U. S. DEPARTMENT OF COMMERCE

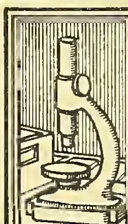
BUILDING MATERIALS AND STRUCTURES

REPORT BMS64

Solar Heating of Various Surfaces

by
HERMAN V. COTTONY
and RICHARD S. DILL

NATIONAL
BUREAU OF STANDARDS



The program of research on building materials and structures, carried on by the National Bureau of Standards, was undertaken with the assistance of the Central Housing Committee, an informal organization of governmental agencies concerned with housing construction and finance, which is cooperating in the investigations through a committee of principal technicians.

The Forest Products Laboratory of the Forest Service is cooperating with both committees on investigations of wood constructions.

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The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

Methods of improving comfort conditions in homes during warm weather were investigated in connection with the low-cost housing program at the National Bureau of Standards, and this report presents one phase of this subject. During this study, the temperatures attained by various surfaces exposed to the sun and weather, as if upon a roof, were observed. Heating by sunlight and cooling by radiation to the sky at night of several paints and commonly used roof coverings can be compared directly by means of the results obtained.

Other factors affecting summer comfort in dwellings, such as the effectivenesses of various insulating materials in the ceiling and of window shades and blinds of several kinds, will be treated in other reports.

Lyman J. Briggs, *Director.*

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ABSTRACT

Measurements were made on the temperatures attained by a number of painted and other surfaces exposed to the sun, and it was found that surfaces covered with white or light-colored paint remained cooler under this condition than those covered with dark paint. A surface covered with glossy white paint was cooler than any other tried, while one covered with flat white paint was nearly as cool.

A lampblack surface was the warmest of the surfaces tried, and one covered with green trim paint was nearly as warm.

The temperature attained by surfaces painted with various shades of gray, yellow, and ivory paint fell between those reached by the white and the green surfaces.

Three colors of commercial roll roofing material—aluminum, green, and red—were tried, and all attained temperatures practically as high as the green or the lampblack surfaces.

A surface covered with aluminum foil was cooler than another covered with aluminum paint but was considerably warmer than the white painted surfaces.

All the surfaces were shown to be cooled below the ambient air temperature on clear nights by radiation to the sky. The surfaces covered with house paints were all cooled about the same amount under this condition, regardless of color, and they were cooled more than the other surfaces tried, whereas the aluminum foil-covered surface was cooled the least.

I. INTRODUCTION

In connection with the researches of the National Bureau of Standards on low-cost housing, a simple apparatus was constructed and used to investigate the relative absorption of heat from the sun by several materials or surfaces which are or might be used on roofs. The practical importance of this problem to anyone interested in keeping houses cool in summer is shown by the fact that under some conditions surfaces exposed to the sun have been observed to be more than 60 degrees F warmer than the air above them.

Two properties, among others, are known to influence the temperature to which surfaces are heated by radiant heat from the sun. One is the absorption coefficient for sunlight, and the other is the ability of the surface itself to radiate heat. A black surface absorbs nearly all the radiant heat falling upon it. Black surfaces exposed to the sun attain higher temperatures than most surfaces of other kinds under the same conditions.

A surface capable of emitting long-wave radiation (radiant heat) will remain cooler when exposed to the sun than another surface which is similar with the exception that it emits less of such radiation. A surface must be permitted to attain a materially higher temperature than its surroundings if this phenomenon is to be of importance. For example, the surfaces of tanks containing water, gasoline, or other liquids will in many cases be cooled by the liquid behind them, so that ability of the surface to radiate heat is unimportant. It is unlikely that any house, wall, or roof falls within this category.

For the purposes of these tests, 17 materials or surfaces, each 10 inches square, were arranged on a board and exposed to sunlight. As all the surfaces were arranged in substantially the same way, it was assumed that the maximum temperature attained by each sample was a measure of its tendency to impart heat to a house on which it might be used as a covering.

II. TEST PROCEDURE

The procedure consisted in exposing the panel bearing the test surfaces to sunlight during each of 5 days. Observation began at 8 a. m. and continued until 4 p. m. The test panel faced south in all cases. Tests were made with the panel at inclinations of 90, 60, 45, and 30 degrees from the horizontal. Temperatures of the various surfaces and of the air were observed at intervals of 30 minutes.

III. SPECIMENS AND TEST EQUIPMENT

The paints selected for the tests were ready mixed and were purchased in the open market. The manufacturers furnished formulas for the paints used as follows:

Glossy white:	*% by weight*
Basic carbonate white lead	20
Basic sulfate white lead	11
Zinc oxide	19
Titanium magnesium pigment	16
Total pigment	66
Linseed oil	31
Japan drier	3
Total vehicle	34

Flat white:	
White lead (basic sulfate)	22
Zinc oxide	40
Magnesium silicate	8
Total pigment	70
Linseed oil	11
Drier	4
Mineral spirits	15
Total vehicle	30

Ivory:	
White lead carbonate	19
White lead sulfate	15
Zinc oxide	27
Magnesium silicate	7
Total pigment	68
Linseed oil	29
Japan drier	3
Total vehicle	32

The paint is tinted with yellow ochre.

Canary yellow:	*% by weight*
Basic lead carbonate	20
Basic lead sulfate	14
Zinc oxide	27
Magnesium silicate	6
Total pigment	67
Linseed oil	30
Japan drier	3
Total vehicle	33

The paint is tinted with chrome yellow.

Pearl gray:	
Basic lead carbonate	15
Basic lead sulfate	17
Zinc oxide	26
Magnesium silicate	6
Total pigment	64
Linseed oil	32
Japan drier	4
Total vehicle	36

The paint is tinted with ivory drop black and ultramarine blue.

Silver gray:	
Basic lead carbonate	19
Basic lead sulfate	15
Zinc oxide	26
Magnesium silicate	6
Total pigment	66
Linseed oil	31
Japan drier	3
Total vehicle	34

The paint is tinted with raw umber and lampblack.

Light lead:	
Basic lead carbonate	19
Basic lead sulfate	15
Zinc oxide	26
Magnesium silicate	6
Total pigment	66
Linseed oil	31
Japan drier	3
Total vehicle	34

The paint is tinted with lampblack and ultramarine blue.

Slate:	*% by weight*
Basic lead carbonate	12
Basic lead sulfate	17
Zinc oxide	27
Magnesium silicate	8
Total pigment	64
Linseed oil	32
Japan drier	4
Total vehicle	36

The paint is tinted with ultramarine blue and lampblack.

Medium green (trim color):	
C.P. Chrome green	14
Magnesium silicate	13
Total pigment	27
Linseed oil	46
Tung oil	5
Japan drier	11
Turpentine	5
Mineral spirits	6
Total vehicle	73

The black paint for the test was made of lampblack and shellac in alcohol.

The apparatus is shown in some detail in figure 1. The test surfaces were mounted on the sheet of ¼-inch plywood shown, and the whole set-up, mounted on trunnions, could be adjusted to any desired inclination.

A copper-constantan thermocouple system was used for surface temperature measurements.

A thermocouple junction was placed in the center of each test surface. Thermocouple wires were secured to the surface for at least 5 inches from each junction. In the case of the painted surfaces, the wires were laid in shallow grooves in the plywood and held there by small staples. The paint was applied over wires and staples. In the case of the three panels covered with roofing roll, the wires were laid in grooves in the asphalt coating just underneath the slate surfacing. The roofing roll samples were tacked to the plywood panel at intervals of 2 to 3 inches, sufficiently close to prevent formation of airpockets under them. For the panels covered by galvanized iron and aluminum foil, the thermocouples were attached to the wood surface. The galvanized-iron sheet was tacked securely over the wires. The aluminum foil was secured to the plywood board over the wires by shellac.

The temperature of the air was measured by a mercury-in-glass thermometer suspended in the shade in the vicinity of the test panels.

The wind conditions prevalent during this series of tests varied from still to light breezes. No corrections were made for changes in wind intensity during the course of the test, but the results of tests during which the wind was too strong or gusty or during which the incident

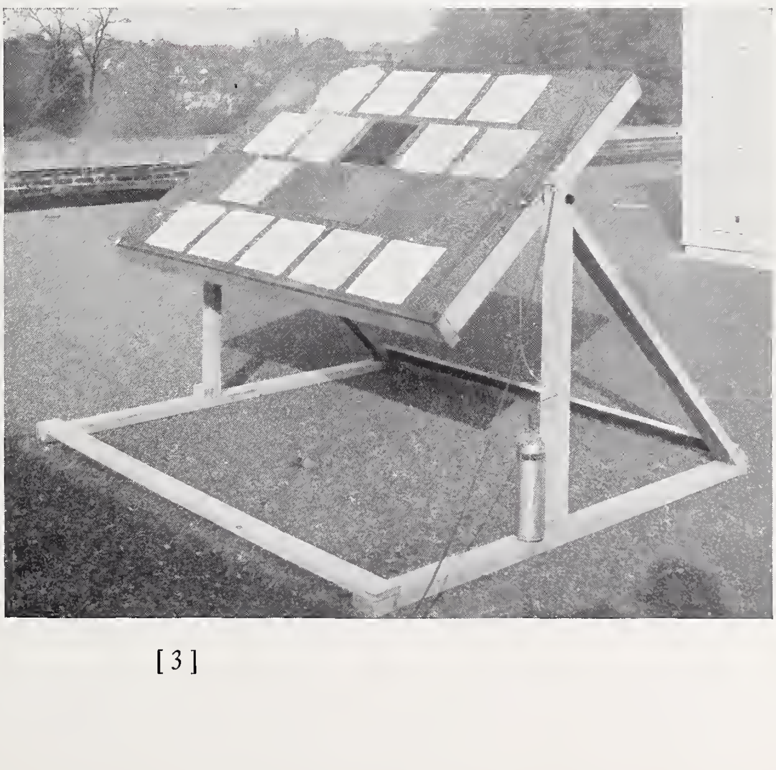

FIGURE 1.—*View of the apparatus and arrangement of the test surfaces.*

solar radiation was varying rapidly because of clouds were disregarded.

A Leeds & Northrup type *K* potentiometer was used for measuring thermocouple electromotive forces.

IV. RESULTS

Table 1 shows the observed average difference between the surface temperature and the ambient air temperature for each material or surface tested. Table 2 contains the same data but in a different form. Here the difference between surface temperature and air temperature for the lampblack coating is arbitrarily called 100, and the air-to-surface temperature differences for the other materials are altered proportionately.

TABLE 1.—*Daily mean rise in temperature in degrees Fahrenheit of test panels exposed to the sun*

Date (1939)	Aug. 2	Aug. 3	Aug. 1	July 31	Aug. 7
Panel inclination from horizontal	90°	90°	60°	45°	30°
	°*F*	°*F*	°*F*	°*F*	°*F*
Black (lampblack)	20.9	21.0	37.4	46.3	48.5
Galvanized iron	16.1	15.3	28.1	32.0	37.7
Roofing shingle, aluminum	19.4	20.2	34.1	40.7	41.6
Roofing shingle, green	19.5	20.7	33.3	41.3	43.4
Roofing shingle, red	21.5	23.1	37.2	44.8	46.0
Aluminum foil	9.8	8.3	15.0	17.3	19.7
White road-marking paint	12.3	12.1	19.7	22.9	24.7
Aluminum paint	14.6	14.5	24.4	29.0	29.3
Glossy white paint	8.9	7.9	12.1	13.0	15.5
Flat white paint	9.1	8.3	13.2	15.6	17.2
Ivory paint	10.2	9.3	14.9	16.8	19.2
Canary-yellow paint	10.9	10.4	16.7	19.2	21.6
Pearl-gray paint	13.3	13.7	20.3	24.3	25.6
Silver-gray paint	13.9	14.2	20.3	24.6	26.3
Light lead paint	15.1	15.2	22.9	27.4	29.7
Slate paint	16.8	17.1	26.7	32.4	35.4
Medium-green paint (trim color)	20.4	20.5	35.3	42.7	46.3

The air-to-surface temperature difference for a surface has been called the temperature rise of the surface and the results show that if the sun intensity varies, the temperature rise of any surface is a fairly constant fraction of the temperature rise of the lampblack surface. It should therefore be possible to "rate" another surface material in terms of the ratio of its temperature rise to that of a lampblack surface.

Table 2 shows that some roofing materials were heated almost as much as the black surface. There appears to be little difference between roofing felts of different colors. Although the roofing felt painted with aluminum paint was the coolest of the three roofing felts tested, the difference between them was small and of the order of the uncertainty of measurement.

TABLE 2.—*Relative rise in temperature of test panels exposed to the sun*

[Black taken as 100]

Date (1939)	Aug. 2	Aug. 3	Aug. 1	July 31	Aug. 7
Panel inclination from horizontal	90°	90°	60°	45°	30°
Black (lampblack)	100	100	100	100	100
Galvanized iron	77	73	75	69	78
Roofing shingles, aluminum	93	96	91	88	86
Roofing shingles, green	93	99	89	89	90
Roofing shingles, red	103	110	100	97	95
Aluminum foil	47	40	40	37	41
White road-marking paint	59	58	53	49	51
Aluminum paint	70	69	65	63	60
Glossy white paint	43	38	32	28	31
Flat white paint	44	40	35	34	35
Ivory paint	49	44	30	36	40
Canary-yellow paint	52	50	45	41	45
Pearl-gray paint	64	65	54	53	53
Silver-gray paint	67	68	54	53	54
Light lead paint	72	72	61	59	61
Slate paint	80	82	71	70	73
Medium green (trim color)	98	98	94	92	96

Aluminum foil was undoubtedly the best reflector of all the surfaces tested, but it proved to be less effective than either of the two white wall paints from the standpoint of coolness. This is not as surprising as it may seem at first because the aluminum foil has very poor emissivity at long wavelengths, whereas the paints are comparatively good radiators and can emit much heat by radiation.

Aluminum paint was definitely inferior to aluminum foil and to most of the house paints. The aluminum paint used in the test was freshly made. Spar varnish was used as the vehicle. No attempt was made to test aluminum paint made with other vehicles. Values other than those obtained are possible if amyl acetate or some other vehicle is used in the aluminum paint.

The paints gave fairly uniform results. The surface which remained coolest was that covered with glossy white paint. This surface had a temperature rise of about one-third as much as the black surface. Flat white paint produced the second coolest surface, with a temperature rise only slightly higher than that covered with glossy white paint. Darker paints tried produced warmer surfaces. The different shades of gray produced the warmest surfaces of all the house wall paints tested. The one trim color tested, a medium green, produced the warmest surface of all the paints. This surface attained nearly the same temperature as the black surface.

The results indicate in general that the relative heating by the sun of different house paints can be foretold approximately by the darkness of the paint because practically all house paints radiate heat at about the same rate at long wavelengths, whereas the darker colored paints absorb a higher percentage of the radiation from the sun.

The fact that the surface covered with green trim paint was warmed by the sun more than that covered with gray paint and nearly as much as the black surface is of interest because green and similar dark colors are frequently used on shutters. If shutters are habitually closed for protection against the sun at midday, a lighter color might be more desirable.

Metallic aluminum foil was less effective as a production against sun than white paint, but if the conditions were such that heat absorbed was rapidly conducted away, as for example in the case of a gasoline storage tank, the loss of heat by radiation would become less important, since the rise in temperature in the latter case is small, and a good reflector, such as aluminum foil, might be the more valuable because the reflecting property and not the ability of the surface to reradiate heat could have the predominating influence.

Of the roofing surfaces the plain galvanized iron proved to be the coolest, although not particularly cool. The more common felt roofing rolls covered with crushed slate were found to be almost as warm as the black surface even when the coloring of the granules was aluminum paint. This is as one would expect because a roughened surface is a good absorber of radiant energy.

No tests were made on stained wood shingles, but, on the basis of the results obtained from the tests of paints, it is expected that they would be little, if any, cooler than the roofing rolls.

The results of the tests indicate that the best surface for protection against heat from the sun would be some smooth covering painted white. This would unquestionably be an unusual practice and moreover, frequent repainting would probably be necessary to maintain the effectiveness of the surface.

In addition to the above, as an incidental study, measurements of the surface temperatures when the surfaces were in the horizontal position were made at night. It was expected that the radiation to the clear night sky by the surfaces would reduce the surface temperatures below the air temperature. The temperature of the black panel and of all the surfaces covered with house paints dropped to a point nearly 13 degrees F. below the air temperature. The aluminum foil surface was the warmest, being about 7 degrees F. below the air temperature, while the temperatures of the surfaces with aluminum paint, traffic road paint, and galvanized iron were about 11 degrees F. below the air temperature. These observations have no direct bearing on the protection against solar heat but are of interest in connection with insulation of houses against loss of heat in winter. In general, surfaces which were good radiators of energy at long wavelength were the coolest at night.

The observations on the night cooling of the surfaces by radiation to the sky are not by any means complete, but they indicate that, at least in the case of roofs, the radiation of heat to the sky may reduce the surface temperature considerably below the air temperature and hence slightly increase the loss of heat from the house at night. The materials used in this investigation were new, and the surfaces were clean when the observations were made. The results, therefore, contain no information on what the relative effectivenesses of the various surfaces in resisting heating by the sun would be after a period of use during which corrosion or soiling occurred. Oxidation of the aluminum-foil surface or of the galvanized-iron surface, for instance, would render them less effective in resisting heating by the sun during the day and would cause them to cool more rapidly by radiation at night. Soiling of the white painted surfaces would have a similar effect on them.

WASHINGTON, JULY 22, 1940.

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