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Storage of

FALL-HARVESTED POTATOES

in the

Northeastern

Late Summer

Crop Area

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Growth Through Agricultural Progress

Preface

This study dealing with the design, construction, and operation of storage facilities and with recent research findings concerning physiological conditions of potatoes is part of a broad program of research aimed at increasing efficiency in the storage and marketing of farm products.

The research was conducted cooperatively by the Transportation and Facilities Branch, Marketing Research Division, Agricultural Marketing Service, U. S. Department of Agriculture; the Agricultural Experiment Station, New York State College of Agriculture, Cornell University; and the New Jersey Agricultural Experiment Station, State College of Agriculture and Mechanic Arts of Rutgers—the State University. The research was done at the Long Island Vegetable Research Farm of the New York State College of Agriculture.

The authors wish to acknowledge the participation of the following on the project: Howard Hunnicutt, formerly agricultural engineer, Transportation and Facilities Branch; William H. Thorne, refrigeration engineer, Cornell University; and John W. Layer, extension agricultural engineer, Cornell University.

Credit is due to Joseph F. Herrick, Jr., agricultural economist, Transportation and Facilities Branch; H. M. Munger, Head, Department of Vegetable Crops, Cornell University; O. C. French, Head, Department of Agricultural Engineering; and John C. Campbell, plant pathologist, New Jersey Agricultural Experiment Station, for their valuable assistance and guidance in planning the work and preparing and reviewing the manuscript.

Earlier work done by Alfred D. Edgar and R. S. Claycomb, agricultural engineers, Transportation and Facilities Branch, and B. C. Haynes, Jr., agricultural engineer, Agricultural Engineering Research Division, has had a direct bearing on this project.

The authors are indebted to many firms and growers who cooperated with them in this research.

Many of the detailed research results, not included here, will be presented in a forthcoming report by the Cornell University Agricultural Experiment Station.

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By A. H. Bennett, R. L. Sawyer, L. I. Boyd, and R. C. Cetas

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STORAGE OF FALL HARVESTED POTATOES IN THE NORTHEASTERN LATE SUMMER CROP AREA

By A. H. BENNETT, R. L. SAWYER, L. L. BOYD, and R. C. CETAS [1]

Summary

Research on storage of potatoes, conducted primarily at the Long Island Vegetable Research Farm, had as objectives: To provide information for a handbook for warehousemen interested in designing, constructing, and operating storage facilities, and also to provide growers and warehousemen with recent findings regarding such matters as quality maintenance and shrinkage.

Fall harvested table-stock potatoes can be stored for as long as 6 months in the eastern summer crop area of New Jersey, Pennsylvania, and New York (Long Island). Deterioration and weight loss can be minimized if facilities are equipped with automatically controlled, forced air ventilation systems. Prevailing fall temperatures in this area, as early as September, are cool enough to remove considerable "harvest" or "field" heat and reduce temperatures of the potatoes to good storage levels. For table stock, a storage temperature as close to 40° F. as possible is desirable. Potatoes for processing require somewhat higher temperatures. In a properly ventilated storage, the 40° temperature is generally reached by late November. The reduction is gradual, with the rate of decrease depending on outside temperatures and on the temperature of the tubers when stored.

In most years, efficient utilization of outside air will retard respiration, rot, shrinkage, and sprouting. Where sprouting cannot be controlled by low temperatures alone, chemical inhibitors may be used to supplement them.

An airflow rate of 0.8 cubic feet per minute (c.f.m.) for each 100 pounds (or 0.5 c.f.m. per bushel) of potatoes stored was found to be optimum. Lower rates studied did not cool the potatoes as rapidly as needed; higher rates did not increase the cooling rate significantly, but increased drying, softening, and black spot.

Above-ground storages are more efficient than the earthbank or below-grade type. Adequate insulation is needed as an effective barrier against excessive heat gain during the early storage period and heat loss when the outside tem-

perature is below that of the storage. Below-grade storages are not as adaptable for other possible uses and are more costly to ventilate because of the necessity to combat ground heat during most of the storage season.

Condensation on the walls and ceiling can be controlled with insulation, combined with ventilation and periodic recirculation techniques.

Drying of the potatoes caused by passing of relatively dry air through the pile is reduced by adding vaporized or finely divided moisture particles to the intake ventilating air. This results in firmer potatoes.

Costs of constructing a modern potato storage depend upon the type of structure, materials used, quality of workmanship, and whether the job is contracted or the grower's own labor is utilized. Based on current prices for construction materials and equipment, the cost will range from $0.75 to $1 per hundredweight of capacity. If price-cost relationships on Long Island continue as in the past 10 years, growers in the area who store their potatoes at harvest time and hold them for sale 4 months later could expect to increase their net returns by $0.22 per hundredweight.

Background

Approximately 340 million bushels of potatoes are produced annually in the United States, 10 percent of which are grown in the eastern summer crop area of New Jersey, Pennsylvania, and New York (Long Island).[2] This area is classified by the Crop Reporting Board of the U. S. Department of Agriculture as late-summer and fall-crop States. Growers usually sell summer potatoes as they harvest them, but they have generally found it necessary to store most of those harvested in the fall. This research was carried on primarily with the fall-harvested crop in this area, particularly Long Island.

Increased potato production in the winter and early spring crop areas of Florida, California, and Alabama and in the late summer crop area of Washington and Oregon has resulted in an increased effect on the marketing of potatoes from the summer crop area.[2] In the South, potatoes harvested in the spring and early summer, and potatoes harvested in the summer, in the Northeastern late summer crop area cannot be stored. They must be marketed almost immediately after harvest. These factors influence prices received for fall-harvested potatoes. Normally, prices are good in July and August, but only a portion of the potatoes can be harvested and marketed during these months. The subsequent slump in fall prices has forced growers to store this portion of their crop for later marketing.

When storage space is not available, potatoes, like other perishable commodities, must be graded, packaged, and shipped to distributors or wholesalers immediately after harvest. Because of increased production and the development of mechanical harvesters, bulk trucks, and other improved harvesting techniques, truckloads of potatoes arrive at the packinghouses in large numbers, causing much congestion and delay for the growers during their rush harvest season. Storage facilities help eliminate much of this difficulty and result in more efficient utilization of labor and equipment. Even in years when prices at harvest time are attractive to growers, owning storages is desirable because of advantages of

[2] United States Census of Agriculture, 1954.

convenient marketing and handling efficiency.

Deterioration and decay of potatoes in storage are caused by various rot organisms, black spot, sprouting, shrinkage, and loss of firmness or resiliency. The tuber must also be stored in an environment that will not materially affect its flavor. The storage operator must constantly be on guard against threats to quality maintenance of potatoes. What the optimum storage environment is has been known for some time. The problem confronting the storage operator is how to provide this storage environment at a cost that will permit him to show a profit.

During 1949 to 1956, prices received by Long Island growers in January averaged $0.42 per hundredweight higher than in October, and $0.41 higher than in September. Peak prices occurred in January and February, with the exception of the marketing period from fall of 1952 to spring of 1954.[3]

Purpose of Study

This report covers primarily the results of research conducted at the Long Island Vegetable Research Farm to develop improved storage techniques. It has a twofold objective: (1) To function as a handbook for warehousemen covering the design, construction, and operation of storage facilities; and (2) to provide growers and warehousemen with recent research findings concerning quality maintenance, shrinkage, and other physiological conditions of potatoes.

A cooperative project between the U. S. Department of Agriculture and the New Jersey Agricultural Experiment Station was initiated at Rutgers University in 1949 to study and develop practical

[3] Crop Reporting Board, U.S. Dept. Agr., Agr. Mktg. Serv., Agricultural Prices—Potatoes, Jan. 1957.

types of storage structures, equipment, and operating procedures, and to adapt automatic ventilation to eastern conditions. The automatically controlled, proportioning type, forced-air ventilation system presently used in many storages was developed as a result of this work. In 1953 the project was moved to the Long Island Vegetable Research Farm to utilize facilities available at that station. A program was set up to determine an optimum airflow rate in potato storages, to study the response of stored potatoes to various cultural and field treatments, and to investigate the stored product.

The method of ventilation described in this report is commonly referred to as *through cooling* (see Definition of Terms). While this method provides the most effective means of ventilating in the eastern summer crop area, it is not satisfactory for use in certain fall-crop areas nor for arid regions. Another method of ventilation called *shell cooling* is under investigation by the U. S. Department of Agriculture at the Red River Valley Potato Research Center, East Grand Forks, Minn. This method is more applicable in cold, dry climates. Because of the humid atmosphere in the Northeast, growers can successfully use the through cooling process of ventilation for the fall harvested crop.

Definition of Terms

AIRFLOW RATE, generally expressed in c.f.m. (cubic feet per minute) per 100 pounds, or per bushel, is a measure of the volume of air supplied to the storage in a given time.

BRITISH THERMAL UNIT (B.t.u.) is the quantity of heat required to raise the temperature of one pound of water one degree F. at constant pressure.

CIRCULATION implies forced movement of air within the storage.

SHELL COOLING is based on the principle of heat transfer by conduction and convection. The ventilating air is passed through wall sections surrounding the

-potatoes and discharged into the space above the potatoes. In this process heat is conducted from the pile to the wall sections where it is removed by the ventilating air. Transfer of heat from the potatoes to the air within the pile causes convection of warm air to the top where it is exhausted by the ventilating system.

STATIC PRESSURE is a measure of the force or pressure that must be exerted on air to move it through potatoes and the ventilation system. It is used in selecting fan sizes and power requirements and is also helpful in determining proper layout and design of ventilation ducts. Static pressure is usually measured in inches of water.

THERMAL CONDUCTIVITY, expressed in B.t.u. per hour per square foot per degree F. per inch of thickness, may be defined as the time rate of steady state heat flow through one inch of a homogeneous material.

THERMAL RESISTANCE, expressed in hours, square feet, degree F. per B.t.u., can be defined as the time required for one B.t.u. to flow through one square foot of a given wall section for each degree F. temperature difference between the two surfaces.

THERMAL RESISTIVITY is the reciprocal of thermal conductivity.

THROUGH COOLING signifies forcing the air through the spaces surrounding the potatoes. In this manner heat is transferred, by forced convection, from the surface of the potatoes to the surrounding air. The air is then exhausted into the atmosphere.

VAPOR PRESSURE DEFICIT is the difference between the vapor pressure of air saturated with moisture at potato temperatures and the vapor pressure of air at storage temperature and humidity. It is usually measured in pounds per square inch or inches of mercury.

VENTILATION, as used here, indicates introduction of outside air into the storage with automatically controlled fans and dampers.

Materials and Equipment

A $125,000 storage laboratory was constructed at the Long Island Vegetable Research Farm, Riverhead, N. Y., in 1952. The two-story brick building provides space for a shop with machinery and equipment, and a dormitory for graduate students on the ground floor. In the basement are 11 storage rooms, approximately 8 feet wide, 14 feet deep, and 11 feet high (fig. 1). Six of these rooms were originally equipped with a forced air ventilation system consisting of a single fan and one main duct, with lateral ducts leading to each storage room.

Because of the inadaptability of the central type ventilation system for controlled potato storage studies, five of the ventilated rooms were provided with automatic, individually controlled, proportioning type, forced air ventilation systems during the course of these investigations. With these systems airflow rates were easily regulated and each room received no more ventilation than was necessary for cooling. The ventilated rooms were designed to simulate, as nearly as possible, a modern forced air ventilated commercial storage.

The remaining five rooms are individually refrigerated. Automatically controlled pneumatic spray nozzles are installed in each for humidification.

Methods of Investigation

In this study potatoes were stored in five ventilated rooms and one refrigerated room for 4 months or longer.

The effect of various airflow rates, different methods and rates of moisture application, and use of sprout inhibitors on the quality of the potatoes were studied. The refrigerated room was included as a check to compare quality of tubers resulting from the various

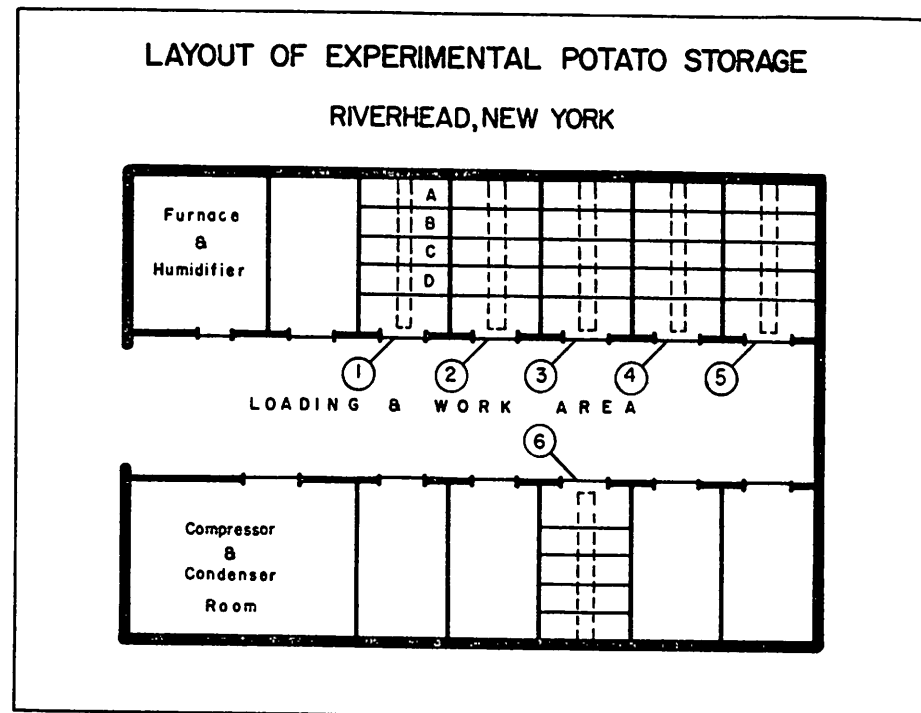LAYOUT OF EXPERIMENTAL POTATO STORAGE

RIVERHEAD, NEW YORK

Figure 1.—Layout of the basement of the storage laboratory at the Long Island Vegetable Research Farm, showing the ventilated rooms, 1 to 5, and the refrigerated room, 6. The equally divided bin compartments are labeled A, B, C, and D.

treatments with the quality of those stored in an atmosphere where temperature and humidity could be more readily controlled. Comparisons of quality were made among treated potatoes in the five ventilated rooms and between different lots of potatoes within each room. The latter was accomplished by dividing each room into four sections, each section having a capacity of 100 bushels (fig. 1).

The floors of the five rooms are constructed of slatted boards, and are raised approximately 4 inches above the soil to permit circulation of air beneath them. Thermal insulation was originally installed on the walls and ceiling of all rooms. Following the first year's studies, additional insulation was installed in the five ventilated rooms to reduce the rate of heat flow through

the walls and ceiling and to maintain a more uniform temperature distribution in each room.

Twelve thermocouple junctions were placed at selected locations within each room to measure the internal temperature of the potatoes and the dry bulb temperature of the air surrounding the potatoes. Thermocouples were also placed outside the storage building, with a shield over them, to measure the dry bulb temperature of the surrounding air, and in each intake and exhaust ventilating duct to measure the dry bulb temperature of the air entering and leaving each room. Temperatures were recorded periodically and the progress of cooling produced by each treatment, including refrigeration, was charted.

The moisture content of the intake and exhaust air was measured in some rooms with hygrothermographs placed in the intake ducts and in the storage room above the pile of potatoes. In other rooms, the moisture content of the intake and exhaust air was measured with an electronic hygrometer, having remote sensing elements located in the intake and exhaust ducts. Measurements obtained supplied information concerning the relative performance of various types of humidifiers, methods and rates of moisture application, and its practicability. Evaluations were made of the effect of various moisture treatments on tuber quality.

Airflow rates were determined by measuring the static pressure drop across sharp edge circular orifice plates. Desired airflow rates were obtained by varying speed of the fan. In this manner, the combined effects of moisture and sprout inhibitor with various airflow rates were studied.

Quality of the stored potatoes was determined by measuring specific gravity, shrinkage, hardness, black spot, pressure bruise, and incidence and severity of Fusarium dry rot. Sprouting was also observed.

All storage rooms were kept at 60° F. for 2 weeks after being filled to permit wound healing and suberization. After this period, the temperatures of all rooms, with the exception of room No. 5 in 1957, were reduced to 40° as soon as possible.

Treatments and Results

Changes in treatments were made each year 1953-1957 to refine the experimental technique, or as completed studies were replaced by others in need of investigation.

Arrangements were made with a local grower to furnish Katahdin potatoes in various lots to satisfy the requirements of the particular study. A technical report describing in detail the experimental procedure, results, and discussion of results is being prepared at Cornell.

The treatments, along with significant findings, are given below.

Test No. 1 (1953)

Rate of airflow per bushel	Treatment and method of cooling
Room No. 1, 0.33 c.f.m.	Forced ventilation from bottom to top with natural air
Room No. 2, 0.25 c.f.m.	Do.
Room No. 3, 0.17 c.f.m.	Do.
Room No. 4, 0.25 c.f.m.	Forced ventilation from top to bottom with natural air
Room No. 5, 0.25 c.f.m.	Forced ventilation from top to bottom with moisture added at top
Room No. 6, ———	Refrigerated

Ventilation in all rooms was accomplished with a single fan. A differential thermostat permitted the fan to operate when the dry bulb temperature of the outside air was below that of the storage rooms. Direction of airflow, whether through the pile from bottom to top, or the reverse, made no difference in the rate of cooling. Weight loss was less where moisture was added to the air before it came in contact with the tubers.

Test No. 2 (1954)

Rate of airflow per bushel	Treatment and method of cooling
Room No. 1, 0.25 c.f.m.	Forced ventilation with natural air
Room No. 2, 0.50 c.f.m.	Do.
Room No. 3, 0.25 c.f.m.	Proportioning ventilation with natural air
Room No. 4, 0.50 c.f.m.	Do.
Room No. 5, 0.25 c.f.m.	Proportioning ventilation with moisture added overhead
Room No. 6, ———	Refrigeration

Room Nos. 3, 4, and 5 were fitted with individually operated, automatically controlled, proportioning type forced air ventilation systems. Air was delivered to the bottom of the pile and exhausted out the top. Each room was filled with the following lots of potatoes:

Bin A—early planted, hand harvested
Bin B—early planted, machine harvested
Bin C—late planted, hand harvested
Bin D—late planted, machine harvested

The 0.5 c.f.m. per bushel rate in room No. 4 cooled most effectively. Moisture applied in the manner described did not reduce weight loss.

Test No. 3 (1955)

Rate of airflow per bushel	Treatment and method of cooling
Room No. 1, 1.0 c.f.m.	Proportioning ventilation with natural air—airflow reduced to 0.25 c.f.m. on November 28
Room No. 2, 1.0 c.f.m.	Proportioning ventilation with natural air
Room No. 3, 0.5 c.f.m.	Proportioning ventilation—MENA gas applied October 27
Room No. 4, 0.5 c.f.m.	Proportioning ventilation with natural air
Room No. 5, 0.5 c.f.	Do.
Room No. 6, ———	Refrigeration

Room Nos. 1 and 2 were fitted with the proportioning forced air ventilation system. Each room was filled with three bins of machine-harvested and one bin of hand-harvested potatoes. Fusarex was applied during loading to bin A of all rooms except room No. 3. Bin C in all rooms except room No. 3 was filled with potatoes harvested from a section of a field sprayed with a recommended dosage of maleic hydrazide (MH-40).

Ventilation at the rate of 0.5 c.f.m. per bushel cooled as well as ventilation at the 1 c.f.m. per bushel rate and resulted in less shrinkage.

Test No. 4 (1956)

Rate of airflow per bushel	Treatment and method of cooling
Room No. 1, 1.0 c.f.m.	Proportioning ventilation—moisture added to intake air
Room No. 2, 0.5 c.f.m.	Do.
Room No. 3, 0.5 c.f.m.	Proportioning ventilation with natural air
Room No. 4, 0.5 c.f.m.	Proportioning ventilation—MENA gas applied at end of dormancy through the ventilation system
Room No. 5, 0.5 c.f.m.	Proportioning ventilation—CIPC gas applied at end of dormancy through the ventilation system
Room No. 6, ———	Refrigeration

Centrifugal humidifiers were installed in room Nos. 1 and 2 to introduce moisture into the intake air duct. Rooms were filled with the following lots of potatoes:

Bin A—high harvest temperature, field run
Bin B—high harvest temperature, sized and dirt removed
Bin C—low harvest temperature, field run
Bin D—low harvest temperature, sized and dirt removed

Moisture application was more effective when applied at an airflow rate of 0.5 c.f.m. per bushel than at the 1 c.f.m. per bushel rate. Sprout inhibitors applied in the manner described gave promising results. Tubers were sized and pickouts were discarded prior to storage. Approximately 5 percent of the field run potatoes can be graded out prior to storage, making extra storage space available for good potatoes.

Test No. 5 (1957)

Rate of airflow per bushel	Treatment and method of cooling
Room No. 1, 1.0 c.f.m._____	Proportioning ventilation—moisture applied to intake air
Room No. 2, 0.5 c.f.m._____	Do.
Room No. 3, 0.5 c.f.m._____	Proportioning ventilation with natural air
Room No. 4, 0.5 c.f.m._____	Proportioning ventilation—CIPC gas applied at end of dormancy
Room No. 5, 0.5 c.f.m._____	Proportioning ventilation—CIPC gas applied at end of dormancy—temperature at 50° F.
Room No. 6, _____	Refrigeration

The following lots of potatoes were studied:

Bin A—early plant, early harvest
Bin B—early plant, late harvest
Bin C—late plant, early harvest
Bin D—late plant, late harvest

Behavior of Potatoes in Storage

Like the dormant stem of almost any common woody plant in winter, the potato in storage has a rest period during which time the buds, or eyes, will not grow even when placed in an ideal growing atmosphere. After the rest period, growth will start whenever the climatic conditions are right—the warmer the temperature, the faster the growth. The potato tuber has the ability to produce new skin tissue (wound periderm) at damaged areas if the environment is favorable. Environmental conditions also affect the texture, respiration, and chemical composition of the potato.

Storage Environment

For potatoes in general, a storage temperature of from 38° to 40° F. and a relative humidity of 85 to 90 percent is considered ideal. Most of the storage research in recent years has been concerned with ways of providing this environment.

Effects of Temperature

SPROUTING.—A temperature of 40° F. is considered ideal for long storage. Sprouts on non-dormant potatoes grow quite slowly at a storage temperature of 38° to 40°. Growth becomes faster as the temperature increases to 50°, and there is a marked increase as the temperature goes above 50°. Thus, at 40°, sprouting is very slow for potatoes that are no longer dormant. Although sprouting would be less at lower temperatures, chilling injury can occur at around 32° even though no actual freezing has taken place. Tubers also tend to develop a sweet flavor at this low temperature.

RESPIRATION.—Because the potato in storage is living plant material, respiration must be considered. The lowest rate of respiration occurs during a storage temperature of 35° to 40° F. As the temperature is decreased below 35° there is a sharp increase in respiration until 32° is reached and then there is a sharp decrease again. There is a gradual rise in respiration rate as the temperature is increased from 40° to 50° with a sharp increase when the temperature rises above 50°. A marked increase in respiration always accompanies sprouting. Thus, at the ideal storage temperature of 40°, respiration rate is low.

COLOR.—Color of the fried product is important to the potato processing industry. Potatoes which fry dark or require excessive time for curing are of little value to processors. Because of the presence of reducing sugars, practically all varieties darken during frying when taken directly from storage at temperatures under 50° F. Most varieties, when brought from temperatures of under 50° to temperatures of 60° to 70° and held there for 3 or 4 weeks, will be light when cooked. This practice is called curing and is common with the potato chipping industry and other types of processing where frying is involved and the color of the fried product is highly important. Some varieties such as Green Mountain will never cure satisfactorily after storage. Processors, then, are willing to accept conditions that allow sprouting and shrinkage in storage if they can have conditions that insure a light colored product. Thus, they prefer tubers which have never been held at temperatures lower than 50°. Strong sprout inhibitors are then required for processors who wish to keep their product firm for a long storage period.

TASTE.—Other reasons for higher storage temperatures are chemical changes which take place in the potato according to storage temperature. Potatoes stored at approximately 32° to 34° F. for any length of time develop a sweet taste. This can be corrected with most varieties by raising the temperature to 60° and holding them at that temperature for several days.

ROT ORGANISMS.—A storage atmosphere of 60° to 70° F. dry bulb temperature and 90 percent relative humidity is ideal for allowing the potato tuber to produce new skin. Much of the tuber decay that develops in storage is caused by bacteria and fungi that enter through wounds. The new skin, which the potato tuber has the ability to produce, is an effective barrier against these rot organisms. Therefore, by handling the tubers carefully, and providing conditions favorable for the reproduction of skin at the beginning of the storage period, the incidence of rot in storage can be reduced.

It must be remembered, however, that the conditions most favorable for healing the tuber wounds are also favorable for rot organisms. The optimum temperature for most rot organisms is between 70° to 80° F., but they will develop at temperatures close to freezing. Bruised tubers stored at about 60° and 80 to 90 percent relative humidity, and provided with adequate ventilation generally will produce an effective wound periderm barrier in 10 to 14 days. After the initial curing period, the storage temperature should be reduced as soon as it is practical to the desired holding temperature. The manipulation of the storage environment in this manner will result in satisfactory control of most storage decays.

In contrast, bruised tubers stored immediately at 40° F. will not readily develop an effective wound barrier and are susceptible to rot organisms throughout the storage period. The incidence of Fusarium dry rot that developed in test samples of tubers stored under various conditions is given in table 1.

Table 1.—Incidence of Fusarium dry rot in samples of Katahdin potatoes inoculated with Fusarium sambucinum f. 6 and stored under various conditions for 4 to 5 months [1]

| Storage treatment | | | Percentage of potatoes affected with dry rot |
Airflow rate per bushel (c.f.m.)	Temperature (° F.)	Other conditions	
Proportioned forced air ventilation:			Percent
1.0	40	Moisture [2]	40
0.5	40	Moisture [2]	32
0.5	40	No moisture	38
0.5	40	Sprout inhibitor [3]	25
0.5	50	Sprout inhibitor [3]	31
Refrigerated:			
None	60–40 [4]	None	41
None	40 [5]	None	100

[1] All samples, except those stored at 40° F. immediately after inoculation, were stored in the center of 100-bushel bins filled with potatoes. Those stored at 40° immediately after inoculation were placed on a shelf in a refrigerated room maintained at 40°.

[2] Water was vaporized into the ducts of the ventilation system to maintain relative humidity at 85 to 90 percent.

[3] One-quarter gram actual Isopropyl-N-Chlorophenylcarbamate (CIPC) per bushel was volatilized into ventilation systems after the potatoes had been in storage for 1 or 2 months.

[4] Temperature of 60° for 2 weeks, then dropped to 40°.

[5] Test potatoes were placed on a shelf in 40° temperature immediately after inoculation.

Humidity

Control of the moisture content of storage air is as important as temperature control. Relative humidity is the ratio of the existing vapor pressure to the vapor pressure occurring when a given volume of air is saturated with water at a given temperature. A low relative humidity in the ventilating air indicates a high vapor pressure deficit. When the tuber is placed in an atmosphere of lower vapor pressure than it exerts, moisture will be lost and the potatoes will get soft and flabby, even when sprouting has been controlled by temperature manipulation or chemical inhibition. Soft potatoes are susceptible to pressure bruises and black spot.

When sprouting starts, moisture loss from the tuber is accelerated. Sprout inhibitors, therefore, reduce moisture loss. However, air movement in excess of that necessary for cooling is undesirable because part of the moisture contained in the exhausted air comes from the potatoes, and is independent of sprouting. By adding moisture to the incoming air, the difference between the vapor pressure exerted by the tuber and the vapor pressure exerted by the surrounding air is minimized, thus reducing moisture loss from the potatoes. Table 2 indicates the effect on potatoes in storage of two rates of air movement for cooling, of moisture application to the air stream, and of sprout inhibitors.

In the tests of moisture application at airflow rates of 1 and 0.5 c.f.m. per bushel (1.6 and 0.8 c.f.m. per hundredweight), the higher air rate caused greater shrinkage, black spot, and softer tubers. A com-

Table 2.—The effect of airflow rate, of moisture application, and of sprout inhibitors on hardness, shrinkage, and black spot of Katahdin tubers stored for 4 to 5 months

| Storage treatment | | | Hardness index [1] | Percent shrinkage | Black spot index [2] |
Airflow rate per bushel	Temperature	Other conditions			
C.f.m.	Degrees F.				
1.0	40	Moisture [3]	82.2	6.2	18
.5	40	Moisture [3]	83.0	5.0	13
.5	40	No moisture	80.9	6.7	33
.5	40	Sprout inhibitor [4]	82.7	5.3	18
.5	50	Sprout inhibitor [4]	82.1	4.8	11

[1] Hardness index measured by a durometer reading 1 through 100 with 100 the hardest index.

[2] Black spot index runs 1 through 90 with 90 the worst possible black spot. Index takes into consideration percent of tubers showing black spot and size of the defect.

[3] Water was vaporized into the ducts of the ventilation system to maintain a relative humidity of 85 to 90 percent.

[4] One-quarter gram actual CIPC per bushel was volatilized into ventilation system after the potatoes had been in storage for 1 or 2 months.

parison of no moisture, and moisture addition at 0.5 c.f.m. per bushel, indicates the advantage of moisture application. Comparisons of treatments with CIPC and other treatments give an indication of the effect of sprout inhibitors even when the temperature cannot be brought down to 40° F.

A storage humidity in excess of 90 percent is hazardous. The tuber becomes more susceptible to rot, especially bacterial soft rot, if free moisture remains on its surface. The lenticels, or breathing pores, swell and provide entry points for soft rot bacteria when the tubers remain wet. As the soft rot develops, the debris and moisture from the rotten tubers not only stain the adjacent sound tubers but also inoculate them with bacteria. Thus, a pocket of soft, wet, foul-smelling, rotten tubers may develop in the pile.

In addition to providing an environment favorable for wound periderm formation, adequate ventilation removes excess moisture from the surface of the potato and pro-

vides conditions less favorable for rot development. When tubers affected with late blight, caused by *Phytophthora infestans* (mont.) De By.; bacterial ring rot, caused by *Corynebacterium sepedonicum* (Spieck & Kotth.) Skapt. & Burk.; black leg, caused by *Erwinia atroseptica* (van Hall) Jennison; etc., are placed in a properly ventilated storage, the decay that develops usually will be dry instead of wet, and it usually will be confined to tubers that were infected before they were stored. Thus, the development of wet pockets in the pile and losses from rotting are reduced to a minimum.

Control of Sprouting

A mature potato at harvest may have a rest period of several weeks when no growth will take place even if the tuber is placed in ideal sprouting conditions. The length of the rest period varies considerably with variety of potato and with its degree of maturity at harvest. Under hot maturing conditions there may be no rest period

at harvest. Since potatoes are normally stored for periods longer than the rest period, cultural and storage techniques are commonly used which prolong the storage life.

Manipulation of storage temperature was the only method used to control sprouting until the introduction of chemical inhibitors. Dusts applied when the potatoes go into storage and a spray which can be applied to potato foliage have found some commercial acceptance. Chemical inhibitors have been applied in waxes and in wash water to keep potatoes from sprouting in market channels. New inhibitors demonstrating much stronger sprout control than any previously available have been used in research programs for several years. Techniques that reduce sprouting should be considered in any storage program where sprouting is a problem.

Because chemical sprout inhibitors are undergoing rapid development, it would be well to consult recent Federal regulations concerning the use of new materials or methods.

Temperature Control

The first consideration in any program to inhibit sprouting is temperature control. It is essential for long term sprout control that the temperature be reduced to the desired level while the potato is still in its rest period. Since most processors, however, prefer never to have their product held at temperatures under 50° F. because of the effect on its curing and color, the use of temperature for sprout inhibition for longer than 3 or 4 months is limited. Even though some accessory method of sprout control will have to be used, the first consideration should be to reduce the temperature as far as possible without harming the potato with regard to curing and color.

Positive temperature control is provided by refrigerated storage; however, this is too costly in most cases. In some late crop areas, natural ventilation has been used to control sprouts. Forced air ventilation systems of the proportioning type provide maximum use of outside air. This technique has increased the sprout-free period of the late summer potato crop areas, such as Long Island and New Jersey, by several weeks. Air movement in these forced air systems maintains uniform air temperatures in all parts of the storage and limits rots that would otherwise cause serious losses.

Cultural Practices Reducing Sprouting

Cultural practices which influence the maturity of the potato at harvest will influence the length of the rest period. For the late summer crop potato area, where there can be considerable variation in planting dates, the late dates of planting give longer sprout free periods in storage than do early dates of planting. That part of the crop to be held the longest in storage should be planted the latest.

In late summer crop areas where harvest dates can vary several weeks, the portion of the crop to be held the longest in storage should not be harvested until storage temperatures can be brought down to the desired holding temperature within a short time. On Long Island, potatoes harvested in September consistently sprout earlier in storage than those harvested in October.

Storage sprouting differs by variety. Sebago and Chippewa inherently have a short rest period and are not good storage varieties. Merrimac variety has a very long rest period and will remain sprout free in storage several weeks longer than Katahdin, the principal storage variety.

Use of Chemical Sprout Inhibitors

Maleic hydrazide. — Of the chemical inhibitors, maleic hydrazide has been tested more and has received a wider acceptance than any other commercial inhibitor. It has been used mostly by potato processors who expect to hold potatoes long enough to require the use of inhibitors.

Maleic hydrazide is applied to the foliage of actively growing plants with few or no yellow leaves. Tubers should be approaching marketable size. Where a stage of plant development can be used, a blossom fall application of 3 pounds active ingredient per acre gives satisfactory sprout suppression for periods up to 1 year. Applications at full bloom and earlier may result in yield reductions—more tubers set on but few of them attain market size and quality. With late applications, insufficient material is translocated from the foliage to the tuber to give satisfactory sprout control.

The acceptance of maleic hydrazide has been slow for two principal reasons: (1) It must be applied before the average grower is able to determine what his storage program will be for the coming year, and (2) the cost per hundredweight of potatoes treated depends on the yield per acre. Thus, this material is expensive for poor yields when the crop may not be stored long enough to require an inhibitor.

Tetrachloronitrobenzene (TCNB).—TCNB is a weak inhibitor; however, it will extend the holding period for several weeks. Its principal acceptance has been on Long Island where an inhibitor is needed almost every year for potatoes held longer than 3 months. With the development of forced air circulation systems, the use of TCNB has declined.

The material is available as a 6 percent dust and is applied at a

rate 1 pound per 10 bushels of tubers. It may be applied to the tuber through a small fertilizer spreader suspended over the storage loading elevator and driven by a belt or chain.

Weak sprout inhibition is the principal disadvantage of this material. The cost of approximately 5 cents per bushel is considered high for the length of time it is effective. The dust occasionally discolors the surface of potatoes even though its color has been made to blend with the skin of the potato as much as possible.

Methyl Ester of Alpha-Naphthaleneacetic Acid (MENA).—MENA had short acceptance on Long Island as a commercial sprout inhibitor. It was applied as a dust to potatoes going into storage. Wound periderm formation was hindered and potatoes had a predisposition to decay. This material is used to control potato sprouting in market channels. It is applied in a wax to washed potatoes or is used in the wash water. A dosage of 0.5 gram per bushel will keep non-dormant potatoes sprout-free in market channels for about 30 days.

Technical grade MENA can be successfully volatilized into the air stream of forced air ventilated storages. The application is made after the potatoes have been in storage long enough for the wound periderm to form but before sprouting occurs. A dosage of 1 gram per bushel is volatilized into the ventilation system by heating to approximately 375° to 400° F. The storage fans are set for recirculation and the storage kept closed 24 to 48 hours after application. After this period the storage ventilation equipment is returned to normal operation.

MENA is still available as a dust or spray to be applied as potatoes are put into storage. This type of application is not recommended be-

cause it can lead to serious rot losses. Well set skins and freedom from injuries are essential for tubers treated as they are placed in storage.

ISOPROPYL-N-CHLOROPHENYLCAR-BAMATE (CIPC).—CIPC is the strongest chemical inhibitor available. It gives effective inhibition as a dust, a water dip, or a spray. The principal drawback with this material is its effect on wound periderm formation. CIPC inhibits wound healing the same as MENA and this predisposes the tubers to rot. Storages with forced air ventilation systems can overcome this detrimental effect on wound periderm with an application of CIPC as a gas after the tubers have been in storage long enough for wound periderm to have formed but before sprouting occurs. Tests to determine the effects of this method of treatment were conducted in 1958 (table 2).

Only the volatilized method of application will be considered here since the dusts, sprays, or dips applied to tubers going into storage can cause serious rot problems. CIPC applied at a dosage of 0.25 gram per bushel of tubers has given excellent sprout control for periods of more than 1 year at a storage temperature of 50° F.

The material is volatilized in the storage ventilation system. Fans are set for recirculation during application and for 24 to 48 hours thereafter. After this time, the storage ventilation equipment is returned to normal operation.

Advantages of this material are its anticipated cost and its very strong sprout suppression. Application can be delayed until after tubers are in storage and a definite need for an inhibitor has been determined. Before this material can be used commercially, toxicological studies, now in progress, must show no harmful results and it must receive clearance by the Food and Drug Administration, U. S. Department of Health, Education, and Welfare.

Irradiation to Inhibit Sprouting

Irradiation is a very potent sprout inhibitor and in strength would compare with CIPC. Effective sprout control of most potato varieties has been obtained at dosage levels of 5,000 to 10,000 roentgens with either gamma or fast electron irradiation. Before use can be made of irradiation, several detrimental side effects must be overcome. Irradiation inhibits wound periderm formation and enhances the entrance of rot organisms as does MENA and CIPC. Irradiation increases after cooking darkening and black spot. Toxicological studies must show no harmful effects before irradiation can be approved for commercial use.

Providing the Optimum Storage Environment

Cooling

Use of air to cool potatoes in storage is economical, convenient, and effective. The technique of supplying this air determines the degree of effectiveness and practicability of long term storage.

Heat within a storage, excluding that in the ventilating air, comes from four principal sources: (1) Field or harvest heat; (2) heat of respiration; (3) heat that enters through the walls, floor, and ceiling by conduction; and (4) heat exchange by infiltration of air through walls, cracks along openings, and open doors. A certain amount of this heat must be removed to maintain proper storage temperature. This is accomplished by ventilation. When the potatoes are cooled to the proper temperature the initial cooling process is completed. Continued ventilation is necessary to remove the heat gained from respiration, conduction, and infiltration. Ventilation is accomplished with an automatic control system that positions the dampers and controls fan operation. The ability of the system to remove heat depends almost entirely upon the difference between outside dry bulb temperatures and inside storage temperature during ventilation.

The peak cooling load occurs during the first few weeks of storage. This is the time when large quantities of field heat plus the heat gain by respiration, conduction, and infiltration must be removed. During this period outside temperatures generally allow only a limited amount of ventilation—mostly at night. An airflow rate that will effectively reduce storage temperatures early in the season is sufficient to maintain a constant temperature throughout the storage period.

Research results show that the rate of heat removal at an airflow rate of 0.8 c.f.m. per hundredweight is essentially equal to the rate of heat removal at an airflow rate of 1.6 c.f.m. per hundredweight. There is a logical explanation for this. The rate of heat transfer from the surface of a potato to air depends upon the temperature difference between the surface and the air as well as the rate of air movement across the surface. The surface temperature is influenced by the rate at which heat is conducted from the interior to the surface of the potato. At an airflow rate of 1.6 c.f.m. per hundredweight, the limiting factor is probably the rate of heat conducted to the surface which, in turn, causes a smaller temperature difference between the surface and the ventilating air. Therefore, the reduction in storage temperature accomplished at a rate of 0.8 c.f.m. per hundredweight compares favorably with that accomplished at an airflow rate of 1.6 c.f.m. per hundredweight (table 3). At higher airflow rates shrinkage and susceptibility to black spot are increased. Airflow rates less than 0.8 c.f.m. per hundredweight do not cool effectively in the eastern late summer crop area.

The cooling load on a system required to maintain a constant temperature during the holding period is not as great as the initial cooling load, and less outside air is needed for cooling. Also when the outdoor dry bulb temperature is below the desired storage temperature (40° F. for table stock), the incoming outside air is mixed with recirculated storage air. This is accomplished with automatically controlled dampers that proportion relative amounts of outdoor and storage air for ventilation. The amount of outside air used depends upon the relative dry bulb temperature of the outside air and storage air.

The optimum storage temperature is generally attained in late November in the Long Island area (table 3). To maintain this temperature it is necessary to continue ventilation and recirculation throughout the storage period. At 40° F., potatoes in storage, when not cooled, accumulate sufficient heat from respiration to raise the temperature about $\frac{3}{4}$° per day. At 50° the temperature rise is about 1° per day. In addition, an accumulation of heat by conduction through the walls of a storage constructed below-grade causes the temperature rise to be more pronounced (fig. 2). A properly in-

Date	Average potato temperature when airflow rate is—	
	0.8 C.f.m./ cwt.	1.6 C.f.m./ cwt.
	° F.	° F.
October 24	57. 9	57. 2
25	54. 8	54. 5
26	51. 8	51. 4
27	50. 0	50. 1
28	50. 0	50. 2
29	49. 3	49. 6
30	49. 9	49. 8
31	50. 5	50. 7
November 1	51. 6	51. 8
2	52. 5	52. 7
3	50. 9	50. 9
4	(¹)	(¹)
5	(¹)	(¹)
6	50. 3	50. 6
7	49. 2	49. 8
8	49. 1	49. 8
9	48. 4	49. 3
10	48. 1	47. 4
11	43. 7	43. 8
12	43. 5	44. 2
13	43. 1	43. 5
14	42. 6	43. 2
15	43. 2	44. 4
16	44. 6	44. 7
17	43. 9	44. 2
18	(¹)	(¹)
19	41. 4	42. 1
20	40. 6	40. 9

¹ Data not available.

sulated above-ground storage will accumulate less heat and thereby reduce the cooling load on the ventilation system.

In 1957 in an earth-banked storage facility on the Long Island Vegetable Research Farm a heat transfer study was made to determine the amount of heat gain by conduction at given times during the storage period. During the latter half of November when the storage temperature was 45° F., the heat flow through an 8- by 14-foot wall having one side in contact with the earth was approximately 1,100 B.t.u. per day. The thermal re-

sistance of this wall is 16, or twice the minimum recommended value for above-ground storage walls. During the corresponding period, above-ground walls of equal thermal resistance would conduct little if any heat into storage from the outside. This difference in heat gain is attributable to an average difference of 7.6 degrees between the average atmospheric dry bulb temperature and average soil temperature at this time of year.

During November, the difference between the average outside air temperature and the average soil temperature of 55° at 3- to 10-foot depths ran as follows:
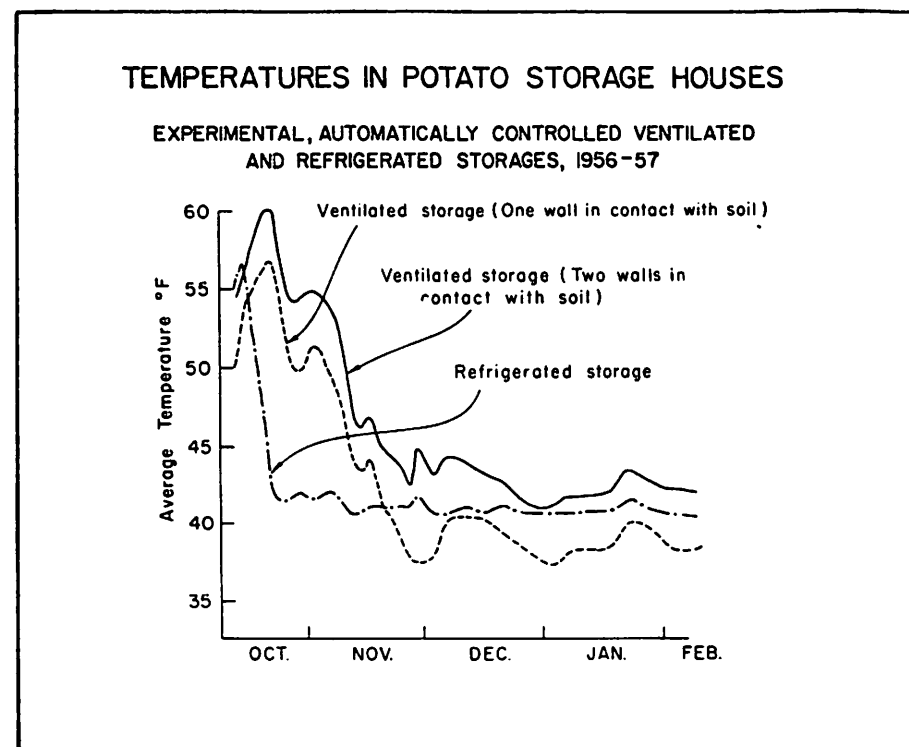

TEMPERATURES IN POTATO STORAGE HOUSES

EXPERIMENTAL, AUTOMATICALLY CONTROLLED VENTILATED AND REFRIGERATED STORAGES, 1956-57

Figure 2

Date	° F. difference
November 15	+3
16	—3
17	—1
18	—6
19	+6
20	—7
21	—13
22	—12
23	—17
24	—11
25	—15
26	—17
27	—20
28	0
29	+1
30	—10

The extra operating time required to remove the 1,100 B.t.u. of heat amounts to approximately one-half hour per day. Roughly 1 to 2 hours of ventilation are required each day just to remove the heat gained by conduction through the four walls of a below-grade storage.

Another problem is the build-up of heat in localized areas, com-

monly known as "hot-spots," within the pile. A uniform distribution of air during ventilation combined with periodic recirculation of inside air will prevent damage from "hot-spots" and will also provide a tempering zone near the walls. Recirculation is done when ventilation is not feasible, as when outside temperatures are too low. Good air distribution depends on the spacing, size, and design of the ventilating ducts. In making calculations to determine duct sizes the pile depth must be considered. In bulk storages the recommended pile depth is 10 feet.

Controlling Humidity

Another factor on which the ultimate quality of stored potatoes also depends is the relative humidity of the ventilating air. The drying effect caused by passing

relatively dry air through the pile of potatoes is minimized by maintaining a consistently high moisture content in the ventilating air. While no specific recommendations are given toward the type of humidifying equipment to use, the method of supplying this moisture is of prime importance.

In this connection there are two principles to consider. First, complete vaporization of all added water is necessary. Unvaporized water particles on the surface of potatoes contribute to decay. Secondly, during ventilation, moisture must be added to the air before it comes in contact with the stored tubers. Each of these principles can be accomplished by placing the humidifying equipment at a point in the main duct where volatilized particles of water are introduced directly into the air stream. The action of the moving air on the tiny droplets (mean diameter not to exceed 40 microns) stimulates vaporization. When properly applied and controlled, all of the added water is vaporized before it comes in contact with the potatoes.

In a test to determine how the moisture should be applied, it was found that moisture vaporized directly into the storage rather than through the ventilation system has little or no effect on retarding shrinkage by loss of water in transpiration. It is, therefore, recommended that if humidifiers are used, the moisture be introduced into the air through the ventilating ducts.

Vaporization of water into the ventilating air reduces its dry bulb temperature, giving it extra capacity to remove heat from the potatoes and storage structure. The amount of extra cooling capacity gained depends upon the initial moisture content of the air and the quantity of water vaporized. An extra 1,000 B.t.u. of heat can be removed from the storage for each pound of water vaporized. This applies whether the water is added to the ventilating air from an external source, or from the tubers themselves. This is particularly important during the first few weeks of storage. To ventilate and humidify a storage of 20,000-hundredweight capacity on a typical day, approximately 75 pounds of water per hour need to be vaporized into the intake ventilating air. This requires 75,000 B.t.u. of heat, or approximately the amount of heat the potatoes in this storage would evolve per hour at 50° F.

Figure 3.—A forced-air ventilated potato storage house showing components of the ventilation system, including a humidifier.

Layout, Design, and Construction of Storage

Figure 3 shows a good arrangement of the ventilation system components in a modern storage facility. Suggestions regarding many of the design, installation, and operating problems are given in the following discussion.

Selection, Installation, and Operation of Ventilating and Humidifying Equipment

Fans

There are two basic types of fans. Axial flow (propeller) fans include all classes of fans from which the airflow is substantially parallel to the shaft upon which the impeller is mounted. Radial flow (centrifugal) fans produce airflow by centrifugal force caused from the rotation of air within the fan housing; and by the force of the impeller imparting a velocity on the air leaving the fan. Both propeller and centrifugal fans are satisfactory for potato storage ventilation.

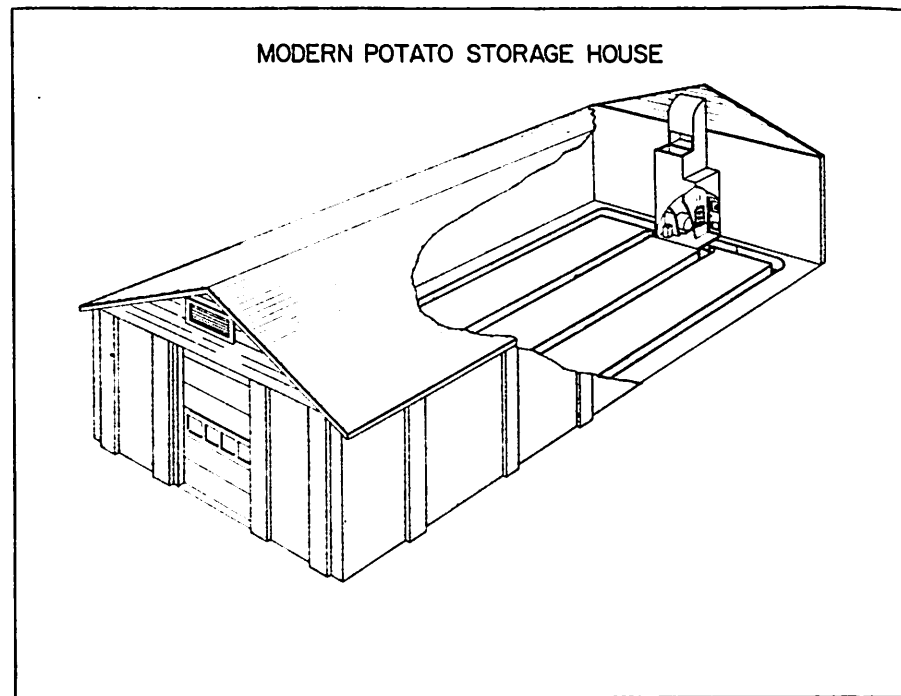Propeller fans are designed to deliver large volumes of air at low static pressures (fig. 4). They perform at any range between design pressure and free delivery (zero static pressure) with very little change in horsepower requirement. Because of this limit-load characteristic, there is no danger of motor overload at reduced static pressures. This type of fan is light in weight, requires little space for installation, and is less expensive than centrifugal fans that will deliver equal volumes of air. Its main disadvantage is the objectionable noise at the high speeds required to deliver large quantities of air.

Centrifugal fans may be roughly divided into three types according to blade design: (1) The forward-curve (2) the backward-curve, and (3) the straight blade. Figure 5 illustrates these types of fans.

The forward-curve fan will deliver large volumes of air against a wide range of static pressures at relatively low speeds. It is a quiet running fan with little vibration. It is constructed of either light or heavy gage metal, each having the same operating characteristics. The lighter gage fans are reasonable in cost, durable, and are easier to install than the heavier gage fans. One objection to this fan is that it does not have the load-limit characteristic. A decrease in static pressure causes the fan to deliver additional air, resulting in possible motor overload. One way to circumvent this problem is to use a larger motor to drive the fan. Because power consumption depends primarily on fan power requirements rather than motor size, the power cost will not increase appreciably. It is entirely possible, that power cost might even be less, particularly if smaller motors are required to run at a continuous overload.
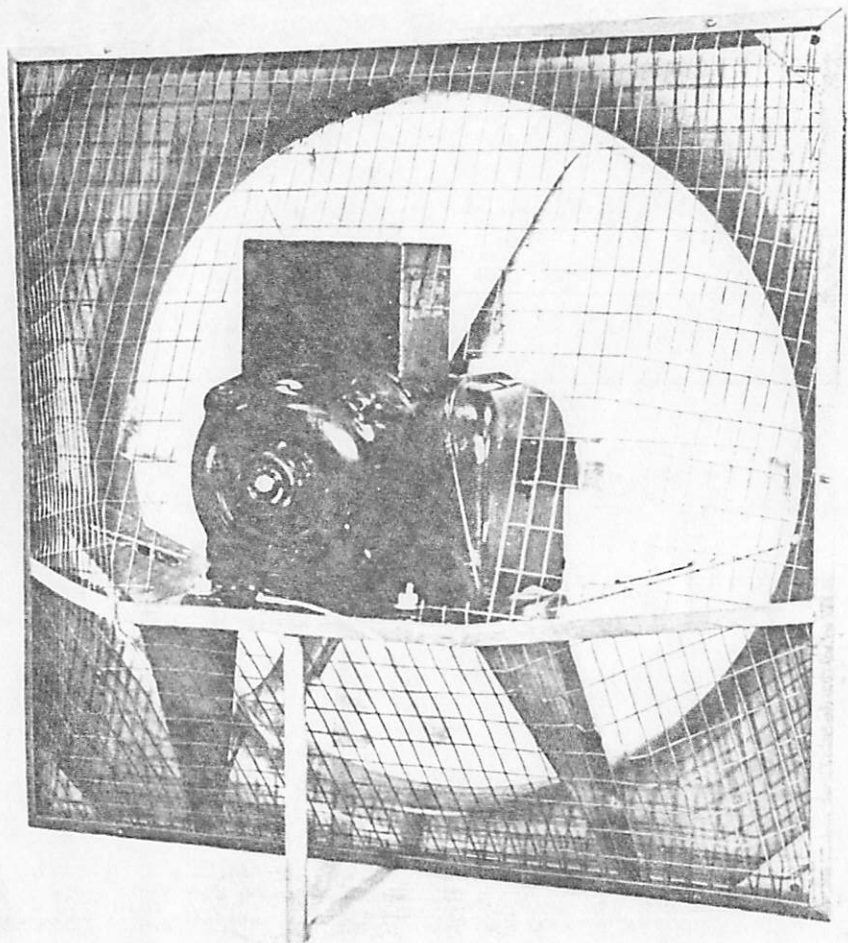
Figure 4.—Axial flow fan equipped with a recommended type of propeller blade.

Figure 5.—Three types of centrifugal or axial flow fans.

There is another problem connected with this fan which also must be considered. A small difference between actual and design static pressures will cause an appreciable change in airflow rate. For this reason it is important to measure the volume of air actually delivered under normal operating conditions after the fan is installed. Air volume can be determined by two methods: (1) Measure static pressure and fan speed 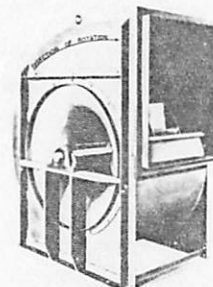and refer to fan performance curves, or (2) measure velocity in the main duct and calculate the air flow. If airflow rate is inadequate, fan speed should be increased.

The backward-curve fan is a high speed fan. It is slightly more efficient than the forward-curve or straight blade fans. It also can be purchased in light or heavy gage construction at approximately the same cost as similar forward-curve fans. One distinct advantage of this fan is that, because of its self-lim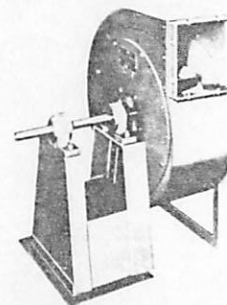iting horsepower characteristic, there is little or no danger of motor overload. Also, there is less tendency for the airflow rate to vary with changes in static pressure.

The straight blade fan is designed primarily to deliver small volumes of air at high velocities against high static pressures. It is commonly called a pressure fan, industrial exhauster, or material handling fan. This fan is generally not suitable for use in potato storages.

Selection of the type of fan is largely a matter of individual preference. Decisions can be governed by availability, cost, adaptability to storage design, or space available for installation. If a centrifugal fan is preferred, the lighter weight fan generally meets all requirements for a potato storage.

One of the factors determining the efficiency and subsequent operating economy of a ventilation system is the proper selection of fan size. The size of a fan is determined by: (1) Volume of air to be delivered; and (2) the static pressure at which the fan must operate to move the air at a predetermined rate through the potatoes. At 0.8 c.f.m. per hundredweight, resistance to moving air through a 10-foot depth of potatoes is measured by a static pressure of approximately 0.125 inch of water. The resistance to the flow of air in the ventilation system will vary according to design and quality of construction of the system. In a typical storage of good design, it is usually found to be 0.25 inch. Generally, in a typical storage having a properly designed ventilation system, fan size can be based on the volume of air to be delivered at a total static pressure of 0.375 inch.

When determining the size of fan needed, prime consideration should be given to horsepower requirements. Large fans deliver an equivalent quantity of air at less power consumption than smaller fans. For example, if a storage of 12,000 cwt. is to be ventilated at the rate of 0.8 c.f.m. per hundredweight, fan size will be based on 10,000 c.f.m. at a static pressure of 0.375 inch. Tables 4 and 5 on fan performance reveal that a number of fans of various sizes can be op-

Table 4.—*Estimated costs of ownership and operation of double inlet-double width centrifugal fans of three different sizes for a 20,000-cwt. capacity potato storage house*

Fan	Wheel diameter	Initial cost			Annual cost				
					Ownership				
		Fan	Motor [1]	Total	Depreciation [2]	Interest [3]	Insurance and taxes [3]	Operation [4]	Total
	Inches								
A	30	$920	$275	$1,195	$60	$30	$24	$120	$234
B	33	1,040	225	1,265	63	32	25	96	216
C	36	1,180	175	1,355	68	34	27	72	201

[1] Motor costs are less on the larger fans because smaller motors are used to move same volume of air.
[2] Based on an assumed expected life of 20 years.
[3] Interest was computed at 5 percent and insurance and taxes at 4 percent of the average investment for the 20-year depreciation period.
[4] Operation costs are based on an expected maximum operating time of 2,400 hours, and power costs were assumed to be $0.02 per kilowatt-hour. No allowance for maintenance and repair is included.

Table 5.—*Comparative ownership and operation costs for a 30-inch double inlet-double width fan and a 30-inch single inlet-single width fan for a 20,000-cwt. capacity potato storage house*

Fan type	Motor size	Initial cost			Annual cost				
					Ownership				
		Fan	Motor	Total	Depreciation [1]	Interest [2]	Insurance and taxes [2]	Operation [3]	Total
	Hp.								
Double inlet—double width	3	$1,000	$275	$1,275	$64	$32	$26	$120	$242
Single inlet—single width	6	650	450	1,100	55	28	22	240	345

[1] Based on an assumed expected life of 20 years.
[2] Interest was computed at 5 percent and insurance and taxes at 4 percent of the average investment for the 20-year depreciation period.
[3] Operation costs are based on an expected maximum operating time of 2,400 hours and power costs were assumed to be $0.02 per kilowatt-hour. No allowance for maintenance and repair is included.

erated at different speeds to deliver nearly equal volumes of air. To deliver a given volume of air, more power is required to drive the smaller than the larger fans. This characteristic applies to all centrifugal and propeller fans. Moreover, some propeller fans operate at less power input than centrifugal fans delivering the same volume of air. Here again, fan size is a determining factor.

Because of the numerous makes, sizes, and types of fans available, it is impossible to list fan performance data of all manufacturers in this report. Tables 6 and 7 are not to be used as rating tables for selecting fans, but rather to point out the relation between size of fan, size of motor, and quantity of air delivered. Fan size can be determined from manufacturers' performance rating tables. Company representatives and experiment station agricultural engineers will assist in the selection of the most suitable size and type fan.

Table 6.—*Outlet size, power required, speed, and volume of air for single inlet-single width centrifugal forward- and backward-curve fans at 0.375 inch static pressure for a 12,000-cwt. capacity potato storage house*

Type of fan and wheel diameter	Outlet size	Power required	Fan speed	Volume of air
Forward-curve:	*Inches*	*Hp.*	*R.p.m.*	*C.f.m.*
32-inch	24⅝ x 32	1.99	283	10,203
36-inch	27 x 35⅛	1.63	230	10,375
39-inch	29½ x 38⅜	1.24	189	10,062
42-inch	32⅛ x 41¾	1.09	162	9,983
46-inch	34½ x 45	1.00	147	10,550
Backward-curve:				
26-inch	19¾ x 25⅝	4.35	1,264	10,320
29-inch	22⅛ x 28¾	2.85	988	10,440
32-inch	24⅝ x 32	1.96	660	10,203
36-inch	27¹⁄₁₆ x 35⅛	1.55	514	10,376
39-inch	29½ x 38⅜	1.17	398	10,062
42-inch	32⅛ x 41¾	.98	326	9,983
46-inch	34½ x 45	.96	287	10,550

Table 7.—*Power required, speed, and volume of air for various sizes of propeller-type fans at 0.375 inch static pressure for a 12,000-cwt. capacity potato storage house*

Propeller diameter and number of blades	Power required	Fan speed	Volume air
	Hp.	*R.p.m.*	*C.f.m.*
27-inch, 6 blades	1.5	1,740	9,080
32-inch, 4 blades	1.5	1,740	10,550
36-inch, 6 blades	1.0	1,160	10,170
42-inch, 4 blades	1.0	870	9,000
42-inch, 6 blades	1.0	870	11,100
48-inch, 2 blades	1.0	1,150	9,800
48-inch, 4 blades	1.0	870	10,800
48-inch, 6 blades	1.0	695	11,300

Controls and Switches

Performance of the automatic control system has been observed in both commercial and research facilities for several years. Its ability to provide ventilation is conclusively p r o v e d. Full-time automatic control of the fan and dampers during storage is accomplished with a minimum of effort on the part of the operator. Being subject to wear, corrosion, and accumulation of dust, the equipment should be inspected prior to each storage season to determine maintenance requirements and to assure correct control adjustment.

The main components of the system are three temperature controllers; a cycle repeating timer; and, where moisture is applied, a humidity controller. Other integral components include relays, magnetic motor starters, transformers, damper motors, and switches. Schematic wiring diagrams of two commonly-used three-damper control system circuits are shown in figure 6. The three temperature controllers are the differential thermostat, proportioning or modulating thermostat, and minimum or low limit thermostat. Each performs a distinct and separate function.

Differential thermostats have two sensing elements that actuate a switch to open or close a circuit when there is a difference in temperature between the two elements. In potato storages the thermostat makes contact when the temperature of the outside sensing element is below that of the inside element and breaks contact when conditions are reversed. Most mechanical differential thermostats are designed to operate within a certain "instrument differential." Those used in potato storages have a 4° F. minimum differential, that is, the outside temperature must be at least 4° below the inside before the thermostat will make contact.

Proper adjustment and maintenance are essential for satisfactory performance.

The proportioning thermostat operates in conjunction with a proportioning damper motor to provide correct damper positioning for proper air mixing. It begins to function when the outside temperature falls below that desired in the storage. This thermostat should be set at 40° F. for table stock potatoes. A higher setting may be desired for potatoes for processing. A check for accurate adjustment can be made after the system is in operation by measuring the temperature of the air at the discharge of the main duct. If it is consistently higher or lower than the dial setting indicates, the dial should be adjusted to agree with the measured temperature. The proportioning thermostats and the damper motors form a single operating unit that has been calibrated to give accurate performance. Therefore, it is very important to select a proportioning thermostat that corresponds with the damper motor recommended by the manufacturer.

The minimum thermostat is employed as a safety device. It provides protection against possible chilling injury or freezing caused by faulty operation of the proportioning thermostat or failure in the damper system.

Humidity controllers (humidistats) are calibrated to respond to the presence of moisture vapor in the air. Mechanical humidistats are available in ranges from approximately 20 to 95 percent relative humidity. Humidifier operation is controlled to provide entering air of 85 to 90 percent relative humidity. Proper calibration and adjustment of these instruments is highly important for good humidifier performance.

The interval timer is essentially a clock with switching action that

WIRING DIAGRAM AND ALTERNATE OF A THREE DAMPER CONTROL SYSTEM

NOTE: RECOMMENDED GROUNDING OF METAL-CLAD MOTORS AND CONTROL SYSTEM COMPONENTS WAS OMITTED FROM THIS DIAGRAM FOR SIMPLIFICATION.

LEGEND

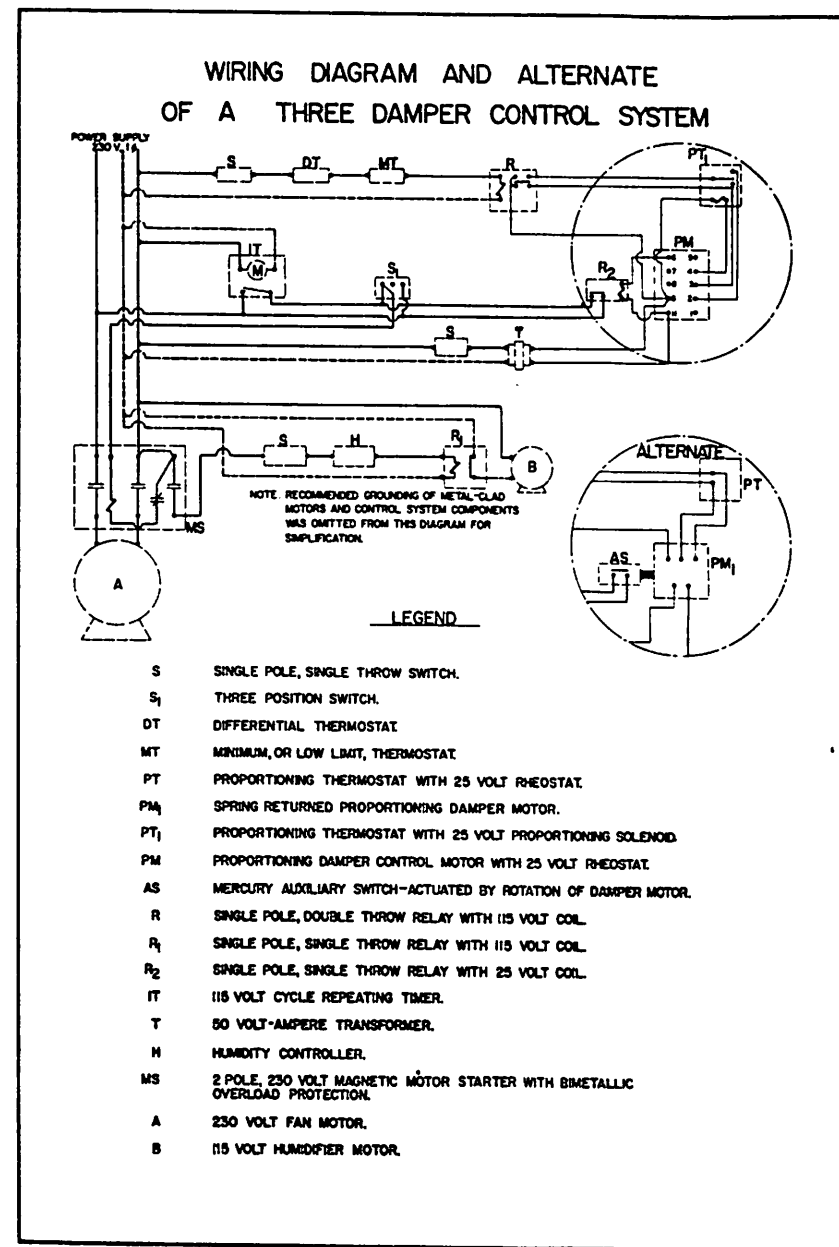|	
S	SINGLE POLE, SINGLE THROW SWITCH.
S_1	THREE POSITION SWITCH.
DT	DIFFERENTIAL THERMOSTAT.
MT	MINIMUM, OR LOW LIMIT, THERMOSTAT.
PT	PROPORTIONING THERMOSTAT WITH 25 VOLT RHEOSTAT.
PM_1	SPRING RETURNED PROPORTIONING DAMPER MOTOR.
PT_1	PROPORTIONING THERMOSTAT WITH 25 VOLT PROPORTIONING SOLENOID.
PM	PROPORTIONING DAMPER CONTROL MOTOR WITH 25 VOLT RHEOSTAT.
AS	MERCURY AUXILIARY SWITCH-ACTUATED BY ROTATION OF DAMPER MOTOR.
R	SINGLE POLE, DOUBLE THROW RELAY WITH 115 VOLT COIL.
R_1	SINGLE POLE, SINGLE THROW RELAY WITH 115 VOLT COIL.
R_2	SINGLE POLE, SINGLE THROW RELAY WITH 25 VOLT COIL.
IT	115 VOLT CYCLE REPEATING TIMER.
T	50 VOLT-AMPERE TRANSFORMER.
H	HUMIDITY CONTROLLER.
MS	2 POLE, 230 VOLT MAGNETIC MOTOR STARTER WITH BIMETALLIC OVERLOAD PROTECTION.
A	230 VOLT FAN MOTOR.
B	115 VOLT HUMIDIFIER MOTOR.

Figure 6

provides for periodic circulation of air when ventilation is not in progress. This circulation is necessary to eliminate hot spots in the pile because of lack of air movement.
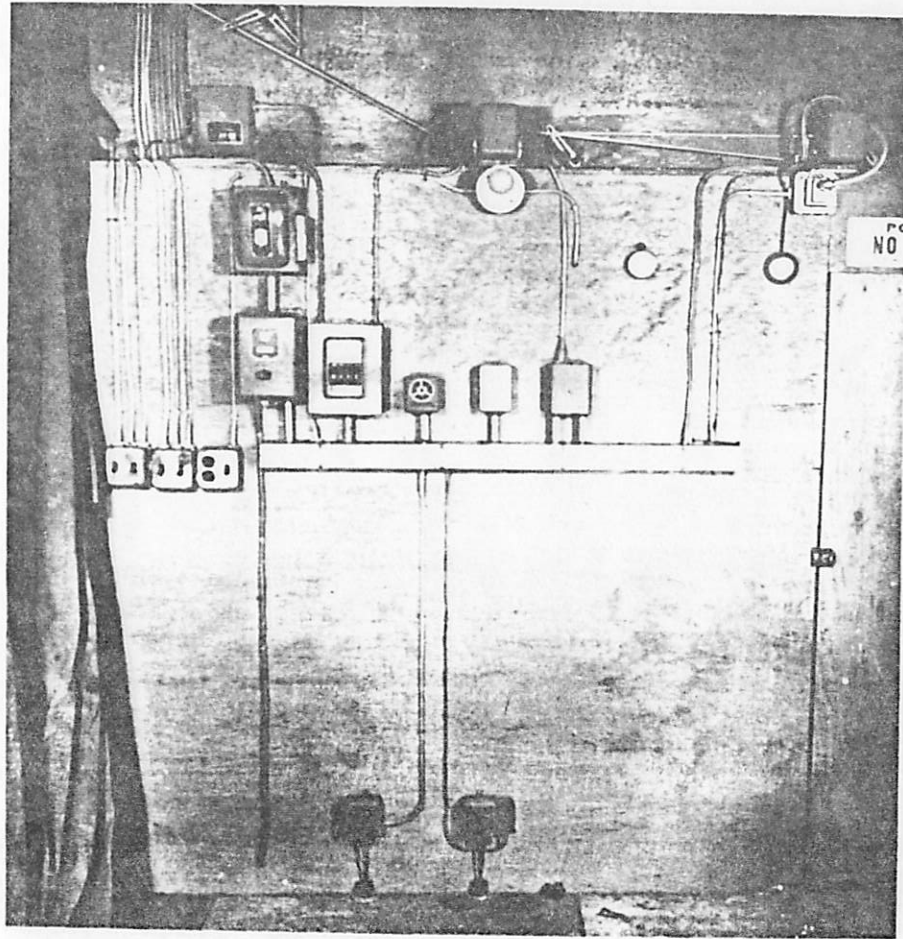
Relays are switching devices designed to take the line current load off of the operating equipment off the contact points of the controllers. Large quantities of current allowed to pass through the controls will damage the contact points.

Magnetic switches with thermal

overload protection automatically open and close the circuit directly from the disconnect switch to the motor. When the magnetic coil is energized by the control system the switch points make contact. The motor full-load current, which is particularly high at starting, then passes through the main contacts instead of through the smaller switching mechanism of the controls. Overload protection is provided by heater elements that cause the switch to open when excessive current is in the circuit. Size 1 magnetic switches, most common in potato storages, are for use with 2 and 3 horsepower, 230 volt motors.

A good rule to follow in selecting controls and component parts is to obtain all of the principal components from a single supplier. A control system consisting entirely of one make of equipment, particularly the principal parts, can be expected to perform better than a system made up of an assortment of controls and components. Detailed information concerning the individual models and types of 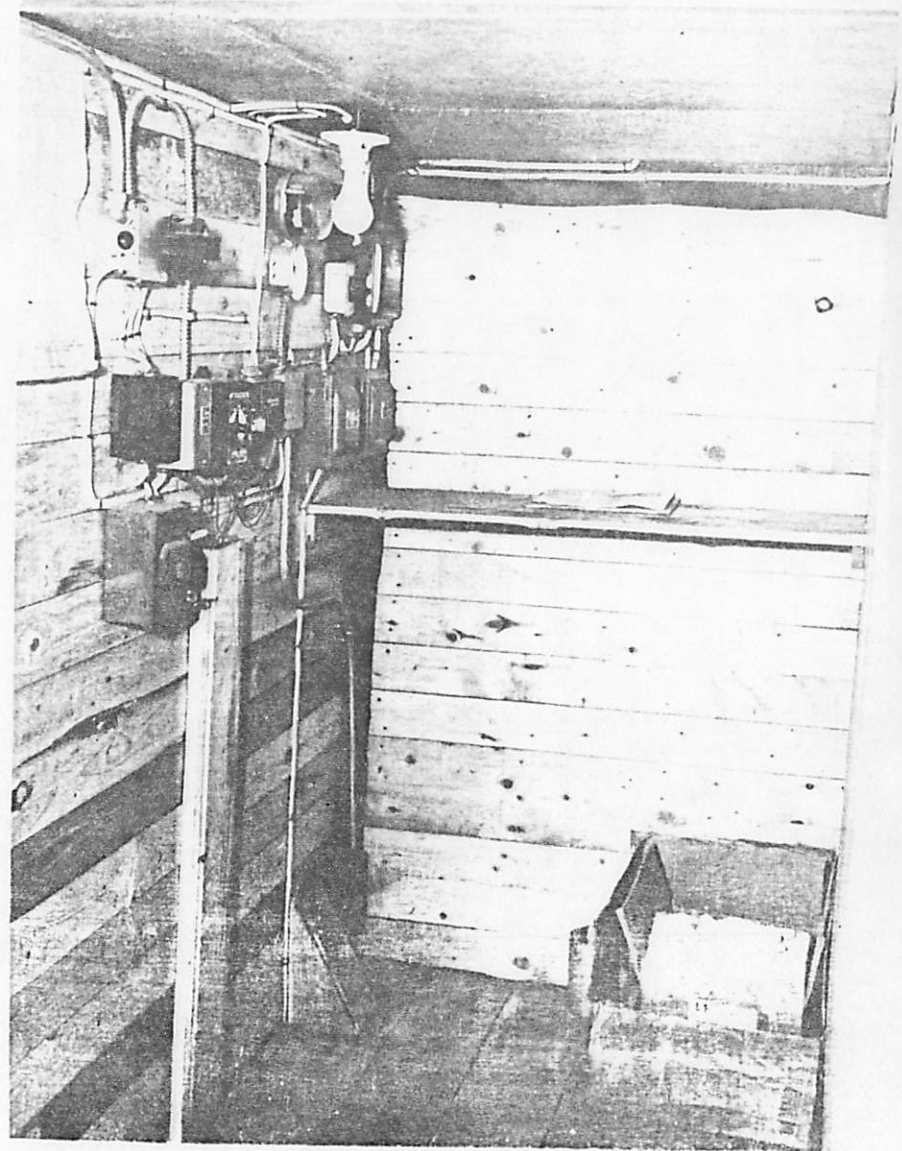controls, sizes and kinds of switch boxes, fuses, motor overload protectors, and others is not given in this report. This information can be obtained from State agricultural extension engineers or local suppliers.

For installation it is usually preferable to group all of the equipment on a single panel. Place the panel so it will be easily accessible for periodic inspection. It can be mounted as shown in figure 7. An inexpensive control room constructed beside the main duct will provide protection against corrosion and accumulation of dust on the contact points of controllers and switches (fig. 8).

BN–7287

Figure 7.—A well laid-out control panel for a ventilating system in a potato storage house.

BN–7288

Figure 8.—A properly protected control panel. A small inexpensive control room provides protection from dust, moisture and other elements.

Faulty operation of the differential thermostat sometimes results from radiant energy absorbed by the external sensing element from the sun and surroundings. Protection from radiation is accomplished by placing the element in a well ventilated wooden shelter, painted white, and attached to the side of the storage (fig. 9). The inside element should be just above the top of the pile.

By virtue of their construction, mechanical humidistats must be located at the point within the duct where moisture control is desired. If ceiling condensation becomes a problem, closer control may be possible by using two humidistats. In this case one should be placed in the distribution duct about 15 feet from the point of moisture introduction and the other located above the pile approximately 6 inches

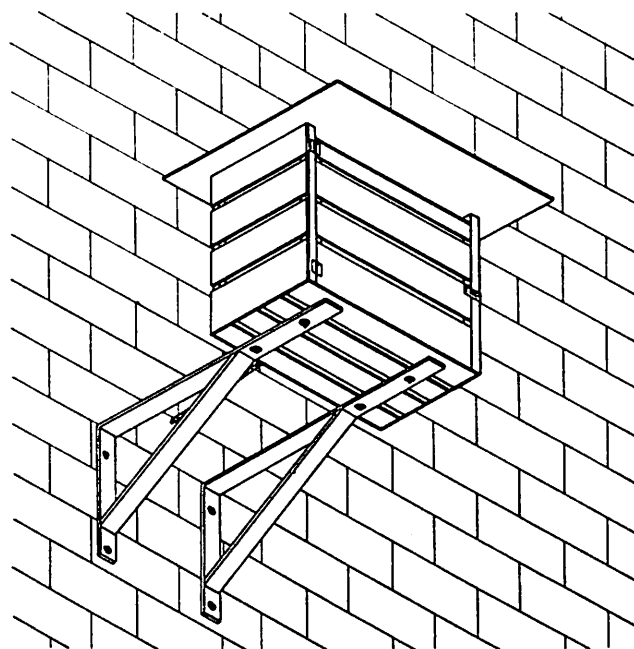**HOUSING FOR DIFFERENTIAL THERMOSTAT**

Figure 9.—Housing to shield outside differential thermostat from radiation.

from the ceiling. These are wired in series to prevent humidification unless both units make contact. The overhead controller should be set to control humidity at 95 percent. Where the single controller is used it should be placed in the distribution duct. Electronic humidistats also have been successfully used in potato storages. A remote sensing element permits installation of the unit on the control panel. The element should be placed within the duct. Electronic controllers are more costly than the mechanical type.

Humidifiers

The relative humidity of ventilating air is raised by increasing the amount of moisture vapor that is mixed with a given volume of air. To do this a humidifier that supplies easily vaporized water particles to the air stream is employed. Such equipment should be capable of maintaining the desired humidity of the intake air during a major portion of the operating time. Occasionally the atmospheric relative humidity is less than the optimum level selected for sizing humidifiers. Under such conditions the addition of moisture is significantly beneficial although it may not be adequate to raise the humidity of the incoming air to recommended level of 85 to 90 percent. A unit large enough to be 100 percent effective at all times would be inefficient and uneconomical.

The mixture of water vapor and volatilized water particles in the air chambers, immediately adjacent to the humidifier discharge outlet, must be dispersed by the action of air movement within the ducts. Therefore, the introduction of nonvaporized moisture into the air ducts, when ventilation is not in progress, is undesirable and not recommended.
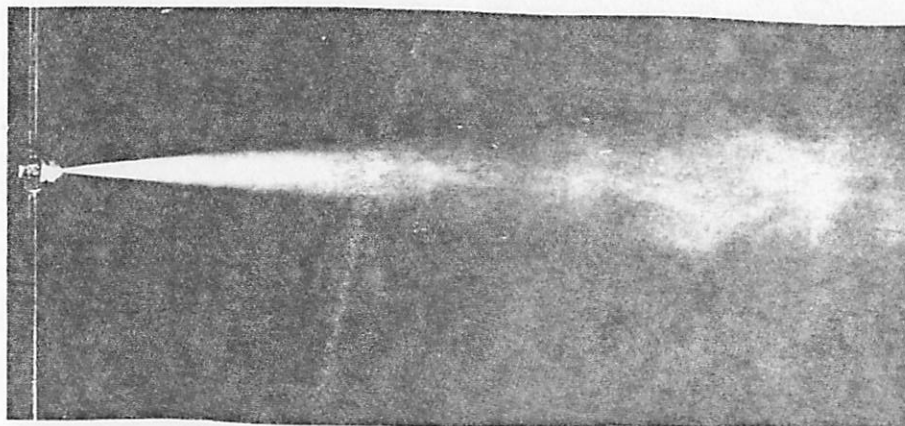
There are several types of humidifiers available that are satisfactory for use in potato storages. To attain the required result, greater emphasis is placed on the method of application rather than the type of equipment used. Two main requisites of any humidifier are: (1) Operation can be automatically controlled and (2) it will discharge a fine mist that is readily vaporized by the incoming air (fig. 10). Three commonly used techniques are: (1) Pneumatic spray jets, (2) centrifugal force combined with high speed fans, and (3) airflow through a wetted surface. Any of these, as illustrated in figures 10 and 11, are adaptable to potato storage usage.

Humidifier requirement is determined by the size of storage, temperature, and moisture content of the outdoor air used for ventilation. Design is based on the level of humidity expected to be most prevalent during early storage. Recommended capacities corresponding to selected storage sizes are listed in table 8.

Table 8.—Humidifier requirements to achieve 65 percent relative humidity in several different size potato storages when the air-flow rate is 0.8 c.f.m. per hundredweight and the design temperature is 55° F.
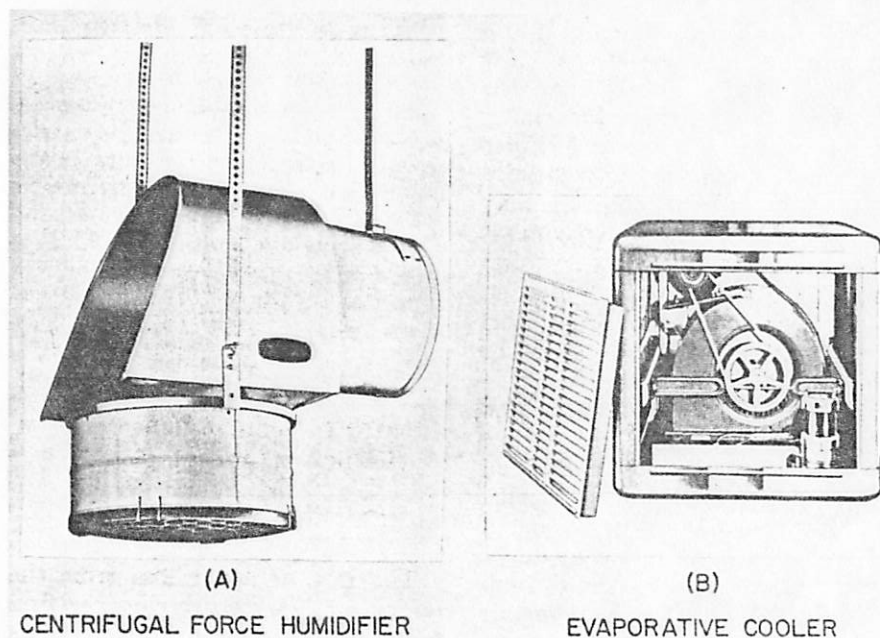
Size of storage		Volume of air delivered	Amount of water required per hour	Approximate hourly humidifier capacity
Cwt.	*Bushels*	*C.f.m.*	*Pounds*	*Gallons*
6,000	10,000	5,000	25	3
12,000	20,000	10,000	50	6
18,000	30,000	15,000	75	9
24,000	40,000	20,000	100	12
30,000	50,000	25,000	125	15

The rate of water loss from the potatoes is greatest during the first few weeks they are in storage. This is normally the time when ventilation is accomplished without pro-

BN-7289

Figure 10.—Spray pattern from a pneumatic jet. The mean diameter of water particles is 25 microns.

(A)

CENTRIFUGAL FORCE HUMIDIFIER

(B)

EVAPORATIVE COOLER

BN-7290

Figure 11.—Two types of humidifiers.

portioning and outside air only is used. For this period, the normal relative humidity recorded at the Suffolk County Air Force Base, Westhampton Beach, L. I., N. Y., is approximately 75 percent. Weather data taken at the Long Island Vegetable Research Farm, for the corresponding period, disclosed few hourly occurrences of relative humidities below 50 percent. To design on the basis of 50 percent relative humidity, however, does not appear practical. When considering all factors, an outdoor relative humidity of 65 percent is suggested as a basis for design. Early in the storage period, ventilating air frequently is brought into the storage at a temperature of 55° F. This is near the maximum anticipated and is suggested as a design temperature. Humidifier capacities calculated on this basis are adequate to satisfy the requirements for the entire storage period.

For a good humidifier installation: (1) Place the centrifugal humidifier, or pneumatic nozzles, on the exhaust side of the fan to discharge moisture into the air stream; (2) arrange the equipment so that it will not cause an appreciable increase in the resistance to airflow; (3) wire the humidifier to avoid operation unless the fan is running; and (4) install the wetted pads for humidification in the main duct or plenum in a manner that will provide enough pad surface area for adequate moisture absorption and to keep the resistance to airflow at a minimum. The velocity through the pads should not exceed 300 feet per minute.

Centrifugal humidifiers are designed to operate most efficiently when the pressures on both the intake and exhaust sides are in balance. This can be accomplished by installing the humidifier in a separate chamber inside the fan house and providing an opening for air to flow from the air plenum to the inside of the humidifier housing. By doing this, fan house pressures are avoided and the pressure across the humidifier is balanced.

Evaporative coolers capable of delivering up to 15,000 cubic feet per minute at free delivery (no resistance to airflow) are available. With this equipment one fan can be used to provide both ventilation and humidification. If this type of unit is selected, care must be exercised to obtain the size of fan which can deliver the required volume of airflow against the static pressures normally encountered during ventilation.

Construction

Structural Features

Modern materials and technological developments have had a strong influence on the design of up-to-date potato storage facilities. Potato warehousemen once found it necessary to construct their storages below ground, or surround them with an earth embankment, to avoid inside temperature fluctuations caused by atmospheric variations. Research has shown that the same protection, plus a considerable number of added advantages, can be gained by making use of newly developed construction techniques above ground. For example, above-ground potato storages allow increased handling efficiency, lessen the amount of heat load on the ventilation system, and are more adaptable to other uses.

Storage structures for potatoes can be divided roughly into three classes: (1) Masonry; (2) wood frame; and (3) prefabricated metal. The buildings should be sufficiently strong to withstand anticipated wind and snow loads as well as lateral pressures exerted on the walls by the potatoes. They should be sealed to prevent mois-

ture loss to the outside as well as infiltration of outside air, and they should be resistant to excessive heat flow through the walls and ceilings. The design should be made to facilitate use of handling equipment. Plans for two storages are given in the appendix. While these plans, as shown, can be used for building construction, they will not fit every situation. Modifications in size, duct layout, and construction materials can be made without altering the basic structural furdamentals.

Wall Construction

In masonry construction, reinforcing bars are placed both vertically and horizontally (indicated in plans) at specific points in the wall sections. The wall sections must be sufficiently strong to withstand lateral pressures of potatoes when filled and wind forces when empty. In frame construction, proper stud size and spacing is necessary for adequate strength. Ties and sway braces prevent damage to the structure by wind when empty, or when loaded unequally.

A vapor barrier is installed on the inside surface of the insulation to eliminate the danger of condensation on the insulating material. It also makes the building more air-tight and reduces the amount of air infiltrating into the storage.

Floor Construction

Some advantages of concrete over earth floors are: (1) Better work floor; (2) easier to use materials handling equipment; (3) subsurface air delivery ducts with masonry walls can be constructed as an integral part of the floor; (4) more adaptable to other usage; and (5) increases the total value of the building in excess of the additional cost. There are no advantages to earth floors other than lower cost of construction.

Concrete floors must be reinforced to avoid failure caused by a variety of different type loads such as heavy handling equipment, trucks, and the potato pile itself. Reinforcing also helps withstand temperature changes and reduces the possibility of cracking. Curing, the process of keeping the concrete damp and at a favorable temperature for a certain length of time, is another important phase of concrete floor construction. Proper and sufficiently long curing greatly improves both the strength and durability of the concrete. The most reliable method of curing is by covering the surface with sand, earth, straw, and other suitable material that is kept saturated with water for 7 days, or longer if possible.

To avoid separation of the air delivery ducts from the floor, or other failure, footings are placed under the duct sidewalls. When the floor slab is properly tied to the duct sidewalls the overall floor strength is increased.

Roof Design

A number of types of roof trusses permit unsupported roof spans exceeding 50 feet in width. Trussed rafters can be prefabricated on the ground and raised to position with block and tackle or other available equipment. In most cases wood construction is desirable. However, there are no restrictions on the use of metal trusses, providing consideration is given to the type of building. Again, adequate reinforcement is accomplished by the use of diagonal ties and braces at specific points along the roof. Care must be exercised in tying the roof trusses to both the side and end wall plates.

Insulation Requirements

The rate of heat flow through the walls and ceiling is controlled with thermal insulation. Any loose dry material that will not pack is essentially an insulator. The quality of insulation, evaluated by its thermal conductivity or resistivity, varies significantly, depending upon the thickness, density, and composition of the material. Most commercial products are rated in terms of conductivity or resistivity for each inch of thickness. Table 9 lists the values of a number of typical materials. The use of a material that will absorb moisture, cause a fire hazard, rot, or attract vermin should be avoided.

Thermal resistance is a measure of the resistance to heat flow through a material from one of its surfaces to the other. It is the reciprocal of thermal conductance. For example, a wall section consisting of 2 inches of rock wool or equivalent (resistivity = 3.70) and 1 inch of wood (resistivity = 1) would have a total resistance of 8.40 and a total conductance of

0.12. Expressing it another way, 8.4 hours would be required for 1 B.t.u. to flow through each square foot of wall section for each degree Fahrenheit temperature difference between inside and outside surfaces. Material added for siding and laminar air layers will increase the time required for this effect.

A minimum overall resistance value of 8 for the walls and 10 for the ceiling is recommended for the late summer crop area. In a sufficiently insulated, ventilated storage, regardless of size, there is little danger of freezing near the walls with normally anticipated outside temperatures.

The hourly rate of heat transfer, or leakage, through a wall or ceiling is determined by multiplying the number of square feet in the total surface area by the number of degrees F. difference in the temperature between the inside and

Table 9.—Density, conductivity (k), and resistivity (1/k) per inch of thickness of some commonly used insulating materials

Type of material and description	Density weight per cu. ft.	Conductivity	Resistivity
	Pounds	*(k)*	*(1/k)*
Blanket and bat insulation:			
Chemically treated wood fibers held between layers of strong paper	3. 62	0. 25	4. 00
Chemically treated hog hair between strong paper	5. 76	. 26	3. 85
Kapok between burlap or paper	1. 00	. 24	4. 17
Cotton insulating bat	. 875	. 24	4. 17
Mineral wool	4. 5	. 27	3. 7.
Insulating board, made from wood fibers	15. 90	. 33	3. 0.
Loose fill:			
Chemically treated wood fibers	4. 0	. 28	3. 57
Fibrous material made from dolemite and silica	1. 50	. 27	3. 70
Glass wool fibers	1. 50	. 27	3. 70
Fibrous material made from slag	9. 40	. 27	3. 70
Expanded vermiculite	7. 0	. 48	2. 08
Regranulated cork	8. 10	. 31	3. 22
Granular mineral wool	5. 74	. 30	3. 33
Rock wool	10. 0	. 27	3. 70
Slab insulation:			
Corkboard (1)	14. 0	. 34	2. 94
Corkboard (2)	5. 4	. 24	4. 17
Expanded polystyrene	2. 0	. 25	4. 00
Cellular glass	9. 0	. 40	2. 50

r

outside and dividing the product by the overall thermal resistance. In a storage 40 x 100 x 14 feet having a wall resistance of 8 and a ceiling resistance of 10, the rate of heat transfer from inside to outside when the atmospheric temperature is 0° F. and the storage temperature is 40° is 35,600 B.t.u. per hour. Assuming a wind velocity of 30 m.p.h., heat loss by infiltration is approximately 15,000 B.t.u. per hour. This represents a total heat loss of 50,600 B.t.u. per hour from the storage. Potatoes at 40° produce heat of respiration at the rate of approximately 60 B.t.u. per hour per ton.[4] If 19,200 cwt., or 960 tons, of potatoes are in this storage, respiratory heat is generated within the storage at a rate of 57,600 B.t.u. per hour. This is 7,000 B.t.u. per hour in excess of the maximum expected loss under conditions specified. Hence, with good air distribution and periodic recirculation of the storage atmosphere, no additional heat is required to prevent freezing under these conditions.

Methods of Installing Insulation

Concrete block or masonry construction is sometimes preferred. Eight- and 12-inch concrete blocks made with sand and gravel aggregate have a resistance of 1.00 and 1.28 respectively. To achieve the necessary total resistance through the entire wall at least 2 inches of good insulation must be added. While extra insulating effect is obtained by filling the cores with loose fill insulation, it is impossible to raise the thermal resistance of blocks sufficiently to eliminate the need for additional insulation. Therefore, it is probably more practical to secure sufficient rigid in-

sulation to the inside surface. A vapor barrier is then installed on the inside surface of the insulation. A coat of plaster or exterior grade plywood can be placed over this to protect the vapor barrier and the insulating material.

In frame construction insulating bats, slabs, or boards are easily installed by tacking them to the studs or outside sheathing. A vapor barrier is then placed over the insulation. If the assembly is constructed with a space between the vapor barrier and the inside sheathing, additional insulating effect is achieved.

In metal construction practically all of the thermal resistance is encountered in the insulation. Three inches of rock wool, or equivalent, is recommended.

Condensation of moisture on the ceiling sometimes becomes difficult to control. This is particularly true when ventilation continues during a period of consistently high outside relative humidity (above 95 percent) for several days or when the metabolic action of the potatoes is excessive. It is also more acute in storages maintaining a temperature higher than 40° F. or when there is a large difference between outside and inside temperature caused by extremely or abnormally cold weather. Bright metallic or other reflective ceiling materials are likely to accentuate the problem. A darker ceiling will absorb more of the heat radiated from the top of the pile, and is not as likely to cool the air coming in contact with it to the dew point. Light colored or highly reflective ceiling materials should be avoided. If condensation prevails, it very likely will be necessary to install additional insulation. However, a temporary expedient would be to ventilate to lower the humidity and absorb condensation.

[4] Green, W. P., Hukill, W. V., and Rose, D. H. Calorimetric Measurements of the Heat of Respiration of Fruits and Vegetables. U. S. Dept. Agr. Tech. Bul. 771, 22 pp. illus. 1941.

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Air Ducts

Ventilation ducts are usually divided into three parts: (1) Main, or plenum; (2) distribution; and (3) delivery ducts. The layout pattern is normally arranged to fit the particular storage design. However, the conventional layout is preferred because it facilitates the use of unloading equipment (fig. 12). In any event, uniformity of air distribution is the foremost criterion. The recommended spacing for delivery ducts is 10 feet on centers.

Duct size is determined primarily by the volume rate of air to be delivered at a specified velocity. Where belt conveyors are used for unloading a minimum width is necessary to accommodate the equipment in the duct. A 20-inch duct width is commonly used when 16-inch conveyors are employed. For larger conveyors, the duct width should be figured accordingly. Other handling methods such as fluming or mechanical scooping are not popular in the late summer

area and therefore are not presently considered in duct design.

The equal friction method for designing ducts provides for equal friction for each foot of duct length.[5] In this manner each section of the entire duct system has equal resistance to air flow, thereby enhancing uniform distribution. For good results, a maximum velocity of 1,000 feet per minute in 100-foot long delivery ducts is recommended. If delivery ducts for example, 50 feet in length, the maximum depth based on a velocity of 1,000 feet per minute would be 16 inches. This is not adequate to permit use of unloading equipment. In this case, it is more desirable to design for a velocity of 500 feet per minute and construct the delivery duct deep enough to permit use of unloading conveyor equipment.

[5] Heating Ventilating Air Conditioning Guide, American Society of Heating and Ventilating Engineers, New York, Vol. 31, 1953, Chapter 32.
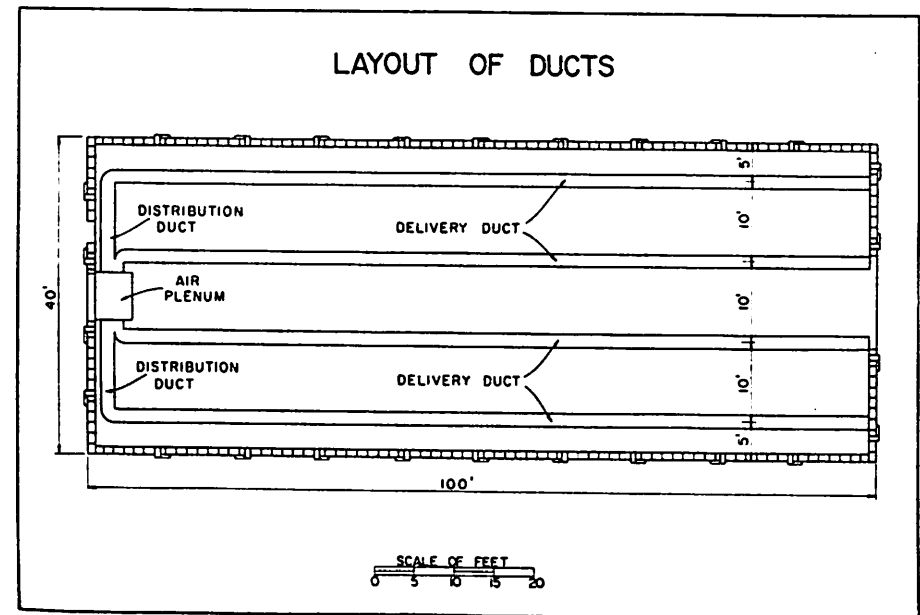

LAYOUT OF DUCTS

Figure 12

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most entirely on proper duct design. Poorly designed ducts decrease the efficiency of the ventilation system. It is advisable to call upon State agricultural extension engineers to assist with duct design problems. Table 10 lists required depths at various lengths for 20-inch wide sloping bottom delivery ducts.

Guide vanes and rounded dividers (fig. 13) reduce the amount of turbulence and increase uniformity of air distribution. They

... constructed either of concrete as an integral part, or made from other material and fastened into place.

Further uniformity of air distribution is gained by reducing the cross sectional area of the delivery ducts as the length increases. This can be done by sloping the bottom of the duct (fig. 14). To facilitate use of an unloader, a false bottom can be placed in the small end so a minimum depth of approximately 18 inches can be maintained.

Table 10.—Depths of 20-inch sloping bottom delivery ducts for various depths of piles of potatoes required to deliver 0.8 c.f.m. of air per cwt. of potatoes

Length of duct	Depth of delivery duct					
	For duct spacing of 8 feet when depth of pile is—			For duct spacing of 10 feet when depth of pile is—		
	8 feet	10 feet	12 feet	8 feet	10 feet	12 feet
Feet	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
0	3.0	3.0	3.5	3.0	3.5	3.5
15	5.5	6.0	7.0	6.0	7.5	8.0
30	8.0	9.0	11.0	9.0	11.5	12.5
45	10.5	12.5	14.5	12.5	15.0	17.0
60	13.5	15.5	18.0	15.5	19.0	21.0
75	16.0	18.5	21.5	18.5	22.5	25.5
90	19.0	22.0	25.0	22.0	26.5	29.5
105	21.5	25.0	28.5	25.0	30.0	34.0
120	24.0	28.0	32.0	28.0	34.0	38.0

Costs

Ownership and Operating Costs

The total initial investment for a modern potato storage facility includes construction cost for the structure and cost of equipment and controls necessary to operate the ventilation system. Construction cost is subject to considerable variation depending upon type of structure, cost of labor, building materials used, and location. While fan, motor, and humidifier prices vary with size of storage, total equipment prices for any given storage size are more or less constant throughout the eastern summer crop area. Following is a list of items, needed for a ventilation system of a 20,000-cwt. capacity potato storage house, and the approximate prices:

```
Fan—30" Wheel Diameter:
    Double inlet—double width_____
    Single inlet—single width_____ $1,000.00
Motor and Base:                                                      650.00
    2 hp_____
    3 hp_____   225.00
Humidifier—7.5 gal./hr_____   275.00
Differential thermostat_____   250.00
Minimum thermostat_____    70.00
Proportioning thermostat_____    35.00
Damper motor (Additional motor required for 4-damper system)___    35.00
Humidistat:                                                        95.00
    Low voltage_____
    Electronic _____    30.00
Relays _____       70.00
Manual switches:                                                  10.00
    Toggle_____
    Fused_____     3.00
Disconnect switch_____        7.50
Motor starter_____       10.00
Transformer_____       30.00
                                                              10.00
```

Total initial cost for a typical 20,000-cwt. capacity potato storage facility is estimated at $20,000, based on a cost of $1 per cwt. of capacity for construction of the facility, and cost of the equipment. The expected life is 20 years. Annual costs to own and operate this typical

DISTRIBUTION AND DELIVERY DUCTS

Tight 3" covering · Concrete floor · 3"x8"s with ½" spaces · Delivery duct · Divider · Distribution duct
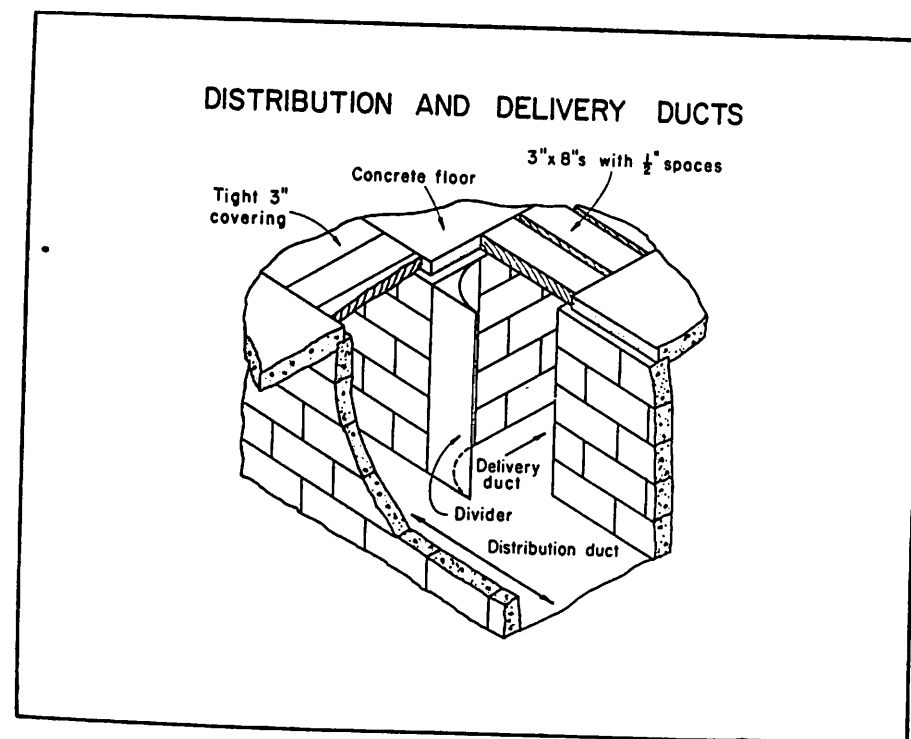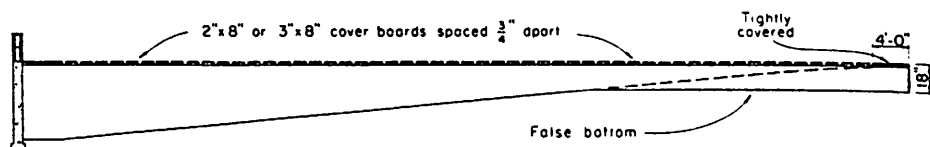
Figure 13

Figure 14.—Slope of air duct is constant to the point where a minimum depth of 18 inches is reached.

potato storage facility, including costs resulting from shrinkage during storage, are shown below:

Ownership costs:

Depreciation	$1,000.00
Interest, at 5 percent	500.00
Insurance and taxes, at 4 percent	400.00

Operation costs:

Power	100.00
Maintenance	300.00
Labor costs	200.00
Cost of shrinkage	1,500.00
Total costs	4,000.00
Cost per cwt.	0.20

Shrinkage losses figured at 5 percent by weight of the potatoes stored at a value of $1.50 per cwt. account for 37.5 percent of the total annual cost. Sound storage practices based on recommendations given in this report can reduce shrinkage and thereby result in a lower annual storage cost per hundredweight.

Comparison of Cost Against Prices Received

The price which growers receive for Long Island potatoes is usually good in July, declines in August, and ordinarily does not improve until January. The average prices they received during the years 1949 through 1957 are shown in table 11. During this period the increase in average prices from October to January was $0.42 per hundredweight. Based on price-cost relationships of this period, growers in the area who store their potatoes at harvest time and hold them for sale 4 months later could expect to increase their net returns by $0.22 per hundredweight or $4,400 yearly from a 20,000-hundredweight storage.

Table 11.—Average prices received per hundredweight of potatoes by Long Island growers, July through February, 1949 to 1957

Market season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
1949–50	2.10	1.75	1.75	1.60	1.50	1.50	1.65	1.85
1950–51	2.15	1.00	.90	.85	.90	1.15	1.35	1.35
1951–52	1.25	1.10	1.50	2.25	3.00	2.75	3.15	3.35
1952–53	4.35	4.60	3.15	3.15	3.50	2.90	2.75	2.35
1953–54	.85	1.00	1.00	1.00	1.00	.85	.85	.75
1954–55	1.85	1.90	1.60	1.15	2.00	2.00	2.25	2.25
1955–56	1.40	1.10	.65	.75	1.25	1.10	1.50	1.50
1956–57	4.75	2.05	1.60	1.30	1.75	1.75	1.90	2.00
Average for 8 seasons	2.34	1.81	1.52	1.51	1.86	1.75	1.93	1.93

Air Velocity Measurement in Large Rectangular Ducts

The velocity of air flowing through a duct can be measured several ways. Three common instruments acceptable for use in potato storages where extreme accuracy is not required are the deflecting vane anemometer, the revolving vane anemometer, and the pitot tube used in connection with an inclined manometer. Of these, either the deflecting vane anemometer or the revolving vane anemometer, although less accurate, is preferred because of simplicity.

The deflecting vane anemometer, referred to as "velometer" by a leading manufacturer, gives a direct velocity reading on the indicating scale. It is more expensive, but more accurate than the revolving vane anemometer. The revolving vane anemometer gives a dial reading of the linear feet of air passing in a measured length of time. It will give a fairly reliable measure of velocity if used with extreme caution.

In either case it is necessary to traverse the cross sectional area of the duct at the point of measurement. This is done by taking the reading in the center of equal areas. The number of spaces should not be less than 16 and need not be greater than 64. The centers of the equal areas should not be more than 6 inches apart when less than 64 areas are used. Suggested traverse points for a 30- by 36-inch duct area shown in figure 15. The indicated velocity is obtained by taking an average of the readings. For greatest accuracy, measurement should be made in the large section of the distribution duct as far from
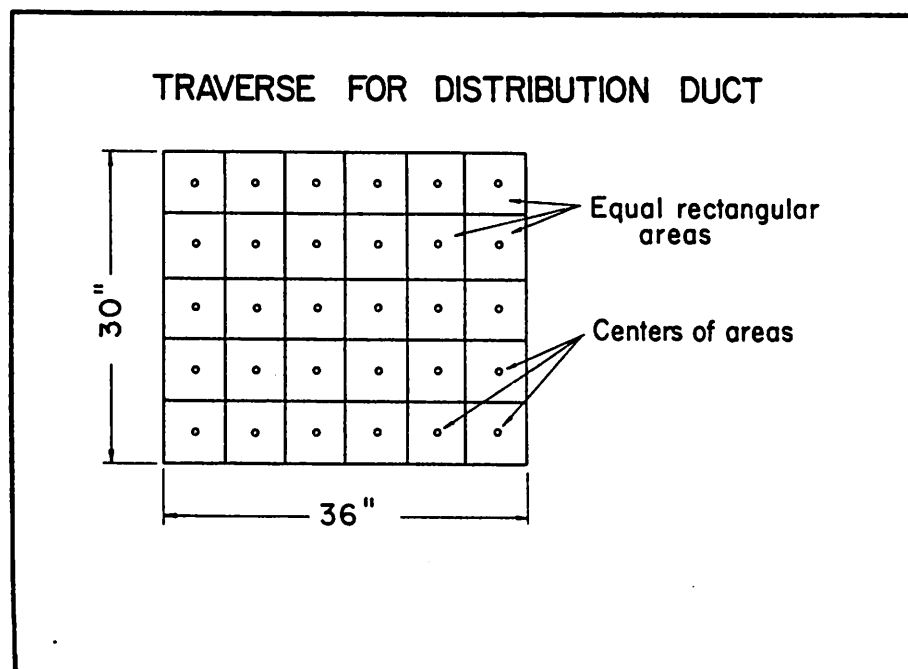

Figure 15

Basis for Design of Storages as Shown in Plans

The plans presented in figures 16 to 20 were developed primarily for storage of potatoes in the late summer and fall crop areas of the Northeast, but can be adapted for use in other areas where through cooling is practical.

Storages in the late summer crop area and the fall crop area of upstate New York generally range in size from 10,000- to 20,000-hundredweight capacity. This corresponds roughly to overall floor dimensions ranging from 30 to 50 feet in width and from 80 to 120 feet in length. The average capacity of permanent storage facilities located on Long Island is approximately 12,000 hundredweight. The plans given here are for storages falling within this size category and give construction of the most economical and efficient type of storage facility. Potato storage house operators requiring larger storages, particularly where the width exceeds 60 feet, may find it less expensive to use other types of roof trusses such as bowstring trussed rafters or steel trusses. Because uniform air distribution is of prime importance, selection of width should be made to provide optimum duct spacing rather than attempting to fit the ducts to a predetermined width.

The plans given here provide for housing the ventilating fan, humidifier, controls, and control components on the ground level for convenience and accessibility. Be- cause of the various acceptable techniques available to supply moisture to the intake air, methods of installation of humidifiers would differ depending upon the type of equipment used. For this reason humidifier installation was omitted from the plans. In most cases, however, the humidifying equipment should be located on the discharge side of the fan to prevent freezing.

Successful proportioning ventilation systems use three or four dampers. While with the three-damper system there is less load on the drive motor, it is felt that use of the extra damper in the intake duct of the four damper system, as a safety precaution, is justified.

Insulation requirements vary according to geographical area. For example, the minimum resistance values of 8 for the walls and 10 for the ceiling that can be used on Long Island do not apply for storages in colder areas. Local extension engineers should be consulted for advice and guidance on amount and types of insulation to install.

Availability of Plans

The plan drawings presented in figures 12, 16, 17, 18, 19, and 20 were developed and drawn by the Department of Agricultural Engineering, Cornell University. Additional wood frame and masonry block storage house designs have been developed for various size houses. Copies of these drawings and those present in the figures above are available upon request from the Department of Agricultural Engineering, Cornell University, Ithaca, N. Y.
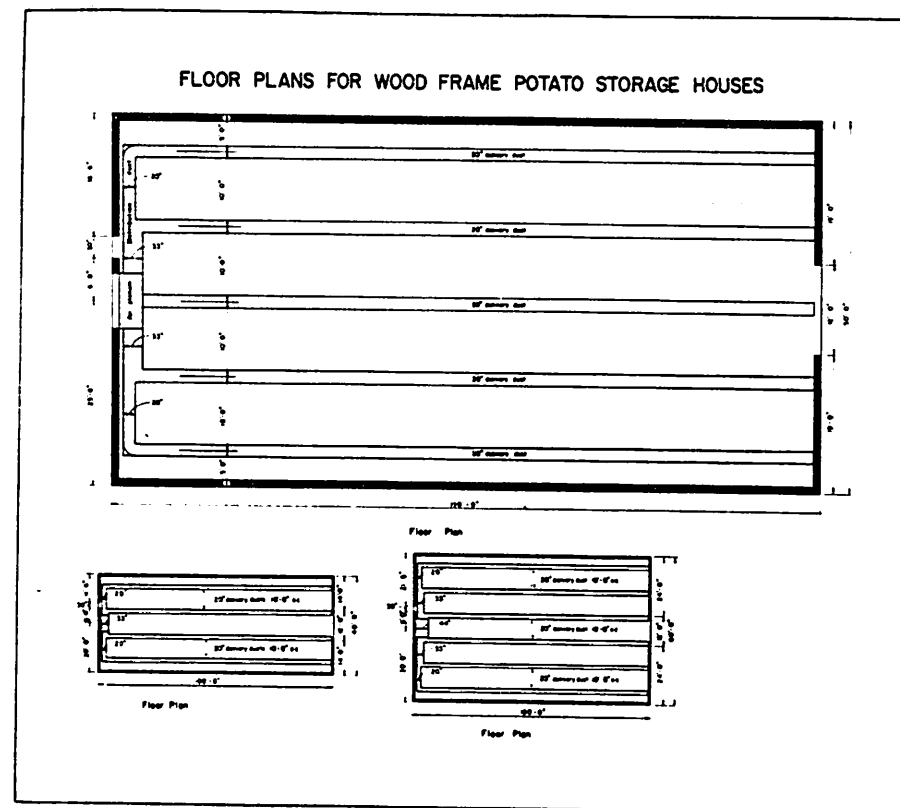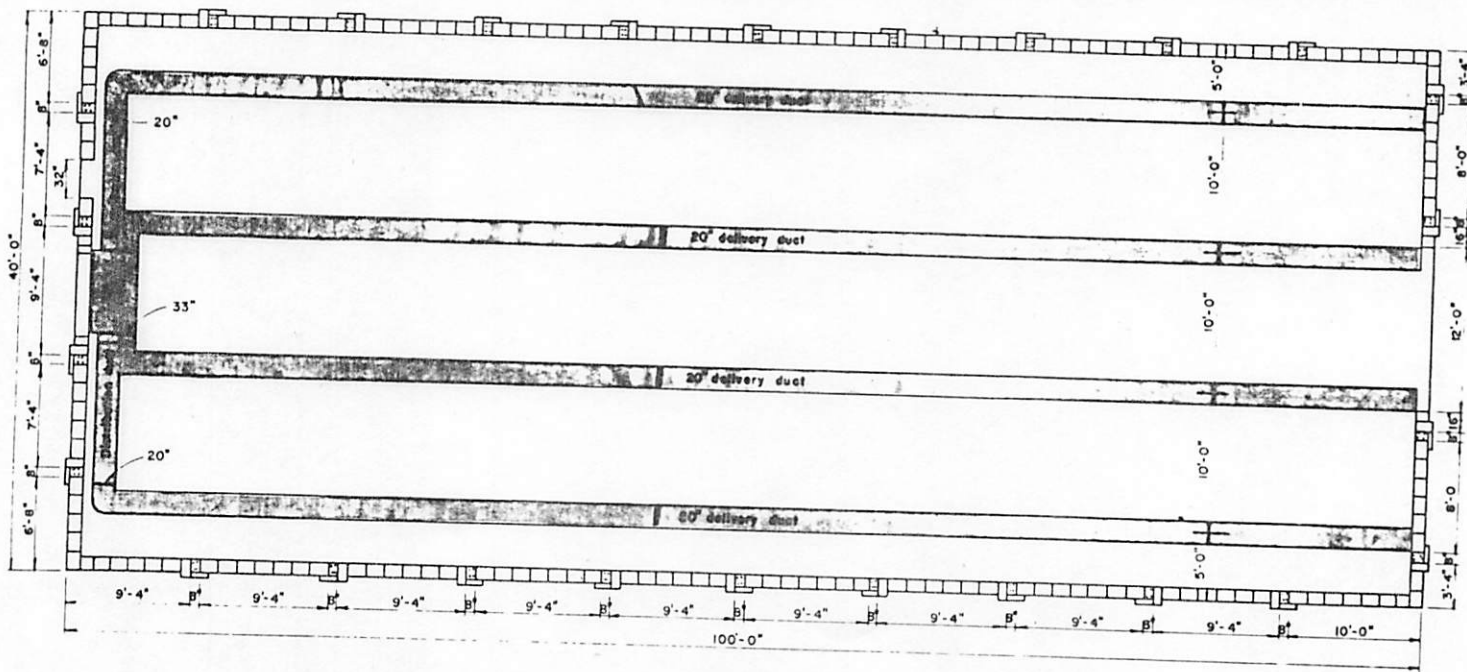

Figure 16

FLOOR PLAN FOR MASONRY BLOCK POTATO STORAGE HOUSE

Floor Plan

Figure 17

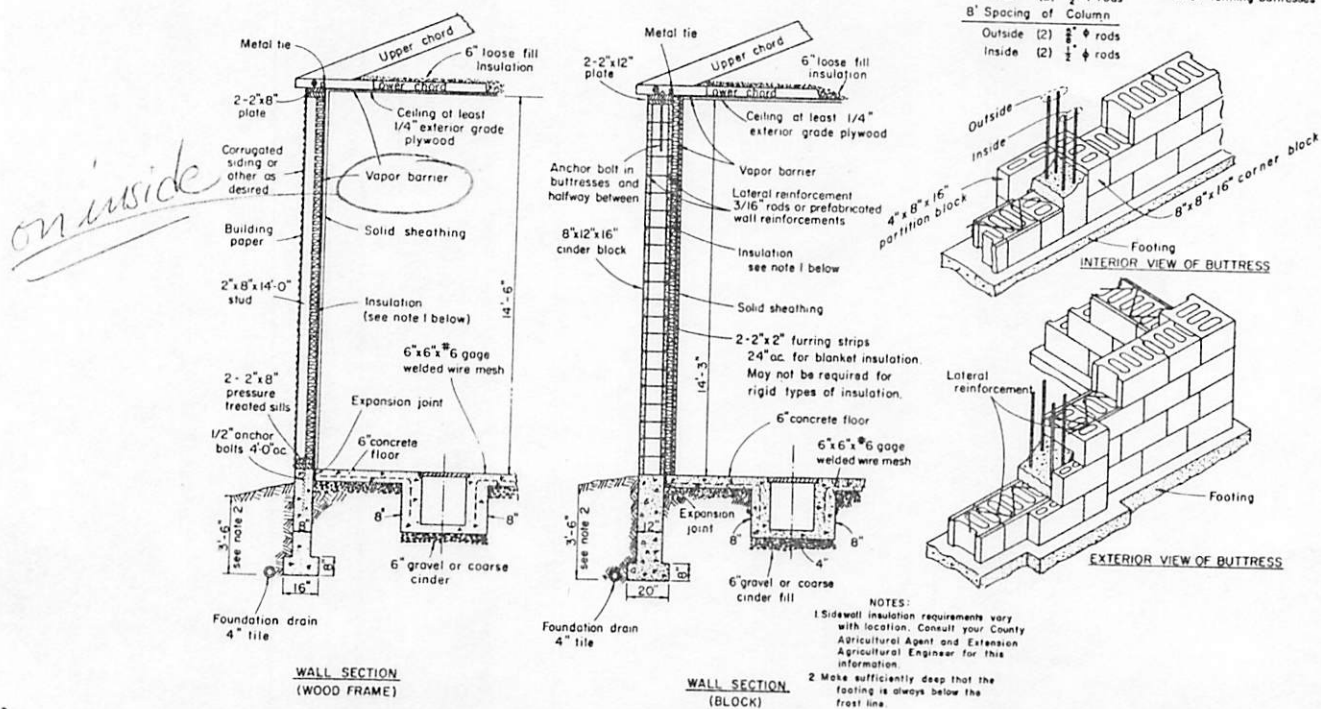## CONSTRUCTION DETAILS FOR WOOD AND MASONRY BLOCK POTATO STORAGE HOUSES

Figure 18
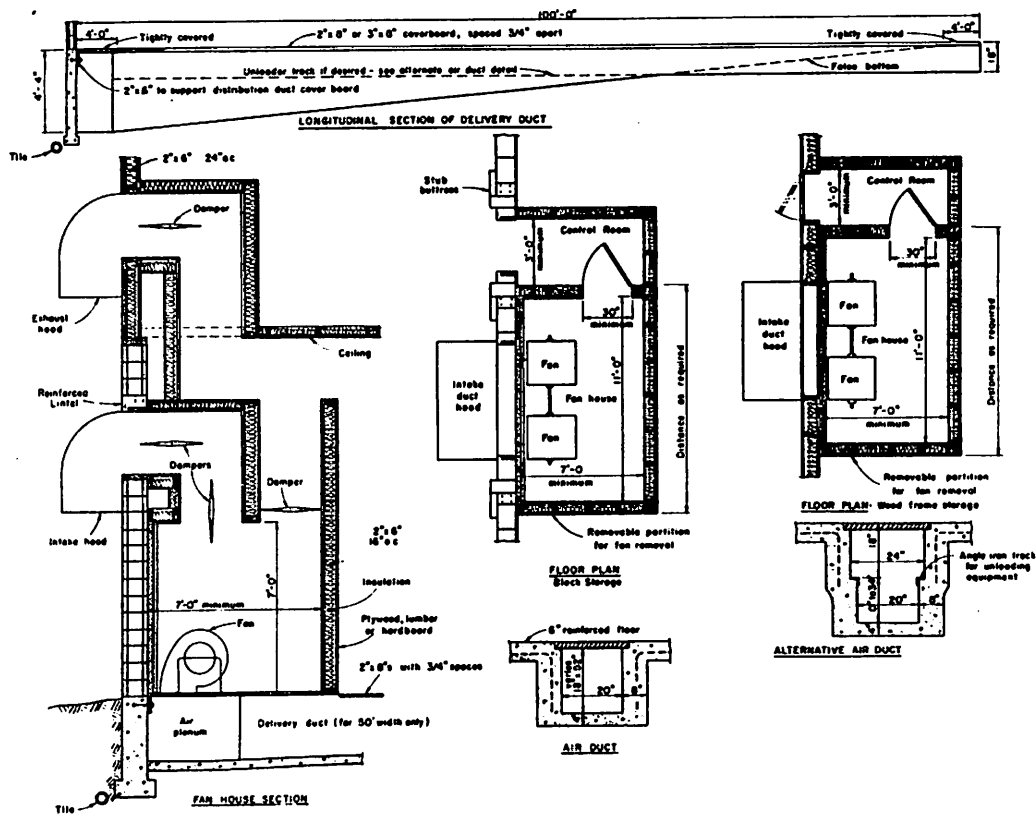
FAN HOUSING AND DAMPER DETAILS FOR POTATO STORAGE HOUSE
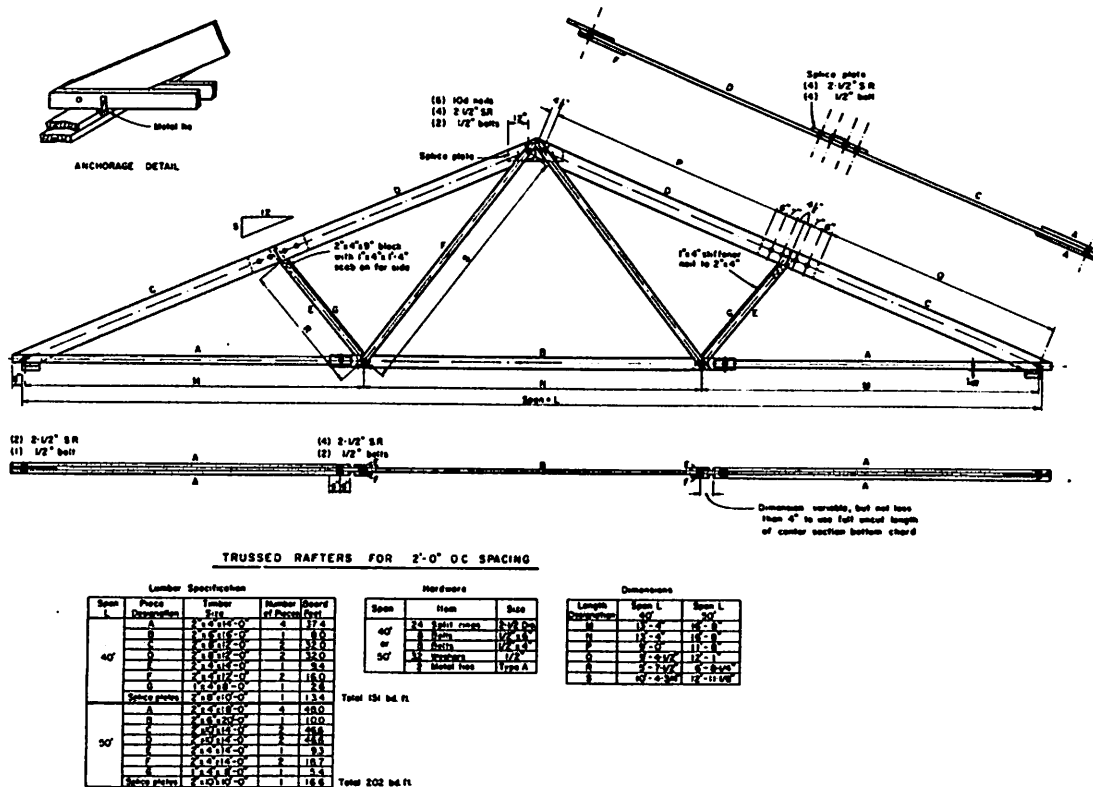
Figure 19

DETAILS OF WOOD TRUSSES FOR POTATO STORAGE HOUSES

Figure 20