NATIONAL BUREAU OF STANDARDS REPORT

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WATER VAPOR TRANSMISSION THROUGH JOINTS AND BREAKER STRIPS OF INSULATED PANELS FOR REFRIGERATED WAREHOUSE, PANEL NO. 1

by

P. R. Achenbach
O. N. McDorman

Report to
Headquarters, Quartermaster Research & Development Command
Natick, Mass.

U. S. DEPARTMENT OF COMMERCE
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To

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NBS

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Abstract

At the request of the Quartermaster Research and Development Laboratories, Natick, Mass., several tests were made of a special insulated warehouse panel representative of the construction currently in use for demountable refrigerated warehouses by the Armed Services. This was the first of several panels constructed for the investigation using different insulating materials and different methods of protecting the wood breaker strips and panel fasteners at the joints between adjacent panels. Four tests were made of the specimen panel. The first two tests were made with only a cold edge gasket to evaluate the basic need for a gasket at the warm edge for limiting vapor transmission into the panel joint and to study the effect of above-freezing and below-freezing temperatures on the cold side of the panel on the moisture and ice deposition in the panel joints. The third and fourth tests employed warm and cold edge gaskets with the cold edge gasket being slotted for the fourth test to provide ventilation of the joint space with cold air from the refrigerated space. The tests revealed that vapor transfer into the panel joint and into the insulation space was rapid without a gasket at the warm edge of the panel indicating the basic need for such a gasket. The double-gasketed panel operated under a vapor-pressure difference of 1.23 in Hg and an air-to-air temperature difference of 113°F for 73 days without moisture or frost being formed in the insulation space although some ice formed and some wetting occurred in the panel joint. Slotting the cold side gasket to the extent of 5% of its length tripled the rate of vapor transfer

into and out of the panel joint for equivalent vapor pressure and temperature differences, caused considerable frost to be formed in the insulation space during 23 days of exposure, and produced a noticeable increase in the amount of ice deposited in the panel joint. This latter test brings into question the value of ventilating the joint space with air from the refrigerated space, but does not answer the question conclusively.

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1. INTRODUCTION

Four tests were made of the first of several specimens of insulated panels for refrigerated warehouses to study the mechanism and magnitude of water vapor transmission through gasketed joints between adjacent panels and through the breaker strips at the gasketed joints. Since the test panels were faced on both sides with sheet metal, impervious to water vapor, moisture ingress into the panels could occur only through the gasketed joints and thence through the breaker strip or the panel fasteners in the breaker strips.

The tests were made with a temperature of about 110°F on the warm side of the panel and a nominal temperature of either 35°F or 0°F on the cold side of the panel. The relative humidities on each side were selected to provide a suitable vapor pressure gradient across the panel. The tests were made in a special apparatus designed for the purpose as illustrated in Fig. 1. The apparatus is described in National Bureau of Standards Report No. 2947 entitled "An Apparatus for Measurement of Simultaneous Heat and Water Vapor Flow through 4x8 foot Insulated Panels"

2. DESCRIPTION OF TEST SPECIMEN

The specimen panel was constructed in accordance with sketch No. N-76 prepared by the Office of the Quartermaster General. It consisted of a center section approximately 78 inches high, 36 inches wide, and five inches thick and four border sections to form a test section about four feet wide and eight feet high. Fig. 2 is a photograph of the assembled panel. The top and bottom pieces were approximately nine inches wide, whereas the side pieces were approximately [illegible] 3/4 inches wide. The center section was framed of 3/4 inch

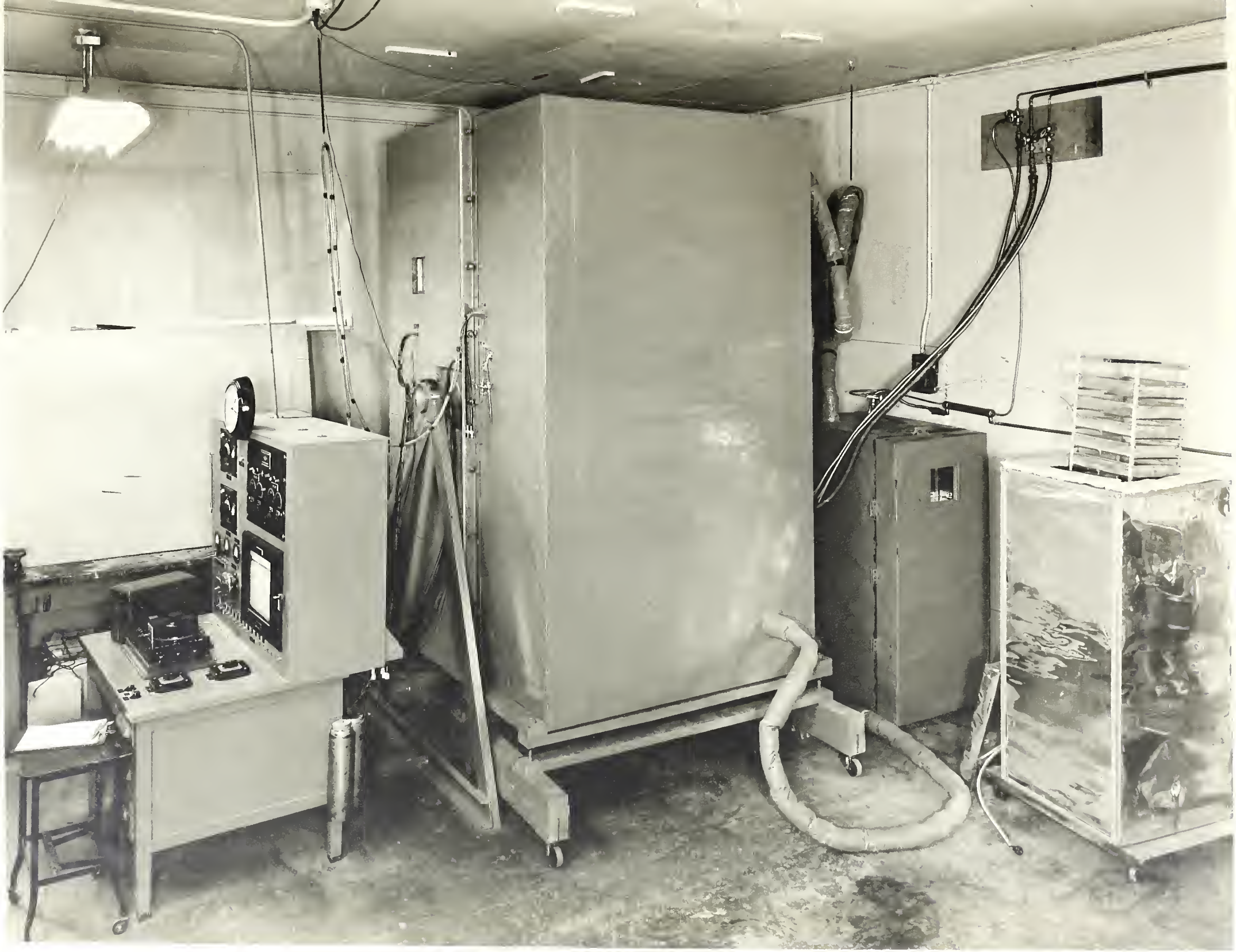

Fig. 1

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Fig. 2

plywood with 3/8 inch plywood stiffeners spaced 12 inches apart horizontally and 26 inches apart vertically. The edges of the vertical stiffeners were reinforced with metal channels. The panel was insulated with Palco wool fibers. Three panel fasteners were used on each of the vertical edges of the center section and two panel fasteners were used on each horizontal edge of the center section to attach the border pieces to it.

Five inspection holes three inches in diameter were cut through the metal skin of the center panel on the cold side. One opening was located in the center of the center section with two other openings located at the same height and at distances of approximately six inches and seven inches from the edges respectively. Two more openings were made directly above the two outer openings and at a distance of approximately 12 inches from the top of the panel. During the test these openings were covered with four inch squares of Plexiglas 1/8 inch thick. The edges of the Plexiglas were sealed with a mastic material.

Humidity sensing elements and pieces of bare iron wire were placed in small recesses made in the fibrous insulation back of these inspection ports and adjacent to the cold skin of the panel. Mastic material was also placed at the four corners of the panel where the border panels met, to eliminate the horizontal travel of moisture at these points which were not considered a part of the joint under test.

3. TEST PROCEDURE

Four tests were made on the specimen panel with different temperature and vapor pressure gradients across the panel or with different conditions of gasketing at the edges of the center section. The conditions for the four tests are summarized in Table 1.

TABLE 1

Summary of Test Conditions

Test No.	1	2	3	4
Gaskets Used	Cold Side only	Cold Side only	Both Sides	Both Sides Ventilation Slots in Cold Side Gasket
Nominal Air Temp Adjacent to Panel, °F				
Warm Side	110	110	110	110
Cold Side	35	0	0	0
Relative Humidity Adjacent to Panel, %				
Warm Side	70	62	48	53
Cold Side	20	71	55	35

The test specimen was installed in the apparatus and sealed at the edges to prevent air and water vapor transfer at these extremities. The entire apparatus was tested for air exchange to and from the laboratory space after fastening the two parts of the box together. The temperature and humidity of the warm and cold sides of the apparatus were brought to the desired values as quickly as possible by operation of the heater and humidifier on the warm side and the refrigerating system and desiccant chamber on the cold side. Temperatures and humidities were kept constant by means of automatic thermostats and humidity controllers for the duration of the test.

Observations were made at regular intervals of the heat input to the warm side, air and panel surface temperatures, relative humidities of air adjacent to test panel, water evaporation from the humidifier, water adsorption of the desiccant, and the temperature differential between laboratory and warm box.

About one week was required to use all of the water (about 5 lb) in the humidifier during Tests 1 and 2, made with a gasket on the cold edge of the panel only. The duration of Test 3 with both gaskets on the panel was 73 days whereas 23 days were required to use all of the water in the humidifier during Test 4

with both gaskets in place, but with six two-inch slots in the gasket on the cold edge of the panel. Three of these slots were made in the horizontal gasket at the bottom of the center section and three were made in the corresponding positions at the top of the center section. The slotted gasket can be seen in Fig. 3 on the right hand border panel.

At the end of each test the apparatus was opened as quickly as possible. The test panel was removed, the Plexiglas covers on the inspection ports were examined for condensation or frost, the Plexiglas covers were removed and the insulation and sheet metal skin examined for moisture, the gasketed joints and breaker strips were examined for moisture or frost, and the panel fasteners were examined for moisture and corrosion. The test panel was weighed for comparison with the original weight.

4. TEST RESULTS

The visual observations made on the panel after each test by a group of five observers are summarized below:

Test 1.

1. Condensation was observed only on the top right Plexiglas window as observed from the cold side.

2. The warm side of the apparatus was opened 10 minutes after opening the cold side.

3. The wood breaker strips were wetted on the upper half of the panel from the warm side through to the cold side at the panel fastener locations and almost the full width of the breaker strip between the fasteners.

4. Free water was observed in the hook openings of the top and middle panel fasteners.

5. The bottom panel fasteners were dry.

6. The top hooks were badly rusted.

7. The insulation back of the inspection ports felt dry.

8. The cold side metal skin was dry on the side adjacent to the insulation.

Fig. 3

9. There was a puddle of water on the floor of the warm side box (2.11 lb were sponged up during the inspection of the panel).

Test 2.

1. There was frost on the insulation side of all five Plexiglas windows. The frost was more prominent on the two upper windows and there was frost on the insulation back of these two inspection ports.

2. The cold side skin was wet adjacent to the insulation, with more water being present at midheight than at the top.

3. There was ice in the top and center panel fastener recesses causing some difficulty in manipulating the fasteners. The top right panel fastener was especially difficult to disengage.

4. Ice was observed between the mating wooden members at the panel joint on the upper half of the panel. The ice was observed in a strip about 1/2 inch wide reaching for one foot down the left side from the top of the center section, and in a strip about one inch wide reaching from the top of the center panel down to midheight on the right side. The ice appeared to be thick enough to fill the entire space between breaker strips at these locations and it was in contact with the cold side metal skin where it overlapped the breaker strip.

5. The breaker strips were dry on the right side of the center panel from midheight to the bottom and on the left side from between the middle and top panel fastener to the bottom.

6. The hooks and the screw heads of the upper panel fasteners were badly rusted.

7. There was no condensation on the warm side metal skin of the panel facing the warm box.

8. Some water was found on the floor of the warm side box, (0.62 lb of water was sponged up during the inspection of the panel).

Test 3.

1. All five of the Plexiglas windows were dry and clear.

2. The insulation adjacent to the cold skin felt dry.

3. There was no evidence of rust on the pieces of bare iron wire that had been placed inside the Plexiglas windows.

4. The humidity indicators installed inside the Plexiglas windows indicated that condensation was not imminent on the cold side skin.

5. There was ice in the joint at the right side of the center section reaching down about one foot from the top. The strip of ice was about 1/2 inch in width and was attached to the cold side metal skin where it overlapped the breaker strip.

6. There was ice on the top edge of the center section reaching about two inches from the same corner that revealed ice in the vertical joint.

7. The wood breaker strips were damp on the left side of the center section covering an area of about two sq. in. near the junction of the center section and the top and left border pieces.

8. The panel fasteners functioned satisfactorily.

9. A small amount of water (0.13 lb) was sponged up from the floor of the warm side box during inspection of the panel.

Test 4.

1. All five of the Plexiglas windows were covered with frost on the insulation side. See Fig. 4. Fig. 5 is a close-up view of two of the Plexiglas windows showing the frost accumulation.

2. There was considerable condensation in the insulation behind the Plexiglas windows.

3. The six two-inch slots in the cold side gasket were clear of frost or condensation.

4. There was ice in the hook recesses of the two panel fasteners at the top of the center section. This ice is visible in Fig. 3.

5. There was a strip of ice from 1/2 inch to one inch wide for the full length of the joint at the top of the center section. This strip of ice was near the cold edge of the joint and can be seen clearly in Fig. 3.

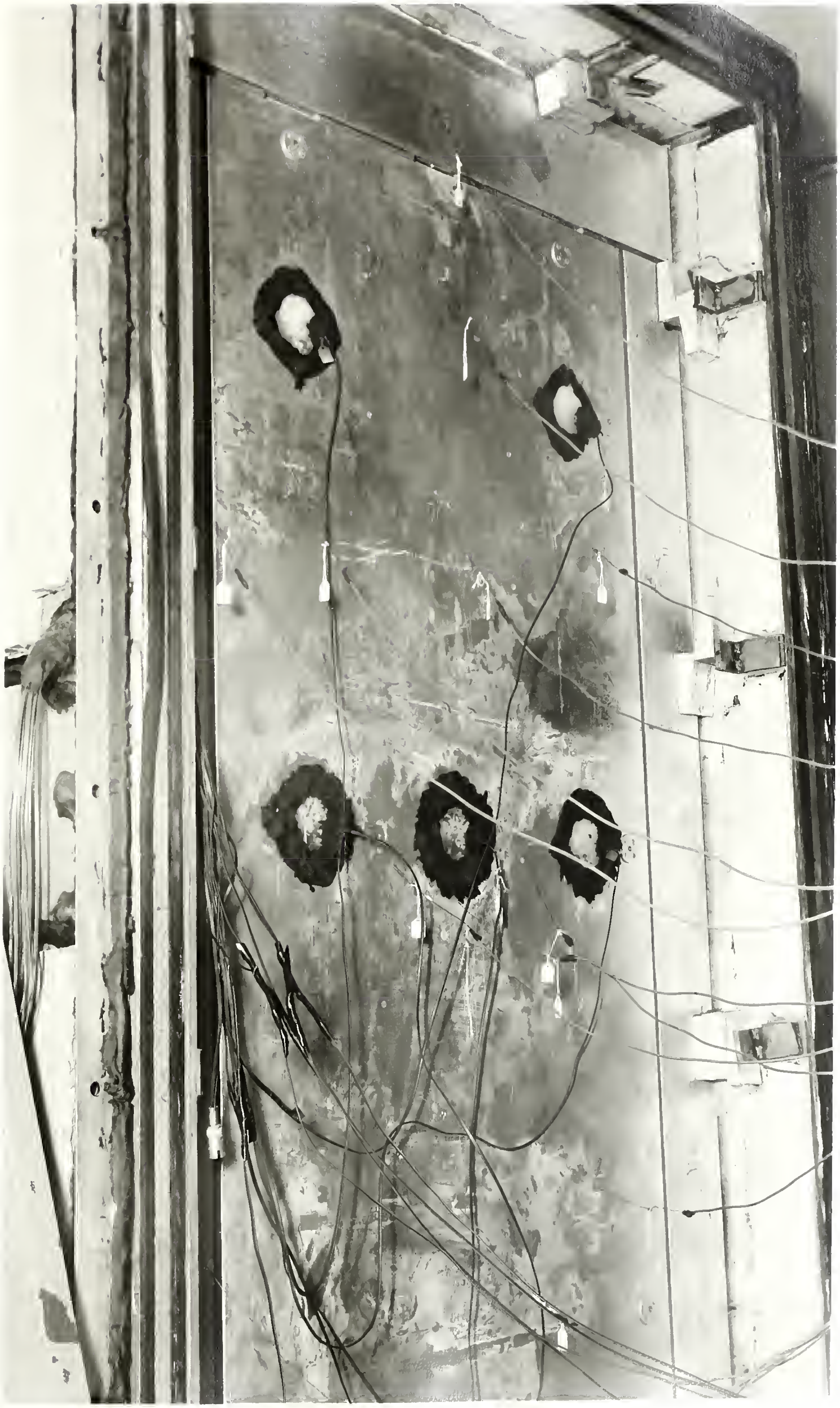

Fig. 1

6. There was a wet streak on the wood breaker strip of the left side border section located about 1/2 inch from the overlapping metal skin on the cold side (the left edge of the joint shown in Fig. 6.

7. There was condensation on the warm skin of all the border sections on the side facing the warm box, but there was none on the warm skin of the center section (0.15 lb of water was wiped from warm side of border panels and 0.26 lb of water was mopped up from the floor of the warm box during the inspection of the panel).

The test conditions and observed results for the four tests of the first panel are summarized in Table 2. Fig. 7 and 8 show the amount of water evaporated on the warm side and the amount of moisture adsorbed in the desiccant on the cold side on a cumulative basis for a period of several days during Tests 3 and 4, respectively.

The inspections of the panel at the end of the tests showed that some free water had drained down into the warm box during each test. This drainage was a maximum in Test 1 during which the warm humid air had access to the joints between the center section and the border sections because the warm side gasket was not present and the temperatures in these joints were above freezing. During Test 2 the gasketing conditions were the same as for Test 1, but some of the moisture entering the joints was frozen and, therefore, did not drain into the warm box. The drainage in Test 3 was equivalent to an average of about 0.5 grain per hour for the duration of the test and about five grains per hour in Test 4. This drainage water probably did not enter the panel joints at all in Tests 3 and 4.

Frost or moisture was observed in the insulation space of the center section in Tests 1, 2, and 4. This condition developed in a week's time in Tests 1 and 2 with a gasket on the cold side of the panel only. This type of gasketing is not found in practice, but the tests reveal the speed with which water vapor passes through the breaker strips and panel fasteners under unfavorable gasketing conditions and shows the need for gaskets on the warm side of the panel joints.

A comparison of the results in Tests 3 and 4 indicates that slotting the cold side gasket to provide ventilation of the panel joints did not have the desired effect in reducing

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TABLE 2
SUMMARY OF RESULTS
WATER VAPOR TRANSMISSION TESTS OF FIRST SPECIMEN PANEL

Test No.		1	2	3	4
Gaskets Used		Cold Side only	Cold Side only	Both Sides	Both Sides Ventilation Slots in Sold Side Gasket
Average Conditions in Warm Box					
Temperature	°F	110.2	109.9	110.6	107.7
Relative Humidity	%	70	62	48	53
Dew Point Temp	°F	98.5	93.8	86	87
Vapor Pressure	In Hg	1.85	1.60	1.25	1.29
Average Conditions in Cold Box					
Temperature	°F	36.6	- 0.1	-3.0	-1.6
Relative Humidity	%	20	71	55	35
Dew Point Temp	°F	3	-7	-14	-20
Vapor Pressure	In Hg	0.04	0.03	0.02	0.01
Vapor Press. Difference Across Panel	In Hg	1.81	1.57	1.23	1.28
Duration of Test	days	7	6	73	23
Rate of Water Evaporation,*	gr/hr	369	481	16.8	49.3
Rate of Moisture Adsorption,*	gr/hr	-	-	6.8	20.5
Rate of Moisture Transfer from Humidifier,*	gr/hr(sqft)(inHg)	6.6	9.9	0.4	1.2
	gr/hr(ft)(in Hg)	10.7	16.1	0.7	2.1
Thermal Conductance of Panel*	Btu/hr(sqft)(°F)	0.189	0.193	0.146	0.153
Weight Gain of Center Panel,	lb	0.75	1.75	0	0.38

*The moisture evaporation, moisture transfer and thermal conductance values reported do not apply to the entire test, but during periods of several days when conditions were steady.

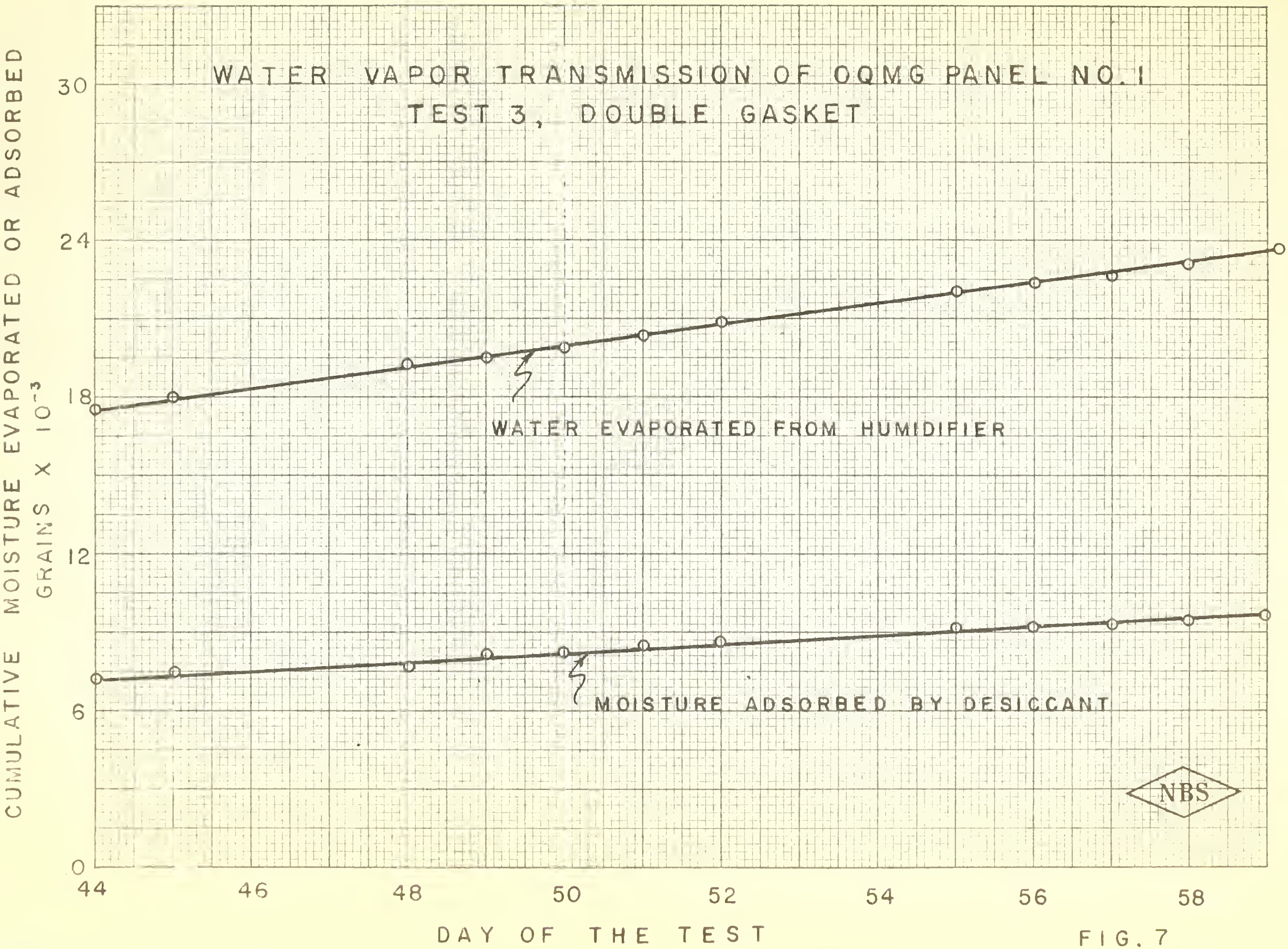
WATER VAPOR TRANSMISSION OF OQMG PANEL NO. I
TEST 3, DOUBLE GASKET
WATER EVAPORATED FROM HUMIDIFIER
MOISTURE ADSORBED BY DESICCANT
CUMULATIVE MOISTURE EVAPORATED OR ADSORBED
GRAINS X 10⁻³
0
6
12
18
24
30
44
46
48
50
52
54
56
58
DAY OF THE TEST
NBS

FIG. 7

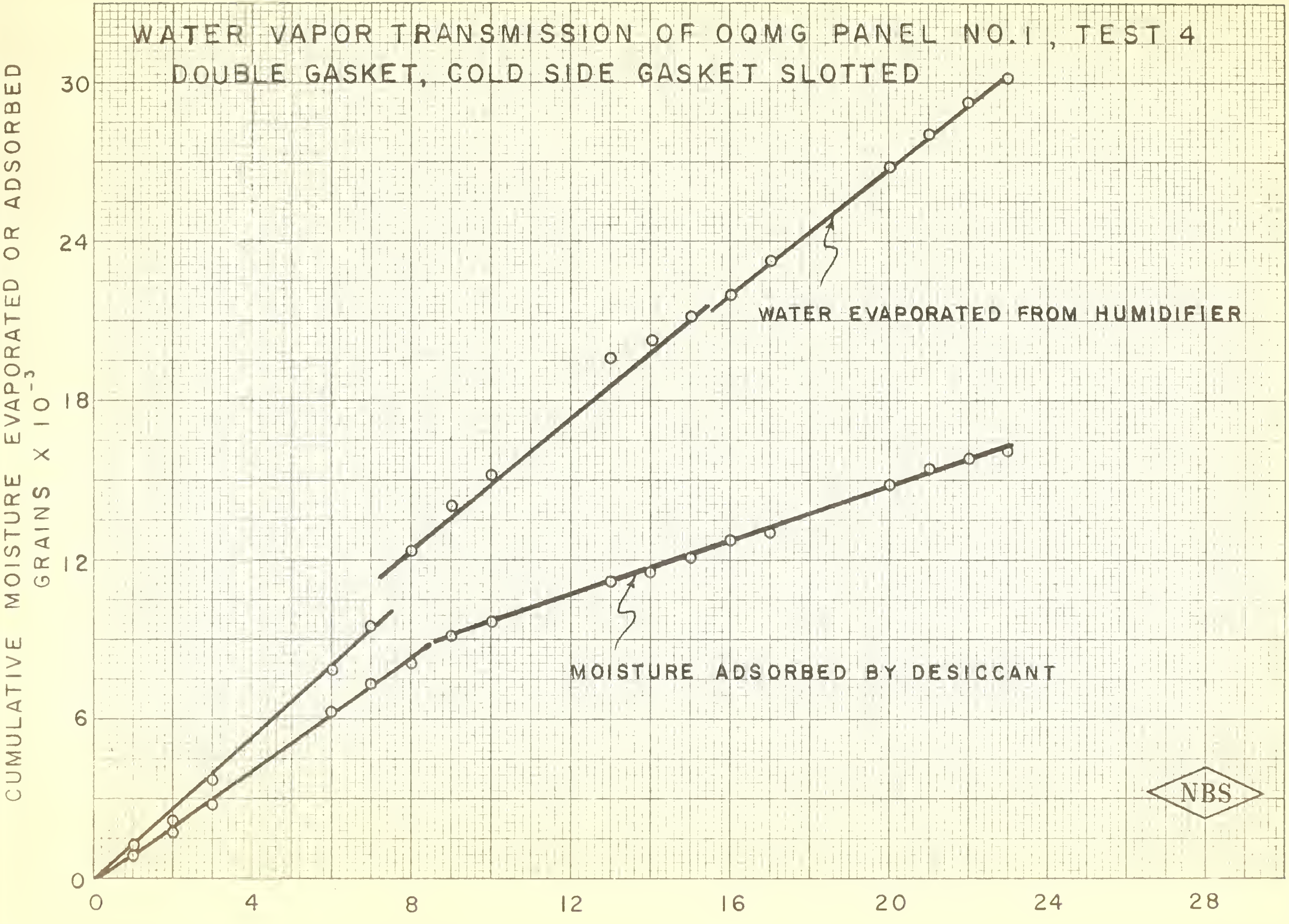
WATER VAPOR TRANSMISSION OF OQMG PANEL NO. 1, TEST 4
DOUBLE GASKET, COLD SIDE GASKET SLOTTED
WATER EVAPORATED FROM HUMIDIFIER
MOISTURE ADSORBED BY DESICCANT
CUMULATIVE MOISTURE EVAPORATED OR ADSORBED
GRAINS X 10^-3
30
24
18
12
6
0
0
4
8
12
16
20
24
28
DAY OF THE TEST
NBS

FIG. 8

vapor transmission into the insulation space. Frost was found at all five points of observation in the insulation after 23 days in Test 4 whereas condensation was not imminent after 73 days during Test 3. The vapor pressure on the warm side and the vapor pressure difference across the panel were comparable for the two tests, but the water evaporation rate required to maintain the vapor pressure on the warm side during Test 4 was about three times as high as for Test 3. The moisture adsorption rate on the cold side during Test 4 was also about three times as high as for Test 3. These results indicate that slotting the cold side gasket permitted higher overall moisture transfer through the panel joints, and also suggests that the vapor pressure in the joint itself adjacent to the wood breaker strips and panel fasteners was probably higher in Test 4 than in Test 3. The moisture content of the air in the panel joints was not measured during these tests.

More frost and ice was found in the joint spaces at the end of Test 4 than at the end of Test 3 even though the joint space was ventilated to the cold space in Test 4. The difference between the total evaporation on the warm side and the total adsorption by the desiccant on the cold side during these two tests indicates that more moisture was accumulated in the panel during Test 3. These results indicate that the ventilation provided by the slots in the cold side gasket did not effectively prevent ice formation in the panel joints.

The rate of moisture transfer from the humidifier is expressed in Table 2 in terms of grains/hour per square foot of panel area per unit vapor pressure difference and also in terms of grains/hour per linear foot of gasketed joint per unit vapor pressure difference. For a panel with vapor impervious faces the panel area is of little significance in expressing permeance. It would be expected that the moisture transfer would be more directly related to the length of the panel joints. The figures recorded in Table 2 for moisture transfer per foot of length in Tests 1 and 2 represent the rates at which vapor was entering the joint space from the ungasketed side, some of which drained back out into the warm box as water. The corresponding values for Tests 3 and 4 represent the approximate rates at which vapor was moving past the gasket on the warm side of the panel. In these two tests the rate of vapor transfer past the cold side gasket was only about 40% of that passing the warm side gasket. Presumably, the difference in these two rates represents the rate of accumulation of moisture in the joints and in the panel.

Water or frost was observed in the panel joints at the end of all four tests. Even though the double gasket apparently prevented condensation or frost formation in the insulation space for 73 days under rather severe exposure conditions in Test 3, the wood breaker strips were wetted in some areas and there was some frost or ice formed in the joints. The presence of water in the panel joints would probably cause rusting of the panel fasteners and hasten deterioration of the wood breaker strips, and the accumulation of ice might cause mechanical damage in the joint. However, the tests do not provide quantitative evaluation of these processes.

Fig. 7 shows the rate of water evaporation on the warm side of the panel and the rate of moisture adsorption on the cold side of the panel on a cumulative basis for fifteen days during Test 3 when these rates were nearly steady. Conditions were not as steady for the entire 73 days as those shown in Fig. 7 because of difficulties in obtaining steady vapor generation in the humidifier. The rates of moisture transfer reported in Table 2 for Test 3 correspond to those plotted in Fig. 7. Fig. 8 shows corresponding water evaporation and moisture adsorption data for the entire duration of Test 4. This figure shows some change in water vapor transmission rates after the first eight days of the test, but nearly constant rates thereafter. The rates of moisture transfer reported in Table 2 for Test 4 correspond to those shown for the last eight days in Fig. 8.

Table 2 shows that the thermal conductance of the whole panel averaged about 0.19 Btu/hr(ft^2)(°F) with only a cold side gasket in use whereas it averaged about 0.15 Btu/hr(ft^2)(°F) with both gaskets in use. The higher conductance observed in Tests 1 and 2 was due almost entirely to the entry of warm humid air into the joint space from the warm side because all other test conditions remained essentially the same for Tests 3 and 4. The condensation of 481 grains of moisture per hour in the joint space in Test 2 corresponds to a latent heat transfer of about 0.02 Btu/hr (ft^2)(°F) for the entire panel area, thus representing approximately half the difference in the thermal conductances observed for the single-gasketed and double-gasketed conditions of the panel.

The test results on this specimen did not show any measurable change in thermal conductance during the course of the tests that could be attributed to the accumulation of moisture or frost in the panel. The accuracy of the thermal conductance measurements is probably no better than two significant figures under

the conditions of operation that prevailed during the four tests made of this first panel. When the evaporation of moisture in the humidifier can be more precisely controlled from hour to hour and day to day more accurate thermal conductance measurements may be possible. Presumably, the drainage of condensed water down the warm side of the panel could cause deviations in the relative humidity in the warm box and affect the demand for water from the humidifier.

5. DISCUSSION AND CONCLUSIONS

The results observed during the four tests of the first specimen of several insulated warehouse panels for the Quartermaster Research and Development Laboratories indicate the following conclusions:

1. A gasket on the warm edge of the panel is necessary. Without such a gasket moisture or frost was observed in the insulation space after a week's exposure to hot humid conditions on the outside while normal refrigerator temperatures were maintained on the inside. Extensive wetting of the wood breaker strips and corrosion of the panel fasteners were also observed under these conditions. The overall heat transmission of the panel was increased about 25 percent as a result of leaving off the warm side gasket.

2. A double-gasketed panel operated for 73 days with a vapor pressure difference of 1.23 in. Hg across the panel and an air-to-air temperature difference of 113°F without moisture or frost being formed in the insulation space. The rate of water vapor entry into the panel joint was about 0.7 grain/hr per foot of joint length per inch Hg of vapor pressure difference across the panel, and the rate of water vapor transfer from the panel joint to the refrigerated side of the panel was about 40% of this value in the same units. Some ice was formed and some wetting occurred in the panel joint under these conditions.

3. Removing about 5% of the cold side gasket in the form of slots at the top and bottom edges of the panel to increase air exchange between the panel joint and the refrigerated space tripled the overall vapor transfer into and through the panel joint. This modification resulted in considerable formation of frost in the insulation space and a noticeable increase in the amount of ice deposited in the panel joint during 23 days of exposure under conditions otherwise comparable to the test with full gaskets on warm and cold edges. Slotting the cold

edge gasket did not significantly increase the overall heat transmission of the panel. This test does not establish categorically that ventilating the panel joint to the refrigerated space is undesirable, but it does indicate that the amount of ventilation provided for this test in relation to the leakage of the warm side gasket resulted in more overall moisture transfer, more moisture entry into the insulated space, and more ice formation in the panel point. Possibly the use of a tighter warm side gasket would have shown that joint space ventilation to the refrigerated space was advantageous.

4. Water or ice was deposited in the panel joint during every one of the four tests made. This suggests that the possible deterioration of wood breaker strips, the corrosion of panel fasteners, the possible mechanical damage from operating the panel fasteners when filled with ice or the physical damage to the panel joint by the growth of ice formations are problems that need consideration as well as the condensation of moisture or frost in the insulation spaces.

Experience with the water vapor transmission apparatus during these tests indicates the need for some modification to the testing procedures and for some additional instrumentation. Condensation of water vapor on the warm side of a test specimen should be avoided to afford better control of the water vapor demand from the humidifier and better control of the warm side humidity.

Methods should be devised, if possible, to determine the moisture content of the air in the insulated spaces of the panel near the cold face of the panel. The electric hygrometer elements now used in the insulation space provide an average value for a layer of air 1/2 inch thick or more, adjacent to but not extremely close to the cold face of the panel. It is not possible under present conditions to analyze with much precision the disposition of the water or ice in the panel joint or the framework of the panel. Determination of the amount of air exchange between the warm and cold boxes through the panel joints would also be halpful in studying the performance of insulated panels and their gasketed joints.

THE NATIONAL BUREAU OF STANDARDS

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