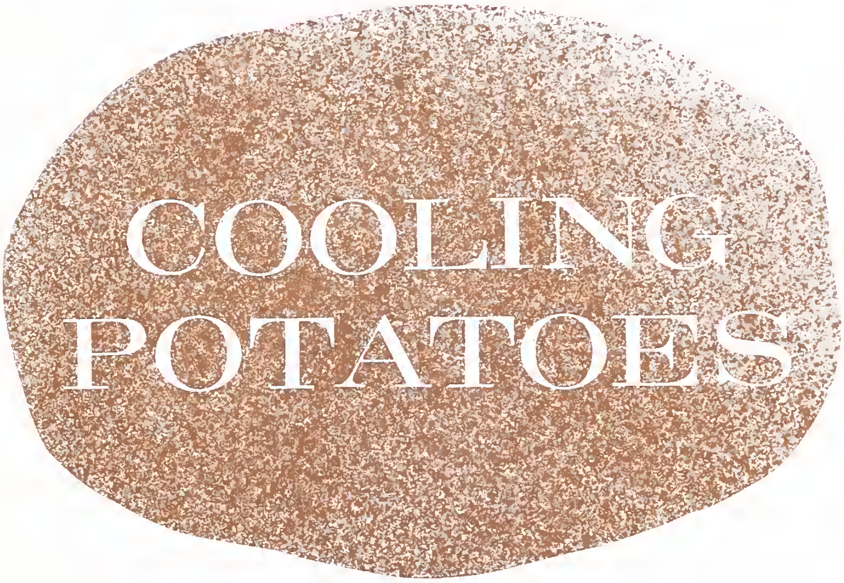

an evaluation of methods for COOLING POTATOES *in Long Island storages*

Marketing Research Report No. 494

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

Growth Through Agricultural Progress

PREFACE

This report is based on research which was part of a project to develop more efficient work methods, equipment, and facilities for the off-farm handling, storing, and preparation for market, of intermediate and early crop potatoes. The data obtained were used to evaluate the engineering, economic, and biological aspects of six practical cooling methods, some of which are presently in use.

The work was conducted under the joint supervision of Joseph F. Herrick, Jr., marketing research analyst, Handling and Facilities Research Branch, Transportation and Facilities Research Division, and B. A. Friedman, plant pathologist, Market Quality Research Division.

Howard Hunnicutt, agricultural engineer, formerly with the Transportation and Facilities Research Division, was the direct project leader and carried out the engineering phase of the study. R. L. Sawyer, plant physiologist, Long Island Vegetable Research Farm, Cornell University, conducted some of the physiological tests and made helpful suggestions during the writing of this report. A. D. Edgar, agricultural engineer, Transportation and Facilities Research Division, reviewed the manuscript.

The following Suffolk County potato growers cooperated by making their storages available for the study:

Joseph P. Celic, Riverhead, N. Y.
Anthony P. Grubb, Bridgehampton, N. Y.
Edward W. Krupski, Riverhead, N. Y.
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June 1961

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AN EVALUATION OF METHODS FOR COOLING POTATOES IN LONG ISLAND STORAGES

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SUMMARY

Test bags of Long Island potatoes of the Katahdin variety were stored during a typical 3- to 4-month period in six storages about equal in size. Each employed a different method for cooling. Storage temperature and relative humidity were recorded, and the tubers from each storage were examined for quality evaluation.

Sprouting, vascular discoloration, decay (mostly fusarium), and internal black spot were the main defects found during storage. Sprouting was serious in some storages (as much as 46.2 percent of the potatoes, by weight) and nominal in others (as low as 1.8 percent). Decay and serious vascular discoloration were slight in all storages except one. Internal black spot was found in all storages in varying amounts. Shrinkage was high in all storages, with weight losses averaging from 7.3 to 9.8 percent. Where ice refrigeration was used, weight loss was less than in the other _through_ ventilated storages.

Supplemental cooling by ice or mechanical refrigeration reduced early season storage temperatures more rapidly than nonsupplemented methods. The relative humidity of the incoming ventilating air was highest in the ice refrigerated storage. Temperature distribution is more uniform in a forced air _through_ ventilated storage than in a naturally ventilated storage.

The annual costs to own and operate equipment for the various systems studied range from 7.4 cents per hundredweight for the mechanically refrigerated storage, supplemented with _shell_ ventilation, to 1.9 cents per hundredweight for the storage using only the automatically controlled, forced air, _through_ ventilation. The ventilation system supplemented with ice cost more to own and operate than the one supplemented with 3 tons of mechanical refrigeration.

It is questionable whether the improved maintenance of quality resulting from more rapid temperature reduction early in the storage period justified the extra investment required for any type of supplemental cooling.

INTRODUCTION

Status of Long Island Storages

Approximately 11 million cwt. (hundredweight) of potatoes are produced annually on Long Island. About half of this crop is placed in permanent or temporary storage, depending upon market conditions at harvest time. If the price is good, growers sell potatoes as they are harvested. When the price is unprofitably low, as many potatoes as possible go into storage. 1/ In 1958, storage facilities of some kind were available on 83 percent of all Long Island farms growing potatoes. The total capacity of permanent storage is 4,575,000 cwt. and the capacity of temporary storage is 1,146,000 cwt. 2/ When these facilities are filled, the remainder of the crop must be marketed.

Most of the storages presently in use are permanent. Many of these are equipped with automatically controlled fans and dampers to provide through cooling. 3/ Some rely on natural ventilation through windows, doors, and attic vents. Others are equipped with mechanical refrigeration for rapid cooling or evaporative coolers to cool and humidify simultaneously.

Problem and Objectives

Most of the potatoes produced on Long Island are sold for table stock. Low fall prices received by Long Island growers for table stock potatoes are attributable to such factors as decreased consumer demand in August and September, competition of potatoes from other areas, and the lack of adequate storage facilities on Long Island. Growers, becoming more keenly aware of this problem, are expanding and improving their storage facilities to achieve greater marketing flexibility. When new storages are constructed, most builders incorporate the latest equipment developments and structural techniques to make possible a more adequate environmental control.

Table stock potatoes keep best at 40° F. and 85 to 90 percent relative humidity. Mature potatoes going into storage should be held for 2 weeks at about 60° F. and 90 percent relative humidity for suberization and wound healing. After this 2-week curing period, the tubers should be cooled at a rate sufficient to reduce the temperature to 40° F. within 4 to 6 weeks.

It is generally late November before an automatically controlled, forced air through ventilation system reduces the storage temperature to the desired level, and in some years moderate fall atmospheric temperatures further retard this cooling. Mechanical refrigeration can, of course, be used to reduce storage temperature as desired. Thus the question arose as to whether some means of supplementing the forced air ventilation to hasten the cooling process could be economically justified.

The objectives of this study were: (1) To observe the nature of the storage environment produced by six different cooling methods, including supplemental cooling; (2) to measure the effects of the different methods on potato quality; and (3) in light of the observations of environment and product quality, to evaluate the relationship between cost and benefits derived for each method studied.

1/ Personal statement of Walter G. Been, Suffolk County Agricultural Agent, New York State College of Agriculture.

2/ New York State Dept. of Agriculture and Markets and U.S. Agricultural Marketing Service. Long Island Potato Survey. July 1958. (Monthly.) Summary Report.

3/ Through cooling signifies forcing cool air through the potato interstices where it picks up heat by forced convection. The warm air is then exhausted into the atmosphere.

PROCEDURE

Types of Cooling Systems Studied

The six storages selected were as uniform in size and structure as possible and yet provide the various means of cooling required for the study. The cooling methods were: (1) Automatically controlled, forced air through ventilation only; (2) a 3-ton refrigeration unit to supplement automatically controlled, forced air through ventilation system; (3) a 15-ton refrigeration unit to supplement automatically controlled, forced air through ventilation; (4) ice, stored in an ice bunker in the air duct, to supplement automatically controlled, forced air through ventilation; (5) natural ventilation, relying on cooling by free convection with manual regulation of air ports; and (6) a 15-ton refrigeration compressor having 6 individual 36,000 btu/hr. capacity air blast units operating simultaneously off the one compressor, combined with a type of shell cooling. 4/

All six storages were located in Suffolk County on Long Island and had similar atmospheric conditions. The study was conducted during the 1955-56 storage season.

Treatments and Quality Measurement

All potatoes used in the experiments were the Katahdin variety grown on the farm of H. R. Talmage and Son, Riverhead, New York. The fully matured potatoes were mechanically harvested, in the usual manner, from about three rows of a single field and conveyed into a bulk truck moving alongside the digger. The tubers were then placed in 70 screened plastic test bags holding about 40 pounds each. The bags were selected so that each of the six storages received potatoes from approximately the same part of the field. Pairs of bags were placed in five different positions within each storage at the time of filling and were removed when the storages were emptied. Ten additional bags were set aside for initial examination.

All of the bags were held at 40° F., to retard decay and weight loss, until the storages were ready for the samples to be placed in position as filling progressed. Each bag was then warmed to 60° F., placed into storage, and held at that temperature for 2 weeks. Temperature was then reduced to 40° F. consistent with the capability of the system and the management practices of the operator. One bag from each position was examined shortly after withdrawal. This group, Sample A, remained in storage 90 to 127 days. The duplicate bags (Sample B) were then held at 40° F. for an additional period until they could all be examined at the same time. The total storage period for Sample B ranged from 122 to 152 days.

From the standpoint of product quality, the tubers were examined for black spot, specific gravity, peeled discoloration, chipping color, decay, shrinkage, vascular discoloration, sprouting, greening, mechanical damage, and surface cracks.

4/ This type of shell cooling can be defined as the forcing of cool air across the top of the pile to expel warm air that ascends to the top by natural convection through interstices in the pile.

Measurement and Control of Storage Environment

Operation and management of the storages were performed under the jurisdiction of the individual owners. While an effort was made to control variation, the individuality inherent in the management of the different storages and in the operation of the cooling equipment prevented attainment of the optimum environment that each system was capable of providing. In fact, the observed cooling rates in some storages were far different from those normally expected. Thus it was impossible to distinguish between the effects of the treatment on quality of the potatoes and effects stemming from other sources. Such unexplainable variations necessitated evaluation of the results in light of previous experience from other studies.

Thermocouples, constructed of 24 A.W.G. copper-constantan, were inserted in a potato in the test bags to observe the progress of cooling and the variations in temperature within the storage for each cooling method. Temperature measurements were made weekly with a portable indicating potentiometer.

A high humidity in the incoming ventilating air is vital for an optimum storage environment. Hygrothermographs were used to measure the relative humidity of the entering air in some storages and the discharge air in others. Measurements of incoming air indicate the degree of achievement of optimum moisture content of storage air. Discharge air includes the moisture content of the entering air plus moisture lost from the tubers in transpiration.

A more thorough study of humidity conditions would have permitted a more accurate evaluation of results, but it would have necessitated observations of both the incoming ventilating airstream and the exhaust airstream of each storage. Unfortunately, because the intake air duct in some storages was inaccessible, this could not be accomplished.

No special effort was made to provide adequate humidity in any of the storages in this study. An attempt to humidify (with some apparent effects observed) was made in the storage supplementing forced air ventilation with 15 tons of refrigeration. This was done by directing a small stream of water into the inlet side of the fan. Coincindental humidification was accomplished in the storage supplementing forced air ventilation with ice refrigeration as a result of vaporization of water from the melting ice.

The rate of airflow was substantially equal in each of the forced air ventilated storages.

STORAGES AND COOLING SYSTEMS STUDIED

All storages in this study are "permanent" but they differ somewhat in structural design according to the date of construction and individual builder preference. Although recent research has shown that properly insulated above-grade storages are preferable, the prevailing storages on Long Island are of the below-grade, or earth-banked, type. 5/ The walls of each storage are concrete or cinder block; the floors are concrete. Where provided, automatic controls were set to prevent reduction of storage temperature below 40° F.

Storage No. 1

This above-grade storage was constructed in 1953 (fig. 1). In lieu of insulation on the side walls, a furred-out "false" wall provided a buffer zone through which ventilating air could pass. Air passing through this space either gains heat from, or loses heat to, the outside wall. This helps to maintain a more uniform temperature around the tubers along the inner wall. Two inches of blanket insulation combined with 3/4-inch treated fiberboard is installed overhead. The relatively flat roof is supported by a center partition. Subfloor ventilating ducts are spaced 8 feet on centers. The machinery shed (used for temporary storage) built onto one side of the structure is generally kept closed during storage. Cooling was accomplished by automatically controlled, forced air <u>through</u> ventilation only.

BN-10586X

Figure 1.--This modern storage was cooled by automatically, forced air ventilation (Storage No. 1).

Storage No. 2

The modern above-grade storage shown in figure 2 utilizes the earth bank as a buffer in lieu of insulation on the side walls. Overhead, in the attic, a 2-inch blanket of insulation is laid on the aluminum "V" crimp roofing, which doubles as a vapor barrier and ceiling. The subfloor ventilating ducts are spaced 10 feet on centers. A 3-ton refrigeration unit was operated in conjunction with the automatically controlled, forced air <u>through</u> ventilation

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5/ Bennett A. H., Sawyer, R. L., Boyd, L. L., and Cetas, R. C. Storage of Fall-Harvested Potatoes in the Northeastern Late Summer Crop Area. U. S. Dept. Agr. Mktg. Res. Rpt. 370, in cooperation with Cornell Univ. and New Jersey Agr. Expt. Stas. 45 pp., (illus.). 1960.

system. When the outdoor air was too warm for cooling by ventilation, heat was removed from the storage by passing recirculated storage air across the cooling coils.

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Figure 2.--In this modern storage (shown here before the earth bank was put in place) a 3-ton air conditioner supplemented the ventilation system (Storage No. 2).

Storage No. 3

Built about 1936, this earth-banked storage shown in figure 3 has blanket insulation overhead but none in the sidewalls. Vents are provided for attic ventilation. A 15-ton refrigeration unit supplements the automatically

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Figure 3.--This storage when filled has adequate refrigerating capacity to reduce potato temperature from 60^{0} to 40^{0} F. within 10 to 12 days (Storage No. 3).

controlled ventilation system. The equipment is integrated so that all cooling air is forced through the pile. Outside dampers are manually closed during periods of mechanical refrigeration.

Storage No. 4

The gambrel roof of this structure (fig. 4) allows space overhead for machinery and temporary storage. Located on a natural slope, it has two sides below grade and two sides earth banked. The side walls are furred out and boarded to the ceiling in the same manner as storage No. 1.

There is no insulation in the walls or the ceiling. The subfloor ventilation ducts are spaced about 13 feet on centers. For this study ice refrigeration supplemented the automatically controlled, forced air through ventilation system. Incoming ventilating or recirculated air was forced through an ice bunker located in a portion of the main duct (fig. 5).

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Figure 4.--One of the early Long Island Potato Storages within which a modern forced air ventilation system was installed (Storage No. 4).

Storage No. 5

The storage shown in figure 6 was built in 1953. It has a shop and machinery shed on each side with an earth bank along the sides and rear. No provision is made for insulation except for 3/4-inch fiberboard in the ceiling. Attic and ceiling vents, windows, and doors are manually adjusted to regulate cooling by natural ventilation.

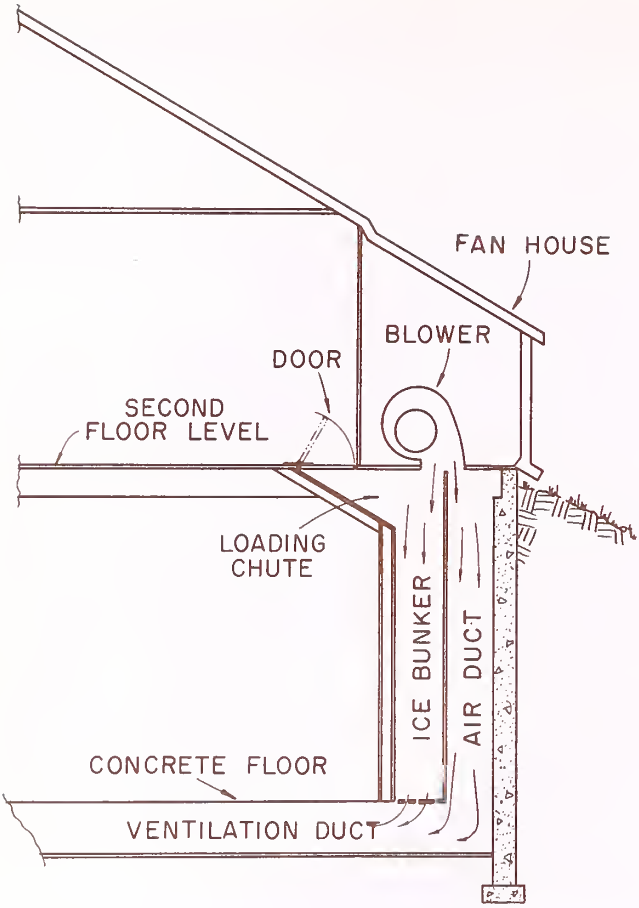

Figure 5.--Installation of the ice bunker, shown at left, in the ice refrigerated storage provided for a portion of the ventilating air to flow across the surface of the ice for cooling (used in Storage No. 4).

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Figure 6.--In this storage, utilizing natural ventilation and free convection, cooling depends upon manual regulation of windows, doors, and ventilating ports. Storage temperature cannot be properly controlled (Storage No. 5).

Storage No. 6

The "permanent storage" portion of this structure is entirely below grade. The above-gound portion seen in figure 7 is used primarily as a shop and machinery shed but is sometimes used for temporary storage. No insulation is provided in the storage. A 15-ton mechanical refrigeration system combined with manually controlled shell ventilation constitutes the cooling system. The storage is divided into 6 bins, each equipped with an air blast coil with a capacity of 36,000 B.t.u. per hour (fig. 8).

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Figure 7.--The 15-ton refrigeration unit in this storage cools the potatoes rapidly but is used infrequently because of high operating costs (Storage No. 6).

Figure 8.--The blast coil in this room cools the air overhead. Flow of heat from the potatoes to the air is accomplished by free convection (From Storage No. 6).

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FUNDAMENTAL PRINCIPLES AND THEORETICAL CAPACITIES OF THE COOLING METHODS STUDIED

Free or natural convection is a term used to describe heat transfer from a solid to a fluid when the fluid currents are generated internally as a result of nonhomogeneous fluid densities arising from temperature variations. Forced convection implies heat transfer from a solid to a fluid when the fluid currents are produced by sources external to the heat transfer region, such as a fan or blower. In potato storages, the cooling fluid is air.

In potato storages cooled by either free or forced convection, the rate of heat removal depends mainly upon the movement of air across the surface of the tubers, the difference in temperature between the surface and the surrounding air, and the rate at which moisture is vaporized from the surface of the potatoes.

In storages utilizing free convection, air movement is influenced by such factors as size, shape, and surface characteristics of the potato, number, size, and location of ventilating ports, the degree of attention given to the adjustment of vents, and the magnitude of the difference in air densities within the storage. The rate of moisture loss depends upon the rate of air movement and the moisture content of the ventilating air. These factors are subject to considerable uncontrolled variation and no set of conditions can be expected to apply for any length of time. For this reason it is impossible to establish heat transfer performance characteristics that could be used to compute the rate of heat removal by free convection in a naturally ventilated storage. Any attempt to compute theoretical cooling rates would likely yield erroneous results.

Forced convection is the principle used in storages cooled by automatically controlled, forced air ventilation. From measured values (obtainable with reasonable accuracy) of the mass rate of airflow and wet and dry bulb temperature of entering and leaving air, the rate of heat removal can be calculated. Ideally, this rate of heat removal is simply equal to the product of the mass rate of airflow and the difference between the enthalpy (heat content) of the entering and leaving air.

The maximum amount of additional heat that a forced air ventilation system can remove, when supplemented with mechanical refrigeration, depends upon the actual capacity of the refrigeration unit under its operating conditions; with supplemental ice refrigeration, heat removal depends upon the rate of ice meltage.

Table 1 lists the approximate theoretical cooling capacities and daily temperature reductions that normally can be expected in an ideal storage with a capacity of 20,000 cwt. of potatoes. Calculations are based on the following conditions: (1) The volume rate of airflow is 5/6 cubic foot per minute (c.f.m.) per cwt. in the ventilated storages; (2) the difference in dry bulb temperature between intake and exhaust air is 4° F.; (3) the rate of water loss, by evaporation from the surface of the tubers during initial cooling, is 2.5 percent per month; and (4) the capacity of mechanical refrigeration is based on its maximum rated output. For this analysis an ideal storage is defined as

Table 1.--Approximate theoretical cooling capacities of 5 methods of cooling potatoes from 60° F. to 40° F. in a potato storage with a capacity of 20,000 cwt., Long Island, New York

Cooling method	Expected maximum cooling capacity		Average daily temperature reduction
	Hourly rate 1/	Daily rate 2/	
	B.t.u.	B.t.u.	°F.
No. 1. --Automatically controlled forced air ventilation....	138,300	2,212,800	0.47
No. 2. --Automatically controlled forced air ventilation plus 3 tons of mechanical refrigeration.............	174,300	3,076,800	1.00
No. 4. --Automatically controlled forced air ventilation plus ice refrigeration....	179,380	2,952,160	.92
Nos. 3 & 6.--15 tons of mechanical refrigeration only........	180,000	3/4,320,000	1.76

1/ Capacity when the blower is in operation.
2/ Blower operating approximately 16 hours per day; refrigeration unit operating 24 hours.
3/ Effects of ventilation neglected; based on a 24-hour day.

one in which the daily heat gain by conduction and infiltration through the walls, floor, and ceiling is equal to the daily heat loss in the same manner. This presumption is validated, to some extent, by an observed similarity between the average daily dry bulb temperature of the outdoor air and the corresponding daily storage temperature for the period from October 15 through November 30. The effect of net radiant energy exchange to surroundings and stored energy within the structural components is neglected. Calculations for the average daily reduction in temperature take into consideration the heat evolved from the potatoes by respiration.

The 15-ton refrigeration systems in this study have a rated capacity sufficient to reduce the temperature in a 20,000-cwt. storage from 60° F. to 40° F. in 12 days. While both systems are rated equally, their actual output could vary, depending upon installation, operation, and management. Maximum output is obtained by maintaining (1) The recommended pressures on the high and low side of the system, (2) the recommended degree of superheat in the evaporator coil, and (3) the recommended rate of airflow and temperature drop across the coil. Thermostatically controlled units are likely to have a better coefficient of performance than manually controlled units.

EFFECT OF COOLING METHOD ON TEMPERATURE AND HUMIDITY

For reasons previously discussed, the cooling pattern in some storages did not conform to expectations. For example, the cooling capacity of storage No. 3 was sufficient to reduce the storage temperature from 63° F. on October 10 to 40° F. by October 30. The curve in figure 9 for this system, however, indicates poor cooling performance and erratic temperature reduction. On the other hand, the temperature in storage No. 6 was reduced from 60° F. to 50° F. during the first week of storage. It is desirable that potatoes be held at 60° F. and 90 percent relative humidity for about 2 weeks, for suberization and wound healing, before reducing their temperature to 40° F. for holding.

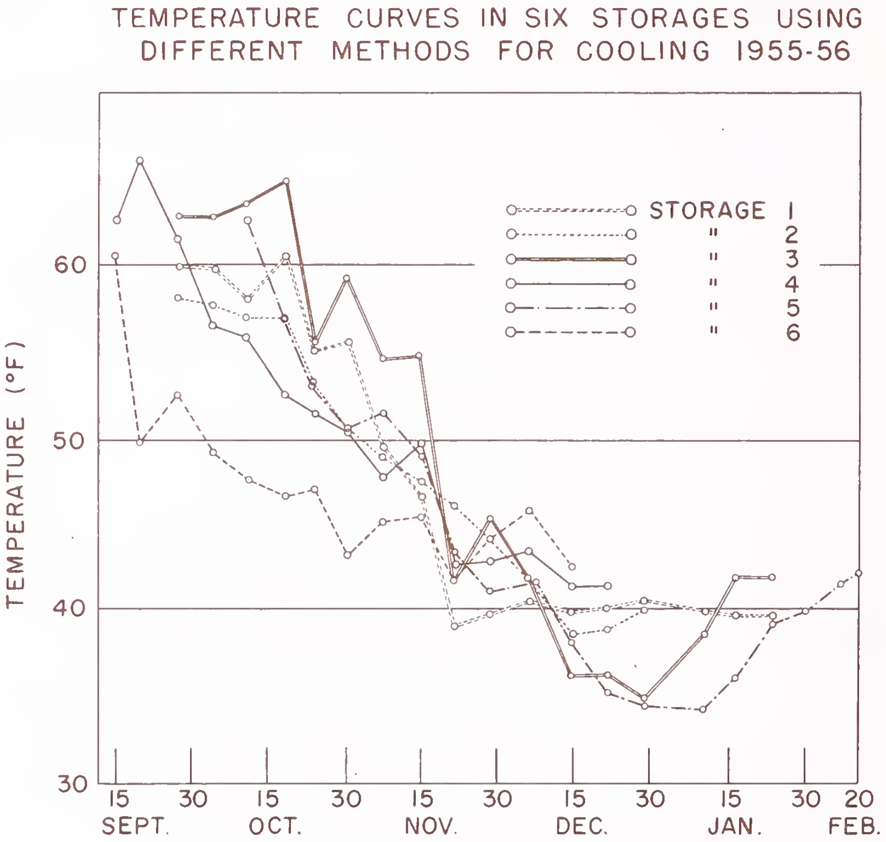
TEMPERATURE CURVES IN SIX STORAGES USING DIFFERENT METHODS FOR COOLING 1955-56

Figure 9

Temperature reduction in storages 1, 2, and 4 conformed somewhat to expectations, although cooling was retarded in storages 1 and 2 as a result of equipment failure and improper adjustment of controls. In storage No. 4 the ventilation system was supplemented with ice refrigeration from September 26 to October 17. The rapid rate of the cooling during this period is noted from the curves of figure 9. If the 3-ton mechanical refrigeration unit combined with forced ventilation of storage No. 2 had functioned properly, it would probably have cooled as rapidly as the system in storage No. 4. Storage No. 2 cooled faster than storage No. 1 during the early storage season. This indicates the effects of small-capacity supplemental refrigeration. Large differences in the temperature of storages 3 and 6 (15-ton supplemental refrigeration) are believed to be the result of different management practices.

Delaying initial storage approximately 1 month permitted reduction of temperature in storage No. 5 (naturally ventilated) at a rate that compares favorably with temperature reduction in forced air ventilated storages. However, the declining outside air temperature during the winter months caused excessive cooling; storage temperature dropped far below the desired level. In automatically controlled, forced air ventilated storages, the desired temperature is maintained regardless of how cold it becomes on the outside.

Another feature provided by forced air ventilation is the maintenance of uniform temperature within the storage. In the naturally ventilated storage No. 5, when the average storage temperature fell below 35° F., the temperature at certain points within the pile was low enough to cause chilling injury. For example, the effect of side wall temperature is more pronounced in naturally ventilated storages. Temperature distribution and cooling rate in the naturally ventilated storage and in a forced air ventilated storage during initial cooling are shown in figure 10.

The six cooling methods investigated are listed in the descending order of their cooling performance only:

Adequately sized mechanical refrigeration, with shell ventilation optional.
Ice refrigeration to supplement forced air ventilation.
Small mechanical refrigeration system to supplement forced air ventilation.
Forced air ventilation only.
Natural ventilation only.
Adequately sized mechanical refrigeration used in conjunction with forced air ventilation.

The above comparisons are based solely on the results of this study. As pointed out previously, some of the cooling systems did not perform as expected on the basis of experience and theoretical computations.

When both temperature and humidity are considered, forced air ventilation supplemented by ice refrigeration, as used in storage No. 4, came nearest to providing optimum storage environment. This was achieved by holding temperature and humidity for ample time at approximately the required level for curing and then reducing the temperature to the desired storage level within a reasonable time.

Because data were unavailable or inconsistent for some storages, proper comparison and evaluation of humidities cannot be made for all storages. The data obtained does permit a reliable comparison between storages 1 and 4. As seen in table 2, the moisture added by the melting ice to the entering air in storage No. 4 resulted in higher relative humidities than in the entering air of storage No. 1. The relative humidities of discharge air in storages 2 and 6 reflect, to some extent, the relative amounts of water lost by the potatoes to the ventilating air. On the other hand, the high humidities shown for storage No. 3 could feasibly but not likely be an indication of good humidity control,

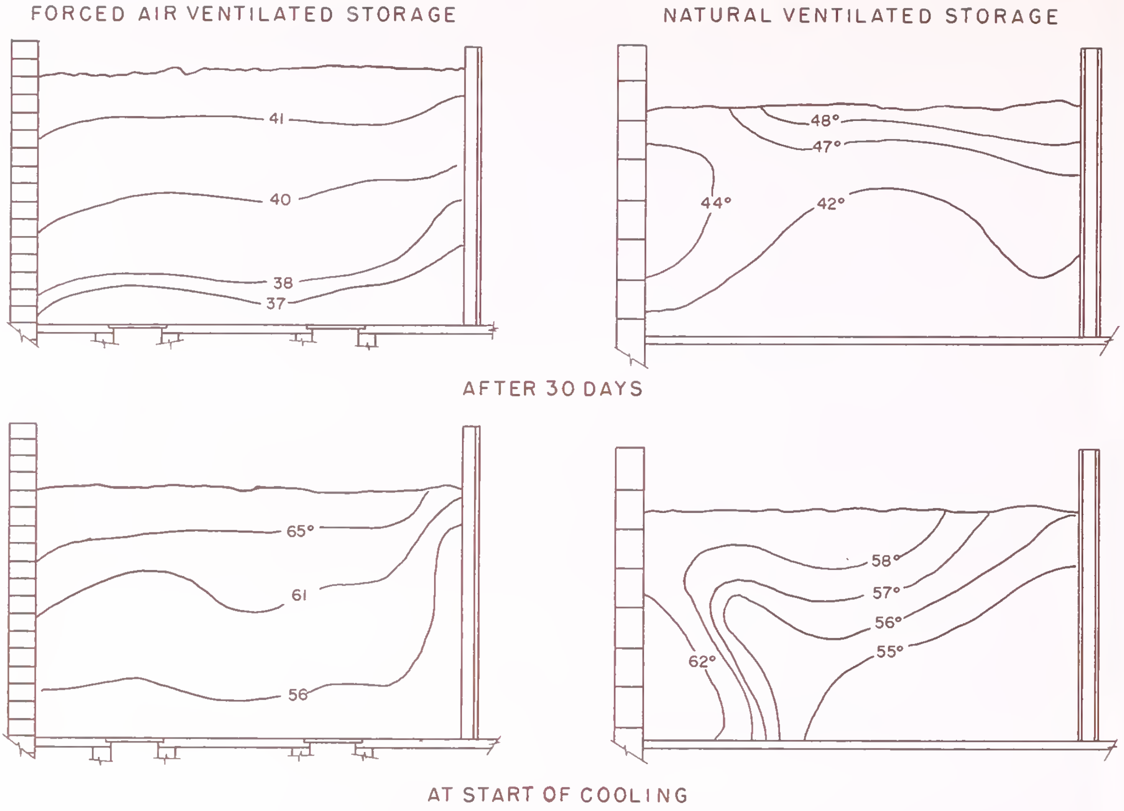

Figure 10.--Cross section of two potato storages showing temperature curves and cooling patterns in a forced air ventilated storage and a natural ventilated storage during the initial cooling period. Note the effect of the side wall on temperature of the potatoes in the naturally ventilated storage. Outside walls are shown on the left.

as a result of the attempt to add moisture to the ventilating air. Weight loss data listed in table 3 strongly suggest that storage No. 3 had poor humidity control.

EFFECT OF COOLING METHOD AND STORAGE CONDITIONS ON PRODUCT QUALITY

In the inspection of the potatoes in the ten 40-pound test bags before storage, no surface cracking or sprouting was observed. Vascular discoloration, considered unimportant at the initial inspection, was not scored. The data in table 3 indicate that greening and mechanical damage were not caused by storage. Decay was generally slight in all storages, because the tubers were well matured when placed in storage. Ring rot did not increase but Fusarium tuber rots increased significantly. It was highest, 4.2 percent, in storage No. 3, probably because of prolonged warm temperature early in the storage season.

Table 2.--Weekly average percent relative humidities in 6 Long Island Potato storages, 1955-56

Week ending--	No. 1		No. 2		No. 3		No. 4		No. 5		No. 6	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
September 28						78						84
October 5				82		80		92				
October 10						80						
October 17				87			89					85
October 24				86		86	84			78		88
October 31						95	80			78		80
November 7		86		84		97	83			85		75
November 14		82		88			85		85			81
November 21	76			80		85	85					78
November 28	67			82		87	85					78
December 5	74			90		78	91					75
December 12	75			84		87	90					73
December 19	75			84		81	92					76
December 27	76			80		88	90					
January 3	74			80		93						
January 10				84		96						
January 17						95						

(a) Entering air
(b) Leaving air

Surface cracks were generally small enough for consumer acceptance. Sprouting was more serious in some storages than in others, probably because of small differences in storage temperatures during the holding period, and improper control of ventilation because of mismangement or the failure of dampers or thermostats. Internal black spot, specific gravity, peeling discoloration, and chipping color are shown in table 4. All other defects are given in table 3.

Ice refrigeration, to supplement forced air ventilation in storage No. 4, checked decay, shrinkage, and black spot. This is probably attributable to good temperature and humidity control. Sprouting was lowest in storage No. 6. Contrary to the evidence from environmental observations, this storage also had low shrinkage and decay. This could be because the potatoes were well matured and relatively free from wounds when they were placed into storage.

Traces of lentical infection (bacterial), noted when the tubers were stored, dried up in storage. Most of the vascular discoloration is attributed to the use of vine killer, although some of it appeared to be Fusarium wilt. Varying amounts of internal black spot were observed on potatoes from all storages. Little variation was noted in specific gravity, which ranged from 1.070 to 1.078. Chipping color was generally poor in all samples tested.

Table 3.--Percentage of potatoes (by weight) having specified defects, and percentage of weight lost, before storage and after storage under 6 methods of cooling, Long Island, New York

Time of inspection and method of cooling	Storage period 1/		Decay 2/ 3/	Vascular discoloration 2/ 4/			Sprouting 5/				Greening 2/	Mechanical damage 2/ 6/	Surface cracks 2/ 7/		Weight loss	
							1/4 in. - 3/4 in.		3/4 in. & over							
	"A"	"B"		Slight	Moderate	Severe	"A"	"B"	"A"	"B"			Slight	Moderate	"A"	"B"
	Days	Days	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent	Per- cent
Before storage....................	0	0	0.5	Not scored			0	0	0	0	1.3	0.4	0	0	0	0
After storage:																
1. Forced ventilation only..	107	133	1.8	15.0	3.4	0.7	2.2	2.1	2.4	8.0	1.0	.6	2.5	1.0	9.1	9.5
2. Forced ventilation and refrigeration (3 ton)...	114	144	.9	16.2	8.3	.2	3.7	5.2	46.2	42.4	.6	.4	.6	0	7.8	8.8
3. Forced ventilation and refrigeration (15 ton)..	127	144	4.7	16.4	5.1	2.0	--	2/4.7	--	2/34.6	.8	.8	.6	0	--	2/9.8
4. Forced ventilation and ice....................	100	152	.8	11.1	4.3	.6	1.9	2.3	10.8	7.8	1.3	.3	1.4	0	7.3	8.2
5. Natural ventilation only....................	115	122	1.4	26.2	6.1	.7	--	2/5.4	--	2/19.8	1.2	.9	7.3	1.0	--	2/9.0
6. Mechanical refrigeration (15 ton)...............	90	138	1.2	12.0	18.0	.5	1.4	1.8	.8	2.0	1.8	.5	3.5	.6	7.5	8.0

1/ Sample A: Half the test potatoes were examined after commercial storage.
Sample B: Duplicate samples, after the commercial storage period, were held at 40° F. until samples from all storages could be examined at the same time.
2/ Samples A and B combined.
3/ Mostly Fusarium rot although some ring rot was also noted.
4/ Slight - trace of discoloration; moderate - marked discoloration but less than 5 percent waste; severe - 5 percent or over waste which would be scored against grade.
5/ Sprouts 3/4 in. or over scored against U. S. 1 grade; under 3/4 in. still within U. S. 1 grade.
6/ Scored only when serious enough to be scored against grade.
7/ Slight - when total amount per tuber is under 2 in.; moderate - total amount (2 to 5 in.)

Table 4.--Internal black spot, specific gravity, and color of potatoes after storage, 4 cooling methods Long Island, New York [1]

Cooling method and location in pile	Internal black spot index [2] "A"	Internal black spot index [2] "B"	Specific gravity "A"	Specific gravity "B"	Peeling discoloration "A"	Peeling discoloration "B"	Chipping color [3]
					Number [4]		Number [4]
1-Forced ventilation only:							
Top	28	10	1.070	1.074	6	7	5.2
Bottom	53	49	1.073	1.075	7	7	
2-Forced ventilation and refrigeration (3 ton):							
Top	15	9	1.074	1.073	4	4	6.2
Bottom	32	20	1.078	1.076	5	7	
4-Forced ventilation and ice:							
Top	27	19	1.074	1.075	6	7	5.0
Bottom	19	8	1.071	1.074	6	8	
6-Mechanical refrigeration (15 ton):							
Top	32	15	1.071	1.076	6	7	5.5
Bottom	20	8	1.071	1.075	7	5	

[1] For explanations of Samples A and B, see table 3.

[2] Schudder, W. T., Black Spot of Potatoes. Cornell University. 1951. The larger the number the greater the incidence of internal black spot.

[3] Chipping was prepared in a commercial plant at the end of storage period for Sample B.

[4] Color index ranges from 1 to 10; No. 10 is the lightest. Color index is a relative value determined by visual inspection.

From the standpoint of product quality, ice refrigeration in storage No. 4 performed best; mechanical refrigeration in storage No. 6 ran second.

COMPARATIVE COSTS OF COOLING SYSTEMS STUDIED

This cost analysis of cooling systems includes costs of ownership, operation, and installation. The data in table 5 are based as nearly as possible on 1960 prices. The analysis does not cover cost of the storage structures. Cost data on storage No. 5 were not listed because a naturally ventilated storage has no cooling equipment.

Table 5.--Costs of owning and operating the cooling equipment in 5 Long Island potato storages

Cooling method	Cooling equipment	Storage capacity	Expected life	Initial cost	Annual costs						Cost per hundredweight
					Ownership			Operation		Total	
					Depreciation	Interest at 5 percent	Insurance and taxes at 4 percent	Power and maintenance	Other		
		Cwt.	Years	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Automatically controlled forced air ventilation:											
1.--No supplemental cooling used....	27" double-inlet, double-width fan, 3 hp. motor.	13,800	20	1,700	85.00	42.50	34.00	[1]106.60	-	268.10	0.019
2.--Plus mechanical refrigeration...	27" double-inlet, double-width fan, 2-hp. motor; 3-ton refrig. unit, 3 hp. motor	16,800	18	3,000	166.70	75.00	60.00	[1][2]150.20	-	451.90	.027
4.--Plus ice refrigeration.........	24" double-inlet, double-width fan with 3 hp. motor 30 tons of ice	16,800	20	1,800	90.00	45.00	36.00	[1]111.40	[6]315.00	597.40	.036
Mechanical refrigeration:											
3.--With cooling coil in air duct; through ventilation optional...	15-ton refrigeration system with 15 hp. motor; 30" single-inlet, single-width fan with 5 hp. motor [3]	19,200	20	[4]7,500	375.00	187.50	150.00	[5]233.30	-	945.80	.049
6.--With overhead cooling coils; overhead ventilation optional.	15-ton refrigeration system with 15 hp. motor 6 individual blower units with 1/4 hp. motor each	11,000	20	6,900	345.00	177.50	138.00	[7]150.00	-	810.50	.074

[1] Maximum expected operating time, 2,400 hours at $0.02 per kilowatt hour.

[2] Includes 480 hours of compressor operating time at $0.02 per kilowatt hour.

[3] For single-inlet, single-width fan, the initial cost is less and operating cost is greater.

[4] Estimated cost.

[5] Includes 336 hours of compressor operating time and 1,400 hours of blower operating time.

[6] 30 tons of ice at $10.50 per ton - ice used from September 26 through October 17.

[7] Includes 336 hours of compressor operating time and 1,000 hours of ventilating fan operating time.

The least expensive to own and operate, of the five methods compared, is the automatically controlled, forced air ventilation without supplemental cooling. Supplemental cooling with ice is more expensive than mechanical refrigeration of equal capacity. Because of its effectiveness in reducing shrinkage, some justification of cost can be given to the use of ice refrigeration. But even though the extra cost for supplemental cooling by ice or the equivalent in mechanical refrigeration is not prohibitive, it is doubtful that the increased benefits will offset the extra investment required.

In view of the satisfactory performance of automatically controlled, forced air ventilated storages on Long Island, there is little justification for use of large mechanical refrigeration systems. Perhaps the strongest argument in favor of large refrigeration units is that it enables the storage operator to store earlier and hold longer, giving him some additional flexibility in marketing his potatoes.

CONCLUSIONS

Of the methods investigated, ice refrigeration provided the nearest to optimum storage atmosphere. Both the 3-ton and the 15-ton mechanical refrigeration systems used to supplement forced air through ventilation did not measure up to expectations in this study.

Because of the uncontrollable variations encountered in this study, no conclusions can be drawn solely on the basis of results of this study. It is possible however, in light of previous experience combined with theoretical and experimental data given in this report, to conclude that the automatically controlled, forced air ventilated storage will provide effective quality control at lower cost than the other systems studied.

Potatoes will keep in a naturally ventilated storage, provided they are stored late and watched closely.

Large mechanical refrigeration systems can be justified for speculative purposes only.

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