COMPARISON OF WHITE VERSUS BLACK SURFACES FOR ENERGY CONSERVATION

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This paper discusses the long-term energy performance of various roofing systems. Specific attention is paid to the effects of dark-colored membranes versus light-colored membranes or ballasted membranes.

A goal of this paper is to propose simple methods that can be used by a roof system designer to approximate the added energy required to heat and air condition facilities roofed with various elastomeric/plastomeric roofing systems.

BLACK VS WHITE ROOFING MEMBRANES

The majority of elastomeric/plastomeric single-ply membranes used in the United States are black, or more accurately, gray-black.

The estimated commercial low-slope roofing market in the United States for 1985 was:

■ talc gray-black EPDM non-ballasted	160 million ft^2
■ black EPDM non-ballasted	10 million ft^2
■ talc gray-black EPDM ballasted	465 million ft^2
■ white EPDM	10 million ft^2
■ white CSPE	75 million ft^2
■ white CPE	45 million ft^2

In general, the question in the industry has related to the effect of light-colored roof surfaces on air conditioning (cooling) cost during the warmer months.

The problem becomes one for the designer: how to make "reasonable" estimates of the added energy required to heat/cool facilities roofed with various systems. Accurate estimates, or even reasonable estimates, become difficult because of the following variables:

1. Color changes caused by aging (weathering) of the membrane.
2. Color changes caused by normal dirt pick-up on the surface of the membrane.
3. Color changes caused by biological attack and/or industrial contamination of the membrane surface.
4. The amount of radiation available from the sun throughout the year.
5. The cooling effect of wind and light breezes on the roofing system during periods of solar radiation.
6. The insulation effect of snow cover on the membranes during the heating season.

For the purpose of this study, the effect of solar heating in the winter months on an exposed black membrane is being ignored. Although real, it is difficult to estimate the effects of variables 5 and 6 (wind and snow cover). A protective snow cover will remain on a white roof longer than a black roof, especially if the roofing system is insulated from the heated interior of the building. In effect, the net economic impact of the membrane's winter heat absorption is minimized when a good roofing system is designed with an insulation rating of R10 or higher, and when a reasonably efficient heating system is used.

EXPERIMENTAL DESIGN

To estimate the heat flow caused by various-colored membranes, seven roofing test sections were assembled and sent to southern Florida for solar exposure analysis. The insulation in the panels was rated R11. The panels were free-mounted at a 5° angle, facing south. Therefore, the temperature on the bottom of the panel was estimated to be near the shaded ambient temperature. A thermocouple was located directly under the membrane, 6 inches from the edges (see detail of test sections in Figure 1).

- Test Panel No. 1 was covered with new factory talc black EPDM sheeting.
- Test Panel No. 2 was covered with four-year-old, talc black EPDM sheeting that had been installed on a non-ponded roof in Carlisle, Pa. for four years.
- Test Panel No. 3 was a new, white EPDM membrane.
- Test Panel No. 4 was a two-year-old, white EPDM membrane that had been installed on a well-sloped, non-ponded roof in Carlisle, Pa. for two years.
- Test Panel No. 5 was a new, beige-colored EPDM membrane which, by field tests, approximates the solar absorption of a very dirty or oxidized white roof and/or a typical ballasted loose-laid system.
- Test Panel No. 6 was covered with a new, white CPE membrane.
- Test Panel No. 7 was covered with a new, white CSPE membrane.

The maximum temperature recorded for a talc black membrane was 178°F. The maximum temperature recorded for a white membrane was 125°F, and 135°F for a beige membrane. The lowest temperature recorded for the 12-hour period was 73°F.

The panels were exposed to high solar conditions, light winds and high ambient temperatures. The combination of these three factors would be rated as severe summer conditions for most climates in the U.S. market.

The panels were exposed from Sept. 5, 1986 through Sept. 19, 1986. The weather conditions and average membrane temperatures are reported in Tables IV and V. These data indicate the average temperature of the membrane for the 12-hour period between 8 a.m. and 8 p.m.

Using these average temperatures, it is possible to approximate the theoretical heat flow and then to estimate costs.

CALCULATIONS

The theoretical heat flow can be determined for the various roofing systems if we know:

- the roof size (RS)
- the average temperature difference between the interior of the building and the membrane (ATD)
- the number of hours on which the average was based (HR)
- the conductance of the roofing system (C). For this paper

$$C = \frac{BTU}{HR \cdot {}^{\circ}F \cdot Ft^2} \quad \text{or} \quad \frac{I}{R}$$

therefore

BTU per day = RS × ATD × HR × C

Once the BTU flow per day is known, then the dollar cost can be calculated by determining the energy efficiency rates (EER) for the air conditioner units:

$$EER = \frac{\text{BTU produced}}{\text{WATT input}}$$

The above equations can be used to approximate the theoretical energy costs for any system. The designer has to estimate the average membrane temperature for the period under study. For discussion purposes, the following was assumed:

Roof size	= 10,000 ft^2
Interior temperature	= 78°F
Number of solar hours per day	= 12 hours
Conductance	= 0.10 (an R of 10)
Cost of one BTU	= $\$1.0 \times 10^{-5}$ based on an EER of 10 for an air conditioner and electricity cost of $0.10/KW or $0.0001 per watt.

As an example, the data in Table 4 can be used to approximate the added air conditioning costs caused by solar energy being absorbed by the roofing system. The data is for the four-year-old, black talc EPDM membrane on Sept. 5, 1986. Roof size for this example is 10,000 ft^2 with an R10 insulation system. The interior temperature is 78°F.

BTU/DAY	RS × ATD × HR × C
RS	10,000 ft^2 roof size
ATD	110°F average membrane temperature minus 78°F interior temperature equals 32°F average temperature difference
HR	12 hours (average based on 12 hours)
C	0.10 BTU/(HR•°F•Ft^2) for a R10 roof system
BTU/DAY	$10{,}000\ ft^2 \times 32°F \times 12\ HR \times \frac{0.10\ BTU}{HR \cdot °F \cdot Ft^2}$
BTU/Day	384,000
Cost of one BTU	= $\$1.0 \times 10^{-5}$ based on an EER of 10 for an air conditioner and an electricity cost of $0.10/KW or $0.0001 per watt.
COST/DAY	$384{,}000\ \frac{BTU}{DAY} \times \frac{\$1.0 \times 10^{-5}}{BTU} = \$3.84/day$

Using the above assumptions, it is easy to mathematically adjust the data to suit various conditions. For example:

- If the **R** value was increased to 20 from 10, the cost per day would be $1.92 instead of $3.84.
- If the **R** value was decreased from 10 to 5, the cost per day would be $7.68 instead of $3.84.
- If the R value was increased to 15 and the cost of electricity was $.05/KW, then the cost would be $1.28 per day for 10,000 ft^2 instead of $3.84.

When the data is averaged for the 15 September days in south Florida, the four-year-old, talc black EPDM had an average daily membrane daylight temperature of 112°F. The two-year-old, white EPDM had an average daily membrane temperature of 93°F. Using the previous model, the energy costs for air conditioning caused by solar radiation would be as follows:

Building size	= 10,000 ft^2
Internal temperature	= 78°F
Number of daily hours of solar radiation	= 12 hours
Cost of electricity	= $0.10 per KW or $.0001 per watt
EER of AC unit	= 10, therefore, 1 BTU costs $.00001

10,000 ft^2 roof system	Black membrane	White membrane	Difference
R 1	$40.80	$18.00	$22.80
R 5	$ 8.16	$ 3.60	$ 4.56
R 10	$ 4.08	$ 1.80	$ 2.28
R 15	$ 2.72	$ 1.20	$ 1.52
R 20	$ 2.04	$ .90	$ 1.14
R 30	$ 1.36	$ .60	$ .76

Table 1 Daily energy cost due to roof design only

The beige color was used in the experiment to approximate a very dirty white membrane on a dead-flat roof. Also, the beige color approximates the temperature readings obtained on a roof using 1/2-inch, tan river-washed ballast over a talc black EPDM membrane.

Using the same assumptions used for Table 1, a beige membrane, a dirty white membrane, or a ballasted system would have an average daily membrane temperature of 98°F. The energy costs for air conditioning would be as follows:

10,000 ft^2 roof system	Black membrane	Ballasted or dirty white	Difference
R 1	$40.80	$24.00	$16.80
R 5	$ 8.16	$ 4.80	$ 3.36
R 10	$ 4.08	$ 2.40	$ 1.68
R 15	$ 2.72	$ 1.60	$ 1.12
R 20	$ 2.04	$ 1.20	$ .84
R 30	$ 1.36	$ .80	$ .56

Table 2 Daily energy cost due to roof design only

The difference between a clean white membrane versus a dirty white membrane on a dead-flat roof or a ballasted system can be quantified in Table 3 as follows:

10,000 ft² roofing system	Beige, dirty white or ballasted membrane	White membrane	Difference
R 1	$24.00	$18.00	$ 6.00
R 5	$ 4.80	$ 3.60	$ 1.20
R 10	$ 2.40	$ 1.80	$ .60
R 15	$ 1.60	$ 1.20	$ .40
R 20	$ 1.20	$ .90	$ .30
R 30	$ .80	$ .60	$ .20

Table 3 *Daily energy cost due to roof design only*

CONCLUSIONS

The data indicates, as expected, that a dark membrane absorbs more radiant energy than a light-colored membrane. Also, the use of traditional insulation systems will reduce the heat flow by a factor equal to the R rating of the roofing system.

The use of simple equations allows the roof designer to approximate the economics of a roof system for various climates. The designer must make some assumptions concerning average membrane temperatures; however, the economic error that may be introduced is generally small when designing roof systems of R10 or higher.

In general, when designing roof systems with less than a R10 rating, the economic assumptions made by using these simple methods should be confirmed. If possible, field data should be obtained from the climatic region in which the roofing system is to be used.

DISCUSSION

Some of the following considerations are not addressed in the paper, which may come to mind when calculating the total yearly savings.

First, after the sun has gone down, both light and dark colored membranes will be at approximately the same temperature. Therefore, the ambient temperature outside will affect the heat load or cooling load on a building. For example, in a desert climate, the low outside temperature for a 24-hour period may be 10°F to 15°F higher than the inside temperature. Therefore, a building with a dark membrane and a higher, R10 insulation rating could possibly have a 24-hour advantage over a light-colored system with an R5 insulation system. Normally, the R10 system will have an advantage during the months when heating is required.

A white membrane will reduce the energy required to cool a building. However, if the white system has a higher installed cost, it **may** be more cost effective to add insulation to the lower cost black system which will be an advantage 24 hours a day, 365 days a year. The "may" needs to be emphasized, because in some buildings more insulation could add to the energy load. It is possible that a poorly insulation roof could help remove a large internal heat load, which otherwise has to be handled by the air conditioning system. Other considerations come into play, such as dew points. An R3 system may make sense in Michigan to help remove an excessive internal heat load in the summer, but other factors may become a problem, such as excessive condensation in or on the bottom of the R3 roofing system during the winter months.

Open-sky effects, which may reduce the membrane temperature below outside ambient temperature, can be estimated. Normally this is only a factor on clear, calm nights. The radiation of dark- and light-colored membranes into the open sky is equal for calculation purposes. The open-sky effect is normally not significant when adequate insulation is used.

What is the advantage of a dark membrane in the winter months? It is fair to assume that the black membrane will be 5°F to 15°F warmer than a white membrane during sunny hours. This advantage is reduced by winds, snow cover, and solar intensity. Snow will be present on a white membrane longer; therefore, the insulation effect of snow must be factored in. Again, all of these conditions are complex and in effect are minimized when adequate insulation is used.

What is the effect of aging on a white membrane versus reflectivity? White surfaces will become darker as the surface of the white membrane crazes and accumulates dirt and/or biological growth. It is difficult to estimate this; however, the beige test panel probably approximates a worst-case condition.

What is the effect of a factory talc black EPDM membrane versus a clean, jet-black sheet? Previous tests indicate that the factory talc membranes based in this study (new or aged four years on a roof) will have a peak temperature of 10°F to 20°F lower than a jet-black membrane. The average 12-hour temperatures of a jet-black membrane may be 5°F to 10°F higher than a talc gray-black membrane.

RECOMMENDATIONS

Light-color (white) systems can be used to reduce air conditioning costs, or when desired for aesthetic reasons. To help preserve the reflectivity and aesthetics of the system, the roof should be sloped to drain to reduce ponding, biological growth, and dirt accumulation.

This study indicates that a significant air conditioning energy savings can be achieved for both light-colored and dark-colored membranes if the roofing system is insulated to R10 or higher. A light color, white membrane, or a ballasted system, may be economically justified for high-solar, high-heat climates, but the justification should probably be based on the assumption that at least a roofing system insulated to R10 or higher will be used under all membranes.

ACKNOWLEDGEMENT

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Date	Factory talc black EPDM New			Factory talc black EPDM 4 year old			New white EPDM			2 year old white EPDM			New beige EPDM			New CPE			New CSPE		
	Avg	(High	Low)	Avg	(High	Low)	Avg	(High	Low)	Avg	(High	Low)	Avg	(High	Low)	Avg	(High	Low)	Avg	(High	Low)
9/ 5/86	112	(162	77)	110	(147	77)	92	(109	75)	93	(110	75)	96	(124	76)	88	(101	75)	91	(106	75)
9/ 6/86	115	(169	75)	113	(171	73)	93	(123	75)	93	(121	73)	97	(131	73)	88	(109	73)	91	(116	74)
9/ 7/86	116	(175	77)	101	(159	75)	91	(119	75)	91	(117	75)	97	(131	75)	87	(106	75)	85	(95	75)
9/ 8/86	94	(163	73)	91	(141	73)	85	(117	73)	86	(121	73)	89	(135	73)	83	(107	73)	81	(100	73)
9/ 9/86	112	(158	79)	110	(161	75)	93	(113	73)	95	(117	74)	100	(132	74)	91	(107	73)	85	(96	73)
9/10/86	115	(151	79)	118	(157	78)	96	(113	77)	96	(114	77)	101	(125	78)	92	(106	77)	91	(106	77)
9/11/86	123	(178	75)	125	(163	73)	99	(122	75)	99	(119	74)	106	(131	74)	94	(107	75)	96	(114	74)
9/12/86	113	(146	77)	119	(163	76)	95	(108	77)	97	(116	76)	102	(123	76)	92	(107	76)	94	(109	77)
9/13/86	112	(139	74)	115	(145	73)	94	(109	74)	94	(108	73)	98	(117	73)	89	(103	74)	91	(104	73)
9/14/86	115	(153	78)	121	(163	77)	95	(115	78)	97	(117	77)	103	(128	77)	92	(109	77)	94	(106	78)
9/15/86	114	(150	75)	123	(165	75)	96	(114	75)	98	(118	75)	104	(130	75)	95	(110	75)	95	(112	75)
9/16/86	114	(154	79)	122	(170	79)	95	(113	79)	98	(121	79)	105	(132	78)	94	(109	79)	90	(104	78)
9/17/86	98	(129	78)	99	(135	75)	85	(105	75)	86	(108	75)	90	(114	75)	83	(101	75)	84	(103	75)
9/18/86	100	(146	77)	105	(165	77)	85	(110	77)	87	(117	77)	92	(129	77)	84	(111	77)	82	(107	77)
9/19/86	103	(139	75)	109	(161	74)	91	(112	74)	92	(115	73)	96	(127	74)	90	(109	73)	94	(125	73)
15 days	110	(178	73)	112	(170	73)	92	(122	73)	93	(121	73)	98	(135	73)	90	(110	73)	91	(125	73)

Table 4 *12-hour membrane temperature °F (8 a.m.–8 p.m.)*

Day	Ambient temp °F Avg (High-Low)			Ambient R.H. Avg (High-Low)			Inches of rain	Avg wind MPH	*Solar radiation 5° south langleys
9/ 5/86	82	(93	75)	79	(94	58)	—	8.6	557
9/ 6/86	82	(93	75)	82	(94	52)	.24	8.3	562
9/ 7/86	81	(91	75)	82	(93	54)	.19	4.8	497
9/ 8/86	82	(90	75)	87	(96	72)	—	6.9	301
9/ 9/86	82	(90	73)	82	(96	57)	.16	4.2	609
9/10/86	82	(90	75)	79	(94	58)	—	4.2	536
9/11/86	84	(90	81)	72	(86	55)	—	6.6	619
9/12/86	82	(90	75)	76	(94	56)	—	5.9	473
9/13/86	82	(90	73)	73	(94	50)	—	4.0	565
9/14/86	81	(90	73)	72	(94	51)	—	4.5	572
9/15/86	84	(93	79)	77	(94	54)	—	4.3	568
9/16/86	84	(93	79)	77	(96	56)	TR	4.5	532
9/17/86	79	(88	75)	81	(94	60)	.04	4.2	365
9/18/86	81	(90	73)	76	(94	56)	—	4.8	492
9/19/86	82	(88	75)	75	(93	58)	TR	3.5	392

Table 5 *Weather conditions*

Solar radiation as measured above does not take into consideration the effect of winds on the membranes or the ability of the membrane to reflect short-wave energy or radiate long-wave energy. Therefore, there is no direct correlation between available solar energy and the temperature of the membrane that is exposed to the elements.

For climatic details in various parts of the United States, a "Climatic Atlas of the United States" is available from the National Climatic Data Center, Asheville, N. C. 704/257-6682. The publication covers variations of temperature, precipitation, wind, sunshine, sky cover, heating degree days and solar radiation.

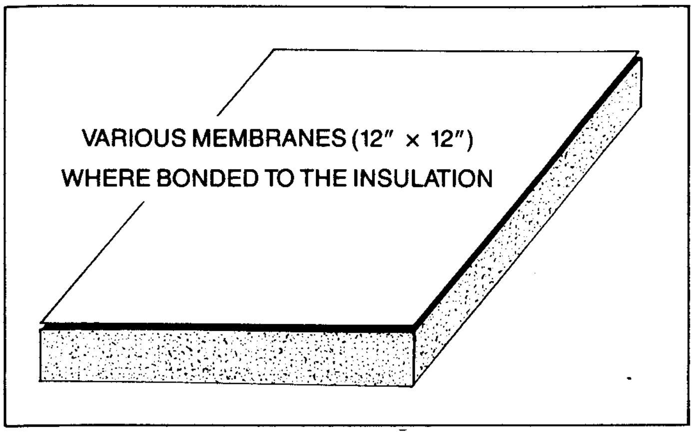

Figure 1 *New polyisocyanurate R11 insulation 12" × 12" × 1.75"*
The thermocouple was located directly under the membrane in the center of the panel.

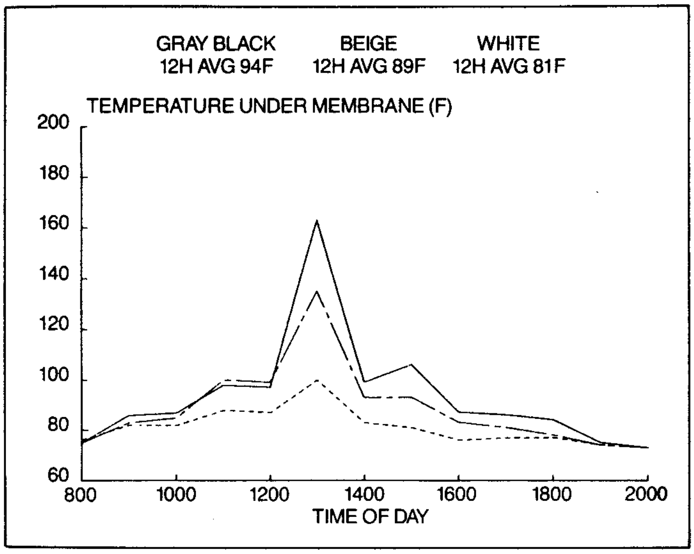

Figure 2 *Low heat absorption day*
Sept. 8, 1986 in south Florida

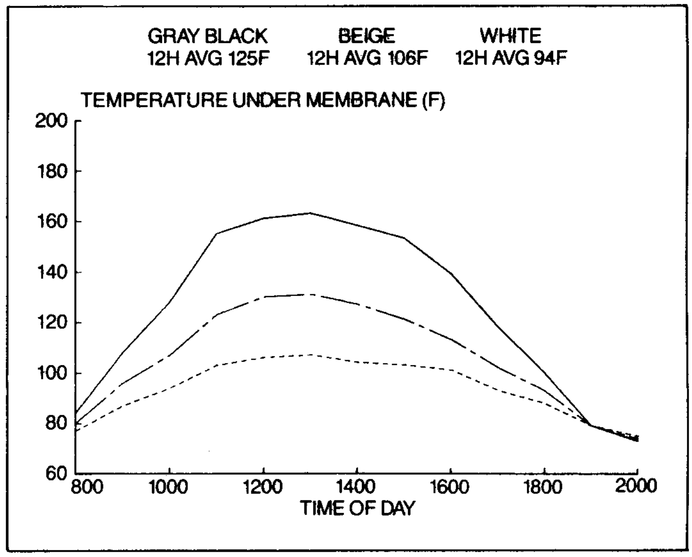

Figure 3 *High heat absorption day*
Sept. 11, 1986 in south Florida