Potato Storages for Michigan
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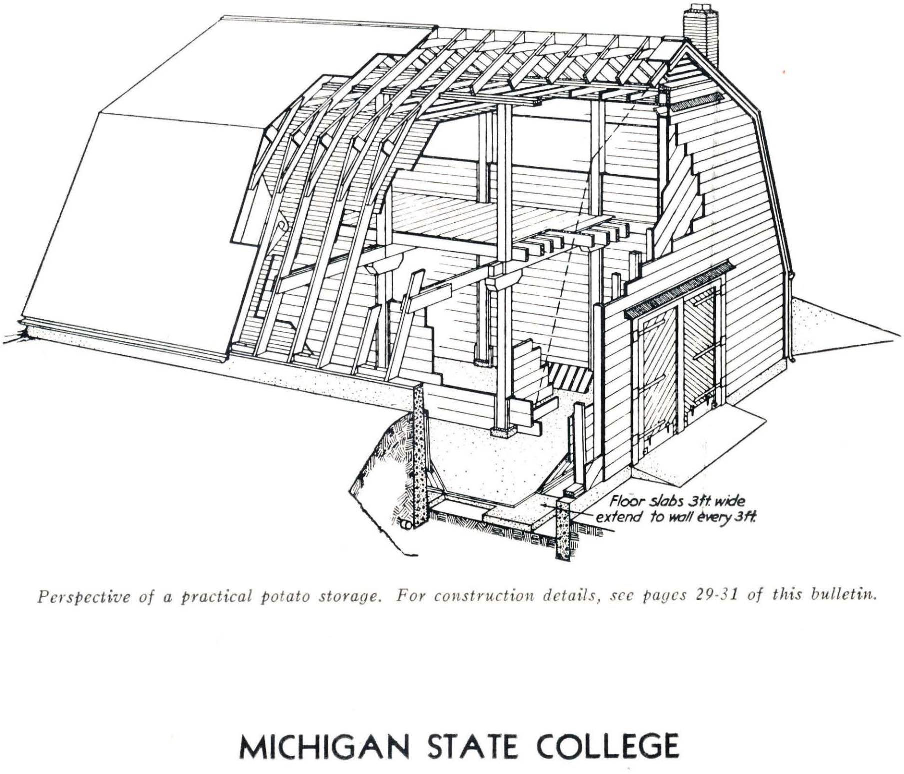
By Alfred D. Edgar, C. H. Jefferson and E. J. Wheeler



Perspective of a practical potato storage. For construction details, see pages 29-31 of this bulletin.

MICHIGAN STATE COLLEGE
AGRICULTURAL EXPERIMENT STATION
SECTION OF AGRICULTURAL ENGINEERING

EAST LANSING

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Potato Storages for Michigan*

BY: ALFRED D. EDGAR, AGRICULTURAL ENGINEER, BUREAU OF AGRICULTURAL CHEMISTRY AND ENGINEERING OF THE U. S. DEPARTMENT OF AGRICULTURE; C. H. JEFFERSON, ASSISTANT PROFESSOR, DEPARTMENT OF AGRICULTURAL ENGINEERING, MICHIGAN STATE COLLEGE; AND E. J. WHEELER, RESEARCH ASSISTANT, DEPARTMENT OF FARM CROPS OF MICHIGAN STATE COLLEGE.

NEED FOR ADEQUATE STORAGE

Michigan produces from 20,000,000 to 25,000,000 bushels of potatoes annually from about 250,000 acres. Potatoes are grown in every county in Michigan, varying from approximately 9,000 bushels in Keweenaw county to 2,750,000 bushels in Montcalm county. The average potato grower harvests annually 500 to 1,000 bushels from 3 to 5 acres, but some growers harvest and store from 30,000 to 40,000 bushels each year.

Present practice is to harvest the potatoes in late September in the northern counties and in early October in the southern counties. About one-third of the crop is sold to truckers at harvest time; one-third is stored in nearby commercial or cooperative warehouses and one-third is stored on farms. Potatoes stored on farms are marketed throughout the storage season, starting soon after harvest and continuing until March or April.

Growers often prefer storing potatoes on the farm because they can use their own judgment as to methods of handling, storing, and marketing. Because of improved roads and transportation, the farm is no longer isolated during the winter and a grower can meet market demands. In many instances, truckers buy direct from the farm, thus relieving the grower of the responsibility of transportation.

There is need for improved warehouses and more adequate farm storage facilities in Michigan to supplement present cooperative and commercial warehouses and farm storages.

Present cooperative and commercial warehouses provide storage for small lots of potatoes from many farms in one large building under one trained manager. This arrangement makes possible carlot shipments at any time and has been of definite advantage to the small grower. Disadvantages of the warehouse storage system are that it requires extra transportation and handling during the harvest season with an attendant increase in serious damage to potatoes.

Farm pit storage is on the decline, since winter shipment from such pits is often unsafe and frequently incurs large losses owing to unfavorable storage seasons or faulty pit construction. Storage in dwell-

*Appreciation is expressed for the cooperation and assistance in carrying forward this investigation to A. M. Berridge of the Lake City Experimental Potato Farm; to S. J. Dennis of the United States Bureau of Agricultural Chemistry and Engineering; and to the many warehousemen in whose storages the data were obtained.

ing basements may be satisfactory for small lots for short periods, but heavy losses occur, owing to the difficulty of handling potatoes to and from the basement and the high temperature and low humidity of basements. Storage in barn basements can be satisfactory where the storage space is properly insulated and ventilated, as has been done at the Experimental Potato Farm at Lake City. Many farms, however, do not have satisfactory and adequate space of this kind. Special storage buildings on the farm are increasing because they can be made to meet the requirements better than any other type. The disadvantage of such storage is that the smaller sizes are relatively high in cost per unit of space.

PURPOSE OF BULLETIN

The purpose of this bulletin is: (1) to discuss the various factors that cause losses of potatoes in storage; (2) to present plans for new storage buildings; (3) to make suggestions for remodeling old storages to meet requirements of Michigan potato growers; and (4) to propose improvements in storage house control and management.

COOPERATION

Information in this bulletin was obtained and is presented through the cooperation of the Bureaus of Agricultural Chemistry and Engineering and Plant Industry of the United States Department of Agriculture and the Sections of Agricultural Engineering and Farm Crops of the Michigan Agricultural Experiment Station. Managers of co-operative warehouses and owners of several farm storages gave assistance in carrying on the investigations.

WHAT WAS DONE

Visits were made to many cooperative or commercial warehouses and to farm storages to determine the general character of present storages, the amount of potato shrinkage during storage, and, if possible, what part of the loss in marketable potatoes is due to mechanical injury. During the storage seasons 1937-39, detailed observations were made in two storages to determine: (1) the shrinkage during storage under common and under improved storage conditions, and (2) the loss due to mechanical injury under common and improved handling methods.

STORAGE COMPARISON

In Fig. 1, warehouse A is a common type of cooperative or commercial warehouse which has mechanical equipment for the rapid handling of small lots of potatoes from many growers. The ceiling and walls of the first floor space are poorly insulated, but potato freezing is prevented by artificial heat and by the wide aisle between the outside wall and the bins. Remodeled barn storage B (in Fig. 1) has

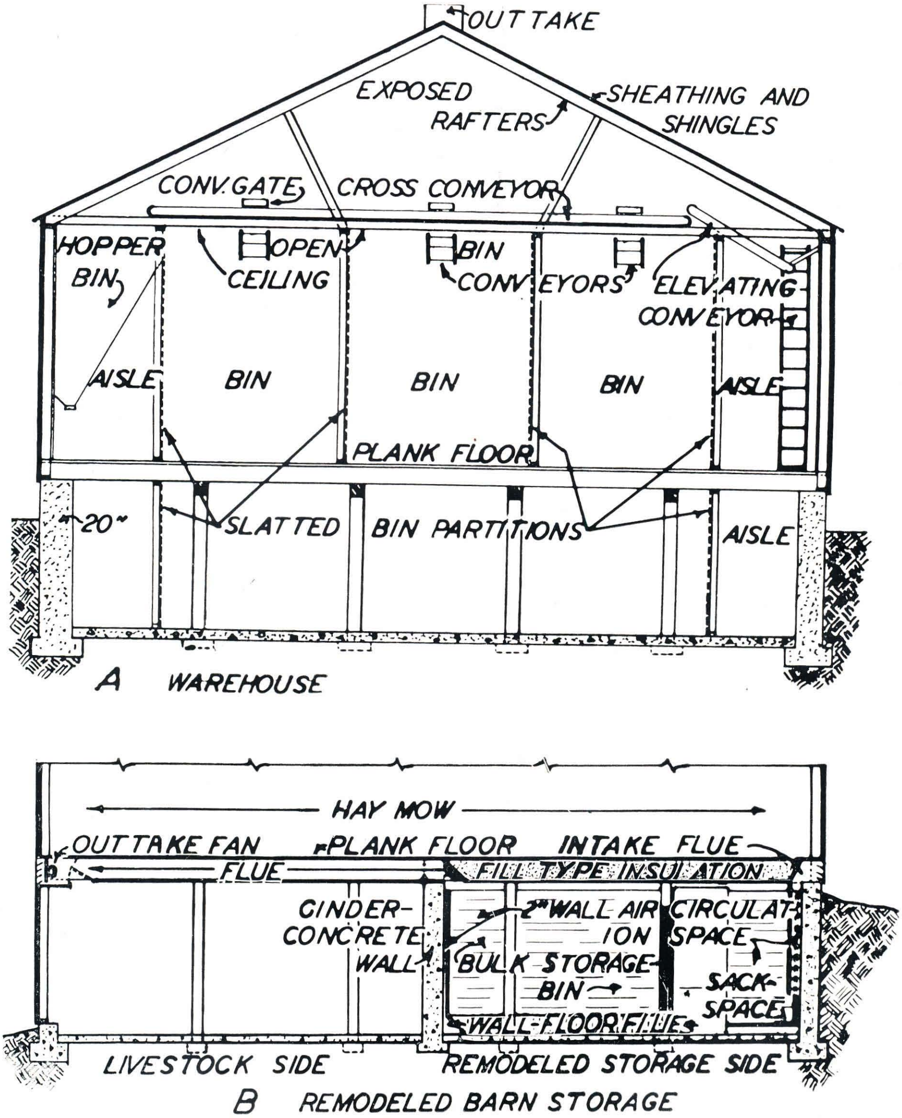


Fig. 1. Storages used in experimental work during 1937-39. Warehouse A—a cooperative trackside storage, designed for rapid mechanical handling; B—remodeled barn storage at Lake City Experimental Potato Farm. The latter provided satisfactory storage space in barn basement.

no mechanical handling equipment but is well insulated and has economical and practical provisions for ventilation and air circulation. Records were kept of potato weights into and from storage and the temperature and humidity during the 20 weeks of the storage period. These data have been tabulated in Table 1.

Table 1. Comparison of Storage Conditions and Shrinkage in Two Storages.

Storage	First 2 Weeks		20-Week Period		Shrinkage Losses* Per cent
	Temp. F.	Rel. Hum.	Temp. F.	Rel. Hum.	
A	44°	85	41°	79	7.0
B	54°	81	44°	86	5.5

*Select quality potatoes stored field-run in picking boxes.

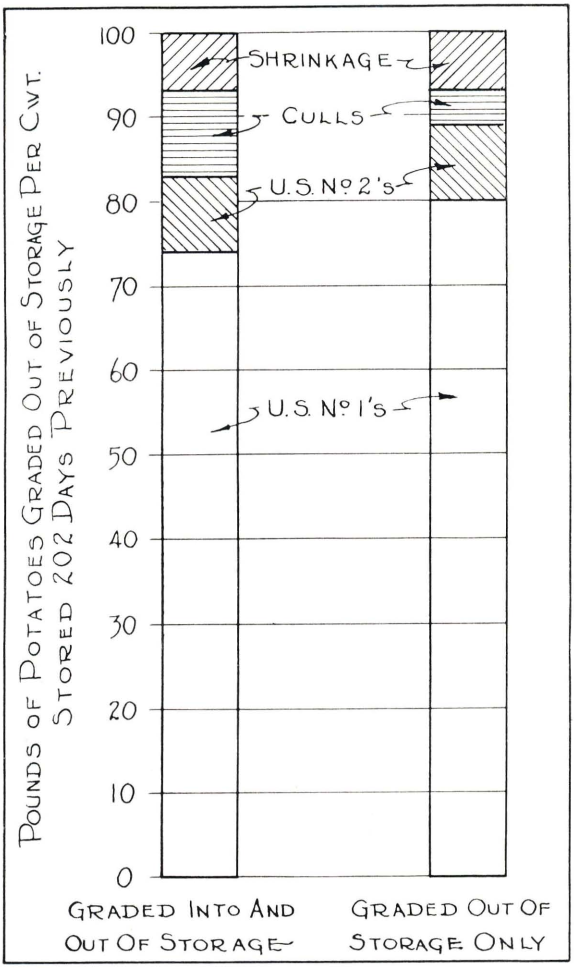


Fig. 2. Proportion of marketable potatoes as affected by number of gradings.

The result obtained in the two storages is indicated by the potato shrinkage. The lower shrinkage rate in house B as compared with that in A may be due to the higher temperature during the first two weeks and higher relative humidity for the whole period in B. The higher temperature during the first two weeks in B was obtained by restricting ventilation while storage A was ventilated continuously. The higher temperature and humidity for the whole period in B was due to less ventilation and better insulation.

Owing to relatively poor construction, house A was frequently heated to maintain an average temperature of 41° F., and condensation on the poorly insulated ceiling helped reduce the humidity to 79 per cent. In house B which had better insulation, no heat was needed but considerable ventilation maintained the humidity at 86 per cent, and moisture seldom formed on the ceiling.

MECHANICAL INJURY COMPARISON

A test was made to determine the loss caused by grading. Three varieties, a lot each of the Russet Rurals, Katahdins, and Chippewas, were harvested and stored field-run, in picking boxes at the Lake City Experimental Potato Farm. When these potatoes had been in storage 36 days, one-half of each lot was graded and returned to the boxes. The remaining half of each lot was not disturbed. At the end of the storage period each lot was graded, which means that one-half of each lot was graded twice (Fig. 2). There was 6 per cent more No. 1 potatoes for sale at the end of the storage season from the lots of potatoes graded only once than from those graded twice.

Further observations upon the amount of mechanical injury were

Fig. 3. Results of various handling methods upon potato injury. Lots may be identified by indicated injury percentages: 3 per cent, picked and stored field-run in picking box—one handling; 15 per cent, graded as picked into crates and stored in bulk—two handlings; 20 per cent, picked into baskets, dumped into crates, graded and stored in bulk—four handlings; 35 per cent, handled as 20 per cent lot, but in addition, graded from storage, shipped to market and delivered to retail store—six to eight handlings. Note that the amount of injury increases with the number of handlings.

made upon potatoes handled and stored according to common methods and those picked and stored field-run in picking boxes. For this purpose one box of potatoes from house B was used for comparison with other lots handled by three methods in common use. These four lots are shown in Fig. 3 and may be identified by the percentage of mechanical injury.

TEMPERATURE, HUMIDITY, AND OTHER STORAGE REQUIREMENTS

A potato in storage is a living, breathing plant tissue. As it breathes, carbon dioxide, moisture, and heat are given off. Little attention need be given to the carbon dioxide, because storage construction is seldom so tight that this gas accumulates in quantities, where it would either be beneficial in retarding respiration and sprouting, or where greater concentration would be detrimental in promoting blackheart. Evaporation of moisture from potatoes reduces the quantity of potatoes for sale. This factor requires attention in designing storages so that moisture which condenses on the cold walls and ceiling will do no harm to the building or potatoes.

Under storage conditions which prevailed during the experimental work, storages cooled from an average of 52° to 44° F. and the relative humidity rose from an average of 78 to 83 per cent during the first month of storage. During January the storage temperature averaged 40° F. and the relative humidity averaged 90 per cent. From those conditions the following heat and moisture calculations were made:

From 400 bushels of potatoes stored at 52° and cooled to 44° F., during the first month of storage more than a barrel of water will be given off by evaporation, and during January, when the temperature is about 40° F., about one-fifth as much water will be given off. The heat of respiration of those 400 bushels of potatoes during the first month of storage, will be equivalent to that available when 100 pounds of coal are burned, in the average storage stove, which is about 50 per cent efficient. The heat of respiration, during January, may be from one-half to one-fifth as much as during the first month of storage.* Thus the heat of respiration of potatoes is readily available in the fall when its disposal is a problem and is least available in January when it could be used to advantage.

In addition to the heat of respiration, potatoes contain a large amount of field heat when stored, which must be removed in lowering their temperature. To absorb the field heat of 400 bushels of potatoes while their temperature is lowered from 52° to 44° F., during the first month of storage, more than 1,000 pounds of ice would have to be melted. The removal of both heat of respiration and field heat is commonly obtained by ventilation and conduction through the storage

*Rose, Dean H., Wright, R. C., Whiteman, T. M., 1941. THE COMMERCIAL STORAGE OF FRUITS, VEGETABLES, AND FLORISTS' STOCKS. U.S.D.A. Agr. Cir. 278, 52 pp. and Smith, Ora, 1933. STUDIES OF POTATO STORAGE. N.Y. (Cornell) Agr. Expt. Sta. Bul. 553, 65 pp. illus.

walls and ceiling. Additional heat which must be removed comes from the earth through the storage floor and walls, or from the outside air through the walls and the ceiling during warm weather.

The principal potato storage requirements are for control of temperature and humidity within a narrow range for a period often as long as eight months, during which time there is a wide range of outside temperature and humidity. In addition, the storage should protect the potatoes from (1) moisture, (2) sun or artificial light, and (3) mechanical injury.

TEMPERATURE REQUIREMENT

In discussing storage temperatures, the whole storage period should be divided into three parts, (1) the curing period; (2) the holding period; and (3) the warming-up period. Each part is discussed separately in the following paragraphs.

CURING PERIOD—Stored potatoes are subject to infection from adjoining potatoes. There is less infection through unbroken skin than through freshly bruised or injured potato skin. If potatoes are held for two weeks at 60° F. temperature and 90 per cent relative humidity, the injured areas of the potatoes heal over by the formation of a corky layer which reduces danger of infection. Potatoes cure more slowly under lower temperatures and humidities, which permit the spread of infection.

A curing-period temperature of 60° F. is usually easy to maintain by restricting the ventilation, but when several weeks are required to fill large storages it is better not to cure all of the potatoes because the first potatoes stored should not be held too long at 60° F.

HOLDING PERIOD—In general, storage temperatures of 50° F. or higher result in high quality of table stock, but potatoes can be stored for only 12 or 14 weeks at this temperature without excessive shrinkage and early sprouting. Prolonged storage at temperatures below 40° F. increases the sugar content, makes the potatoes soggy for table stock, but does retard sprouting. A temperature of approximately 40° F., however, has been found to be a most desirable compromise for long storage periods because at this temperature the shrinkage is very small, the cooking quality is fair, sprouting is retarded, and the potato will germinate satisfactorily when planted in warm soil. While the quality of potatoes decreases rapidly at temperatures below 40° F., the tubers do not freeze until 28° F. is reached. Freezing may cause large losses because every frosted potato in bulk storage may cause discoloration or rot of a peck to 10 bushels of adjoining potatoes.

Lowering of the potato temperature from 60° to 50° F., following curing is usually brought about without much attention, but lowering from 60° to 40° F. within six to eight weeks after curing requires much attention to ventilation because the outside temperature may average above 40° F. for most of this period. Artificial heat may be required to maintain a temperature of 40° F. in the coldest part of the winter.

WARMING PERIOD—During the last two weeks of storage, it is desirable to raise the potato storage temperature to about 50° F. to reduce injury during grading.

The warming of a bin from 40° to 50° F. during the last two weeks of storage is often a problem because adjoining bins may be intended for continuous storage at 40° F. Heating may be done by forcing warm air into floor flues or by using fans during grading to force warm air over the top of the inclined pile of potatoes as they roll down in the open bin.

HUMIDITY REQUIREMENT

High humidity in potato storages is desirable to reduce shrinkage. High humidity tends however to cause ceiling condensation and subsequent dripping of water on the potatoes, which is undesirable. A relative humidity of 85 per cent is recommended. This relative humidity is high enough to retard shrinkage and low enough, under average atmospheric conditions, to prevent formation of free moisture on the surface of the potatoes. Even at this relative humidity it may be difficult to prevent condensation of moisture upon the walls and ceiling. It has been customary to remove this condensation by ventilation.

The disadvantages of using ventilation for cooling are that the ventilating air also removes moisture from the storage, and that the removal of this moisture lowers the storage humidity. Some moisture is also removed from the storage air by condensation upon the cold walls and ceiling surfaces. The moisture condensed on walls may be drained away without harming potatoes. Condensation and evaporation are becoming increasingly recognized as factors of humidity regulation since these go on without attention of the storage operator.

OTHER STORAGE FACTORS

DISEASE—The late blight epidemic of the past few years has become a serious problem in potato storage. The blight organism is active when the potatoes are wet and the storage temperature is above 40° F. Under those conditions a wet rot develops and juice from the infected tubers spreads to uninfected tubers, carrying the blight organism with it. In this manner an entire bin of potatoes may be lost from blight rot.

Experience has demonstrated that a cool, well-ventilated storage will minimize the loss from late blight rot. Proper ventilation retards the spread of the disease by rapidly drying the potatoes and the low temperature keeps the blight organism in a dormant condition. The prolonged ventilation desirable for controlling late blight will result in higher shrinkage losses which would not be a factor in storing sound potatoes. Other soft rot organisms are also controlled by keeping the potatoes dry and cool. The potatoes shown in Fig. 7 are in excellent condition for storage because they are clean, dry and free from disease.

VARIETY OF POTATOES—Some potatoes have tougher skins than others, and are less subject to injury than thin-skinned varieties.

Others are more subject to bruising because of their tendency to form knobs. Variety also influences the rest and dormant period. For example, the dormant period for Russet Rural is longer than that for the Chippewa.

Some varieties seem to be more subject to freezing injury. In one storage where the temperature fell below freezing several times during the storage season, most of the tubers of the Chippewa variety showed frost injury, 20 per cent of the Katahdins were affected, and none of the Russet Rurals was affected.

STATE OF MATURITY—Mature potatoes are less subject to injury and will keep better than those not fully ripe, although they may start sprouting from one to eight weeks earlier than immature potatoes stored under the same conditions.*

STORAGE PERIOD—It is obvious that the longer the storage period, the greater the shrinkage loss, but potatoes may be kept in good condition under a storage temperature of 40° F. and relative humidity of 85 per cent for at least 180 days without sprouting or undue shrinkage.

STORAGE HOUSE DESIGN AND MANAGEMENT

TEMPERATURE AND HUMIDITY

Regulation of storage temperature without regard to its effect upon humidity is often carried out in storages. But these factors are both important and should be considered together as they influence both the condition and the shrinkage of potatoes. Regulation of storage temperature and humidity is dependent upon storage construction as well as management. The effect of various construction features and management practices in obtaining desirable storage conditions will be discussed in the following paragraphs.

USE OF INSULATION—If insufficient insulation is used, so much heat will be lost by conduction through the walls and ceiling, even in average winter weather, that the heat of the potatoes will have to be supplemented by artificial heat from stoves to maintain a desirable temperature. If too much insulation is used, the additional ventilation required for temperature regulation will lower the humidity and cause undue shrinkage. Thus, an attempt should be made to insulate a storage sufficiently to give a balance between expected heat production and loss for average conditions. Plans should be made for heating during prolonged cold spells, or for ventilation during unusually warm weather.

The amount of insulation used in a storage affects the humidity within the building. In cold weather moisture will condense on poorly insulated (and therefore cold) surfaces at relatively low interior humidities. With increase in insulation the humidities in the building may be higher before condensation occurs.

*Wright, R. C., Peachock, Walter M. Influence of Storage Temperatures on the Rest Period and Dormancy of Potatoes, U.S.D.A, Tech, Bulletin 424, May 1934.

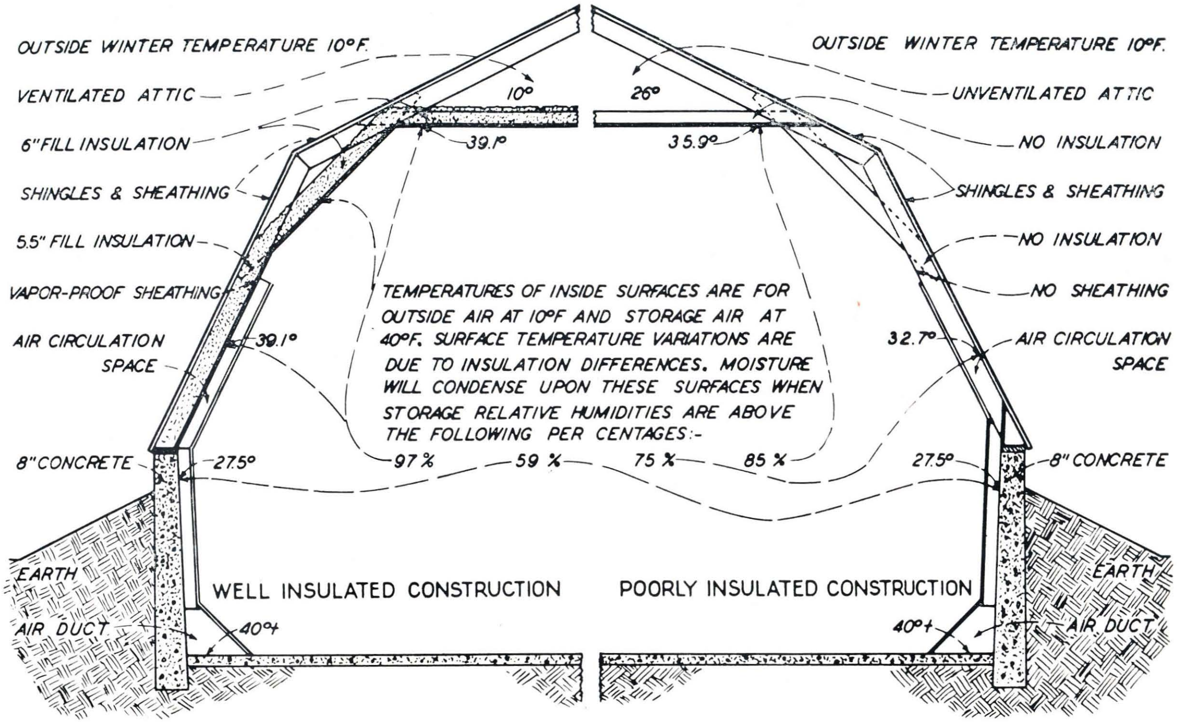


Fig. 4. Comparison of inside wall surface temperatures and storage relative humidities at which moisture will condense upon these surfaces for well-insulated and poorly-insulated storages. Note that the wall air circulation space is between the wall surfaces and the stored potatoes.

The insulation values and the effect of insulation upon storage humidity for average winter conditions is shown in Fig. 4. Note that where the insulation value is high condensation is low, resulting in a high storage humidity and a low potato shrinkage rate.

Insulation is sometimes used in such a way that it absorbs considerable moisture. While this regulates humidity to a certain extent it is undesirable because moisture reduces the value of insulation. For many years storage walls and ceilings have been insulated by filling them with straw or sawdust with no protection from the moisture inside the building. When so used, the insulation absorbs moisture and loses its value quickly. Because of this loss of efficiency and the decay of the insulating material, fill-type insulation was found unsatisfactory until the practice of placing a vapor-retarding membrane between the insulation and the storage air was developed. Even with good construction, a good rule in applying insulation to a storage is to make it more difficult for the moist air from the storage to reach the insulation than for the dry air from outside to reach it. This can be done by providing a vapor barrier on the inside surface of the outside wall. The following discussion and Table 2 are taken from *"Condensation in Modern Buildings"* by L. V. Teasdale, Senior Engineer of the Forest Products Laboratory:

> Tests have been made to determine the comparative vapor resistance of various papers and wall materials used in building construction. Samples were sealed in copper pans containing water and exposed in a room controlled at 80° F. and 30 per cent relative humidity and weighed regularly for 90 days or more. The values obtained after the rate of loss became constant were calculated on a basis of grains of moisture lost per square foot per hour.

Table 2. Comparative Resistance of Various Materials to Vapor Transmission.

Material	Loss in Grains per Sq. Ft. per Hour
Foil surfaced reflective insulation (double faced)	0.061— 0.093
Roll roofing—smooth surface—40 to 65 lb. per roll 108 sq. ft	.093— .123
Asphalt impregnated and surface coated sheathing paper glossy surfaced—	
50 lb. 500 sq. foot roll	.153— .555
35 lb. 500 sq. foot roll	.123— 1.480
Duplex or laminated papers 30-30-30	.990— 1.850
Duplex or laminated papers 30-60-30	.370— .617
Duplex papers reinforced	.493— 1.480
Duplex paper coated with metal oxides	.370— .930
Insulation backup paper, treated	.617— 2.462
Gypsum lath with aluminum foil backing	.061— .277
Plaster—wood lath	7.90
Plaster—3 coats lead and oil	2.650— 2.770
Plaster—3 coats flat wall paint	3.080
Plaster—2 coats aluminum paint	.831
Plaster—fiber board or gypsum lath	14.20 —14.80
Slaters felt	3.700—18.50
Plywood—¼" Douglas fir, soybean glue plain	3.080— 4.620
2 coats asphalt paint	.308
2 coats aluminum paint	.930
½" 5-ply Douglas fir	1.920— 1.975
¼" 3-ply Douglas fir, art. resin glue	3.080— 4.620
½" 5-ply Douglas fir, art. resin glue	1.975— 2.420
Insulating lath and sheathing—board type	18.50 —24.65
Insulating sheathing, surface coated	2.19 — 3.05
3/16" compressed fiber board	3.640
1" insulating cork blocks	4.440
½" and 1" blanket insulation between coated papers	1.380— 1.440
4" mineral wool—unprotected	20.950

Several different types of commercial insulation and native farm materials may be used for insulation. The type of construction and amount of insulation used will depend upon individual circumstances. The important considerations are that adequate insulation be used to protect the potatoes from frost during ordinary winter weather and that the insulation be protected against moisture.

Experience has shown that potato storage houses in Michigan should have about the amount of insulation indicated on the plans shown in this bulletin.

A few wall sections are shown in Fig. 5 that represent good practices in storage house construction.

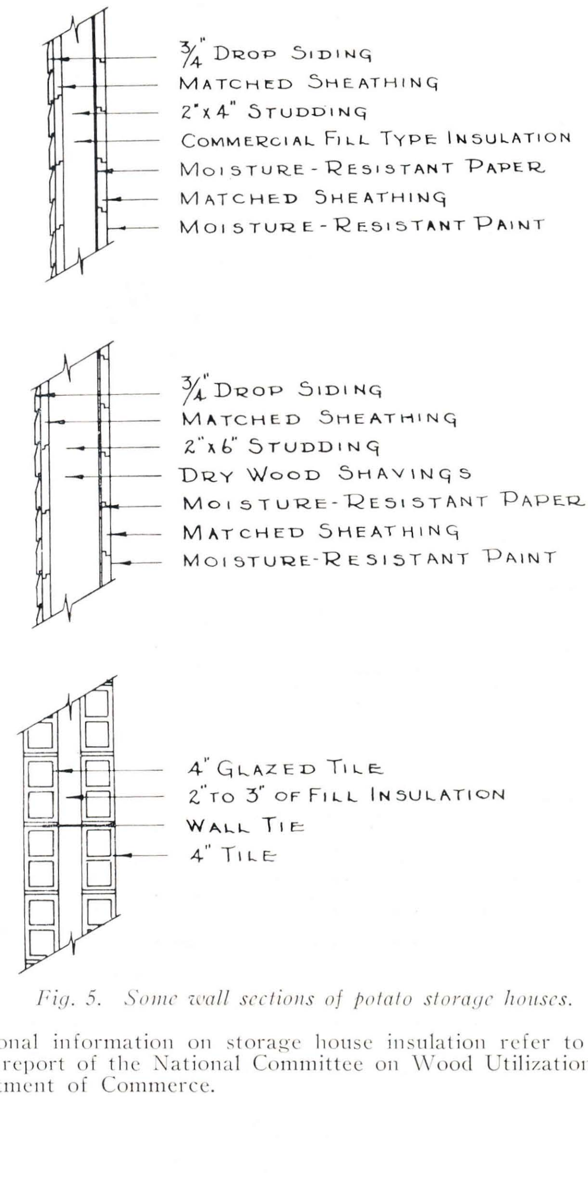


Fig. 5. Some wall sections of potato storage houses.

For additional information on storage house insulation refer to "Insulation on the Farm," a report of the National Committee on Wood Utilization of the United States Department of Commerce.

PURPOSE OF VENTILATION—Ventilation serves as the quickest means of changing both temperature and humidity within a storage, provided outdoor weather conditions permit. Ventilation is subject to a wide range of regulation; it may vary from forced ventilation to the smallest amount admitted through cracks. Night ventilation serves to remove heat with a minimum of moisture. Night air, up to the time dew forms, has the same absolute amount of moisture but less heat than day air. Therefore, night ventilation is more desirable in the fall as it lowers the temperature and maintains high storage humidity. Day ventilation may be more desirable in winter as it lowers the humidity and reduces ceiling condensation while maintaining desirable temperature. During the winter months in well-designed storages, usually little ventilation is required but may be needed during unseasonably warm weather in winter, or in storages filled beyond their normal capacity. In the spring months, night ventilation may be employed to keep the storage temperature below the outside average daily temperature. In general, it is advisable to take advantage of outside temperature and humidity below those inside the storage for fall ventilation whether it be day or night.

NEED FOR AIR CIRCULATION—Adequate air circulation within a storage is necessary to obtain reasonably uniform conditions in the various parts of the house. Moving air is the principal means of carrying heat and moisture between the cold and warm spaces and between the wet and dry areas. Storages should be designed so that there is adequate space between the top of the bins and the ceiling to permit free circulation of air. It is especially important that there be circulation spaces between the stored potatoes and the exterior wall whether it is above or below ground (Fig. 4). To make wall circulation effective, the wall circulation space should be open to the air above the bins, and at the bottom it should connect with a horizontal flue extending entirely around the storage area and opening into the work alley near the air-intake door (Fig. 12). Air circulation in these spaces serves to remove heat from both the outside wall and the potatoes, thus permitting more rapid cooling to the desirable holding temperature. In the winter the spaces serve to carry the heat from the center of the house to the cold wall space and prevent freezing of potatoes adjoining these walls. Moisture in the form of water vapor is also conveyed back and forth between the storage interior and the air space around the wall. Present information indicates that with well-designed wall circulation, very little air movement through the mass of potatoes is needed to maintain desirable temperature and humidity conditions.

CONDENSING SURFACES—During the course of this and previous studies, it has been found that condensation of moisture upon the inside walls of a potato storage may be used to advantage in controlling humidity.*

Condensation occurs where there is a large difference between the inside air temperature and the temperature of the inside surface

*Studies of Potato Storage Houses in Maine, by A. D. Edgar, May 1938. Tech. Bul. 615, U. S. Dept. of Agr.

of the outside walls. The inside surface of insulated walls will be warmer than similar surfaces of uninsulated walls. Therefore, condensation will collect first on the colder, uninsulated surfaces.

When the outside temperature rises, the uninsulated surfaces will become warm and some of the condensed moisture will be again evaporated. Thus, a higher storage humidity will result than if ventilation is used to remove moisture and prevent condensation throughout the storage period.

This condensation factor can be used to control storage humidity if some uninsulated sidewall areas are provided. This has been done in the plans shown in Figs. 12, 13 and 14 by leaving from 12 to 18 inches of uninsulated concrete wall. The rest of the wall is protected by banking it with earth.

Condensation on these outside walls will not drip back onto the potatoes as it would from condensation on the ceiling, and it does no damage to the concrete wall. Furthermore, condensation on these surfaces does not materially increase the loss of heat from a storage, but the removal of moisture from a storage by ventilation results in relatively large heat losses.

Another method of handling this problem of condensation would be to increase the amount of insulation. The amount of insulation required to prevent condensation on inside surfaces can be determined if certain factors are known, as shown in Fig. 4. For ideal storage conditions of 85-per cent relative humidity and 40° F., condensation can be prevented by adding approximately 4 inches of fill insulation between the walls of standard frame construction if the outside minimum temperature does not exceed 0° F.

If the relative humidity increases to 95 per cent, as it frequently does during the storage period, or if the outside temperature drops below 0° F., the increased amount of insulation required to prevent condensation would appear prohibitive in cost.

Since previous discussion has shown that it is also impractical to remove this condensed moisture by an exchange of air through the building because of excess potato shrinkage, a desirable compromise may be to provide adequate ceiling insulation to prevent condensation under ordinary storage conditions, and to provide cold surface areas where moisture may condense without damage and be re-absorbed into the air after a "cold spell" to maintain humidity.

POTATO HANDLING

In the past some emphasis has been placed on methods of reducing handling injury in the field at harvest time, but too little attention has been given to reducing injury in putting potatoes into and removing them from storage. Storages should be designed with provisions for handling potatoes quickly with least chances for mechanical injury. The amount of mechanical injury sustained in digging, picking, grading or in transportation increases storage losses in several ways. Any injury which breaks the potato skin permits greater evaporation of moisture and results in excessive shrinkage. These injuries also permit decay organisms to enter and are a means of spreading disease. Even though the injuries heal, scars are left that keep the potatoes from selling as U. S. No. 1 grade.

FIELD TO STORAGE—The common method of harvesting in Michigan is to pick potatoes from the row into picking baskets, dump the baskets into crates, transport to storage and dump from crates into bins. This requires three handlings from field to storage, in addition to movement in transportation. Some growers have potatoes picked directly into crates in the field, and in this manner one handling operation is eliminated, making only two handlings from field to storage bin. Another "two-handling" method that has proved very desirable in some potato states is picking and storing field-run in the picking boxes. This method was used in field tests at Lake City and is an excellent way (Fig. 3) to eliminate injury and obtain a select grade of potatoes, but cannot be generally recommended because of its cost. Enough boxes to fill a storage cost as much as the storage building, and only 80 per cent as many potatoes can be stored when boxes are used as when stored in bulk. However, some producers of select grade potatoes are finding that the extra cost of box storage is justified.

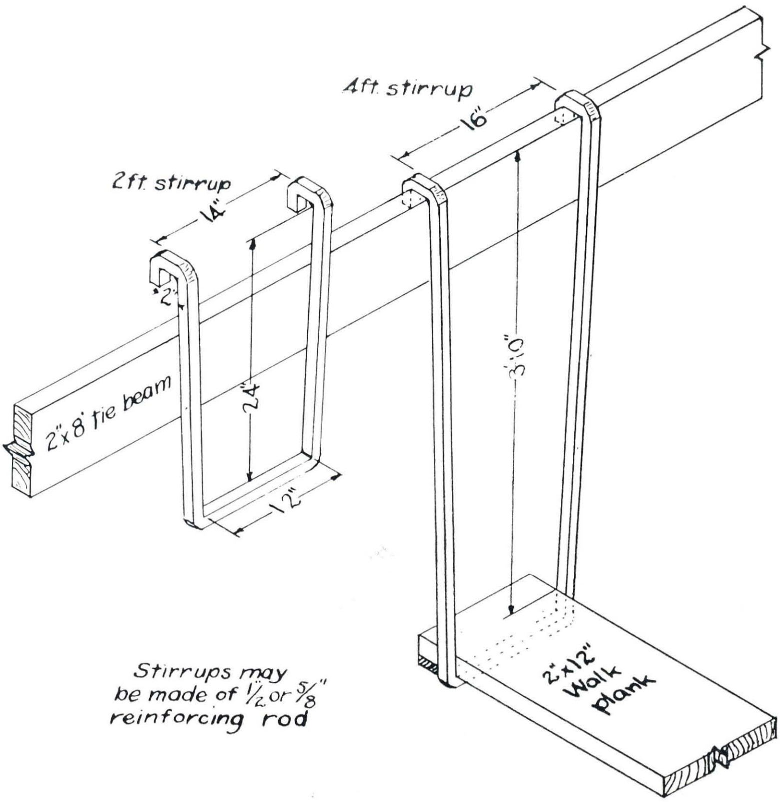


Fig. 6. Movable stirrups used for supporting walk planks in filling bins.

FILLING BINS—In filling storage bins, the harvest time rush results in considerable carelessness and injury to the potatoes stored. Workmen often step on the pile of potatoes, throw crates upon the pile in dumping them, and do other things that increase mechanical injury. A good practice in filling storage bins is to keep the top of the bin level by adding shallow layers of potatoes over the full width and length of the bin. In dumping the crates, the workmen walk on planks supported just over the potatoes by movable stirrups hooked over girders or other supports (Fig. 6). Where potatoes must be dropped (as through ceiling hatches) to the bottom of the bin, the twisted sack chute seems most practical, although immature potatoes going through such chutes are often seriously skinned by the rough sacking.

ELEVATORS AND CONVEYORS—In the present study, an experimental portable elevator and conveyor, shown in Fig. 7, has been found to elevate from the floor to a height of approximately 8 feet with a minimum of man labor and little damage to the potatoes. To prevent dropping and rolling from the delivery end of the conveyor, it should be moved for every few crates of potatoes handled.

BINS AND WORK ALLEYS—Big crop years are usually big injury years because potatoes are often forced into the tops of bins

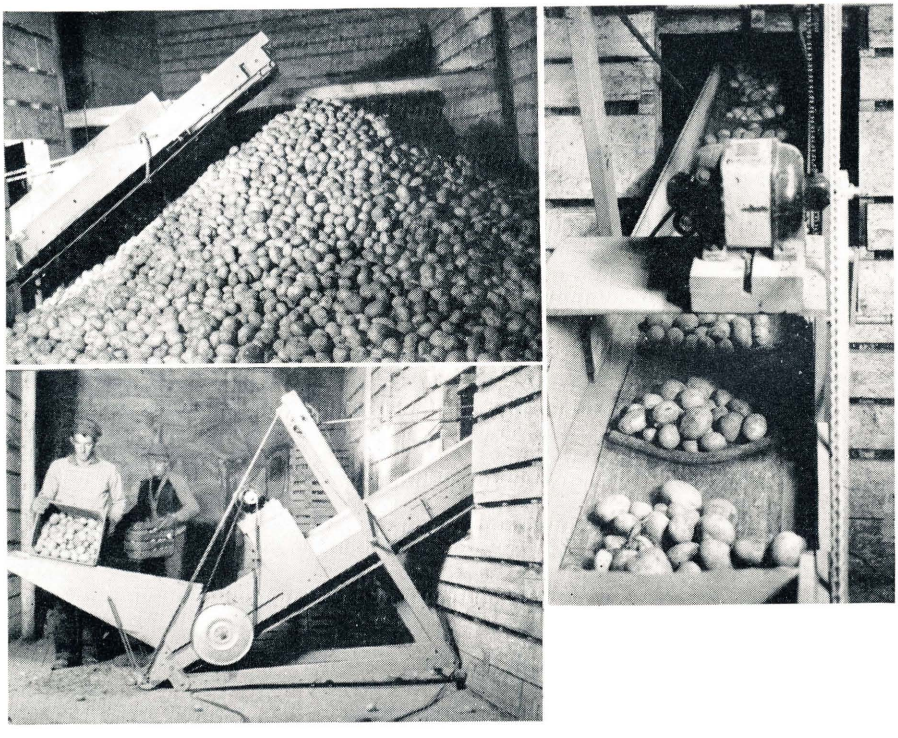


Fig. 7. Portable elevator with 16-inch belt with which potatoes may be moved horizontally or raised at an angle to the top of an 8-foot pile.

Fig. 8. Ceiling hatches of storage cellar. Potatoes are often injured in filling storages through such hatches even when sack or padded chutes are used. The accumulation of a cone of dirt under the hatches is also undesirable.

against the ceiling with no allowance for circulation above the bin or care to prevent injury in handling the potatoes. Such injury has been most noticeable where bins are filled through small ceiling hatches in which case the potatoes must be shoved back from under the hatch in order to use all of the space (Fig. 8).

It may be more desirable in the long run to be sure the storage is large enough for all of the potatoes which may be expected during large crop years.

Attention should be given to work alleys through which potatoes are moved into storage and graded and removed from storage. In filling bins of 6 feet or greater depth, it is advantageous to have two work-alley levels per bin. This permits filling from the lower level to a depth of 3 or 4 feet, then filling the remainder of the bin from the upper level. This reduces the amount of potato roll as the bins are filled. For very large storages it is desirable to have the work alley designed so that trucks or wagons may be driven or backed into the storage and the potatoes loaded or unloaded directly from two levels. For small storages a walk-way on the upper level is sufficient and a concrete alley on the lower floor is desirable.

CONSTRUCTION FEATURES

Other features which should be given consideration in building a storage, are economical use of materials, durability and safety.

ECONOMY—To be economical, a storage must meet the requirements as to insulation, design, and handling facilities, as discussed previously. The square storage is more economical than a long narrow storage or one with shallow bins. Windows are an undesirable extravagance in storages because they must be shuttered to exclude light during the storage season. The use of local material is economical and practical if attention is given to proper construction.

DURABILITY—Potato storages may be built to resist weathering and deterioration. Surfaces on which moisture may form should be treated with asphalt paint or a similar protective coating. Wall and ceiling surfaces should be smooth to permit free circulation of air and rapid evaporation of moisture.

SAFETY FEATURE—No structure is sound that does not provide a safe working place for the men handling the potatoes. Structural members should be of adequate size to prevent failure. The workmen should have adequate head room and be required to do a minimum of climbing ladders and over braces in carrying on the usual activities. Where electricity is available, the storage should be wired to provide lights and provide current for grading and conveying potatoes and operating fans. In general, the outlets and lights should be placed where they are not likely to be struck by trucks, grader, or other movable equipment. Molded rubber receptacles without switches are preferred because they are moisture resistant and not easily damaged. One switch near the entrance on the lower floor level is all that is needed. Flexible, non-metallic conduits placed according to wiring code are preferred because of economy. Experience has indicated that unless rigid conduits are filled with a hot molten compound like "pot-head compound" before being placed in service, condensation will eventually result in "shorting" between wires.

REMODELING OLD STORAGES

Many storages now in use have inadequate insulation, no protection of structural members against decay, no provision for air circulation and ventilation, and no provisions for handling the potatoes to and from storage. If these old storages were remodeled and properly managed, they would give results almost as satisfactory as obtainable in new storages.

STORAGE TYPE AND CAPACITY

Capacities may be increased by removing unnecessary partitions and by increasing effective bin depths. Bin depths may be increased by altering the ceiling and providing an upper level walkway as is done in the new storages (Figs. 13 and 14). In underground cellars with concrete ceilings the additions of a driveway and shed at one end which may be used for grading will increase storage capacity (Fig. 9), as all of the central alley thus is made available for storage.

INSULATION

To obtain the advantages of insulation for temperature and humidity regulation, most old storages need a complete new job of insulation as

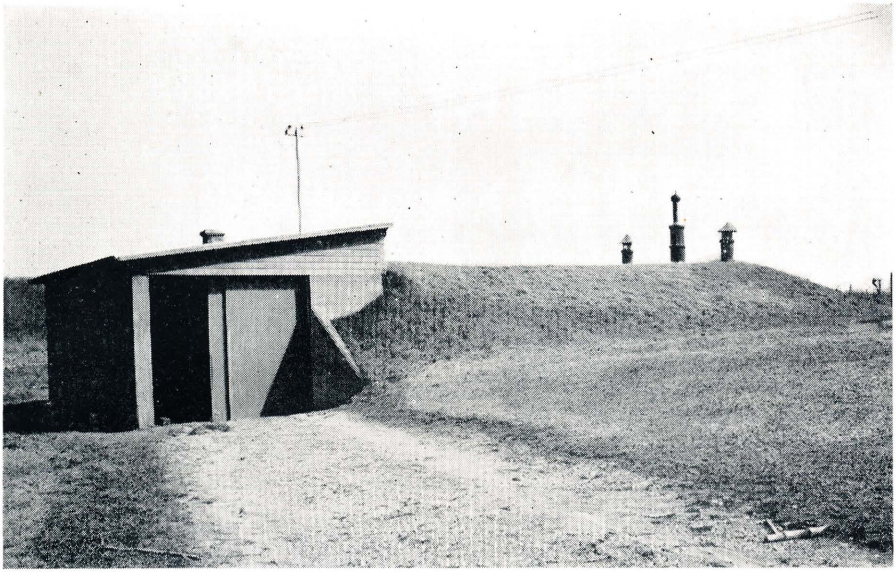


Fig. 9. A reinforced concrete underground storage. The drive shed at left may be heated for grading operations in the winter.

has been done in the old storage shown in Fig. 1-B. In remodeling old storages it may be desirable to insulate the ceiling only and protect the inside surface from vapor damage. It will be necessary to use some judgment in choosing between commercial and non-commercial insulation owing to the differences in cost and condition of the old storage.

VAPOR PROTECTION

Where the frame of the structure is not badly decayed, a vapor barrier provided by a layer of vapor-resistant paper or a coat of asphalt emulsion paint may be placed over the inside sheathing. Where walls are decayed to a point that replacement seems desirable, consideration should be given to the use of sheet metal where adequate insulation has already been provided or of ¾-inch, vapor-resistant insulation for replacing old sheathing. This will provide a surface not easily injured by condensation.

CEILING DRIP PANS

In underground storages with reinforced concrete ceiling, protection against injury from vapor is often impractical but a ceiling drip pan may be found desirable to prevent moisture which condenses on the ceiling from dripping on the potatoes. The principle of the ceiling drip pan is to allow ceiling condensation to regulate the storage humidity, but to prevent the drip which accompanies such condensation from wetting the potatoes in the top of the bins. This is done by spacing corrugated metal sheets between the tops of the bins and the concrete ceiling, the sheet metal being supported so that the moisture which drips from the ceiling will drain to the air circulation space at the side walls. Alternate sheets should be at different heights so that the air rising from the potatoes may pass between them to the ceiling, as may be seen in Fig. 10.

Fig. 10. Experimental ceiling drip pans. Upper view, notice wet potatoes under bare ceiling and dry potatoes under drip pan. In lower view note staggering of pan to permit air to flow to ceiling between alternate sheets.

CIRCULATION AND VENTILATION

The importance of air circulation spaces between the stored potatoes and the walls is discussed on page 17. A method of installing such air circulating spaces in old storages is shown in Fig. 11. The type of ventilation shown in Fig. 12 is both economical and effective. The intake is placed at the bottom of the lower alley door and the outtake is placed

Fig. 11. Interior view of the Lake City storage showing entrance of triangular wall-floor air flue which connects the open work alley with a two-inch wall air circulation space. Later practice uses tight bin fronts.

just under the ceiling at either end of the storage. The use of an exhaust fan as in Fig. 1B is often desirable. Where an outtake is provided on each end of the storage as in Figs. 13 and 14, the one on the lee side only should be opened when ventilating with outside air that is much below freezing.

PLANS FOR STORAGE HOUSES

As a result of the investigation plans have been developed for farm potato storages with provisions for adequate circulation, ventilation, insulation, and handling. Features of the new plans are discussed in the following paragraphs. Blueprints for the various sizes and types of storages may be obtained from the Department of Agricultural Engineering, Michigan State College, East Lansing, Michigan.

SIZE OF STORAGES

It has been necessary to design several sizes of storages to meet the wide variation in farm potato acreages. A series of 14 storage plans have been developed for houses varying in size from 550 to 11,450 bushels capacity. All plans are for square storages, owing to their advantages in economy, handling of potatoes, and regulation of storage conditions. Where plans are not available for intermediate sizes, it will often be practical either to enlarge the square plan by 2 feet each way, or to retain the width and increase the length by one bin.

CARRY-IN STORAGES

For storages having capacities of from 550 to 4,700 bushels the center work alleys vary in width from 4 feet 8 inches to 9 feet 4 inches. In these relatively small storages it is practical to carry the potatoes from the truck at the door back into the bins. In the smallest storages of this group, 550 to 800 bushels capacity, there is but one level of work alley, but by using a movable plank supported on steps in this alley, potatoes may be conveniently stored in the bins to a 7- or 8-foot depth. The larger storages of this group, from 1,900 to 4,700 bushels capacity, have movable plank walkways on an upper level and a concrete floored, lower level alley (Fig. 12). In filling, the potatoes are carried in at the lower level to fill bins up to a 3- or 4-foot depth and then by using movable walk planks from the upper walkway, the bins may be filled to a depth of 10 or 11 feet.

DRIVE-IN STORAGES

The larger storages are of the drive-in type and are of 6,800 to 11,450 bushels capacity; they have two levels of work and a drive alley of from 10 feet 8 inches to 12 feet in width, which permits farm trucks to back or drive into the storage for unloading or loading from either level. With a relatively large quantity of potatoes to be stored and graded from storage the expense of the two alleys is justified. The head room in the two work alleys is just enough to clear a man walking on the truck bed. Most of the potatoes should be carried

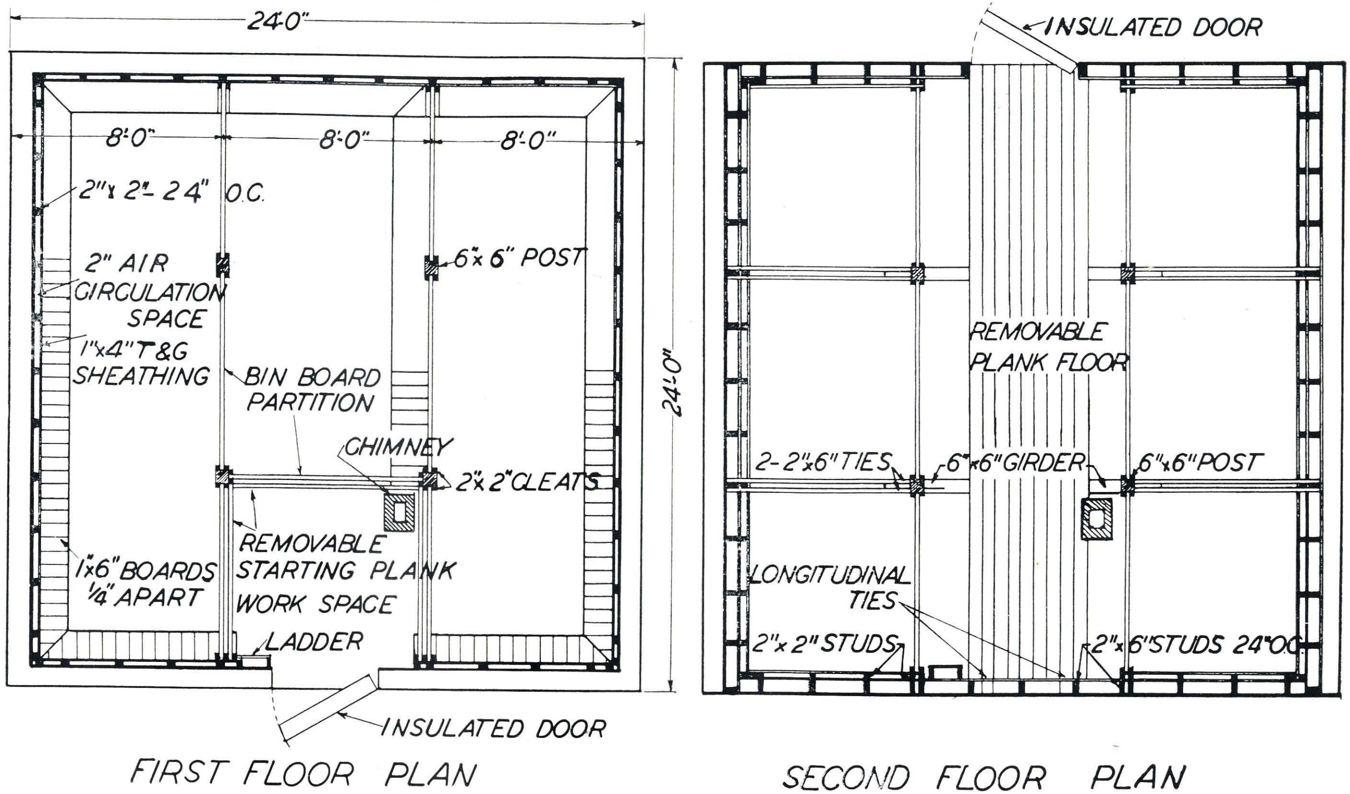
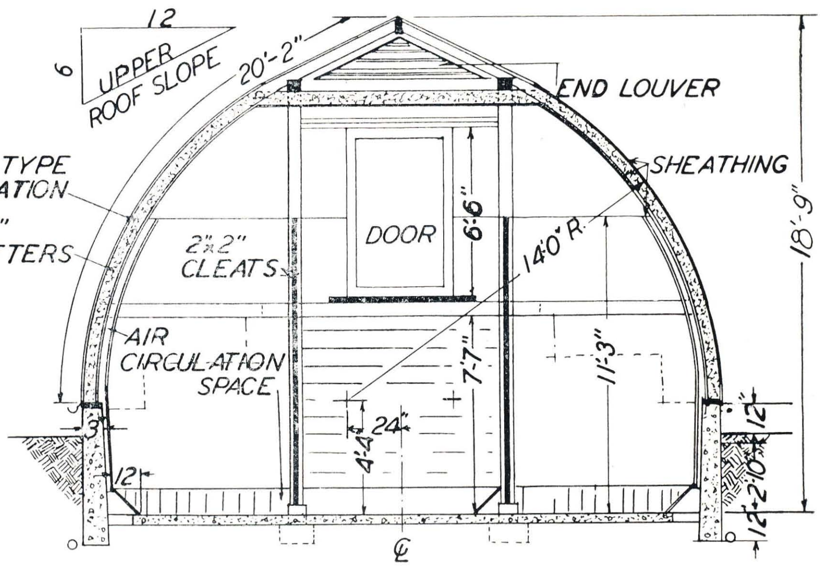
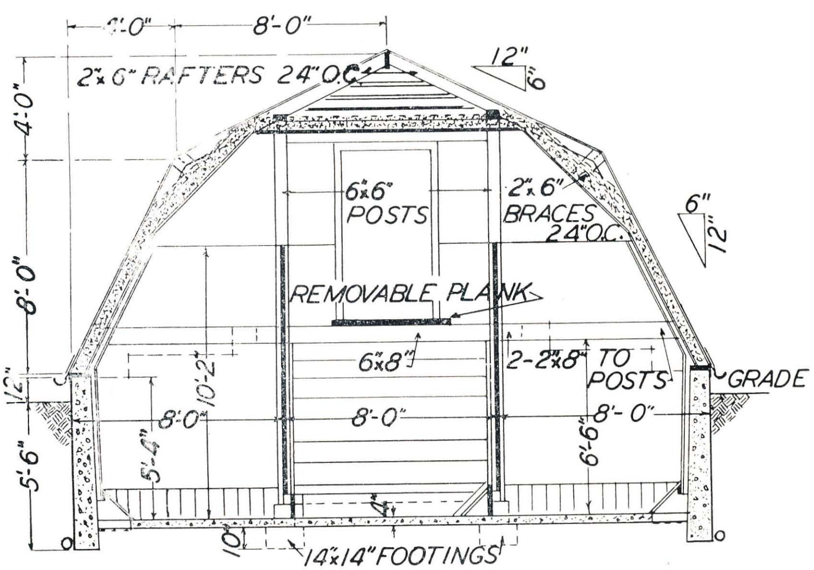


Fig. 12a. Plan and section of typical carry-in storage.



GOTHIC ROOF SECTION

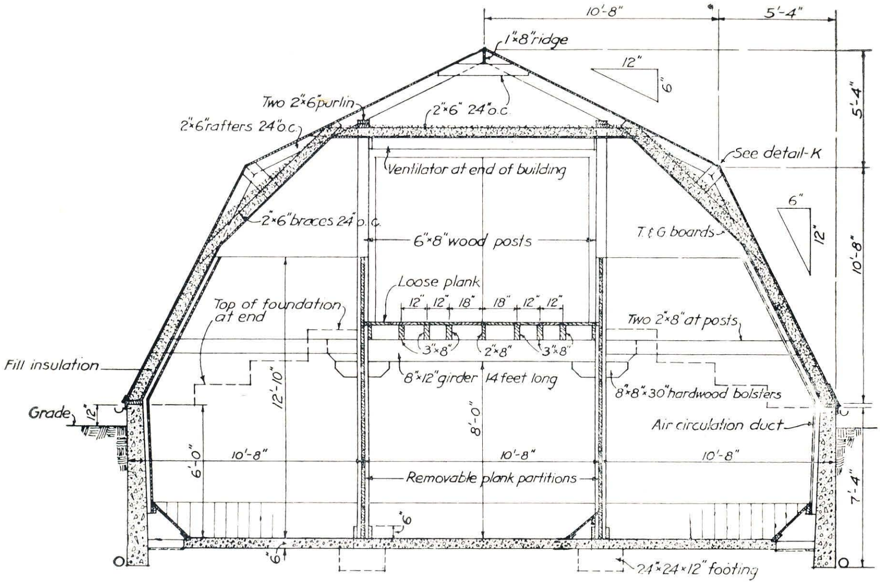
Fig. 12b.

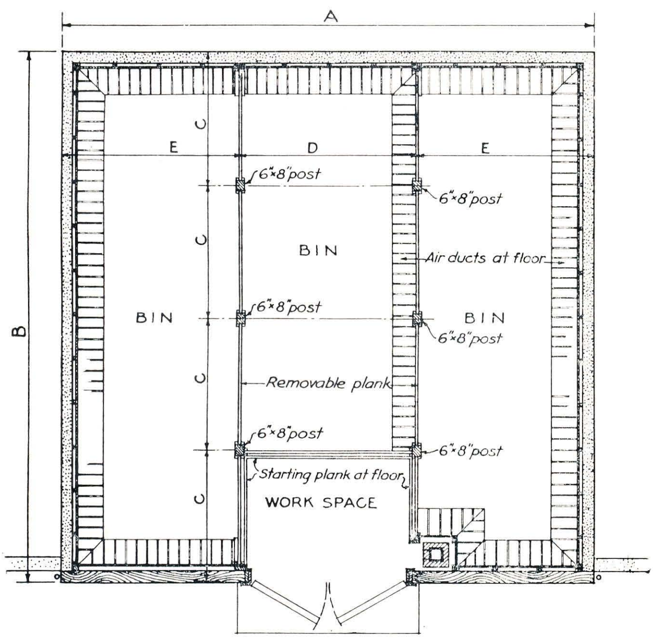


GAMBREL ROOF SECTION

Fig. 12c.

NOTE: *Sections shown in Figs. 12b and 12c are adapted to plans shown in Fig. 12a.*





TYPICAL FIRST FLOOR PLAN

PLAN DIMENSION SCHEDULE				
A	B	C	D	E
40'-0"	40'-0"	10'-0"	12'-0"	14'-0"
36'-0"	36'-0"	9'-0"	12'-0"	12'-0"
32'-0"	32'-0"	8'-0"	10'-8"	10'-8"

Fig. 13. Details of construction for a 6,000- to 7,000-bushel storage. Capacity may be increased or decreased by altering dimensions.

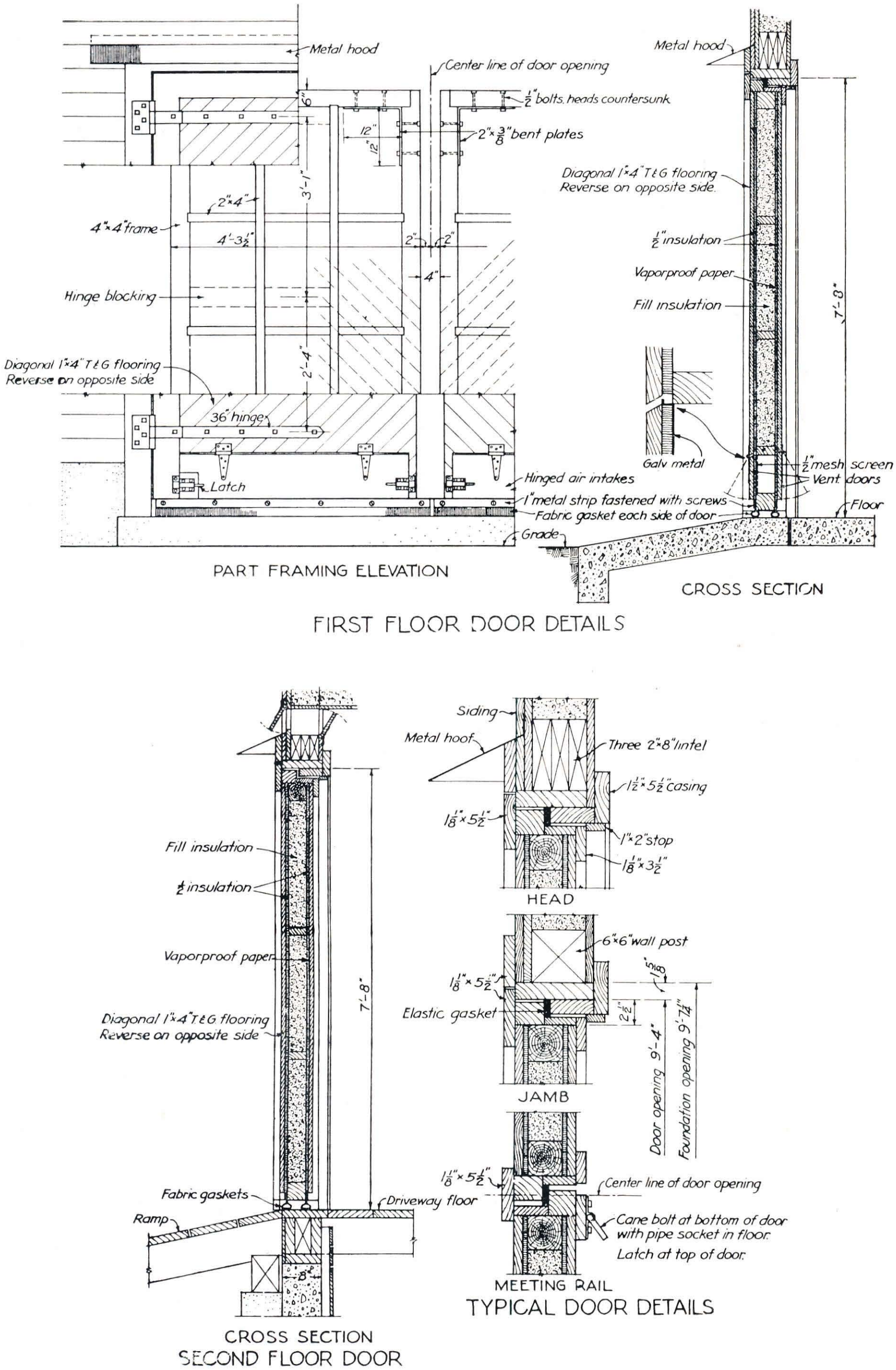
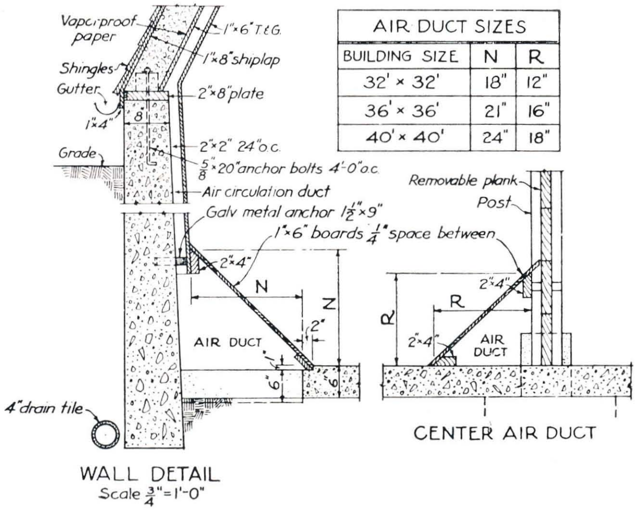
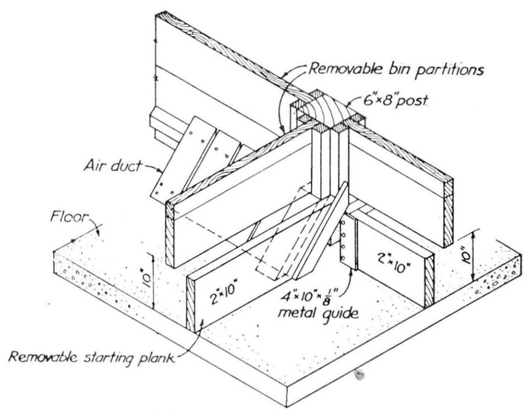


Fig. 13. (Continued).



AIR DUCT SIZES		
BUILDING SIZE	N	R
32' × 32'	18"	12"
36' × 36'	21"	16"
40' × 40'	24"	18"



CENTER AIR DUCT DETAIL

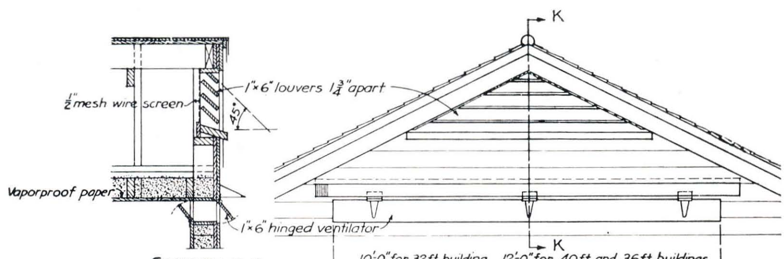


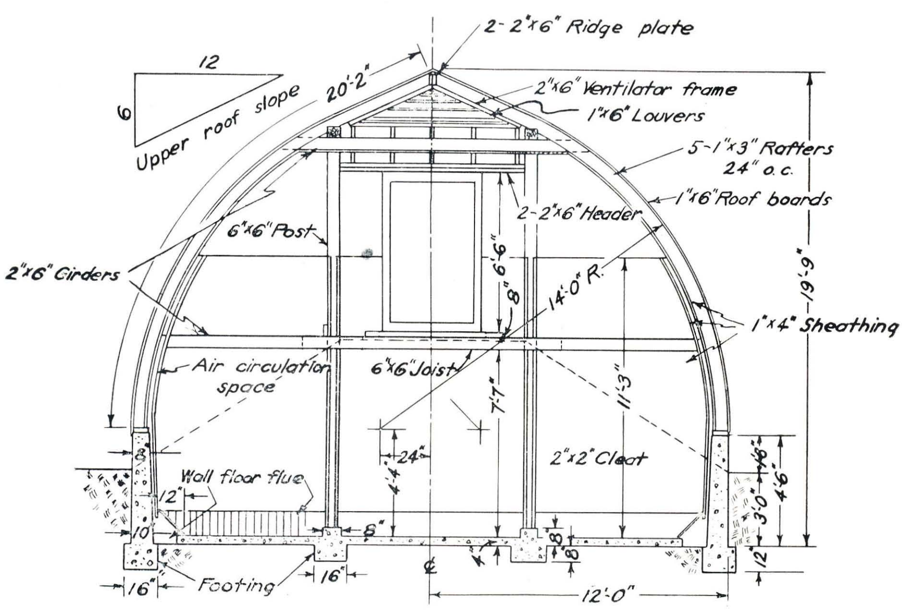
Fig. 13. (Continued).

from the truck and dumped into the bin, especially from the upper level, rather than being dumped from the truck bed and allowed to roll down long inclines. To utilize home-sawed lumber, the gambrel and gothic roof types were designed for each storage size, except the two smallest, for which the gambrel roof only was planned.

GAMBREL ROOF

The gambrel roofed storages (Fig. 13) use 2 by 4 or 6-inch dimension lumber for the rafters. The upper and lower slope rafters are interchangeable. The roof and ceiling slopes are as follows: (1) the lower roof rafters have a slope of 2:1, (two vertical to one horizontal) which is steep enough to give adequate head room during the filling of the bin; (2) the upper roof rafters have a slope of 1:2, which is about as flat as is practical to use with the common types of roofing materials; (3) the braces at the junction of the upper and lower rafters slope 1:1; (4) the ceiling follows the slope of the lower rafters to the braces and follows the braces to the horizontal ceiling which connects the upper rafters and provides a shallow attic space above. The attic space is desirable for ventilating the insulation above the ceiling. The purlin is supported by posts extending upward from either side

FIRST FLOOR PLAN



END SECTION

Fig. 14. Laminated rafter potato storage house. Note: Construction details are similar to those in Fig. 13.

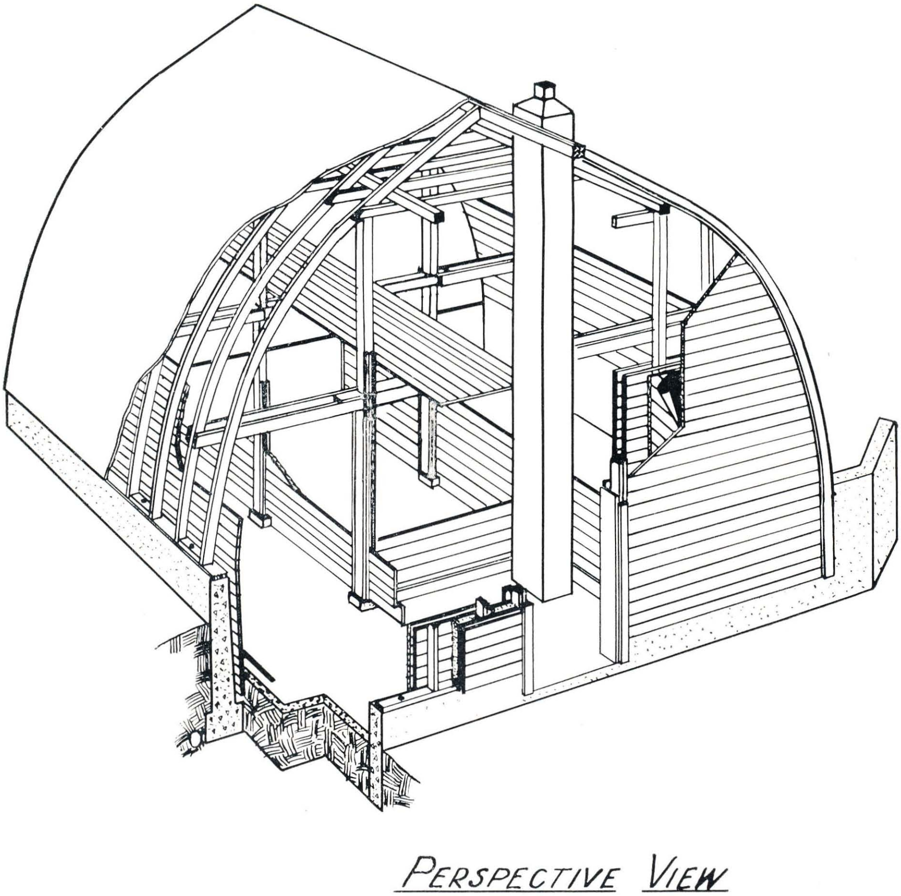


Fig. 14. (Continued).

of the work alley. This member provides the upper anchorage for the posts and some stiffness to the roof. The purlin is placed above the ceiling to permit unobstructed flow of air below.

GOTHIC ROOF

The gothic roofed storage (Fig. 14) has been designed particularly to use small dimension, home-sawed lumber. For this type roof a minimum radius of roof curvature of 14 feet has been used. The rafters for each side of this roof are made up of five 1- by 3-inch pieces which are to be bent up and nailed together in forms on the storage floor. The roof is of the type developed by the Michigan State College for other classes of farm buildings. As in the gambrel roof type, the purlin gives additional roof stiffness. The upper part of the gothic roof, has a minimum slope of 1:2, this slope starts tangent to the curved portion and extends to the ridge.

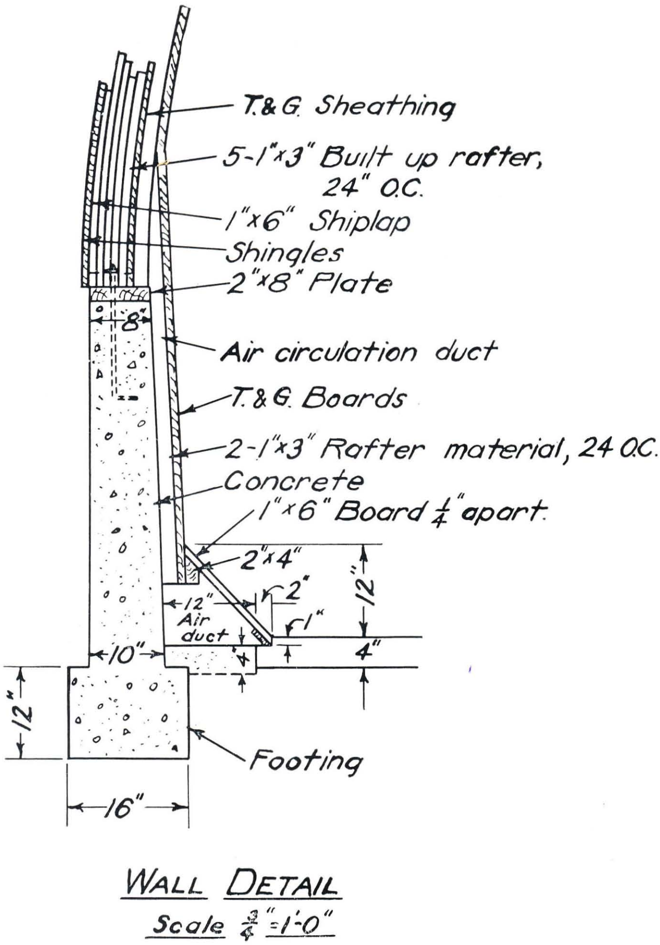


Fig. 14. (Continued).

ESTIMATES OF COST

Tables 3, 4, and 5 show the amounts of material required and the itemized cost at assumed unit prices for labor and material. The basis of estimating and notes on construction are given in the following paragraphs.

LUMBER—A bill of material is included in Tables 3 to 5. By following through the total unit cost of materials in these tables, it will be seen that lumber used in one place has a greater unit cost than lumber used in another. The unit costs are made up of three factors: (1) the lumber cost, with values ranging from $35 per thousand for plank to $120 per thousand for hardwood bolster material; (2) the cost of nails which varies from 70 cents per thousand board foot for framing to $3 per thousand square feet of roof shingled; (3) the cost

Table 3. Cost Estimates for Michigan Potato Storages.

Item	Building Unit	Cost Unit	Unit Cost [2]	14 ft. x 14 ft. Gambrel (500 bu.)		16 ft. x 16 ft. Gambrel (800 bu.)		20 ft. x 20 ft. Gambrel (1,900 bu.)		20 ft. x 20 ft. Arch (1,960 bu.)		24 ft. x 24 ft. Gambrel (3,150 bu.)	
				Amount	Cost	Amount	Cost	Amount	Cost	Amount	Cost	Amount	Cost
1......	Excavation.....	Cu. yd...	$ .50	29	$ 14.50	38	$ 19.00	82	$ 41.00	44	$ 22.25	96	$ 48.00
2......	Concrete.......	Cu. yd...	7.00	10	70.00	12	84.00	23	151.00	18	124.60	26	182.00
3......	Sills...........	M [1]......	61.70	75	4.63	86	5.31	107	6.60	107	6.60	128	7.90
4......	Posts..........	M.......	56.70	54	3.06	60	3.40	84	4.76	90	5.10	180	10.21
5......	Girders—Ties...	M.......	81.70	8	.65	10	.82	50	4.09	40	3.37	155	12.66
6......	Plank [3].........	M.......	48.70	446	21.72	502	24.45	1,180	57.47	831	40.50	1,505	73.24
7......	Studding.......	M.......	56.70	78	4.42	93	5.27	160	9.07	190	10.77	312	17.67
8......	Cleats [4]........	M.......	76.70	149	11.43	190	12.20	253	19.41	191	14.65	307	23.55
9......	Joists—floor....	M.......	61.70	......	......	......	......	......	......	......	......	......	......
10......	Joists—ceiling...	M.......	61.70	48	2.96	60	3.70	74	4.57	88	5.43	104	6.42
11......	Rafters [5].......	M.......	61.70	197	12.15	240	14.81	308	19.00	480	33.20	649	40.04
12......	Purlin..........	M.......	81.70	56	4.58	64	5.23	40	3.27	133	10.75	48	3.92
13......	Shiplap [6].......	M.......	54.90	496	27.23	619	33.98	995	56.63	2,095	124.60	1,400	76.86
14......	Boards D & M [7].	M.......	56.40	878	49.52	1,071	60.40	1,784	100.62	1,100	57.60	2,328	131.30
15......	Siding..........	M.......	79.20	188	14.89	235	18.61	395	31.28	570	45.20	536	42.45
16......	Bolster.........	M.......	136.20	......	......	......	......	......	......	......	......	......	......
17......	Shingles........	Square...	10.30	3.08	31.72	3.84	39.59	6.00	61.80	640	65.90	8.64	88.99
18......	Insulation [8].....	Sq. ft....	.081	4.30	34.83	559	45.28	904	73.22	1,000	81.00	1,906	154.39
19......	Surfacing [9]......	Square...	4.00	4.3	17.20	5.6	22.40	9.0	36.00	10.0	40.00	12.7	50.88
20......	Surfacing [10].....	Square...	5.94	1.9	11.20	2.4	14.26	4.0	23.80	5.1	30.00	5.4	32.00
21......	Chimney.......	Ln. ft....	2.25	13	29.25	14	31.50	19	42.75	20	45.00	20	45.00
22......	Sill Bolts.......	Each.....	.24	14	3.36	16	3.84	20	4.80	20	4.80	24	5.76
23......	Post Dowels....	Each.....	.16	2	.32	2	.32	2	.32	2	.32	4	.64
24......	Troughs [11]......	Ln. ft....	.22	36	7.92	40	8.80	50	11.00	48	10.58	58	12.76
25......	Hardware [12].....	Each.....	9.45	1	9.45	1	9.45	2	18.90	2	18.90	2	18.90
TOTAL................................				....	$386.99	....	$466.62	....	$781.36	....	$801.12	....	$1,085.54
120% of Total Est. Bldg. Cost..............				....	$464.39	....	$599.94	....	$937.63	....	$961.34	....	$1,302.65
Cost of Bldg. per Bu. of Storage............				....	$ 0.928	....	$ 0.750	....	$ 0.493	....	$ 0.490	....	$ 0.413

[1] = M = ~~100~~ 1000 Board feet of lumber.
[2] = Unit Cost = Cost of material and labor.
[3] = Plank = Bin fronts, walk, and driveway planks.
[4] = Cleats = 2″ x 2″ air-space studding and bin-front cleats.
[5] = Rafters for arch roof at $69.10 per M.
[6] = Shiplap = Sheathing used on outside wall and roof.
[7] = Boards D & M = Boards used for all inside sheathing and air spaces.
[8] = Insulation = 4″ thickness of fill-type insulation; 6″ are used in 24-40′ buildings.
[9] = Surfacing = Vapor protection of insulation from inside of building.
[10] = Surfacing = Exterior paint 3 coats.
[11] = Troughs = Eaves troughs and down spouts.
[12] = Hardware = Door hinges and locks.

Table 4. Cost Estimates for Michigan Potato Storages.

Item	Building Unit	Cost Unit	Unit Cost [2]	24 ft. x 24 ft. Arch (3,130 bu.)		28 ft. x 28 ft. Gambrel (4,700 bu.)		28 ft. x 28 ft. Arch (4,600 bu.)		32 ft. x 32 ft. Gambrel (6,800 bu.)		32 ft. x 32 ft. Arch (6,960 bu.)	
				Amount	Cost	Amount	Cost	Amount	Cost	Amount	Cost	Amount	Cost
1......	Excavation.....	Cu. yd...	$ .50	64	$ 32.00	124	$ 62.00	87	$ 43.60	200	$100.00	164	$ 82.25
2......	Concrete.......	Cu. yd...	7.00	22	157.60	31	217.00	28	193.60	48	336.00	45	314.80
3......	Sills...........	M [1]......	61.70	128	7.90	150	9.26	149	9.20	171	10.51	171	10.51
4......	Post...........	M.......	56.70	180	10.20	192	10.86	192	10.86	432	24.49	306	17.34
5......	Girders—Ties...	M.......	81.70	48	3.92	174	14.22	75	6.13	328	26.80	216	17.65
6......	Plank [3].........	M.......	48.70	870	42.40	1,890	92.04	1,152	56.20	2,564	124.87	2,482	121.00
7......	Studding.......	M.......	56.70	229	13.00	364	20.64	270	15.30	532	30.16	371	21.50
8......	Cleats [4]........	M.......	76.70	220	16.88	366	28.07	272	20.90	502	38.50	400.	30.70
9......	Joists—floor....	M.......	61.70	....	....	....	....	....	....	512	31.39	192	11.85
10......	Joists—ceiling...	M.......	61.70	122	7.53	130	8.02	150	9.24	272	16.78	182	11.22
11......	Rafters [5]........	M.......	61.70	533	36.90	870	53.68	900	62.20	1,122	69.23	1,250	82.80
12......	Purlin..........	M.......	81.70	128	10.45	56	4.58	224	18.30	122	10.46	213	17.40
13......	Shiplap [6].......	M.......	54.90	2,959	175.80	1,895	104.04	3,752	222.80	2,456	134.83	4,710	280.00
14......	Boards D & M [7].	M.......	66.40	1,430	75.00	3,058	172.47	1,740	91.20	3,864	217.93	1,600	83.90
15......	Siding..........	M.......	79.20	687	54.50	719	56.94	810	64.20	920	72.86	1,113	88.00
16......	Bolster.........	M.......	136.70	....	....	....	....	....	....	80	10.94	45	6.15
17......	Shingles........	Square...	10.30	984	103.00	11.8	121.60	12.6	130.00	15.4	158.50	16.0	164.80
18......	Insulation [8].....	Sq. ft....	0.081	1,854	150.40	2,572	208.33	2,395	194.00	3,190	258.59	2,979	241.50
19......	Surfacing [9]......	Square...	4.00	14.1	55.40	17.1	68.56	18.1	72.40	22.3	89.04	22.5	90.00
20......	Surfacing [10].....	Square...	5.94	6.2	36.90	7.2	42.71	7.3	43.30	9.2	54.65	10.0	59.40
21......	Chimney.......	Ln. ft....	2.25	21	47.25	22	49.50	22	49.50	24	54.00	24	55.25
22......	Sill Bolts......	Each.....	.24	24	5.76	28	6.72	28	6.72	32	7.68	32	7.68
23......	Post Dowels....	Each.....	.16	4	.64	4	.64	4	.64	6	.96	6	.96
24......	Troughs [11]......	Ln. ft....	.22	56	12.32	66	14.52	64	14.08	76	16.72	75	16.50
25......	Hardware [12].....	Each.....	9.45	2	18.90	2	18.90	2	18.90	4	37.80	4	37.80
TOTAL..........				....	$1,074.65	....	$1,375.30	....	$1,353.27	....	$1,933.69	....	$1,870.96
120% of Total Est. Bldg. Cost..........				....	$1,289.58	....	$1,662.36	....	$1,623.92	....	$2,320.43	....	$2,245.15
Cost of Bldg. per Bu. of Storage..........				....	$ 0.412	....	$ 0.353	....	$ 0.353	....	$ 0.341	....	$ 0.330

1 = M = ~~100~~ 1000 Board feet of lumber.
2 = Unit Cost = Cost of material and labor.
3 = Plank = Bin fronts, walk and driveway planks.
4 = Cleats = 2″ x 2″ air-space studding and bin front cleats.
5 = Rafters for arch roof at $69.10 per M.
6 = Shiplap = Sheathing used on outside wall and roof.
7 = Boards D & M = Boards used for all inside sheathing and air spaces.
8 = Insulation = 4″ thickness of fill-type insulation; 6″ are used in 24-40′ buildings.
9 = Surfacing = Vapor protection of insulation from inside of building.
10 = Surfacing = Exterior paint 3 coats.
11 = Troughs = Eaves troughs and down spouts.
12 = Hardware = Door hinges and locks.

Table 5. Cost Estimates for Michigan Potato Storages.

Item	Building Unit	Cost Unit	Unit Cost [2]	36 ft. x 36 ft. Gambrel (8,600 bu.) Amount	36 ft. x 36 ft. Gambrel (8,600 bu.) Cost	36 ft. x 36 ft. Arch (9,050 bu.) Amount	36 ft. x 36 ft. Arch (9,050 bu.) Cost	40 ft. x 40 ft. Gambrel (11,450 bu.) Amount	40 ft. x 40 ft. Gambrel (11,450 bu.) Cost	40 ft. x 40 ft. Arch (11,480 bu.) Amount	40 ft. x 40 ft. Arch (11,480 bu.) Cost
1	Excavation	Cu. yd	$ .50	190	$ 90.00	184	$ 91.80	178	$ 89.00	178	$ 88.90
2	Concrete	Cu. yd	7.00	49	343.00	80	353.00	53	371.00	55	387.50
3	Sills	M [1]	61.70	192	11.85	192	11.86	214	13.20	214	13.20
4	Posts	M	56.70	432	24.49	306	17.34	456	25.86	306	17.34
5	Girders—Ties	M	81.70	544	44.44	243	19.80	560	45.75	334	27.30
6	Plank [3]	M	48.70	3,048	148.44	2,864	140.00	3,352	163.24	3,070	149.50
7	Studding	M	56.70	600	34.02	624	35.40	708	40.14	700	39.70
8	Cleats [4]	M	76.60	537	41.19	432	33.20	572	43.87	463	36.50
9	Joists—floor	M	61.70	664	40.97	252	15.55	760	46.89	282	17.40
10	Joists—ceiling	M	61.70	342	21.10	228	14.08	378	23.32	280	17.30
11	Rafters [5]	M	61.70	1,444	89.09	1,944	134.50	1,848	114.02	3,140	217.00
12	Purlin	M	81.70	144	11.76	288	23.70	160	13.07	400	32.70
13	Shiplap [6]	M	54.90	3,000	164.70	5,815	346.00	3,703	203.29	6,923	412.00
14	Boards D & M [7]	M	56.40	4,591	258.93	1,800	94.40	5,644	318.32	1,945	102.00
15	Siding	M	79.20	1,092	86.49	1,248	98.80	1,303	103.20	1,400	111.00
16	Bolster	M	136.70	88	10.94	45	6.15	80	10.94	45	6.15
17	Shingles	Square	10.30	19.1	196.70	19.44	200.00	24.0	247.20	24.0	247.00
18	Insulation [8]	Sq. ft	0.081	4,122	333.88	4,097	332.00	4,966	402.25	4,973	403.00
19	Surfacing [9]	Square	4.00	2,751	109.92	27.3	109.50	33.0	132.16	33.21	132.60
20	Surfacing [10]	Square	5.94	10.9	64.86	11.2	66.50	13.0	77.40	12.61	74.80
21	Chimney	Ln. ft	2.25	25	56.25	25	56.25	26	58.50	26	58.50
22	Sill Bolts	Each	.24	36	8.64	36	8.64	40	9.60	40	9.60
23	Post Dowels	Each	.16	6	.96	9	.96	6	.96	6	.96
24	Troughs [11]	Ln. ft	.22	80	17.60	82	18.04	86	18.92	88	19.36
25	Hardware [12]	Each	9.45	4	37.80	4	37.80	4	37.80	4	37.80
TOTAL					$2,248.02		$2,265.27		$2,609.90		$2,658.11
120% of Total Est. Bldg. Cost					$2,697.62		$2,718.32		$3,131.88		$3,189.73
Cost of Bldg. per Bu. of Storage					$ 0.313		$ .300		$ 0.274		$ 0.278

1 = M = Board feet of lumber, 1000

2 = Unit Cost = Cost of materials and labor.

3 = Plank = Bin fronts, walk and driveway planks.

4 = Cleats = 2″ x 2″ air-space studding and bin front cleats.

5 = Rafters for arch roof at $69.10 per M.

6 = Shiplap = Sheathing used on outside wall and roof.

7 = Boards D & M = Boards used for all inside sheathing and air spaces.

8 = Insulation = 4″ thickness of fill-type insulation; 6″ are used in 24-40′ buildings.

9 = Surfacing = Vapor protection of insulation from inside of building.

10 = Surfacing = Exterior paint 3 coats

11 = Troughs = Eaves troughs and down spouts.

12 = Hardware = Door hinges and locks.

of labor which is figured at $1 per hour, varying from $8 a thousand for the random-width, walk drive and bin planks and $32 per thousand for the built-up rafters for gothic roof to $40 per thousand square feet of roof shingled. Thus, the total unit cost for placing the various types of lumber which includes material, labor, and nails, varies from $48.70 for planks to $136.70 for bolsters.

CONCRETE WORK—Where there is a good banked site and gravel and sand are available for concrete work, the cost per cubic yard of concrete in place may be much less than the $7 used in this estimate. On the other hand, owing to higher cost of aggregate and the placing of forms, the contract price for the concrete work may exceed $7. It is desirable to make strong concrete walls for the underground part of the storage. The diameter of the largest stones in the aggregate in this case should never exceed one-sixth of the thickness of the wall. The walls are all 8 inches thick at top and increase in thickness at the rate of one-half inch per foot of height. For these storages, which have relatively low walls, no reinforcing is required. The details of construction as shown in plans should be carefully followed.

INSULATION—Insulation used in the end walls and roof, if of the granular type, will ordinarily fill the space between the studding and between the rafters. Insulation is separated from the inside storage air by a vapor-resistant membrane, and exposed to the outside air which circulates through the louvered attic space.

SURFACING AND VAPOR PROTECTION—The vapor-resistant membrane, usually of reinforced waterproof paper, is used to protect the insulation from the moisture in the storage air. A good three-coat paint job is used to protect the siding from the weather.

MISCELLANEOUS ITEMS—There will also be the additional items of hardware, eaves troughs, and a brick chimney* which are not discussed separately but are included in the tables.

RELATION OF HOUSE SIZE TO BUSHEL COST—While the capacities and total and unit costs of the various storages are given in Tables 3-5, a better idea of the relation of storage size to cost per bushel of storage space may be had by reference to Fig. 15. It will be noted on the graph that the smaller storages cost about 85 cents per bushel of capacity, the medium sizes 40 cents, and the largest sizes about 27 cents per bushel. From this chart it would seem advantageous for two or three farmers to cooperate in building a large storage. The disadvantages of cooperative storages are the division of work at filling time and in grading out of storage and the divided responsibility for control of storage conditions. Many growers would rather pay more and have exclusive control of their storage.

*To facilitate the use of artificial heat all Michigan storages should be equipped with fire-safe chimneys and stoves for heating during prolonged cold spells.

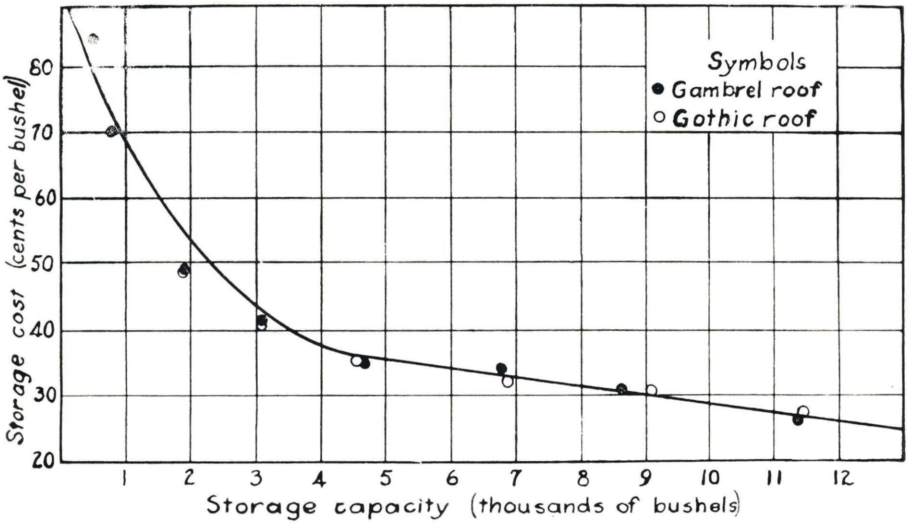


Fig. 15. Relation of storage size to cost per bushel. From tables 3-5.

CONCLUSIONS

Many Michigan potato storages were developed for conditions that no longer exist. In the past, the sole dependence upon railroads for shipping resulted in the development of commercial and cooperative warehouses along the track, but with the development of good highways and trucking it has been found desirable to plan new storages on the farm. Farm storages are also favored by growers who want to keep the stored potatoes under their own control and to use their "slack" time for grading.

As a result of investigations conducted during the past few years, a better understanding of storage requirements and methods of meeting these requirements has been reached. New farm-type storages have been developed to meet the requirements of a wide range of sizes, sites, and available material. Of outstanding importance has been the attention given to handling. The new storages have been developed with two-level work alleys that are particularly desirable when filling bins, and consideration has been given to conveyor handling in reducing mechanical injury. These storages use insulation efficiently and are planned to use condensing surfaces and air circulation spaces to supplement the usual ventilation in the control of storage conditions.

For the immediate future, most of the farm-stored potato crop will continue to be placed in existing storages so attention has been given to remodeling old storages. The new developments for improving old storages are (1) the ceiling drip pans; (2) planned condensation against vapor-protected surfaces; and (3) better planned circulation and ventilation provisions.

4M