From the NRCA/NBS PROCEEDINGS OF THE SYMPOSIUM ON ROOFING TECHNOLOGY, Sept 1977 PAPER NUMBER 32

FIELD MEASUREMENT OF ASPHALT TEMPERATURES DURING COLD WEATHER CONSTRUCTION OF BUR SYSTEMS

R. M. Dupuis, J. W. Lee, and J. E. Johnson
Engineering Research Consultants, Inc., Madison, Wisconsin, U.S.A.

I. INTRODUCTION

Construction costs, bidding pressures, and overhead expenses are forcing roofing contractors to apply built-up roofs during cold weather. Cold weather application problems are thus of growing concern to the roofing industry.

Ideally, a roofing specification should provide for cold weather construction. Material selection and behavior, chill factor, construction difficulty, and built-up roof system performance should all be considered together with the effects of cold weather application. Quantitative field data are not, however, available for use in such a specification.

The purpose of this report is to present cold-weather application data, based on a field research program. This program involved the instrumentation of substrate, rigid insulation, and various plies of built-up roofing with rapid-response thermocouples, to record quantitative data on such cold-weather construction factors as wind, chill factor, etc. Based on the information generated from the field studies, an empirical relation was established for hot asphalt temperature decay time vs. peak application temperature in the builtup roof system. We also performed laboratory experiments to determine the adhesive behavior of a cold-weather, builtup roof membrane with respect to attachment problems.

The field and laboratory data presented in the following sections should provide the basis for a cold-weather roofing specification. Here, in summary, are our key conclusions:

- Hot asphalt applied at subfeezing temperatures to light gauge steel decks congeals so rapidly that mechanical fastening is probably the only effective technique for securely anchoring the insulation.
- Rapid temperature decay of hot asphalt makes good adhesion extremely difficult to attain (as indicated by a fivefold increase in laboratory-constructed membranes' bonding failures for samples constructed at 25°F vs. samples constructed at room temperature).
- To assure good bond, coated felt base sheets must be applied in roughly one-third the time allowed for saturated felts after the asphalt temperature starts dropping in cold weather.

II. INSTRUMENTATION

Temperature measurements were made with kapton-insulated copper/constantan thermocouples. A solid-state amplifying thermometer system was used in conjunction with the thermocouples. An automatic electronic temperature reference is utilized in this system.

Several types of thermocouple configurations were used. A flexible probe measured interply asphalt temperatures. These probes had a spherical tip with a diameter of 0.029". A gold alloy circular contact probe with 0.25-in. surface diameter, made surface measurements. All flexible probes were severed as the built-up roof construction progressed, eventually becoming sealed into the roof system.

A dual pen recorder was used in conjunction with the thermocouples. This 10" strip chart recorder has a pen response of 0.05 seconds per inch. A linear chart speed of 16 inches per minute was used during the application of asphalt and felt.

For purposes of calibration, a linear signal generator was designed and built to interface the amplifying thermometer with the strip chart recorder. This signal generator has the capability of spanning −50°C to a +300°C. All temperature measurements were calibrated in the Celsius scale.

Wind measurements were taken with a portable anemometer. A minimum of 4-5 mph is required to overcome mechanical and electrical inertia for this instrument. This particular device is hand held and was easily adaptable to roof-top work at any location.

III. EXPERIMENTAL RESULTS

A. Field Study

The four field sites selected for cold weather roofing observations were located in the Madison and Milwaukee areas. Attempts were made to observe steel, wood and gypsum decks. (No poured concrete decks were available for study).

The built-up roof system details for each study site are listed in Table 1. All bitumens utilized on these jobs were identified in the field as steep asphalts (ASTM D 312-71 Type III), with a 190°F melt point. In addition, no vapor barriers were specified for any of these roofs.

In conducting this study the normal field procedures were as follows:

1. Examine and record type and condition of the roofing materials including insulation.
2. Record ambient air temperature and wind speed data at one foot above the roof deck level.
3. Prepare flexible probes for embedment in substrate or built-up roof membrane.
4. Lay out flexible probes perpendicular to the direction of the felts.(Mechanically fasten probes into the built-up roof system.)
5. Gather field data in the late morning or early afternoon. (Roofing crews were given time to "work in" the equipment.)
6. Monitor corresponding asphalt temperatures in roof-top application equipment and ground storage vessels.
7. Cut built-up roof membrane samples.

The four tested roofs' asphalt temperature variations with time are shown in Figures 1, 2, 3 and 4. A brief discussion of each roof site follows:

1. Lake Mills Site

Hand mopping was used during the construction of this roof since roof top heating and ventilating units obstructed machine application. Perlite insulation boards were mechanically anchored around the perimeter of the roof. Along with the temperature decay curve, Figure 1 details the built-up roof system construction as well as the weather data. As shown in Figure 1, rapid cool-off rates were experienced during the first phase of built-up roof construction. As more plies were added to the roof, temperature decay time increased.

2. Madison Site

This was a reroofing project on an existing office building. Asphalt temperature decay curve is shown in Figure 2. Again, due to roof-top obstructions and the need for phased construction, the asphalt was hand mopped. Composite perlite/urethane insulation board was nailed to the wood deck; hot bitumen was then applied to attach the coated base sheet. As shown in Figure 2, the cooling rates were highest during the construction of the initial plies. Ambient temperature was 20°F; wind-chill factor - 4°F.

3. McFarland Site

This was a protected membrane roof with roof deck of 2-in. gypsum plank, 2-ft. wide, with bulb-T's paralleling the planks' longitudinal direction. The bulb-T's were grouted in, giving a level deck surface for membrane construction. A 3-ply glass felt system was applied over the gypsum plank with Styrofoam insulation atop the 3-ply membrane. A total of four flexible probes were installed, two over the bulb-T's and two over the centerline of the gypsum board. Figure 3 shows the resulting temperature decay curve. The bulb-T peak application temperature did not reach that experienced by the centerline of the board.

4. Waukesha Site

The roof system was a 4-ply organic felt with fiber glass insulation and 22 gauge steel substrate. This job utilized machine application of asphalt and felts. The peak temperatures reached during the first phase of construction were very low, with rapid cool-off following (see Fig. 4). Again, as in the other studies, the final plies of built-up roof membrane construction experienced higher peak application temperature and correspondingly slower decay rates.

Machine application gave the most uniform asphalt temperature decay response. Figures 1 and 2 (representing hand mopping) display wide temperature fluctuations, whereas Figures 3 and 4 (representing machine application) display uniform decay curves. The variable temperatures associated with mopping are starkly evident in Figure 1. As the mop traversed back and forth over the probe system, erratic temperature spikes would occur. Machine application, however, has a relatively smooth temperature profile (see Figures 3 and 4).

It was possible to detect the "brooming" effect with the instrumentation system. Usually the broom followed right behind the machine or hand mop. In general, the temperature would peak and then begin a smoooth decay. If the brooming was lagging behind by 3-5 seconds, the temperature peak would maintain a plateau for 2-3 seconds before decay would occur. However, the decay rate was observed to be more rapid. This behavior was illustrated in Figure 2 for Probe #1 as well as the probe for the centerline of gypsum board in Figure 3.

B. Laboratory Work

To establish a base for the temperature decay characteristics and to qualitatively study the interply adhesion effectiveness for cold weather roofing construction, a laboratory study was carried out to augment the field-study results.

Temperature decay rates were also determined in the laboratory, using 1" wide and 12" long samples. Samples were made up of a coated base sheet and three 15# organic felts on perlite or fiber glass. Even though the flexible probes were very small, there is reason to believe that a 1" wide strip of membrane as laid up under laboratory conditions does experience edge cooling.

It was first observed that temperature decay constants for top of first ply were nominally twice as high as those for top of 15# plies and that the laboratory results were in general agreement with the field results. (Decay rates will be presented later.)

To check the interply adhesion effectiveness, a series of built-up roof membrane adhesion tests were conducted in the laboratory. Two inch diameter pieces of felt were die cut; three 15# organic felts and a coated base sheet were used in the construction of the samples. Eight samples of 4-ply membrane were constructed under laboratory conditions at room temperature. The 2" diameter built-up samples were adhered with steep asphalt to 2" diameter wood pulling blocks. These eight samples were used as control specimens.

A set of twenty-four samples with the same materials as the control samples were assembled in a cold chamber at 25°F. Again steep asphalt heated to 445°F was used as the bonding agent.

Since there is no standard test, all specimens were pulled in a tension machine at a rate of 0.1 inches per minute. The purpose of this test was to determine qualitatively the type of adhesion failure that would occur in samples prepared at low temperatures. Among the eight control-group specimens, one failure occurred from inadequate bonding of the coated base sheet; others failed from tearing of 15# plies or failure of the adhesive bond to the pulling block.

Of the twenty-four samples prepared in the cold environment, fifteen failed from poor coated base sheet bond. The remaining modes of failure were tearing of 15# plies or failure of adhesive bond to the pulling block.

These qualitative tests indicate that coated base sheets do experience a marked increase in bonding or adhesive failure when constructed in cold temperature environments.

IV. DISCUSSION

A. Material Behavior

Peak contact temperature is defined as the highest temperature recorded **during** asphalt application. Figure 5 presents the peak contact temperatures as they relate to asphalt temperatures **before** application, plus kettle (tanker) temperatures of asphalt stored at ground level. Peak contact temperatures generally fell below asphalt temperatures before application, by 50°F-75°F (see Fig. 5).

A short term temperature decay plot for asphalt applied to steel decks is shown in Figure 6. In this figure, two of the field observed decay curves are shown along with two curves obtained in laboratory work. Decay curves generally converge after seven seconds of decay time, regardless of peak contact temperature, according to Fig. 6.

This evidence of rapid temperature decay raises a question of adhesion. It is doubtful that effective adhesion of insulation to steel deck can be made uniformly, over an entire substrate system, during any cold weather roofing activity.

Due to the flexibility of 22 gauge steel deck, adhesion to some types of insulation may be a problem even under ideal field conditions. Consequently, mechanical anchoring should probably be considered during cold weather work for 22 gauge steel decks.

Long-term temperature decay behavior for asphalt applied to various insulation materials is shown in Figure 7. Perlite, perlite/urethane and fiber glass insulations were observed.

The highest temperature decay rates for the built-up roof membrane were experienced during the first ply phase of construction, as shown in Figures 1 and 4. In general, the cold weather effects of felt laying were very noticeable. Coated base sheets were quite stiff and required immediate brooming into the hot asphalt. By contrast, the 15# organic felts (vented) remained pliable and worked into the hot asphalt satisfactorily. The only noticeable problem with the 15# felt was during machine application in cold weather. Many tears would develop as the machine laid down a ply. The broken felt would require that a patch be made and the roll trimmed off to start anew on the machine. Consequently, temperature decays in the asphalt reservoirs of the felt laying machine would occur. Under ideal weather conditions the felt tearing would not pose such a problem.

B. Asphalt Temperature Decay Rate

The temperature decay data suggested an exponential decay curve. From Newton's Law of Cooling, the decay temperature can be expressed by Equation 1:

$$T = T_S + (T_O - T_S)e^{-K\tau}$$

where T is the asphalt temperature at time τ, with T_S the temperature of the surroundings, and T_O the initial temperature at $\tau = 0$.

Utilizing the data obtained in the cold weather field study, an exponential least squares curve fitting routine was used to determine the temperature decay constants k for the various field studies. A typical correlation coefficient of 0.91 resulted from the curve fitting process. Table 2 presents the observed temperature decay constants for the various systems including laboratory results. As shown in this table, temperature decay constants are largest for the inital phases of construction of the built-up roof. Decay constants for asphalt applied to steel deck were not calculated since the decay was too rapid.

Though it was not possible to draw a theoretical correlation between wind-chill factor and temperature decay constants, a general trend does exist. Wind-chill factor is an indication of potential heat loss relative to wind velocity, expressed in degrees Fahrenheit. Figure 8 shows a plot of temperature decay constants versus temperature due to wind chill for the three field study sites in this temperature range. The temperature decay constants as shown experience a rapid increase with lower equivalent wind chill temperatures for top of insulation and top of first ply.

C. Nominal Asphalt Temperature Decay Times

Using the temperature decay constants from Table 2, it is now possible to determine the nominal decay time, (i.e., the time required to reach a certain specified temperature from the peak contact temperature). Equation 1 can be solved for time τ, utilizing the temperature decay constant k, temperature of surroundings T_S, peak contact asphalt temperature T_O, and decay temperature T.

Since coated base sheets have a hard asphalt coating with a correspondingly high melt point (250°F +), a decaying temperature of 275°F can be considered a reasonable temperature at which good adhesion can still be attained. The decay time, which signifies the available time for good application, can be obtained from Equation 1, with the temperature of the surroundings, T_S, assumed as 20°F. Decay time can also be obtained for a decay temperature of 200°F, near the softening point of steep asphalt. For a k value of 179.0×10^{-4}/second, Equation 1 yields the curve as shown in Figure 9. Raising peak contact temperatures during cold weather increases decay time, which is necessary to adhere the interply bitumen and first felt ply.

A similar plot of nominal decay times can be determined for 15# felts used in the top plies. Figure 10 shows relative decay times needed to reach 275°F and 200°F respectively. Again, the peak contact temperature serves as the initial temperature T_O in Equation 1. The temperature of the surroundings T_S is assumed as 20°F. The temperature decay constant of 76.1×10^{-4}/second was used to derive the decay time curve shown in this figure.

Since 15# felts have a low melt point saturant, it is now quantitatively evident why coated base sheets experience more bonding problems in built-up roof membranes. The nominal decay time available as indicated in Figure 9 is much shorter than the decay time available for 15# felts as shown in Figure 10.

V. SUMMARY AND CONCLUSIONS

In this paper, quantitative as well as qualitative data were presented regarding the range of contact temperature, as well as the characteristics of temperature decay during the construction of a built-up roof. As a result of this study, the following observations were made:

1. The peak contact temperature during the application of asphalt is significantly lower than the asphalt temperature before application, which, in turn, is lower than the asphalt temperature in the kettle (tanker) at the ground level.
2. In general, after application, the asphalt temperature decayed rapidly. The most rapid decay was observed on light gauge steel deck substrates, indicating that mechanical fastening may be required for cold weather roofing construction on light gauge steel decks.
3. The temperature decay curve behaved quite closely to an exponential decay curve, as expected from Newton's Law of Cooling. The average decay constants were found to range from 76.1 for top ply construction to 179 for the first ply construction.
4. Field observed temperature decay time for upper plies is roughly three times longer than that of the first ply, allowing more time for the upper plies to bond together. This could explain why field investigations of roof membranes have found the upper plies loose and unattached to the coated base sheet.
5. Laboratory study indicated the twelve percent of the samples constructed under room temperature failed through bonding, compared to sixty-two percent for the samples constructed at 25°F. Problems of obtaining good

bonding under cold weather conditions were clearly indicated.

6. It was found that a definite relationship existed between the temperature decay rate and the wind chill factor. As the wind chill factor dropped, the decay rate would increase.

The data and observations presented in this paper threw some light on the temperature characteristics of asphalt during application. Despite their limited scope, the consistent results contribute significantly to the understanding of cold weather roof application.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Mr. Cyril Tilsen of Tilsen Roofing Company and Mr. Arthur Blodgett of Waukesha Asbestos Company for their cooperation and assistance in this study.

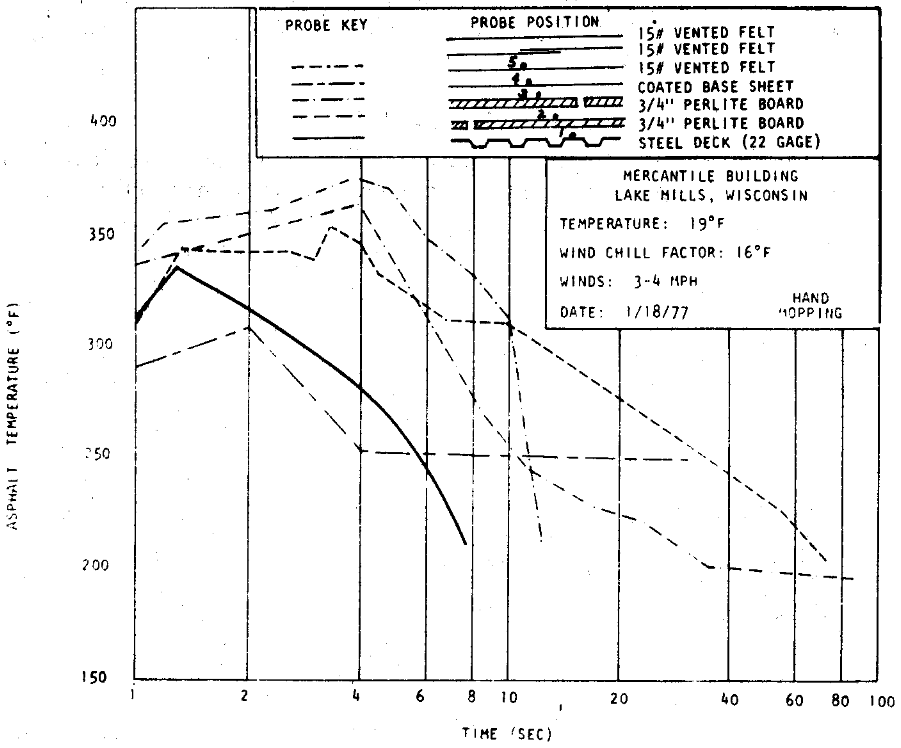

FIGURE 1 - ASPHALT TEMPERATURE DECAY - LAKE MILLS

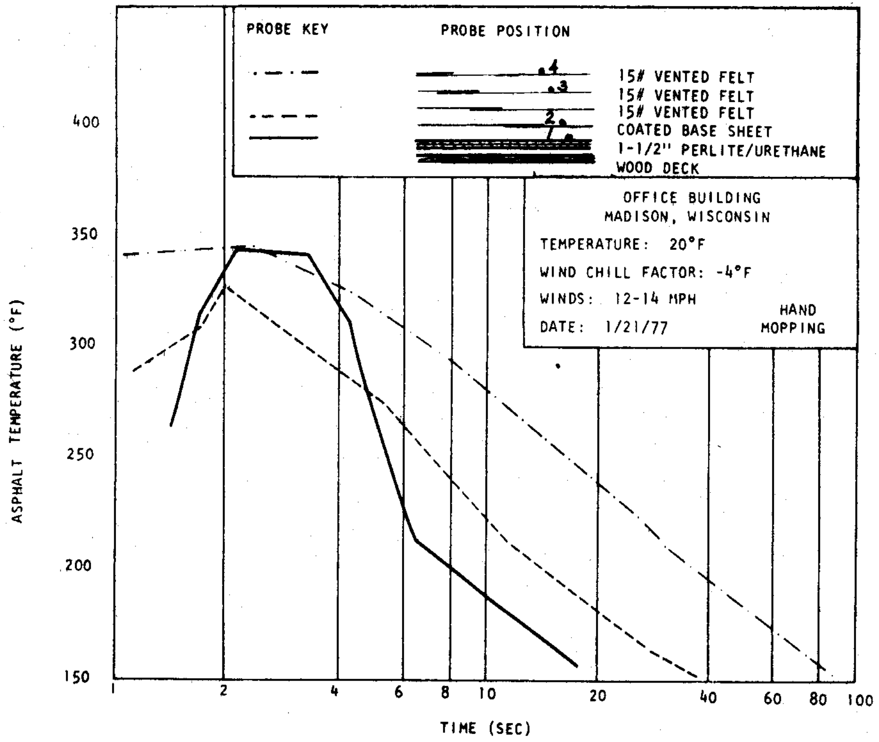

FIGURE 2 - ASPHALT TEMPERATURE DECAY - MADISON

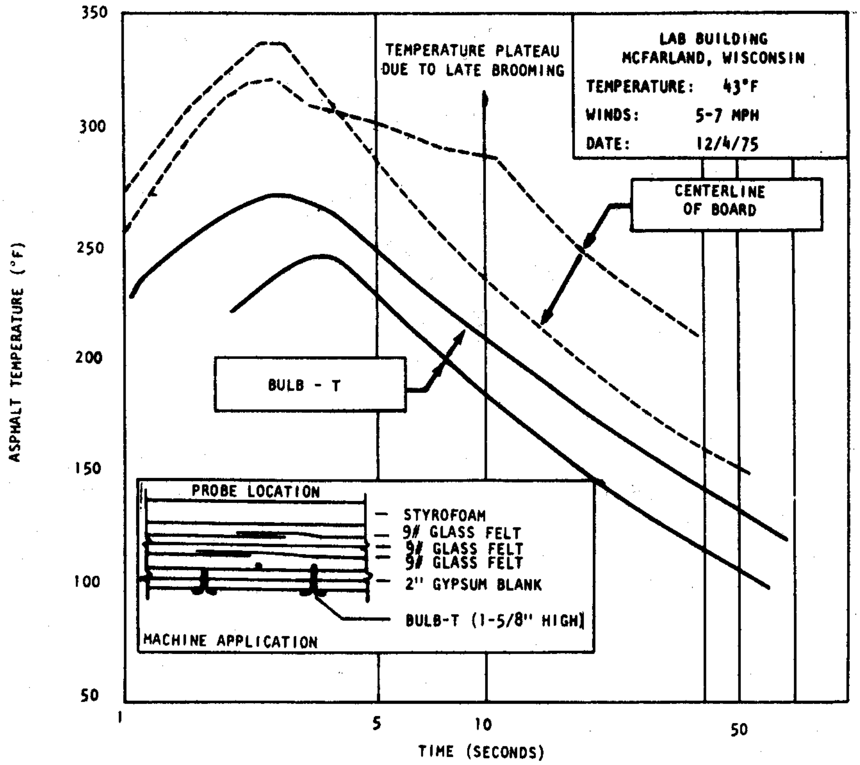

FIGURE 3 - ASPHALT TEMPERATURE DECAY - McFARLAND

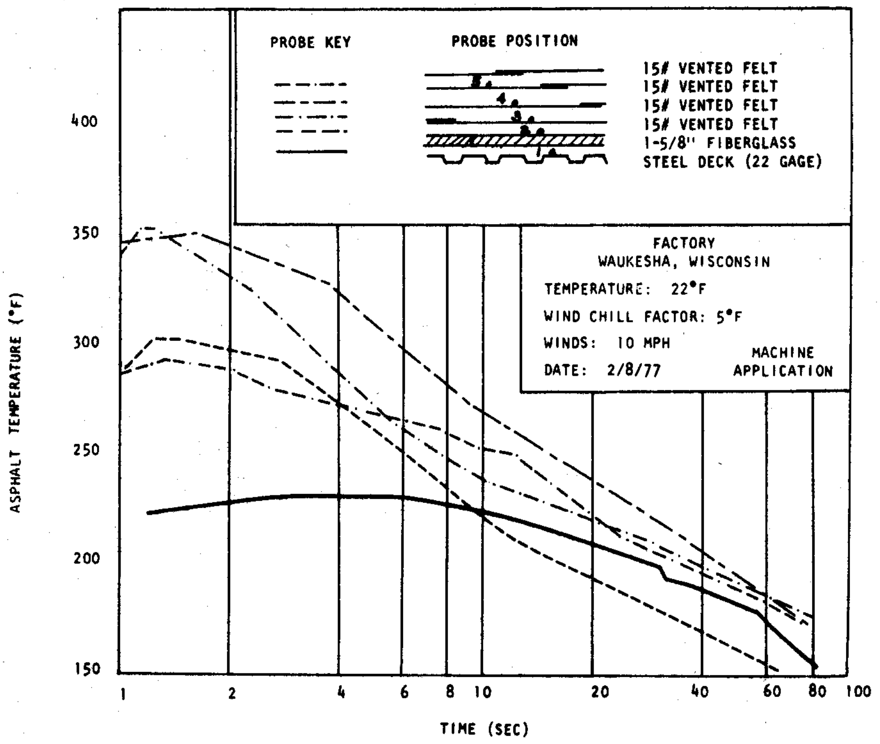

FIGURE 4 - ASPHALT TEMPERATURE DECAY - WAUKESHA

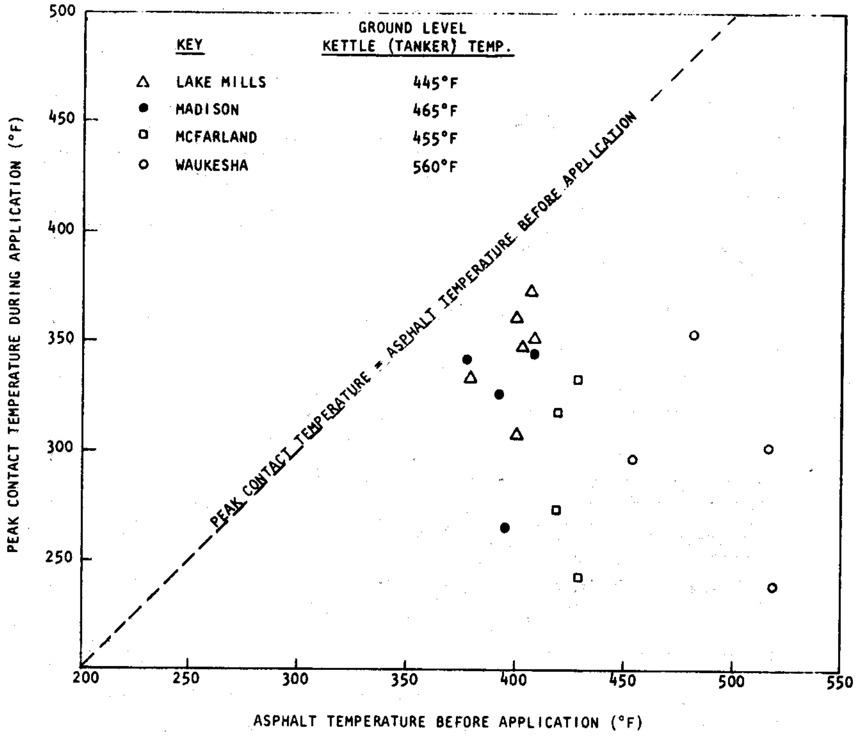

FIGURE 5

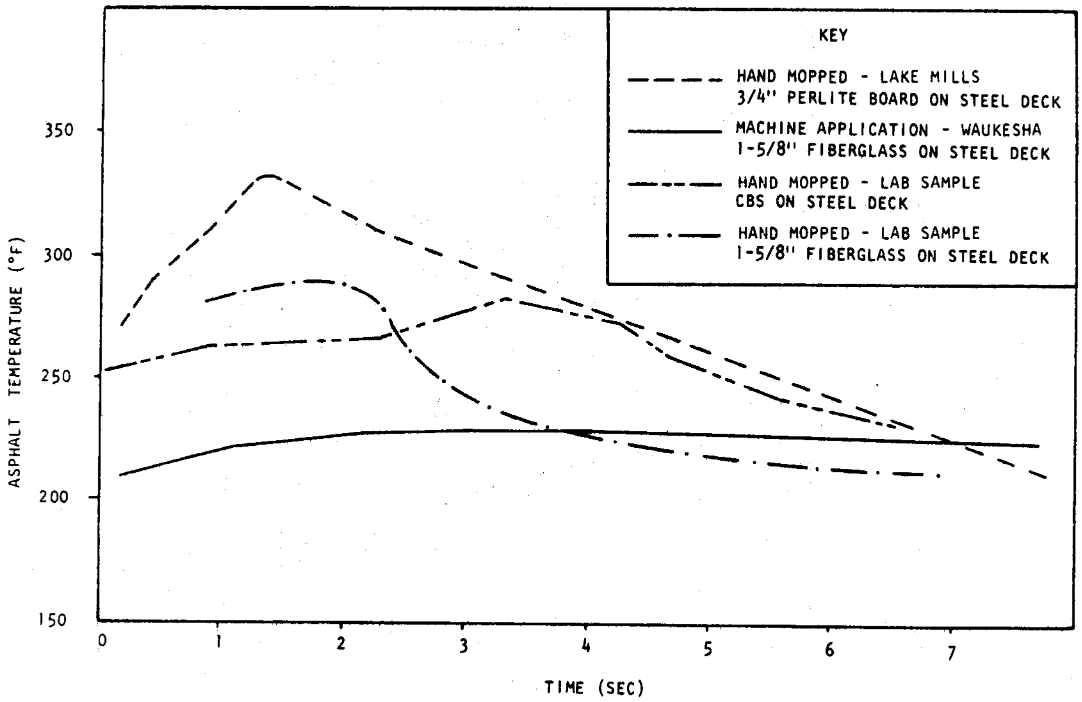

FIGURE 6 - SHORT-TERM TEMPERATURE DECAY TIME FOR ASPHALT APPLIED TO STEEL DECK

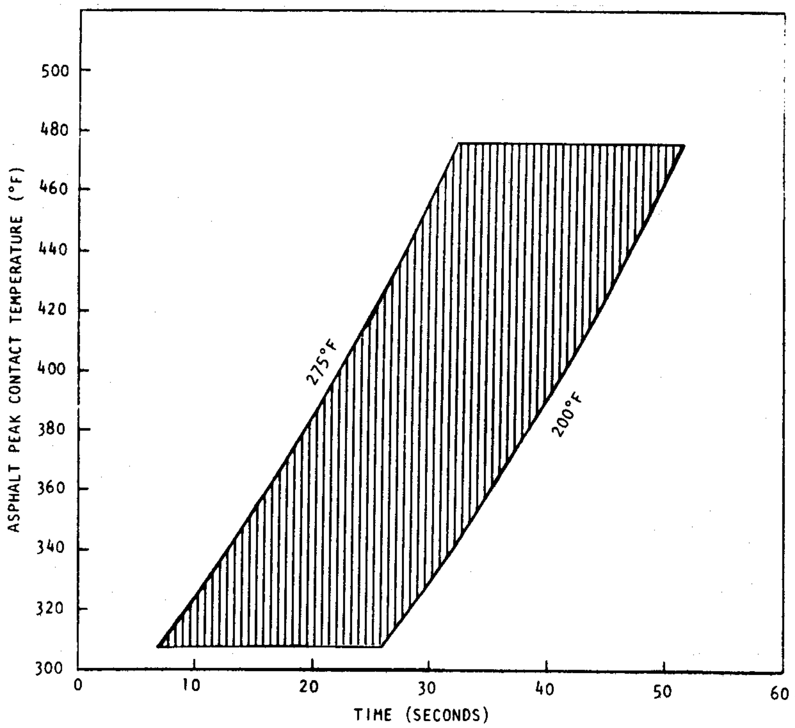

FIGURE 9 – NOMINAL ASPHALT TEMPERATURE DECAY TIME FOR TOP OF FIRST PLY (CBS AND 15#)

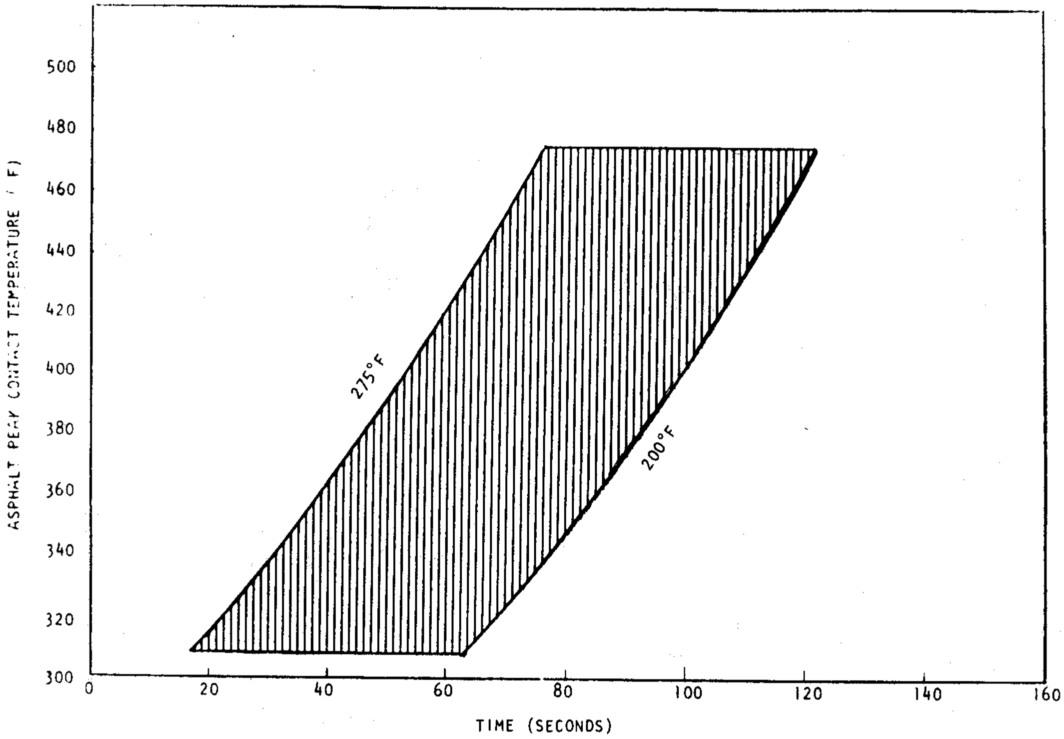

FIGURE 10 – NOMINAL ASPHALT TEMPERATURE DECAY TIME FOR TOP PLIES (15# FELTS)

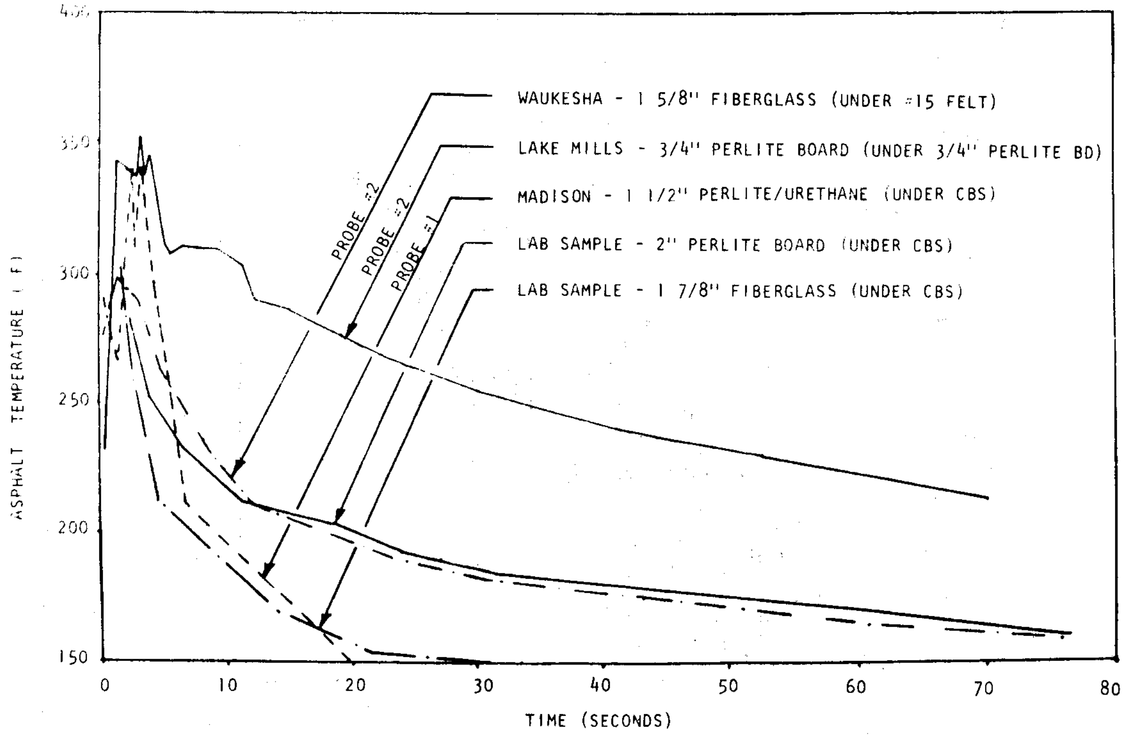

FIGURE 7 - LONG-TERM TEMPERATURE DECAYS FOR ASPHALT APPLIED TO INSULATION MATERIALS

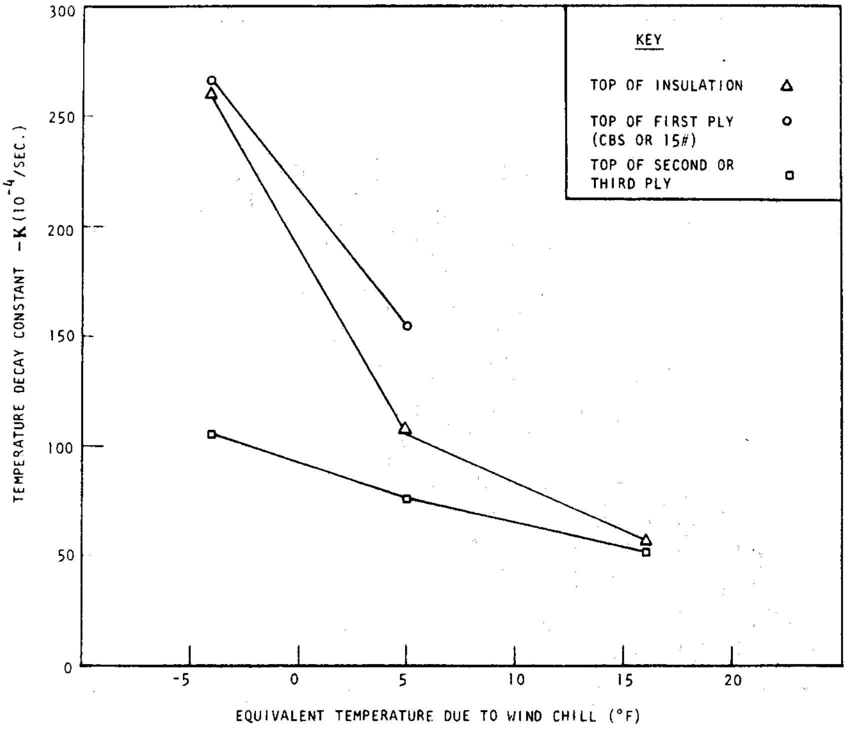

FIGURE 8

TABLE 1 - BUILT-UP ROOF CONSTRUCTION OBSERVED DURING COLD WEATHER

JOB SITE	BUILDING USE	ROOF SIZE (SQUARES)	ROOF SLOPE	DECK	INSULATION	BUR
LAKE MILLS, WI*	MERCANTILE	65	FLAT	22 GA. STEEL	PERLITE	4-PLY ORGANIC
MADISON, WI†	OFFICE	44	FLAT	1 X 6 WOOD	PERLITE/URETHANE	4-PLY ORGANIC
MCFARLAND, WI*	LABORATORY	31	SLOPE-1/12	2" GYPSUM PLANK	STYROFOAM	3-PLY GLASS (IRMA)
WAUKESHA, WI*	FACTORY	220	FLAT	22 GA. STEEL	FIBER GLASS	4-PLY ORGANIC

* NEW CONSTRUCTION

† REROOF CONSTRUCTION

NOTES: 1) NO VAPOR BARRIERS WERE UTILIZED ON THESE JOBS.

2) ALL BITUMENS WERE STEEP ASPHALT (ASTM D312-71) TYPE III.

3) INTERPLY BITUMEN WEIGHTS WERE DETERMINED TO BE:

MADISON - 48.0 LB/SQ.
WAUKESHA - 23.9 LB/SQ.
LAKE MILLS AND MCFARLAND - NOT AVAILABLE

TABLE 2 -OBSERVED TEMPERATURE DECAY CONSTANTS (10^{-4}/SEC.)†

JOB SITE ACTIVITY	LAKE MILLS	MADISON	MCFARLAND	WAUKESHA	LAB RESULT	FIELD AVERAGE	OVERALL AVERAGE	RATIO OF FIELD/LAB
TOP OF INSULATION	56.8 PERLITE	261.0 PERLITE/ URETHANE	125.0* GYPSUM PLANK	107.0 FIBER GLASS	163.0**	137.0	143.0	0.84
TOP OF FIRST PLY (CBS OR #15)	*** (CBS)	266.0 (CBS)	NOT OBSERVED	155.0 (#15)	115.0 (CBS)	211.0	179.0	1.83
TOP OF #15 PLIES	52.7	105.0	NOT OBSERVED	75.9	70.9	77.8	76.1	1.10

* TOP OF GYPSUM PLANK, UNDER FIRST PLY OF GLASS FELT

** PERLITE = 163, FIBER GLASS = 164; USED AVERAGE OF 163

*** PROBES LOST DURING CONSTRUCTION ACTIVITY

† THE TEMPERATURE DECAY CONSTANT IS USED IN EQUATION (1); $T = T_S + (T_O - T_S) e^{-Kr}$