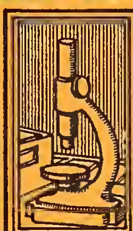
U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS41

Effect of Heating and Cooling on the Permeability of Masonry Walls

by CYRUS C. FISHBURN
and PERRY H. PETERSEN



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Foreword

This paper gives the results of further studies of the resistance of masonry walls to penetration by dampness when exposed to wind-driven rains. With the changing seasons, the average temperature of the exterior walls of buildings varies within limits determined by the geographical location of the building. Since the coefficients of thermal expansion of masonry units and of mortars are unequal, the changes in temperature produce differential volume changes which may result in the formation or enlargement of cracks in mortar joints. The influence of such temperature changes has been studied by measuring the water permeability of eleven masonry walls before, and again after they were subjected while in a dry condition, to extremes of temperature over a range of 105° F, the minimum temperature being about 20° F.

The effect of exposure to other weathering agencies, such as wetting and drying, or freezing and thawing, and to local outdoor climatic conditions is also under study and the results will be described in subsequent reports.

Lyman J. Briggs, *Director*.

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CONTENTS

ABSTRACT

Since the coefficients of thermal expansion of masonry units and mortars are unequal, changes in temperature may tend to cause cracks in the mortar joints of masonry walls. Exposure to wind-driven rain may then result in the leakage of water through the walls.

Permeability tests were made on 11 small masonry wall specimens before and after exposing them to a number of cycles of heating and cooling. Seven of the specimens were 12-in. brick walls, two were of clay tile with stucco facings, and two were brick walls with hollow-unit backings. The walls were dry when subjected to extremes of temperature over a range of about 105° F. The maximum air temperature was about 125° F and the minimum less than 20° F. For each cycle, the walls were stored in the heating or cooling rooms until they attained room temperature. Data obtained from the tests indicated that repeated exposures of dry walls to extremes of temperature did not have an important effect on the permeability of all-brick walls. The permeabilities of the walls with facings of brick and backings of hollow units and of those faced with stucco increased slightly as the result of exposure to cycles of heating and cooling.

I. INTRODUCTION

Exterior masonry walls of buildings are subjected to extremes of temperature produced by seasonal changes, the maximum annual range in air temperature over the greater portion of the United States being more than 100° F. As the coefficients of thermal expansion of mortars and masonry units are unequal, changes in temperature of a masonry wall produce differential volume changes which may result in the formation of enlargement of cracks in the mortar joints. Subsequent exposure of the wall to wind-driven rain may then produce leaks, the penetration of water through cracks in the masonry being aided by gravity, capillarity, or a pressure gradient. The coefficient of thermal expansion of masonry usually is within the following limits: [1]

	Millionths per °F
Clay brick	2.0 to 4.2
Mortar	4.5 to 6.5
Brick masonry	2.5 to 4.5
Concrete	4.0 to 6.0

This paper reports the effects of heating and cooling on the permeability of masonry walls. The walls were tested for permeability before and after their exposure, while in a dry condition, to bathing in alternately hot and cold air.

II. THE WALLS

Eleven walls, about 40 in. long and about 50 in. high, having a comparatively high resist-

[1] D. E. Parsons, Eng. News-Record **122**, 81 (1939).

ance to moisture penetration, were selected from a group previously tested for permeability and described in a publication [2] of the National Bureau of Standards. Seven of them were 12-in. brick walls, two were of structural clay tile with stucco facings, and two were brick walls with backings of hollow units. Three kinds of brick, two kinds of stucco, three mortars, and three kinds of hollow-unit backings were represented.

All except walls 9, 2, and 3 contained two copper flashings so placed as to collect any leakage passing through the wall or dropping down the interior between the wythes. Water passing completely through the wall was collected on the upper flashing. Water penetrating the facing wythe and dropping inside the wall was collected on the lower flashing. Walls 9, 2, and 3 contained no flashing, and it was not determined if moisture collecting on the supporting channel at the back of the wall had penetrated the facing or had leaked through the bed joint between the bottom of the wall and the channel. The materials and workmanship used in the walls are listed in table 1. The designations given in the last column of the table will be used to describe the walls when referred to in the text.

TABLE 1.—*Description of walls* [a]

Wall Number [b]	Kind of facing	Kind of backing	Nominal thickness	Kind of mortar	Designation [c]
			Inches		
77	Brick *a*	Brick *a*	12	1	*aa1*
74	do	do	12	3	*aa3*
A1	Brick *b*	Brick *b*	12	1	*bb1*
A4	do	do	12	2	*bb2*
A2	do	do	12	3	*bb3*
94	Brick *c*	Brick *c*	12	1	*cc1*
75	do	do	12	3	*cc3*
9 [d]	Brick *b*	Tile *d*	12	2	*bd2*
A3	do	Block *m*	12	2	*bm2*
2 [d]	Stucco (plain)	Tile *j*	9	2	*sj2*
3 [d]	Stucco (waterproofed).	do	9	2	*sj2*

[a] All walls were of workmanship *A*, as described in BMS7, p. 10.
[b] The wall numbers correspond to the original numbers of the walls n BMS7; see table 4, p. 7, thereof.
[c] The first two lower-case letters denote the kind of masonry units used, respectively, in the facings and backings. The final numeral is the kind of mortar used.
[d] Wall not flashed.

[2] Cyrus C. Fishburn, David Watstein, and Douglas E. Parsons, Water Permeability of Masonry Walls, Building Materials and Structures (1938) NBS Rep. BMS7.

1. MATERIALS

Brick.—Brick *a* (table 1) was a low-absorptive side-cut shale brick having an absorption during a 48-hr cold immersion of 0.6 percent by weight and an average coefficient of thermal expansion of 1.7 millionths per degree F over the temperature range 14° to 104° F. Brick *b* was a side-cut shale brick having an absorption of 9 percent and a coefficient of thermal expansion of 3.4 millionths per degree F. Brick *c* was a dry-press brick having an absorption of 17 percent and a coefficient of thermal expansion of 3.7 millionths per degree F. The coefficients of thermal expansion of the bricks were determined by C. W. Ross, of the Bureau staff.

Stucco.—The stucco was mixed in the proportions, by weight, of 1 part of portland cement to 3 parts of building sand. That applied to wall 3 contained ammonium stearate in amount equal to 0.2 percent by weight of cement. The amount of water used produced a consistency satisfactory to the mason and amounted to 18.7 percent by weight of dry materials or 8.5 gal per sack of cement. Two coats of stucco, each ⅜ to ½ in. thick, were applied to each wall. Twenty-four hours elapsed between the application of the first and second coats, and the walls were cured by wetting daily for 3 days. The coefficient of thermal expansion of the stucco was not determined.

Hollow-unit backings.—Structural clay tile were used for the backings of one wall with a brick face, wall 9, and two walls with stucco facings, wall 2 and 3. The backing for wall 9 was a 6-cell, double-shell, end-bearing tile. The stretcher units were 8 by 12 by 10½ in., having an absorption of 2.8 percent during a 24-hr cold immersion. The backings for the walls with stucco facings were 6-cell, 8- by 12- by 12-in. tile laid on end. These tile had an absorption of 4.1 percent.

The coefficients of thermal expansion of the hollow-unit backings were not determined.

Stone-concrete block, 8 by 12 by 8 in., laid on end, were used for the backing of wall *A3*. These block were laid when air-dry, and they had an absorption of 8.9 percent during a 24-hr cold-water immersion.

Mortars.—The mortars used in the walls differed in the relative proportions of cement and lime. Table 2 gives the physical properties of the mortars. The masons were satisfied with the working properties of all of the mortars.

TABLE 2.—*Physical properties of mortars*

Properties	Mortar 1	Mortar 2	Mortar 3
Proportions of cement, lime, sand:			
By dry weight	1:0.11:2.6	1:0.42:5.1	1:0.85:7.7
By volume [a]	1:0.25:3	1:1:6	1:2:9
Average water content, percentage by weight of dry materials	19.3	22.6	23.7
Compressive strength in 28 days, lb/in.² [b]	2,850	640	250
Flow after 1 min of suction on porous base, percent [c]	86	95	97

[a] Proportioning was by weight, assuming portland cement weighs 94 lb/ft³, dry hydrated lime 40 lb/ft³, and that 1 ft³ of loose damp sand contains 80 lb of dry sand.
[b] Cured according to Federal Specification SS-C-181.
[c] Test made for a mortar having an initial flow of 110 percent, Federal Specification SS-C-181b.

2. WORKMANSHIP

The method of filling the joints (designated workmanship *A* in BMS7) was similar for all walls. The bed joints were spread to a uniform thickness, and both head and collar joints were filled solidly with mortar. Mortar was applied to the lower edges of all brick before laying, and, when necessary, the head and collar joints were slushed full of mortar before the bed joint for the next course was applied. For the walls containing hollow units faced with brick, the joints in the brickwork were filled with mortar as described. The brick facing was laid to the elevation of a header course and then parged on the back with about ⅜ in. of mortar before the hollow units were set. Head joints in the backing were completely filled, and mortar for the bed joints was placed on the top surface of all webs and face shells.

III. PERMEABILITY TESTS

The permeability test was designed to simulate the effect of a windstorm accompanied by a heavy rain. An isometric projection of the test chamber and a description of the test are given in section IV–2 on page 12 of BMS7.[3]

[3] See footnote 2.

Each wall was supported on metal skids and clamped into position so that the face formed one side of an airtight pressure chamber in which air pressure of 10 lb/ft² above atmospheric pressure was maintained. Water was applied near the top of the wall through a perforated metal tube so that the face was covered with a sheet of water. The amount of water applied over an exposed length of 35 in. was between 10 and 15 gal per hr per linear foot of wall (about 40 gal per hr per wall). The relative humidity in the testing room was 80 percent or more, but the temperature of the water applied to the walls was not recorded. It is possible, therefore, that for some tests the water temperature was lower than that of the air in the testing room.

The tests made before heating and cooling the walls were numbered A_1, A_2, etc. (table 3), and those tests made after the exposure to heating and cooling cycles were numbered B_1, B_2, etc.

The observations made during the permeability tests were as follows:

Time for appearance of moisture (dampness) on back of walls.

Time for appearance of visible water on back of walls.

Time for leakage to occur on lower flashings.

Maximum rate of leakage, if any.

Extent of damp area on back of walls in 1 day.

Observations were made on the walls at short intervals during working hours and one or more times at night. Tests on each wall were continued for at least 1 day or usually until about 25 percent of the back of the wall was damp. The results of the observations are given in table 3.

IV. HEATING AND COOLING OF THE WALLS

After being given at least two permeability tests, the walls were dried to nearly constant weight. They were then subjected to alternate exposures in heating and cooling rooms.

The hot room used for storage of the walls was equipped with a thermostatically controlled fan and heater unit. The mean air temperature within the room was about 126° F. The average air temperature at the top of the walls was 130° F and at the bottom 123° F. After placing five or six chilled walls in the room, the time intervals required to raise the air temperature to the maximum values at the top and bottom of the walls were, respectively, about 15 and 36 hours.

The cold room was equipped with a vertical bank of brine coils along one wall. The coils were enclosed in baffles to insure circulation of air in the room and around the coils. The air circulation was such that the difference in air temperature between the top and the bottom of the walls rarely exceeded 4° F. Although the cooling unit was equipped with a thermostatically controlled valve, the air temperature was largely dependent upon the temperature of the brine in the system so that the average mean air temperature in the cold room was between 17° and 20° F.

The walls were moved from one room to the other every third or fourth day and about 1 week was required to complete a temperature cycle. It was estimated that at the end of a storage period the temperature of the masonry at the center of the wall was within 5° F of the mean air temperature in the room. Each of the walls was subjected to at least 30 temperature cycles. The average range in mean air temperature per wall was between 105° and 108° F. The minimum temperature range per cycle was 95° F and the maximum 116° F.

V. DISCUSSION OF PERMEABILITY TEST DATA

The permeability data and performance ratings for the heavy rain test, of walls listed in table 4 of BMS7 [4] show the wide range in performance between walls rated "Poor" or "Fair" to those rated "Good" or "Excellent." The performance ratings are arbitrary, because it is not known how much extensive damp areas, water plainly visible in the joints, or leaks through the wall would damage plaster applied directly to the wall. It is probable that visible water on the back of a wall or rates of leakage greater than 1 liter per hour from the flashings would cause damage to the interior of a building. The data (table 4 of BMS7) show that for walls rated "Good" or "Excellent" the time interval in excess of 24 hours for extensive penetration of moisture varies considerably. The test exposure is more severe than natural exposures for most building walls, and their continuation in excess of 24 hours provides data of diminishing practical value.

1. All-Brick Walls

The seven 12-in. all-brick walls were highly resistant to moisture penetration in tests made both before and after exposing them to heating and cooling. The walls constructed of either brick *b* or brick *c* were more permeable than those built with brick *a*. Unpublished data from recent tests made by the authors on brick masonry walls indicate that the absorptivity of brick at the time of laying has an effect on permeability. Although the brick *c* were wetted before laying, the absorptivity, or "brick suction", of brick *a* was much less than that of either brick *b* or brick *c*, and the difference in wall permeabilities was largely due to the condition of the brick at the time of laying. Wall 77 (*aa1*) showed no penetration by dampness during test periods lasting 2 weeks and was much less permeable than wall 75 (*cc3*). The slight leakage, 0.01 liter per hour, from wall *A1* and the late appearance of visible water, 42±3 hr, on the back of wall *A4* are results of negligible importance.

The data indicate that the all-brick walls were less permeable after exposure to heating and cooling than before. Although the time intervals for the appearance of the first or second damp areas are, in some cases, inconsistent, it is significant that the percentages of the damp to the dry areas on the backs of the walls at 24 hours, for tests made after heating and cooling, are equal to or less than the percentages noted for tests made before exposure to heating and cooling. A slight decrease in permeability has been observed for repeated permeability tests, as can be seen by comparing tests A_1 and A_2. It appears, therefore, that effects of heating and cooling on the permeability of all-brick walls were insignificant or at least not large enough to offset the comparatively slight decrease in wall permeability resulting from repeated exposure.

[4] See footnote 2.

Table 3.—*Data from permeability tests*

Wall number	Designation	Number of temperature cycles	Average range of air temperature	Test number	Duration of test	Time to failure as indicated by— Damp through wall— First damp area	Second damp area	Average	Visible water through wall	Leak from flashing (lower)	Area damp in 1 day	Maximum rate of leakage
			°*F.*		*Days*	*hr*	*hr*	*hr*	*hr*	*hr*	%	*Liters/hr*
77	*aa1*			$A_{1\,2}$	7						0	0
				A_2	14						0	0
		31	108	B_1	15						0	0
74	*aa3*			A_1	4	66 ±5	66 ±5	66			0	0
				A_2	5	91 ±5	91 ±5	91			0	0
		33	106	B_1	3	39 ±6	39 ±6	39			0	0
A1	*bb1*			A_1	1	13.5	16 ±3	15			5	0
				A_2	2	26	39	33			0	0
		33	106	B_1	7	33 ±2	33 ±2	33		12	0	.01
A4	*bb2*			A_1	1	18 ±4	18 ±4	18			5	0
				A_2	2	6.3 ±0.2	24	15			2	0
		30	105	B_1	3	31 ±4	31 ±4	31	42 ±3		0	0
A2	*bb3*			A_1	2	41 ±7	41 ±7	41			0	0
				A_2	2	1.3	42 ±3	21			1	0
				A_3	3	42	55	48			0	0
		30	107	B_1	2	28	38 ±6	33			0	0
94	*cc1*			A_1	1	11 ±1	11 ±1	11			13	0
				A_2	1	13 ±0.4	14 ±0.4	13.5			6	0
		30	105	B_1	1	14.5	16.5	15.5			1	0
75	*cc3*			A_1	1	4.6	5.4	5			30	0
				A_2	1	7 ±1	10 ±1	8.5			17	0
		30	107	B_1	1	15 ±6	15 ±6	15			18	0
				B_2	2	18 ±3	18 ±3	18			10	0
9[a]	*bd2*			A_1	1	2.5	3.5 ±0.2	3			6	
				A_2	1	2.3	9 ±0.2	5.8			12	
		31	108	B_1	1	2.3	2.5	2.4			20	
A3	*bm2*			A_1	1	2.3	6.5	4.4	23	5.5	30	Trace
				A_2	1	2.5	11 ±0.3	6.7		12	14	0.05
		31	108	B_1	1	3	5	4	15 ±6	15 ±6	20	.11
2[a]	*sj2*			A_1	3	41 ±4	65 ±4	53		([b])	0	0
				A_2	4	58 ±2	67 ±3	62		([b])	0	0
		30	107	B_1	3	39 ±6	54	46		([c])	[c] 8	
3[a]	*sj2*			A_1	14	207	255	231		([b])	0	0
				A_2	2	37	41	39		([b])	0	0
		33	107	B_1	2	25.5	39 ±6	32		([c])	[c] 10	

[a] No flashings.
[b] No dampness at bottom of wall.
[c] Damp at bottom of wall from water on supporting channel, no drip.

2. Walls With Brick Facings and Hollow-Unit Backings

The two walls with brick facings and hollow-unit backings, *9* (*bd2*) and *A3* (*bm2*), were much more permeable than 12-in. all-brick walls of the same brick and mortar. Since the absorption of the brick used in the facings was high and the walls contained only one parged collar joint, it is probable that considerable water passed through the facings, and the type of hollow backing had little effect on permeability. Since wall *9* (*bd2*) was not flashed, data on leakage could not be obtained.

Both walls showed a decrease in permeability between tests A_1 and A_2 and an increase in permeability for test B_1. It would appear, therefore, that the exposure of the walls to heating and cooling had an effect on permeability large enough to be noticeable. However, the increase in permeability of these walls was not sufficient to change their performance ratings as given in BMS7.

3. Walls With Stucco Facings

The two stucco-faced walls showed excellent performances under all tests. The walls were not flashed, but the bond between the walls and the supporting channels was intact for tests A_1 and A_2. The moving of the walls on lift trucks during exposure to heating and cooling cycles appeared to break this bond, and both specimens were damp at the bottom of the inside face during test B_1. The dampness at the end of 1 day, indicated for test B_1, was therefore probably caused by moisture penetrating under the wall and not by penetration through the stucco facing. In all tests the time for penetration, or appearance of damp areas, given in table 3 was for areas located well above the supporting channel.

Exposure to heating and cooling noticeably reduced the time required for the penetration of moisture through the walls. However, a slight increase in permeability has been noted for repeated tests made on other stucco walls,[5] and the increases noted for walls 2 and 3 are not considered to be of great importance. It is possible that the repeated exposures to extremes of temperature resulted in a slight enlargement of old cracks and the formation of a few new ones. There was no spalling of stucco or extensive crazing noted as a result of the temperature exposures.

[5] Unpublished data from tests made by the authors on stucco walls stored outdoors for 3 years.

VI. CONCLUSIONS

The following conclusions pertain to the effects of heating and cooling on dry masonry walls. The effects of freezing and thawing and of temperature differences between the facing and backing and between large walls and other structural members were not determined.

1. The exposure to heating and cooling did not have a significant effect on the permeability of 12-in. all-brick masonry walls.

2. Although the data are meager, exposure to heating and cooling appeared to increase slightly the permeability of brick walls with backings of hollow units.

3. Exposure to heating and cooling appeared to reduce the time required for moisture to penetrate walls with stucco facings. However, the performance of the stucco-faced walls, both before and after exposure to heating and cooling, was comparable to that of the 12-in. all-brick walls.

WASHINGTON, September 19, 1939.

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