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EVALUATION OF POTATO STORAGE STRUCTURE AND VENTILATION SYSTEMS IN RUSSIA

for

USAID/NIS TASK FORCE

Prepared by

Henry Waelti, Potato Storage Specialist

January 1994

University of Idaho
College of Agriculture

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EXECUTIVE SUMMARY

According to US and Russian estimates, more than one-third of the potatoes produced in Russia are lost during postharvest handling and storage. Part of this loss is due to poor storage conditions. This report focuses on determining structural and mechanical system (ventilation) problems in Russia.

Most Russian potato storages are old, partially underground, reinforced concrete structures. They are well built, but some have insufficient or deteriorated insulation, resulting in condensed water dripping from the ceiling into the stored potatoes. Storage managers are concerned about inadequate ventilation systems. They are old, some are designed poorly and are inefficient, which results in insufficient and uneven air distribution.

There is a need for testing ventilation systems to determine what corrective measures need to be taken. There is also a need to provide educational programs covering storage design, ventilation, humidification system operation and storage management.

INTRODUCTION

The purpose of this trip was to (1) visit potato storages to identify problems existing with the design and operation of the storages with emphasis of ventilation systems and (2) to discuss with Dr. Yuri Moiseev the potential options for producing potato storage ventilation systems in Russia. This was accomplished by visiting potato storages near Moscow, in the Vladimir Region and in Kirov, and by conversations with managers and personnel in charge of storages. Two of these managers were participants of the Postharvest Short Course conducted by PIP last summer. I also visited a corporation near Moscow that is researching and developing special materials for application in extreme environments such as in space, high temperature and medical application. Similarly, I visited a Research and Project Institute in Kirov which specializes in biotechnological applications. These two institutions are being considered by Dr. Moiseev as potential manufacturers of potato storage ventilation systems.

METHODOLOGY

An itinerary for my visit to Russia was presented at the first meeting with Dr. Moiseev and his staff. Potato production in NIS, organization of the Russian Potato Concern (RPC), privatization of enterprises and its effect on management and marketing were discussed. We also discussed design of storages and ventilation and explored the potential for producing ventilation modules in Russia. Also, I met with two representatives from a Joint

Stock corporation in Kirov, who have plans to build potato processing plants and storage capacity for 40,000 tons of potatoes in the Kirov Region.

Work Schedule

Thursday	December 2	Arrive in Moscow
Friday	December 3	Russia Potato Concern (RPC) Office
Saturday	December 4	AM Visit with Olga Strokova; PM holiday, report preparation
Sunday	December 5	Holiday
Monday	December 6	Visit Orlovsky Farm outside of Moscow
Tues.-Wed.	December 7 & 8	Visit to Farm Russia in Vladimir region.
Thursday	December 9	Visit "Kompozit" advanced materials conversion corporation near Moscow, a potential manufacturer of ventilation modules.
Thursday	December 9	Leave for Kirov via night train
Fri. & Sat.	December 10 & 11	Visit Institute of Biological and Technical Industries Visit a potato storage and processing plant.
Sunday	December 12	Visit local market, travel to surrounding area of Kivov
Sunday	December 12	Depart for Moscow via night train
Monday	December 13	Russia Potato Concern Office
Tuesday	December 14	Depart

I visited three storages: (1) a 1,000-ton storage for seed potatoes at the Orlovsky Farm located near Moscow and (2) a 3,000-ton seed potato storage at the Vladimir Farm located about 200 km NE of Moscow. The latter farm also has an unfinished steel construction storage with a 2,500-ton capacity (Global Steel Corporation); and (3) two 1,000-ton storages, one non-refrigerated and one refrigerated for storing potatoes for processing, in Kirov, which is located 1,000 km NE of Moscow. During inspection of various storages and discussions with managers and operators, I could identify specific problems related to design and operation of the storages.

RESULTS AND DISCUSSION

Farm Visits

Orlovsky Farm. Mr. Valery S. Ginin, General Manager and Mr. Nikolay Khalezov, Storage Manager. This farm which is located NW of Moscow, has 1,200 ha with 380 ha under cultivation, of which 100 ha are in potatoes. They produce 25 million eggs per year. Cattle operations produce 400 tons of meat and they have 200 dairy cows. They have a large machinery park which includes 40 tractors, 40 trucks, 300 pieces of agricultural machines and a large repair shop. The farm is located in a wooded area with a small village near by.

The potato storage is built partially underground. It has two sections, with a capacity of about 600-700 tons in each section with 3 m pile depth. One section was only partially filled with about 350 tons. Pile depth was approximately 1.4 m. Each section has two bays with

an alley through the center. The air plenums are located along the outside walls with wooden ducts at right angle to the plenum spaced about 1.5 m. A ventilation fan provides air for each bay. Rated fan capacity is 60 m^3/min for each bay with a 300-350 ton capacity.

Farm Russia, Vladimir Region. Mr. Stepan P. Ginin, Director and Mr. Alexander Zinyakov, Manager of Crop Production and Storage. This farm is a share holding corporation and includes a village of 1,200 people including a school, infirmary and recreational facility. The farm is located in an area that has been spared of industrial pollution, thus it is considered ecologically "pure". This farm is situated in a forested area, and includes a total of 14,000 ha, of which 3,000 ha are under cultivation. They produce 400 ha of potatoes with an average yield of 32 tons per ha. Other crops grown include corn, wheat, red beets and hay. They have 1,000 dairy cows. Some 1,600 ha are irrigated. An existing potato storage holds 3,000 ton of seed potatoes. This storage is partially under ground with soil bermed up along the sides for protection from the cold. It has a 3-4 m wide alley lengthwise through the center. The air plenums are along the side with ducts branching off into the pile. Fans are located at the plenum entrance. A large duct system for bringing in fresh outside air, and for the exhaust air has a louver control so it can be automatically adjusted to operate at any setting from bringing in 100% fresh air to recirculate 100% of the air. Fan capacity was unknown. Potatoes were piled 3 m deep. At the time of visit there was heavy condensation on the ceiling with water dripping down indicating insufficient insulation in the ceiling. The top of the pile was covered with straw to keep the potatoes from getting wet. This straw is changed periodically as it gets too wet. The system was not running at the time of my

visit. Ventilation is continuous in the fall when the potatoes are brought in. After desired temperatures are achieved the system runs only as needed to maintain desired temperatures.

This farm also has a new Global Steel storage building with a 2,500-ton capacity. The storage was not completed. It needs to be insulated, water hooked up for the humidifier and electrical hookup and check out of ventilation system.

Potato Storage in Kirov. There is a partially underground potato storage complex owned by the city of Kirov. The facility consists of four non-refrigerated and four refrigerated storage rooms with a capacity of 1,000 tons in each room to supply potatoes for a processing plant. The potatoes are stored in pallet bins holding approximately 400 kg each. The ventilation system for each 1,000-ton storage has two 30 kW (40 HP) fans; one to distribute the supply air through an in-floor duct system throughout the room, then discharge it through slotted outlets into the storage area. Another duct system near the ceiling draws the air to be recirculated or exhausted to the outside. Temperature sensors along the walls provide data to a regulator to adjust louvers to recirculate air through refrigeration coils, or if no refrigeration is required, to bring in the right amount of fresh air to maintain the desired storage temperature. Actual fan output is not known. No doubt, these fans and air ducts are not very efficient. For comparison, a 1,000-ton storage in the US would use one multi-blade propeller fan producing 26,000 cfm with a 7.5 kW (10 HP) motor.

The humidity level was determined by reading dry bulb and wet bulb temperatures, then calculating the relative humidity (RH) level. A data log showed that the RH level during the previous week had been 90 percent and the temperature 5°C. The ceiling was dry during the below-freezing weather indicating that there was some insulation in the ceiling. Being partially underground and having the bins stacked in rows about 20 cm apart allows enough convection currents to maintain a constant temperature with a minimal amount of mechanical ventilation.

Kirov area. A large collective farm has changed into a joint stock corporation with employees who have been working on the farm as stockholders. They want to increase potato production for processing into starch. They have a plan to build two processing plants to process 20,000 tons of raw material (potatoes initially, adding other crops later) per year in each plant. Two more plants will be built later. With reorganization and owning their own processing plants, the farmers will have more control over production and processing and they hope to improve economic status.

Storage Evaluation

Existing storages at Orlovsky Farm, Farm Russia and in Kirov are well built, reinforced concrete structures between 15 to 30 years old. They are partially underground with soil bermed up along both sides up to the roof line. They all appeared to be in good structural condition. The layout includes a large room about 20 m wide, with various lengths. Air

plenums are located on each side. The storage bays extend from the plenum toward a centrally located 4 m wide alley reaching from one end of the building to the other. This alley is used for hauling potatoes in and out of the building. Filling the bays is somewhat mechanized, but removal of potatoes requires a lot of manual labor to shovel the tubers into a conveyor for loading of the trucks.

Having a central alley reduces the storage capacity significantly. For example, having a 4 m alley through the center of a 20 m wide storage compartment reduces the storage capacity by 20 percent. A central alley may be required for seed potato storage, with several compartments storing different varieties, all requiring access. However, if there is no need to separate different lots, the central alley could also be filled which would increase the storage capacity by 20 percent.

Being almost entirely underground protects the stored product during extended cold periods in the winter and keeps them from freezing. Compared to storages entirely above ground, being underground reduces the exposed area where heat loss occurs and increases the area where heat gain from the soil takes place. This type of storage has been proven successful for severe winter weather that exists in Russia. These can maintain desired storage temperatures even when partially filled and total respiration heat is low. The storages in Kirov, where daily removal of potatoes is required for processing, had long entrances with two doors about 8 m apart to provide a buffer zone to keep infiltration of cold air to a minimum during removal.

Evaluation of Global Steel Storage Facility

The Global Steel storage facility at Farm Russia differs greatly from the existing partially underground storages. The floor is level with the ground surface, thus all of the wall and roof area is exposed to cold outside temperatures. This means that the percentage of exposed area is much larger for the Global building than for existing concrete storages. Therefore, the heat loss per ton of potatoes stored in the Global building will be much higher than in the underground concrete buildings, unless the Global storage is much better insulated and sealed. Also, the heat gain through the floor in the Global building is much smaller because the non-exposed floor area is much smaller than in traditional storages.

Insulation. It is my understanding that the building specifications for the Global storage include 3.5 inches (9 cm) of sprayed-on polyurethane insulation, which provides a heat flow resistance of R21(0.21 $W/m^2 \cdot °K$). This may be enough in a relatively mild climate such as exists in the Columbia Basin, a major potato growing area in the State of Washington with average temperatures of -1°C, -4.4°C, and 0°C for the months of December, January and February. The climate in Russia would be similar to that in North Dakota, where it is recommended to use R-35 (0.16 $W/m^2 \cdot °K$) which requires 15 cm of polyurethane insulation. Also insulation around the periphery is necessary to prevent excessive heat loss near the walls, and prevent freezing of potatoes near the periphery.

Vapor Retarder. An effective vapor retarder is required in storages to keep moisture from penetrating into insulation and other building materials to preclude loss of insulation effectiveness, steel corrosion of reinforcing bars, or wood decay. The installed permeance should not exceed 0.1 perm (6 ng/s · m^2· Pa). Experience in North America has shown that potato storages with humidification and exposed to polyurethane insulation, that an excessive amount of moisture is absorbed by the insulation during the storage season, causing rust in steel or rot in wooden members.

Polyurethane insulation should also be protected with a fire protective coating unless exempted from fire code.

Humidifier. The humidifier is a centrifugal-type which puts a fine mist into the air. With this type of humidifier some moisture is not evaporated and does precipitate in the plenum and possibly in the ducts. Provision must be provided to drain excess water from the plenum. When potatoes get wet from excess moisture, decay usually follows.

A more appropriate type of humidifier for Russian storages may be an evaporative-type, such as "Humidicell", "Velcell"™ and other similar products. These humidifiers are made from cellulose material. The corrugated sheets are arranged into a board with passages for air and water, providing large wet surfaces over which air flows and moisture is evaporated. Major advantage of this system are low power requirements, relatively trouble-free operation and effective humidification with low power requirements.

Other Considerations. Junctions between roof and end walls. When I inspected the building, I observed gaps up to 1 cm wide at some of these junctions. These should be caulked with elastomeric material before applying the urethane insulation to prevent air infiltration in case that cracks develop in the insulation at the junctions.

Need To Determine Ventilation Rate and Uniformity

Although all storages had a mechanical ventilation with an air plenum and duct air distribution system, some of the managers did not know what the total ventilation rate was and how uniformly the air was distributed throughout the storage. At the Orlovsky farm, an attempt was made to measure the velocity of the air flowing out of the pile with an air velometer obtained through PIP. Since the velocity of air coming off the pile is very low, it is impossible to obtain reliable information because the air velocities are below the range of the instrument. In talking with storage personnel, I got the feeling that they don't operate the air systems often enough. In the State of Washington, ventilation fans operate for several hours every day to minimize temperature differences between various locations in the pile. Research results also have shown that with frequent ventilation, there is less sprouting. With low pile height, air flow can be reduced because there is less heat to be removed than with higher piles.

Storage Evaluation Program

Based on my 20 years experience of measuring air flow and distribution and evaluating various types of potato storages in the Pacific Northwest, I have concluded that it is essential to establish a potato storage evaluation program in Russia to document system performance for storage rooms and indicate what improvements, if any, are required for the structure and mechanical system.

Air System Check. A storage evaluation program should include the following steps.

1. Evaluating the ventilation system design. Items included are:
   a) Obtain rated output of fan(s) at 30-40 mm water gauge static pressure.
   b) Determine cross-sectional areas of plenum, ducts, and duct orifices. Also, areas of fresh air inlet and exhaust louvers.
   c) Calculate rated fan output, and air velocities and compare to guidelines.

2. Test system with fan(s) running in an empty room with all ducts in place. Determine air velocities in the plenum, at the duct entrances, and through duct orifices, also inlet and exhaust louvers. Calculate fan output. Compare calculated values to guidelines.

3. Determine uniformity of air flow out of the ducts.

4. Determine improvements required to bring the system to recommended standards.

Note: Past experience has shown that often the fan output is adequate, but there is uneven flow among various ducts and/or uneven flow along the length of the ducts. To correct uneven flow among ducts, appropriate air baffle at duct entrance or partially covering entrance can be used to adjust air flow into ducts.

Humidification. Optimum storage relative humidity (RH) levels should be at least 95 percent during most of the storage season. High RH is especially needed during the suberization and wound healing period. During long term storage, a high RH environment minimizes moisture loss and maintains turgidity in tubers, thus maximizing quality. High humidity and good temperature control keeps the seed pieces physiologically young, resulting in higher yields and larger tubers.

It is important to keep the surface of the stored potatoes dry at all times to prevent physiological disorder and rot, thus it is essential that all moisture added to the ventilating air be evaporated. Nozzle-type and similar humidifiers may produce droplets that don't evaporate and precipitate in ducts and on the skin of the potatoes. This should be avoided.

A more appropriate type of humidifier for regions in Russia with a humid climate is an evaporative type humidifier, even though this type may not provide humidity levels over 95 percent. It is easier to control and simpler to operate and does not require filtration and

treating of the water as is required for mister-type humidifiers to prevent plugging of the orifices.

Visit to Research, Development and Production Corporation, Kalinigrad, Moscow Region.

This is a research and development corporation that produces specialized materials for medical applications (plates, joints, etc.), bearings, optical instruments, and other highly specialized items. They also have developed insulation materials for use under extreme conditions, such as on space ships. This corporation is housed in a huge complex with over 100 large designated areas measuring about 40 m x 40 m, each devoted to some specific project. Until recently, it was used for defense projects. Dr. Moiseev is contemplating the possibility of manufacturing potato storage ventilation systems at this facility.

Another facility under consideration is the Scientific, Research and Project Institute of Biotechnological Industry in Kirov. This is another organization that was involved with defense projects.

Both of these organizations have, no doubt, highly educated, specialized and capable researchers. In the past, they operated in a system where they were provided a budget and all the needs to develop and produce specific processes and products. They were isolated from the "real world" where they must be competitive, and a company has to build things that are competitive in the market place, all within a limited budget.

The question is whether these two organizations are likely candidates to develop and produce potato storage ventilation systems that can be marketed economically for the Russian potato industry. These systems need to include readily available materials and techniques that are reliable, durable and economical.

During the past 20 years, the potato storage industry in the US has developed building techniques using materials and equipment that meet high performance standards with proven durability in a very humid and harsh environment. These systems use readily available materials and techniques that are economical and durable. Ventilation systems use highly efficient fans that operate effectively over a range of static pressure requirement for various storage conditions. Temperature and humidity monitoring and control systems use proven sensors and microprocessors and control panels that offer lasting protection for the electronic system. Remote PC computer programs provide complete storage data year round.

It seems that in the immediate future, complete, assembled and tested ventilation systems ready to "plug in" would offer the most economical and dependable way of upgrading existing storages in NIS. Or they could be built in NIS under a licensing agreement. This would provide immediate access to a proven technology and would prevent major efforts with large expenditures to "reinvent the wheel".

Problem Areas Identified

1. Insufficient insulation in potato storage. Condensation of moisture on inside surfaces during cold weather is an indicator of insufficient insulation. One of the storages visited had a serious condensation problem on the ceiling with outside temperature near freezing. Since condensation increases with lower ambient temperatures and higher humidity levels, it is expected that condensation problems will increase as ambient temperatures get lower and would be much more serious if they had humidifiers to increase the storage humidity to more desirable levels.

2. Insufficient humidity levels without humidifiers. Only one storage checked the relative humidity by measuring wet bulb and dry bulb temperature and subsequent calculating relative humidity. The daily log showed that in the past 10 days the temperature was 5°C and the relative humidity was 90 percent. The accuracy of this method depends on how accurately one can measure the temperatures. Errors of 5 percent are common with this method. High humidity (95 percent or higher) is necessary during the suberization period to enhance wound healing and increase resistance to infection by disease organisms.

3. Significant moisture loss and shrinkage does occur during long term storage, such as is required for seed potatoes. Storing seed potatoes in low humidity causes excessive dehydration and tuber aging which results in lower yields. Since seed potatoes are

smaller than potatoes for table use in processing, the dehydration problem is more severe.

4. Inefficient ventilation system. Example: a 1,000-ton storage had two air systems, one in the floor to distribute air throughout the storage room, the other one near the ceiling to collect the air and return it to be recirculated or exhausted from the room. Both of these systems had a centrifugal fan powered by a 30 kW (40 HP) motor. For a similar size storage in the U.S. Pacific Northwest a ventilation rate of approximately 25,000 cfm (12 m3/s), would be used, utilizing a multi-blade propeller fan powered by a 10 HP (7.5kW) motor. This is only 12.5 percent of the power used in the Russian storage.

5. Uneven air flow. Practices observed that would result in uneven air distribution are (1) varying pile depth (1.5 m to over 3 m), (2) slotted triangular, above-the-floor ventilation duct with excessive slot area, (3) ducts reaching to the end of the pile, thus allowing the air to short-circuit without flowing through the potatoes, and (4) not blocking the openings of in-floor ducts in areas where there were no potatoes stored (for example, in alleys).

6. Removing of potatoes from storage. This operation requires a lot of manual labor to shovel the tubers into the hopper of the truck-loading elevator.

7. Ventilation system testing. Many storage operators suspect that they have problems with uneven air flow, but they don't have the knowledge nor the instrumentation for air flow measurement and evaluation of the entire system.

8. Transportation, handling and sorting equipment. Lack of good equipment and methods for "bruise free" handling is apparent. These problems are addressed in a report by Will Anderson, titled "*Identifying Causes of Potato Bruising in Russia and Ukraine*", August 1993.

RECOMMENDATIONS

1. It is recommended that a potato storage program be established to evaluate various storages, including testing of ventilation system performance and evaluating structural soundness. This program should include documentation of system performance (air flow and uniformity) and recommendation of what improvements, if any, are required for the structure and the mechanical system.

2. Provide educational programs (short course) for storage managers. Topics to be covered in these programs should include principles of storage design, design and operation of aeration systems, control of temperature and relative humidity, and storage management.

3. Demonstrate to storage management personnel how to evaluate potato storages when they are empty, how to determine what improvements are needed and how to implement these improvements. These should be hands-on workshops. Note: Air flow measuring equipment needs to be provided. Participants would need to take a storage short course before participating in this program or the demonstration could be part of the short course.

4. The Global Steel storage structure in the Vladimir region (Farm Russia) should serve as a demonstration model of a modern, state-of-the-art, potato storage structure when it is completed. However, it requires some improvements from the existing plan. The following items need to be addressed: (1) more insulation, 15 cm instead of 9 cm presently planned. (2) insulation needed around the periphery to prevent excess heat loss and freezing of potatoes near the periphery in this area, (3) a vapor barrier needed on the inside surface if the humidifier is used throughout the storage season, (4) junctions between end walls and ceiling need to be caulked with elastomeric material.

5. Production of ventilation system modules for remodeling of old storages and new storage construction: Initially these systems should be imported from the US or built in Russia under a licensing agreement. This would provide Russia immediate access to a proven technology and would prevent major efforts with large expenditures to "reinvent the wheel".

6. Production of ventilation system modules does not require expensive hi-tech materials or components. It includes putting together proven readily available components into a system (module) that can be tested at the assembly plant and be ready to "plug in" at the storage site. A small enterprise could do this most effectively and most economically, as has been demonstrated in the US during the past 25 years.

APPENDIX A

Russian Potato Concern (RPC)

Dr. Yuri Moiseev, President

Nadya G. Rodina, Vice President and Assistant to the President

Gennadiy T. Chanov, Head, Potato Production, Storage and Processing Department

Elena S. Barinowa, Chemical Analysis

Tamara A. Kostenko

Farm Russia

Stepan P. Ginin, President

Alexander Zinakov, Manager of Storage

Orlovsky Farm

Valery Ginin, Manager

Nikolay Khalezov, Storage Manager

Joint Stock Company, Kirov

Victor Sidokov, Director

Matanzev Valeriy, Technical Manager

Scientific and Research & Project Institute of Biotechnology Industry, Kirov

Jury V. Kirillin, General Director

Grigory G. Nekipelov, Commercial Director

Komposit, Research Development & Production Corporation.

Kallningrad, Moscow Region

Valdimir N. Eremenko, Deputy Director General

RAAS Agrarian Institute

Olga Strokova, Senior Researcher

APPENDIX B

DESIGN AND MANAGEMENT OF STORAGES FOR BULK, FALL-CROP, IRISH POTATOES

Developed by the ASAE Environment of Stored Products Committee; approved by the Structures and Environment Division Standards Committee; adopted by ASAE August 1990.

SECTION 1—PURPOSE AND SCOPE

1.1 This Engineering Practice provides a guide for the functional design and management of permanent, bulk storages for Irish potatoes.

1.2 This Engineering Practice applies specifically to the late-crop (fall-crop) area of the United States and Canada. This area is north of 40 deg north latitude. It may be applicable in other geographic areas with similar climatic conditions and potato varieties. For more precise guidelines contact individuals that are knowledgeable about unique local weather conditions and potato varieties.

1.3 This Engineering Practice applies to storages that will hold the product for more than two or three months. Temporary storages are used for shorter periods.

SECTION 2—DEFINITIONS

2.1 **Cool-down period:** The period following suberization when potato temperatures are reduced to desired holding temperatures.

2.2 **Holding period:** The period that follows cool-down. Potatoes are held at a constant temperature which is consistent with end use criteria, and minimizes respiration rates. This period may be two to nine months.

2.3 **Recirculation:** Recycling of air that is contained within the building.

2.4 **Reconditioning period:** The period following the holding period when potatoes are warmed up to improve processing quality or reduce risk of subsequent bruise damage due to handling.

2.5 **Suberization/wound healing period:** The initial storage period when suberin is deposited at the wall surface of exposed cells and when new cells are formed under wound surfaces (wound healing).

2.6 **Sugar accumulation:** Starch cells in the potatoes are converted to sugars that are accumulated. This results in a dark color in french fries and chips and causes a sweet flavor in fresh potatoes.

2.7 **Ventilation:** The process of moving air through the potatoes. It may include recirculation of air within the storage or exchanging inside air with outside air to control temperature, humidity, oxygen level, carbon dioxide level, and condensation.

SECTION 3—GENERAL CONSIDERATIONS

3.1 The main purpose of the storage is to provide conditions that will maintain high tuber quality, control diseases, and provide a marketable raw product with minimal weight loss.

3.2 The layout of the storage should be amenable to mechanized, high-volume loading and unloading systems while minimizing the handling impact on the potato.

3.3 Potatoes for different end uses are stored at different temperature conditions.

3.4 There may be up to four phases of a storage season. Their sequential order is: 1) suberization and wound healing, 2) cool-down, 3) holding, and 4) reconditioning.

SECTION 4—DESIRED ENVIRONMENTAL CONDITIONS

4.1 **Temperature**

4.1.1 **Suberization/wound healing period.** Immediately after harvest, suberization can be accomplished in as few as 3 to 4 days at 18 to 24 °C (65 to 75 °F). However, because of increased disease risk at high temperatures, the most commonly used temperature is 10 to 16 °C (50 to 60 °F) for 10 to 14 d. This period should be lengthened if chipping potatoes do not appear to have the desired low internal levels of sugars or if 10 °C (50 °F) is used with certain disease situations. In years when late blight, leak (pythium spp.) or field frost are severe, potatoes should be brought down to the holding temperature as soon as possible.

4.1.2 **Cool-down period.** During this period, bin temperature is reduced at the rate of 0.3 to 0.6 °C (0.5 to 1.0 °F) per day. If sufficient cooling capacity is not available and final holding temperatures cannot be maintained, cool-down should be done in stages so the potatoes do not reheat during periods of warm weather. Potatoes that are to be processed into chips should be cooled at the 0.3 °C per day rate. Potatoes for all other uses can be cooled at the 0.6 °C per day rate if weather conditions permit.

4.1.3 **Holding period.** When cooling has been completed, the holding temperature should be:

Seed use: 3 to 4 °C (38 to 40 °F), varietal dependent

Table use: 4 to 7 °C (40 to 45 °F)

French fry use: 7 to 10 °C (45 to 50 °F)

Long-term chip storage (over 4 months): 10 to 13 °C (50 to 55 °F)

Short-term chip storage: 13 °C (55 °F)

4.1.4 **Reconditioning period.** Temperatures should be increased above the holding temperature for at least a week before unloading a bin to reduce incidence of subsequent handling damage. This increase in temperature may be needed for several weeks if accumulation of sugars has occurred due to low storage temperatures, and there is a dark color of the subsequent processed product. Temperatures should be:

Seed or table use: 7 to 10 °C (45 to 50 °F) to reduce handling injury or 15 °C (60 °F) to stimulate seed sprouting

French fry use: 10 °C (50 °F) to reduce handling injury

Long-term chip storage or french fry use if there is sugar accumulation: 13 to 16 °C (55 to 60 °F) to enhance internal sugar balance or reduce handling injury.

If a dark color processed product is due to accumulations of sugar because of senescence, raising the storage temperature will increase the color problem. Once the reconditioning temperature has been reached and internal (end product) quality is satisfactory for process potatoes, it is recommended that a bin be emptied within one week. This limits quality degradation during the bin unloading period.

4.2 **Relative humidity.** Relative humidities should be at least 90 to 95% during all phases of normal storage. Maintaining high relative humidity during the suberization period is most important for reducing weight loss. Since much of the weight loss occurs through skin wounds, maintaining the highest possible humidity level is not as critical later in the storage period. Where exterior temperatures may be -18 to -29 °C (0 to -20 °F) for several weeks, it is not feasible to insulate storages to maintain relative humidities over 90%. If late blight, leak (pythium spp.) or frozen potatoes are present, the relative humidity should be reduced to approximately 85% to remove moisture that is freed by cell breakdown. Once the problem is controlled, the relative humidity level should be maintained at 90% or greater. High relative humidities reduce weight loss which reduces the incidence of pressure flattening in deep, bulk piles. The minimum weight loss for continuous ventilation may be estimated by the relationship:

$$L = (A+0.1S)D$$

where

L	=	percentage of original weight lost per week
A	=	0.7 for first two weeks of storage period
	=	0.2 for remainder of storage period
S	=	percentage of sprouts by weight
D	=	water vapor pressure difference, mm of mercury
	=	$P_S(1.00 - RH)$
P_S	=	saturation pressure of water at average temperature of potato, mm of mercury
RH	=	average relative humidity of the air entering the potatoes, a decimal

BEST AVAILABLE DOCUMENT

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Field experience indicates weight loss could be twice that shown in the above relationship if potatoes are immature or there is a high degree of harvest damage.

4.3 Controlled atmosphere. Long-term storage atmospheres with reduced oxygen content are detrimental to potatoes. A level of 1.0% CO_2 should be considered the upper allowable threshold. A common level of CO_2 in ventilated bins is 0.2 to 0.3%.

4.4 Cross contamination/sensitivities. Potatoes should always be stored in the dark. Light causes greening of the potato surface due to chlorophyll development and also initiates glycoalkaloid synthesis that gives a bitter flavor. Potatoes should be stored separately from other fruits and vegetables to avoid transfer of odor or flavors.

4.5 Chemical treatment. If potatoes are to be stored longer than 3 months, a sprout inhibitor should be applied. The most commonly used inhibitor is isopropyl-N-(3-chloro-phenyl) carbonate, CIPC, which is applied in the storage. This controls the sprouting of table and processing potatoes that normally occurs two to three months after harvest. It is volatilized and distributed through the ventilation system after suberization and cool-down have been completed. All exposed structural surfaces and air contact surfaces shall be thoroughly steam cleaned if seed potatoes are subsequently stored in a bin that has been treated with CIPC. Some countries will not allow entry of potatoes treated with CIPC.

SECTION 5—FACILITIES AND OPERATION

5.1 Structural

5.1.1 Wind and snow loads. Design loads should be those specified in ASAE Engineering Practice EP288, Agricultural Building Snow and Wind Loads.

5.1.2 Product loads. Design loads for potatoes should be based on information in ASAE Engineering Practice EP446, Lateral Pressure of Irish Potatoes Stored in Bulk.

5.1.3 Floor loads. The maximum floor load is due to loaded field trucks. If specific information on size of trucks is not available, use ASAE Engineering Practice EP378, Floor and Suspended Loads on Agricultural Structures Due to Use, for design loads.

5.2 Insulation

5.2.1 Thermal requirement. The amount of insulation that is specified for ceilings and exterior walls should be based on the need to avoid condensation at high relative humidities in the storage. Based on interior storage temperature and relative humidity and exterior design temperatures, common ranges of thermal resistance, R, values are:

Walls: 4 to 7 $m^2 \cdot °C/W$ (20 to 40 $h \cdot ft^2 \cdot °F/Btu$)

Ceilings: 5 to 7 $m^2 \cdot °C/W$ (30 to 40 $h \cdot ft^2 \cdot °F/Btu$)

Refer to ASAE Standard S401, Use of Thermal Insulation in Agricultural Buildings, for use of insulation.

5.2.2 Fire retardant. Exposed plastic foam insulations shall be protected with a fire coating as specified in ASAE Standard S401, Use of Thermal Insulation in Agricultural Buildings, unless exempted from fire code.

5.2.3 Vapor retarder. A vapor retarder shall be installed to form a continuous seal on the warm side of the insulation. Six-mil, 0.2 mm (0.006 in.) thick, polyethylene plastic sheets are commonly used. All seams and edges shall be securely sealed. The installed permeance should not exceed 6 $ng/s \cdot m^2 \cdot Pa$ (0.1 $grains/h \cdot ft^2 \cdot in.$ Hg or 0.1 perm) wet-cup test, as specified in ASTM Standard E96, Standard Test Methods for Water Vapor Transmission of Materials. Installed vapor retarder performance is extremely important to preclude wood decay, steel corrosion and rusting of reinforcement bars.

5.2.4 Moisture removal. A vented air space at least 25 mm (1 in.) wide should be provided between the outside face of the insulation and the exterior sheathing of all exterior walls. This provides exterior air movement into the attic space to remove moisture that penetrates the wall vapor retarder. The attic vent area shall be at least 1/150 of building ceiling area. One quarter of the vent area is at each eave and one half is at the roof ridge or gable ends.

5.3 Mechanical

5.3.1 Ventilation system

5.3.1.1 Fan capacity. Recommended capacities vary based on hours of available cooling temperatures, internal storage temperature (product respiration rate), and potential losses due to disease or frozen potatoes. Maximum rates shall be used during the cool-down period and for the control of disease outbreaks or cell breakdown of field frozen product. Ranges in airflow rates are:

Seed or table use: 0.3 to 0.6 $m^3/(min \cdot t)$ (0.5 to 1.0 $ft^3/min \cdot cwt$)

Process storage: 0.6 to 1.0 $m^3/(min \cdot t)$ (1.0 to 1.5 $ft^3/min \cdot cwt$)

With all dampers/louvers in place and with thin-wall, relatively rough ducts (corrugated metal) with hole outlets, fans should deliver the required ventilation capacity at 250 Pa (1.0 in. H_2O) unless specific design considerations require air delivery at a higher static pressure. With thick-walled, smooth ducts (wood, concrete) and slotted outlets, an operating static pressure of 190 Pa (0.75 in. H_2O) is common for the ventilation system. Once holding temperatures are reached, sufficient ventilation capacity to maintain a 1 °C (2 °F) difference between the bottom and top of the pile is required. Operating capacity is often reduced by one half by utilizing intermittent operation, or two-speed fans, or by reducing the number of operating fans.

5.3.1.2 Duct size and spacing. Based on duct roughness and physical dimensions, the maximum velocity should not exceed 5 to 8 m/s (1000 to 1500 ft/min). Maximum duct spacing should not exceed 80% of the pile depth. Spacings of 2.5 to 3.0 m (8 to 10 ft) on centers are common.

5.3.1.3 Duct discharge area. For slotted ducts, it is recommended that constructed, exposed slot area be 1.5 to 4 times duct inlet area. A constructed slot area of three times duct inlet area is commonly used. There is limited information on actual slot blockage by potatoes. If a recessed slot which is not in contact with potatoes is used, a constructed area 0.5 to 1.0 times the inlet area is recommended.

5.3.1.4 Plenum area. The plenum cross-sectional area should be sized so air velocities do not exceed 4 m/s (800 ft/min).

5.3.1.5 Intake and exhaust vents. These should be sized so that the velocity does not exceed 4 to 5 m/s (800 to 1000 ft/min) for the gross area. In very cold climates, these are often sized to handle 80% of the total fan capacity. Successful operation at extremely cold outside temperatures requires that the moist exhaust airstream does not in any way come in contact with the intake vent. An air-lock type chamber or insulated covers are recommended.

5.3.2 Heating system. Supplemental heat may be required to warm the storage structure, warm incoming ventilation air or raise potato temperatures during reconditioning. Typical rated heater output may range from 1.0 to 3.2 kW/100 t (1.5 to 5.0 Btu·h/cwt) depending on storage fill and operating conditions. In a well- constructed, completely filled storage, there is sufficient potato respiration heat so that heaters usually do not operate. All direct combustion heaters shall be vented and have ignition systems that will not flameout in turbulent air conditions. All heaters shall be installed in accordance with prevailing safety and fire codes. Heaters are installed in the fan plenum or in the overhead bin space above the potatoes.

5.3.3 Humidification system. Humidification is required during the storage period. Centrifugal humidifiers, pneumatic nozzles, or high-pressure water spray nozzles, should be downstream from the heaters and near the duct inlets. Provision should be made for containing liquid discharge fallout and channeling it to a floor drain. In locations where hot, dry weather frequently occurs during harvest and the storage cool-down period, air washer systems are used for simultaneous cooling and humidification. System capacity varies with local climatic conditions and the amount of outdoor air being introduced. Common capacities may be as great as 13 to 39 L/h per 100 m^3/min (1.0 to 3.0 gal/h per 1000 ft^3/min) ventilation capacity.

5.3.4 Refrigeration system. Refrigeration systems should be sized based on spring and summer holding conditions. Direct expansion, freon systems, with evaporation coils that are mounted on individual bin ceilings, should be used in multiple bin storages. In large single bin storages, a central compressor and evaporator should be used. All units should operate at 3 °C (5 °F) incoming air to incoming refrigerant temperature difference. Often refrigeration is integrated in an air washer system. Size varies according to local operating conditions. Sizes frequently range from 35 to 50 W/t (6 to 8 Btu·h/cwt). If refrigeration is being used to remove field heat and elevated respiration heat levels at harvest time, larger system capacities are required. Electric, hot gas or room air defrost are common in systems that require defrosting.

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5.4 Electrical and control systems

5.4.1 Electrical service. The electrical service shall conform to the American National Standard ANSI/NFPA 70, National Electrical Code, or the Canadian Electrical Code and local codes where applicable. Service size should be sufficient for lighting, ventilation system, heating/refrigeration system, and potato handling systems. Where available, three phase power should be used. All wiring should be surface mounted (exposed) to protect the integrity of the structural vapor retarder. All boxes should have a drip hole to prevent water accumulation. Nonmetallic conduit should be used.

5.4.2 Control systems

5.4.2.1 Ventilation system. The intake and exhaust dampers/louvers may be controlled with an automatic system that contains a differential thermostat to sense bin-outdoor temperature differences and a proportional thermostat that controls the damper/louver drive motor. In very cold locations, manual damper/ louver control is common. If the intake control motor is exposed to exterior air, it should have an internal crankcase heater. All systems should contain a low limit or safety thermostat that shuts the fan off if there is a damper/louver or heater failure and the duct air temperature becomes too cold. A 24-h interval timer may be incorporated for intermittent fan operation. Motor controllers that vary frequency and voltage may be used to reduce operating fan capacities. All control systems shall have a manual override provision with a mechanical safety lockout for use during servicing. Control panels should be located in the driest possible location.

5.4.2.2 Heater system. Heaters should be thermostatically controlled. If more than one heater is installed in a bin, a 1 °C (2 °F) difference should be maintained between thermostat settings so heater operation is staged.

5.4.2.3 Humidification system. Automatic systems may contain humidistats to control bin relative humidity. Care is required in selecting humidistats because of the high desired relative humidity operating levels and moisture and dirt particle contamination of the sensors. Long-term drift should not exceed 2%RH. All humidistats should be checked periodically with a reliable psychrometer. Systems may be manually operated until water droplets start forming on the ceiling of the bin. Then the humidifiers shall be temporarily turned off.

5.4.2.4 Refrigeration system. In automatic control systems, the operator may have two selections: 1) the refrigeration system will come on only when outdoor air is too warm for cooling, otherwise outdoor air is used; 2) refrigeration operates continuously, except for defrost cycles, because there are no opportunities for outdoor cooling. In manual control systems, a manual on-off switch is used, and temperature should be controlled with a bin thermostat.

5.4.3 Sensor locations. All sensors located in air ducts should be mounted at least 1 m (3 ft) beyond the duct entrance. This tends to insure that mixed air conditions are sensed and reduces the risk of sensors being coated with water from the humidifier discharge in the air plenum. All sensors should be protected from radiant energy and should be in well-protected areas that receive a uniformly mixed representative airstream. In a well-ventilated storage, the highest potato pile temperature is usually located 300 to 400 mm (12 to 16 in.) below the pile surface.

5.5 Operation/management

5.5.1 Ventilation. Air distribution systems are normally operated as pressurized (divided) flow systems rather than suction (combining) flow systems, and the ducts are designed accordingly. Unless cooling or humidification is required, fan operating time should be minimal during the suberization period. Unless very tight dampers or louvers are used, the wind action on a storage will often keep CO_2 levels from becoming excessive. If CO_2 monitoring equipment is not available, the fans should be operated for several hours per day with the dampers or louvers closed to preclude any excessive CO_2 accumulation. If the potatoes are wet, have suffered field frost or there is a high risk of disease breakdown, fans should be run continuously with no humidification until suitable holding conditions are reached. When extremely cold weather conditions and subsequent ceiling condensation occur, several options may be used individually or in combination. The main ventilation fans are often run continuously in storages that have a single exterior structural wall with a vertical air wall which contains discharge slots along the ceiling. If overhead unit evaporators have been installed, their fans may be run. If there are heaters in the overhead bin space, they may be switched on. The subsequent air movement across the ceiling reduces condensation problems.

5.5.2 Control systems. It is recommended that automatic control systems be switched to manual control in winter to preclude damaging the damper/louver motors in case the dampers/louvers become frozen shut. All control systems and sensors should be tightly covered with plastic bags during the application of sprout inhibitor to the bin.

5.5.3 Storage inspection. All bins should be inspected at least once per day to check the bin environment, appearance of the potatoes, operation of the mechanical system, and sensor outputs.

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ASAE S401, Use of Thermal Insulation in Agricultural Buildings
ASAE EP446, Lateral Pressures of Irish Potatoes Stored in Bulk
ASTM E96, Standard Test Methods for Water Vapor Transmission of Materials

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EM2799

POTATO STORAGE AND VENTILATION

COOPERATIVE EXTENSION
Washington State University

27

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POTATO STORAGE AND VENTILATION

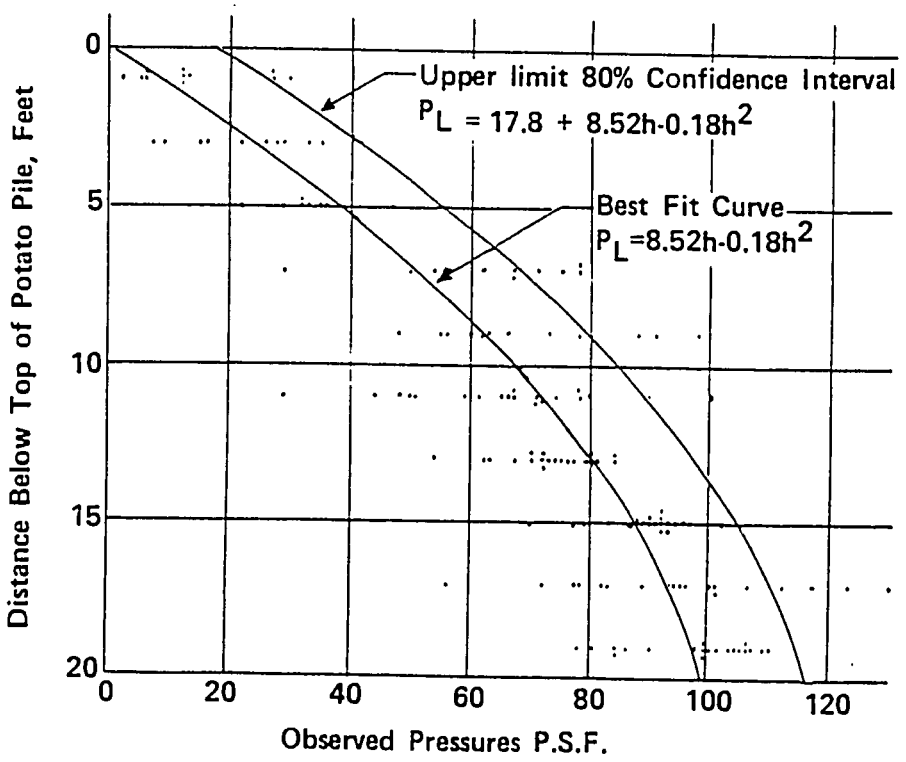
The necessity of maintaining high-quality, sprout-free potatoes over an extended storage period for the processing industry has resulted in an increased emphasis on the proper construction and management of potato storage facilities. Although the fresh market did not make such high demands for quality, the improved potato storage facilities are also increasing the quality of potatoes for the fresh market. The potato processing industry wants a continuous supply of potatoes for their processing lines in order to keep their high investment in machinery working and to maintain a better trained, more interested permanent labor force.

A potato storage properly constructed and managed prevents the development of rot, retards growth of sprouts, reduces dehydration, and reduces the number of pressure bruises.

Wall Pressures

Walls must be constructed to withstand the high horizontal pressures exerted by the potatoes.

Figure 1



The horizontal pressures of potatoes on bin walls were measured at the Red River Valley Potato Research Center a few years ago.

Figure 1 shows the results of the Red River Valley tests. Note the two curves as well as all of the small dots representing actual observed pressure measurements. The dots indicate that the pressures vary tremendously for one reason or another. The upper limit curve includes 80

per cent of the observed pressures but there are still some not included. For this reason, it is safer to use the upper limit curve where, at a depth of 15 feet, the pressure of 105 pounds per square foot is indicated and, at 20 feet, nearly 120 pounds per square foot is the safer figure.

Table 1 summarizes these pressures for various depths of potatoes and indicates what potato storage structures must be designed to withstand.

Table 1. Reaction Forces at Sill and Plate and Bending Moment for Various Depths of Potatoes and Wall Heights–Per Foot of Wall Length

Depth of Potatoes	Height of Wall	Reaction Force– At Sill	Reaction Force– At Plate	Maximum Bending Moment
Feet	*Feet*	*Pounds*	*Pounds*	*Inch-Pounds*
12	14	525	267	17,706
12	18	584	208	22,338
14	16	713	374	27,870
14	20	788	299	34,530
16	18	929	501	41,240
16	22	1,020	410	50,350
18	20	1,169	644	58,240
18	24	1,276	537	70,190
20	22	1,430	805	79,180
20	26	1,554	680	94,460

Walls must be designed to withstand the pressures indicated in Table 1. They apply whether the walls are constructed of wood, steel, or concrete. This is the information that an engineer must use to calculate the size of studs, columns, bin wall sheathing, or bulkhead planks as well as the type and size of fastenings, footings, and other structural members.

Three Storage Periods

There are three recognized storage periods for potatoes: the wound healing and curing period, the holding or storage period, and the removal period.

In the *wound healing and curing period,* immediately after being placed in storage, potatoes need a temperature of about 50 degrees F. and a relative humidity of 90 per cent to heal the wounds caused by harvesting and handling. After maintaining this temperature for two to three weeks, potatoes should be further cooled to the storage temperature.

Conditions for the holding or storage period are a temperature of 45 to 48 degrees F. with 90 per cent relative humidity. If sprout inhibitors have been used, the storage temperature may be as high as 48 degrees but, without sprout inhibitors, a temperature of 40 to 42

degrees F. is necessary to prevent sprouting. Actually the storage temperature is a compromise between the temperature which will best reduce the conversion of starch to sugar and the temperature which will keep sprouting to a minimum. In the potato, starch is turned to sugar at temperatures below 50 degrees F. The lower the temperature the greater the conversion of starch to sugar. Temperatures near 32 degrees F. would best keep potatoes from sprouting; however, very little sprouting will occur at 40 degrees F. If sprout inhibitors are used, very little sprouting will take place during a normal storage period if the temperature is held at 48 degrees F.

In the *removal period* cold brittle potatoes are easily injured. Therefore it is advisable to warm the tubers to a temperature of 50 or 60 degrees F. before removing them from storage. Closing the air vents to prevent cold air from entering the storage is an easy way to raise the temperature. Heat from the respiring tubers will be enough to raise the temperature several degrees in a few days.

Insulation

In order to maintain the proper storage conditions indicated above, a well-insulated, well-ventilated structure is necessary.

There are two functions of insulation in a potato storage. First is the usual function of maintaining proper temperature, and second is to prevent condensation on the inside surfaces. Any condition which causes or permits free water on the surface of the potatoes will enhance the possibility of decay and disease. The function of preventing condensation generally requires more insulation than would otherwise be needed to maintain the proper temperature. Condensation results whenever the temperature of the vapor in the air is cooled to its *dew point*. With high relative humidities the dew point is nearly as high as the ambient temperature. Thus a surface only slightly cooler than the surrounding air will cause condensation. See Table 2.

Table 2. Dew Points at Various Relative Humidities

(Ambient Inside Air Temperature 45 degrees F.)

Relative Humidity	*Dew Point**
96	44
93	43
89	42
86	41
82	40
78	38
74	37
71	36
57	31
44	25
31	18

* Surface temperature where condensation begins.

gaps in the vapor barrier must be repaired and sealed. Even a pin hole will permit a large amount of water vapor to seep through over a period of time. Some insulations, such as expanded polystyrene and polyurethane, have a relatively high resistance to vapor penetration. With these insulations a separate vapor barrier may not be necessary. However, if this insulation is installed as a board, it is very desirable to use a sheet material as a vapor barrier because the joints between boards and between the insulation board and framing members will, in many cases, permit moisture vapor to escape to a colder outside surface where it will condense and drip back through the insulation.

Ventilation

If it pays to store potatoes for several months, it will pay to ventilate to maintain top quality. In general, a ventilation system should force air up through the pile of potatoes. The air must be maintained at the proper temperature and relative humidity.

A practical method of forcing air through a pile of potatoes is to introduce the air into a system of delivery ducts installed under the pile.

Air Requirements: The amount of air required will vary with the storage period, the climate, and the variety of potatoes.

The maximum amount of air is required for the wound healing and curing period. This is immediately after the potatoes are placed in storage. It is necessary to remove the field heat as rapidly as possible to reduce the possibility of creating a favorable climate for the growth of decay and disease organisms.

A minimum of 17 cubic feet per minute per ton of potatoes is required during this period. During harvest, there are relatively few hours per night when the outside air is cool enough to bring into the storage. However, all cool night air should be utilized, and air should be circulated frequently during the day to prevent hot spots from forming within the pile of potatoes.

It would be helpful at this time if refrigerated air could be supplied to the storage in order that the potatoes could be cooled faster.

After the potatoes have been cooled to storage temperature, and after the outside air temperatures are somewhat lower than during harvest, a smaller amount of air, about 7 or 8 cubic feet per minute per ton on an intermittent basis, will maintain storage temperature. This reduced rate will tend to reduce shrinkage from dehydration.

Dropping the air rate can be accomplished by changing the pulley ratio or by using only half as many fans during this period. It may, however, be necessary to use portable fans to circulate air over the top of the pile to reduce condensation in cold weather.

During the removal period, little or no forced ventilation air is required.

The roof of a potato storage should have an insulation resistance (R) of 20 or higher. Table 3 shows how low the outside temperature can drop before condensation begins to form on the inside surfaces of roofs with varying amounts of insulation.

Table 3. Outside Temperatures at Which Condensation Will Appear on Ceilings with Varying Insulation

(Based on Storage Temperature of 45 degrees F. and R. H. of 89 per cent)

Insulation Value R	*Outside Temperature at which Condensation Starts*
9	22.9 degrees F.
12	15.5 degrees F.
16	5.6 degrees F.
20	- 4.2 degrees F.
24	-14.0 degrees F.
30	-28.8 degrees F.

A roof with an insulation value R of 20 will not begin to condense moisture out of the air of a 45 degree F., 89 percent relative humidity storage until the outside temperature drops to 4.2 degrees F. below zero. However, a roof with an R of 9 will not prevent condensation below 22.9 degrees F. The insulation resistance values of sheet metal roofs with varying amounts of insulation are given in Table 4.

Table 4. The Insulation Resistance (R) Values of Sheet Metal Roofs with Varying Amounts of Insulation

	Thickness of Insulation				
	2"	*3"*	*4"*	*5"*	*6"*
Mineral Wool Base*	9.09	12.79	16.49	20.19	23.89
Polystyrene Board	9.69	13.69	17.69	21.69	25.69
Urethane	13.35	19.60	25.85		

* Includes rock wool, slag or fiberglass

Thus, a roof for a potato storage to have at least an insulation resistance of 20 must have 5 or 6 inches of most insulations. For urethane, which has a higher heat resistivity than most other insulations, 3 inches plus is needed.

Vertical walls of potato storages need about three-fourths as much insulation as the roofs or a resistance (R) of approximately 15 in the Columbia Basin Area.

Vapor Barrier: A vapor barrier installed on the inside of wall or roof is essential in keeping the insulation dry. With the inside air at a relative humidity of 90 per cent or more, this vapor barrier becomes much more important than in ordinary dwellings. Any holes, tears, or

High Humidity Required: A relative humidity of 90 per cent is desirable during all of the storage periods and especially during the wound healing and curing period. Relatively large amounts of water are required to supply the desired high humidity during the wound healing and cooling periods. Thoroughly wetting the floors and walls of the storage before filling with potatoes is helpful, but the installation of a humidifier is necessary.

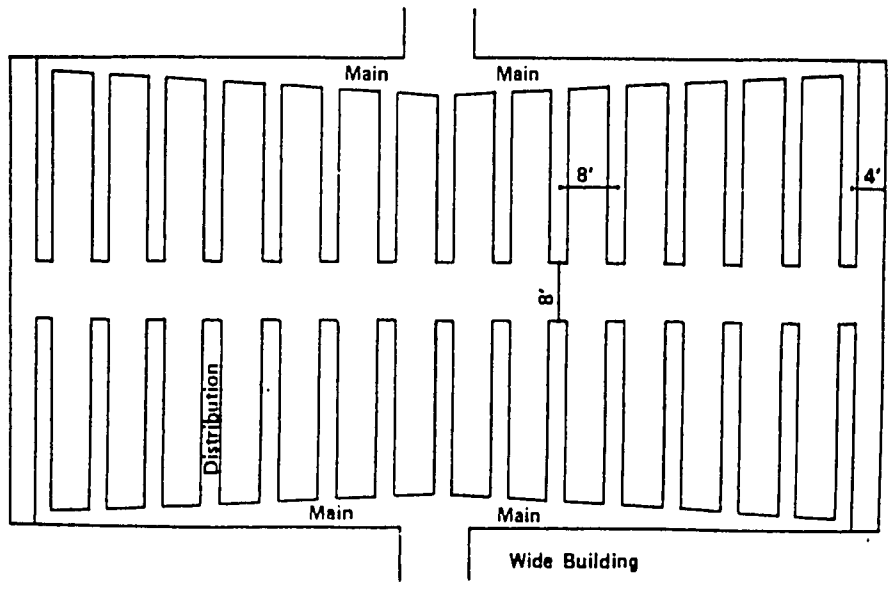
A humidifier consists of spray nozzles or other devices which break the water up into very fine particles for easy evaporation into the air stream.

A humidifier with a capacity of about 1 gallon an hour per 1,000 cfm of air is needed. This amount of water is needed during the healing and cooling period. During the storage period, less moisture is needed per hour, but the fan will operate only a fraction of each hour so roughly the same capacity may be needed for the time the fan is operating.

Using the humidifier for evaporative cooling is discussed later in this bulletin.

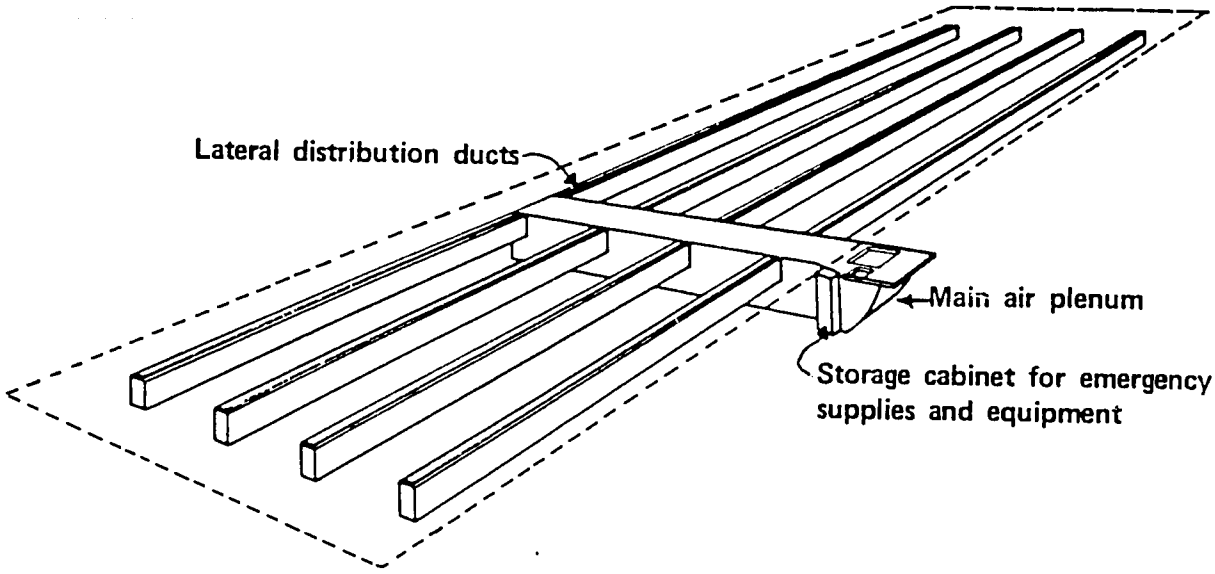
Air Duct Systems: Air delivery ducts may be either portable on the floor or permanent under the floor. Portable ducts of lumber, plywood, or sheet metal can be laid on the floor as the potato storage is being filled.

Figure 2. Portable Above–Floor Duct System



Permanent concrete ducts installed under the floor are out of the way and more satisfactory, though a little higher in first cost. Portable aboveground air ducts use storage space, are in the way of machinery both when filling and emptying the storage, are frequently torn up by equipment, and consequently require considerable maintenance.

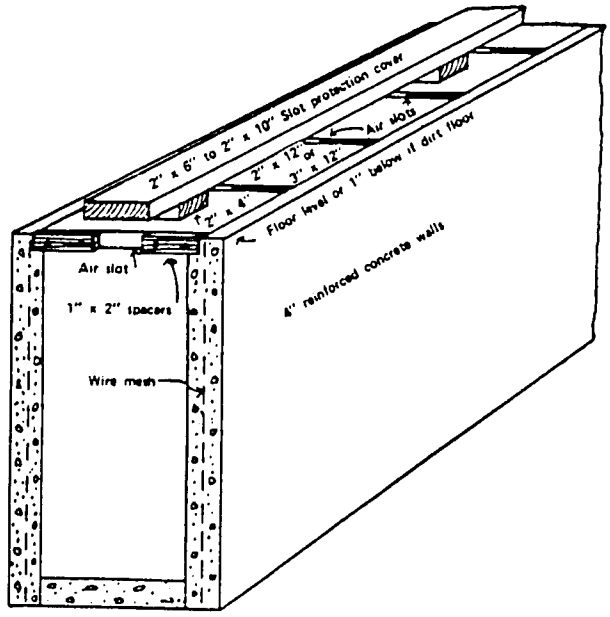
Figure 3. Concrete Underfloor Air Duct System



Distribution Ducts: A section of a nominal size concrete air distribution duct is shown in Figure 4. The sides of this duct can be cast on a floor or leveled sand, then picked up with a tractor loader and placed in the trench.

By using the underfloor air duct system, smaller lateral distribution ducts will result because the main air plenum can be placed in the center to supply air to distribution ducts in both directions.

Figure 4. Section of Air Distribution Duct



Size of distribution ducts: Distribution ducts should be spaced 8 to 10 feet, center to center. They should be 3 to 4 feet in from walls. They should have a cross section of 1 square foot for each 1,000 to 1,200 cubic feet per minute of air they must carry.

For example, if a duct is to supply air to a portion of the pile of potatoes 8 feet wide (ducts 8 feet apart), 20 feet deep, and 50 feet long, it should have a cross section area of 2.7 square feet. This is calculated as follows:

Volume of potatoes = 8 x 20 x 50 = 8,000 cu. ft.

Weight of potatoes $\frac{8,000}{50}$ = 160 ton (based on 50 cu. ft. per ton)

Rate of air required = 160 x 17 = 2,720 cu. ft. per minute
(based on 17 cfm per ton)

Area of cross section = $\frac{2,720}{1,000}$ = 2.72 sq. ft.
(based on 1 sq. ft. per 1,000 cfm)

A nominal size for such a duct would be 14" x 28" (14 x 28 ÷ 144 = 2.72 sq. ft.) Is is advantageous for the duct to be deeper than it is wide; thus keeping the length of the cross cover plank to a minimum. However, it should not be more than 2½ times as deep as it is wide, for efficient air movement.

The air slot between cover planks, Figure 4, is of critical size depending upon the amount of air to be discharged. It is suggested that 1" x 2" spacers be nailed to one edge of each cover plank in such a way that they leave a slot in the center of the duct 3/4 inch wide and the correct length.

Based on a pressure within the duct of about ½ inch of water, each square inch of opening will discharge approximately 13 cubic feet of air per minute. If the ducts are spaced 8 feet apart, center to center, and 17 cfm per ton of potatoes is required, the length of a 3/4-inch wide slot every 12 inches of duct can be obtained from Table 5.

Table 5. Length of 3/4 Inch Slot to Provide 17 cfm of Air Per Ton from Ducts 8 Feet Apart

Depth of potatoes–feet	10	12	14	16	18	20
Length of 3/4" slot–inches	2-7/8	3-3/8	4	4-1/2	5	5-5/8

Note: If ducts extend toward but not to a wall, allow extra slot width for the distance not covered. For example, if the duct ends 3 feet from the wall, make the last slot 3 times as long as the others.

Slot protection covers: Since the size of slot is critical, any closing of the slot with potatoes or dirt is undesirable. A plank about 2 inches wider than the length of the slots should be positioned about 2 inches above the slots. A simple way to do this is to nail 2" x 4" cleats to the underside of the plank about every 3 feet. See Figure 4. When unloading the storage, this plank can be pulled out as it is cleared of potatoes to provide a smooth floor for operating mechanical equipment.

Circular distribution ducts: Distribution ducts of circular cross section may have some advantages costwise over rectangular ducts when standard aluminum, steel, or concrete pipe is used. This is true especially in the smaller sizes.

As with rectangular openings, the discharge through a circular opening may be considered to be 13 cubic feet per minute per square inch when the static pressure within the pipe is the assumed ½ inch of water.

Although decreasing the size of the duct along its length is not necessary to maintain uniform pressure, it can be done as a means of reducing the cost of air ducts. However, a pipe with less cross sectional area than 1 square foot for each 1,200 cubic feet of air per minute should not be used. Table 6 gives the area and maximum suggested air flow for each size of pipe.

Table 6. Circular Pipe Areas of Cross Section

Inside Diameter	Area of Cross Section	Air Capacity at 1,000 Ft. Per Min.
Inches	*Square Feet*	*Cu. Ft./Min.*
8	0.35	350
10	0.54	540
12	0.79	790
15	1.23	1,230
18	1.77	1,770
21	2.41	2,410
24	3.14	3,140
27	3.97	3,970
30	4.91	4,910

When circular pipe is laid on the floor, air discharge holes should be on each side near the floor. Holes 1 to 1-1/2 inches in diameter may be used. See Figure 5. For pipe spaced 8 feet o.c., air discharge holes may be spaced according to the depth of potatoes as shown in Table 7.

Figure 5. Circular Pipe with Air Discharge Holes

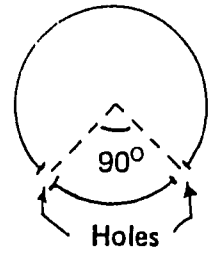


Table 7. Spacing of 1 and 1-1/2 Inch Holes on Each Side of Circular Pipe to Ventilate Various Depths of Potatoes. Ducts Spaced 8 Feet o.c. for 17 cfm Per Ton

Depth of potatoes–feet	10	12	14	16	18	20
Spacing of 1" dia. holes	9"	7-1/2"	6-1/2"	5-1/2"	5"	4-1/2"
Spacing of 1-1/4" dia. holes	14-1/8"	11-3/4"	10-1/8"	8-7/8"	7-7/8"	7"
Spacing of 1-1/2" dia. holes	20-3/8"	17"	14-1/2"	12-3/4"	11-3/8"	10-1/4"

Ends of the circular ducts must be closed, but a few extra holes in the end will provide air to the potatoes beyond the end of the duct.

Main Underground Plenum: The main plenum, if it is underground where it will not take up storage space, should be of masonry construction. See Figure 3. Its top should be flush with the floor of the storage and reinforced to support the maximum depth of potatoes. For potatoes 20 feet deep, it should be designed for 800 pounds per square foot. The walls should be reinforced, also, especially with a dirt floor, since in this situation, it becomes virtually a retaining wall.

The cross section of the main plenum should have 1 square foot for each 1000 to 1,200 cubic feet of air per minute. Its size can be calculated by multiplying the total capacity of the storage, in tons, by the recommended rate of air per ton. For example, a storage 50 feet wide, 100 feet long, with potatoes 20 feet deep will need a main plenum of 34 square feet if 17 cfm per ton is required. It is calculated as follows:

Volume of potatoes = 50 x 100 x 20 = 100,000 cu. ft.

Weight of potatoes = $\frac{100{,}000}{50}$ = 2,000 tons
(assuming 50 cu. ft. per ton)

Air flow required = 2,000 x 17 = 34,000 cu. ft./min.

Area of main plenum = $\frac{34{,}000}{1{,}000}$ = 34 sq ft.

Nominal size = 6' x 5' 8" (6 x 5-2/3 = 34)

Fallout Shelter: An extra bonus, at no extra cost, for a large underground air duct system is its value as a fallout shelter. The main plenum is always large enough to admit people. It will have a protection factor of about 50 when the storage is empty and in the neighborhood of 1,000 when filled with potatoes.

All that is necessary to use it as a fallout shelter, in case the need should arise, is to shut down the fan and enter through an existing trap door. An additional feature that would make it more valuable as a fallout shelter would be a small concrete enclosed storage cabinet, off one side of the plenum, where canned food and emergency equipment may be stored. See Figure 3. Without this, however, it would still be useable as a fallout shelter, assuming that there will be time to carry supplies and equipment into it after the attack warning is sounded.

Main Aboveground Plenum: The size of an aboveground plenum is determined by the same method used for the underground plenum. In small storages, the main plenum may be placed across one end with the lateral or distribution ducts taking off from it at 8- to 10-foot intervals. For large storages, those over 3,000 tons capacity, it is more common to run the main plenum lengthwise of the building. It can be on one side, both sides, or down the center. The lateral or distribution ducts take off every 8 or 10 feet and, in order not to be cumbersome, should not be over 60 feet long–50 feet is better. This limits the width of the potato structure to about 50 or 100 feet. For a 50-foot-wide storage, the plenum usually is placed on one side; whereas, in a 100-foot storage, the plenum may be placed in the center or two plenums may be used, one on each side.

Location of fan room: The fan room also serves as a mixing chamber where cold air from outside is mixed with warm return air from inside to supply the desired temperature air to the plenum and air ducts. With the plenum on the side, either one side or both sides, the fan room should be located at the center of the side. This reduces the plenum to a size 1/2 as large as if the fan was placed at the end of the plenum; the reason being that, with a fan room located at the center, the air splits, 1/2 of it going each way. For very large storages or when two or more fans are needed on one side, it is sometimes advantageous to put two fan houses on one side so that the total air required for this side is split up into four parts rather than just two. This, then, will decrease the required cross sectional area of the plenums to 1/4 that required if one fan location was selected at the end of the plenum.

Fan Size and Specification: The size of fan can be determined by providing the air requirement per ton during the wound healing period for the total capacity of the storage. See sections on Air Requirement and on Main Plenum for calculations of total air requirement. After the wounds are healed and the potatoes cooled to the storage temperature, a requirement of approximately half this is all that is necessary. The ducts and fan, however, should be designed for the maximum air requirement.

With ducts of adequate size, a static pressure may be estimated at approximately 1.0 inches of water. This, of course, will vary with the length and size of ducts, the type of louvers, and other openings; but 1.0 inches of water may be taken as a fairly safe assumption.

The type of fan most frequently recommended for potato storage ventilation is a centrifugal fan with backward curved blades. This type has good efficiency, will deliver a fairly constant amount of air at varying pressures, and will not overload at low pressure.

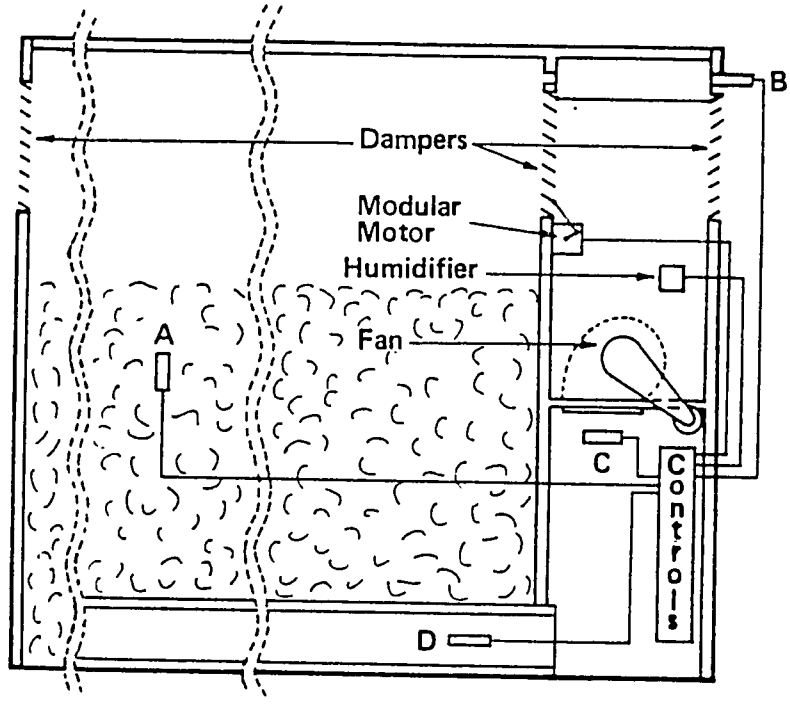
Controls and Accessories: The fan should be started and stopped by means of a thermostat in the pile of potatoes.

If the potatoes need to be cooled, cool outside air must be supplied. If, however, when the potatoes need to be cooled the outside air is warmer than the potatoes, the fan must not circulate outside air. It must, however, be capable of recirculating the inside air at these times to prevent the formation of "hot spots" within the pile of potatoes.

Air must be circulated intermittently to maintain a uniform temperature throughout the storage. Sometimes the outside air is too warm, while at other times it may be cold enough to freeze the potatoes. Therefore, a system of dampers must be used so that outside air can be mixed with inside air in quantities sufficient to cool but not freeze the potatoes.

A rather complicated set of controls is required. Controls are available for the automatic operation of such a system. Automatic controls are recommended not only as a labor saver but because they can maintain a more constant temperature and humidity than is possible manually. See Figure 6.

Figure 6. Diagram of Control System



The sensing element (A) in the potato pile activates the control which turns the fan on and off. The thermostatic unit (C) operates the damper control to regulate automatically the amount of outside and inside air necessary for the desired cooling temperature. Thermostatic unit (B) closes the outside air inlet damper whenever the air is warmer outside than is desired inside. Thermostatic unit (D) prevents freezing by stopping the fan in case of malfunctioning equipment.

Cooling Potatoes with Night Air, Evaporation, or Refrigeration

Cooling potatoes in storage is most commonly done with cool night air and, in many cases, some evaporative cooling. Refrigerated air is used occasionally and, of course, cools very well but is more expensive. Ice may, in some cases, be feasible and adequate for short periods of cooling.

From the standpoint of controlling disease or rot organisms, it is advisable to cool the potatoes quickly when they are placed in storage. However, lowering their temperature too far and too fast may interfere with needed suberization or wound healing. It appears that lowering the temperature to 50 degrees F. immediately or within the first 24 hours is most desirable. After suberization is complete, their temperature may be lowered on down to 45 degrees F. or whatever storage temperature is desired.

Amount of Cooling Required: Cooling is the removal of heat. The amount of heat to be removed is mainly from two sources: the field heat of the potatoes and the heat of respiration. Other minor sources of heat include the heat that is transferred through the walls and roof, outside air infiltration, and miscellaneous items such as electric motors, tractors, trucks, and men working.

Heat of respiration: Potatoes are living things and as such respire. In this process, they give off heat. The amount of heat given off depends upon their temperature and the amount of wound healing taking place. Figure 7 shows graphically the amount of heat of respiration given off during the first 30 days of storage.

The wound healing period is considered to be the first 10 to 15 days in storage. Suberization or wound healing causes much more heat of respiration than normal so these curves begin high, decrease during suberization, and then level out for the long storage period.

Heat of product: Field heat within the potatoes is referred to as heat of product. A certain amount of heat must be removed from a tuber at field temperature to bring it down to 50 degrees F.

In Figure 8, the heat of product (field heat) line starts high on the first day of storage and gradually decreases. These values are based on the premise that sufficient heat is removed from the potatoes in the first 24 hours to reduce their temperature to 50 degrees F. It decreases every day because normally the average daily temperature decreases. The total amount of heat is based on placing 200 tons of potatoes in storage every day.

Heat of respiration (Figure 8) is small the first day because there is only the first 200 tons in the storage. It increases each day as the amount of potatoes in storage becomes larger. On about the tenth day, the rate of increase lessens because the potatoes placed in the first day have completed their wound healing period. In 25 days, at 200 tons per day, the 5,000 ton storage used as an example will be filled. Therefore, on the 26th day, the heat of respiration begins to drop, and since no potatoes are brought in, there is no heat of product to remove. This is continuing the assumption that each day's potatoes are cooled to 50 degrees F. the first day. After about 40 days, when all of the potatoes have completed their wound healing period, the heat of respiration line would continue horizontally during the remainder of the storage period.

Heat of transfer, although only a small part of the total, decreases each day along with the decrease of the average daily temperature. It actually goes negative; that is heat is transferred out instead of in, when the outside average daily temperature is lower than inside temperature.

The miscellaneous heat gain virtually stops when the storage is full, doors are closed, piler motors, tractors, trucks, and workers have been removed.

Figure 7

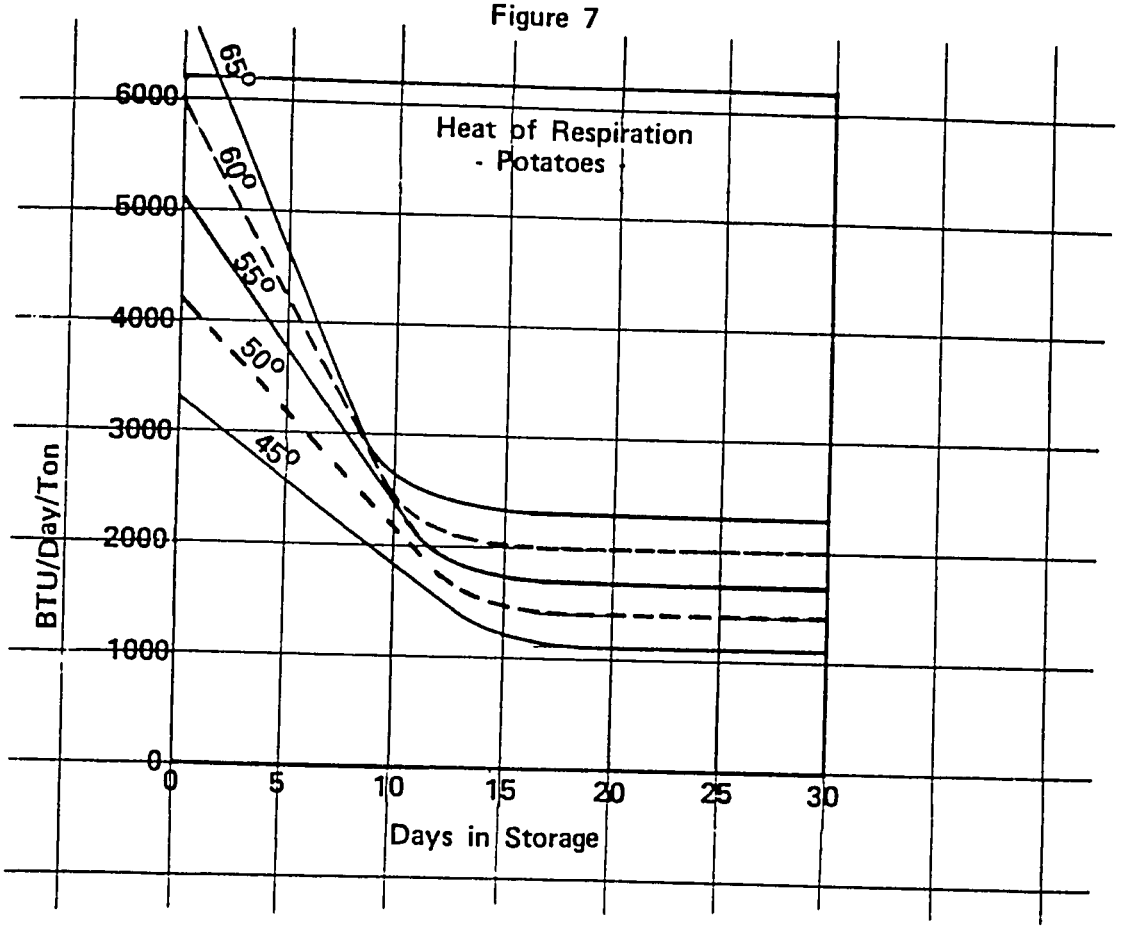
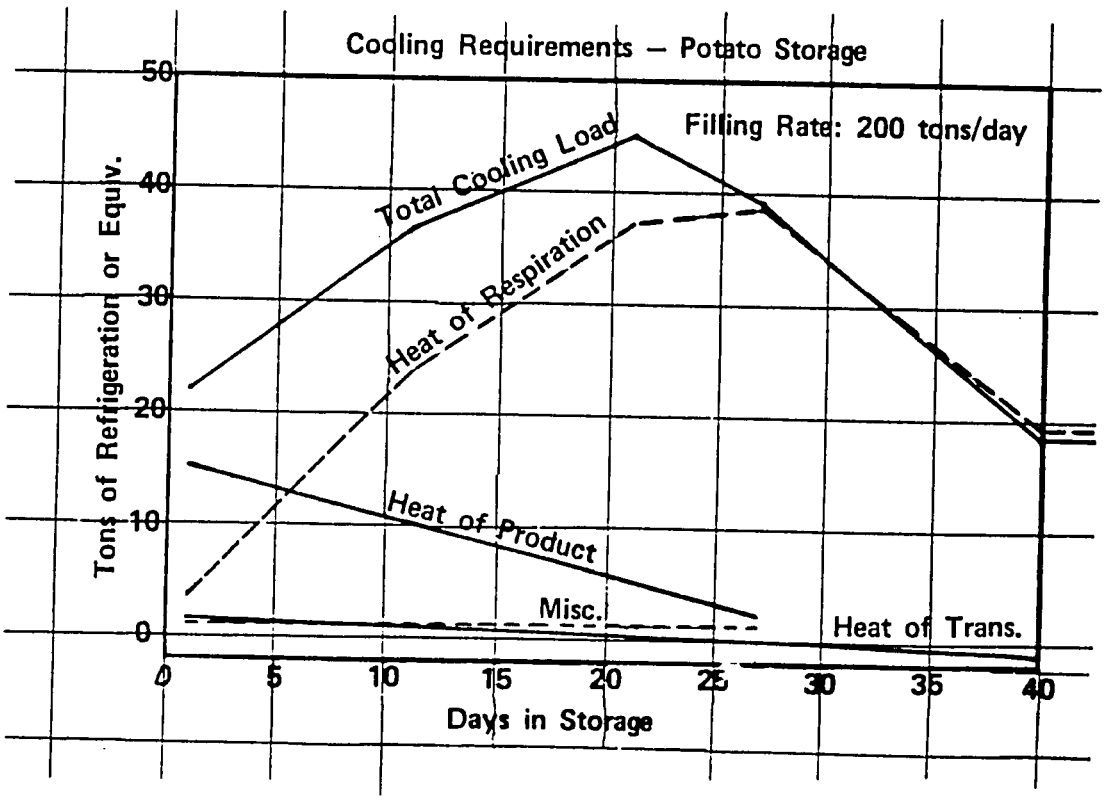


Figure 8

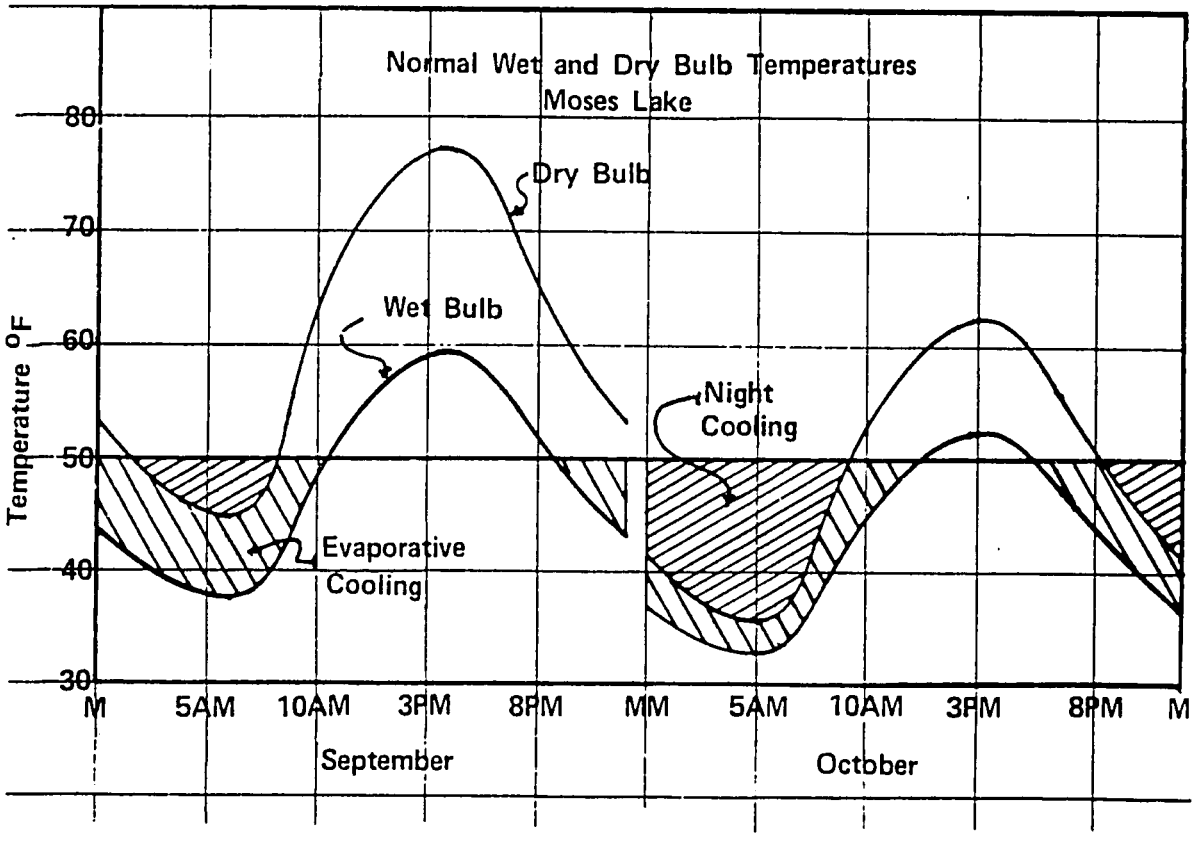


Amount of Night and Evaporative Cooling Normally Available

Night cooling: Figure 9 indicates that amount of cooling available from normal days in September and October. Normal dry and wet bulb temperatures at Moses Lake are the basis. If the potatoes in the storage from a previous day's loading are to be maintained at 50 degrees F., *no outside air above 50 degrees F. can be admitted.* Thus, only air with a dry bulb temperature (ordinary thermometer temperature) below 50 degrees F. can be used for cooling. In Figure 9, the normal night cooling is only that part of the graph where the dry bulb temperature is below 50 degrees F.

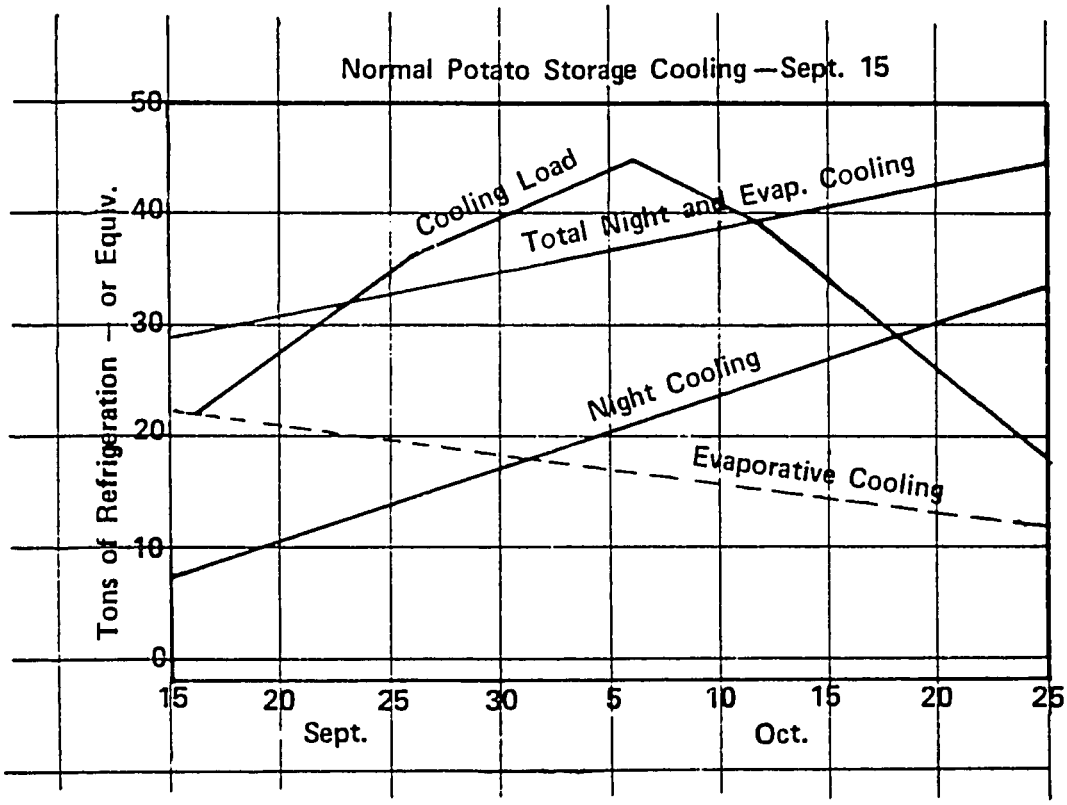
Evaporative cooling: Heat is required to evaporate water. Thus, when water is evaporated into air, the heat must be obtained from somewhere. In the case of ventilating air, about the only source of heat is the air itself. Thus, when water is evaporated in a stream of ventilating air, heat is withdrawn from the air; thereby lowering its temperature. The theoretical limit to lowering the temperature is the wet bulb temperature. The wet bulb temperature represents the point at which the air contains all the water vapor it can hold. Thus, no more can be evaporated into it. Therefore, the dry bulb temperature of air cannot be lowered below its wet bulb temperature by evaporation. Actually, on a practical basis, the dry bulb temperature can only be lowered about 80 per cent of the difference between the dry and wet bulb readings and this only with special equipment designed to obtain the maximum evaporation of water into the air stream.

Figure 9



Comparison of Cooling Needed to Cooling Available: Calculations have been made for normal storage seasons beginning at two dates at Moses Lake: September 15 and September 25. In neither case does night air alone provide adequate cooling. However, by beginning on September 25, night cooling plus good evaporative cooling is adequate for the normal year.

Figure 10



In years when temperature is higher than normal, night cooling plus all available evaporative cooling is likely to be less than needed to cool the potatoes to 50 degrees F. in the first 24 hours. It is these years that make refrigeration attractive for cooling. Refrigeration may also prove beneficial to lengthen the storage season the following spring and summer.

Methods of Obtaining Effective Evaporative Cooling: The more water that can be evaporated into the air stream before it enters the pile of potatoes, the greater will be the cooling effect.

Many small, even microscopic, droplets evaporate into an air stream much easier than larger droplets or sheets of water. Thus, equipment that breaks up the water into a mist containing very small droplets is desirable.

Ordinary humidifying equipment creates minute droplets, but it is not entirely satisfactory for evaporative cooling. Most of the equipment available for evaporative cooling or humidification is designed to operate at higher temperatures, 70 degrees F. and above. To be effective in cooling potatoes to 50 degrees F. or below, they must operate at 60 degrees F. or lower. If wetted pads are used, as in ordinary evaporative coolers, such a large pad area is required that it becomes very cumbersome.

Measurements of existing humidifying equipment installations indicate a fairly insignificant amount of evaporative cooling. For example, humidifiers that appeared adequate for humidification gave only 0.5 to 3.5 degrees F. of cooling in an air stream with a temperature between 40 and 60 degrees F. This same equipment did improve when more water was forced through it. For example, with three times the recommended amount of water going through, cooling of from 3.5 to 10 degrees F. was obtained. In the latter, only about 70 per cent of the potential evaporative cooling (70 per cent of the difference between dry bulb and wet bulb temperatures) was realized.

It is possible that equipment designed specifically for these conditions will be available in the future and will provide more efficient evaporative cooling. Spray nozzles, such as those used in cooling towers, may be placed in the main plenums to provide effective cooling. Whatever system is used, the plenums should be so constructed that excess water falling on the floor will drain away or back into a pit from which it can be recycled through the spraying system.

Refrigeration: Refrigeration is, of course, an excellent method of cooling. It is, however, more expensive than using night air and evaporative cooling.

If refrigeration is to be installed, the size of the refrigeration system as well as the cost of operation can be reduced by making full use of night air and evaporative cooling; too. Referring to Figure 10, only the difference between the cooling load and cooling available from night air and evaporative cooling need be installed for normal years. For the warmer than normal harvest seasons, it would be well to have perhaps 20 per cent more refrigeration capacity than is indicated for the normal year.

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