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NATIONAL BUREAU OF STANDARDS REPORT

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PROPOSED SPECIFICATION OF REQUIREMENTS FOR INSULATIONS AND SELF-DRYING FLAT-ROOF CONSTRUCTIONS AT NORMAL OCCUPANCY

by

F. J. Powell and H. E. Robinson
Heat Transfer Section
Building Research Division

Final Report
to
Office of the Chief of Engineers
Bureau of Yards and Docks
Department of the Air Force
Washington 25, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
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PROPOSED SPECIFICATION

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Requirements for Insulations

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Proposed Specification of Requirements for Insulations and Self-Drying Flat-Roof Constructions at Normal Occupancy

by

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1. INTRODUCTION

In this report, a draft of a proposed specification is given for complete insulated flat-roof designs having the property of self-drying, if wet, through their undersurfaces, as a result of summer seasonal exposure with daily solar heating of the roofing. In short, a roof design to be admitted by this specification should be capable of self-drying in place, if wetted, to a degree which allows the construction to function with fair insulating value.

To ascertain such performance, it is necessary to consider the entire insulated roof assembly, or ensemble of components, excluding here only the built-up roofing which is common to all flat roofs, and which can be regarded as simply a practically vapor-impermeable membrane subject to temperature changes due to climatic variations.

Present typical designs for insulated flat roofs generally provide a selected arrangement, possibly with options, of a supporting deck (concrete slab or plank, steel, or wood, or formboard), with a suitable thickness of insulation (factory-made board or slab form, or cast-in-place insulating concrete) placed over it, this being covered by the roofing. The associated specification generally concerns the required properties, and method of application, of the individual component materials, and often requires a selected vapor barrier placed between the deck and the insulation. The vapor barrier is usually included in an effort to prevent ingress of vapor from the building, with possible condensation and wetting of the insulation. However, what happens to the performance of the construction if the roofing or flashing leaks accidentally, or if the insulating materials were wet or damp when placed, or when roofed over? In such case, the vapor barrier effectively prevents or slows the drying of the wetted insulation, and the insulating effect of the construction is seriously impaired [see References 1, 2 and 3].

The solution to such almost inevitable accidental wetting of a construction is to provide a roof design that will dry out in place and under service conditions, once the roof leak or source of accidental moisture entry is corrected. It has not proven feasible to evaluate the self-drying ability of a proposed construction simply from data on the properties of the components. It seems necessary, at the present time, to conduct a suitable test of the performance of a proposed construction. This specification refers to a test method and procedure developed for this purpose, and gives quantitative criteria for acceptability based on current experimental data. This report presents also a discussion of the specification requirements and lists, for guidance, several insulated flat-roof constructions which tests have indicated have adequate self-drying characteristics.

The test method and procedure on which this specification is based are described in detail in Reference 4 (Method 2). Figure 1 illustrates in a general way the possible behavior of an acceptable construction under test, in response to the schedule of conditions or events indicated. It will be noted that the criteria for acceptability given later concern both the moisture content of the construction and its insulating effect (thermal resistance).

2. THE SPECIFICATION

The following specification gives minimum requirements. The use of equivalents or better is permitted.

Section I. Scope

This specification covers the insulating and self-drying performance requirements of insulated flat-roof constructions intended for normal occupancy buildings. Normal occupancy spaces in buildings are defined here as those in which the dew-point temperature does not exceed 60° F, which corresponds to a relative humidity of 50 percent at 80° F dry bulb. Laboratory tests are specified for simultaneously determining insulating value and moisture content. The testing procedure requires exposure of a sample of the proposed construction to repeated daily cycles of simulated in-service environmental conditions of temperature and relative humidity, starting with the specimen containing normal construction moisture. The tests required cover the determination of: (a) The time required for the specimen to expel initial construction moisture by a process of self-drying to an approximate moisture content equilibrium when exposed to a simulated summer exposure condition; (b) rate of moisture gain during an immediately following winter exposure condition; (c) duration of a second summer exposure condition required to expel the winter-gained moisture; (d) self-drying performance of the specimen during a summer exposure condition after it was wetted with water in simulation of a roof leak. The tests include simultaneous measurement of insulating effect during these exposures. Adjunct laboratory tests to determine particular physical properties of the component materials are also specified.

The specification sets limits for the performance of an acceptable construction. These are illustrated in Figure 1.

Section II. Applicable Publications

The publications listed here or their latest revisions form a part of this specification to the extent indicated by reference thereto.

a. American Society For Testing And Materials

(1) Measurement of Effect of Moisture on Heat Transfer Through Insulated Flat-Roof Constructions, ASTM Special Technical Publication No. 312, Symposium on Testing Building Constructions, pp. 35-66, 1962.

(2) Standard Method of Test For Thermal Conductivity of Materials By Means of the Guarded Hot-Plate: ASTM Designation C 177.

(3) Tentative Methods of Test for Water-Vapor Transmission of Materials in Sheet Form: ASTM Designation E96-53T (Method A).

(4) Tentative Methods of Test for Water-Vapor Transmission of Materials Used in Building Construction: ASTM Designation C355-59T (Desiccant Method).

Section III. Performance Requirements

The construction shall have performance characteristics as specified below when evaluated in accordance with the methods referenced or described.

a. Thermal Insulating Value

The criterion of insulating performance of the construction shall be a thermal resistance ratio, $\overline{R}_t/R_d$. $\overline{R}_t$ is the average thermal resistance of the specimen over the total test period, evaluated as described below. R_d is the dry thermal resistance as calculated on the basis of test results for the thermal conductivity of the dry components. The minimum acceptable value of $\overline{R}_t/R_d$ shall be 0.6. The thermal resistance of the construction shall be reckoned from its underside (indoor) surface to the top surface of the construction underneath the roofing.

The thermal resistance of the construction as tested, R_t, shall be determined daily (usually 5 days per week) by using the National Bureau of Standards Calorimeter Plate Method (Method 2) of test described in ASTM STP No. 312 [applicable publication a(1)]. The individual daily measured values of thermal resistance of the construction shall be averaged for each week. The average of the weekly averages, over a period totalling 37 weeks (the 29th week is excluded from this average) constitutes the thermal resistance, $\overline{R}_t$, of the construction as tested. The total test time specified is 38 calendar weeks. (See attached Figure 1.)

The thermal conductivity of the dry materials used in the specimen shall be determined at 75° F mean temperature using the method of test ASTM C 177. The thermal resistance, R_n, of each component shall be calculated using the formula $R_n = X_n/k_n$, where X_n is the thickness of the component in inches and k_n is its thermal conductivity in Btu/hr ft^2 (deg F/in.). The thermal resistances of the tandem components shall be summed ($R_1 + R_2$ . . . etc.) to determine the total calculated dry thermal resistance, R_d, of the construction.

b. Self-Drying Time for Initial Construction Moisture and Equilibrium Moisture Content

The maximum testing time under the first summer exposure condition for the construction to expel initial construction moisture by self-drying to a moisture content equilibrium shall be 16 calendar weeks. Specimen weight loss shall be determined from daily weighings, using scales sensitive to 0.01 lb., made simultaneously with the daily thermal resistance measurements. The average of the daily weight observations for each week constitutes the average gross specimen weight G_t for that calendar week. The gross weight, G_t, is the sum of the actual net specimen weight N_t and a tare.

Weight measurements and thermal exposure and testing shall begin immediately upon fabrication and installation of the test specimen. The start shall in no case be later than one week after cast-in-place components are poured. When installed, component materials shall be in a moisture condition similar to that to be expected when roll roofing would be applied over such a construction in the field--

that is, materials shall be not more than air-dry, and cast-in-place components shall not have been subjected to air-drying for longer than one week after pouring.

The specimen shall be considered to be at an approximate moisture content equilibrium during exposure testing when its change of weight, W_t, does not exceed 0.05 lb/ft^2 (week) for 2 consecutive weeks.

c. Equilibrium Moisture Content

The value of the approximate equilibrium moisture content of the construction achieved as a result of self-drying at the conclusion of the first summer exposure period shall be evaluated by means of the ratio M_t/M_c, where M_t is the average specimen moisture content at the end of the first 16-week summer exposure period. M_t is evaluated as $(1/A)[(G_t - G_f) + (N_f - N_d)]$ where A is the plan area of the specimen, G_t is defined above, G_f is the gross specimen weight after week 38 and just before determining $(N_f - N_d)$, which is the loss of total weight of the net specimen on oven-drying its components to constant weight. M_c is the calculated moisture content based on equilibrium hygroscopic moisture content determinations of the component materials, and is defined below. The maximum acceptable value for the ratio M_t/M_c shall be 2.0.

The equilibrium hygroscopic moisture absorption of each component material shall be determined by exposing a conveniently-sized sample having a thickness of at least 1 inch and an exposed surface area of about 1/2 ft^2 to a uniform temperature of 75° F ± 2° and a relative humidity of 90 percent ± 3 percent until the sample shows no further change of weight. The dry weight of the sample shall then be determined by oven-drying it to constant weight at a temperature commensurate with the use limit of the material. For drying most building materials an oven temperature of 215° F can be used but for some materials the softening point temperature or other factors must be observed. The equilibrium hygroscopic moisture content, M_c, in lb/ft^2 is calculated as follows:

$$M_c = \frac{\rho_1 x_1}{12}\left(\frac{W_{h_1} - W_{d_1}}{W_{d_1}}\right) + \frac{\rho_2 x_2}{12}\left(\frac{W_{h_2} - W_{d_2}}{W_{d_2}}\right) + \ldots$$

where ρ = dry density of each component material, lb/ft^3

x = thickness of each component material, in.

W_h = constant weight of each component specimen at 75° F ± 2° and 90% ± 3% relative humidity

W_d = constant weight of each component specimen after oven-drying

d. Regain of Moisture--Winter Exposure Conditions

The maximum permissible average rate of moisture regain under winter test exposure conditions shall be 0.05 lb/ft^2(week). The time of exposure to determine the average rate shall be the six calendar weeks immediately following the first summer exposure period at the conclusion of which an approximate moisture content equilibrium was established.

e. Summer Self-Drying Time for Winter Regain Moisture

The maximum permissible testing time under the second summer exposure period for expulsion by self-drying of moisture gained under the first winter exposure period (d. above) shall be six calendar weeks. The second summer exposure test shall immediately follow the first winter exposure period. The specimen shall dry to a moisture content not greater than that at the end of the first summer exposure period.

f. Summer Self-Drying Time for a Simulated Roofing Leak

During the second summer exposure period and following e., above, a roof leak shall be simulated by adding water to the center of the upper surface of the top component material of the specimen in an amount equal to 10 percent of the total specimen volume.

In order to facilitate water admission and its lateral distribution, a small well 1/8-inch deep and 1 inch in diameter shall be made if necessary in the upper surface of the top component of the specimen, directly under the water feed tube through the calorimeter plate, and one layer of well-washed cotton muslin 1 inch less in size than the specimen shall be interposed without folds between the upper surface and the calorimeter undersurface. For admission, the head of water over the calorimeter plate shall not be more than 6 inches. The maximum time allowable for admission of water shall be one week. If the full 10 percent by volume cannot be introduced in this time, the amount actually introduced shall be noted. If dripping of water from the undersurface of the specimen occurs, the rate of admission shall be slowed to prevent dripping, if possible. Thermal resistance values obtained during this week shall not be used when averaging to determine the test thermal resistance, $\overline{R}_t$.

The maximum allowable exposure time for expulsion of added water by self-drying during the second summer exposure period to a moisture content equilibrium shall not exceed 9 calendar weeks. During this time period (9 weeks) the insulating value of the specimen shall return to approximately the same value as that observed before water was added.

After the test is completed the amount of moisture in each component shall be determined by oven-drying to constant weight.

g. Water Vapor Permeance and Hygroscopic Moisture Capacity

The ability of the construction to self-dry in service shall be evaluated by the ratio P_t/M_c, where P_t is the overall water vapor permeance in perms (grains/hr ft^2 in. Hg) of the construction (exclusive of roofing) calculated from water vapor permeability determinations and M_c is the calculated moisture content in lb/ft^2 of the construction based on equilibrium hygroscopic moisture content determinations of the component materials. The calculated value of the ratio P_t/M_c shall be numerically between 2 and 50.

The over-all water vapor permeance, P_t, shall be calculated from values of water vapor permeability and thickness of each component of the construction as follows:

$$\frac{1}{P_t} = \frac{x_1}{u_1} + \frac{x_2}{u_2} + \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot$$

where u is the water vapor permeability in perm-inch units [grains/hr ft^2 (in. Hg/in.)] determined by either ASTM E-96-53T, Procedure A, or ASTM C 355-59T, Desiccant Method.

The hygroscopic moisture capacity, M_c, shall be calculated and determined as described in Section IIIc, Equilibrium Moisture Content.

h. Exposure Conditions

During exposure the atmosphere beneath the specimen shall be maintained constant at 90° F and 30% relative humidity.

The temperature of the calorimeter covering the upper surface of the top specimen component material shall be programmed to repeat daily the following (24-hour) cycle:

Clock Time	Calorimeter Plate Temperature, °F		
	Winter		Summer
10 a.m.	38		75
10 a.m. to 12:30 p.m.	75	← in transition to →	138
12:30 p.m. to 4:30 p.m.	75 (Steady)		138 (Steady)
4:30 p.m. to 7:30 p.m.	38	← in transition to →	75
7:30 p.m. to 10 a.m.	38 (Steady)		75 (Steady)

Measurements of the heat flux and temperatures at the surfaces of all materials and the specimen moisture content shall be made each working day between the hours of 7:00 and 10:00 a. m.

For convenience when testing, instead of using clock time as shown above, the temperature of the calorimeter may be programmed as (A + x) hours, where A is any chosen clock time and $(0 \leq x \leq 24)$. For example, if A = 10 a.m. then 12:30 p.m. = A + 2.5 hours. If the time of day for making measurements is more suitable as 2 to 5 p.m., the clock time schedule may be adjusted accordingly.

i. Report

A report of the results of all tests shall include the following:

(1) Exposure Tests (STP 312)

(a) The name and any other pertinent identification of the test construction.

(b) A description of the test specimen, including the thicknesses of each component material, the technique used to seal and prepare the specimen, and the time required for preparation. A description of the test apparatus used including the procedures and specimens used for calibration. A description of the water addition procedure including observations of wetting, if any, of the exposed (indoor) surface of the test specimen.

(c) The daily values of the test data shall be numerically averaged for each week of testing (usually five values per working week) and a tabulation of the following items prepared:

[1] Test week number in consecutive order

[2] Simulated exposure condition (summer or winter)

[3] Weekly test thermal resistance, R_t, for the construction, deg F/$\frac{\text{Btu}}{\text{hr ft}^2}$

[4] Weekly test thermal resistance, R, of each component material, deg F/$\frac{\text{Btu}}{\text{hr ft}^2}$

[5] The specimen moisture content, M_t, lb/ft^2

(d) Calculated thermal resistance, R_d, based on thermal conductivity determinations of the dry component materials and their thicknesses, deg F/$\frac{\text{Btu}}{\text{hr ft}^2}$

(e) The numerical average of the values of specimen thermal resistance, $\overline{R}_t$, for thirty-seven (37) weeks of testing, deg F/ $\frac{\text{Btu}}{\text{hr ft}^2}$.

(f) The numerical value of the ratio $\overline{R}_t/R_d$.

(g) The change of specimen moisture content, lb/ft^2(week), during each of the last two weeks of the first summer exposure period during or after which a specimen moisture content equilibrium was achieved.

(h) The numerical value of the ratio M_t/M_c for the last week of the first summer exposure period after a moisture content equilibrium was achieved.

(i) The average rate of moisture regain during 6 weeks of exposure of the specimen to the first simulated winter test period, lb/ft^2(week).

(j) The self-drying time in weeks required for the specimen to achieve an equilibrium moisture content during the second summer exposure period starting immediately following the first winter exposure period.

(k) The maximum value of the specimen moisture content in lb/ft^2, obtained after adding water in the amount of 10 percent by specimen volume, and the week number during which water was added.

(l) The self-drying time, in weeks, required, after water was added during the second summer exposure period, for the specimen to reach a moisture content equilibrium.

(m) The dry weight per square foot of the specimen and of each of the component materials, lb/ft^2.

(n) A graphical representation of the results. This shall consist of plots of pertinent data obtained versus the corresponding test week number, plotted as ordinates and abscissas, respectively. Figure 1 is a sample plot.

(o) A sample plot of the calorimeter plate temperature for a daily cycle of a winter and summer test condition.

(2) Thermal Conductivity Tests.

(a) A report as required in ASTM Designation C 177.

(3) Equilibrium Hygroscopic Moisture Content Tests.

(a) For each component material of the specimen, give name and any other pertinent identification.

(b) A description of the size of the test specimen.

(c) The equilibrium water content in percent of dry weight, at 75 ± 2° F and 90 ± 3% relative humidity.

(4) Water Vapor Permeance Tests.

(a) A report as required in ASTM designation E-96-53T or C 355-59T.

3. DISCUSSION

The main feature of this specification is the requirement that a laboratory test demonstrate that a particular design of an insulated flat roof will give reliable long-term insulating value and remain free of serious moisture problems that have been and are being experienced in the field. Laboratory testing of designs selected is considered necessary because it is impossible to accurately predict long-term insulating and moisture performance on the basis of the more quickly and easily measured physical properties of the component materials. Such factors as variable moisture contents of materials when installed in the roof, difficulties in obtaining consistent and high-quality workmanship on the job, and the ever-present possibility of roofing leaks being accidentally created preclude predicting field performance. The requirement of testing the design by laboratory exposure offers assurance before the construction of large-area roofs that the design is such that the construction is capable of drying out in place if wetted from roofing leaks during and subsequent to construction. Thus the costly replacement of large areas of roofing and insulation is prevented and maintenance would consist of simply patching and sealing roofing. Further, the test procedure allows several designs to be tested simultaneously for comparison and selection of the best, most economical construction to suit the needs for a specific building use.

A critical discussion of the requirements listed under Section III of the Specification follows.

<u>Thermal Insulating Value</u>

For any component material the value of its thermal resistance, R_n, can be firmly fixed because the thermal conductivity of a dry specimen is determined by a standardized method--ASTM C 177. The value of the test thermal resistance of a specimen or a component varies with time, moisture content, arrangement of the components of the specimen, and exposure conditions. The requirement that the average test specimen resistance achieve a minimum of 60 percent of its dry value may at first appear to be easily accomplished. However, the procedure for calculating $\overline{R}_t$ consists of numerically averaging values that are obtained by exposure under moist conditions during simulated summer and winter seasons. For some specimens that are wet the weekly value of R_t may be as little as 25 percent of the dry value. Also, limits of time of exposure are specified. Thus, the average value $\overline{R}_t$ includes values obtained with the specimen both dry and moist, as well as values for two seasonal exposures. From laboratory data obtained on specimens that demonstrated good ability to dry in place the value of 0.6 for the ratio $\overline{R}_t/R_d$ was selected as a minimum to assure a reasonably efficiently-insulated construction year round. For many constructions that are installed with only normal hygroscopic moisture in them, the weekly value of the ratio R_t/R_d will be mostly in the range from 0.8 to 1.0. Further, some constructions that have decks that are relatively quite permeable to water vapor will indicate high values of R_t when covered with a wet material of high water absorptive capacity. This occurs because the heat entering the bottom face of the specimen during measurement is largely used as latent heat of evaporation and the quantity of heat remaining to be absorbed by the calorimeter is small. The apparent thermal resistance of the specimen thus indicated may exceed the dry value and in such cases the maximum value that should be used to obtain $\overline{R}_t$ is the dry value R_d. Such exceptional results were obtained only with rapidly-drying specimens having quite permeable decks, so the procedure of allowing dry values for obviously wet specimens occurs for only a small fraction of the total time of averaging.

Self-Drying Time for Initial Construction Moisture and Equilibrium Moisture Content

The quantity of moisture present initially will vary widely with various types of constructions. Manufactured insulation normally will contain only hygroscopic moisture. Green concrete will contain a relatively high percentage of free moisture by weight.

Those constructions that are placed in the field with all materials nearly dry will under laboratory exposure conditions for the first summer exposure condition reach a moisture content equilibrium rapidly and the values of R_t should be high and stable. For these cases it may be permissible to reduce the time of testing to less than the maximum of 16 weeks specified. However, when averaging weekly values of R_t over the aggregate of 37 weeks the appropriate values of R_t should be included for the full time period of 16 weeks.

For those specimens containing relatively much moisture, the maximum of 16 weeks for the first summer exposure condition will probably be needed to establish a moisture content equilibrium. It is important that the weight and heat transfer measurements begin within one week after concrete is poured because prolonged laboratory air drying can reduce the moisture content considerably and this would not be compatible with field installation where roofing is usually applied as soon as possible to prevent rain-wetting.

Equilibrium Moisture Content

Evaluation of the approximate equilibrium moisture content at the conclusion of the first summer exposure condition is specified to assure that the quantity of moisture present is not excessive.

Laboratory results on specimens have shown that for two-component constructions, after several weeks of the summer exposure condition, the evaporable moisture present in the construction is widely distributed throughout it. To set a limit on the amount of evaporable moisture an allowable construction may contain after 16 weeks of summer condition exposure, a maximum value of 2 for the ratio M_t/M_c was selected, where M_t is the average evaporable moisture content of the specimen at that time, and M_c is the hygroscopic moisture content of the total specimen if each of its components has the moisture content corresponding to its hygroscopic equilibrium at a condition of 75° F and 90 percent relative humidity. It has been found that for most constructions the latter quantity of moisture does not markedly affect the insulating value under the winter exposure conditions.

The value of M_c differs considerably among constructions of different kinds, depending both on their weight and on the hygroscopicity of their materials. Information on hygroscopicity at this condition available in the literature is sparse, and what is available indicates considerable variation for ostensibly the same material, and also with specimen size. Hence it appears necessary to require test measurements to ascertain M_c for a construction. The quantity of hygroscopic data obtained thus far as an adjunct to the NBS tests on roof constructions is small. It is felt that as more information becomes available it may be possible in some cases to omit specific measurements to obtain M_c. It may also be desirable in the future to change the present limiting value of the ratio M_t/M_c.

<u>Water Vapor Permeance and Hygroscopic Moisture Capacity</u>

The ratio P_t/M_c is included in the specification to assure that the specimen and especially its deck component is permeable enough to permit adequate self-drying. Permeability measurements to determine P_t are sometimes variable on the same type of material. The value of the ratio P_t/M_c is also subject to variations of M_c as discussed above. Therefore the specified interval of 2 to 50 should be subject to future adjustment as more data become available.

4. EXAMPLES OF CONSTRUCTIONS FOUND ACCEPTABLE

The following constructions have demonstrated in laboratory tests satisfactory insulating value and a capability for self-drying, when moist from initial construction moisture or when wetted later ~~from~~ by a simulated roofing leak, when they were subjected to simulated in-service exposure conditions of temperature and relative humidity. They constitute a guide to which other constructions may be added upon approval of laboratory tests that show similar acceptable performance. Pertinent materials specifications and tests are included in the listing.

Sheet or mastic type vapor barriers were not used between the deck material and the top cover material of any specimen listed, and light spray-painting of the under-surface, sufficient to change its color but not to set as a continuous film, did not seriously affect the performance characteristics.

Construction Number	Formboard or Deck Material Thickness and Dry Density	Top Cover Material Thickness and Dry Density
I	1 in., 11.4 pcf, glass fiber formboard; (HH-I-526a; CS-131-46; ASTM C 378; ASTM E-96-53T; ASTM C 355-59T)	3 in., 34.2 pcf, perlite aggregate concrete; (CE 219.03; ASTM E-96-53T; ASTM C 355-59T)
II	1 in., 11.4 pcf, glass fiber formboard; (HH-I-526a; CS-131-46; ASTM C 378; ASTM E-96-53T; ASTM C 355-59T)	3 in., 39.6 pcf, vermiculite aggregate concrete; (CE 219.04; ASTM E96-53T; ASTM C 355-59T)
III	1-1/2 in., 11.6 pcf, glass fiber formboard; (HH-I-526a; CS-131-46; ASTM C 378; ASTM E-96-53T; ASTM C 355-59T)	3 in., 30 pcf perlite aggregate concrete; (CE 219.03; ASTM E-96-53T; ASTM C 355-59T)
IV	1-1/2 in., 11.6 pcf, glass fiber formboard; (HH-I-526a; CS-131-46; ASTM C 378; ASTM E-96-53T; ASTM C 355-59T)	2 in., 56.7 pcf, gypsum concrete; (CE 219.02; ASA A59.1-1954; ASTM E-96-53T; ASTM C 355-59T)
V	1-1/2 in., 18.9 pcf, wood-fiber formboard--upper inch with asphalt binder; (LLL-I-535 Class C; CS 42-49; SPR R 179-56; ASTM E-96-53T; ASTM C 355-59T)	3 in., 31.6 pcf, perlite aggregate concrete; (CE 219.03; ASTM E-96-53T; ASTM C 355-59T)
VI	1-1/2 in., 18.9 pcf, wood-fiber formboard--upper inch with asphalt binder; (LLL-I-535 Class C; CS 42-49; SPR R 179-56; ASTM C 208; ASTM E-96-53T; ASTM C 355-59T)	3 in., 41.1 pcf, vermiculite aggregate concrete; (CE 219.04)
VII	3 in., 24 pcf, wood-fiber cementious binder formboard; (ASTM E 96-53T; ASTM C 355-59T)	2 in., 56.7 pcf, gypsum concrete; (CE 219.02; ASA A 59.1-1954; ASTM E 96-53T; ASTM C 355-59T)
VIII	2 in., 56.7 pcf gypsum concrete tile; (CE 219.02; ASA A59.1-1954; ASTM E 96-53T; ASTM C 355-59T)	1-3/4 in., 12.6 pcf, glass fiber insulation board; (HH-I-526a; CS 131-46; ASTM C 378; ASTM E 96-53T; ASTM C 355-59T)

Construction Number	Formboard or Deck Material Thickness and Dry Density	Top Cover Material Thickness and Dry Density
IX	2 in., 56.7 pcf gypsum concrete tile; (CE 219.02; ASA A 59.1-1954; ASTM E 96-53T; ASTM C 355-59T)	2-1/2 in., 16.3 mineral wool board with asphalt binder; (HH-I-526a; CS 136-46; ASTM C 378; ASTM E-96-53T; ASTM C 355-59T)
X	2 in., 56.7 pcf gypsum concrete tile; (CE 219.02; ASA A 59.1-1954; ASTM E 96-53T; ASTM C 355-59T)	2-1/2 in., 14.2 pcf, wood-fiber insulation board; LLL-I-535 Class C; CS 42-49; SPR R 179-56; ASTM C 208)
XI	3 in., 30 pcf, perlite aggregate concrete, plank or tile; (CE 219.03)	1-1/2 in., 11.6 pcf, glass fiber insulation board; (HH-I-526a; CS 131-46; ASTM C 378)
XII	3 in., 30 pcf, perlite aggregate concrete, plank or tile; (CE 219.03)	1-1/2 in., 18.9 pcf, wood-fiber board--lower inch with asphalt binder; (LLL-I-535 Class C; CS 42-49; SPR R 179-56; ASTM C 208)
XIII	3 in., 30 pcf, perlite aggregate concrete, plank or tile; (CE 219.03)	1 in., 2 pcf, expanded polystyrene insulation board; (HH-I-524)
XIV	3 in., 30 pcf, perlite aggregate concrete, plank or tile; (CE 219.03)	None
XV	2-1/4 in., 12.3 pcf, wood-fiber insulation board; (LLL-I-535 Class C; CS 42-49; SPR R 179-56; ASTM C 208)	None
XVI	1-3/4 in., 8.1 pcf, cork insulation board; (HH-C-561b)	None

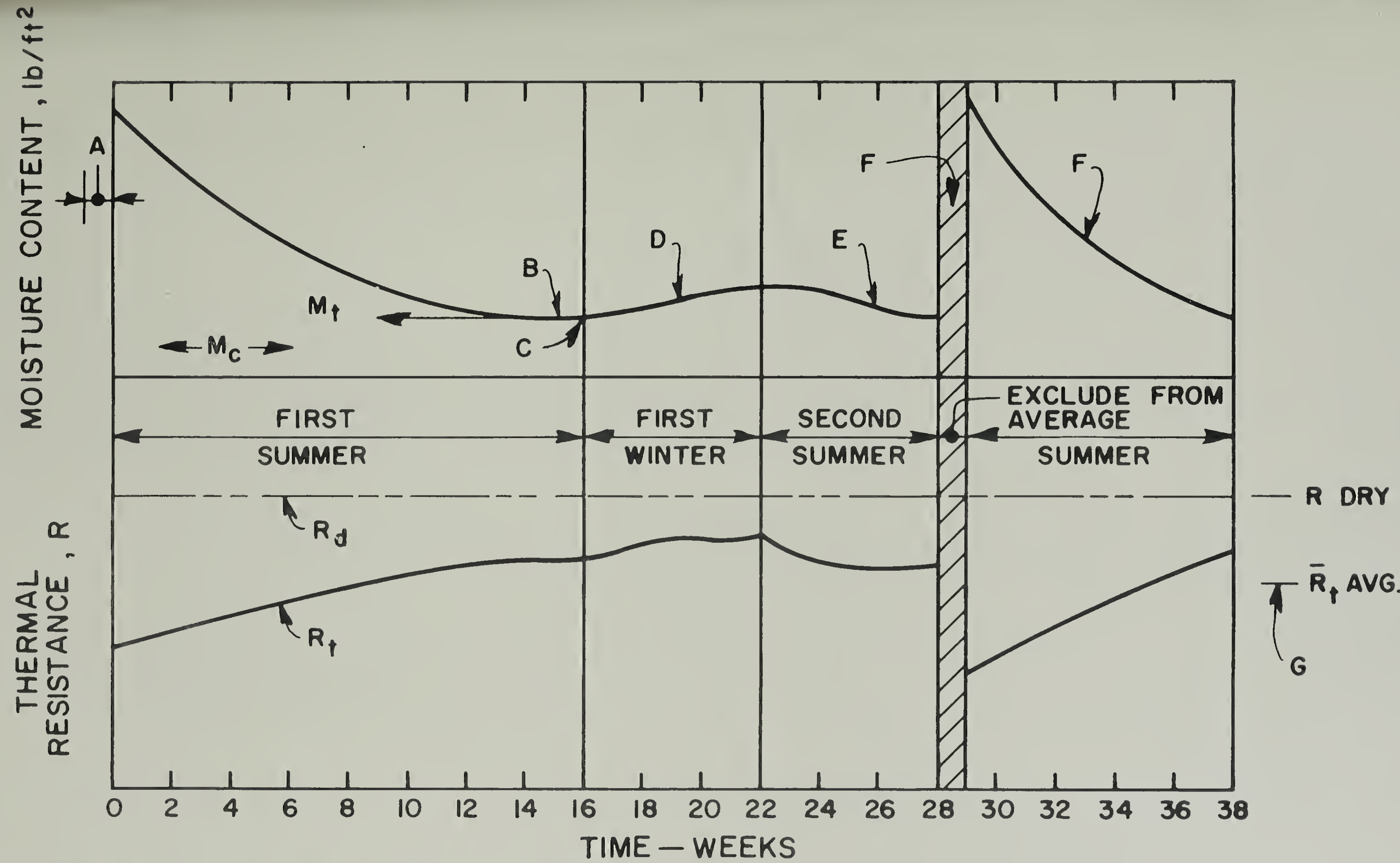
5. REFERENCES

1. NBS Report 6283, The Effect of Moisture on Heat Transfer Through Insulated Flat Roof Constructions, January 15, 1959.

2. NBS Report 7347, Heat Transfer and Self-Drying Characteristics of Insulated Flat Roof Constructions, October 3, 1961.

3. NBS Report 7817, Heat Transfer and Self-Drying Characteristics of Formboard-Type Insulated Flat-Roof Constructions, March 15, 1963.

4. F. J. Powell and H. E. Robinson, Measurement of Effect of Moisture on Heat Transfer Through Insulated Flat-Roof Constructions, Special Technical Publication No. 312, Symposium on Methods of Testing Building Constructions, Am. Soc. for Testing and Materials, pp. 35-66, (1962).



A. MAXIMUM FABRICATION TIME 1 WEEK (SECTION III B).
B. MOISTURE CONTENT EQUILIBRIUM, DEFINED BY RATE OF LOSS, 0.05 lb/ft^2 WEEK (SECTION III B)
C. $M_t/M_c \leq 2.0$ (SECTION III C).
D. WINTER MOISTURE REGAIN, AVERAGE RATE OF GAIN < 0.05 lb/ft^2 WEEK (SECTION III D).
E. PERIOD OF SELF-DRYING OF WINTER REGAINED MOISTURE (SECTION III E).
F. PERIOD OF SELF-DRYING FOLLOWING WATER ADDITION (10% BY VOLUME) IN SIMULATION OF ROOF LEAK (SECTION III F).
G. AVERAGE VALUE OF $\bar{R}_t$ FOR 37 WEEKS. RATIO $\bar{R}_t/R_D \geq 0.6$ (SECTION III A).

FIG. 1

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage. Absolute Electrical Measurements.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING LABORATORY

Cryogenic Processes. Cryogenic Properties of Solids. Cryogenic Technical Services. Properties of Cryogenic Fluids.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Troposphere and Space Telecommunications. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Spectrum Utilization Research. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Standards Physics. Frequency and Time Disseminations. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Microwave Physics.

Radio Standards Engineering. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

Joint Institute for Laboratory Astrophysics - NBS Group (Univ. of Colo.).

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