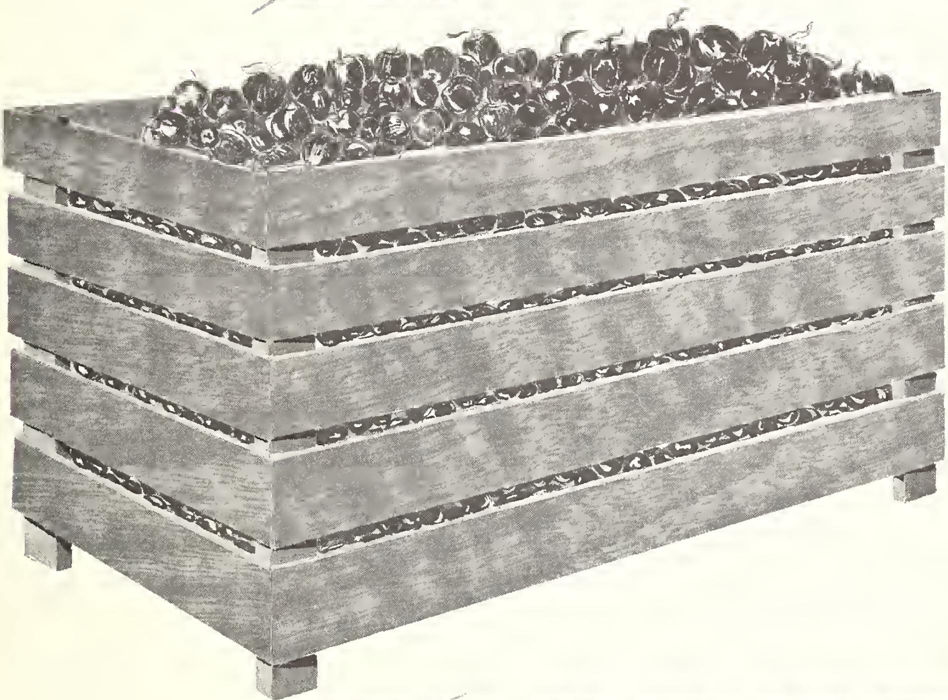
Marketing Research Report No. 532

COOLING APPLES IN PALLET BOXES



Agricultural Marketing Service
Transportation and Facilities Research Division
U.S. Department of Agriculture

PREFACE

In the Pacific Northwest alone, large sums of money are spent annually for pallet boxes and related equipment. This report should furnish guidance to the manufacturer and purchaser alike on the requirements for obtaining the best cooling qualities from a pallet box. Cooling studies are being continued, and information on these will be published as soon as the data become available.

The results reported are based upon cooling studies conducted in four apple cold-storage houses. There has been an increasing interest in the cooling rate of apples stored in pallet boxes. It is the purpose of this report to show the general requirements for proper cooling of apples in pallet boxes.

This report is part of a broad program of research conducted by the Agricultural Marketing Service of the U.S. Department of Agriculture in the Pacific Northwest, designed to cut costs of handling and packing fruit. The apple industry estimates that savings to the packers who have adopted the practices recommended earlier now amount to more than $2 million annually.

Other reports will cover the following: An automatic pallet-box filler for apples; labor and equipment requirements for handling apples in pallet boxes; evaluation of dumping methods for pallet boxes; and packing-room layout for sorting and sizing apples before storage.

Some of the results of this research are now available in summary form in AMS-236, "Handling and Storage of Apples in Pallet Boxes," and through the U.S. Department of Agriculture film entitled "Handling and Storing Apples in Pallet Boxes." A print of this film may be obtained on loan from:

Visual Aids Service
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This report is based on research conducted partly by the Fruit Industries Research Foundation, Inc., of Yakima, Wash. (now Food Industries Research and Engineering), under a research contract, and partly by personnel of the Agricultural Marketing Service. Joseph F. Herrick, Jr., marketing research analyst, administered the research contract and supervised the assigned personnel of the Agricultural Marketing Service.

Harold A. Schomer, Market Quality Research Division, Agricultural Marketing Service, made suggestions for conducting the cooling-rate studies. Individuals and organizations in the apple industry made their storages available for tests on pallet boxes.

Washington, D.C. August 1962

CONTENTS

SUMMARY

The practice of handling and storing apples in standard 1-bushel-capacity wooden boxes has been extensively transferred to the use of pallet boxes for this purpose in the United States, especially in the Pacific Northwest.

This report describes a number of types of pallet boxes that were studied by Agricultural Marketing specialists; both specially built pallet boxes and commercial pallet boxes were used. Variations in these boxes included design, materials, and dimensions. The cooling rates of apples in pallet boxes were evaluated and compared with the cooling rates of pallet loads of apples stored in standard 1-bushel-capacity wooden boxes. The influence of structural features of various types of pallet boxes on cooling performance was also determined.

The cooling tests indicated that, in general, apples stored in pallet boxes cooled as well or better as those stored in standard boxes on pallets. Pallet boxes of apples which cooled better than apples stored in standard boxes on pallets had a total free air space (ventilation area) on the sides or bottom ranging from 8 to 11 percent. Free air space on the sides gave cooling results comparable with free air space on the bottoms of the pallet boxes.

The use of pallet boxes has made a considerable saving in storage space. About 20 percent more fruit can be stored in pallet boxes in the same storage space, depending on the dimensions of the pallet box, than fruit stored in standard boxes handled on pallets. The increased capacity and speed of volume handling with the use of pallet boxes materially increases the load on a refrigeration system, and this fact must be taken into consideration when changing the handling system from standard boxes to pallet boxes in a storage plant.

Cooling Apples in Pallet Boxes

by Glenn O. Patchen, mechanical engineer, Transportation and Facilities Research Division, Agricultural Marketing Service,

and

G. F. Sainsbury, consulting engineer [1]

BACKGROUND

With the adoption of pallet boxes by the apple industry, the cooling of the fruit in these large containers became a problem of paramount importance. Apple producers and storage and packinghouse operators need to know the cooling rates of apples stored in pallet boxes of various designs and the effects on cooling of different stacking arrangements.

Cooling studies were undertaken, some covering test pallet boxes, and some covering those in commercial use, to determine the design and arrangement which would permit the maximum cooling rate of fruit. Cooling rates and cold-storage-room designs for use with pallet boxes were compared with those for the standard 1-bushel capacity wooden box.

Importance of Rapid Cooling

The keeping quality of apples depends, to a large extent, upon the temperature at which the apples are stored and upon how quickly they are cooled to the optimum storage temperature after harvesting. After apples are harvested, they remain alive until they are consumed. As all living things do, they carry on the process of respiration. This process involves evolution of heat and the more rapidly it takes place, the more quickly the fruit will ripen or deteriorate.

Respiration varies with the temperature: A low temperature slows the rate of ripening and allows better preservation of the quality of the apples. To take advantage of this, apples must be harvested at the correct stage of maturity and cooled as quickly as possible. The temperature of most varieties of apples should be reduced as rapidly as possible to 30°–32° F.

Cooling in Pallet Boxes

When conduction is the sole means of heat removal, cooling occurs almost as the square of the distance from the center of the apple container to its nearest face, where heat can be transferred to the air. If the heat can be disposed through more than two parallel faces, the relationship becomes more complex; however, if the distance from the center to one set of parallel faces is much less than the distance to the other pair of parallel faces, then most of the heat is conducted to the nearest faces and the influence of the farthest pair is slight. Usually stacks of pallet boxes are placed tightly together in rows so that the backs and fronts of the pallet boxes have little access to air.

The depth of the pallet box is usually about 2 feet, which is about half the width or length. Consequently, most of the cooling occurs from the top and bottom areas. The depth also affects the quantity of air which passes through the fruit, and as the air quantity is decreased, air temperature increases proportionately. As a result, the temperature difference between the air and the fruit is less and the cooling time becomes greater.

A provision to let air into the pallet box to accomplish as much cooling as possible by convection is of prime importance. In some pallet boxes, the air entered through the sides, in others through the bottom and in some through both. The most important cooling consideration is the total space for air to enter the box—"free area." This measurement seems to be the best index of the accessibility of the pallet box to the air flow. Free area was calculated for the bottom and the sides of each type of pallet box. In the calculations, deductions were made for the area of cross members where spaced sides or bottoms were used.

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[1] Formerly agricultural engineer, Transportation and Facilities Research Division, Agricultural Marketing Service, U.S. Department of Agriculture.

PURPOSE

To compare rates of cooling between standard apple boxes and pallet boxes, cooling performance was evaluated by determining the average half-cooling time for each type of pallet box and comparing this with the half-cooling time for pallet loads of standard boxes. Half-cooling time is the time required for the fruit to cool to one-half the difference between the initial fruit temperature and the air temperature in the cold storage room.

The average stabilized temperature of each type of pallet box was also determined and compared with the stabilized temperature of standard apple boxes. Stabilized-temperature difference is the difference between the fruit temperature in the center of the pallet or apple box and the air temperature next to the box after cooling has been completed.

Determinations for half-cooling times and stabilized-temperature differences are in the appendix.

PALLET BOXES STUDIED

Selection

The cooling studies were essentially an investigation of the effects of pallet-box dimensions and ventilation characteristics on their cooling performance. Both convection and conduction play a part in the cooling of these containers and their contents. The relative importance of each factor in the total performance is unknown. The cooling that is accomplished by conduction is influenced by a number of variables, but the most important factor in these tests is the distance from the center of the pallet box to the face or faces of the mass of apples where heat can be transferred to the air. The most important variables influencing the cooling accomplished by convection are the temperature and quantity of air passing through the apples in the pallet box. The provisions for air to enter the pallet box have a great effect on these variables. Test pallet boxes were designed and selected for this study for the greatest efficiency in handling, cooling, and storage of apples. Boxes of various sizes and of various materials, including metal, were used in the study. The side-lift boxes were included because of the possible saving in storage space; the stringers (pallets) that are underneath conventional boxes were eliminated, leaving no air spaces beneath the box. Cooling is by conduction only, except in the box on top of the stack. The forks lift these boxes by sliding under flanges along two outside top edges of parallel sides.

In all pallet boxes, except box No. 3, the steel box, and the side-lift boxes, the pallets provided air flow above and below each pallet box. The minimum dimension from center to exposed face of the body of fruit was one-half the depth. For 15 of the pallet boxes, this distance (D/2) ranged from 11¾ to 14 inches, with an average of about 12 inches. For the 35-inch deep pallet box with solid sides and spaced bottom, D/2 equaled 17.5 inches, and for the 32-inch-deep pallet box with fiberboard liner, D/2 was 16 inches. For the box without a pallet, the minimum center-to-side face distance was 20 inches.

Variations

The variations in construction were included to provide a comparison among pallet boxes with:

- solid bottoms and sides;
- solid bottoms and sides, but with a 1½-inch slot around the bottom;
- solid bottoms and spaced sides;
- spaced bottoms and solid sides;
- spaced sides and bottoms.

Included in the comparison were two pallet boxes furnished with fiberboard liners with perforations for ventilation. The free area for these two pallet boxes was substantially less than the free area for most of the pallet boxes that had either the bottoms or the sides spaced.

The variations also allowed a comparison for pallet boxes of different depths, but with the same provisions for ventilation. The 35-inch deep pallet box with solid sides and spaced bottom may be compared with the similarly constructed 24-inch-deep pallet box. The two pallet boxes with perforated fiberboard liners may be compared on the basis of depth; one was 24 inches deep and the other was 32 inches deep.

The construction variations allowed a comparison between pallet boxes with and without liners. The metal side-lift box was constructed with no ventilation through the sides or bottom. This was done to see if the conduction rate of steel and aluminum, which is better than the rate for wood, would provide adequate cooling.

In test No. 3 the various pallet boxes were loaded with apples of different sizes to see if the cooling rate would be affected by the size of the apples.

The pallet boxes used in the cooling tests are illustrated in figures 1 through 26.

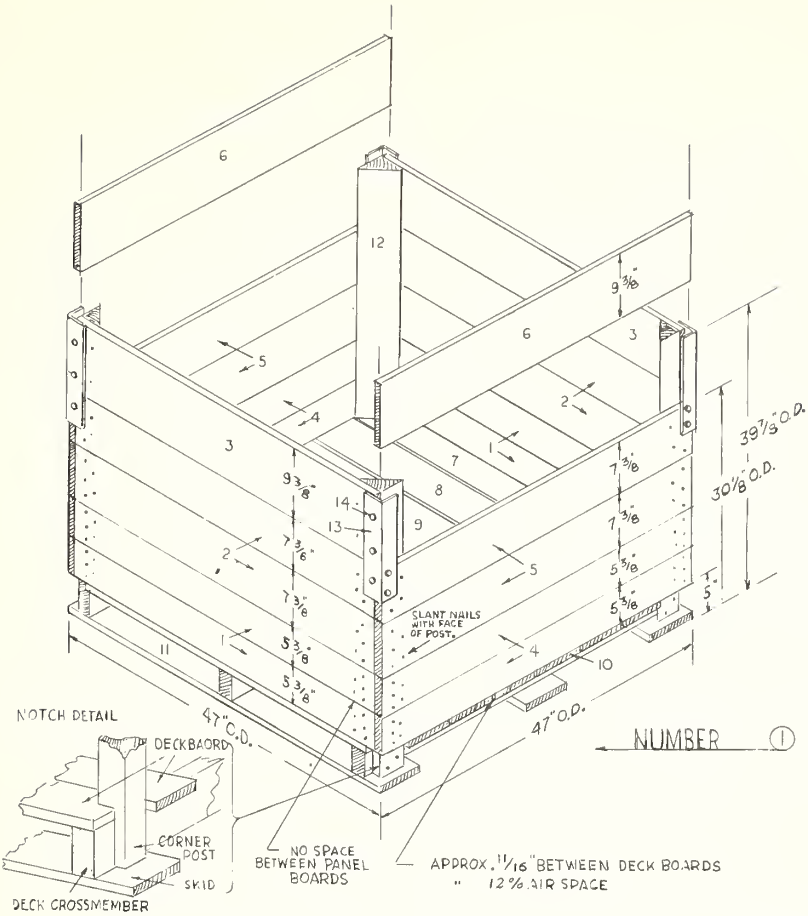

Figure 1.—Test pallet box No. 1 with solid sides and spaced bottom with two removable 9½-inch end sections, and an inside depth of 34⅞ inches.

PROCEDURES

The instruments used in the tests are a 32-point temperature recorder, potentiometer, and circular-chart temperature recorder. They and the ways in which they were used are described in the appendix.

When the circular-chart temperature recorders were started at the test site, each was calibrated by covering the bulb with melting ice and adjusting the pen on the chart to 32° F. The continuous recorder was checked for calibration at each test site by placing one or two of the thermocouples in a thermos bottle filled with melting ice and observing the temperature recorded for these thermocouples. This was done at the beginning and end of each test. In most cases, the instrument read 32.5° F. for these positions. It was concluded that the instrument was reading about 0.5° high and adjustments in the data were made accordingly.

First Test

The characteristics of the various pallet boxes included in Test No. 1 and Test No. 2 are listed in table 1.

Because all of the pallet boxes were about the same height, the continuity of fork spaces, which allows airflow, was maintained by using filler stacks of the second type of box mentioned above. The first three types of pallet boxes were located in one test row, the other two types were located in a second row, and the check stack of standard boxes was placed in the third row. One group of these test stacks was placed in positions near the back wall of the storage; however, in all test rows a filler stack was used facing on the aisle and walls. In this manner, no test stack had either the back or the front of the pallet box exposed.

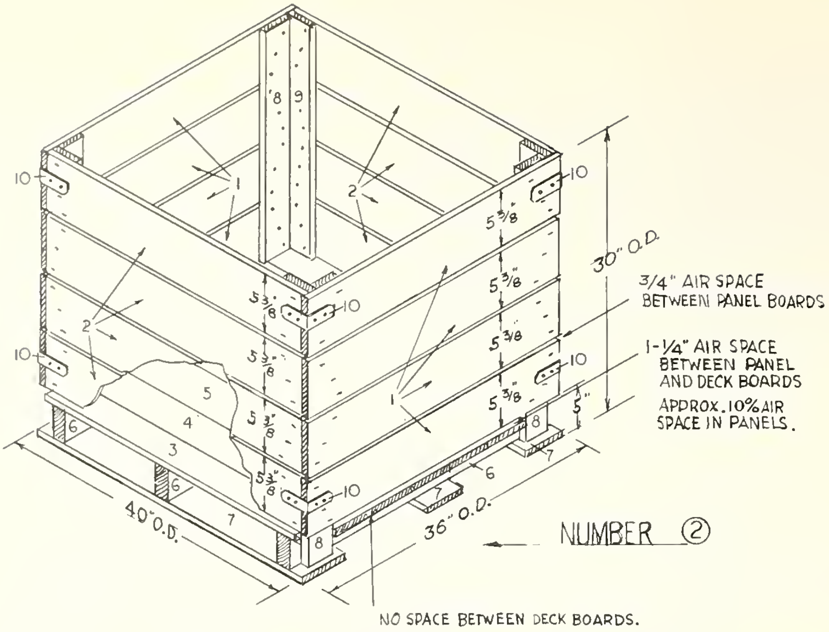

Figure 2.—Test pallet box No. 2 with spaced sides, solid bottom, and an inside depth of 25 inches.

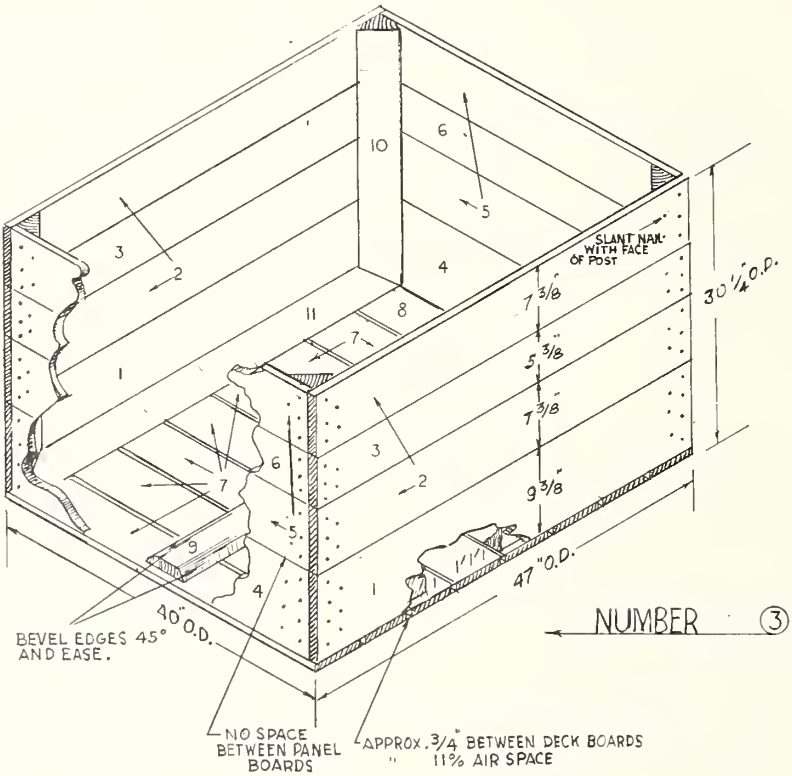

Figure 3.—Test pallet box No. 3 with solid sides, spaced bottom, and an inside depth of 29½ inches. Box does not have pallet.

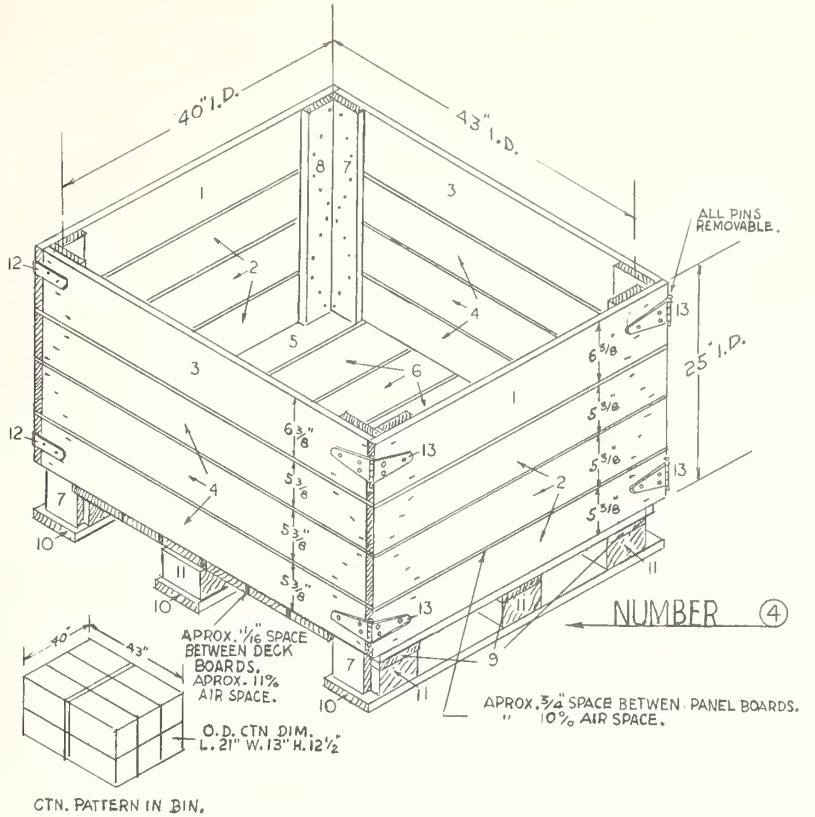

FIGURE 4.—Test pallet box No. 4 with spaced sides and bottom, and an inside depth of 25 inches.

TABLE 1.—*Dimensions and specifications of pallet boxes used in cooling performance for tests 1 and 2*

Container	Characteristics and remarks	Outside dimensions			Inside depth	Free area in—	
		Width	Length	Height		Bottom	Sides
		Inches	*Inches*	*Inches*	*Inches*	*Percent*	*Percent*
Pallet box No. 1 (fig. 1)	Solid sides, spaced [1] bottom with removable 9½″ high sections on both ends for ease in filling	47	47	39⅞	34⅞	9. 5	0. 0
Pallet box No. 2 (fig. 2)	Spaced sides, solid bottom	40	36	30	25	. 0	11. 3
Pallet box No. 3 (fig. 3)	Solid sides, spaced bottom, without pallet	40	47	30¼	29½	8. 0	. 0
Pallet box No. 4 (fig. 4)	Spaced sides and bottom	46	43	30¼	25	5. 7	8. 3
ARS pallet box No. 1 (fig. 5)	Solid sides, spaced bottom	40	47	30	24¼	8. 7	. 0
Commercial pallet box No. 1 (fig. 6)	Fiber [2] over widely spaced sides and bottom	48	47. 5	36	32	1. 2	. 7
Commercial pallet box No. 3 (fig. 7)	Fiber over widely spaced sides and bottom	48	48	29½	24	. 5	. 7
Commercial pallet box No. 2 (fig. 8)	Solid sides and bottom [3] with 1½″ slot around bottom	48	48	29	24	. 0	. 6
Commercial pallet box No. 2M (2 modified)	Solid sides and bottom, [4] no vents around bottom	48	48	29	24	. 0	. 0
Standard apple box filled with loose fruit	Free area in bottom varies somewhat with type of bottom shook used	12. 25	19. 5	10¾	10½	10. 0	. 0

[1] Spacing refers to openings from ⅝ to ¾ inch on the bottom; side spacing means from ⅝ inch to approximately 1 inch.

[2] For picture of fiber liner see figure 11.

[3] Sides and bottom lined with paper for test to eliminate effect of small cracks in the pallet box.

[4] Paper-lined to form solid interior.

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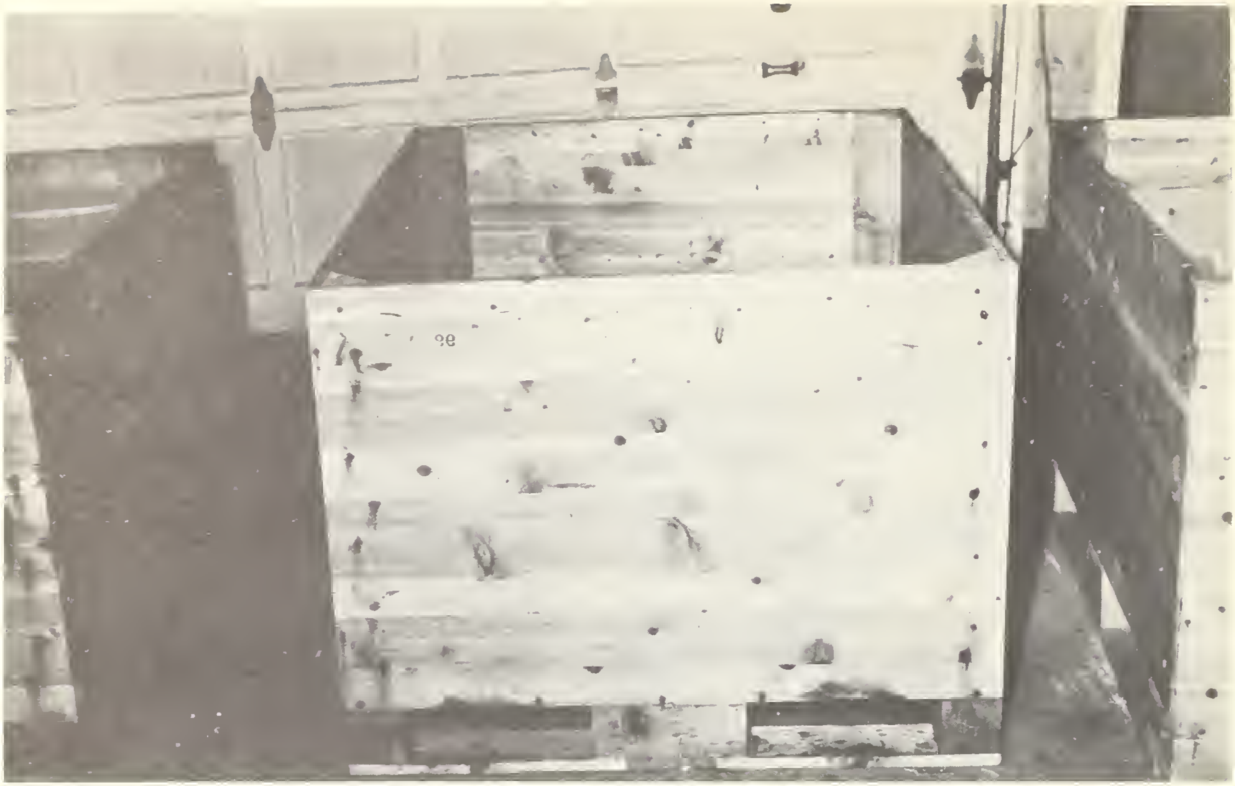

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FIGURE 5.—ARS pallet box No. 1 with solid sides, spaced bottom and an inside depth of 24¼ inches.

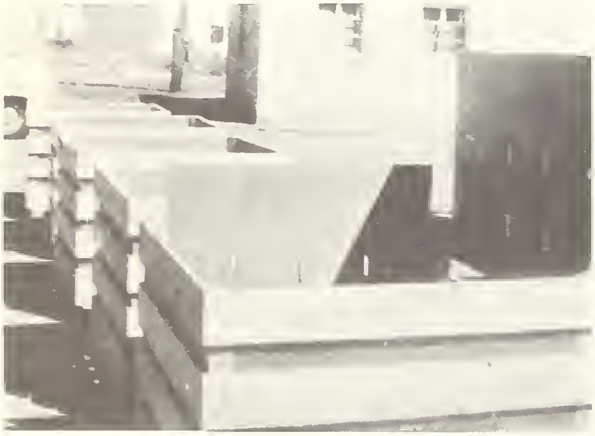

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FIGURE 6.—Commercial pallet box No. 1 with fiberboard-lined sides and bottom over widely spaced sides and bottom. The inside depth is 32 inches.

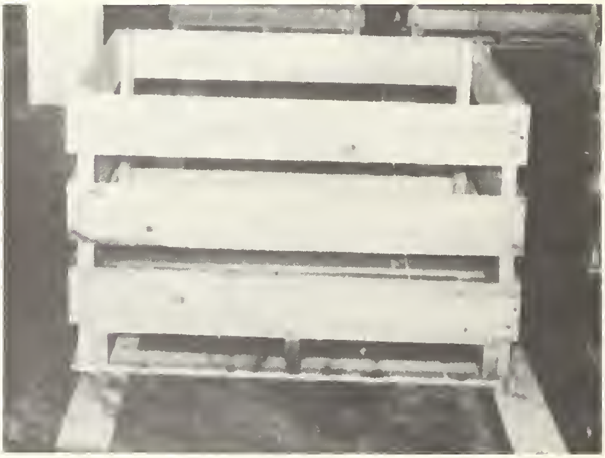

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FIGURE 7.—Commercial pallet box No. 3 with fiberboard-lined sides and bottom over widely spaced sides to bottom and inside depth of 24 inches. Liner is shown in figure 11.

Temperatures were recorded in the center of the top and bottom pallet boxes in each stack of test pallet boxes which were placed six-high in this storage. In the check stacks of standard apple boxes on pallets, the temperatures were recorded in boxes in the middle of the top and bottom pallet loads of fruit. The pallet loads of standard boxes were stacked three-high. In this storage, the direction of the air flow was from the wall toward the aisle.

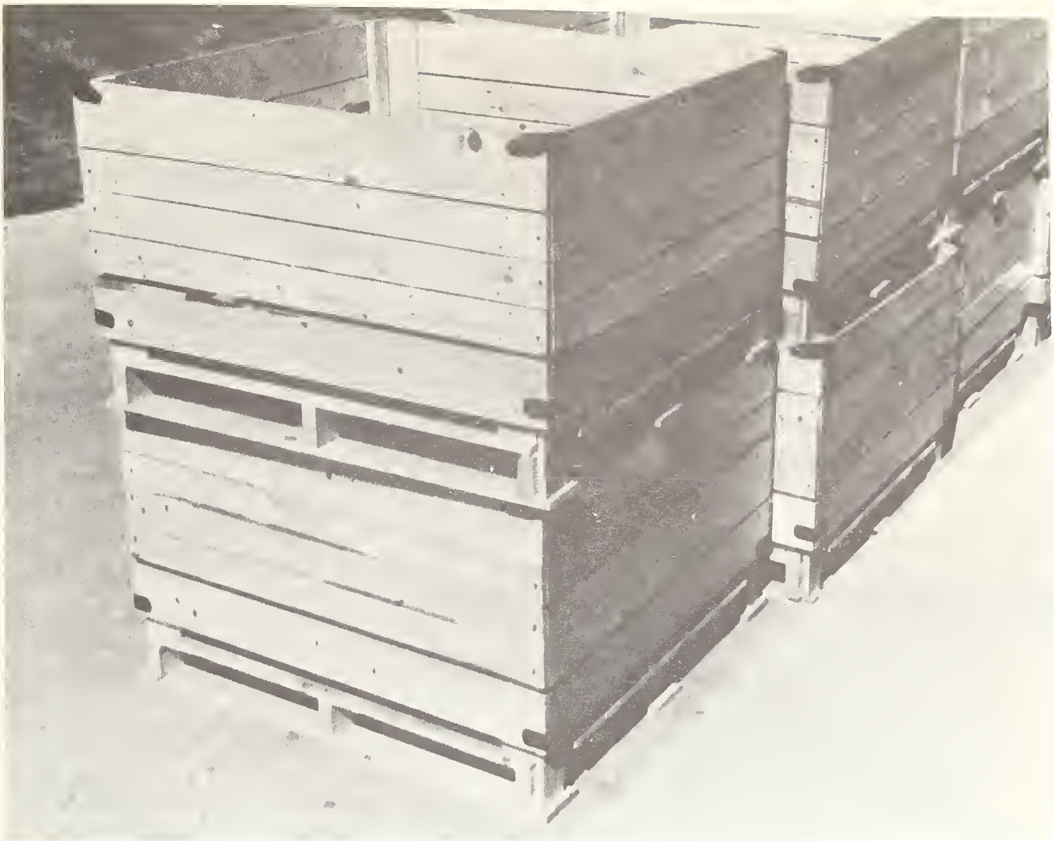

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FIGURE 8.—Commercial pallet box No. 2 with solid bottom and solid sides, with 1½-inch slot at bottom of side, and an inside depth of 24 inches. Commercial pallet box 2M, not illustrated, was similar but was lined with paper to simulate solid sides and solid bottom.

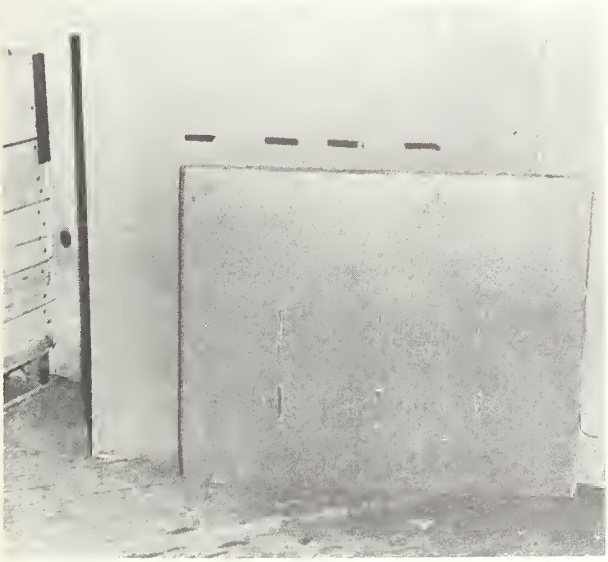

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FIGURE 9.—Corrugated fiberboard-liner with ¼″ x 4″ air space, used with commercial pallet box No. 3.

Second Test

The direction of the major air flow in this storage was from the aisle toward the wall at the end of the row.

Because an exceptionally large crop had been harvested in the area, cold-storage plant space for the test was limited, and most of the test stacks were placed in one row. This row of stacks contained two experimental lots. The first lot consisted of single stacks of each type of container in the following order: Pallet box No. 3, pallet loads of standard boxes, pallet box No. 4, commercial pallet box No. 1 and pallet box No. 1. The second lot was continuous with the first and was made up of stacks of pallet box No. 4, commercial pallet box No. 1, pallet box No. 1, and a check stack of pallet loads of standard boxes. There was a filler stack at both ends of the row. In the adjoining row, the second stack from the aisle was the stack of pallet boxes without pallets.

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FIGURE 10.—Commercial pallet box No. 1–G.

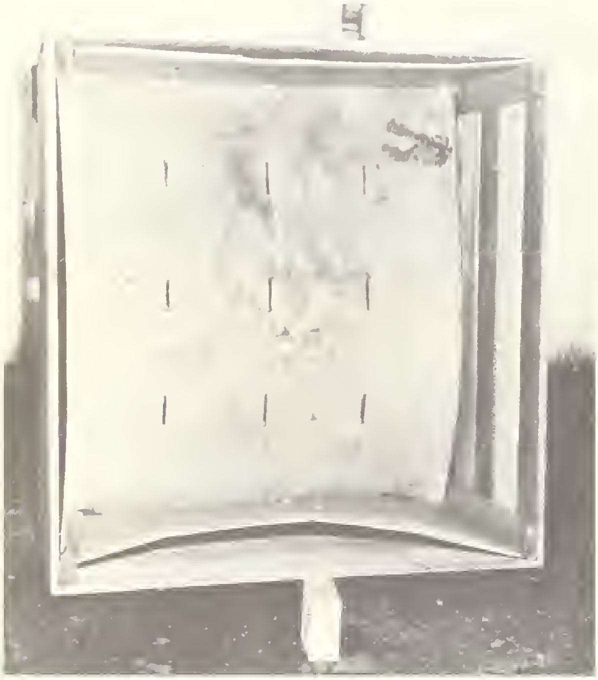

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FIGURE 11.—Commercial pallet box No. 1–G showing bulged liner.

The pallet boxes were not all the same width, and therefore the fork spaces were not continuous. This made it possible for some air to escape from the fork spaces.

The pallet box without a pallet did not have a clear space for the air to pass below. For that reason these pallet boxes were placed in the adjoining row to avoid impeding air flow into the main test row.

The pallet boxes in this test differed considerably in height. Therefore, continuity of the fork space from stack to stack was provided by placing an extra pallet or pallets beneath the more shallow pallet boxes in such a manner as to assure continuous passages through the row. Six-box-high test stacks of pallet boxes filled the last row available in this room.

Thermocouples were placed in test pallet boxes in the same manner as in the first test.

Third and Fourth Tests

The descriptions of the pallet boxes used in tests 3 and 4 are summarized in table 2.

Commercial pallet box.—The commercial pallet box No. 1–G is illustrated in figures 10 and 11. This pallet box was 48 by 48 inches outside and 24 inches deep inside. The sides and bottom were rough 1- by 4-inch lumber widely spaced. It used a vented heavily waxed corrugated paper liner.

Bruise-prevention pallet box.—This pallet box was constructed to give strength and light weight. Diagonal (sway) braces were placed on the sides in a pattern designed to withstand racking—that is, being forced out of shape (figs. 12 and 13). This pallet box was lined with a water-resistant polystyrene core covered on both sides by a 42-pound natural kraft paper on the inside of sides and bottom. The dimensions for this pallet box were 47 by 48 inches outside and 24 inches deep inside.

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FIGURE 12.—Bottom view of bruise-prevention pallet box showing pallet without skid boards.

TABLE 2.—*Dimensions and specifications of pallet boxes used in cooling tests No. 3 and 4*

Pallet box name	Test No.	Characteristics and remarks	Outside dimensions			Inside depth	Free area in—	
			Width	Length	Height		Bottom	Sides
			Inches	*Inches*	*Inches*	*Inches*	*Percent*	*Percent*
Commercial No. 1–G (figs. 10 and 11).	3	Wide spaced boards on sides and bottom, lined with heavy corrugated waxed paper.	48	48	29	24	6	3
Maximum-bruise prevention (M.B.) (figs. 12 and 13).	3	Diagonal wood braces on sides and spaced wood on bottom lined with paper-covered, water-resistant polystyrene.	47	48	30	24	6	3
Maximum cooling (M.C.) (figs. 14 and 15).	3	Sides and bottom, wood, wide spaced.	47	48	30	24	15	11
Wooden side-lift (S.L.) (figs. 16 and 17).	3	Diagonal wood braces on sides, hard board lined sides; spaced wood bottom and lined with paper-covered, water-resistant polystyrene.	48	47	29	27⅞	11	4. 8
Plywood (P.) (fig. 22)	3	¾-inch plywood sides and bottom.	47	47	30	24	None	None
Standard apple box	3 & 4	Free area in bottom varies with shook used.	12¼	19½	10¾	10½	6–10	None
Steel side-lift (figs. 18 and 19).	4	Galvanized corrugated steel, no lining, no pallet.	47	48	28½	27	None	None
Aluminum (figs. 20 and 21).	4	Corrugated aluminum, no lining, on pallets.	47	47	30	24	None	None
Commercial plywood No. 5 (figs. 23 and 24).	4	⅝-inch plywood sides and bottom.	47	47	30	24	2	4
Commercial slatted No. 6 (figs. 25 and 26).	4	Spaced wood sides and bottom, no lining.	47	47	30	23½	4	6

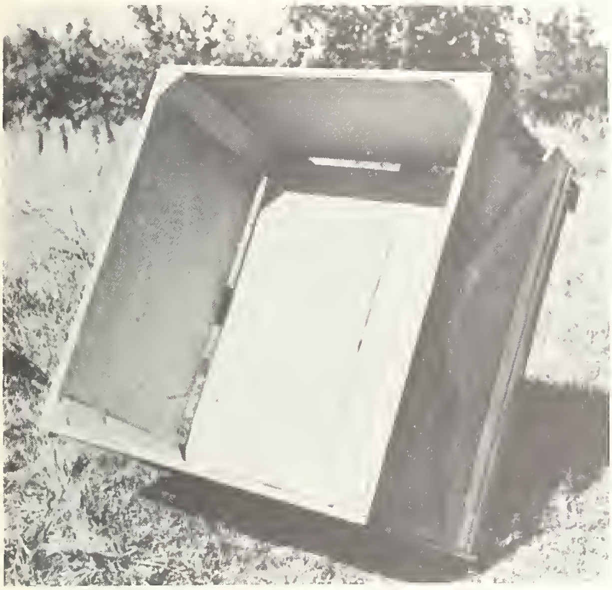

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FIGURE 13.—Inside view of maximum-bruise-prevention pallet box, showing airspace along edge of deck for cooling.

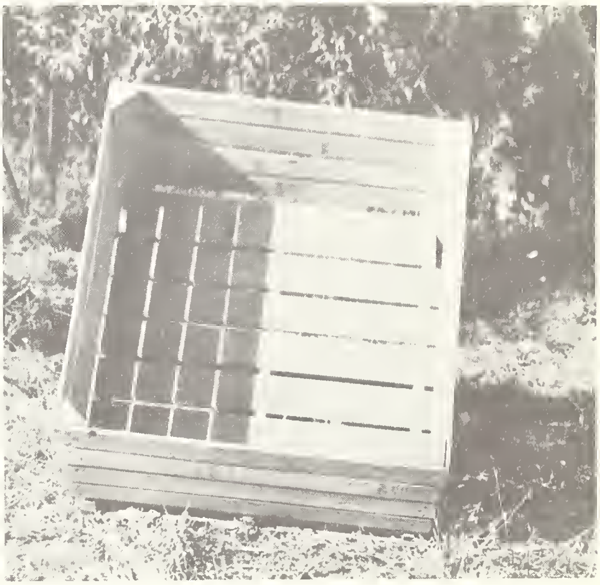

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FIGURE 14.—Inside view of maximum-cooling pallet box, showing free airspace in deck and side panels.

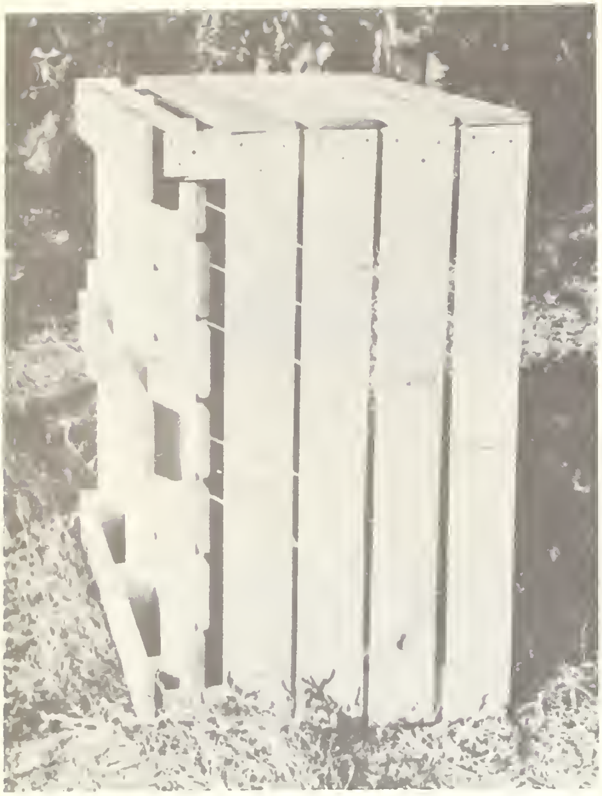

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Figure 15.—Side view of maximum-cooling pallet box showing 1-inch space between deck and sides to provide additional cooling.

Maximum-cooling pallet box.—This pallet box was designed to provide a maximum amount of air circulation for the stored fruit. The sides and bottom were constructed with 1- by 6-inch finished panel boards, all with bullnosed (rounded) edges. To provide additional cooling space, a 1-inch airspace was maintained between the deck boards and the lowest side panel board. The spacing of the lumber in the sides and bottom of this box gave a 12-percent free-air surface. This pallet was 47 by 48 inches outside and 24 inches deep inside (figs. 14 and 15).

Wooden side-lift box.—This box was designed to be lifted at the sides to eliminate storage space lost by using a pallet. The sides were of hardboard masonite with vent holes and the bottom was lined with a water-resistant polystyrene pad, covered on both sides by a 42-pound natural kraft paper, with a 1-inch free-air space around the bottom (figs. 16 and 17). This box was 47 by 48 inches outside and 27⅞ inches deep inside.

Corrugated-steel side-lift box.—This box was made of 22-gage galvanized corrugated steel reinforced with angle irons. Ventilation was not provided in this box (figs. 18 and 19). This box was 47 by 48 inches on the outside, and 27 inches deep inside.

Corrugated-aluminum metal pallet box.—The construction of this pallet box was of 0.032-inch-thick corrugated sheet aluminum and aluminum tubing. There was no ventilation. The box was 47 by 47 inches outside, and 24 inches deep inside. A tubular aluminum pallet 5 inches high was attached to the bottom (figs. 20 and 21).

Plywood pallet box.—This pallet box was made from ¾-inch thick plywood and was 47 inches square on outside, 24 inches deep inside, and was used in test No. 3. There was no provision for ventilation (fig. 22).

Commercial plywood pallet box No. 5.—The construction was of ⅝-inch plywood, 47 inches square outside by 24 inches deep inside, and was used in test No. 4. The bottoms of two sides had 4 slots, each 1½ by 7 inches, for free air circulation. The bottom had eight slots, ⅜ by 15 inches long, for air circulation (figs. 23 and 24).

Commercial slotted pallet box No. 6.—This pallet box, which was used in test No. 4, was constructed of ¾-inch finished lumber. The sides and bottom were of 1- by 6-inch boards spaced ¼ inch apart. To allow for free circulation through the sides, on each side, two 1- by 11-inch additional slots were provided at the base on each side. The box was 47 inches square outside and 23½ inches deep inside (figs. 25 and 26).

All of these pallet boxes were of approximately the same height. The pallet boxes were arranged in two rows near the center of the building and stacked eight high. Filler stacks of approximately the same height were made up of pallet boxes and pallet loads of standard boxes of loose apples.

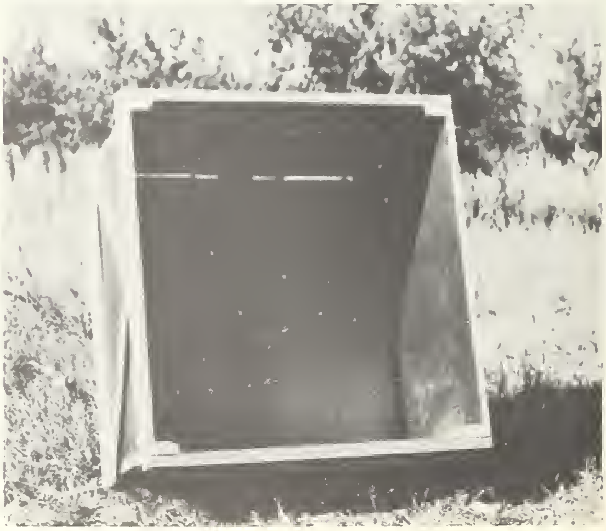

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Figure 16.—Inside view of wooden side-lift box showing cooling vent around bottom and vents in side.

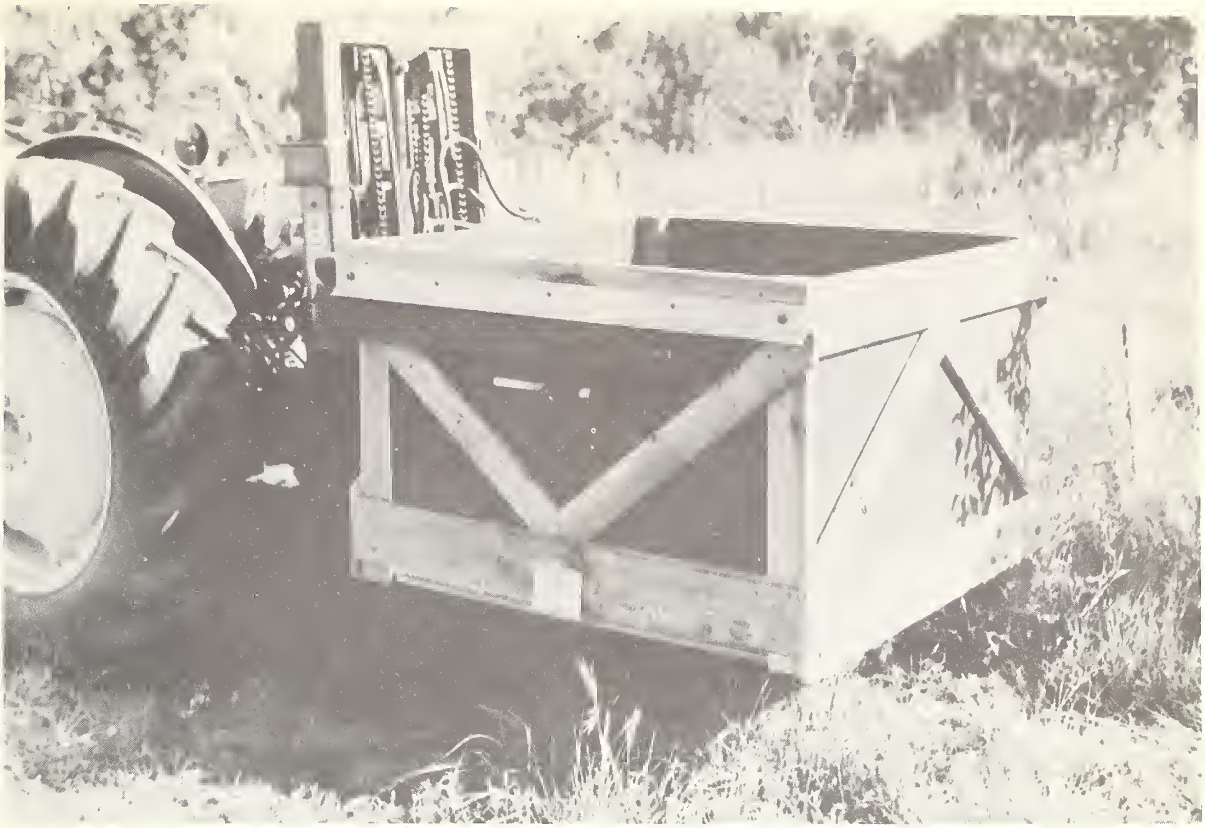

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FIGURE 17.—Outside view of wooden side-lift box showing construction and method of lifting.

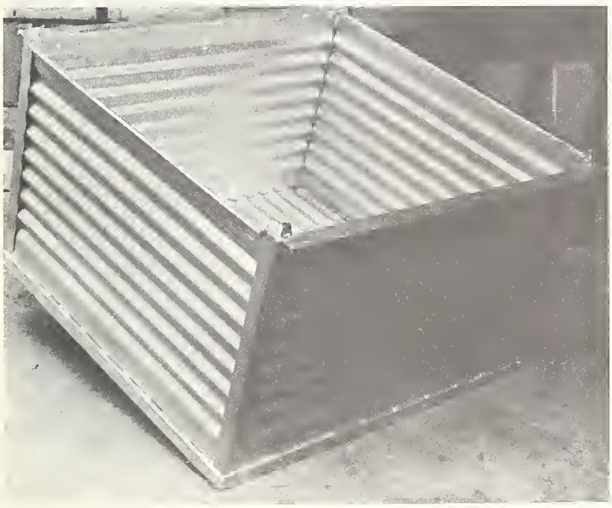

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FIGURE 18.—Corrugated-steel side-lift box.

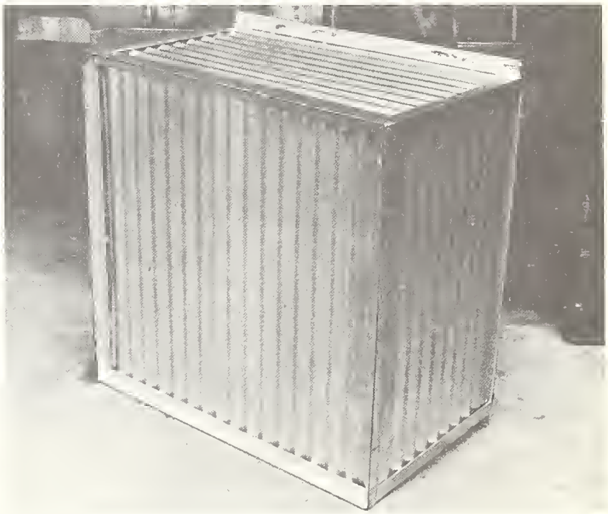

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FIGURE 19.—Bottom view of corrugated-steel box.

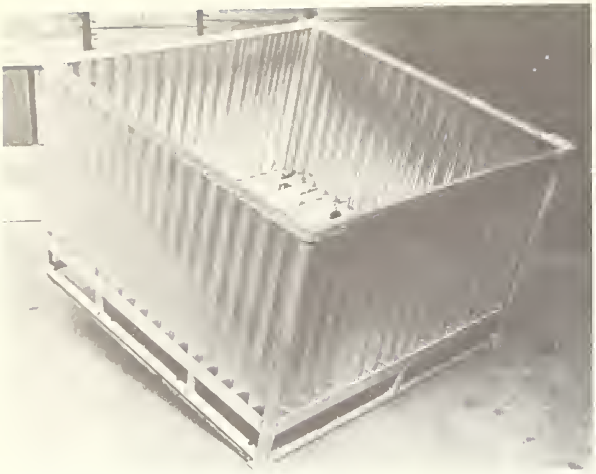

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FIGURE 20.—Inside view of aluminum pallet box.

The side-lift boxes were tested in the stacks by placing paper over the facing of the filler, or buffer stacks because the side-lift boxes were constructed without a pallet and air could not circulate above or below the boxes within the stacks.

In both test rows, a filler stack was used facing on the aisle and also next to the wall; thus no test stack had either the back or front exposed. The row to the right and row to the left of the test rows had been filled previously with packed boxes of apples.

Temperatures were recorded in the center apple of the top and bottom pallet boxes in each of test pallet boxes.

The pallet boxes were filled with sized apples to try to determine whether the size of the apple had any effect on the cooling rate. The sizes used were: Orchard run (O), small apples (S), medium apples (M), and large apples (L). The air circulation in this storage was from overhead to the side walls and down, then back to the center aisle and up to the circulating units. (Test No. 3.)

In this storage plant, the air flow was from one side of the building to the other, parallel to the stacked rows of fruit, with air reversal every hour. The stacked pallet boxes were located in one row and the check pallet load of standard boxes in the next row. Both sides of the rows were filled with packed boxes of apples. Because of the limited headroom, the stacks of pallet boxes were only four high. A filler stack was used at the end of each row. Thermocouples were located in apples in the center of the pallet boxes as in the previous tests. In addition, thermocouples were located in the center of an apple box and an additional thermocouple was placed at the center of the pallet box of apples to measure the air temperature. (Test No. 4.)

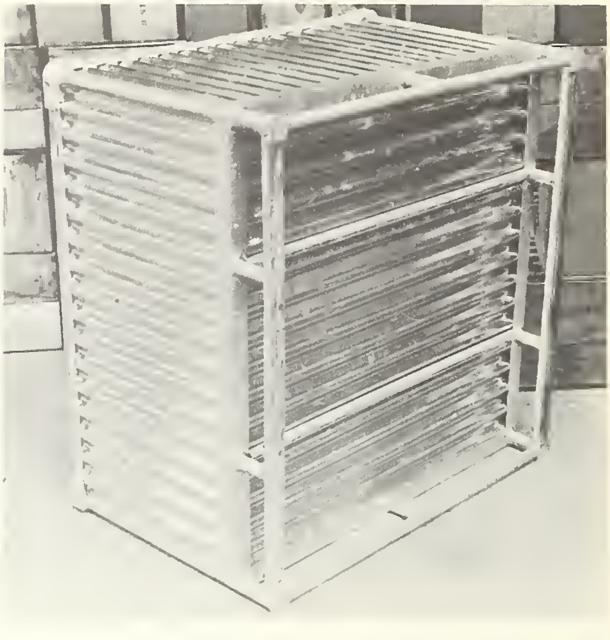

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FIGURE 21.—Bottom view of aluminum pallet box, showing pallet constructed of aluminum tubing.

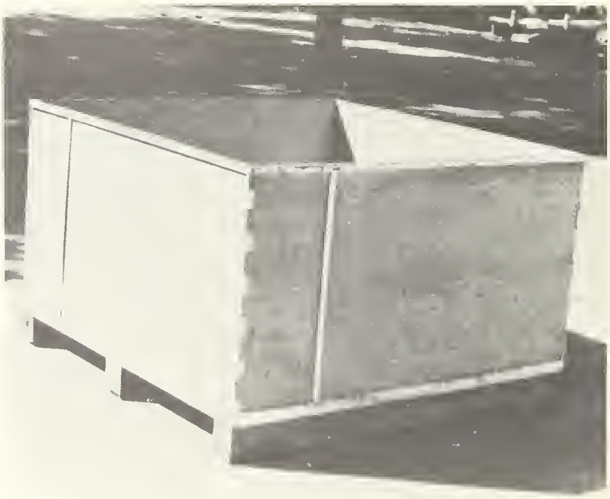

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FIGURE 22.—Plywood pallet box used in test No. 3.

Tests Numbers 1 and 2

The half-cooling time and stabilized-temperature difference for the various types of pallet boxes and the standard boxes for the first two tests are summarized in table 3. The half-cooling time for the standard boxes shows a considerable difference between the performance at the two test locations. Previous tests of the cooling performance of pallet loads of unpacked apples in standard boxes showed a half-cooling time that ranged from 15.4 to 23.4 hours. The performance at the location of test No. 1 approaches the best results that have been observed for cooling in these containers whereas the performance at the location of test No. 2 is slower than any previously observed test cooling of unpacked apples in pallet loads of standard boxes. Therefore, the results from the two tests are not directly comparable.

The first test shows that the two pallet boxes which were constructed with good provision for ventilation (the pallet box with solid sides and spaced bottom and the pallet box with solid bottom and spaced sides) cooled slightly faster than pallet loads of standard boxes. However, the other pallet boxes in this test, which had a low percentage of free ventilation area, took from 66 to 85 percent longer to cool than the standard boxes.

TABLE 3.—*Half-cooling time and stabilized-temperature difference for nine types of pallet boxes and for pallet loads of standard boxes of unpacked, or loose, apples for two tests*

Test and type of box	Half-cooling time		Stabilized-temperature difference
	Time	Index [1]	
Test No. 1:	*Hours*		*° F.*
Standard apple box	16.1	100	0.7
Commercial pallet box No. 3	29.8	185	.7
Commercial pallet box No. 2	26.7	166	.9
Commercial pallet box No. 2M	29.2	181	.9
Pallet box No. 2	15.5	96	.8
Pallet box No. 1	15.6	97	.8
Test No. 2:			
Standard apple box	30.9	100	.7
Commercial pallet box No. 1	33.0	107	.5
Pallet box No. 1	32.4	105	.5
Pallet box No. 3	32.4	105	.6
Pallet box No. 4	10.0	32	.2

[1] Half-cooling time for pallet loads of standard boxes=100.

The second test shows that the performance of pallet box No. 4 which had spaced sides and spaced bottom (the greatest free area of any pallet

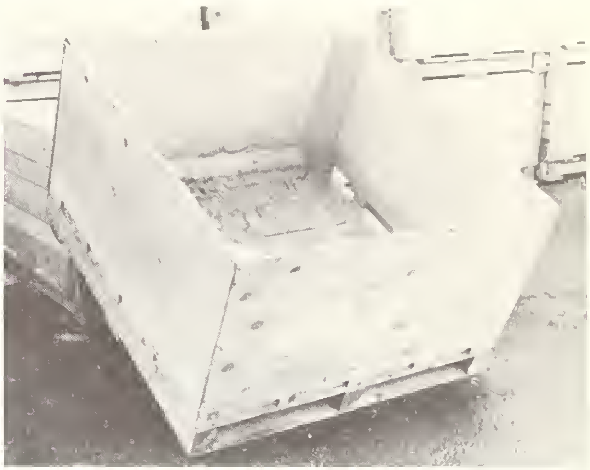

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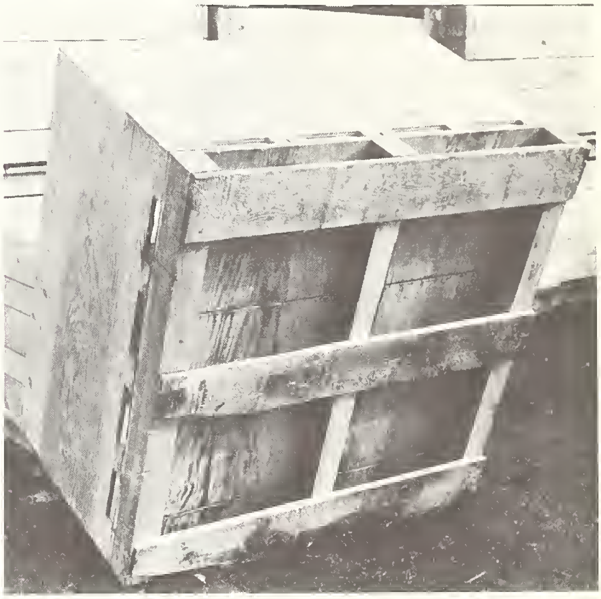
FIGURE 23.—Commercial plywood pallet box No. 5 showing vent slots at bottom of sides. End slots are blanked off with a triangular piece of wood.



BN-14871

FIGURE 24.—Commercial plywood pallet box No. 5, showing pallet and side-vent slots.

box in the two series of tests) was far superior to all the other pallet boxes in the second test. The remaining pallet boxes cooled slightly more slowly than the pallet loads of standard boxes.

Tests Numbers 3 and 4

The half-cooling time and stabilized-temperature difference for the various types of pallet boxes and the standard boxes for tests No. 3 and No. 4 are summarized in table 4.

The stabilized temperatures for tests No. 3 and No. 4 show that all types of pallet boxes, except the steel box, stabilize closer than 1° F. to the adjacent air. This is generally considered to be satisfactory performance. The stabilized-temperature difference is very similar to that of pallet loads of standard boxes.

TABLE 4.—*Average cooling coefficients, calculated half-cooling time, index, and stabilized temperature difference for pallet boxes, tests No. 3 and No. 4*

Test and container	Cooling coefficient (C)	Half-cooling time (Z)	Index [1]	Stabilized temperature difference
		Hours	*Percent*	*°F.*
Test No. 3: [2]				
Check	0.0409	16.94	100.0	0.42
M.C	.0526	13.20	77.8	.30
M.B	.0399	17.37	102.3	.52
G	.0624	11.12	65.6	.60
P	.0243	28.55	168.5	.75
S.L	.0526	13.18	77.7	.72
Test No. 4: [2]				
Check	.0297	23.35	100.0	.60
Steel	.0156	44.40	190.0	1.30
Aluminum	.0215	32.25	138.2	.60
Commercial No. 6 Slatted	.0464	14.95	64.2	.50
Commercial No. 5 Plywood	.0379	18.30	78.4	.10

[1] Check=100.
[2] Abbreviations are from table 2, p. 13.

FIGURE 25.—Commercial slatted pallet box No. 6, showing slots at bottom of sides for ventilation.

FIGURE 26.—Commercial slatted pallet box No. 6, showing pallet and side slots for ventilation.

FACTORS AFFECTING COOLING

Pallet-Box Design

In all tests, pallet boxes with the greatest ventilation area afforded the best cooling results. Those with air slots in the side or bottom cooled fastest and the fruit temperature stabilized at a temperature closest to the cooling air.

The metal pallet boxes did not have slots in the sides or in the bottom for air circulation and although heat conduction through the metal is greater than that for wood, they did not perform as well as wooden pallet boxes which had slots for free air circulation.

The tests are not satisfactory for drawing measurable conclusions regarding the effect of depth on the cooling characteristics of the pallet box. The ventilation features of the pallet boxes with solid sides and spaced bottoms in the first two tests are similar, but the pallet box in the second test is 42 percent deeper. The half-cooling time of the shallower pallet box was half of that observed for the deeper pallet box. Some of this difference may be due to the difference in cooling performance of the two storages. When the performance of each pallet box is compared with the cooling of standard boxes on pallets in the respective storages, the shallower pallet box has a half-cooling time that is 97 percent of that required for standard boxes, and the deeper pallet box has a half-cooling time that is 105 percent of the standard boxes. This is not a very substantial difference, but it does indicate that increased depth has an adverse effect on cooling.

A depth comparison between the two fiberboard-lined pallet boxes in the first two tests cannot be made with any degree of reliability, although the shallower pallet box cooled in less time. When the comparison is made with performance of the standard boxes at each test location, the deeper pallet box shows the better performance. Actually, this may be true, because an examination of table 1 shows that the ventilation provisions in the two pallet boxes are not the same, and that the deeper pallet box with fiberboard liner has the highest percentage of free area.

Pallet-Box Liners

Liners retarded the cooling rate of apples stored in pallet boxes even when they had the same amount of free air circulation as that in unlined pallet boxes. The better the insulation of the liner, the greater the cooling rate is retarded (for comparison, see table 4 for the cooling rate of the commercial box G and maximum-bruise-prevention pallet box MB). Although these two boxes had the same general construction and free air space, apples in the maximum-bruise-prevention pallet box, which had a liner made of more efficient insulating material, took 31 percent longer to cool to the half-cooling point than apples stored on pallets in standard wood boxes.

Spacing of Pallet Boxes in Storage

Previous studies have shown that when containers of fruit are placed directly against the outside storage walls, heat is transmitted through the wall into the container, and there is no opportunity for room air to pick up the heat before it enters the pallet box.[2] Consequently, fruit in such locations may be 1° or 2° higher in temperature, or lower, than fruit in adjoining pallet boxes, depending on whether outside temperatures are higher or lower than those inside. To eliminate this difficulty, stacks should be at least 6 inches away from outside walls. Similar space should be left near inside walls because placing the pallet box against the walls interferes with air circulation past and through the stack, and the ability for air to enter or leave the fork spaces.

Rows should be formed in a straight line with the aid of floor markers, to provide approximately a 5-inch space between rows of pallet boxes.

Stacking Patterns

Stacked rows should be parallel to the direction of air flow in the storage.[3] When two-way-entry pallets are used in the pallet-box construction, a row of pallet boxes constitutes an almost solid barrier to the flow of air, and placing the stacks perpendicular to the normal air-flow pattern results in great interference with uniform air flow. Previous tests have indicated that more uniform holding temperatures are obtained when stack rows are parallel to air flow.

Other Considerations

Stack rows should be made up of similar pallet boxes so that the fork space of the pallet boxes is continuous from front to back of the row, allowing a continuous air channel. Although pallet boxes may be very nearly the same height, the difference is cumulative, and at the upper positions in the stack a 1-inch difference in height in each layer can serve to blank off the channels framed by the fork space.

Air Circulation

Air circulation appeared to play the greatest part in the cooling rate of the apples stored in pallet boxes.

When the cooling air units are overhead in the center of a storage, the air circulates over the top of the fruit and out to the side walls; then downwards and back through stack row channels and pallet fork spaces. The volume of air moving in the channels and pallet fork spaces is less near the bottom of the stack than near the top. This causes a small rise in temperature of the cooling air as it passes by successive stacks (especially when the fruit is warm) in the rows. Therefore, the last pallet boxes passed by the air cool more slowly than the first pallet boxes that are in contact with the colder air. The results shown in table 4 are the average of the four positions used in the test.

When thermocouples were placed in apples at the outer edge, at bottom, top, and middle positions, and in the air at the center of the pallet box, the sides and bottom were found to cool the fastest. The air temperature beside the center apple was always slightly colder than the adjoining apple. Warm air rises, and as the air was warmer for most of the test at the top of the pallet box, this indicated a circulation of air up through the

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[2] Sainsbury, G. F. Heat Leakage Through Floors, Walls, and Ceilings of Apple Storages. U.S. Dept. Agr. Mktg. Res. Rpt. 315, 65 pp., illus. 1959.

[3] Sainsbury, G. F. Cooling Apples and Pears in Storage Rooms. U.S. Dept. Agr. Mktg. Res. Rpt. 474, 55 pp., illus. 1961.

apples. This shows the necessity of having air circulating above the pallet box to remove this warm air. The apples at the top of the pallet box remained slightly warmer than the apples at the center of the pallet box until near the stablizing temperature, at which time they were approximately the same.

The apples at the bottom and sides of the pallet box cooled very rapidly and stayed from 1° to 3° cooler than the center apple, until near the stabilized temperature. The widest variation occurred near the beginning of the test.

From the data obtained in these tests, the cooling-rate variation for apples of different size could not be determined, if any existed. The variation of air circulation and location of the pallet box in the stack had the largest effect upon the cooling rate.

RECOMMENDATIONS FOR PALLET-BOX DESIGNS

Although there were some types of pallet boxes in the test that required three times as long to cool as others, the half-cooling time of the slowest was not prohibitive of use. Half-cooling time for apples in a standard wrapped-pack in wooden boxes on pallets has been observed to range from 45 to 66 hours. Packed apples stacked in single rows require a half-cooling time of from 27 to 50 hours, according to a series of previous U.S. Department of Agriculture tests. From these figures, it appears that the poorest cooling in pallet boxes is generally faster than that of apples wrapped and packed in standard boxes.

While it appears from the cooling studies that all of the pallet boxes tested could be recommended as giving results as good as a standard pack of "hot" fruit, it must be remembered that investment in equipment for refrigerating a plant is expensive.

To preserve the quality of apples the field heat should be removed as soon after picking as possible, and the fruit cooled to the correct storage temperature. For that reason, every possible means should be devised for using the refrigeration machinery as efficiently as possible making it only logical to select and use those features of pallet-box construction that give greatest cooling efficiency. Some pallet boxes will require less refrigeration than others because the faster cooling brings the respiration heat of the fruit down so rapidly that less total heat is generated and less total heat needs to be removed.

These tests indicate that a pallet box constructed with either sides or bottoms having approximately 8 to 11 percent free area will provide cooling characteristics as good as those of the present standard box filled with loose fruit and handled in pallet loads; also, a pallet box constructed with this much free area in both sides and bottom will have substantially better cooling characteristics than do the presently used packed containers. When the apple industry adopted the use of pallets, it accepted some penalty in cooling performance, because unpacked apples in standard boxes stacked in individual rows have a half-cooling time of about 50 percent of that obtained when placed in pallet loads. Proper pallet-box design offers an opportunity to regain some of the cooling performance that was lost when palletized handling was adopted.

The tests indicate that side ventilation is as effective as bottom ventilation. This conclusion, however, is subject to some qualifications. The pallet box with spaced sides and solid bottom, and the pallet box with solid sides and spaced bottom, which are representative of these two types of construction, differed somewhat in dimensions and percentage of free area, and the difference in both cases favored the pallet box with the side ventilation.

The pallet box with solid sides and bottom, but with an air space around the bottom, gave the best performance of those pallet boxes in which the percentage of free area was low. However, cooling was definitely much slower than in the well-ventilated pallet boxes that were included in the same test.

Those pallet boxes with fibreboard liners probably should be provided with more slots to bring the free area of both bottoms and sides to some figure above 5 percent, thus improving the cooling rate.

RECOMMENDATIONS FOR COLD-STORAGE-ROOM DESIGNS

Ceiling Height

With the change from the use of small 1-bushel-capacity boxes, transported by two-wheel hand trucks and conveyors, to the larger pallet boxes, which hold 25 bushels or more of fruit each, and are handled by industrial forklift trucks, came a need for a radical change in cold-storage-room design.

Previously, when field or standard boxes of 1-bushel capacity were hand-stacked, storage rooms were built with a ceiling height of 8 to 10 feet but present-day requirements have increased this height to 21 feet and even higher in the larger storages.

Capacity of Refrigeration Equipment

The capacity of the refrigeration equipment should not be overlooked when shifting to storing apples in pallet boxes, as about 20 percent more fruit can be stored in the same storage space, depending on the dimensions of the pallet boxes used, than with standard boxes of unpacked fruit stacked on pallets. This increased load, together with the fact that a large quantity of pallet boxes of apples can be moved into a storage plant in a relatively short time when industrial handling equipment is used, puts an added load on the refrigeration equipment. If the additional refrigeration capacity is not available, it may not be possible to maintain the desired storage temperature. Storage operators should review their refrigeration capacity, gear their receiving of fruit to the available refrigeration capacity, and be careful not to overload the refrigeration equipment.

Air Temperature Differential

The circulated air in a cold-storage room contains water vapor, and the lower the temperature the less quantity of vapor the air can hold. When the air passes through a cooling unit, its temperature is lowered. As the temperature of the air is lowered, a point is finally reached where some of the water vapor can no longer exist as vapor, and it condenses in the form of water or frost on the coils. The greater the drop in temperature the greater the condensation. It is important, therefore, to operate the storage plant without reducing the air temperature any lower than necessary to cool the fruit to the desired storage temperature. In an air-circulation system, this can be accomplished by using a large quantity of air and an adequate cooling surface. If the quantity of circulated air is small, its temperature must be greatly reduced, and excessive condensation will occur. If there is not enough coil surface, the coils will have to be extremely cold to cool the air passing through them, and the air in coming in contact with them will lose a large part of its moisture as frost which collects on the coils.

A brine spray cooling system does not add humidity to the air. It may absorb moisture from the air, thus diluting the brine. "For this reason some of the brine must be drained off occasionally and more salt added. If a brine spray system results in higher humidity than a direct-expansion or dry-coil bunker system, it is because the cooling surfaces with which the air comes in contact are not so cold as when brine coils are used." [4]

[4] W. V. Hukill and Edwin Smith. Cold Storage for Apples and Pears. U.S. Dept. Agr. Cir. 740, pp. 27–28. 1946.

Air Velocity Requirements

In order to keep a cold-storage room at an even temperature throughout, the air must be circulated, or kept in constant motion.

As the air circulates throughout the storage room it picks up heat from the fruit; thus, the temperature of the air is increased, and the air returning to the cooling unit is warmer than the air leaving the cooler. The difference in temperature between return and delivery air is known as the "split" or spread, and is directly related to the volume of air circulated in the cold-storage room and the amount of heat picked up. This split should not exceed 1.5° to 2° F. If it is greater, more air should be circulated. The split may be, and usually is, greater at the beginning of the storage season, reaching the desired split as the fruit is cooled.

It is false economy to circulate a volume of air larger than that required to give the desired split, as it requires larger motors and fans. Because the air is not picking up the heat any faster, the excess air is being circulated without doing any work. Similarly, it is false economy to have a fan of a capacity lower than necessary to circulate the required volume of air. Increasing the speed of a fan to get more air circulation is done at the cost of more power for every cubic foot of air circulated.

During the cooling period, when the refrigerating equipment is operating at full capacity, the volume of air circulating may be considered in balance, if the temperature difference between delivery and return air does not exceed 10° F. A lower split, as this difference is called, is desirable, but if it is greater than 10°, an increased volume of air circulation will be beneficial. As the load is cooled and less warm fruit is brought in, the split will decrease, and should reach 1° to 2° F.

After fruit temperatures become almost stationary, a split exceeding 1.5° F. is an indication of insufficient volume of cold air. During this period, further cooling is not required, but it is necessary to maintain a uniform temperature throughout the room.

Uniformity of temperature depends largely on an adequate volume of air. If the volume is sufficient, as indicated by the split between delivery and return, and if temperatures in some parts of the room are still too high, the air is not being distributed to the best advantage. This may sometimes be corrected by adjusting the delivery or return of the air volume.

Humidity Requirements

The optimum humidity for cold-storage rooms of apples is 85 percent.[5] Higher humidities have

[5] Wright, R. C., Rose, Dean H., and Whiteman, T. M. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. U.S. Dept. Agr. Handb. 66, 77 pp. 1954.

a tendency to favor mold growth in cold-storage plants. On the other hand, low humidity in a cold-storage room may cause shriveling of apples. Apples with little wax protection on their skin, like Golden Delicious, are very susceptible to low humidity.

There are many types of water vaporizers on the market which can be used to increase the humidity in a cold-storage room. One or more of these can be installed when the need is apparent.

In modern well-designed and well-filled cold-storage plants, little difficulty is experienced in maintaining desirable atmospheric humidity during the cold-storage season.

Air Circulation

The temperature of the fruit in a storage room is not all at the same level because the temperature of the air rises as the air passes through the room and absorbs heat from the fruit. In a duct system the air near the return ducts will be warmer than that near the delivery ducts. However, if all duct openings can act alternately as delivery and return ducts, the fruit in the different parts of the room will be exposed part of the time to the delivery air and part of the time to the return air. This can be done with a reversible air system and usually results in a more uniform fruit temperature. This system reverses the direction of air circulation every hour or so by means of dampers and special duct arrangements near the fans.

Advantages

Reversible air system.—(1) Can circulate colder air during precooling; (2) less danger of freezing the fruit; and (3) best suited where flow of air is restricted to narrow space and air ducts are required.

Overhead air system.—(1) Greater movement of air; (2) less horsepower per cubic foot of air required; (3) no duct resistance; (4) easier to move large volume of air; (5) cooling units can be located overhead where they will not take up valuable storage space; (6) multiple units can be used, giving greater reliability; (7) large evaporator surfaces can be used; and (8) the resistance through the unit is low.

Disadvantages

Reversible air system.—(1) Duct constructions are costly; (2) usually a single fan of large size and large horsepower required; (3) complicated duct systems build up high resistance to air flow and tend to result in warm air spots; and (4) ducts require careful adjustment for uniform air distribution.

Overhead air system.—Requires careful stacking of boxes or pallets to obtain the best cooling pattern.

APPENDIX

Equipment and Methods

Figure 27 shows the three types of temperature-measuring apparatus used in these tests. On the left is the 32-position temperature recorder that was used to obtain a continuous record of temperatures at the test locations during the cooling period. This instrument records a temperature every minute, thus the temperature for any one thermocouple is recorded every 32 minutes.

The temperatures were recorded by a copper-constantan thermocouple placed in the center of an apple that is located in the center of the test pallet box and another thermocouple placed in the air on the outside of the test pallet box. The thermocouple wires were connected to the recording potentiometer (fig. 28).

In the center of figure 27 is the hand-balanced potentiometer used for intermittent reading of holding temperatures at the test locations after the cooling period was finished. The same thermocouples were used for these observations by disconnecting the thermocouple cables from the continuous recorder at the end of the cooling period.

On the right of figure 27 is one of the two circular-chart temperature recorders that recorded the temperature of air returning to the cooling unit in each storage room throughout the cooling and holding period.

Determination of Cooling Rate in Pallet Boxes

The continuous temperature records at each thermocouple location were plotted for the first week on charts. The temperature record for each test pallet box was examined and a test period was determined, starting at the point where the first sustained decline of temperature was noted and ending at the point where fruit temperature no longer decreased or where the decrease was at a rate equal to or less than the decrease in adjacent air temperature. When the test period was established, the average fruit temperature and average adjacent air temperature during the test period was determined by measuring the area under these curves with a polar planimeter, and dividing by the length of the period to determine average height. The temperature scale was applied to this height to calculate the average temperature. The range through which the fruit cooled during

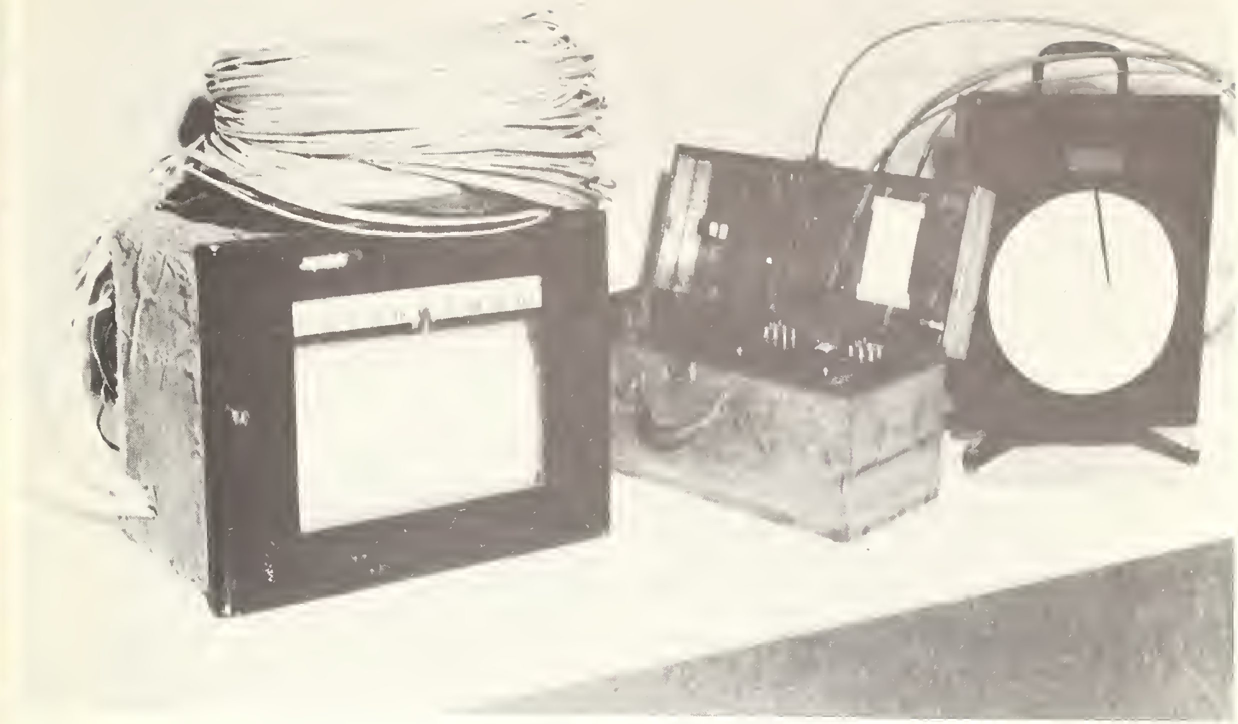

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FIGURE 27.—32-point temperature recorder, hand-balanced potentiometer, and circular-chart temperature recorder used in cooling tests.

the test period and the number of hours in the period were noted.

With the foregoing information, the cooling coefficient for each test location was calculated by the following formula:

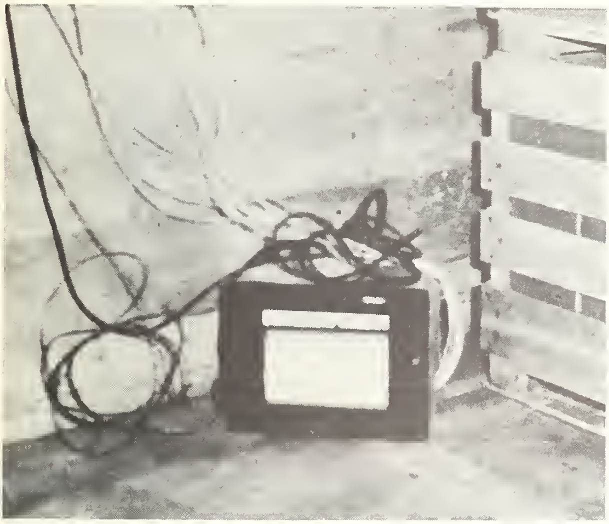

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FIGURE 28.—Wires from thermocouples leading to recording potentiometer.

$$C = \frac{\text{Temperature range}}{(\text{hours in period})\ (\text{average fruit temperature} - \text{average air temperature})}$$

C is expressed as degrees Fahrenheit per hour per degree-temperature-difference between fruit and air.

An average cooling coefficient was determined by averaging the four test values for each type of box and this average was converted to half-cooling time, Z, by the formula:

$$Z\ (\text{in hours}) = \frac{\log_e 2}{C}$$

Half-cooling time, Z, is the time required for the fruit to cool through 50 percent of the difference between the initial fruit temperature and the air temperature, assuming a constant air temperature. Roughly, this approximates removal of ½ of the field heat. A period of 2Z is required for removal of ¾ of the field heat; a period 3Z for removal of ⅞ of the field heat.

Determination of Stabilized-Temperature Difference and Its Meaning

Stabilized-temperature difference (or approach temperature, as it is sometimes called) is the difference between fruit temperature in the center of the pallet box and air temperature adjacent to the pallet box after the fruit temperature is stabilized or has reached equilibrium—that is, after cooling has been completed. If some fruit in a cold room is stored in a container in which the fruit cools slowly and has a stabilized-temperature difference of 3° or 4°, while other fruit in the same room is stored in a container where it can cool rapidly and the stabilized-temperature difference is negligible, it follows that even with absolute uniformity of air temperature in the room there will be considerable variation in fruit temperature from container to container after the fruit is cooled. The warmer fruit cannot be cooled with colder air to the optimum temperature for fear of freezing the colder fruit. In general, the slower the fruit cools, the greater will be the final difference between fruit and air temperature.

In actual practice there is always some variation of air temperature in the room and this is added to the difference associated with different containers to cause variation in fruit temperature. For this reason, the stabilized-temperature difference is a very important aspect of the cooling performance of any container for fruits.

In these tests, the stabilized-temperature differences at the test locations of fruit in pallet loads of standard boxes were determined for the last 20 hours of the continuously recorded test during which air temperature was lower than fruit temperature. This was done by a graphic method of determining average fruit temperature and average adjacent air temperature at each location during the 20-hour period and subtracting the air temperature from the fruit temperature at each location. The stabilized-temperature differences for each location were then averaged to give the average stabilized-temperature difference for standard boxes. This was done for each test.

Intermittent readings were taken for at least 6 weeks following the continuous record. For each test pallet box location, the intermittent temperature readings were averaged and the above-average fruit temperature for the comparable location in standard boxes was subtracted from this average. This difference was then added to the stabilized-temperature difference for the standard boxes in that particular location as previously determined. The stabilized-temperature difference for the test pallet box in the comparable location was then obtained. For each type of pallet box, the stabilized-temperature difference is the average of the stabilized-temperature difference determined at the four test locations.

The analytical method for the preceding determination was obtained as follows:

Fruit temperature − air temperature = Stabilized-temperature difference between the fruit and adjacent air = K (a constant).

Let F_B = Fruit temperature of standard apple boxes
F_P = Fruit temperature of pallet box
K_B = Stabilized-temperature difference for the comparable standard apple boxes (a constant)
A = Adjacent air temperature

Then: $F_B - A = K_B$ or $A = F_B - K_B$ and $F_P - A = S$, where: S = Stabilized-temperature difference for pallet box.

Substituting for A its equal, $F_B - K_B$, we have $F_P - (F_B - K_B) = \pm S$ or $F_P - F_B + K_B = \pm S$.

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