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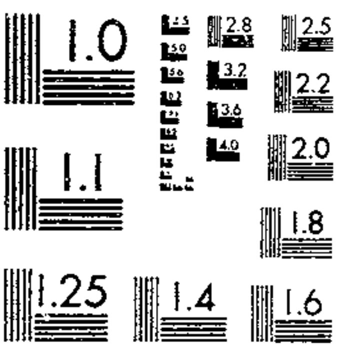

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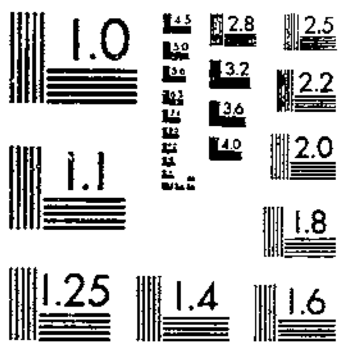

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Technical Bulletin No. 615 May 1938

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

STUDIES OF POTATO STORAGE HOUSES IN MAINE[1]

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CONTENTS

INTRODUCTION

The Maine potato-harvest season is short, extending only from about September 15 to October 15. The market will not absorb the entire crop during this time hence storage houses within easy reach of the fields are absolutely necessary. Even if the market could absorb the crop, immediate grading and shipping would be impossible with the present facilities and labor supply. Also, local storage is cheaper than storage at the consuming points.

About half of the crop is stored on the farm in bank-type storages. Most of the remainder is hauled directly to nearby shipping points and placed in large trackside storages, the majority of which are owned by the larger growers. After an average of about 5 months in storage the potatoes are graded, sacked, and shipped, the grading usually being done in the trackside storages. The chief advantage that growers find in controlling trackside storage space is greater independence in marketing their crop.

An idea of labor and transportation problems in handling the potato crop of Maine is gained by considering that the average farm production of 2,600 barrels must be harvested and stored in the 15 or 20 days

[1] Received for publication October 25, 1937.

[2] Appreciation is expressed for the cooperation and assistance in carrying forward this investigation, to the many Aroostook County warehousemen, in whose storages the data was secured; to R. C. Wright of the Bureau of Plant Industry; to Fred C. Griffee and S. O. Hanson of the Maine Agricultural Experiment Station; and to Verne C. Beverley and Richard O. Dolloff of the Maine Extension Service.

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of favorable weather during the harvest period, and that for digging, picking, hauling, and storing 1 man-day will handle an average of 33 barrels. Thus the average farm requires about 79 man-days or must have a crew of 5 men working every suitable day during harvest. Grading and loading into cars for shipping, which is not generally practical at harvest time, is best done after a few weeks in storage when handling over the grader does not bruise the potatoes. These processes require about 1 man-day per 33 barrels of potatoes. For transporting the 50,632 cars per year (1928–32 average) to the consuming centers the maximum rail handling has been 525 cars per day. Thus at maximum handling rate 96 days would be required to move the entire crop which is harvested during a 30-day period. These facts are given further to show the absolute necessity of storing potatoes near the point of production. The necessity is so positive because any other system would be financially insupportable.

The farm and trackside storages in the Aroostock potato-producing area have been developed over a period of years into two fairly satis-

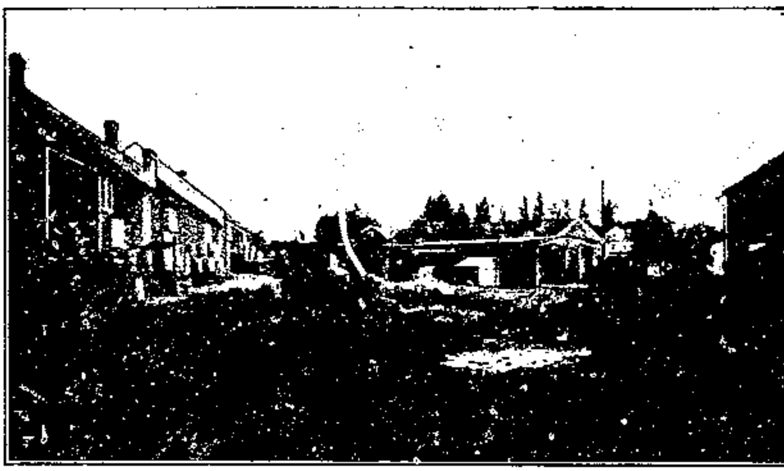

FIGURE 1. —Unloading trucks and wagons at trackside storages during potato harvest.

factory types, storages of each type being remarkably similar whereever found.

Certain practices not usually followed in other sections have been developed, more attention being given to rapid handling than in the storages farther south. Trackside storages (fig. 1) are almost always equipped with electrically operated barrel hoists. The Aroostook-type farm storage (fig. 9) has a frame superstructure over the cellar storage which permits driving in over the bins and dumping through sack chutes to the cellar below. The storage houses developed as a result of gradual evolution in this section are in many ways remarkably suited to the local storage conditions but they fall short as to ease of control, permanence, and arrangements for careful handling. The design of the houses permits excessive condensation of moisture on walls and ceilings and if doors and windows are opened during cold weather to remedy this condition it is necessary to fire heavily, thus lowering the humidity and increasing shrinkage. If the house is not so ventilated, dripping of condensed moisture from the ceiling causes rotting and sprouting of the potatoes and decay of structural members. Although the life of the storage houses is often prolonged to 20 or 30 years, periodic repairs are necessary, important structural members often failing after 5 or 6 years' service.

OBJECTS OF INVESTIGATION

The investigational work reported in this bulletin was begun in 1931 at the request of Aroostook County growers and the Maine Agricultural Experiment Station.

The purpose of these investigations were:

1. To determine the most satisfactory storage conditions for potatoes in the colder regions of the United States.
2. To develop durable structures in which desirable storage conditions could be maintained with a minimum of attention.
3. To work out a system of handling potatoes in the houses that would decrease labor requirements and reduce injury to the potatoes.

METHOD OF PROCEDURE

The Bureau of Agricultural Engineering carried on most of the field work. The Maine Agricultural Experiment Station, the Maine Extension Service and the Bureau of Plant Industry acted in an advisory capacity and made special studies as noted. A number of Aroostook County growers cooperated in furnishing buildings for experimental use and in following recommended practices.

When this work was started no definite information was available as to the amount of potato losses in the common types of storage. Since it was essential to know the relation between losses and storage conditions, the first work undertaken was to measure the potato losses and the air temperature, humidity, and circulation in common types of houses as well as under specially arranged test conditions.

BUILDINGS

The experimental work was conducted in typical storage houses in which either certified seed potatoes or high-grade table stock were stored. The owners of the houses furnished potatoes, storage space, heat, light, and all labor ordinarily required in the filling, operation and control of the house, and the grading and shipping of the stored potatoes. The Department furnished the extra labor needed for weighing the potatoes into storage and for special sorting and weighing out of storage. Most of the observations were of full-sized bins, the conditions of the entire storage building being controlled by the owner with the cooperation and assistance of the Department representatives. Some observations, however, were made of both ordinary sized and small test bins where the temperature was controlled by special means and differed from that maintained in the rest of the building. Records of potato losses and air conditions in the houses were obtained as described on pages 8 to 11.

While the basic requirements of trackside and farm storage are similar, each type represents a somewhat different problem and in the following discussion the two types are considered more or less separately.

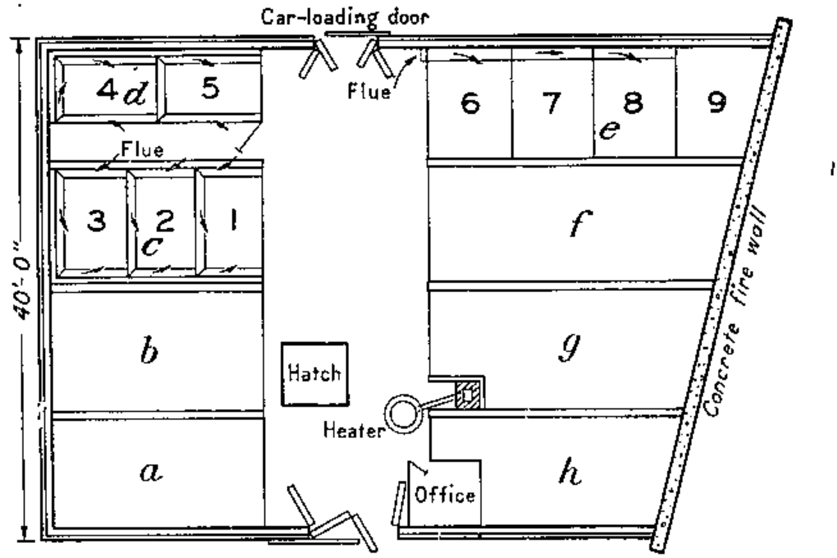

FIGURE 2.—First-floor plan, trackside storage at Presque Isle, Maine: *a* to *h*, Large bins three of which (*c*, *d*, *e*) were subdivided into smaller bins numbered as shown.

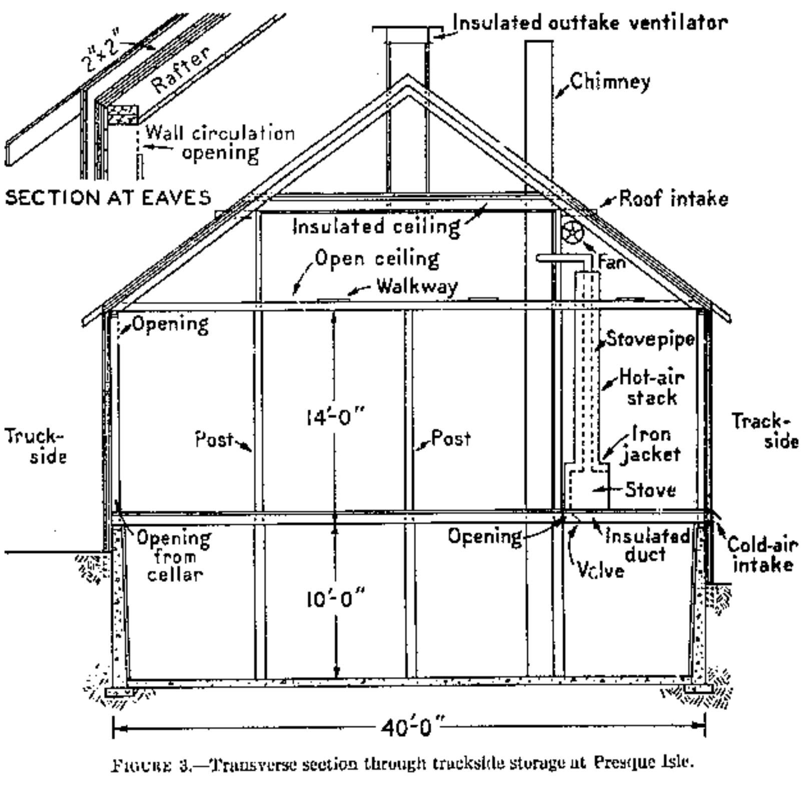

FIGURE 3.—Transverse section through trackside storage at Presque Isle.

The work was first carried on in a trackside storage at Presque Isle, Maine. This storage was built in 1929 and has a capacity of 8,000 barrels. Figures 2 and 3 show a plan and a transverse section of this house. For the first year's work, three of the large bins were divided as shown into nine experimental bins in which temperature and humidity could be controlled. The partitions between main bins were of the double-slatted type nailed to 6-inch studding on the first floor and to 8-inch studding in the basement. The partitions between the experimental bins were of 2-inch plank laid in bulkhead fashion.

FIGURE 4.—Intermediate alley floor, experimental heater-ventilator (right), double-slatted bin partitions (at left), and barrel hoist.

The design of the storage (fig. 2) allowed a 6-inch air-circulating space in the outer walls above the concrete foundation wall to permit the warm air of the house to circulate between the outer walls and the potatoes. Outside the circulating space the house was insulated with 1-inch commercial-board-form insulation, two thicknesses of board sheathing, one 2-inch air space, and drop siding. Six thicknesses of building paper were used for waterproofing and to reduce air leakage. Louvered roof ventilators instead of the usual galvanized-iron roof ventilators were installed when the house was built. The central outtake ventilator shown in figure 3 was added for this work. The house could be heated by stoves in the basement and first-floor work alleys.

There were a few changes in the bin arrangement for the second year's work. Experimental bins 6 and 7 were thrown together as bin 6, and experimental bins 8 and 9 were taken together as bin 7 (fig. 2). The intermediate alley and the circulating heater-ventilator (fig. 4) were added the second year, to simplify handling and storage control.

In 1933 the work in the trackside storage was discontinued and the investigation was continued under farm-storage conditions at the Aroostook Experiment Farm, the storage being in the basement of a barn remodeled for storage (fig. 5), and having a capacity of about 5,000 barrels. The lower parts of the walls, which were of concrete, were banked with earth. With the exception of specially constructed test sections the parts of the walls above the concrete were of sheathing, paper, and shingles on the outside of the studding, the studding being exposed on the inside. The ceiling over the entire space consisted of 3 inches of wood and no air space; some of the ceiling, particularly over bin No. 1 was covered with several feet of straw, but most of the area above was unprotected from the too-well-ventilated attic space.

During the 1933 storage season observations were also made in two improved farm storages built during the previous summer, one at New Sweden and one at Houlton both of which embodied recommendations based on the work of the previous 2 years. The special features included a well insulated wall and ceiling, cellar bins extend-

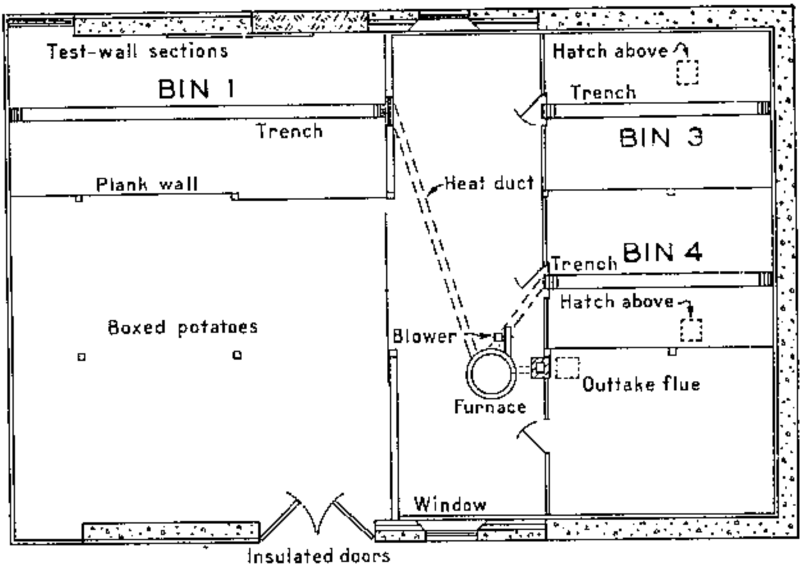

FIGURE 5.—Plan of Aroostook Experiment Farm storage and test-wall sections.

ing above the drive floor, and improvements in air circulation above the bins and improved ventilation (fig. 9).

Observations were made in 1934 at the Aroostook Farm and in a new track storage built that fall at Bridgewater. In this storage (fig. 6) potatoes could be stored to a depth of 7 feet in the basement and 18 feet in the upper bins. The potatoes were stored directly against the outside wall which was insulated with 4 inches of commercial fill insulation. There was no air-circulating space inside the wall.

The bin partitions were of single plank secured between posts which took up about 3 inches of bin width in place of the 8 inches of width required by double-slatted partitions. Bin ventilation was obtained by a combined floor flue and conveyor trench, air rising from slatted openings in top of the trench cover through the entire depth of the potatoes. The wall construction, which depended on insulation without air circulation, proved inadequate as a protection against freezing.

The following year (1935–36) this storage (fig. 6) was used for experimental purposes and was remodeled as follows before the potatotes were stored: The basement walls were divided up into 22 test panels insulated with various combinations of insulating materials, and 2-inch circulating-air spaces were provided between the potatoes and the outer walls. These air spaces were so arranged that air from the upper part of the house could flow down along the walls and return to the main alley. To avoid structural damage from condensation of moisture (p. 39), protective coatings were applied to the inner surfaces of the walls. Types of protective coatings used included paper coated with aluminum foil (fig. 7), paper coated with copper foil, asphalt paper, creosote, and aluminum paint. To avoid accu-

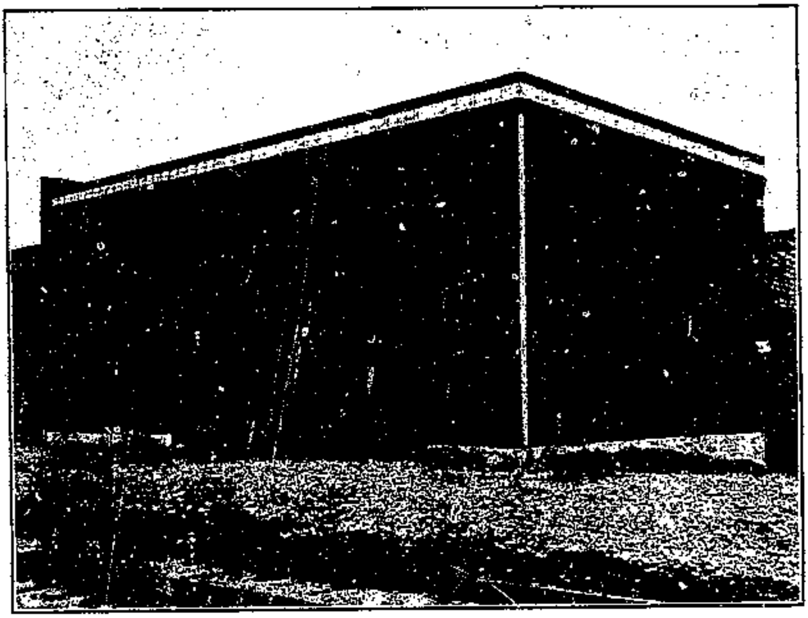

FIGURE 6.—New type storage at Bridgewater, Maine.

mulation of moisture inside the wall the fill insulation was ventilated by breather openings to the outside air.

The heater for the house, originally placed in the first-floor alley, was placed in the basement, to be out of the way and handy to the fuel supply (fig. 8). In one bin the floor was removed between the basement and first floor, making a total bin depth of 26 feet and increasing the storage capacity of this bin from 3,600 to 3,850 bushels. The first-floor conveyor trench was left in place so that the upper 18 feet of potatoes could be removed on the first-floor level. Since the original two 9-foot work alleys proved too narrow for loaded trucks to drive into the house, a single 12-foot central truck door opening into a 20-foot work alley was constructed. This permitted backing trucks into the alley and hoisting potatoes direct from the truck bed.

In addition to the work in the above storage, observations were made in farm storages in which cold-air returns were built against the basement walls as in figure 9, for the purpose of increasing air circulation and preventing freezing adjacent to the walls.

The operation of the system is as follows: Warm moist air above bins enters wall circulation space through openings between boards at *A* (fig. 9) and at north wall under driveway. On coming in contact with cold surface of outside walls, the air contracts and drops in circulation spaces, *B*, and travels horizontally through spaces *C*. Air from *C* discharges into work alley *D*. A portion of the air enters wood trenches at *E* and rises between board trench covers at *F* due to expansion from heat of potatoes, then circulates upward through bins and again enters wall circulation spaces at *A*. The temperature of the air entering wood trenches at *E* may be raised by operating the heater.

FIGURE 7.—Waterproofing outer surface of wall air-circulating space with aluminum foil

MEASUREMENT OF POTATO LOSSES AND STORAGE CONDITIONS

Potatoes were weighed into storage the first year over a wagon or truck scales, but since a load was often divided into two bins this method was inaccurate. For the remainder of the investigation a small automatic platform scale was used which weighed each barrel quickly and accurately. Weights out of storage were determined by weighing separately the No. 1, No. 2, small, and cull potatoes. In addition all dirt in the bin and at the grader was collected and weighed.

Hygrothermograph and air-soil thermographs were used for continuous records of temperatures and humidities. Bin temperatures at various points in the mass of potatoes were periodically determined by means of thermocouples. Temperatures and air velocities in the air-circulation spaces and ducts were determined by means of thermocouples and by special low-velocity anemometers developed by the Bureau. The air velocities were checked where possible with a Biram-type anemometer. Both thermocouple temperatures and special anemometer velocities were read with a semi-precision portable potentiometer. Figure 10 shows one of the test bins with the thermocouple wires in place. Wet-and dry-bulb temperatures in the house alley, above the bin and in outside air were periodically determined with sling psychrometers. Wind velocities were obtained with a revolving-cup anemometer.

STORAGE CONDITIONS AND METHODS OF CONTROL

In general the storage conditions maintained in connection with the present studies were based upon optimum temperatures of 38° to 40° F. as recommended by Wright (*9*)[3] and by Stuart, Lombard, and Peacock (*6*) who showed that 40° is about the maximum temperature for complete dormancy. However, due to differences in construction and management of the houses, the temperatures actually obtained varied by several degrees from this desired level.

Since Wright, Peacock, Whiteman, and Whiteman (*10*) had called attention to the fact that cooking quality is affected by storage conditions because potato starch is converted into sugar when the potatoes

FIGURE 8.—Twenty-foot conveyor delivering potatoes from bin to barrel in cellar bin. Stove next to trackside wall and louvered intake in background.

are stored below 50° F., three large test lots were stored at 50° to determine whether the advantage in price received for the high table quality would overbalance the extra losses. A study was also made of the effect on losses of holding potatoes at relatively high temperature for the first 5 to 15 days of storage. This holding at high temperatures and high humidities immediately after storing is termed "curing." The high initial temperatures and high initial humidities promote the healing of cuts and bruises received by the potatoes during digging and aid in the formation of the suberin layer which tends to prevent the entrance of rots and to retard excessive evaporation of moisture. Wright (*9*) indicated 68° curing temperature and high humidity as desirable; Weiss, Lauritzen, and Brierley (*7*) showed that 4 days curing at 70° excluded certain rots as well as 10 days curing at 50°. The highest curing temperature for the first 10 days during the present study was 63°.

[3] Italic numbers in parentheses refer to Literature Cited, p. 46.

The storage conditions in general were controlled by heating or ventilating as required. Wood stoves were the principal source of artificial heat, although for some test bins electric strip heaters were

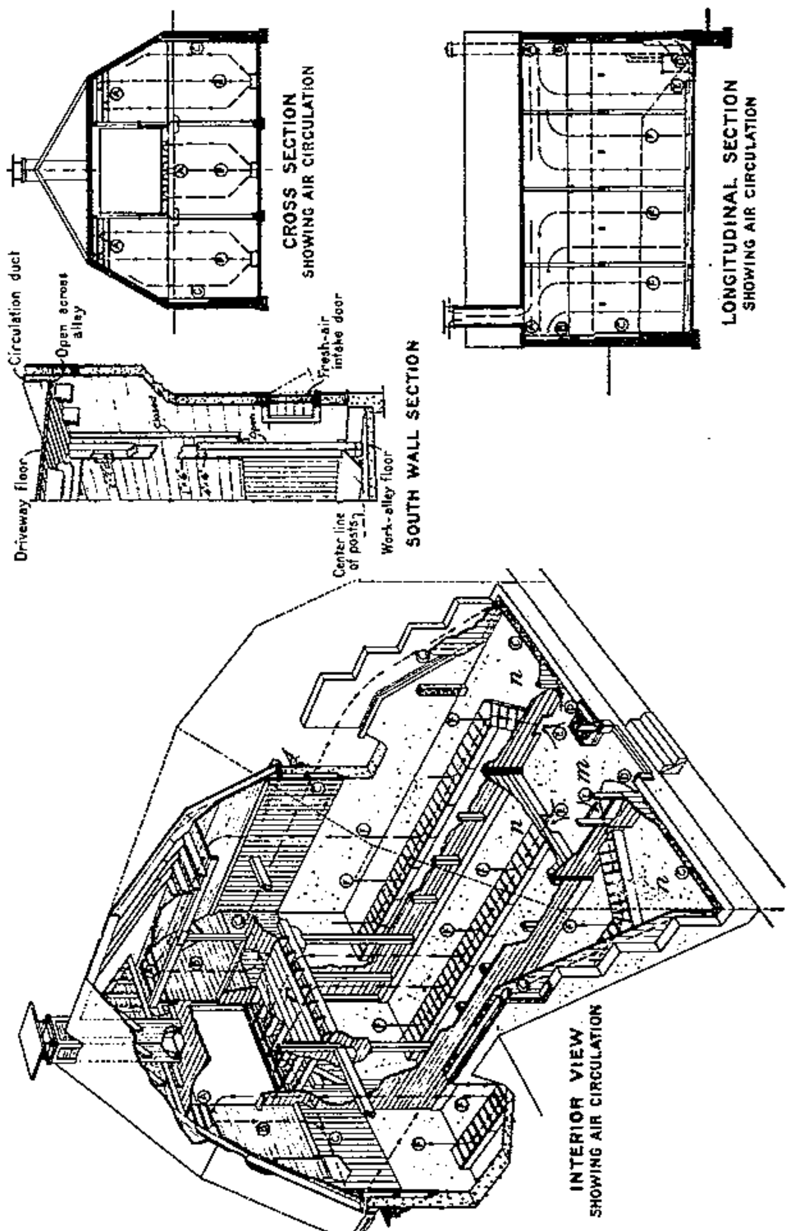

FIGURE 9.—Perspectives and transverse section of deep-bin farm storage showing details and circulating system, *A* to *F*: See text discussion. *m*, Workalley floors; *n*, bin floors; *r*, driveway floor.

used. Ventilation was obtained by using adjustable intake doors and insulated outtake ventilators depending on gravity circulation. Upon one occasion an intake fan was used in connection with night cooling. Fans and blowers (fig. 11) were sometimes used for air circulation above bins and for control of individual bin conditions. These were usually controlled manually although thermostats were used in a few cases.

Since other workers (*8*) had emphasized the importance of careful handling as a factor in successful storage of potatoes, several methods of reducing or eliminating losses due to mechanical injuries were studied.

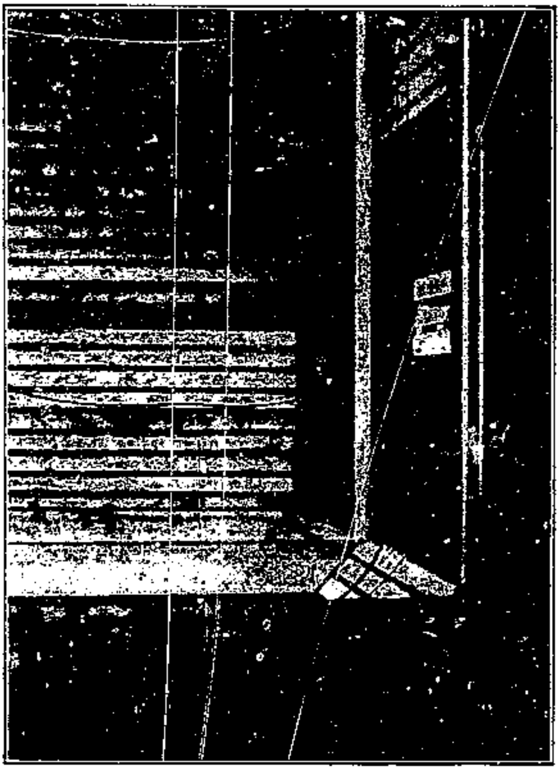

FIGURE 10.—Ventilation ducts and thermocouple wires in test bins.

In a study made in cooperation with C. N. Turner of the Maine Agricultural Experiment Station, twisted sack, spiral and zigzag chutes were tried for lowering potatoes from first floor to cellar bins. Since the injury caused by forking potatoes from floor to grader is another cause of major damage, a series of tests were made upon conveyors to eliminate fork handling. First a conveyor was designed which would elevate potatoes from storage floor level with the work alley to the grader hopper 2 feet above, and later tests were made of conveyors running level in floor trenches above the grader hopper. Some tests were also made of grader designed to reduce handling injury. To study the practicability of box handling as compared with barrel handling, some time studies were made at the Aroostook Farm in 1932.

RESULTS OF THE INVESTIGATION

The following discussion of losses of potatoes in storage is based upon work carried on in the houses and under the conditions discussed on pages 3 to 11 from September 1931 to April 1936. Data obtained in a previous study by Betts, Hill, and Pentzer [4] and a large amount of information gained from farmers were also considered in arriving at the conclusions stated here. During the course of these studies

[4] Unpublished report of M. C. Betts, Bureau of Agricultural Engineering (then Division of Agricultural Engineering, Bureau of Public Roads), R. G. Hill, Division of Fruits and Vegetables, Bureau of Agricultural Economics, and W. T. Pentzer, Office of Horticulture, Bureau of Plant Industry, covering potato-storage investigations carried on in Aroostook County from 1924 to 1927.

24,000 bushels [5] of potatoes were weighed into and out of storage in each of two of the years and in all over 100 carlots were so weighed in order to determine losses under various storage conditions.

SHRINKAGE LOSSES

The shrinkage losses discussed in this section are those due to the normal physiological processes of the potato and to evaporation. Losses due to freezing, overheating, sprouting, disease, dripping of moisture, or unusually rough handling were avoided so far as possible by carrying on the work in well-constructed and carefully managed houses filled with sound potatoes. Where small losses due to freezing or field disease occurred, suitable corrections were made in the data.

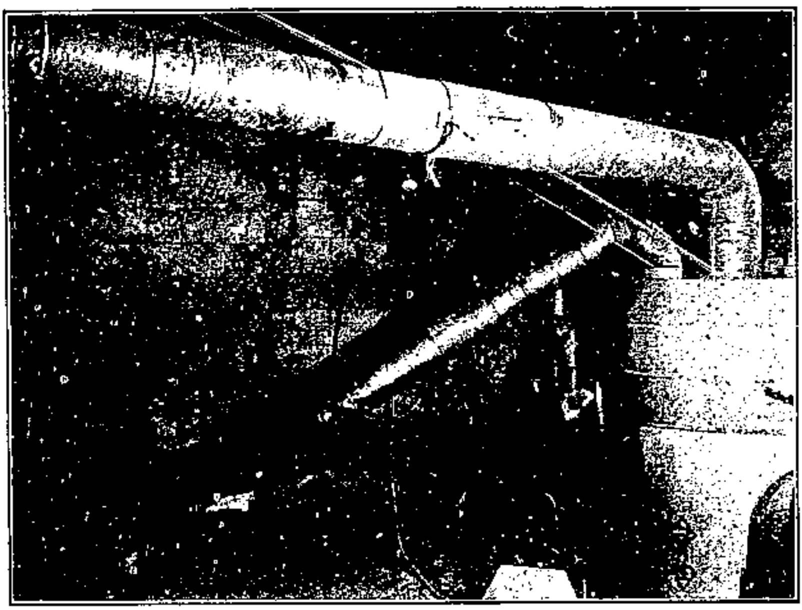

FIGURE 11.—Blower as used with furnace for controlling farm bin temperatures and in storages shown in figures 2 and 5.

All shrinkage data for the present investigation and the unpublished study by Betts, Hill, and Pentzer have been tabulated in table 1, which lists the lots in order of length of storage period. This table shows the year of the test, the size of the test lot, depth of bin or type of container, type of air circulation, length of storage period, average temperature and relative humidity during the first 10 days, average temperature, average relative humidity, and average saturation deficit [6] for the whole storage period and the shrinkage loss in percent of weight of the potatoes when placed in storage.

[5] The bushel referred to in this report is of 60 pounds, the barrel unit is 165 pounds, and the carlot averag 40,000 pounds.

[6] The saturation deficit is an approximate measure of the moisture-absorbing capacity of the air, and is related to both the relative humidity and temperature. It is defined as the difference in vapor pressure of air of given temperature, (1) at 100-percent relative humidity and (2) at the observed relative humidity. It is expressed here in millimeters of mercury. Figure 12 shows relation of temperature, relative humidity, and saturation deficit.

TABLE 1.—*Relation of storage conditions to losses in storage, 1925–36*

Item No.[1]	Period of work	Potato weight[2]	House[3]	Bin depth[4]	Air circulation[5]	Storage period	Curing[6] Temperature	Curing[6] Relative humidity	Whole period[7] Temperature	Whole period[7] Relative humidity	Whole period[7] Saturation deficit	Losses
	Year	*Pounds*		*Feet*		*Days*	*° F.*	*Percent*	*° F.*	*Percent*	*Millimeters of mercury*	*Percent*
1	1935–36	621	A	a	Ag	25	61	84	61	84	2.2	1.6
2	1935–36	1,926	B	b	Ag	28	49	82	48	88	1.0	1.8
3	1935–36	631	C	a	Ag	28	46	62	46	65	2.8	4.0
4	1935–36	621	A	a	Ag	56	61	84	58	82	2.2	3.4
5	1935–36	1,926	B	b	Ag	56	49	82	47	80	.9	2.0
6	1935–36	631	C	a	Ag	56	46	62	44	65	2.5	4.8
7	1932–33	73,676	D	14	Fe	72	54	78	44	82	1.3	2.1
8	1932–33	46,529	D	7	Rg	77	47	83	41	88	.9	3.2
9	1935–36	621	A	a	Ag	84	61	84	57	79	2.4	5.2
10	1935–36	1,926	B	b	Ag	84	49	82	46	82	1.4	2.2
11	1935–36	631	C	a	Ag	84	46	62	43	67	2.3	5.0
12	1932–33	84,483	D	14	Ag	88	52	76	43	80	1.3	4.1
13	1933–34	103,829	C	8	B	101	50	80	51	70	2.9	5.5
14	1935–36	166,307	B	18	Ag	107	55	75	40	78	1.9	5.7
15	1933–34	22,880	C	a^1	Ag	110	50	80	44	66	2.6	6.9
16	1935–36	621	A	a	Ag	119	61	84	55	77	2.5	6.8
17	1935–36	1,926	B	b	Ag	119	49	82	45	84	1.2	2.2
18	1935–36	631	C	a	Ag	119	46	62	37	63	2.1	6.0
19	1932–33	29,824	D	8	Rg	128	47	83	40	86	.8	4.2
20	1932–33	59,167	D	9	Ag	140	47	80	40	85	.9	3.3
21	1932–33	29,506	D	14	Fe	140	56	82	47	70	2.4	8.0
22	1935–36	621	A	a	Ag	140	61	84	55	76	2.6	8.0
23	1935–36	1,926	B	b	Ag	140	49	82	44	83	1.2	2.5
24	1935–36	631	C	a	Ag	140	46	62	38	64	2.0	6.8
25	1926–27	85,221	E	14	Rg	146	56	86	38	81	1.0	3.5
26	1932–33	65,210	D	9	Ag	147	49	80	39	87	.8	4.9
27	1933–34	157,877	C	11	Ag	147	50	80	46	75	2.0	8.3
28	1926–27	84,062	E	14	Rg	147	50	82	38	81	1.0	3.9
29	1926–27	76,290	E	13	Ag	149	50	90	38	88	.6	3.2
30	1926–27	72,782	E	13	Ag	150	49	87	38	88	.6	3.5
31	1925–26	65,048	E	13	Ag	153	46	87	38	87	.7	3.4
32	1925–26	80,615	E	14	Rg	157	46	82	37	83	.9	5.1
33	1932–33	79,656	D	9	Ag	159	49	80	40	83	1.0	4.6
34	1925–26	53,695	E	13	Ag	164	46	87	38	87	.7	3.3
35	1925–26	69,263	E	13	Ag	165	46	87	38	87	.7	2.6
36	1932–33	64,555	D	14	Ag	165	54	78	42	80	1.3	2.3
37	1935–36	382	F	b	Ag	166	48	84	39	88	.7	4.0
38	1935–36	395	G	b	Ag	168	55	87	42	90	.7	1.4
39	1931–32	29,400	D	14	Fe	170	53	85	44	73	2.0	8.6
40	1931–32	33,230	D	14	Fe	171	55	80	41	82	1.2	5.0
41	1925–26	66,222	E	14	Rg	172	46	82	37	83	.9	7.2
42	1931–32	31,510	D	14	Ag	173	53	85	41	82	1.2	5.4
43	1931–32	32,060	D	14	Fe	174	55	80	42	81	1.2	5.5
44	1925–26	78,543	E	14	Rg	176	46	82	37	83	.9	4.7
45	1935–36	168,656	B	18	Ag	178	55	75	47	79	1.7	4.4
46	1935–36	1,926	B	b	Ag	184	49	82	43	86	.9	3.7
47	1935–36	631	C	a	Ag	184	46	62	41	72	1.8	7.2
48	1931–32	36,320	D	14	Ag	188	54	82	41	82	1.2	8.0
49	1931–32	28,370	D	14	Fe	189	54	81	42	82	1.2	5.6
50	1931–32	28,520	D	14	Fe	189	58	78	42	81	1.3	2.5
51	1932–33	120,150	D	14	Fe	189	52	76	42	78	1.4	4.5
52	1931–32	50,010	D	14	Fe	190	55	75	42	80	1.3	4.4
53	1925–26	64,025	E	13	Ag	192	48	90	38	87	.7	2.2
54	1925–26	73,165	E	13	Ag	192	48	90	38	87	.7	3.7
55	1925–26	68,978	E	14	Rg	192	49	86	37	83	.9	2.9
56	1925–26	87,321	E	14	Rg	196	46	82	37	83	.9	5.3
57	1932–33	63,136	D	9	Ag	196	49	80	40	85	.9	4.8
58	1935–36	162,110	B	18	Ag	199	55	75	45	78	1.5	2.9

[1] Items 1, 4, 9, 16, and 22 are for 1 lot of potatoes weighed periodically, items 2, 5, 10, 17, 23, and 46 are a second lot of potatoes weighed periodically, and items 3, 6, 11, 18, 24, and 47 are a third lot of potatoes weighed periodically. All remaining items are for separate lots weighed in and at end of storage period only.

[2] Potato weight indicates the weight at time of storing of the test lot.

[3] A = furnace-heated residence basement; B, D, E, are trackside storages; C, F, G, are farm storages.

[4] Bin depth is for bulk storage depth with the following exceptions: a indicates bushel boxes stacked 5 high; a^1 boxes stacked 10 high (see fig. 18); b indicates 13-peck barrels not stacked and open at top; c indicates slatted bushel crates stacked 4 high.

[5] Ag (assisted gravity) indicates bins with slatted walls, floor flues, or combination of provisions for circulation; Rg indicates no provision for circulation in bulk storage; Fc=fan curing, Fe is fan "circulation" aided by electric heat for entire storage period; B is for blower and furnace heat for entire period.

[6] Curing-period temperature and humidity are averages for first 10 days of storage.

[7] Whole-period temperature, humidity, and saturation deficit (in millimeters of mercury) are averages for the entire storage period, including the curing period.

TABLE 1.—*Relation of storage conditions to losses in storage, 1925–36*—Continued

Item No.	Period of work	Potato weight	House	Bin depth	Air circulation	Storage period	Curing: Temperature	Curing: Relative humidity	Whole period: Temperature	Whole period: Relative humidity	Whole period: Saturation deficit	Losses
	Year	*Pounds*		*Feet*		*Days*	° *F.*	*Percent*	° *F.*	*Percent*	*Millimeters of mercury*	*Percent*
59	1935–36	234,000	B	25	Ag	199	61	71	45	81	1.3	3.6
60	1935–36	41,802	B	7	Ag	200	63	71	43	86	.9	3.7
61	1935–36	30,955	B	7	Ag	202	63	71	43	86	.8	3.2
62	1932–33	70,740	D	14	Ag	205	54	79	42	81	1.2	4.4
63	1932–33	27,030	D	14	Fe	206	56	83	43	80	1.3	4.9
64	1932–33	4,883	D	c	Ag	207	55	82	46	81	1.5	5.3
65	1932–33	60,093	D	9	Ag	208	49	83	40	85	.9	3.2
66	1932–33	28,866	D	14	Fe	208	55	83	43	78	1.5	4.6
67	1935–36	39,156	B	7	Ag	209	63	71	43	86	.9	2.5
68	1932–23	30,421	D	14	Fe	210	57	80	43	77	1.6	4.7
69	1932–33	62,077	D	9	Ag	213	49	83	40	85	.9	3.4
70	1932–33	27,172	D	14	Fe	214	56	82	43	80	1.3	4.9
71	1932–33	96,087	D	14	Ag	219	52	78	42	81	1.2	5.1
72	1932–33	59,661	D	9	Ag	224	49	83	40	85	.9	7.4

In order to determine which of the factors measured during the study and tabulated in table 1 had materially influenced shrinkage losses, the losses were plotted against the data for the separate factors, and the effects of some factors were studied by the graphic correlation method developed by Bean.[7] As a result of these studies it was concluded that in houses where little or no freezing, sprouting, or rotting occurred, the three most important factors related to shrinkage loss were length of storage period, average saturation deficit during the storage period, and curing temperature for the first 2 weeks. The correlation between shrinkage loss and length of storage period, average saturation deficit, and curing temperature are shown in figure 13, the data being analyzed by the graphical correlation method referred to above. The average storage period was 153 days; the average saturation deficit was 1.32 mm of mercury; the average curing temperature was 52.5° F.

Figure 13, *A* shows the observed shrinkage loss plotted against length of storage period for each lot in table 1, the line indicating the average relationship between loss and days stored. The deviation of each observation from the line may be assumed to be due to factors other than length of storage period, such as saturation deficit during storage or curing temperature. Accordingly the deviation of each point from the line in figure 13, *A* is plotted against saturation deficit in figure 13, *B*.

Figure 13, *B* shows the same data as figure 13, *A* the ordinates being the percentage variation from the line drawn in *A*. The abscissas are saturation deficits. It will be seen that in general the points showing shrinkage in excess of normal (the line in fig. 13, *A*), had been exposed to a high saturation deficit, and those having a shrinkage lower than normal had been exposed to a low saturation deficit. This relationship is expressed graphically by the line drawn in figure 13, *B*. Deviations from this line may be assumed to be due to factors other than length of storage period or saturation deficit.

[7] BEAN, L. C. APPLICATION OF A SIMPLIFIED METHOD OF GRAPHIC CURVILINEAR CORRELATION. PART 1 U. S. Bur. Agr. Econ. 20 pp. 1929. [Mimeographed.]

Figure 13, *C* shows the relation between the curing temperature and deviations from the normal line in 13, *B* for each lot of potatoes. This graph indicates a tendency for the loss to be higher in lots in which the curing temperature was in the lower part of the range. The line in figure 13, *C* represents this tendency graphically. The deviations from this line may be assumed to be due to factors other than length of storage period, saturation deficit, or curing temperature. Such factors include mechanical injury, freedom from disease, weather conditions at time of harvest, etc., and these are not accounted for in this study.

Figure 13, *D* has the same coordinates as figure 13, *A*, namely shrinkage loss and length of storage period, but is constructed by replotting the deviation above or below the line in *C* as percentages above or below the line which has the same position as the line in *A*. It will be noted that the deviations of the points from the line in figure 13, *D* are less than from the line in *A*. This is because the effects of saturation deficit and curing temperature have been accounted for.

By this procedure the average effect of each of the three factors upon shrinkage loss is derived. The effect of storage period is shown by the line in figure 13, *A* and *D*, that of saturation deficit by the line in *B*, and that of curing temperature by the line in *C*. It may be said that slightly closer successive approximations of these relationships may be had by repeating this graphical process but such repetition does not substantially change the lines representing the three relationships.

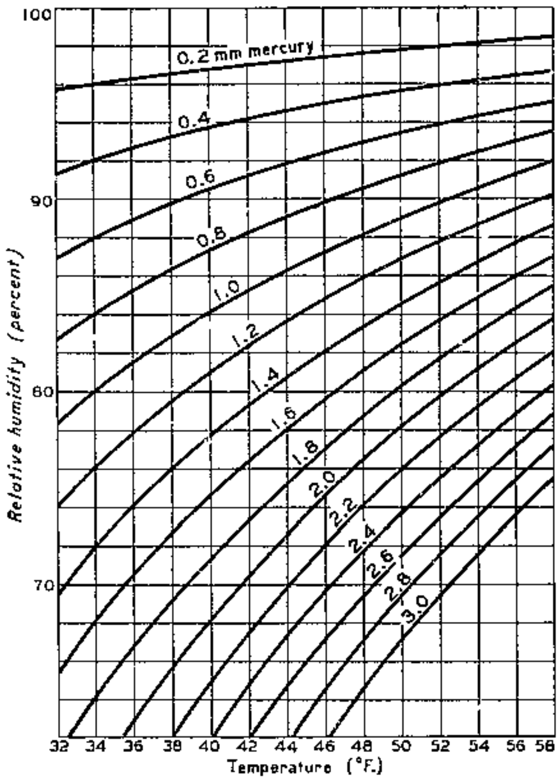

FIGURE 12.—Saturation deficit (in mm. of mercury) for given conditions of temperature and relative humidity.

Figure 13, *D* shows that the average shrinkage ranged from 1.6 pound per hundredweight for 28 days to 6.35 pounds per hundredweight for 224 days. Since the data include storage losses for period between 28 and 224 days the curve is shown only between these points.

Figure 13, *B* shows that shrinkage loss tends to increase directly with an increase in the saturation deficit. If the average saturation

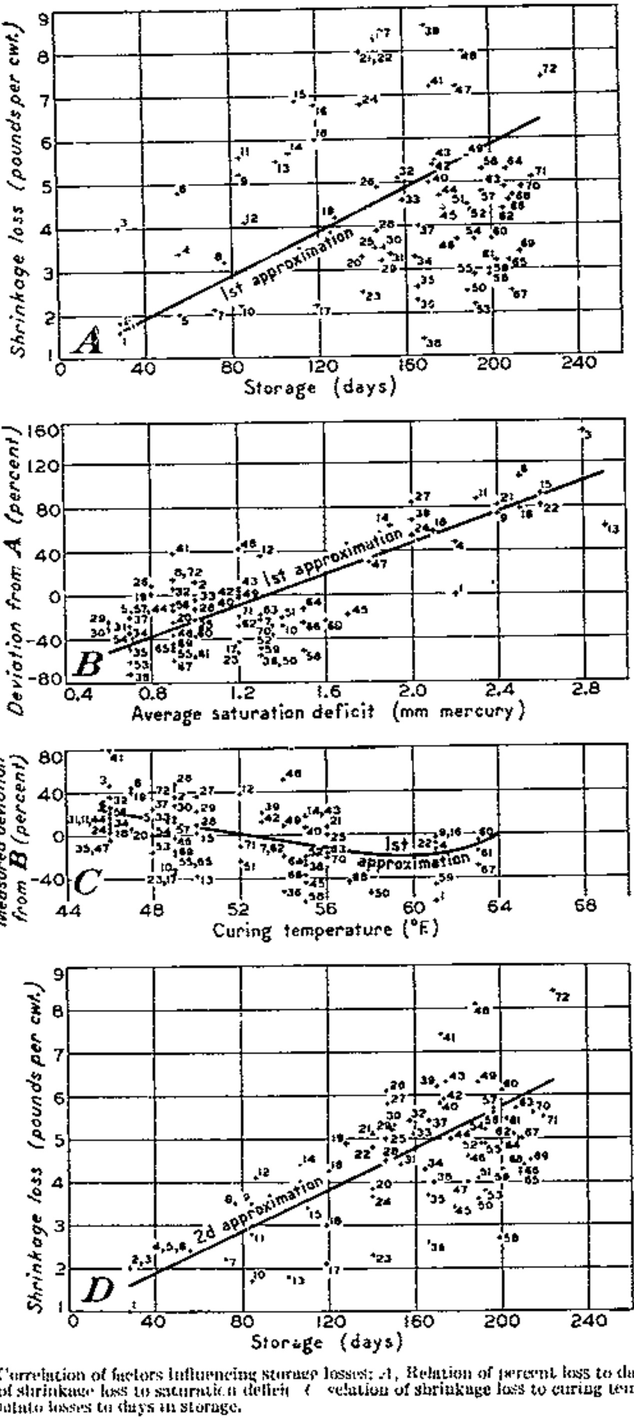

FIGURE 13.—Correlation of factors influencing storage losses: *A*, Relation of percent loss to days in storage *B*, relation of shrinkage loss to saturation deficit *C*, relation of shrinkage loss to curing temperature; *D*, relation of potato losses to days in storage.

deficit during storage is 0.6 mm of mercury, the expected loss for a given storage period should be about half of the loss indicated by the line in figure 13, *D*, but if the average saturation deficit is 2.7 mm of mercury, the expected loss should be approximately twice that indicated by figure 13, *D*.

The saturation deficit is of particular interest both because of its large effect upon losses and because it is controlled by the construction of the storage as will be discussed in the section on Management and Control of Storage conditions. A desirable limit for saturation deficit is about 1 mm of mercury.

Figure 13, *C* shows that temperatures between 50° and 60° F. or slightly above during the curing period tend to decrease the shrinkage, indicated in figure 13, *D*, while low temperatures tend to increase it. For example, in potatoes cured at 46° the loss would be increased by 20 percent. The data indicate that the advantage of using curing temperatures much above 60° is questionable. The data of Smith (*4*) show quite as much shrinkage with curing temperature of 68° F. as was found in this study at the lower curing temperature of 46°. This confirms the indications of figure 13, *C*, that under usual storage conditions there is an advantage in raising the curing temperature to 58° or 60°, but beyond that the advantage is questioned.

The combined effect of the three factors may be estimated as follows: Potatoes stored for 170 days normally might be expected to lose 5 pounds per hundredweight in storage (fig. 13, *D*) but if the saturation deficit during storage were 0.6 mm of mercury this loss would be one-half of 5 or 2.5 pounds, while if the saturation deficit during storage averaged 2.7 mm of mercury, this loss would be twice 5 or 10 pounds (fig. 13, *B*). Further, if the potatoes stored for 170 days at a saturation deficit of 0.6 mm of mercury had been cured at 58° F. the expected loss would be less than 2.5 pounds by 1 pound, or 20 percent of 5 pounds, showing a net loss of 1.5 pounds per hundredweight, but if this same lot had been cured at 46° the expected loss would be 1 pound greater, or 3.5 pounds. Or if the potatoes stored 170 days at a saturation deficit of 2.7 mm of mercury had been cured at 58° F. the expected loss would be 9 pounds (1 pound per hundredweight less than 10); or if cured at 46° the same lot would be expected to lose 1 pound more than 10 or 11 pounds. That is, two lots each stored 170 days might shrink from 1½ pounds to 11 pounds per hundredweight had their storage conditions and curing temperature varied within the limits shown in figure 13, *B* and *C*.

QUALITY OF STORED POTATOES

Tests were made by Mrs. Marion D. Sweetman, professor of home economics of the University of Maine to determine the effect of storage conditions upon table quality. Cooking tests were made upon 40° and 50° F. storage lots in 1931–32 and 1932–33 with the following results: The potato-chip test indicated that the 40° potatoes gave a dark-colored and unsatisfactory chip while the 50° potatoes produced an amber-colored and very satisfactory chip; and boiling and baking tests of the 40° potatoes proved them to be much sweeter to the taste and slightly less mealy than the 50° lot.

Cooking tests also were made on potatoes from the top and bottom of a 14-foot bin. The potatoes from the top of the bin were so

41735°—38——3

slightly superior as to mealiness in the cooking tests that the difference was undoubtedly due to the 2° or 3° higher temperature in the bin top, and not caused by pressure on the bottom potatoes.

During the investigation of 1931–32 the Peacock-Brunstetter (*2*) method of determining sugar content was used in a series of check tests of potatoes where the average storage temperature for the preceding 30 days was known. The results of these tests are given in table 2 which indicates that in general the sugar test is a reliable indicator of the temperature for the preceding 30 days. The variations that exist may be because the samples were not representative of the lots for which temperatures were obtained; or it may be that the test indicated the effect of the latter part rather than the entire 30-day storage period.

TABLE 2.—*Storage temperature indicated by the Peacock-Brunstetter sugar test as compared with actual average storage temperatures for the preceding 30 days of storage*

Date of test	Actual average and indicated storage temperatures preceding test									
	Test 1		Test 2		Test 3		Test 4		Test 5	
	Actual	Indicated	Actual	Indicated	Actual	Indicated	Actual	Indicated	Actual	Indicated
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
Nov. 9, 1931	50	50	45	50	55	60	53	50	47	40
Dec. 11, 1931	50	50	40	50	45	55	40	40	([1])	32
Jan. 19, 1932	50	50	40	50	40	40	38	36	40	32
Feb. 16, 1932	38	38	38	38	([2])	50				
Mar. 5, 1932	40	38	40	32	40	40	40	40	40	40
Mar. 17, 1932	40	40	40	40	40	40	([1])	34		

[1] Exposed to freezing temperature. [2] Unknown temperature but sprouting.

PREVENTING MECHANICAL INJURY

Mechanical injury to potatoes in storage is caused either by dropping or crushing them and is increased when the potatoes come in contact with an unyielding surface or sharp corner.

Most of the Aroostook potatoes are stored in deep bins (fig. 14) and since this practice has been questioned a study was made of losses in bins from 7 to 25 feet in depth (table 1) filled with sound potatoes, which indicated very little increase in temperature in deep bins and some reduction in shrinkage; probably because of higher humidity in the deep bins.

In bins 14 feet or more deep only an occasional potato showed impression or injury due to pressure, and then only when the potato rested against a sharp corner. However, injuries due to walking on, or resting plank or barrels on potatoes were easy to locate.

The cracked and bruised potatoes sometimes found in terminal markets, where the damage is attributed to deep storage, was found to be caused by handling rather than by crushing due to bin depth.

It should be emphasized that these results were obtained under conditions existing in Aroostook County, Maine, and do not indicate that deep storage would be satisfactory in a warmer climate. Deep storage is generally not approved in warmer sections. Stuart (*5*) advises against storing potatoes 10 to 15 feet deep because of heat generated in large piles. Heating is most likely to occur if the potatoes are diseased.

Several methods and various pieces of handling equipment were tried in an effort to reduce handling injury. The use of sack chutes for lowering potatoes into bins from an upper level (fig. 15) seems to be more practical than either zigzag or spiral chutes, because a sack chute is more easily moved from bin to bin, and is much more economical, being usually made from a worn-out tire casing for the top and old sacks for the chute. The bruising of potatoes when filling deep first-floor bins is reduced by providing supports for a "roll" plank at the middle of the bin height. A floor dividing the main alley into two

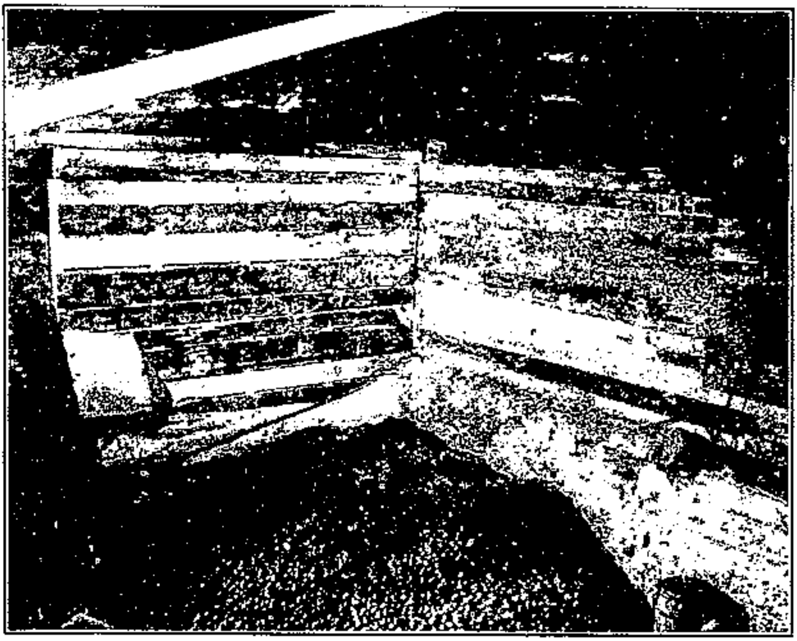

FIGURE 14.—Over 6,600 barrels of potatoes were stored in this 30- by 40-foot bin, the potatoes being stored to a depth of 27 feet. Thermocouples in the bin center at various heights indicated but a small range of temperature.

levels to facilitate filling is shown in figure 15. Such a floor is used in the trackside storage shown in figure 23.

To reduce the injury to potatoes from forking them into a grader a hinged rope conveyor was first tried but it was found unworkable because dirt and small rocks accumulated at the central hinge and stopped the rope belt. Next a hinged canvas conveyor was tried. Its principal fault was that it would not raise potatoes at an angle of more than 10° and therefore required such a long inclined flight for elevating potatoes from floor to grader hopper that it blocked the work alley, making it difficult to handle bagged and barreled potatoes from the grader. Next, a single horizontal flight belt conveyor was tried at the Aroostook Farm, first in connection with a rope hopper to eliminate dirt in storing potatoes and later for moving potatoes from bin to grader. This conveyor did good work from a level floor when there was plenty of alley room, and when used in the house at Bridgewater which was designed for conveyor handling with the bin floors 3 feet above the work-alley floors,

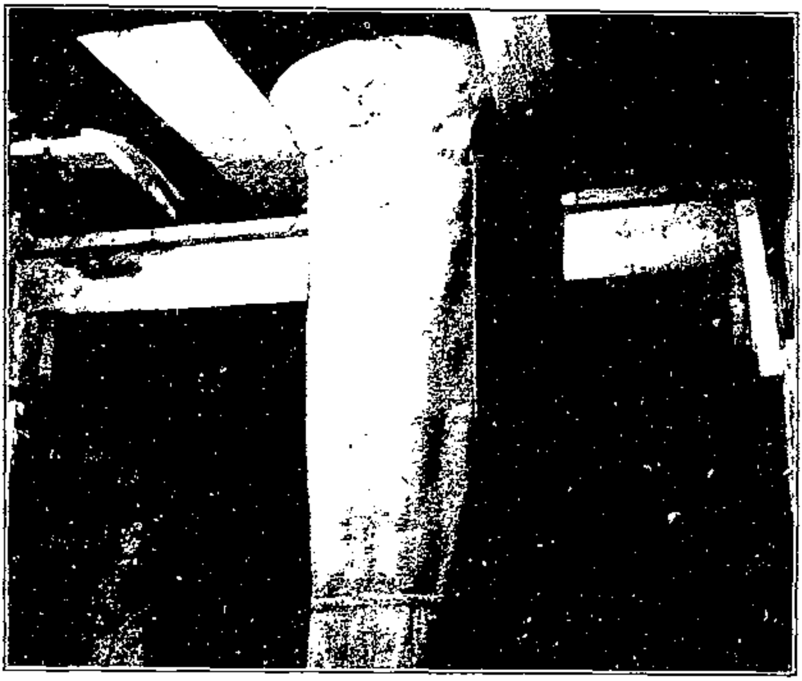

FIGURE 15.—Sack chutes used for lowering potatoes from one level to another. The best method is to bend the chute, by means of a rope tied to bottom, while the barrel of potatoes is being dumped, then lower slowly into the bin below.

it proved very satisfactory and has been used for three seasons. The details of construction for a similar conveyor are shown in figure 16.

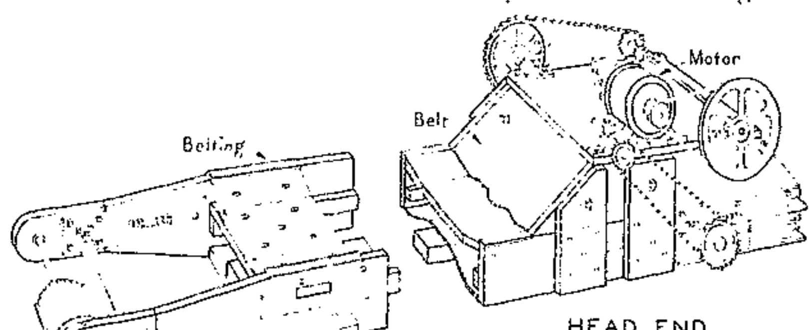

FIGURE 16.—Belt conveyor for moving potatoes from bin to grader. Refer also to figure 8.

A rope-bottom hopper (fig. 17) was developed to remove dirt and small potatoes when filling farm storages, taking the place of the slat-

See footnote [illegible], p. [illegible].

bottomed hopper commonly used. The use of the rope bottom materially reduced damage during this operation.

With the thought of reducing grader injury, a rope-belt grader was designed and built which eliminated the dropping of potatoes from belt to belt which occurs in the common graders. The difficulty in securing proper tension on the rope-grader belts indicated that such a grader would be too expensive to build commercially. However, the building of the rope grader resulted in renewed interest in reducing grader injuries and in improvements in commercial graders.

Studies by Schrumpf (*3*) show that grade injury averaging 4.4 percent occurs during the barreling or bagging operation; this injury is serious because these potatoes are not graded again before they reach the consumer. It was found during the present investigation that if potatoes are warm when passing over the grader, the injuries due to drops are largely eliminated. It was found also that when potatoes at 50° F. passed over the grader they remained dry and free from thumbnail cracks while at least 50 percent of potatoes graded at 36° had damp spots indicating thumbnail cracks. These injuries, both major and minor, are increased by the time the potatoes reach the market and greatly injure their appearance and quality. In a test of preheating before shipment 1,000 bushels of potatoes were warmed 4° in 4 days using the blower and electric strip heaters described on page 11; 85 kilowatt-hours of current were used. A wood stove and blower similar to the outfit shown in figure 11 is well-adapted for this purpose, and requires little fuel and electricity.

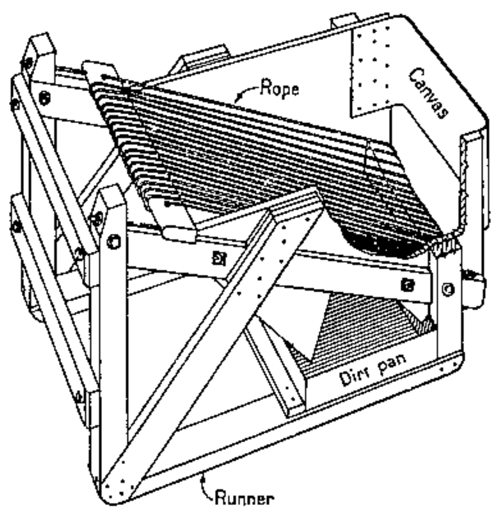

FIGURE 17.—Rope-bottom hopper for removing dirt and small potatoes when filling farm storages.

Warming potatoes before grading is a new and very promising development, provided buyers learn to appreciate the value of potatoes free from minor injuries and bruises. Warming also improves the flavor of potatoes stored at low temperatures by converting some of the sugars formed at the low temperatures back to starch. It is thought that there is less danger of blackheart developing during shipment if the potatoes are warm when loaded.

A comparison of lots of potatoes stored in bulk and in boxes was made at the Aroostook Farm in 1933–34. One phase of this test was the determination of the market price of potatoes stored by the two methods when they were graded out in Fancy and Unclassified grades. Table 3 indicates the advantage of box storage when there is a fair price as in 1933–34. The larger percentage of Fancy potatoes is due to the elimination of major bruising in handling. A similar test was run in 1934–35 but the potatoes were not weighed into storage, and they were weighed out on the U. S. No. 1 grade basis instead of the

Fancy grade of the previous year. In this test there was a slight advantage in the quality of the boxed potatoes but the selling price for No. 1's was so near the starch price that no price advantage was apparent. The starch grade shown in table 3 includes all potatoes usable only for making starch. Box storage eliminates the following operations in handling: Emptying into barrels, dumping barrels into storage and forking into grader. When shipped in boxes, most of the injury in dropping from grader to barrel or bag is eliminated as the drop from grader to shipping boxes is small.

TABLE 3.—*Comparison of box and bulk storage, showing the percentages of different grades weighed out and the over-all selling price per hundredweight of potatoes stored, Aroostook Farm storage, 1933–34*

Stored in—	Time held	Storage		Weight	Out-weight grades				Respiration loss	Price per hundredweight
		Temperature	Relative humidity		Fancy	Seconds and peas	Unclassified	Starch		
	Days	*°F.*	*Percent*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Dollars*
Boxes	110	41	71	22,660	72.7	9.7	8.8	1.8	7.0	1.80
Bulk	120	38	77	258,033	64.9	11.9	13.5	2.4	6.6	1.71

A comparison of time and labor requirement for box and barrel handling was made and the results are shown in table 4. This table

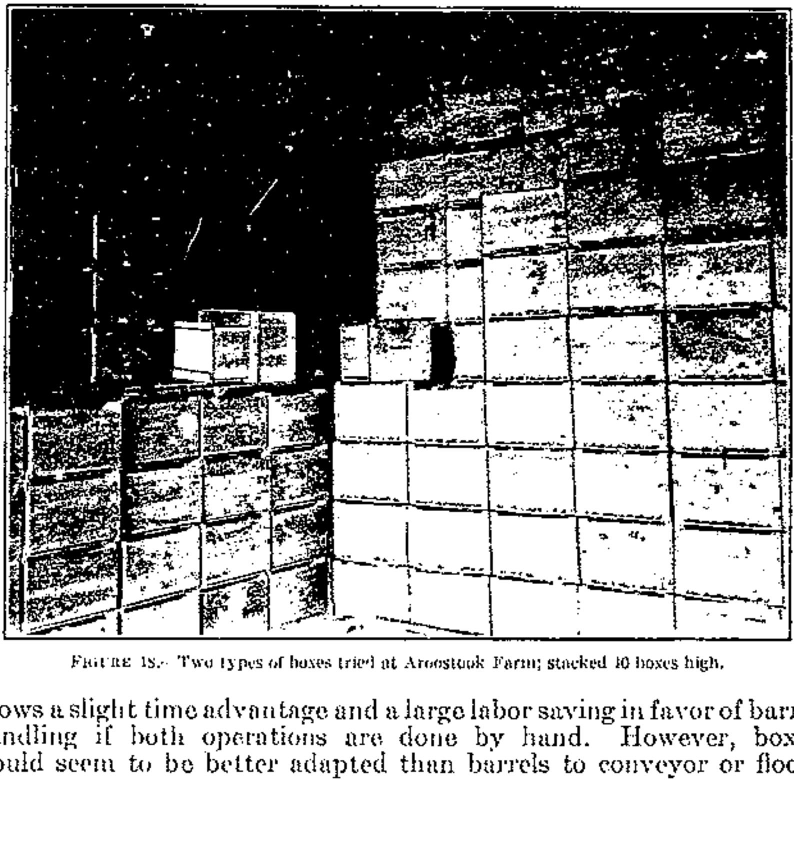

FIGURE 18.—Two types of boxes tried at Aroostook Farm; stacked 10 boxes high.

shows a slight time advantage and a large labor saving in favor of barrel handling if both operations are done by hand. However, boxes would seem to be better adapted than barrels to conveyor or floor-truck handling. The use of boxes in the present storages would probably reduce the capacity if stored only in the present bins, but by removing bin partitions and storing boxes in main and cellar alleys there would be little difference in capacity (fig. 18). When handling by hand the usual first-floor bins should preferably be divided into two levels for boxes.

TABLE 4.—*Time required for placing boxed potatoes into storage as compared with dumping into storage from barrels*

Truck load [1]	How handled	Men required	Time required
		Number	*Minutes*
52 boxes	Stacked 1 to 9 high	4	8
Do	Stacked 1 to 5 high	4	6
Do	Stacked 6 to 9 high	4	7
20 barrels	Dumped through hatch	2	6

[1] A 52-box or a 20-barrel truck load required the same time for loading in the field.

ACCIDENTAL LOSSES

Another common cause of storage losses noted during this study is freezing, which often occurs at the first-floor level in track storages if the wall insulation is defective. This causes the loss of not only the potatoes actually frozen, but makes grading and handling difficult, for adjoining potatoes may become discolored, and damp. Frozen potatoes, if not sorted out by the graders, may cause heavy loss when shipped with sound potatoes. Storing potatoes after heavy frosts often results in great difficulty in grading, because field-frosted potatoes scattered through a bin sometimes will each wet a peck or more of sound potatoes. In the weighed samples of the present investigation the losses due to decay of potatoes in storage where mechanical injury would not have been sufficient cause for grade rejection ran about 0.1 percent. Potatoes rejected due to late blight during the 1931–32 study amounted to 1.1 percent and in 1932–33 to only 0.2 percent. This loss is due to field infection and cannot be charged to poor storage conditions.

COMMON FAULTS OF STORAGES

The principal faults of the old-type farm storages are that when the bins are filled to capacity there is so little space between ceiling and potatoes that air circulation is retarded. Some of these storages are ventilated entirely through the cracks in the drive floor and others by opening the filling hatches during October and November, and on mild days during the winter. In either case many are insulated after the bins are filled by spreading straw or shavings over the drive floor. A common result of this practice is shown in figure 19. Moisture which condenses in the porous material or on the floor boards causes dripping on the potatoes.

To prevent the freezing of potatoes against the outer wall of the cellars near the ground level, some houses have been banked well up on the roof with straw and even with manure which, though preventing freezing has hastened the decay of the roofing.

The old-type trackside storage also has several faults. The heavily stressed first-floor beams and girders over the cellar bins soon decay at the sill where they are spiked to the wall studding, which also decays. These members and the wall insulation are alternately wet and dry at this point. Three types of failure result: (1) The heavily stressed floor beams and joists fail; (2) the wall studding kicks out under the lateral thrust of the potatoes, opening a part of the bin to freezing; and (3) the insulation and sheathing become damp, and decay opens cracks in the sheathing which may result in leakage of fill-type insulation with resulting freezing of potatoes at the junction of the outside wall and floor.

The ventilation problem in old-type trackside storages is similar to that in the farm storages. The ceiling, whether directly over the potatoes or at the collar-beam level, is often made of boards having cracks between and sawdust or shavings above. In other cases commercial insulation is used on the ceiling (fig. 20) and an opening pro-

FIGURE 19.—Ventilation through cracks in farm storage drive floor increases losses of potatoes and early decay of floor.

vided for ventilation, but not connected with the roof ventilator above. The result in either case is that warm, moist air arising from the potatoes either passes through the cracks in the ceiling or through the ceiling opening. Part of this moist air coming in contact with the underside of the shingled roof causes accumulation of frost and ice which melt and drip during the occasional bright sunshiny days, wetting the insulation below. Another fault in track storages as well as farm storages is too many windows, which have to be covered with shutters to prevent greening of potatoes and loss of heat during the winter, while in houses where electric lights are available they are not essential during any part of the year.

PRINCIPLES OF STORAGE-HOUSE DESIGN AND MANAGEMENT [9]

One of the principal developments of the present investigation is a better understanding of the use of moisture condensation in the control of storage conditions. In the past, warehousemen have attempted

[9] Acknowledgement is made to S. J. Dennis, Associate Refrigeration Engineer of this Bureau in the application of the principles of air physics to the solution of the problems encountered.

to regulate storage conditions by heating and ventilating sufficiently to control storage temperature and avoid condensation of moisture in the buildings because too much ceiling condensation causes dripping and rotting of potatoes, and condensation in any part of the building causes decay of unprotected structural members. However, during the course of this study it was found that condensation has been an unrecognized helpful factor in control of storage conditions, but that a high humidity conducive to low shrinkage loss could be maintained only in well-insulated structures. Further it was found that moisture could be removed by condensation with far less heat loss and with less attention by the operator than when removed by ventilation. Under

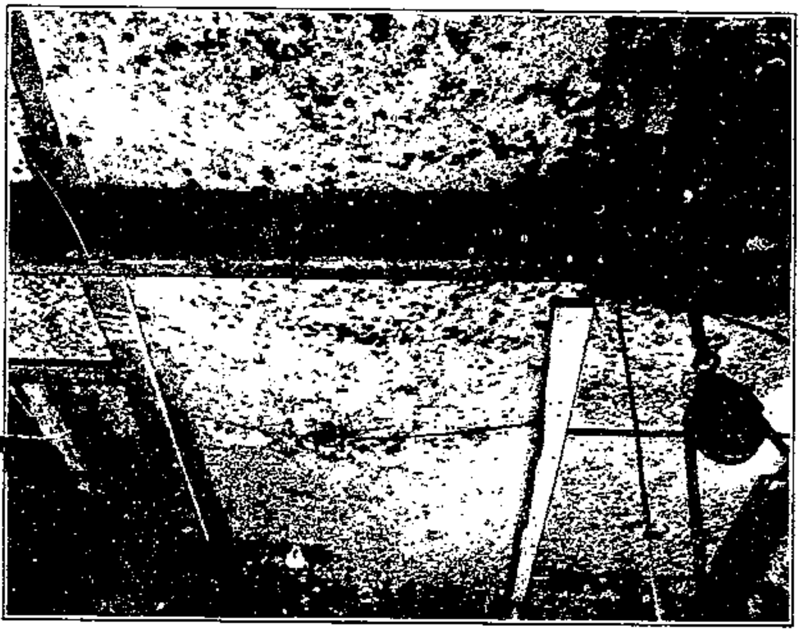

FIGURE 20.—Damaged insulation caused by poor house design.

the new control method discussed in this section, a proper balance between storage-house insulation and air circulation prevents ceiling condensation, and, in combination with waterproofed wall surfaces, provides for removal of excess moisture by harmless condensation on the walls. This assists in the maintenance of the high humidity necessary for minimum shrinkage of the stored potatotes. Thus condensation, formerly avoided, is now used to save potatoes, fuel heat, and the operator's time.

Temperature, humidity, and condensation are closely related factors in storage-house control. These factors will now be discussed separately.

REGULATION OF STORAGE TEMPERATURE

This discussion of temperature control in potato storage relates specifically to the climatic conditions and typical storages of Aroostook County, Maine. It illustrates the sources of heat available for maintaining desired temperature and how this heat is lost from the storage.

The three sources of heat for controlling storage temperature are (1) the heat of respiration, or metabolic heat; (2) the sensible heat given off as the potatoes cool from a higher to a lower temperature; and (3) heat from stoves or other types of heater.

Heat of respiration of the stored potatoes materially affects the conditions in a potato-storage house. It may cause the temperatures to rise above the optimum during warm periods but aids in holding optimum temperatures when outside temperatures are low. The rate at which heat is produced by respiration of potatoes under typical storage conditions is indicated in figure 21 which was prepared from data published by Smith (4) and based on studies of the respiration rate of potatoes over a 200-day storage period.

Heat released in cooling potatoes or sensible heat amounts to about 90 B. t. u. per 100 pounds of potatoes per degree drop in potato temperature. (A like amount of heat is absorbed in warming 100 pounds of potatoes 1°.) Under desirable storage control the temperature of the potatoes should be lowered from the initial storage temperature

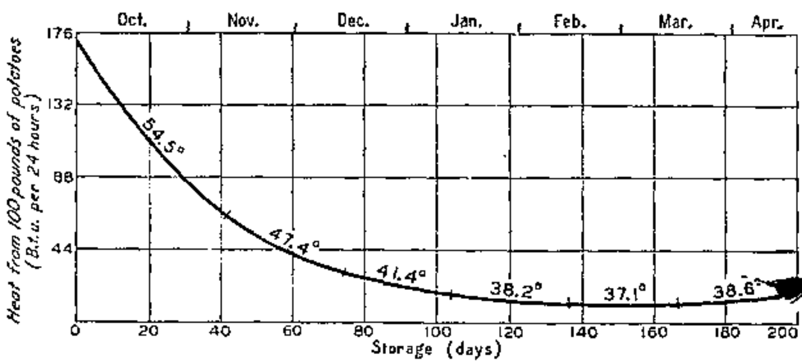

FIGURE 21.—Relation of rate of respiration and heat production to storage temperatures and storage period.

of about 50° F. to the holding temperature of 40° during October and November. Thus the sensible heat must be dissipated in the fall and is not available in the winter when it could be used. However, in small amounts loss or gain of sensible heat serves as a governor retarding either quick cooling or quick warming up of the storage.

In northern potato-storage areas provision should be made for supplying artificial heat to storages, for although no great amount is required it is more quickly available than heat from the other sources just mentioned, and must be depended upon to provide uniform temperature during extremely cold weather. The burning of 1 cord of hard wood or 1 ton of coal in the average storage-house stove will supply about 20,000,000 B. t. u. of heat, or an amount equal to the sensible heat released in cooling 1,000 tons, or about 12,000 barrels, of potatoes from 50° to 40° F.

Heat is lost from storage houses either by conduction through the walls and ceiling or by being carried off in the ventilating air. The heat loss by conduction is inversely proportional to the insulating values [10] of the walls and ceiling and directly proportional to the difference between the inside and outside temperatures. For storages in

[10] The insulating value indicates the number of degrees difference between inside and outside temperatures which will cause the loss through the wall of 1 B. t. u. per square foot of wall surface per hour.

northern Maine, wall and ceiling insulating values of 5, 10, and 20 are considered poor, average, and good, respectively. Desirable inside temperatures and average outside temperatures for the storage months considered in the following discussion are given in table 5, the inside air temperatures usually being the same as the potato temperatures.

TABLE 5.—*Desirable inside storage and outside air temperatures for Aroostook County, Maine*

Item	October	November	December	January	February	March	April
	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Desirable inside air and potato temperature	50	46	40	40	40	40	40
Average outside air temperature	44	30	15	10	12	24	36
Difference	6	16	25	30	28	16	4

Heat lost through the walls and ceiling by conduction is supplied by the circulating air that comes in contact with these surfaces. Circulation spaces are generally required along all vertical above-ground walls against which potatoes are stored. In the typical Aroostook storage house there is a 2-inch air-circulation space between the outside wall insulation and the stored potatoes. This wall-circulation space is open at both top and bottom and permits air from the top of the house, which has been warmed by the potatoes or by artificial heat, to pass down along the cold walls. Air circulation through such an air space prevents the temperature of the walls and the adjoining potatoes from falling much below the average house temperature. Cooled air flows from the bottom of this wall-circulation space towards the center of the house where it is warmed by the potatoes or by the heater and again rises to the top of the house and the wall-circulation cycle is repeated.

However, during the course of the study it was found that potatoes on top of a deep bin could be safely stored against the well-insulated lower roof slope of a farm storage, even though no air circulation space was provided. The higher ceiling temperature probably can be explained by the fact that heat is carried upward through the potatoes by rising air currents, but lateral currents through the potatoes are insufficient to warm the wall.

Under typical winter conditions in Aroostook County, the circulation of moist air from the interior of the house along the cold outer walls results in the condensation of considerable amounts of moisture on the wall surfaces.

If the cold surface of the wall-circulation space is waterproofed, and drainage is provided at the bottom of the space, condensation against this protected surface will do no harm to the building. Under average conditions in well-insulated storages condensation on the protected side walls will remove moisture from the air in the house at a rate that will prevent the condensation of moisture upon the ceiling, so that no ventilation may be needed to remove the excess moisture. This conserves heat since condensation of moisture on the wall increases the conduction losses very little, but under average winter conditions the removal of a pound of moisture by ventilation carries from the storage about 2,000 B. t. u. of heat.

The approximate amounts of heat per hundred pounds of potatoes per day supplied to and removed or lost from an average storage under average conditions are shown in figure 22. The general method of control is to ventilate sufficiently in October and November to lower the potato temperature to 40° F., at which temperature they are to be held for the rest of the season. The method of control for the rest of the season is to heat or ventilate as necessary to hold the temperature at 40° and also to ventilate if necessary to prevent moisture condensing on and dripping from the ceiling. Figure 22 illustrates average conditions obtained in a full storage. In a better insulated storage less artificial heat will be required (see table 7). As the storage is emptied the available metabolic heat is reduced, making it necessary to supply more artificial heat. The recommended procedure in temperature control may be summed up as follows:

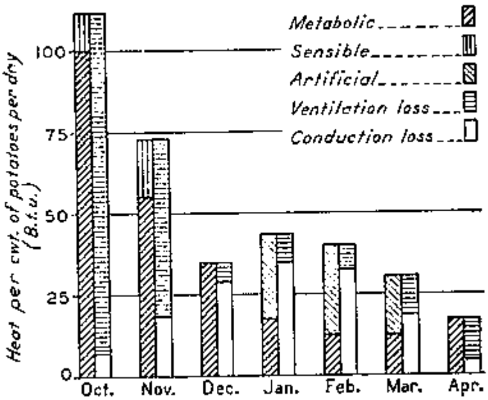

FIGURE 22.—Heat balance for an average potato storage filled to capacity, Aroostook County, Maine, conditions.

(1) In October and November plenty of ventilation is necessary to remove the metabolic heat and sensible heat released in cooling the potatoes.

(2) For average December conditions little attention is required either to ventilating or heating, but for extreme conditions heating or ventilating may be required.

(3) In January, February, and March, artificial heat will be required to balance losses by conduction and ventilation.

(4) In April, night ventilation will be necessary to minimize rise in potato temperature. This is especially important if potatoes are stored until May.

SPECIAL TEMPERATURE-CONTROL MEASURES

It is often desirable to hold the temperature of one bin above that of adjoining bins. This may be for curing potatoes received after the other potatoes have been cured and cooled to the holding temperature, or for preheating a bin before shipping to prevent bruising injury (p. 21), to lower the sugar content of the stored potatoes or as an aid in insuring frost-free shipping. Preheating before shipping should be very much worth while if the price of high-quality potatoes justifies it. During the 1932–33 season, electric strip heaters and electric fans were used to maintain a temperature in one bin 8° above adjoining bins (see Buildings, p. 3) and during 1933–34 a wood stove and electric blower were used for the same purpose. The results are summarized in table 6, which shows that electric heat, while giving closer control, is far more expensive than wood. Where electric heat and an electric fan requiring one-twelfth horsepower were used the heating was regulated so that the fan was in almost continuous operation. However, where the wood-burning furnace and blower requiring 1 horsepower were used the heating could not be regulated low enough for continuous operation, so that 2 or 3 hours operation per day was sufficient to maintain the desired average temperature although the range was 4° or 5° greater than where electric heat was used. All control was by hand. For wood heating the blower was set beside a jacketed stove (fig. 11) forcing air from the alley into the jacket, and the warm air was delivered through sheet-iron pipes to slat-covered flues running lengthwise through the bottom of the bins.

TABLE 6.—*Comparative costs of electricity and cordwood for heating 1,000 bushels of potatoes for the storage season*

Year	Average temperature above adjoining bin	Time held	Source of heat	Air circulation	Power consumption	Total estimated cost [1]
	° F.	*Days*			*Kilowatt hours*	*Dollars*
1932-33	8	140	Electricity	Fan using 1/12 horsepower.	755	18.88
1933-34	8	101	Cordwood	Blower using 1/4 horsepower.	61	3.52

[1] Electric current for heat and power at 2.5 cents per kilowatt-hour and cordwood at $8 per cord.

One method tried for ventilating without the danger of freezing potatoes was the use of a circulating heater (fig. 4), which worked much like an ordinary warm-air heating system taking cold air from outdoors. This method was safe whether a fire was going or not, but occupied considerable space in the work alley. When there was no fire, moisture from the inside air condensed on the metal intake flues and caused them to rust. For these reasons and because an ordinary wood stove seemed adequate it was not used in the new storage.

REGULATION OF STORAGE HUMIDITY

In the preceding discussion of temperature control, only optimum temperatures were considered because they can be maintained in almost any storage. However, the optimum relative humidity is practically 100 percent, and such high humidity cannot ordinarily be secured during the storage season with the existing outside and desirable inside temperatures. For in actual storage practice maximum relative humidities obtainable in storage houses are definitely limited by the following factors: (1) The excess of inside over outside air temperatures, (2) the insulating values of storage walls and ceiling, (3) ventilation to remove excess heat, and (4) artificial heating. Since the lowering of relative humidities results in increasing shrinkage losses, humidity control has for its purpose the carrying of relative humidities as high as is practical in view of counterbalancing ill effects from depreciated buildings or rotted potatoes due to condensed moisture.

In common storage practice condensation of moisture upon the ceiling is used as an indicator that too high relative humidity has been reached and that ventilation is needed to prevent dripping of moisture and decay of the potatoes. Ventilation lowers the humidity of the air below the ceiling until the dew point of the air is below the ceiling-surface temperature and ceiling condensation stops. Further ventilation will cause evaporation into the air of moisture already condensed and will lower the air humidity from the maximum reached when ceiling condensation commenced. Thus the operator of the old-type storage must choose between maintaining (1) a condition causing relatively low shrinkage but inducing structural decay, and (2) a condition causing relatively high shrinkage but little structural decay.

During the course of this study it was found (1) that it is practical to increase the ceiling insulation to a value at which condensation will not occur during average winter weather, thus allowing a very high relative humidity with corresponding low potato shrinkage, (2) that once the ceiling condensation point is reached, with given air temperatures and insulation values, further evaporation of moisture into the air from the potatoes will not raise the relative humidity of the air because moisture is condensed as rapidly on the ceiling as it is evaporated from the potatoes, and (3) that with values of ceiling insulation equal to or higher than the insulation values of the wall adjoining the freely circulating spaces, wall condensation tends to limit air humidities below the condensing point of the ceiling surface.

The "limiting" or maximum relative humidity of air below a ceiling is reached when the dew point of the air becomes equal to the ceiling-surface temperature. With a given inside temperature and insulating value, a lowered outside temperature will result in a lowered ceiling-surface temperature and consequently a lower relative humidity of the air in contact with it. For a given inside and outside temperature, a lower insulating value of the ceiling will result in a lower ceiling-surface temperature and resultant lower relative humidity of the air below the ceiling. For given inside and outside temperature and ceiling insulation the limiting value of the relative humidity can be closely approximated by the following method:

(1) Calculate the temperature, t_s of the ceiling surface as follows:

$$t_s = t_1 - \frac{(t_1 - t_2)0.6}{Rc} \qquad (1)$$

Where t_1 = inside air temperature;

t_2 = outside air temperature;

0.6[11] = surface resistance to heat flow, and

Rc = total ceiling resistance to heat flow in degrees temperature difference in British thermal units of heat loss per square foot per hour.

(2) Using the values of t_s as found by equation (1) the limiting relative humidity may be found from psychrometric tables, taking t_s as the dew-point temperature and t_1 as the dry bulb.

For example with $t_1=40°$; $t_2=10°$; and $Rc=10.0$, substituting in equation (1)

$$t_s = 40 - \frac{(40-10)0.6}{10} = 38.2°,$$

which is the ceiling surface temperature or limiting dew point for the air below; and (2) with $T_1=40°$ and $t_s=38.2°$ psychrometric tables show a relative humidity of 94 percent. Limiting relative humidities[12] calculated for various insulation values and temperature conditions during the usual storage period are shown as items 8, table 7.

The application of the principles developed in this investigation to the design of storage houses for potatoes is illustrated in table 7, which shows the estimated performance of three storage houses,

[11] Approximate value for a dry interior wood surface.

[12] "Limiting relative humidities" are as high as can be secured under given temperature and ceiling-insulation values because ceiling condensation tends to prevent humidity from going higher.

provided with light, medium, and heavy insulations, respectively. The range of insulation values shown covers most insulations which would ordinarily be used in potato storages. The storage periods, and inside and outside air temperatures, assumed as a basis for the table, are shown in items 2, 3, and 4, respectively, these having been chosen to correspond as closely as possible to average Maine conditions and are the same for each of the three houses. Calculations of heat, moisture, and potato shrinkage, shown in succeeding items, are all based on a "hundredweight" (100 pounds) of potatoes, so that the size of the house does not enter into the calculations except in the computation of item 6, as explained below.

The probable performance of each house is estimated for two methods of management, "Case A" representing the optimum, or best possible conditions which can be maintained, under the given conditions of outside temperature and house insulation, while "Case B" represents a general average of storage conditions observed in actual practice during this study. The relative merits of the three houses and the two methods of management, are shown by comparison of artificial heat requirements (items 18 and 19) and potato shrinkages (items 20–21, and 22–23).

TABLE 7.—*Estimated performance of potato-storage houses having different insulation values*

Item	Light insulation			Moderate insulation			Heavy insulation		
1. Storage-wall and ceiling-insulation resistance [1]	[2] 5.0			[3] 10.0			[4] 20.0		
	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring
2. Length of storage period . . . days	60	90	60	60	90	60	60	90	60
3. Average inside air temperature . . . ° F	45	40	40	45	40	40	45	40	40
4. Average outside air temperature . . . ° F	37	12	30	37	12	30	37	12	30
5. Heat from potatoes (metabolic and sensible) per hundredweight per day . . . B. t. u	93	22	14	93	22	14	93	22	14
6. Heat removed from storage by conduction, per hundredweight per day . . . do	14	52	18	7	26	0	4	13	5
7. Moisture removed from storage air by wall condensation, per hundredweight per day . . . grains	32	100	40	16	52	20	8	26	10
Relative humidity under ceiling, per hundredweight:									
8. Case A [5] . . . percent	[6] 83	[7] 88	[7] 96	[6] 83	[7] 94	[6] 95	[6] 83	[6] 95	[6] 96

[1] Insulation resistance based upon inside-outside air-temperature difference in degrees Fahrenheit for conduction of 1 B. t. u. of heat through 1 square foot of wall or ceiling area per hour, or ° F. — ft.[2] — hr. per B. t. u.

[2] Ceiling construction with insulation resistance of approximately 5: Waterproof paper and matched sheathing under rafters or ceiling joists; an air space; and tight sheathing and wood shingles over rafters.

[3] Ceiling construction with insulation resistance of approximately 10: Same as for resistance of 5 with (1) an added air space and 1 inch of flexible or blanket-type fiber insulation, or (2) with 2 inches of dry shavings over matched-sheathing ceiling.

[4] Ceiling construction with insulation resistance of approximately 20: Same as for resistance of 5 with (1) 4½ inches of fluffy rock, slag, or other mineral fiber added between rafters, or (2) 6 inches of dry shavings added between rafters. Various other combinations of insulation and air spaces might be built up to give same value.

[5] Limiting values which can only be approached in practice.

[6] With this storage condition the use of ventilation to remove heat removes more moisture than necessary to prevent ceiling condensation.

[7] With this storage condition the relative humidity is limited by ceiling condensation. Night ventilation may be used to increase ratio of heat to moisture removal. Day ventilation may be used to increase ratio of moisture to heat removal.

TABLE 7.—*Estimated performance of potato-storage houses having different insulation values*—Continued

Item	Light insulation			Moderate insulation			Heavy insulation		
	5.0			10.0			20.0		
	Fall	Winter	Spring	Fall	Winter	Spring	Fall	Winter	Spring
9. Case B[1] .... percent..	83	72	91	83	81	94	83	89	90
Potato moisture shrinkage, per hundredweight per day:									
10. Case A .... grains.	290	108	42	290	58	50	290	50	42
11. Case B .... do...	290	228	84	290	162	60	290	94	42
Moisture carried off by ventilation per hundredweight per day:									
12. Case A .... grains..	258	2	2	274	6	30	282	24	32
13. Case B .... do...	258	122	44	274	110	40	282	68	32
Ratio of heat to moisture removed by ventilation per grain:									
14. Case A .... B. t. u.	0.312	0.428	0.300	0.312	0.407	0.306	0.312	0.402	0.300
15. Case B .... do.	.312	.520	.316	.312	.462	.306	.312	.427	.300
Heat removed by ventilation per hundredweight per day:									
16. Case A .... B. t. u.	80	1	1	86	2	9	88	10	9
17. Case B .... do.	80	63	14	86	51	12	88	29	9
Artificial heat required during period, per hundredweight per day:									
18. Case A .... B. t. u.	------	31	5	------	6	4	------	1	------
19. Case B .... do..	------	93	18	------	55	7	------	20	------
Potato moisture shrinkage during period, per hundredweight:									
20. Case A .... pounds..	2.3	1.4	0.4	2.3	0.7	0.4	2.3	0.6	0.4
21. Case B .... do..	2.3	2.9	.7	2.3	2.1	.5	2.3	1.2	.4
Accumulated potato moisture shrinkage to end of period, per hundredweight:									
22. Case A .... pounds	2.3	3.7	4.1	2.3	3.0	3.4	2.3	2.9	3.3
23. Case B .... do	2.3	5.2	5.9	2.3	4.4	4.9	2.3	3.5	3.9

[1] Adjusted averages from observed storages.

From a study of 391 weekly hygrothermograph charts, which recorded actual storage temperature and humidity conditions in 12 different potato storages, average values adjusted to items 1, 3, and 4 have been tabulated as item 9 (table 7) for comparison with the limiting humidities of item 8. It will be noted that, the seasonal averages were all under the limiting relative humidity. Two of the three hundred and ninety-one weekly average recorded humidities were found to equal the limiting humidities, but no weekly recorded humidity exceeded the corresponding limiting values. In several cases, sets of sling psychrometer readings have been taken during a day when actual humidities were above calculated limiting humidities, probably because of the lag in conduction loss due to changing outside temperature and the stored heat of the building materials. Further comparison between average humidities and limiting humidities show that limiting values for ceiling resistances of 5 are very near the average values from ceiling resistance of 20, which suggests that under ideal control much higher humidities are possible than are usually obtained. Usually intermittent and excessive ventilation tends to cause the storage humidity to fluctuate from the limiting to relatively low values.

The potato shrinkage (moisture losses) listed in items 20–23 were calculated for the definite temperature and humidity given in table 7, the rate being based upon the graphs of figure 13 previously discussed. Note that the accumulated shrinkage (item 23, case B) to the end of a 210-day storage is decreased 1.0 percent by increasing the ceiling-insulation resistance from 5 to 10 and the shrinkage was decreased another 1 percent by increasing the ceiling-insulation resistance from 10 to 20. That is, the first increment of added insulation results in a greater proportionate saving than the addition of any succeeding increment, and the calculations indicate that 6 inches of insulation is about the limit that can be economically justified. In practice, insulating values are estimated at about 75 percent of the values calculated from laboratory tests of the insulating materials in order to allow for variations in materials themselves and irregularities in installation. Thus, where 4 inches of insulation, based upon laboratory values, seems adequate, actual installation of 6 inches may be advisable.

HEAT AND MOISTURE CALCULATIONS

The purpose of this section will be (1) to compare heat and moisture relations with optimum and recorded storage conditions in poor, average, and well-insulated storages and (2) to illustrate the method used in obtaining these relations which might be followed in studying storage problems in other areas.

Table 7 has been prepared for optimum inside temperature and average outside temperatures of northern Maine. Houses of insulation resistances of 5, 10, and 20 are considered separately for fall, winter, and spring, and are compared in items 2 to 7. For the nine different conditions items 3 to 7 are the same for either case-A or case-B storage control.

Item 5, heat from the potatoes is the amount of metabolic heat given off by the potatoes plus the sensible heat given off during fall cooling, based upon figure 22 already discussed.

Item 6, the heat removed by conduction per hundredweight of potatoes, was calculated as follows:

$$\text{Item } 6 = 24\frac{(\text{item } 3 - \text{item } 4)R}{\text{item } 1} \qquad (2)$$

The factor R in equation (2) is the ratio of the total insulated surface of the storage in square feet to the capacity of the storage expressed in hundredweight of potatoes, that is

$$R = \frac{\text{Total insulated surface (square feet)}}{\text{Capacity of storage (hundredweight)}} \qquad (3)$$

The total insulated surface in equation (3) includes all wall surface above the ground level and the ceiling of the storage house.

The values for item 6 shown in table 7 were calculated, using the value of R for the trackside storage (fig. 23). The surface to capacity ratio, R, for this house is 0.385 square feet per hundredweight.

For example, if the inside temperature is 40° F.; outside temperature 12°; insulation resistance=5.0 and R=0.385. For a 24-hour period item 6 as computed by equation (2) would be as follows:

$$\text{Item } 6 = 24 \times \frac{40-12}{5} \times 0.385 = 52 \text{ B. t. u. per hundredweight}$$

The amount of moisture condensed upon the walls (item 7, table 7), was estimated as follows: From a study of 84 cases of heat loss from air circulating down a wall-circulating space, covering the range of conditions listed in table 1, it was found that approximately one-third of the heat conducted through the walls and ceiling of a storage was accounted for by moisture condensation. For fall and spring storage about 1,070 B. t. u. (latent heat of evaporation at average wall-circulating temperature of 38° F.) are given up in condensing a pound of moisture. In the winter since part of the moisture condensed is frozen, approximately 1,140 B. t. u. of heat (based upon half condensed at latent heat of evaporation of 1,070 B. t. u. and half frozen at the combined latent heats of evaporation and fusion of 1,214 B. t. u.)

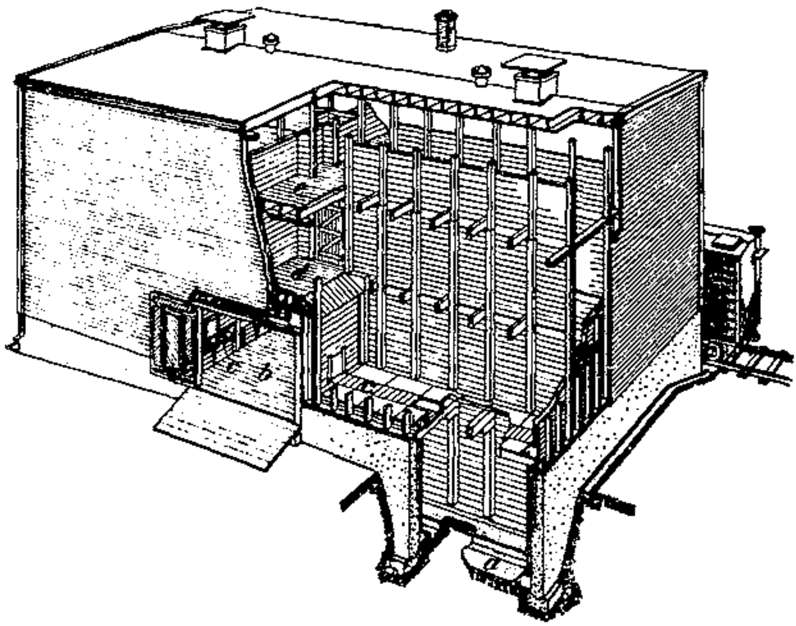

FIGURE 23.—Cut-out perspective of new-type trackside storage: *a*, Basement bin-storage floor; *b*, driveway floor; *c*, first-floor bin storage; *d*, lower work floor; *e*, upper work floor.

may be given up with a pound of moisture condensed, with part of it frozen. Moisture condensed upon storage-house walls (item 7), in grains per day per hundredweight of potatoes is found as follows:

$$\frac{\text{Conduction (item 6)}}{3} \times \frac{\text{Grains per pound}}{\text{B. t. u. per pound condensed}}.$$

For example, where item 6 is 52, and for winter ventilation when 1,140 B. t. u. of heat is given up per pound moisture condensed, then item 7 $= \frac{52}{3} \times \frac{7{,}000}{1{,}140} = 106$ grains condensed per day per hundredweight.

The remainder of the items in table 7 are arranged in comparable pairs, cases A and B, respectively. Case A, with optimum humidity, that is with humidity as high as can be maintained with ventilation necessary to maintain the inside temperature (item 3), but no higher than the limiting values as determined by insulation values (item 1 and temperatures items 3 and 4). Case B, with average humidity, that is with approximate average values of relative humidity determined from weekly averages of humidities recorded in 12 storage houses, adjusted for values in items 1, 3 and 4. In both cases the inside temperature listed in item 3 is maintained with the outside temperature as in item 4. The heat and moisture in the outside air is based upon 75-percent saturation throughout. The heat and moisture of the inside air are based upon the humidities listed for cases A and B, items 8 and 9, respectively. The relative humidities, in item 8 which are referred to in footnote 6, are comparatively low because more ventilation would be required to lower storage temperature than would be needed to control moisture. The relative humidities referred to in footnote 7 are the limiting values discussed upon page 30. Item 9 gives the average humidities based upon recorded values taken during the storage investigation.

The potato moisture shrinkage (items 10 and 11) is based upon the shrinkage rate for the corresponding period and saturation deficit, from figure 13. The saturation deficit corresponds to the conditions in items 3, 8, and 9.

The quantities of moisture to be removed by ventilation, as considered in this discussion, are shown in items 12 and 13, which are found by subtracting moisture condensed (item 7), from moisture given off by the potatoes (items 10 and 11, respectively).

In ventilating, both heat and moisture are taken up by the incoming air and the moisture and heat so taken up are carried off by the outgoing air. The ratios of heat to moisture so taken up by the ventilating air are tabulated in items 14 and 15. These values are the ratios of the difference in the heat and moisture content of the inside and outside air. A study, of this ratio under night and day conditions indicates (1) when removal of heat is the chief consideration night ventilation is best, and (2) when removal of moisture is the principal object day ventilation is best. Items 14 and 15 are based upon ventilating at average daily temperatures.

Heat removed by ventilation is shown in items 16 and 17, which are the products of item 12 by item 14 and item 13 by item 15, respectively. Where artificial heat is not required item 16 or 17 plus item 6 equals item 5. Where item 16 or 17 plus item 6 is greater than item 5 the difference must be added in the form of artificial heat (items 18 and 19, respectively).

Potato shrinkage has been calculated from the values in items 10 and 11 upon a period basis, in items 20 and 21, that is for the 60-day fall period; the 90-day winter period and the 60-day spring period. These values have been summed up (items 22 and 23) giving the total shrinkage to the ends of each successive period. The relation of storage conditions and insulation to shrinkage has been previously discussed (pp. 16 and 17) but it is to be noted that for the fall period, in which ventilation is so necessary to remove heat and a low humidity is unavoidable, the shrinkage during the first 60 days on the average is approximately half that for the total of 210 days. Also with near-optimum control (case A) there is little decrease in shrinkage between houses with insulating values of 10 and 20. The principal advantage is that less heat is required to balance conditions in the better insulated storage.

SPECIAL HUMIDITY-CONTROL MEASURES

Under some conditions condensation may occur upon the ceiling. There will be times when, due to the very high humidity of air in the above-bin space and falling outside temperature, moisture will condense upon the ceiling. The projection of girders or other irregularities below the ceiling surface restricts circulation and forms still-air pockets which causes condensation. Condensation on a ceiling, even at very high humidities, may be prevented by rapid air movement along the surface. When ventilating a storage, good air movement is secured between the point where air rises freely into the above-bin space and the roof ventilator. Condensation is prevented in this case both because of rapid air movement, and because air rising freely into the above-bin space is drier than that rising through the potatoes. For this reason ventilators should be placed at the end (in farm storages) or ends (in track storages) farthest from openings admitting the drier air into the space above the bins. By means of electric fans air circulation may be made so rapid that no condensation will occur upon the ceiling even with very high humidities.

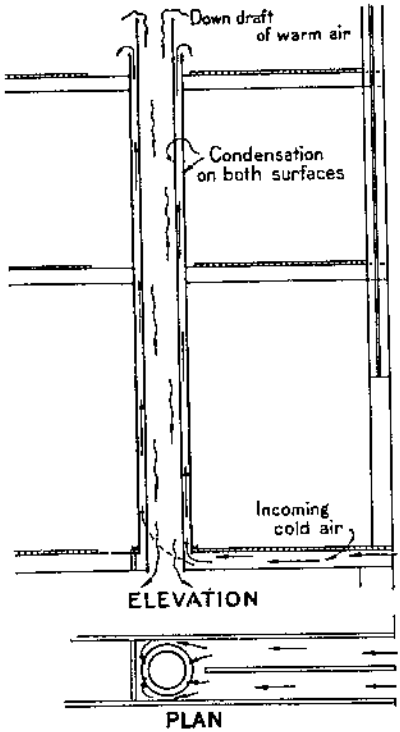

FIGURE 24.—Condensing intake with cross-sectional area of 1.64 feet and condensing surface of 226 square feet, under average conditions tempered 500 cubic feet per minute of incoming air to the average inside-outside air temperature. In 1 week 20 gallons of water were condensed from its surface.

In removing moisture from a storage by winter ventilation, the admission of a considerable amount of cold air may freeze the potatoes near the inlets before it is warmed and mixed with the air in the house. One way of warming the air is by passing it through a condensing intake.

The condensing intake (fig. 24) is made up of two vertical concentric sheet-metal pipes so arranged that the cold air enters through the annular space between the two pipes. The inner sheet metal pipe is open at top and bottom, to the air inside the storage house. Cold air entering through the annular space between the pipe, chills both pipes. Moisture from the inside air condenses on the cold metal surfaces, both on the inner surface of the inner pipe and on the outer surface of the outer pipe, and trickles down the pipe to a drain at the bottom. The latent heat of condensed moisture, in addition to the sensible heat from partly chilled air, warms the entering air. Since some of the inside air is dried in the process, less outside air is needed to lower storage humidity when a condensing intake is used.

The first intake, built during the 1931–32 season, had a cross section of about 2 square feet and a condensing surface of only 16 square feet. It served to check the cross draft from the incoming air and condensed some moisture. However, the relation between the area of the opening and the condensing surface was not right and the incoming air was not noticeably warmed.

A second condensing intake (fig. 24), built and tried out during the season of 1935–36, proved to be very effective. The incoming air was tempered sufficiently that when discharged in the space above the bin, no freezing of potatoes near the intake occurred even under the most severe conditions.

The condensing intake proved to be a safe method of introducing ventilating air and removing some moisture and has now been used three seasons. The use of a condensing intake for ventilation and moisture removal offers a safe method for the regulation of storage conditions during extremely cold weather. This method is applicable to old trackside storage, but is not used in the new storage (fig. 23) as the condensing wall surface later developed proved to require no attention and removed moisture effectively during most of the winter without ventilation.

ESSENTIAL FEATURES OF A POTATO-STORAGE STRUCTURE

The most important function of a potato storage is to furnish protection from the weather. A storage should be well-roofed and well-drained, as a protection both from storm water and from ground water. There should be adequate insulation and air circulation to protect against freezing and to equalize temperatures as nearly as possible so that potatoes will not sprout in one part and freeze in another.

Next in importance to the control of temperatures is the control of humidity, and as has been shown in the preceding pages, where a storage is properly designed and insulated, desirable humidities may be maintained with a minimum of attention.

An adequate storage should be so designed that potatoes may be conveniently stored and removed from storage, with a minimum of bruises from drops and damage from contact with sharp corners. The number of handling operations should be reduced to a minimum.

NEW-TYPE FARM STORAGE

To meet the requirements of an adequate farm storage and to avoid common faults of storages discussed on pages 23 and 24 a new type of farm storage (fig. 9) has been designed and tested under actual storage conditions. It is designed to be safe structurally, to be durable, and to maintain the best storage conditions with a minimum of attention to control. It is essentially a bank storage, and may be constructed at small cost if located on a hillside in a well-drained location. This deep-bin farm storage [13] (fig. 9) is designed to protect against losses from freezing, from rotting caused by water dripping on potatoes, mechanical damage caused by levelling off potatoes in bins under ceiling hatches, high losses caused by low relative humidity, and deterioration by decay and mechanical failure of the structure itself. The initial cost per barrel of storage is comparable to that of shallow-bin storages.

[13] For working drawings of the designs mentioned in this bulletin write the extension agricultural engineer of your State agricultural college.

Protection from freezing is built into the structure. The upper part of the concrete wall, where it is not practical to insulate, is protected by circulating-air spaces from which the moisture that condenses against the concrete will drain off to the work-alley space without wetting either the potatoes or the wood structural members. The frame portions of the structure above ground are protected by adequate insulation on the roof and ceiling and insulation plus circulating-air space in the gable and walls.

Protection from dripping water is provided by adequate means for ventilation in emergency, but mainly by circulation of air against a large area of relatively cold concrete wall which will ordinarily remove moisture from the air rapidly enough so there will be no condensation and drip from the roof or ceiling.

Protection from mechanical damage is secured principally in the side bins by the elimination of the floor at the drive-floor level, so

FIGURE 25.—Driveway of deep-bin storage.

that it is no longer necessary to dump through hatches. Once a wedge of potatoes is built up at one end of a bin by means of sack chutes the rest of the bin may be filled by dumping at truck-bed level onto this pile for the full width and length of the bins (fig. 25). The central bin may be filled by taking up the drive floor. The floor joists necessary here are objectionable but the removable floor causes less damage than filling through hatches.

Where adequate provisions for air circulation are not provided it is often necessary to carry high temperatures in one portion of a storage in order to keep another part above freezing. In the storage described herein adequate circulation is provided for (1) by the installation of an adjustable intake door and an adequate outtake flue which will be required after the curing period until the house temperature is lowered to about 40° F., and (2) by an air-circulating system which provides for natural circulation of air from the floor flues, up through the potatoes, into the wall-circulating space at either end of the house, and back to the heater space through the circulating and condensing space along the top of the concrete wall. In this type of house there is less shrinkage than normally because less ventilation is required to prevent moisture from condensing on walls and ceiling and hence a relatively high humidity may be maintained.

Condensation against the insulated walls and ceiling and the banked concrete walls will not occur until a high relative humidity has been reached. Practically all of the condensation should be against the concrete, which will not be damaged by moisture. Crushing of softwood beams at support due to overloading, when exposed to high humidity, has been guarded against by using hardwood bolsters and knee braces at highly stressed points. Decay of sheathing and timber is prevented (1) by a design that fosters condensation and collection of moisture against concrete walls and in concrete trenches, (2) by protecting cold surfaces of circulating space against a frame wall with a coating of waterproof metal-clad paper, and (3) by planning so that no post or beam rests on a surface where moisture may be expected to collect. The practical use of fill-type insulation in this structure is dependent upon its being ventilated to the cold exterior air and separated by an airtight membrane from interior warm moist air. This is done by placing waterproof paper between the insulation and the interior, protecting from the weather on the outside by placing paper between sheathing and siding, and by ventilating the insulation to the cold attic space which in turn is vented to the outside air by means of louvers in the gable ends.

An alternate deep-bin farm-storage [14] plan has been prepared which facilitates conveyor handling of potatoes from bin to grader. In this plan one end of the building is used for a work alley, with a storage floor directly above the work alley and connecting with the bins. Doors are placed opposite the conveyor-trench opening to provide for moving a long conveyor from bin to bin.

REMODELING OLD FARM STORAGES

A study of the new-type as compared with the old-type farm storage by means of figure 26 will be of assistance in remodeling the old-type into the more efficient deep-bin type.

In the old-type storage, potatoes could hardly be leveled off closer than 2 feet below the drive floor and then only by considerable pushing and bruising as they were shoved back from below the filling hatches, and with joists running across the house the space for air circulation between potatoes and ceiling was further cut down. By the elimination of the floor on either side of the driveway of these old storages potatoes can be conveniently stored from 4 to 6 feet deeper in the side bins, and by making drive-floor planks removable potatoes may be stored to the same height in the center. The lower run of the roof, the ceiling, and gable ends should be insulated with fill-type insulation, the extra cost of which is more than compensated by the increase in storage capacity, and the saving of periodic reflooring of two-thirds of the floor.

The roofs of above-ground portions of the shallow-bin storages have generally followed gambrel lines as this gives plenty of head room when dumping potatoes through hatches in the side bins; the tendency

[14] See footnote 13, p. 37.

however, in building these roofs has been to follow haymow practice and make the roofs much higher than is required for the storage needed. This fault has been particularly noticeable when converting a shallow-type into a new-type bin, for it was often 14 feet or more from the drive floor to the purlin level. In remodeling storages the new ceiling should not be over 9 feet above the drive floor. This is an adequate height for storage and handling space, while a greater height necessitates added insulation and greater heat loss. However, a ceiling below the purlin is not difficult to support, for even though it may be wider than at the purlin it may conveniently be supported by extra purlins resting on posts at the sides of the central-drive floor.

Where the drive floor at either side of the central driveway is not eliminated in old-type farm storages, there is usually poor circulation

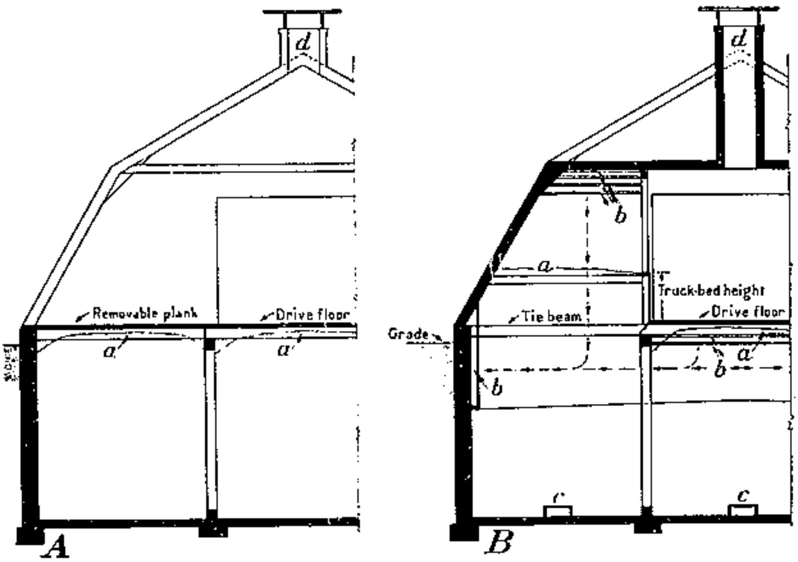

FIGURE 26.—Comparison of old shallow-bin with new deep-bin farm storage: *A*, Old type; *B*, new type; *a*, height of stored potatoes; *b*, direction of air currents; *c*, floor flues; *d*, outtake flues.

of air above the bins. The air pocketed between the floor joists results in condensation and decay (fig. 19).

An insulated outtake flue designed to carry the escaping moisture-laden air through the cold space above the driveway and out of the house was found to remedy this condition (fig. 27). Waterproof paper should be used under any insulating material spread on the drive floor, after filling bins, to keep the insulation dry and effective.

NEW-TYPE TRACK STORAGE

The new trackside storage (fig. 23) like the deep-bin farm storage, is designed to protect against destructive losses by freezing, water dripping on potatoes, and mechanical injury; to reduce shrinkage due to low relative humidity, and to lengthen the useful life of the structure.

An air-circulating wall space has been designed as the first defense against loss by freezing, while backing this up above ground is a wall with 6 inches of fill-type insulation. Along the concrete basement wall from its top to at least 16 inches below grade the circulation space is backed by 4 inches of fill insulation. The ceiling is covered with 6 inches of fill-type insulation.

The wall and bin circulation is greatly improved over previous storages with the result that there is a smaller range in temperature

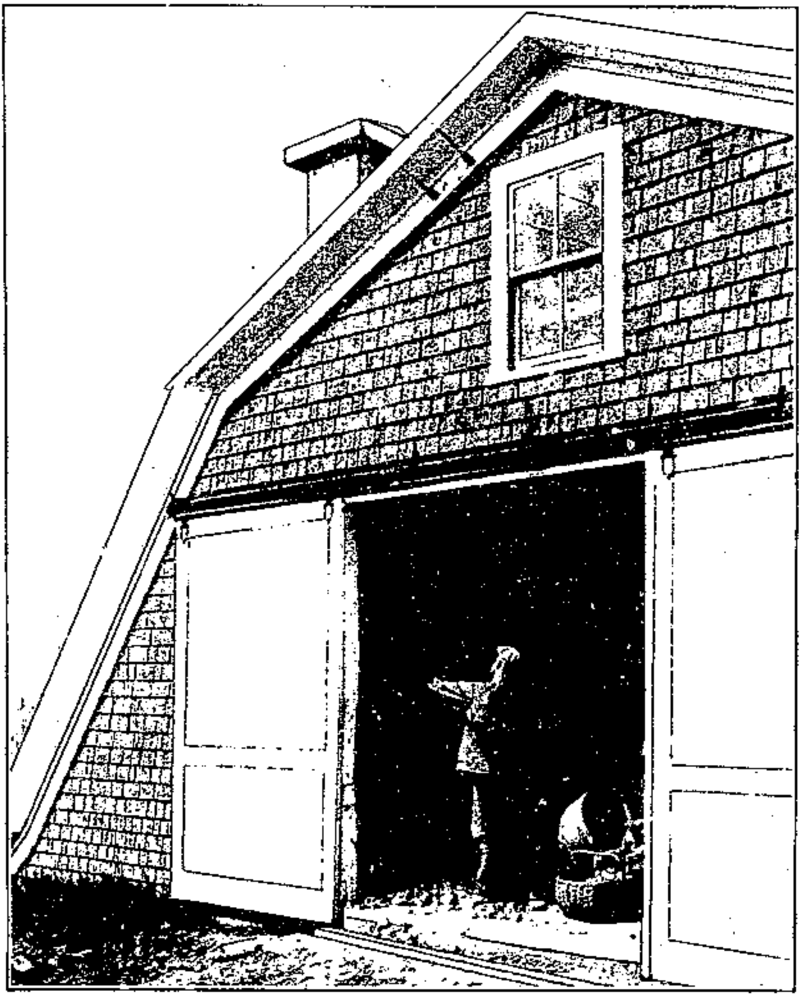

FIGURE 27.—An insulated outtake flue in a farm storage recommended for shallow-bin farm storage.

between the various storage levels which should permit the carrying of all the potatoes stored within a range of 6° F.

In colder weather the large waterproofed condensing surfaces of the upper air-circulating wall spaces may reduce the humidity to below 90 percent, but the average should remain much higher than in other types of houses, and should therefore reduce shrinkage much below the normal rate. Provisions are made to drain moisture which condenses on walls into gutters which conduct it either to the driveway alley or to the cellar work alley, and from which it may be drained to a sump.

Much attention has been given to reducing labor and mechanical injury to the potatoes. A 16-foot driveway floor, clear of posts, and with a 12 foot-doorway is provided to permit loaded trucks to back into the house to any bin or directly under either hoist opening. This feature reduces labor and injury to potatoes in filling. The first-floor bins may be filled from the floor over the driveway to a depth of 8 feet and from the upper work floor to a depth of 20 feet. The bin floors are 3 feet above the driveway floor and the cellar alley floor, which permits a conveyor running level in the conveyor trench to deliver potatoes from bin to grader hopper, greatly reducing injury and the labor of handling as compared to forking into the grader by hand. A hatchway in the driveway floor is provided through which a grader and conveyor may be lowered into the cellar alley for grading, the graded and sacked potatoes being hoisted to the driveway floor. The cellar bins must be filled from the first floor, but all of the planking at the sides of the conveyor trenches may be removed for this purpose.

The framing dimensions were based on the fact that the strength of structural timbers surrounded by high-humidity air are much less than under usual conditions. Larger timbers are used throughout with hardwood bolsters used where shear of softwood might otherwise occur. The full strength of the timbers will be reached before joints fail because of the use of bolts and ring connectors. Although provision is made for condensation of moisture within the structure, the few structural members which might be wetted by condensation are flashed, and sheathing which forms the backing of condensation surfaces is protected from moisture by metal-clad paper or lightweight asphalt[15] roofing. The usual pocketing of air above cellar bins, with resultant condensation, is avoided by running the floor joists lengthways of the bin. This permits free circulation from between joists to work alley. The fill insulation is ventilated to the outside air by means of openings just below the plates in the outside wall sheltered by small hoods.

The condensing surface provides an impervious membrane between the insulation and the warm moist inside air. The ceiling fill insulation sandwiched between impervious surfaces must be ventilated by breather openings or ventilators on the roof. The roof rafters must be notched so that the entire roof space may be ventilated to these openings.

REMODELING OLD-TYPE TRACK STORAGES

Old-type track storages that have been kept in a fair state of repair may be made over into more efficient storages, by some remodeling and insulation of the roof and ceiling. This has been discussed in some detail by Edgar (*1*) but briefly consists of removing most of the ceiling directly over the above-ground bins and insulating the roof to a value equivalent to or better than the walls. Roof ventilators should be provided at either end.

The closed-ceiling track storages have the same fault as the farm storages—insufficient space between the potatoes and ceiling for proper ventilation. It was found that this condition could be corrected by an insulated outtake flue similar to that recommended for

[15] Tarred felt or other low-grade building papers are not satisfactory.

the farm storages. This plan is recommended wherever there is a cold attic space as in the new deep-bin farm storage (fig. 9) or in track storages where the steep-pitch roof makes it economical to carry the insulation across at the collar-beam level rather than running it over the ridge.

COST OF STORAGE HOUSES

The costs of a few storages recently built in Aroostook County are given in table 8.

The first two houses listed are insulated with 1 inch of board-type insulation, and at least three thicknesses of paper. The first is the house in which the investigations of 1931–33 were carried out. All of the above storages have concrete cellar walls and floors. The Presque

FIGURE 28.—First deep-bin farm storage with fill insulation in roof.

Isle house is apparently in first-class condition, but the Fort Fairfield track-storage house was repaired and insulated with fill-type insulation in 1937. The Bridgewater house is the one in which the 1935–36 experimental work was done. The Houlton farm storage is the first one of the type built (fig. 28). It was insulated with 4-inch mineral-wool bats. The Fort Fairfield farm storage is the one shown (fig. 29) and the roof lines follow the design of figure 9. This storage was insulated with 4 to 6 inches of dry shavings.

A survey of actual storage conditions in New York carried out by Wilson and Hardenburg (*8*) found that the cost of materials for bank storages similar to Aroostook farm storages was between 18.5 and 20 cents per bushel of capacity. Figuring total cost to be 1.7 times material costs the New York farm storages would cost from 31 to 34 cents per bushel.

TABLE 8.—*Potato-storage costs in different Aroostook County storages*

Location	Year built	Aroostook type	Bin depths		Capacity	Cost per bushel of capacity
			Cellar	First floor		
			Feet	*Feet*	*Bushels*	*Cents*
Presque Isle	1929	1925-model, track	8	14	24,000	25
Fort Fairfield	1929	1926-model, track	10	14	30,000	33
Bridgewater	1934	1934-model, track	[1] 7	20	40,000	26
Houlton	1933	New deep-bin, farm	13		9,000	17
Fort Fairfield	1935	do.	16		18,000	13

[1] This storage was designed for a 12-foot cellar but due to the swampy location at the railroad track the bins could be made only 7 feet deep.

The annual cost per bushel of storage will vary widely because of the variations of first cost and in depreciation. A warehouseman of

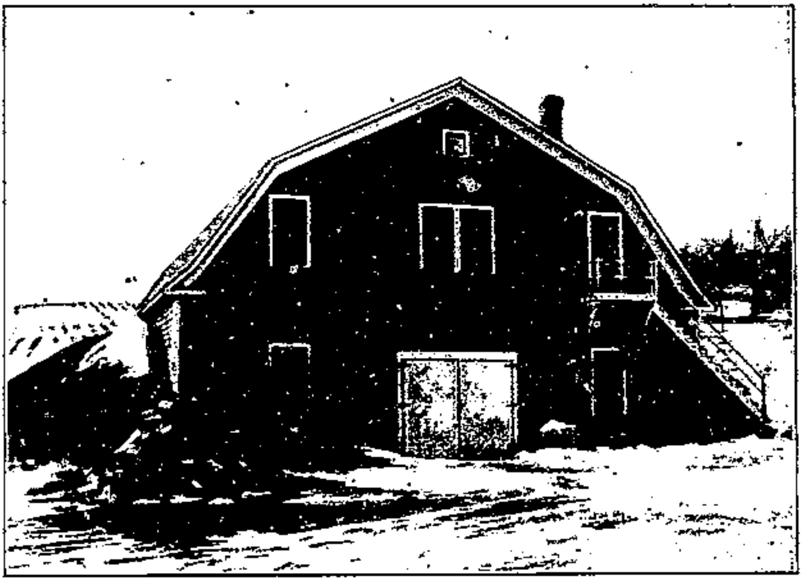

FIGURE 29.—Example of deep-bin storage following roof lines of figure 9.

Presque Isle, who is in charge of 40 track storages says the life of storages will vary at least 50 percent depending upon the care given by the operator, and for all of their houses they figure an annual depreciation of 4 percent, or a 25 year life, a very short life as compared to the life of a dwelling. The farm-housing survey made by the Department of Agriculture in 1934 showed that 74 percent of the farmhouses in New England were more than 50 years old, and many were well over 100 years old. Many feel that the depreciation rate for potato houses should be nearer 10 than 4 percent and for the county the average depreciation is probably 5 percent or more, corresponding to a life of 20 years or less. Houses can be found that have had to have new floors after 5 or 6 years, and repairs need to be made on some houses every 2 or 3 years. It is also true that many houses 20 years old are in a good state of repair, and have been kept in repair by the owner operator. As shown by the above figures, a well-designed and operated storage should last 25 years and the repairs made during that time should extend its useful life. On this basis table 9 has been prepared to show the annual costs per bushel of such a storage, where the original cost was 30 cents per bushel.

TABLE 9.—*Annual costs per bushel*[1] *chargeable to rent in trackside storage*

Item	Annual cost for indicated period							
	1 year	2 years	3 years	4 years	5 years	10 years	15 years	20 years
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Original investment less depreciation	30.0	28.8	27.6	26.4	25.2	19.2	13.2	7.2
Depreciation at 4 percent of original cost, per year	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Interest at 6 percent on depreciated value	1.80	1.73	1.66	1.58	1.50	1.15	.79	.43
Insurance at 2 percent on depreciated value	.60	.58	.55	.53	.51	.38	.26	.14
Total annual costs chargeable to rent	3.60	3.51	3.41	3.31	3.21	2.73	2.25	1.77

[1] In Aroostook County where barrel measure is used a close figure can be secured by multiplying the above figure by 3 to get price per barrel.

This table is based upon an original cost of 30 cents per bushel of storage capacity, which, with a sum of 1.2 cents per bushel per year set aside to cover depreciation, would give a fund of 30 cents to build a new house the twenty-sixth year. The interest and insurance would naturally be upon the depreciated value of the building as the sum set aside for depreciation might either be invested in other buildings or be invested at interest.

The costs in table 9 are annual charges on the buildings alone and do not include handling charges, which average about 1.7 cents per bushel per year for extra help in storing and for heat and storage-house control. This latter figure will vary with the number of houses one man takes care of in the winter and with house capacity. As a house gets older repairs frequently reduce the storage space, and an old house is harder to heat and control. In a short-crop year potatoes will be stored in the more dependable and convenient houses leaving the less desirable houses empty or only partly filled.

CONCLUSIONS

As a result of this investigation of the management and construction of white potato storages the following findings are significant.

1. Potatoes stored at 40° F. and at a uniform relative humidity have a uniform rate of shrinkage between the thirtieth and the two-hundred and tenth day which is about half the rate for the first 30 days.

2. Holding potatoes for the first 2 weeks of storage at temperatures of 56° to 60° F. decreases shrinkage to about 20 percent below average, while holding during the early period between 40° and 46° increases shrinkage to 20 percent above average.

3. Within the range of temperature and humidities studied in this investigation potato shrinkage increases uniformly with increases in saturation deficit.

4. Condensation of moisture in the wall-circulation space has been an unrecognized factor in the control of storage conditions and a recognized factor in building depreciation. Such condensation tends to make storage temperatures uniform and removes moisture from the air automatically; and if waterproof wall-circulation surfaces are provided will not increase the building depreciation rate.

5. Walls and ceilings having high insulation resistance permit the carrying of high relative humidities; while high relative humidities cannot be carried where wall- and ceiling- insulation resistance is low.

6. Day ventilation (warmer outside air) tends to remove more moisture for a given amount of heat, so is desirable in the winter when there is little heat to spare. Night ventilation (colder outside air) tends to remove less moisture for a given amount of heat, so is desirable for fall or spring ventilation when potatoes must be cooled by ventilation.

7. Limiting wall-insulating values are reached when the necessity of removing surplus heat by ventilation results in lower humidities than would be obtained with a lower insulating value.

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