POTATO STORAGE AT JOS, NIGERIA USING EVAPORATIVE COOLING PAD SYSTEMS

by

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INTRODUCTION

The purpose of this paper is to correlate the information to existing conditions on the Jos Plateau of Nigeria and to propose a design data for the storage system. Because of the end use of the potato crop (as table stock) in Nigeria, the paper inclines more to the storage of table stock. Nevertheless, a few points of comparison between table stock and potatoes based on other end uses are mentioned.

Potatoes are not one of the major commercial crop in the country, but there is a great potential for the crop. For that reason it is not advisable to invest much in a potato storage project, and this is why this system is designed to use evaporative cooling pads which is relatively economical as compared to high power cooling systems.

COMPOSITION OF TUBERS

To provide for effective potato storage, it is necessary to have some knowledge of the potato: what it is, its composition, its responses to varying conditions and the favorable conditions for its storage.

The potato is a living plant that is continuously respiring at some level of intensity, therefore it should be considered perishable. The potato tuber is formed from the rhizome when elongation of the rhizome stops and enlargement starts.

The major parts of the matured tuber looking from the outside are the periderm, cortex, vascular ring which is surrounded by vascular storage parenchyma tissues and the pith (See Figure 1). The periderm has a thickness

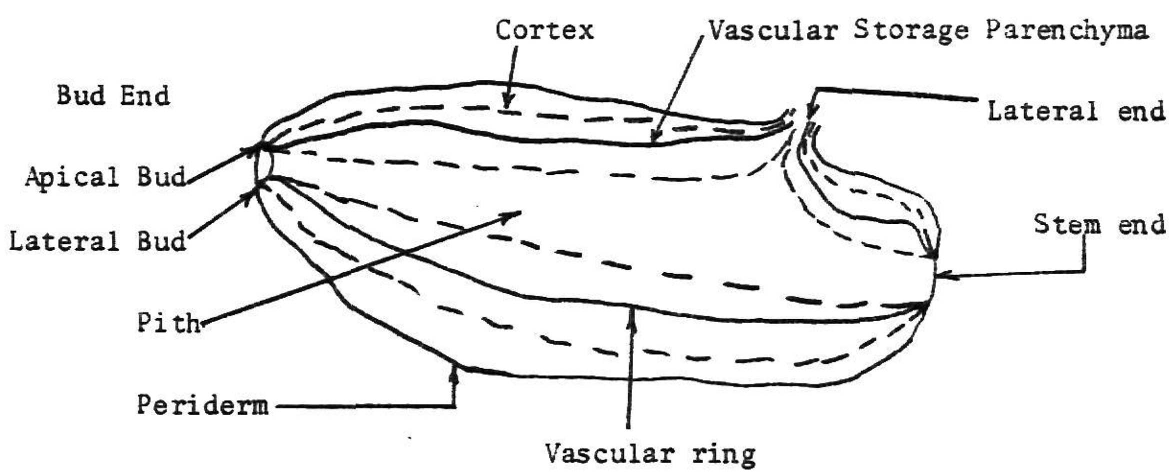

Fig. 1. Principal Parts of a Potato Tuber

of six to ten cell layers and acts as a protective coating over the tuber. The cortex is a storage tissue characterized by its narrow band of storage tissue. The outer layer of the cortical cells contain protein crystals, tannins, pigments, and some starch. The narrow vascular cylinder zones contain secondary xylem and phloem conductive tissue. The storage parenchyma is immediately inside the vascular ring. The pith cells are lower in starch, higher in water content and more translucent than the other tissues.

Tuber Cell Composition

A potato tuber contains about 10-100 million cells, each about 0.1 to 0.2 mm in diameter and are joined together by pectins. Between the cells are the gaps which account for the two per cent of the tuber volume. The bulk of the tuber consists of water which makes up about 75-80% of the tuber. This water can evaporate easily from any exposed part of the tuber and that is bad.

The potato cell contains sugar, amino acids, proteins, mineral salts, and other constituents which although they may seem insignificant, affect the nutritive value of the potato. There are chemical changes constantly taking place in the tuber, such as the conversion of starch into sugar and back to starch depending on the temperature. Potatoes store best between 35-45°F. At 30-35°F the conversion of starch to sugar takes place and below 30°F the potato freezes. At temperatures above 42°F the sugars in the potato are converted back to starch.

OBJECTIVES OF POTATO STORAGE

The most important goals considered in potato storage are to:

1. Maintain minimum respiration - During respiration the tubers take in oxygen and give out carbon dioxide, water and heat. The respiration rate increases at temperatures below 38°F resulting in rapid weight loss and reduction in quality.
2. Retain water in the tubers - This is an important factor to consider because the marketability of the potato is dependent

on the moisture content of the tubers. The tuber could be considered to be of 100% R.H. And because the relative humidity of the environment is always lower than that of the tuber, there is a vapor pressure deficit. The greater the deficit, the greater is the water loss from the tuber. Therefore, a relatively humid environment that is free of condensation is required for storage.

3. Control temperature based on end use - High temperatures favor the maintenance of starch or the conversion of sugar to starch. At 42°F the sugars are gradually converted to starch. The reaction speeds up at higher temperatures but temperatures higher than 55°F may activate bacteria causing the potato to rot.
4. Maintain appearance - It is highly impossible for potatoes coming from storage to look as good as they looked before going in but with careful attention, much of the appearance is maintained, and this is accomplished by maintaining the right temperature and humidity.
5. Protection from light - Greening on the surface of the potato occurs after prolonged exposure to light. This greening is objectionable to the buyer, thus affecting the grade and ultimately the price.

CONSIDERATIONS FOR STORAGE

Damage occurs to potato tubers during harvest, which can result in diseased tubers, weight loss and this influences the kind of care to be given the potatoes at storage. Fig. 2 demonstrates the influence of curing and of the relative humidity during curing on subsequent weight loss. For an illustration of how weight loss of adequately cured tubers are affected by storage duration, temperature, and potato variety, see Figures 3 & 4 (pp. 7-8).

The total storage period may involve three stages:

1. The curing period
2. The holding period, and
3. The removal stage.

It is essential that wounded potatoes undergo suberization which is a would healing or curing period. At this stage the tubers are subjected to temperatures between 45°F and 65°F and relative humidity of about 90-95% for a minimum period of 7 days. It is advisable to suberize at temperatures that will be close to storage temperature to avoid drastic changes which may result in shock. The desirable storage temperatures depend on the potato use:

For seed and fresh use store between 35°-40°F
For dried or flaked potatoes store at 45°F
For French fries store at 45°-50°F
For chips store at 50°-55°F

These temperatures should be maintained at ± 2°F.

The practical consequences of the relationships mentioned in the preceding paragraph is the influence on weight loss in storage cooled especially by forced ventilation and outside air. Figure 5 illustrates this point further by presenting the relationship between time, vapor pressure deficit and weight loss for three varieties. Figure 5 also illustrates that it does not matter how the drying effect is obtained, the tubers would lose as much moisture if they were kept for one day under very dry conditions as

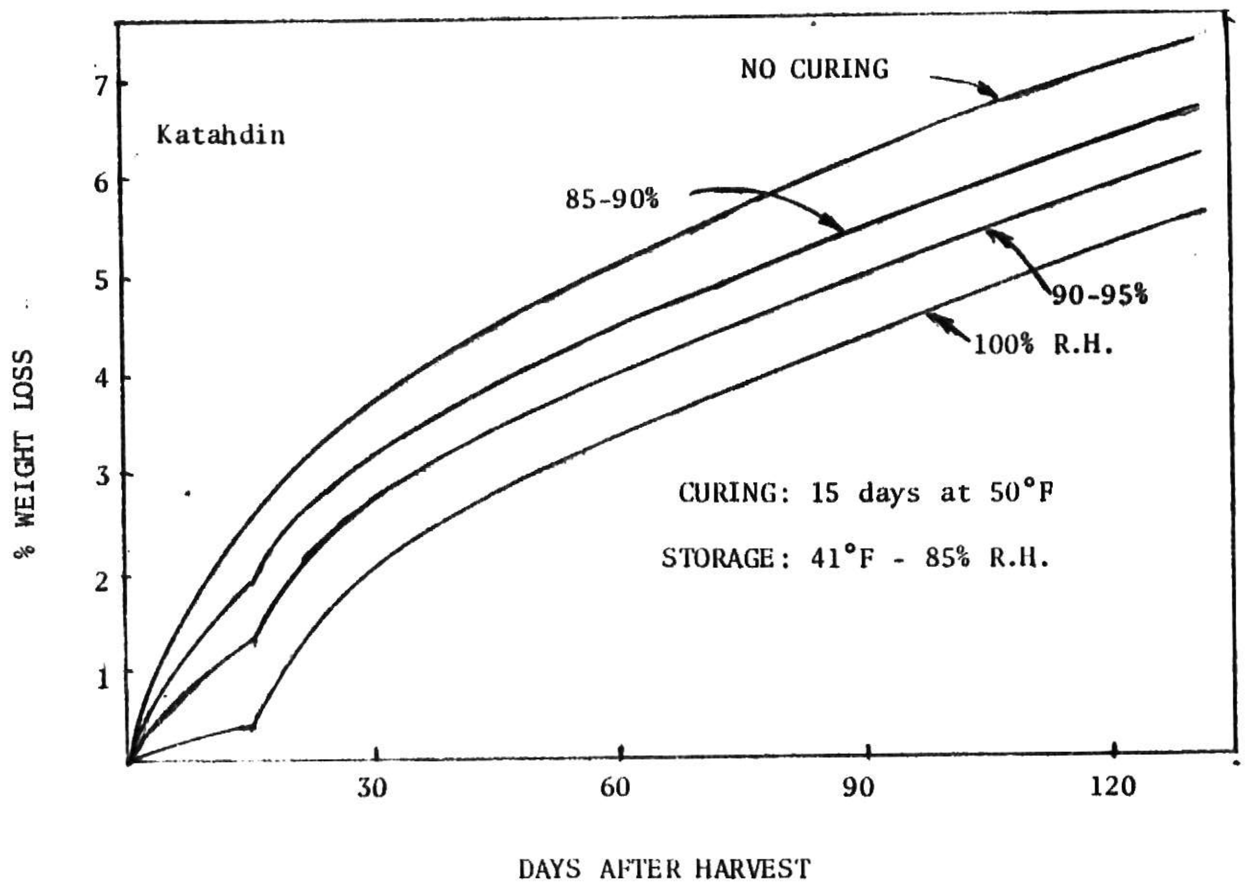

Fig. 2. Percentage Weight Loss of Potatoes during Storage under Influence of Preceding Curing Conditions

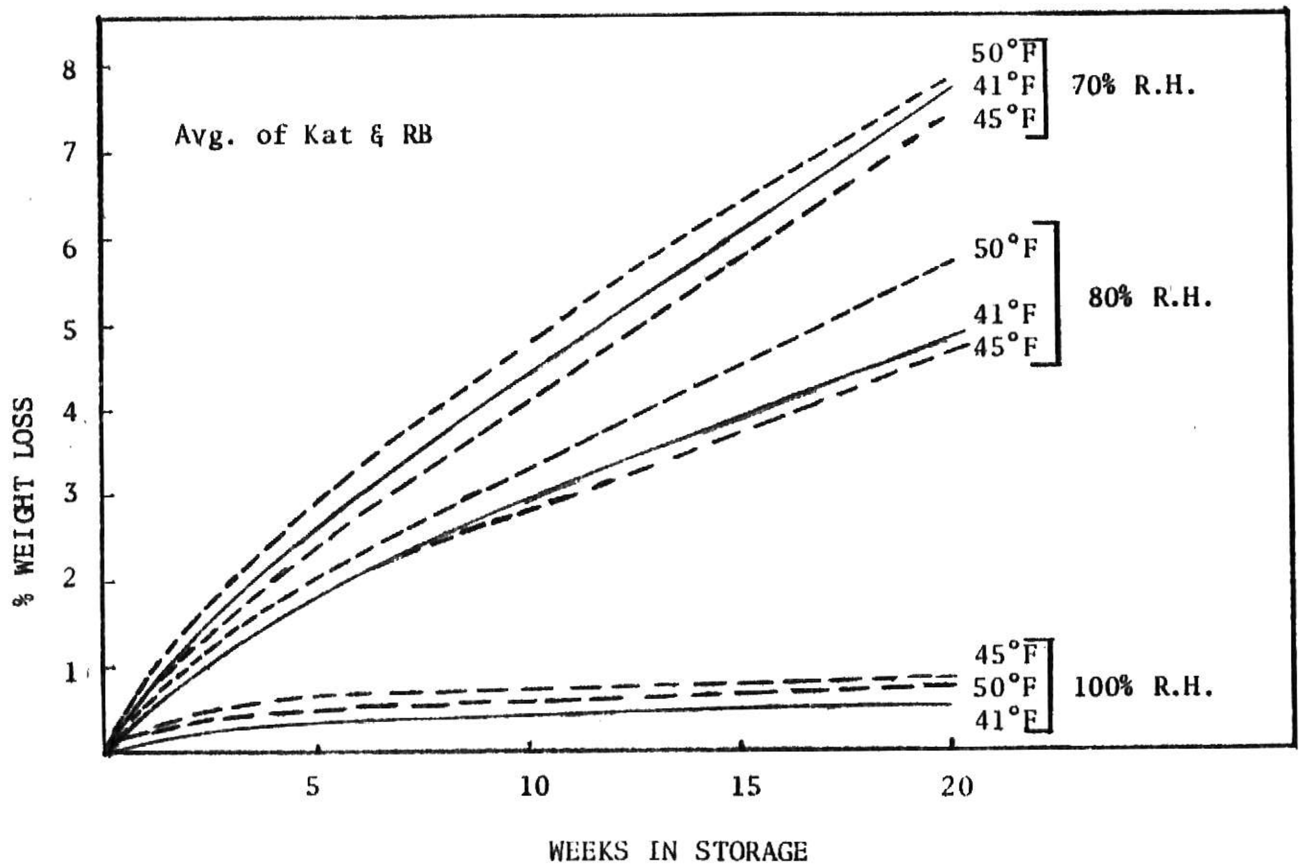

Fig. 3. Weight Loss of Potatoes during Storage at Various Temperatures and Relative Humidities.

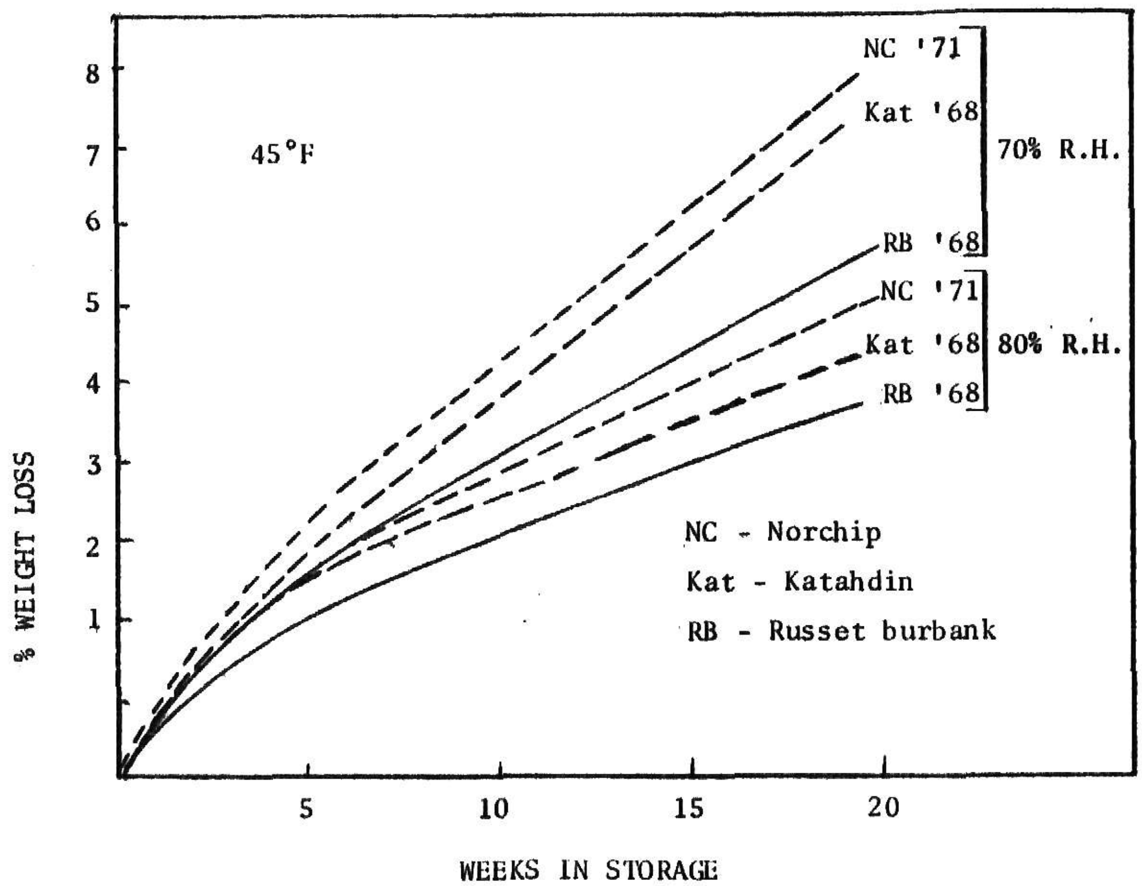

Fig. 4. Weight Loss of Potatoes during Storage at Two Relative Humidities.

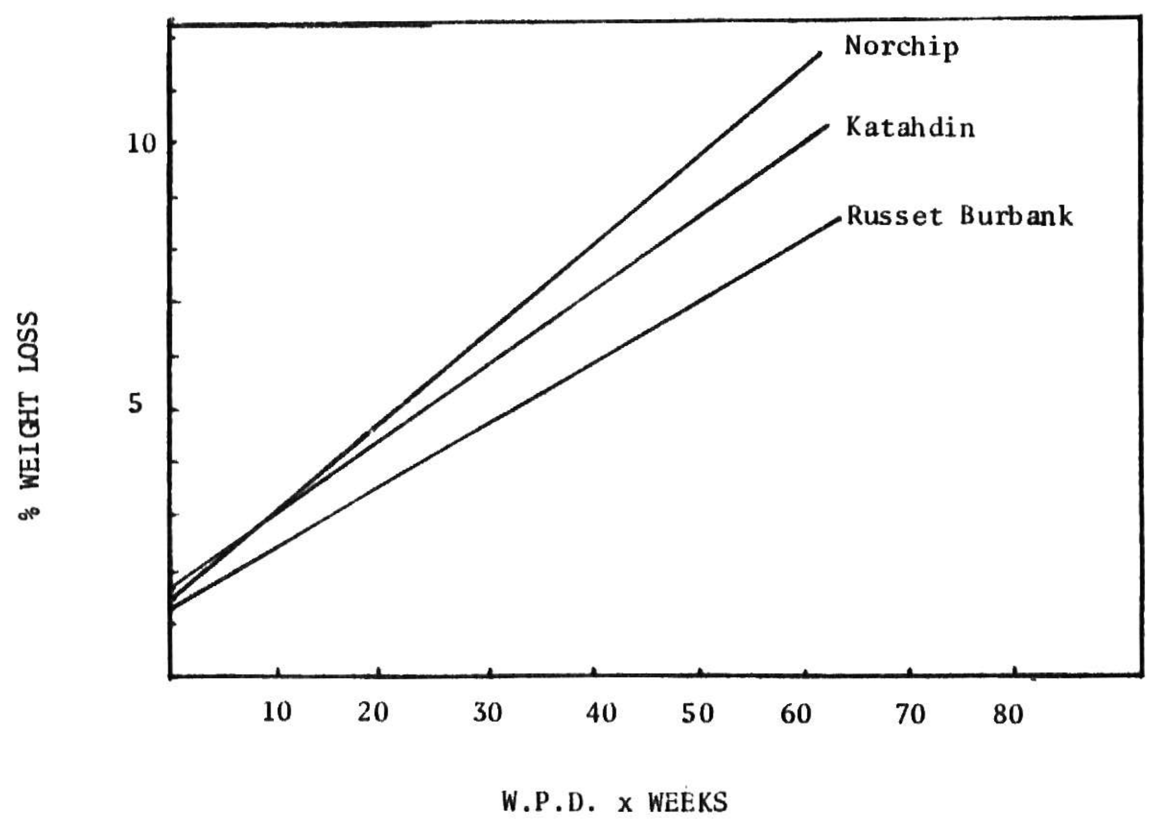

Fig. 5. The Relationship between Weight Loss of Potatoes during Storage and Drying Conditions of the Surrounding Air (Expressed as the Product of Water Pressure Deficit of the Air in MMHg and Duration of Storage in Weeks).

they would when kept for ten days in air with only 1/10th of the drying power.

Weight loss should be considered an important economic factor. Weight losses below 5% are acceptable at which point the tubers have soft skin but are sufficiently firm. Firmness decreases with increased weight loss, and this can be felt by pressing the tubers. The tubers feel increasingly soft between 5 and 10% weight loss and when the loss is in the neighborhood of 8-9% the skin begins to wrinkle and a subsequent deterioration in appearance follows. At this stage, the tubers are no longer good for table use but could be used for other purposes. Table potatoes store well at 38°-40°F and potatoes to be processed keep well at 45°-50°F for about 3 months. For longer storage period, use sprout inhibitors.

Location Factor

The greatest problem in most storage facilities is temperature and humidity control. A location that will help avoid the problem should be considered. Doors that would be frequently opened such as shipping doors should be located in positions to avoid the prevailing winds.

The storage should be as close as possible to the production area for easy handling distance. It is also important to locate storage at an easy access to an interrupted highway. There should be a residence close by the storage to ensure proper maintenance and operation of the systems.

The storage size should be given good thought. The size should be as it is needed to accommodate the quantity of potatoes produced and to provide space for future expansion. There is no sense in building a large storage for potatoes while consumption of potatoes is on the decline. Therefore, a study of the market is deemed imperative. The storage should be such that can pay off in a few years (in about 4-6 years). This might offset rapid unfavorable changes in the industry.

To determine the actual storage size or bin size, start with the seed potatoes. An increase factor of 10:1 to 12:1 could be used but to be on the safe side in case of a larger yield than anticipated, it is good to use 12:1. That is for every one seed potato 12 potatoes are produced, etc. The depth of storage should be considered. As depth exceeds 10 ft, the storage problems are increased at a high rate.

Site Selection

In selecting a site, consider the total cost of developing the site, not just the initial cost of the land. The developing cost should be compared to the developing cost of alternative sites. Cost of development includes, earthwork, drainage, roads, wast disposal, utilities, etc. Another cost factor to consider is the cost of operating the completed facilities as they are influenced by the site such as the availability of water, taxes, etc.

Soil Condition and Drainage

The soil should provide adequate load bearing capacity, to support the building and its content. The soil type could really provide a problem when clear span rigid frame constructions are used, which concentrate the load at column bases. An evaluation of the soil should be done by a soils engineer. Soil load bearing can be improved in some cases by adequate drainage. A well drained soil is also good for the general use of the site. A site with a 3 to 5% slope will improve drainage without much earth movement.

Transportation

A centrally located storage in relation with production fields is appropriate for short hauls. This could vary with the volume of crop to be hauled from each field. Transportation to the market is very important. Therefore, the site should be as close as possible to different modes of transportation as they are available. Future shipping methods should be considered since the facility is designed to serve for many years.

Utility Service

Electrical service is probably the most important of the utility requirements. There should never be a power interruption. The electric company should be contacted for availability of electrical service at the site. Single phase power may be adequate but three-phase will provide better performance from the standpoint of large electrical motor (7 hp or greater) operation.

The water supply for storage could be obtained from the immediate locality by providing a well. The water supply should be adequate to provide for: washing, cooling pads, for fluming in some cases, and for fire protection, etc. If a well is used, it should be located away from possible contaminations such as leaching from main fields and ponds. A safe minimum distance of 100 ft. is adequate.

Waste Disposal

Provide for proper means of disposing of the waste from washed potatoes and from sanitary facilities. Decayed tubers should be disposed of according to the local requirements.

STORAGE LAY-OUT

There are different designs of bins. There is the single-room type, where all the potatoes are placed in one room under one air circulation and ventilation system. There are the "room per bin" and the "door- per- bin" which have several large bins per storage. The room per bin and door per bin could be used where there are several growers using a common storage or where the storage is used for different varieties. Regardless of the type of storage, if potatoes are stored in large quantity, the loads should be piled up as shown in Fig. 6 for better potato appearance and efficient use of space.

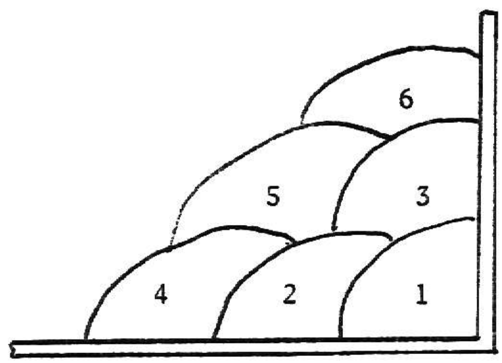

Fig. 6. Method of Stacking Potatoes in Storage.

The storage capacity of a bin can be determined by

$$\frac{L \times W \times D \times 42 \text{ lbs/ft}^3}{100 \text{ lbs/cwt}} = \text{CWT} \qquad \text{Equation 1}$$

where:

L = length
W = width
D = depth of potatoes in storage
and 42 lbs. is used as the weight of potatoes per cubic ft.

CWT is used here because it is the common measurement of weight. To determine the capacity in tons as sometimes the case may be, use equation 2.

$$\frac{L \times W \times D}{50 \text{ ft}^3/\text{ton}}$$ Equation 2

where:

50 ft.^{3} is an estimated volume of potatoes per ton load.

The storage lay-out is of a several bin in one storage with an under floor duct ventilation cooling system using water cooling pads. The lay-out also includes a work area and an office and room for expansion.

VENTILATION COOLING

This is through-the-pile, cooling by moist air system. The principle involves blowing in cool air through the bottom of the pile and expelling the warm air at the top to the outside. During this process of cooling, the surface of the potato transfers energy to the passing air by convection. This energy that is lost at the surface is replenished by energy flowing from the inside of the tuber to the surface by conduction. This energy conducted to the surface makes the average pulp and surface temperatures of the potato practically equal. Table 1 shows the equality in temperatures. This equality in temperature is due to the fact that energy transferred by conduction is faster than that transferred by convection.

The through-the-pile cooling system does not cool uniformly; it cools in stages with the time. The area of the pile that is experiencing temperature change is referred to as "the cooling zone" and the topmost or forward line of the cooling zone is called the "cooling front." There are three regions during the cooling process: the cooled region, the cooling region, and the warm region. The cooling region progresses through the pile and when its trailing end passes through the pile, the pile is cooled. Fig. 7 and 8 illustrate the different regions.

TABLE 1. Example of the Simulation Output of the Heating of a 12-foot Depth Potato Pile from 45°F. to 65°F. at an Air Flow Rate of 1 cfm/cwt. (inlet RH = 94 percent).[a]

Depth Ft.	Air Temp F	Prod Temp F	Surface Temp F	Abs Hum Lb/Lb	Rel Hum	Film Thick Ft.
.00	65.00	64.02	64.02	.0126	.9357	.28E-03
.50	65.12	64.51	64.50	.0130	.9586	.48E-03
1.00	65.25	64.85	64.84	.0132	.9721	.57E-03
1.50	65.37	65.08	65.07	.0134	.9803	.62E-03
2.00	65.44	65.17	65.17	.0135	.9861	.64E-03
2.50	65.35	64.99	65.02	.0136	.9933	.65E-03
3.00	64.96	64.28	64.38	.0135	.9999	.62E-03
3.50	64.11	62.75	62.94	.0131	.9995	.56E-03
4.00	62.40	60.11	60.42	.0123	.9986	.46E-03
4.50	59.53	56.47	56.86	.0110	.9972	.33E-03
5.00	55.69	52.58	52.95	.0096	.9964	.20E-03
5.50	51.80	49.42	49.69	.0083	.9971	.10E-03
6.00	48.85	47.43	47.59	.0074	.9985	.46E-04
6.50	47.11	46.43	46.50	.0070	.9994	.18E-04
7.00	46.28	46.01	46.03	.0068	.9998	.61E-05
7.50	45.96	45.86	45.87	.0067	.9999	.19E-05
8.00	45.85	45.82	45.82	.0067	1.0000	.68E-06
8.50	45.82	45.81	45.81	.0066	.9999	.25E-06
9.00	45.83	45.82	45.82	.0066	.9992	.15E-06
9.50	45.85	45.82	45.82	.0066	.9988	.20E-06
10.00	45.85	45.82	45.82	.0066	.9988	.24E-06
10.50	45.85	45.82	45.82	.0066	.9989	.24E-06
11.00	45.85	45.82	45.82	.0066	.9990	.21E-06
11.50	45.85	45.82	45.82	.0066	.9990	.21E-06
12.00	45.85	45.82	45.82	.0066	.9989	.22E-06

[a]Cargill, B. F. ed. The Potato Storage: Design, Construction, Handling and Environmental Control. (Michigan State University, 1976)

The movement of the cooling air through the potatoes is dependent on: 1) the air flow rate, 2) the initial temperature difference between the cooling air and the potatoes, and 3) the amount of evaporation in the pile. The depth of the cooling zone which determines the rate of cooling is a function of the air flow rate. High air flow rates result in deep cooling zones (see Fig. 7).

Fig. 7 and 8 also illustrate the position of the cooling zone after 35 hours at flow rates of 0.5 and 1.5 cfm/cwt. respectively, in a 12 ft. deep pile of potatoes. Fig. 9 shows the temperature distribution in the pile at different times when a 65°F pile of potatoes is ventilated with 45°F air at a flow of 1.0 cfm/cwt. The effect of the air flow on the cooling rate of a pile of 65°F is illustrated in Fig. 10 in which three air flows (0.5, 1.0, and 1.5 cfm/cwt.) are compared after 40 hours of ventilation cooling with 45°F air.

After the cooling zone has passed through the pile, there still exists a temperature difference of about 1° to 3°F between the bottom and the top of the pile due to respiration temperatures. This is shown in Fig. 9.

Through-the-pile ventilation rates in potato storage may vary a great deal from place to place. It could range anywhere between 0.5 to 2 cfm/cwt. or more. But we should bear in mind the marked significance of a two-fold and a three-fold increase of the air flow rate as illustrated in Fig. 10. This could be dramatically illustrated taking, for example, 6 ft. up the pile after 40 hours of ventilation at air flow rates of 0.5, 1.0 and 1.5 cfm/cwt. respectively; the tuber temperature is 65°F, 54°F and 47°F.

The simulation data of the cooling of a 12 ft. pile of potatoes, initially at 65°F at an air flow rate of 1.0 cfm/cwt. is shown in Table 2,

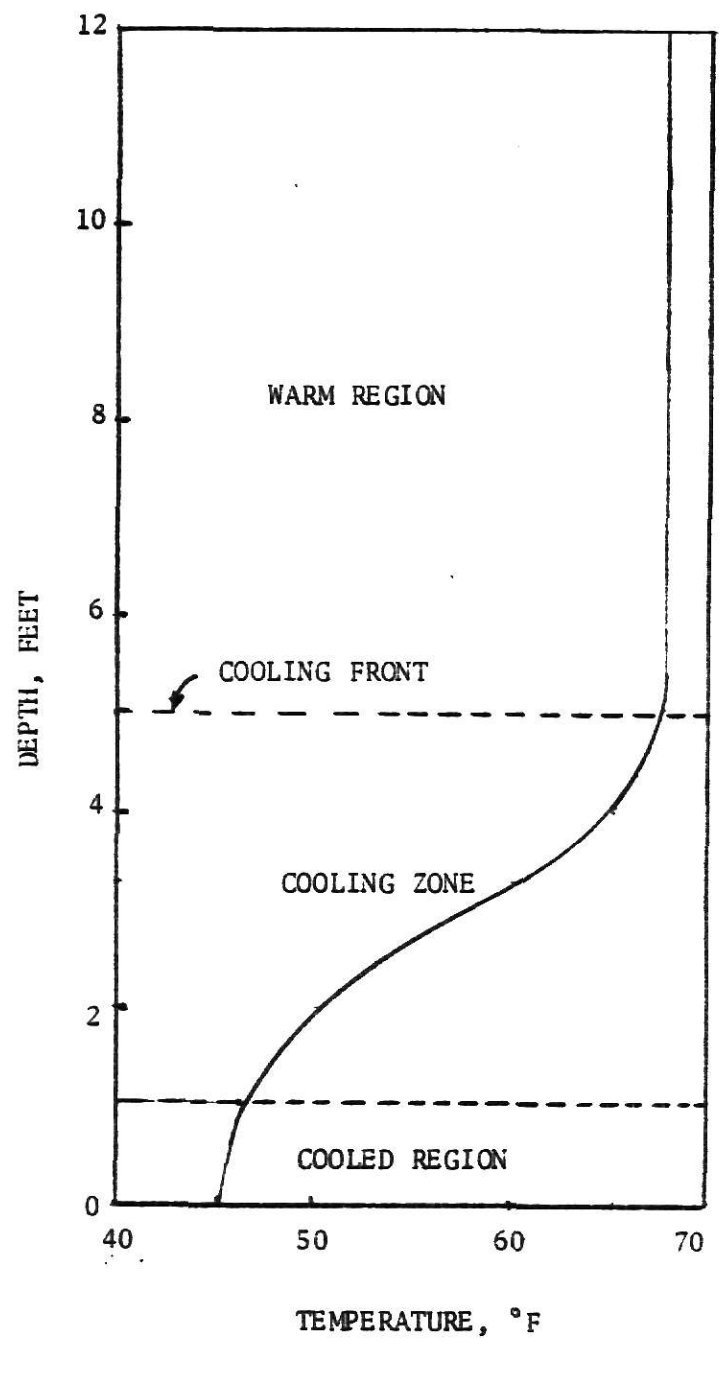

Fig. 7. Temperature Distribution in a Potato Pile after 35 Hours of Cooling at 0.5 cfm/cwt.

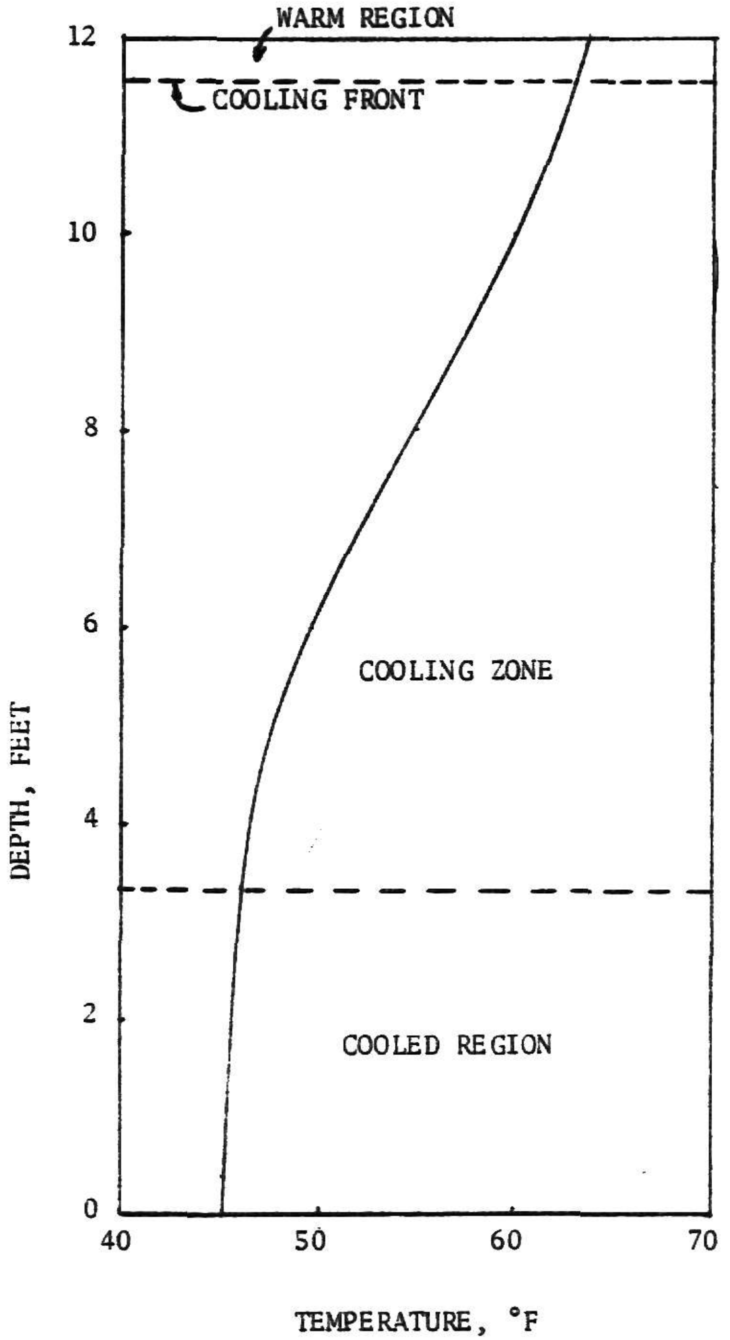

Fig. 8. Temperature Distribution in a Potato Pile after 35 Hours of Cooling at 1.5 cfm/cwt.

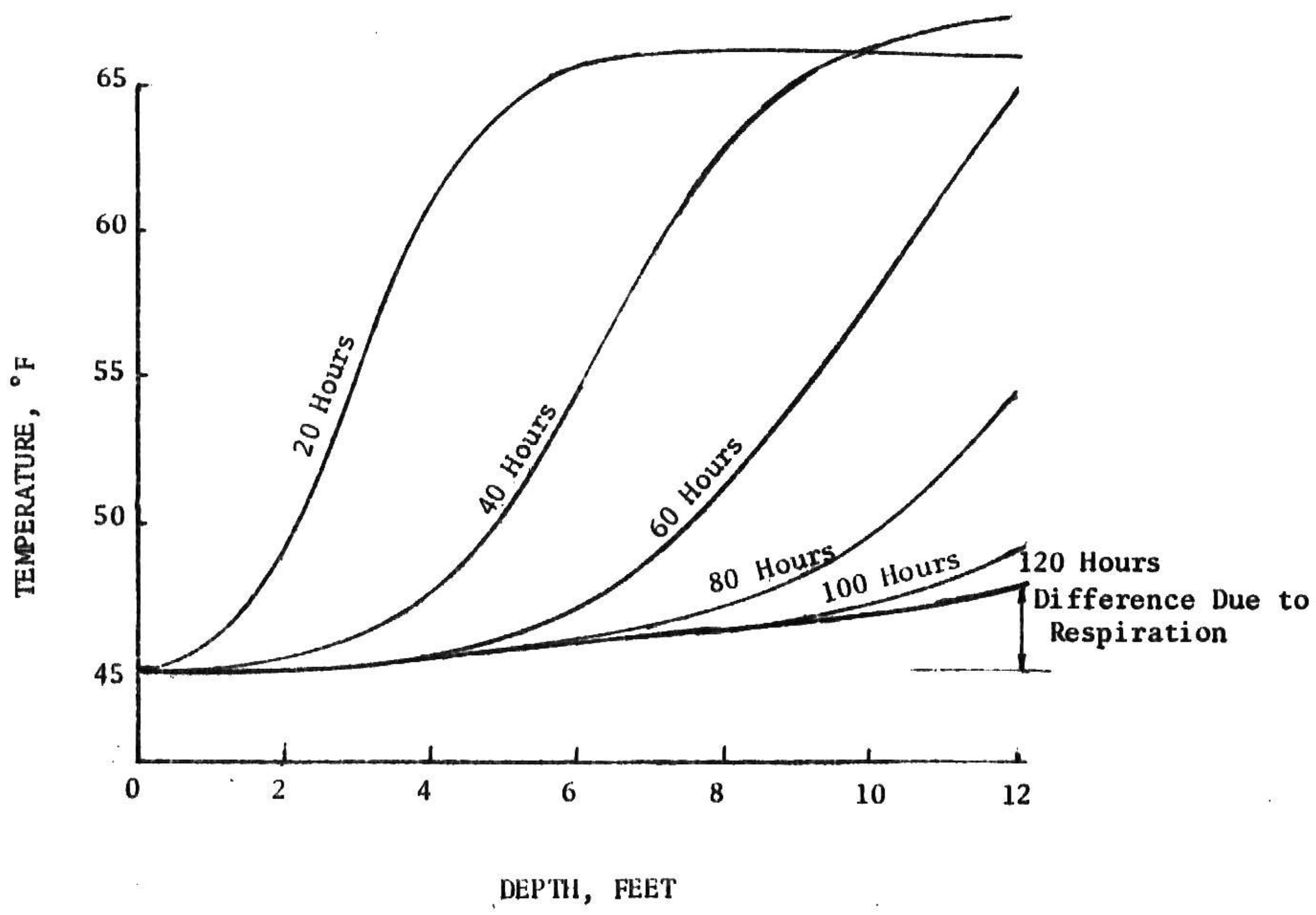

Fig. 9. Temperature Distribution after Different Time Periods of Cooling at 1.0 cfm/cwt. in a Pile.

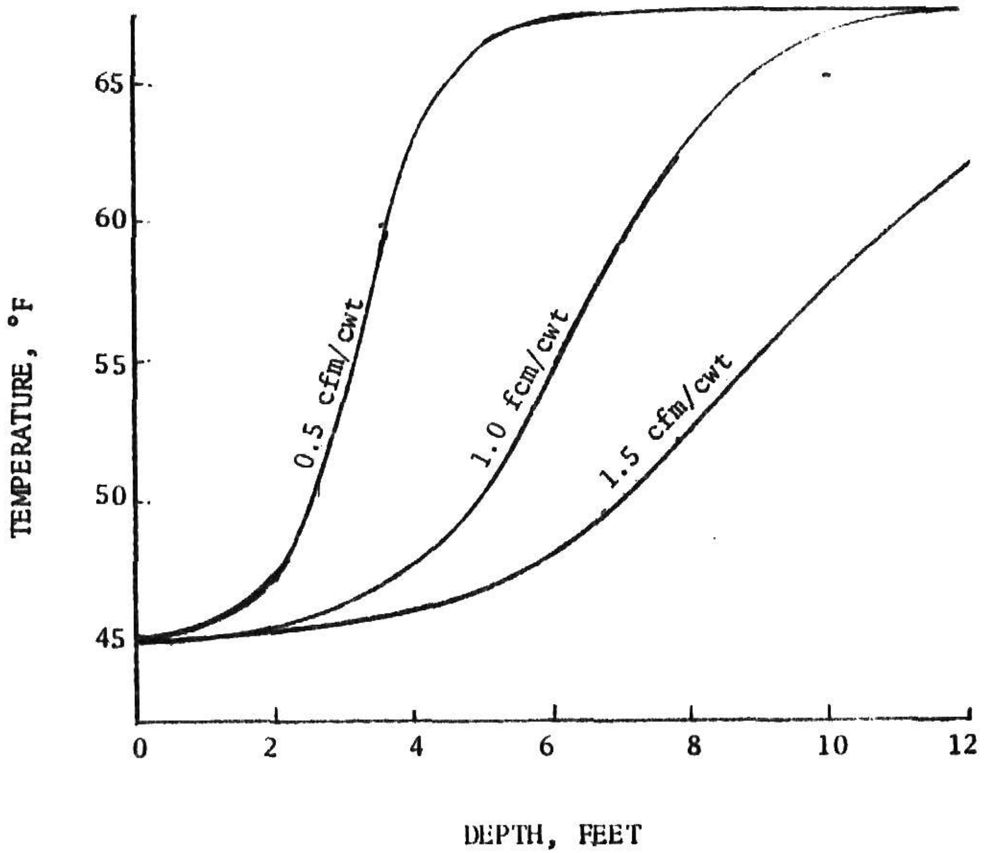

Fig. 10. Temperature Distribution after 40 Hours of Cooling at Different Flow Rates.

3 and 4 and Figs. 11 and 12. In addition to the weight loss, the values for the tuber temperatures and relative humidities at different times at 0 ft., 6 ft., and 12 ft. depth are also tabulated. Piles that are kept at a constant temperature (45°F Table 2) attain rapid cooling and experience a minimum weight loss. It can also be noted that during the cooling period the relative humidity of the outlet air first decreases then increases.

The simulation results of the ventilation cooling shows that a great deal of the cooling effect on the potatoes is due to vaporization of water from the surfaces of the tubers. It was earlier observed by Meyers and Hylmo[1] that as much as to per cent of the cooling of a potato pile was due to vaporization.

Effect of Respiration

In the cooling process, fans are turned off when the desired temperature is reached to minimize weight loss due to dehydration. At a certain period, when the fans are off, the tuber temperature will rise sufficiently to require the fans to be turned on. This temperature rise is from the heat produced by the tubers during respiration (heat of respiration). Fig. 13 shows how the temperature of a pile stored at an original temperature of 45°F rises rapidly due to respiration heat at the rate of about 1.5°F per 24 hours. It is also indicated in Fig. 13 that the rate of temperature drop of a pile is indirectly proportional to the rate of ventilation. At the 0.5 cfm/cwt. air flow rate, the potatoes will remain for an additional 65 hours above 55°F before their temperature begins to drop.

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[1]Cargill, B. F. ed. The Potato Storage: Design, Construction, Handling and Environmental Control. (Michigan State University, 1976).

TABLE 2. Cooling Rate of a 12-Foot Pile of Potatoes Initially at 65°F. Ventilated with Air at 45°F. and 93.2 Percent Relative Humidity at a Rate of 1.0 cfm/cwt.[b]

Time Hours	Potato Temperature at 0 Ft.	6 Ft.	12 Ft.	Relative Humidity at 6 Ft.	12 Ft.	Weight Loss lbs/cwt x 10^{-2}
0	65.0	65.0	65.0	100.0	100.0	0
20	45.1	65.3	65.8	45.7	44.9	1.95
40	45.1	54.4	66.5	71.2	43.6	3.36
60	45.1	47.2	63.6	87.2	49.8	4.28
80	45.1	46.6	54.1	88.4	70.3	4.74
100	45.1	46.5	48.9	88.4	82.1	5.03
120	45.1	46.5	48.0	88.4	83.9	5.29

TABLE 3. Cooling Rates of a 12-Foot Pile of Potatoes Initially at 65°F. Ventilated with 5°F. Daily Adjustment of Inlet Air Temperature Starting at 60°F. and Relative Humidity Adjusted to a Constant 95 Percent with 1.0 cfm/cwt. Air Flow Rate

Time Hours	Potato Temperature at 0 Ft.	6 Ft.	12 Ft.	Relative Humidity at 6 Ft.	12 Ft.	Weight Loss lbs/cwt x 10^{-2}
0	65.0	65.0	65.0	100.0	100.0	0
20	60.1	65.7	65.8	78.1	77.9	0.78
40	55.1	63.6	63.6	70.0	63.6	1.85
60	50.2	59.8	66.7	68.9	53.5	2.99
80	45.4	55.6	64.3	66.0	48.8	4.08
100	41.4	51.5	60.5	63.4	46.4	5.03
120	40.1	47.3	56.4	73.8	53.4	5.86

[b]Cargill, B. F. ed. The Potato Storage: Design, Construction, Handling and Environmental Control. (Michigan State University, 1976)

TABLE 4. Cooling Rate of a 12-Foot Pile of Potatoes Initially at 65°F. Ventilated with a Linearly Decreasing Inlet Air Temperature Starting at 60°F. to 35°F. with Constant Relative Humidity of 95 Percent with 1.0 cfm/cwt. Air Flow Rate[b]

Time Hours	Potato Temperature at 0 Ft.	6 Ft.	12 Ft.	Relative Humidity at 6 Ft.	12 Ft.	Weight Loss lbs/cwt x 10^{-2}
0	65.0	65.0	65.0	100.0	100.0	0
20	56.5	65.7	65.8	67.4	67.5	1.00
40	52.4	62.7	66.6	66.2	56.5	2.18
60	48.2	57.4	66.5	68.0	49.2	3.37
80	44.0	53.1	63.0	67.8	48.3	4.43
100	39.9	49.0	58.2	67.4	48.3	5.34
120	35.7	44.8	53.9	67.0	48.7	6.14

[b]Cargill, B. F. ed. The Potato Storage: Design, Construction, Handling and Environmental Control. (Michigan State University, 1976)

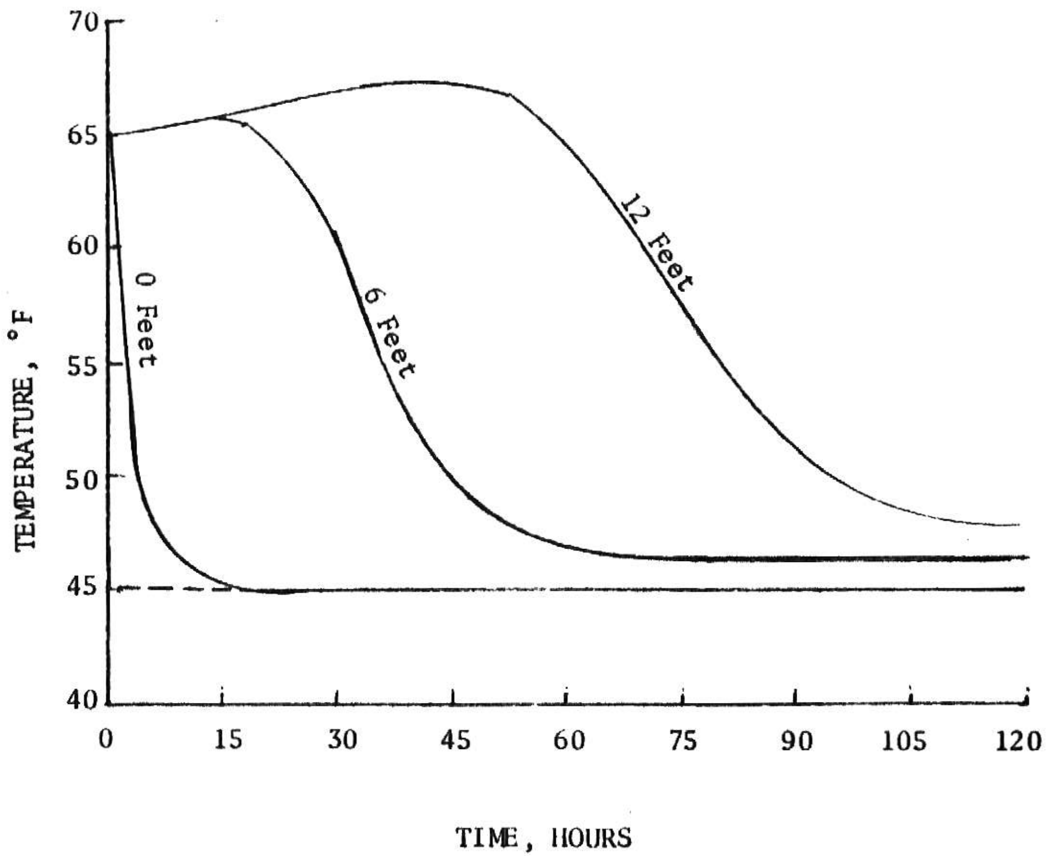


Fig. 11. Tuber Temperature Versus Time at Three Locations in a 12-Foot Pile of Potatoes during Ventilation Cooling at 1 cfm/cwt. Inlet R.H. = 94%.

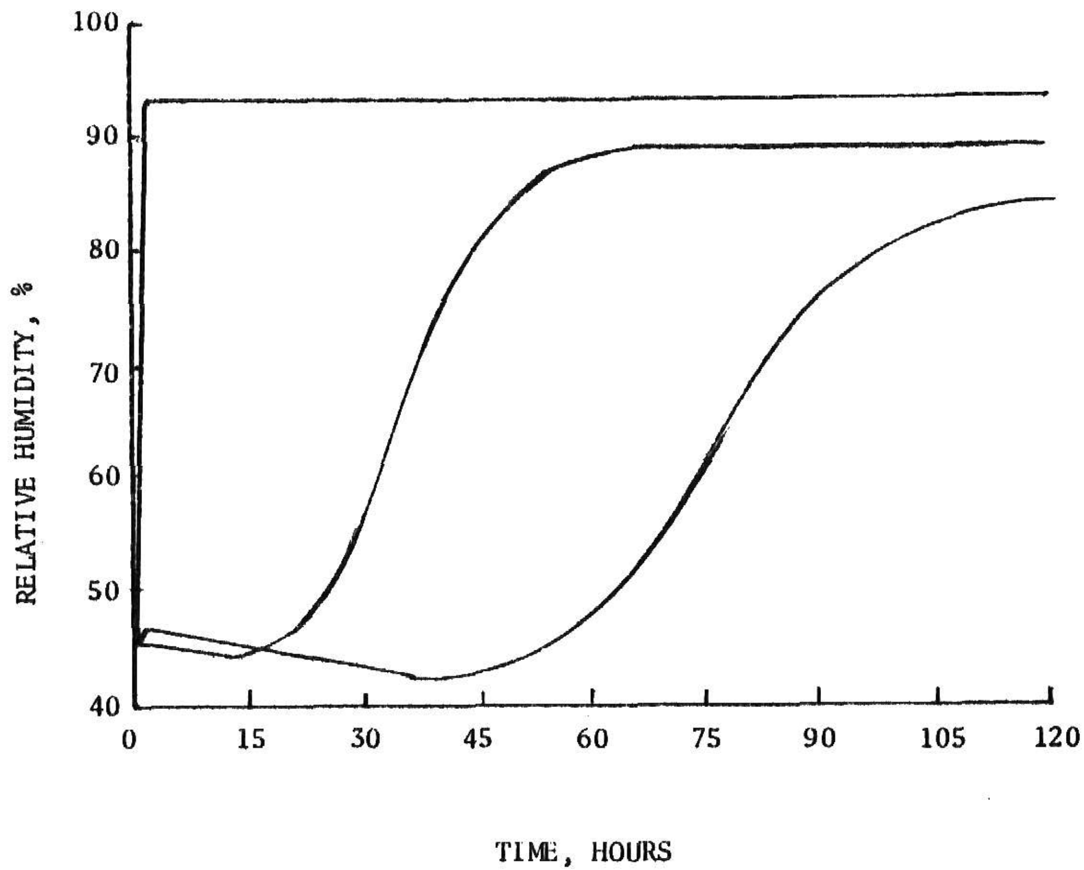


Fig. 12. Relative Humidity of the Interstitial Air Versus Time at Three Locations in a 12-Foot Pile of Potatoes during Ventilation Cooling at 1 cfm/cwt. Inlet R.H. = 94%.

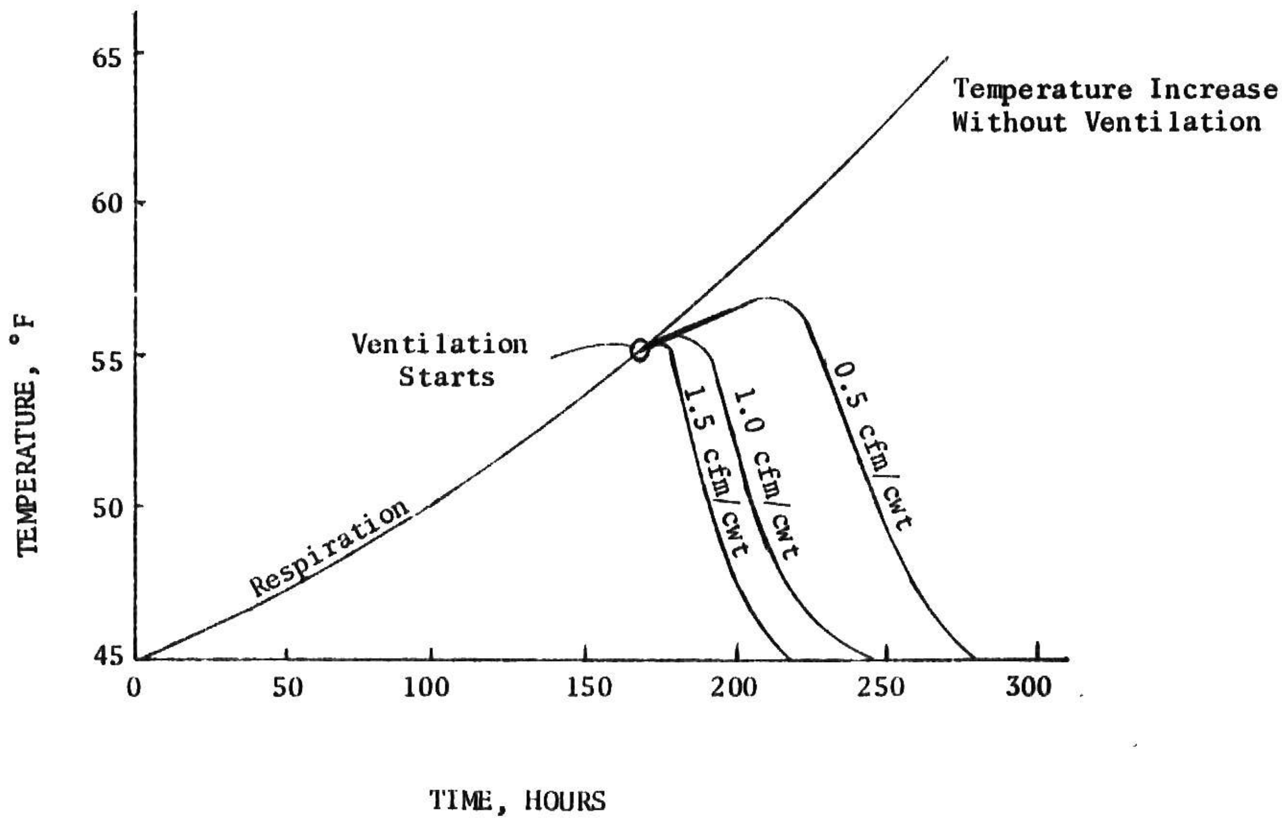


Fig. 13. Temperature Change in a Pile of Potatoes at the 6-Foot Level Due to Respiration and Cooling at Three Air Flow Rates.

While at 1.5 cfm/cwt., the same potatoes will stay above 55°F only a little over 10 hours. On the whole, the ventilation rate will depend on the depth of the pile and the storage temperature required and the other design factors.

Ventilation Design Requirement

The design of the ventilation system is very critical. An improper design could result in loss of the potatoes. The quality of ventilation air required depends on the climate, the cleanliness of the potatoes as they go into storage, the end use of the potatoes and the variety. It is generally recommended to provide 3/4 to 1-1/2 cfm of air per cwt. of potatoes; 3/4 to 1.2 cfm/cwt for cold storage (table stock or seed potatoes) and 1 to 1.8 cfm/cwt for warm storage (chipping or processing).

For design purposes the hundredweight of potatoes in a bin can be obtained by multiplying the cubic feet of potatoes by 0.42 $cwt./ft.^3$ (it is estimated that 1 ft. of potato weigh 42 lbs. - 42/100 lbs x 1 cwt).

The system has to be designed in accordance with the total pressure it has to overcome for effective cooling. If the ventilation air moves through the pile, its pressure changes as a result of the variation in velocity and because of friction losses and turbulence. Keeping the total pressure drop to a minimum requires good design of duct sizes and length, discharge slots, and duct and return port air velocity. The size and cleanliness of the potatoes affect the total pressure.

The total pressure (TP) at any point is the sum of the static pressure (SP) and velocity (VP) pressure.

$$TP = VP + SP \qquad \text{Equation 3}$$

$$VP = \frac{V}{4,000}$$

where:

VP = velocity pressure, inches of water

V = air velocity, ft. per min.

The greatest pressure drops in the system are caused by turbulence at entrances to ducts, at the discharge slot and in return ports.

Pressure drop due to turbulence can be calculated from

$$\Delta P = C\ i\ VP \qquad \text{Equation 4}$$

where:

P = pressure dep. inches of water

Ci = loss coefficient

VP = velocity pressure inches of water

The coefficient ranges from 0.03 for well-formed entrance to the duct to 2.5 for a square edge orifice. The pressure losses can be minimized by maintaining low velocity and by introducing gradual transitions in air flow by eliminating bends. In a well designed system, a static pressure of 0.5 to 0.75 inches of water should be adequate. See Fig. 14 for fan selection in relation to static pressure.

The ducts should be sized to carry enough air flow without excessive velocities. There should be one square ft. of duct cross-sectional area to each 1,000 dfm of air to provide an entrance velocity of 1,000 fpm.

Usually, to obtain adequate and uniform air discharge from ducts covered with potatoes at a reasonably low static pressure, the slotted duct should be designed such that the total slot discharge area is equal to 2 to 4 times the cross-sectional area of the duct. If the duct is not covered, the effective slot discharge area is equal to the total slot area.

Performance of Standard 6 Blade Fans - Direct-Connected

Fan Speed RPM	Motor H.P.	cfm at Indicated Static Pressures .50"	.75"	1.00"	1.25"	1.50"	1.75"	2.00"	2.25"	2.50"	2.75"	3.00"	3.25"	3.50"
1725	1/3	1250												
1725	3	13750	12000	9900	6750	3600								
1725	5	20500	19000	17300	14500	11000	6800	3500						
1725	5	22200	20200	18200	16200	14000	12400	8300	5800	2500				
1725	7 1/2	29500	27400	25200	23000	20500	17500	14000	9300	6000	2500			
1725	20	52000	50000	48000	45500	43000	40000	37000	31500	29000	25000	18000	14000	9500
1725	10	37500	35500	33500	31200	28500	25000	20500	17000	14000	11000	8000	4000	
1725	15	45500	44000	42000	39500	36000	33500	31000	27500	22500	18500	15000	12500	9000
Performance of Standard 4 Blade Fans - Direct-Connected														
1725	5	25150	22600	19750	16250	11150	3500							
1725	7 1/2	35000	32000	29000	25800	23000	20000	12000	6000	2000				

Fig. 14. Performance Data in Fan Speed, Horsepower Rating and cfm Output at Various Static Pressures for 4 and 6 Blade Fans.

Let us assume that a slotted duct is designed to handle 8,000 cfm.

The covered duct cross-sectional area = $\frac{8,000\text{cfm}}{1,000\text{fpm}}$ = 8 ft.^{2} If the slots are covered (and normally it is assumed that 75% of the slots would be covered),

the slotted area = 8 ft.^{2} x 4 = 32 ft.^{2}

In this case, 75% is covered and that is 24 ft. leaving an 8 ft.^{2} open space, which is adequate.

Using a slot width of 1 inch, it will require 12 ft. of slot to give one square ft. of slot area

1" x 1 ft./12" x 12 ft. = 1 ft.^{2}

Therefore, a 32 ft. of slot area would require:

32ft.^{2} x 12 ft./ ft.^{2} = 384 ft. of 1-inch wide slots.

The slot width and length can be adjusted to give the desired slot area.

Sometimes leaning ducts are used at the curves of the bin to provide a more uniform air flow. It is adequate to use a duct height (h) of 5 ft. (see Fig. 15) for pile depths of less than 14 feet deep. To calculate for the L on the leaning duct when the duct width is known and the air flow in the duct is known, divide the cfm/duct by 1000 cfm/ft^2 to obtain the

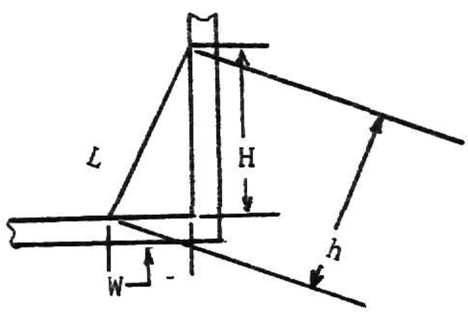


Fig. 15. Leaning Ducts

cross-sectional area of duct.

$$H = \frac{A}{1/2W} \qquad \text{Equation 5}$$

$$h = h^2 + W^2 \qquad \text{Equation 6}$$

Combining equation 1 into equation 2 it becomes

$$h = \left(\frac{A}{1/2W}\right)^2 + W^2 \qquad \text{Equation 7}$$

where:

H = vertical height of leaner (L)

A = cross-sectional area of duct

W = width of duct

h = height of (L)

<u>Lateral Duct Spacing</u>

The spacing of lateral ducts can vary from 6 ft. to 12 ft. on center. It is economical to have the ducts spaced farther apart, but the wider the spacing, the less effective is the air distribution. The air is discharged out of the ducts at about an angle of 45° and requires a good overlap to reduce the ineffective cone. If the ducts are spaced closer together a more uniform flow is obtained but the system is more expensive. See Fig. 16 for relationship of duct spacing and the ineffective cone of air flow for an in-the-floor duct system. In general, a 6 ft. to 8 ft. on center spacing is preferred.

<u>Condensation</u>

Condensation on the top of the pile and on the underside of the roof can cause considerable problems in storage of potatoes. Condensation on the top of the pile occurs as a result of a temperature difference as the warm air

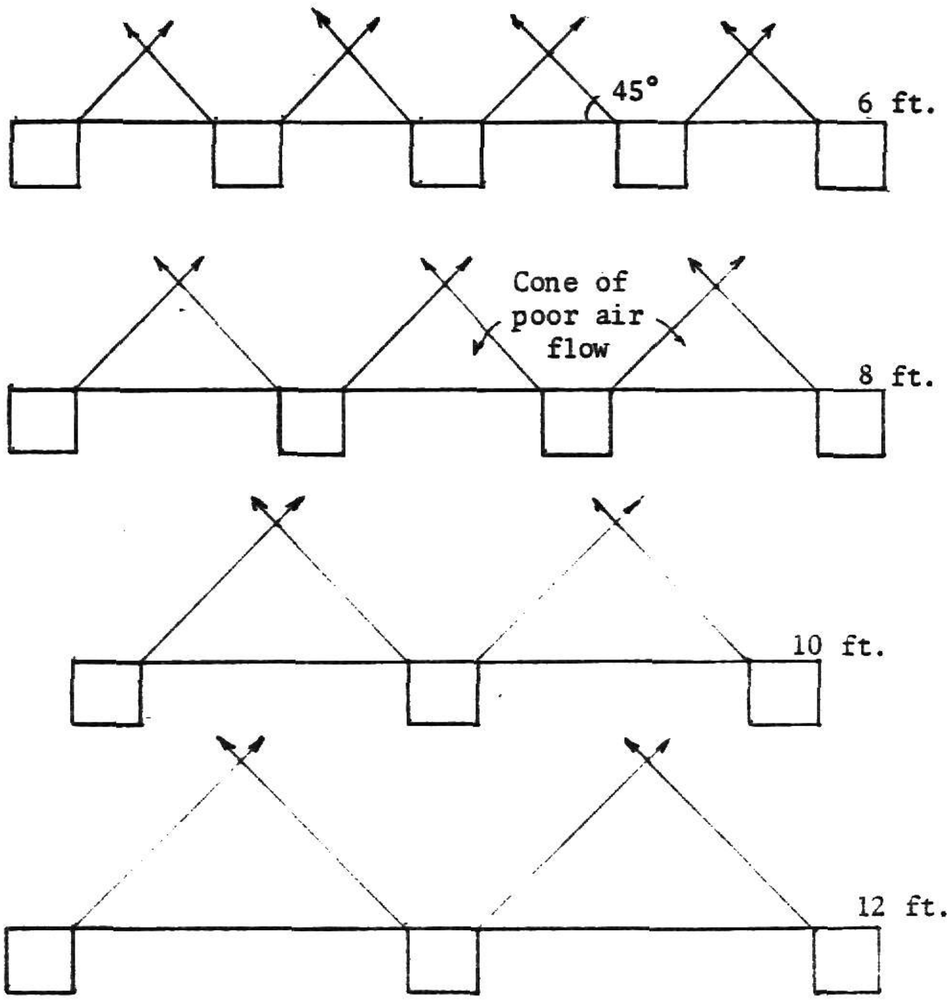


Fig. 16. Schematics of in-the-floor Lateral Ducts at 6, 8, 10, 12 ft. O.C Spacings Showing the Large Areas of Poor Air Flow Cones due to Increased O.C Duct Spacings.

moves up the pile as convectional current. Condensation can also occur on the underside of a cool roof as a result of warm moisture laden air coming in contact with the roof. This condensation problem can be overcome by providing a good air circulation over the pile by fans. In extreme cases such as in cold climates, it may be necessary to use some type of heating device.

Table 5 presents some dew point temperatures for given inside dry bulb temperatures and relative humidity.

STRUCTURE DESIGN

This storage system is designed for Nigeria, to be located in the Jos Plateau under the following climatic conditions. There are two different seasons, the wet and the dry. The wet season starts in April and lasts through September accompanied by a relative humidity of 60-65% and a temperature range of 75-85°F dry bulb. The dry season starts in October, but the dry season proper begins in November. At this period, the relative humidity ranges from 10-15% and the temperature ranges from 45-65°F. The lowest mean annual temperature is 51°F and the highest is 81°F.

The storage is a concrete structure measuring 104 ft. x 24 ft. x 14 ft. to store table stock potatoes 10 ft. deep, and consists of two doors, one to load in and the other to load out. There is a work and load out area and an office space.

The system is ventilated by an evaporative cooling pad system and under the floor ducts.

TABLE 5. Allowable Ceiling Surface Temperatures Under Various Assumed Conditions.[c]

Inside Air Temperature	Inside Relative Humidity	Dew Point Temperature	Temperature Difference Between Air and Surface
t_i	Q_i	t_{dp} or t_s	$t_i - t_s$
40	80	34.5	5.5
40	85	36.0	4.0
40	90	37.5	2.5
40	95	38.6	1.4
45	80	39.5	5.5
45	85	40.8	4.2
45	90	43.5	2.5
45	95	43.6	1.4
50	80	44.5	5.5
50	85	45.7	4.3
50	90	47.5	2.5
50	95	48.6	1.4
55	80	49.0	6.0
55	85	50.6	4.4
55	90	52.0	3.0
55	95	53.6	1.4
60	80	54.0	6.0
60	85	55.6	4.4
60	90	57.0	3.0
60	95	58.6	1.4
65	80	58.5	6.5
65	85	60.5	4.5
65	90	62.0	3.0
65	95	63.5	1.5

[c]Cargill, B. F. ed. The Potato Storage: Design, Construction, Handling and Environmental Control. (Michigan State University, 1976)

Storage Capacity

The effective length of the storage is 100 ft. The extra 4 ft. is utilized for alley space leading to the cat-walk above the pile. The width of storage is 24 ft. and the depth of the pile is 10 ft.

$$\text{Storage capacity} = \frac{100 \text{ ft.} \times 24 \text{ ft.} \times 10 \text{ ft.} \times 42 \text{ lbs.}}{100 \text{ lb/cwt} \times 1 \text{ ft.}^3} = 10{,}080 \text{ cwt.}$$

Ventilation System Sizing

At 1.5 cfm/cwt (i.e. for table potatoes),

Ventilation air required = 1.5 cfm/cwt x 10,080 cwt = 15,120 cfm.

Due to soil attached to the potatoes from the field and to give an allowance for pressures, a static pressure of 1 inch of water is used. So a 42 inch blade 5 hp fan delivering 19750 cfm is used.

Fan House

$$\text{Area} = \frac{19750 \text{ cfm}}{1000 \text{ ft m}} = 19.75 \text{ ft.}^2 = 4.4 \text{ ft.} \times 4.4 \text{ ft.}$$

Main Air Duct

$$\frac{19750 \text{ cfm}}{1000 \text{ fpm}} = 19.75 \text{ ft.}^2$$

A depth of 4 ft. is used and a 4.9375 ft. width using 4 ft. front depth and 5 ft. back depth.

Lateral Ducts

The lateral ducts are 6 ft. on center

$$\frac{24 \text{ ft. building width}}{6 \text{ ft. on center}} = 4 \text{ ducts}$$

Four ducts are used for economic reasons:

$$\frac{19750\ \text{cfm}}{4} = 4937.5\ \text{cfm/duct}$$

$$\frac{4937.5\ \text{cfm}}{1000\ \text{fpm}} = 4.9375\ \text{ft.}^2\ \text{cross section}$$

$$\frac{4.9375\ \text{ft.}^2 \times 144\ \text{in}^2/\text{ft.}^2}{20\ \text{in. deep duct}} = 35.55\ \text{inch wide}$$

Use 36 inches. Use 2 inch thick lumber over the ducts.

Slots

Each slot is 1 1/4 inch wide $\frac{1.25\ \text{in.} \times 1\ \text{ft.} \times 9.6\ \text{ft.}}{12\ \text{inches}} = 1\ \text{ft.}^2$

$$\frac{4937.5\ \text{cfm}}{1000\ \text{fpm}} = 4.9375\ \text{ft.}^2$$

$$4.9375\ \text{ft.}^2 \times 4 = 19.75\ \text{ft.}^2$$

$$19.75\ \text{ft.}^2 \times \frac{9.6\ \text{ft.}}{1\ \text{ft.}^2} = 190\ \text{ft. of 1 1/4 inch slot per duct.}$$

The two side ducts are leaning ducts each 5 feet high.

$$\frac{190\ \text{ft. of 1 inch slot}}{5\ \text{ft.}} = 38\ \text{inch slot per leaning duct 5 ft. each.}$$

Air Pressure Relief

$$\frac{19750\ \text{cfm}}{1000\ \text{cfm}} = 19.75\ \text{ft.}^2$$

Use two ducts 3.2 ft. x 3.2 ft. each, one at each end of the building.

COOLING PADS

The pads are made of sisal fiber enclosed in wire frame panels. As a result of the very low humidity in the dry season, it is necessary to provide a large area of pads and sufficient water flow through the pads. A pad size of 1 ft.^{2} per 55 cfm is assumed.

$$\frac{19750 \text{ cfm}}{55 \text{ cfm}} \times 1 \text{ ft.}^2 = 360 \text{ ft.}^2 \text{ of pad.}$$

A pad height of 4 ft. and a pad length of 90 ft. is used.

Pad Water Flow Rate

For adequate wetting and efficient cooling more water than is evaporated should be supplied. The minimum water flow rate is 1/3 gallons per minute per linear foot of pad. A rate of 1/2 gallons per minute per linear foot of pad would be adequate. The water flow is controlled by a valve.

Piping and Pump

An overhead distributor pipe having metered outlet holes distributes the water to the pad. The pipe delivering water to the overhead distributor is connected near the mid point of the distributor. The pump pumps the water up 8 ft. high and works against a 50 lbs. pressure per square inch and has an 85% efficiency.

Water is applied to the pads at 1/2 gpm per linear ft. of pad.

1/2 gpm/ft. x 90 ft. = 45 gpm

$$\text{Motor Size (BHP)} = \frac{45 \text{ gpm} \times (50 \text{ psi} \times 2.3 \text{ ft./psi})}{3960 \times .85} = 1.54 \text{ hp.}$$

Water Sump

The water sump holds return water from the pads. The sump is designed to hold 1/2 gallon per square foot of pad system.

$$1/2 \text{ gal/ft.}^2 \text{ of pad} \times 360 \text{ ft.}^2 \text{ pad} = 180 \text{ gal but } 1 \text{ gal.} = .1337 \text{ ft.}^3$$

$$\therefore 180 \text{ gal needs } \frac{180 \text{ gal} \times .1337 \text{ ft.}^3}{1 \text{ gal}} = 24 \text{ ft.}^3 \text{ of sump capacity}$$

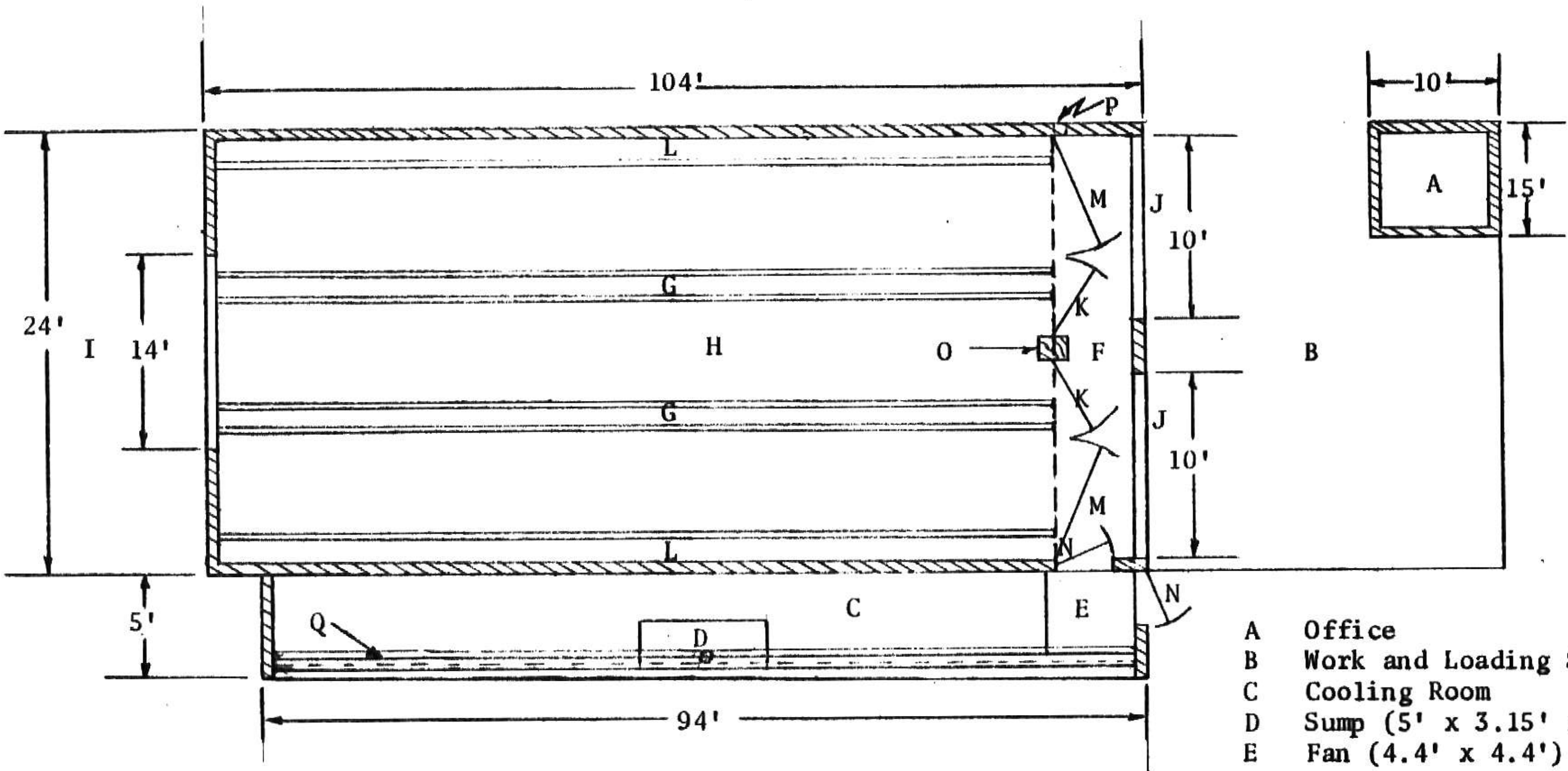
The sump measures 5 ft. x 3.15 ft. x 2 ft. (length, width and depth respectively). The extra 7.5 ft.^{3} is added to the volume to allow for any depth loss or excess water. So an actual 31.5 $ft.^3$ capacity is used.

Make Up Water

Because the water consumption by the cooling system varies, from maybe zero at some nights and wet periods to maybe 1 gal. to 3 gal. per 100 $ft.^2$ in warm periods, the make up water is needed to replace the water used up. An automatic float is used to maintain the water level in the sump.

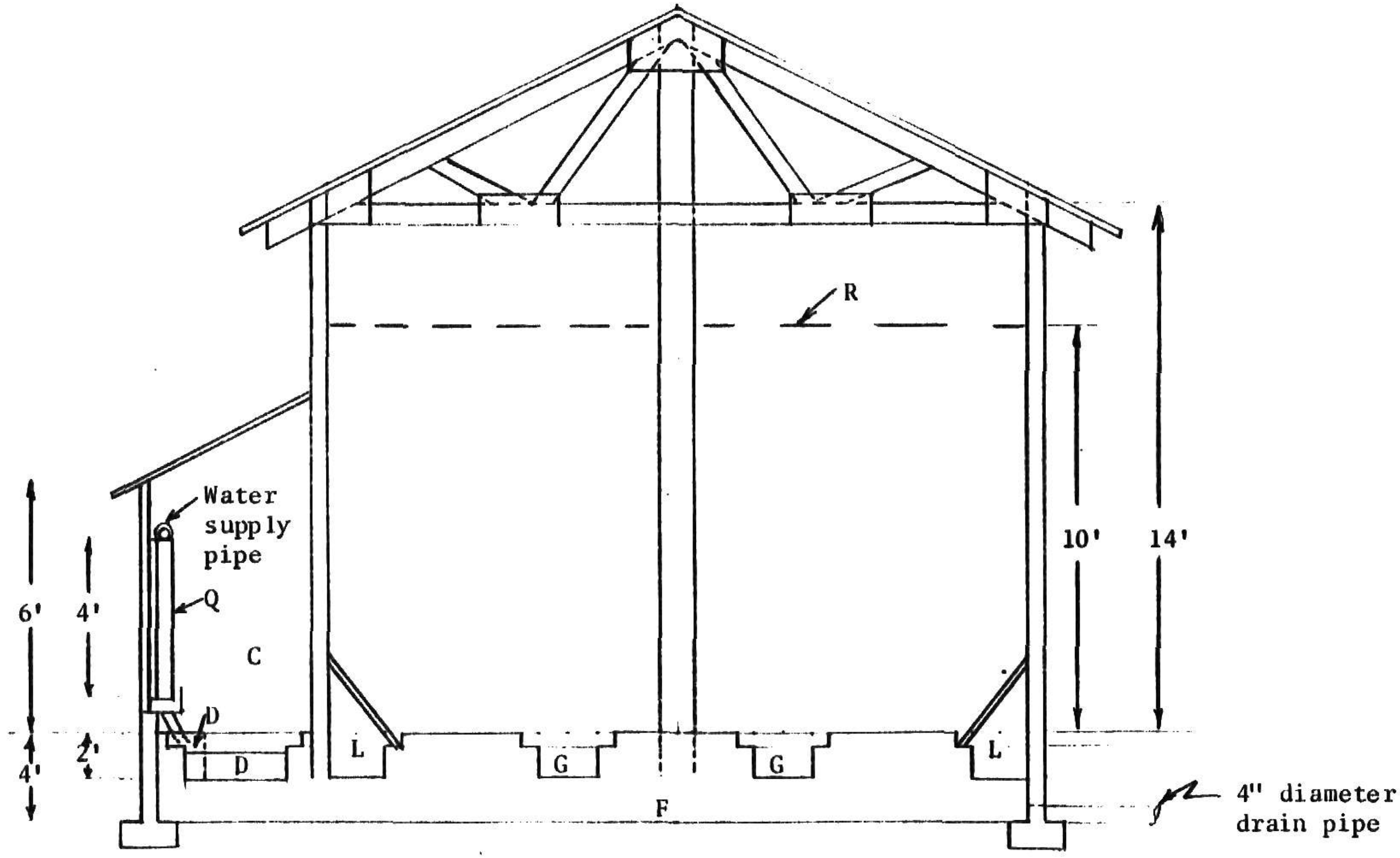
BIN DOORS

Because the storage has a wide span, it is adequate to provide more than one door to provide structural strength. There are two doors in this structure. The doors are basically a partition to keep the potatoes behind the alley. A post is in the middle of the span which serves as a common structure to both doors. This is shown in the drawings by letter "O".



A Office
B Work and Loading Space
C Cooling Room
D Sump (5' x 3.15' x 2')
E Fan (4.4' x 4.4')
F Main Duct
G Lateral Ducts
H Floor Space
I Load-In Door
J Load-Out Door
K Bin Doors 4' Each
L Lateral Ducts
M Bin Doors 7.6' Each
N Entrance Door 2 1/2'
O Post
P Drain
Q Pads (94' x 4' x 2")

Fig. 17. Plan of Storage Area.



Q Pads (4' x 2")
R Potato Height

Fig. 18. Elevation

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POTATO STORAGE AT JOS, NIGERIA USING EVAPORATIVE COOLING PAD SYSTEMS

by

OSCAR P.D. FOM

B.S., Kansas State University, 1976

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Agricultural Mechanization

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977

In an attempt to treat potato storage, the author presents the tuber composition and why it needs storage. The objectives of potato storage are explained from the standpoint of: maintaining minimum respiration, retaining water in the tuber, controlling temperature based on potato end use, maintaining appearance and protecting the tubers from light.

Certain considerations are given thought before laying out a storage place, as explained by the author under different headings such as: the location factor, consideration for site selection, soil condition and drainage, transportation, utility services, and waste disposal.

The storage lay-out explains the different bin designs possible, and shows diagrammatically a method of stacking the potatoes in the bins. Equations are given leading to the determination of the storage capacity.

The most important factor in potato storage is the ventilation system, and this is demonstrated by charts and tables. Calculations leading to the ventilation design requirement are also given consideration in the paper, supplemented by charts and tables.

The final design of the structure is shown and treated under respective subheadings. The storage capacity is calculated in hundred weight (cwt). In sizing the ventilation system, the author calculates the total required air flow (cfm) from which is derived the fan size. The main and lateral ducts are also sized in respect to the total air flow, and so are the slots. The cooling pad system and its component parts are sized in proportion to the storage requirement.

The plan and end view of the building are presented showing the dimensions of the building.