular ducts around the base of the lower outside wall. The air is then permitted to flow up the outside walls, is exhausted over the top of the potatoes on the upper floor, and returns toward the fan for recirculation or ventilation.

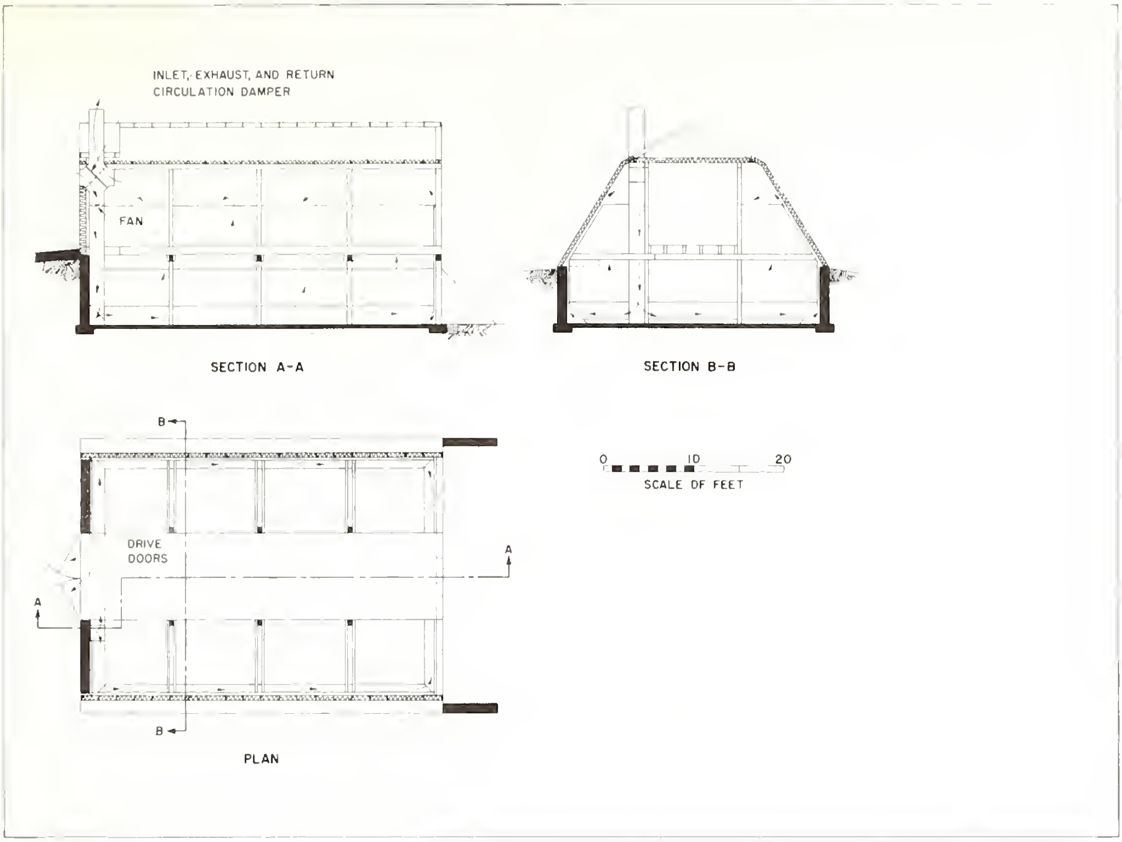

Figure 23.--Storage H.

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