NBSIR 80-2100

# Thermal Resistance Measurements of A Built-Up Roof System

NBSIR 80-2100

# THERMAL RESISTANCE MEASUREMENTS OF A BUILT-UP SYSTEM

S. J. Treado

Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, DC 20234

October 1980

Prepared for
Department of Energy
Architectural and Engineering
Systems Branch
Buildings Division
Office of Buildings and
Community Systems
Washington, DC 20585

U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*

Luther H. Hodges, Jr., *Deputy Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report describes factors which affect the thermal performance of built-up roof systems, and a technique for making in-place measurements of thermal resistance. This measurement technique utilizes a combination of infrared thermographic imaging, surface heat-flow meters and surface thermopiles. The thermal resistance of the roof system is computed based on temperature differences across the roof and the measured heat flow through the roof.

A field test of the measurement procedure is detailed, along with an examination of the time period required to perform a roof thermal resistance measurement, as related to the thermal time lag for heat flow through the roof due to the effect of the thermal mass of the roof.

Roof thermal resistance determinations performed according to this measurement procedure are found to be very accurate, if measurements are performed over a sufficient time interval, the minimum interval being dependent upon the thermal mass of the roof system.

Key Words: Built-up roofs, measurement technology; moisture accumulation, nondestructive tests; thermal resistance.

ACKNOWLEDGMENTS

The author is grateful to D. M. Burch for the assistance concerning the experimental procedure and analysis, to B.A. Peavy for his help with the mathematical modeling and computer simulation, and to R.G. Mathey for the information provided about the roofing systems.

This investigation was done under Oak Ridge National Laboratory subcontract No. DE-A105-78OR06113 and the U.S. Department of Energy and is part of the National Program for Building Thermal Envelope Systems and Insulating Materials.

TABLE OF CONTENTS

# 1. INTRODUCTION

Buildings are among the largest energy consumers in the United States comprising approximately one-third of the total annual energy consumption [1]. The roof of a building is a major contributor to heat flow through the building envelope. Bituminous built-up membrane roofing (BUR) is widely used in building construction in the United States. A conservative estimate of the amount of low-slope roofing in place in the United States is 25 billion $ft^2$ ($230 \times 10^7$ $m^2$). About 3 billion $ft^2$ ($280 \times 10^6$ $m^2$) is constructed each year [2]. The average thermal resistance of these roofs is less than 7 $\frac{°F \cdot ft^2 \cdot h}{Btu}$ (1.23 $K \cdot m^2/W$), and over 40 percent of them contain no insulation at all [3].

The uninterrupted design of low-slope roofs makes them readily accessible, providing a significant potential to conserve energy expended for heating and cooling through the utilization of retrofit measures to reduce heat-flow through the roofing materials. Increasing the thermal resistance of the Nation's 25 billion $ft^2$ of low-slope, built-up roofs by an additional 10 $\frac{°F \cdot ft^2 \cdot h}{Btu}$ (1.76 $K \cdot m^2/W$), would result in a savings of 155,000 barrels of oil per day (based on a 5000 heating degree day climate during the heating season). Seven hundred million kilowatt hours could be saved during a cooling season requiring 1,000 equivalent operating hours.

Many factors affect the thermal performance of roofing systems, including design, workmanship, materials, age, weathering, and moisture intrusion. The actual thermal performance of built-up roofs may differ substantially from the design or expected performance [4]. With increasing concern for conserving energy in buildings, there is a need to develop a reliable field measurement technique for assessing the thermal resistance of built-up roof systems. Such a technique would provide information to determine if the thermal resistance of these systems meets design expectations, and possibly lead to improved design procedures. Also, roofs having inadequate thermal resistance could be identified and treated as part of a thermal retrofit program.

The objective of this report is to identify factors which affect the thermal performance of existing built-up roof systems, and to describe a technique for measuring the thermal resistance of roof systems. This measurement technique utilizes a combination of infrared thermographic imaging, surface heat flow meters and surface thermopiles. The thermal resistance is computed based upon the measured inside-to-outside surface temperature difference across the roof and the measured heat flow through the roof. A field validation of the measurement system was performed and the results examined and reported. The technique for measuring the thermal resistance of roof systems described in this paper can be used to assess the thermal performance of many different types of roof systems.

## 2. FACTORS AFFECTING THE THERMAL PERFORMANCE OF BUR SYSTEMS

The principle function of a roof is to protect the enclosure beneath it from the weather elements, and to maintain desired environmental conditions within the structure. In this regard, a roof must be able to withstand a variety of wind pressures, temperature cycles, and moisture conditions. Throughout a typical year, low-slope BUR systems are subjected to rain, snow, solar radiation, ice, and to wide variations in surface temperature. A roof system must have structural integrity and be durable and serviceable to withstand these conditions or exposures. Increasing concern for energy conservation has added another factor to the list of desirable characteristics for roof systems, that of thermal efficiency. The methods utilized to achieve the goal of a thermally efficient roof are not always consistent with the methods which produce the most durable and serviceable roof, since the strongest materials may not be good insulators, and the best insulators generally provide little structural strength. However, some types of failures will affect the integrity of the water-proofing membrane and insulation as well as the thermal performance. An example of this is the splitting of the membrane which could lead to water penetration and mechanical and thermal degradation of the insulation due to moisture intrusion.

Many factors can affect the thermal performance of a BUR system. Since a low-slope roof is made up of several layers of composite elements, one or more of these factors can affect its performance. A typical BUR system will consist of a metal or concrete deck covered with insulation, four piles of felt alternating with layers of bitumen, and a bitumen asphalt coat topped with slag or crushed rock.

The primary factor, and one of the most important, affecting the thermal performance of a BUR system is the initial design. The characteristics of the materials used, such as the thermal conductivity, moisture permeance, thickness and durability, as well as the construction details and design, play a large part in determining the thermal performance of a roof. Adequate slope of the roof and the location and design of drains and flashing are important in preventing premature failure [5]. Utilization of larger thicknesses of insulation requires special attention because of thermally and mechanically induced stresses in the roof membrane [6]. Some insulations may not be a stable substrate for the membrane, particularly if they are very thick. In addition, the membrane is more likely to be punctured by foot traffic or by objects which are dropped on the roof by accident, since insulation is softer than deck materials. Extreme temperature variations can occur in a black roofing membrane over insulation exposed to the normal day and night solar radiation cycle. Daily variations as large as 140°F (78°C) have been recorded, as well as seasonal variations up to 250°F (139°C) [7]. The stresses associated with the expansion and contraction of a roofing membrane in response to these large temperature fluctuations can contribute to premature failure in some cases. An example is membrane splitting due to large decrease in temperature to well below freezing over a short period of time. Ultra-violet radiation and corrosive atmospheric deposits can also contribute to degradation of a roofing system.

Similarly, workmanship and construction practice can strongly influence the long-term thermal performance of a roof. The exterior membrane is constructed of a number of felt plies, bonded together with asphalt or coal tar pitch which are generally applied hot. Attachment problems can occur due to rapid cooling of the hot asphalt [8]. Incorrect installation of flashings or other roof penetrations can also contribute to leakage or premature failure.

Moisture can have a serious effect on the thermal performance of a roofing system. The intrusion of moisture into BUR insulation can cause a reduction in the thermal resistance of a roof [9] and lead to premature failure of the roofing system. Moisture can invade a BUR system from the exterior through leakage, from the interior as water vapor generated within the structure migrates outward, or can even be present during construction and entrapped upon application of the waterproof membrane. Failure of the membrane for any reason can result in moisture related problems.

Other factors which affect the thermal performance of a BUR system include insulation joints, metal fasteners, roof penetrations and aging and weathering of the membrane. Heat flow through the roof can occur at insulation joints and penetrations and through metal fasteners which attach insulation to the deck. Aging and weathering of the membrane can be controlled to some extent through the utilization of adequate materials and design procedures and periodic maintenance, such as visual inspections followed by repairs to prematurely failing areas, cracks or penetrations.

The incidence of rain can temporarily alter the thermal performance of a roof due to the cooling effect of the runoff as well as evaporation. Similarly, a bed of snow on a roof can function as an additional insulation layer, changing its overall thermal resistance.

## 3. BUR THERMAL PERFORMANCE ASSESSMENT PROCEDURES

Several methods are currently utilized for detecting moisture in BUR systems [1]. These methods include gravimetric techniques and nondestructive evaluation methods (NDE) such as nuclear backscatter, electrical capacitance and infrared imagery (thermography) [10]. Although most accurate, the gravimetric technique has the disadvantage of being a destructive test method. Data are not available on the accuracy, validity, and reliability of NDE methods to quantitatively detect moisture in roofs.

Thermal resistance determinations for BUR systems have also been performed utilizing heat flow meters and thermocouples [11]. In using this method, the heat flow through a roof and the temperature difference between its interior and exterior surfaces are measured. The thermal resistance of the roof is subsequently calculated from the relation:

$$R = \frac{\Delta T}{Q} = \frac{\int_o^p \Delta T \, d\tau}{\int_o^p Q \, d\tau} \qquad (1)$$

where $\Delta T$ = temperature difference
$Q$ = heat flow
$p$ = period of integration

To make an accurate thermal resistance determination, measurements must be made over a sufficiently long period (p) to reduce the transient effects which can occur due to heat storage in the roof and due to the thermal time lag of the roof, in which case heat flow lags behind temperature difference. These effects are most noticable in roof systems with large amounts of thermal mass, such as BUR systems with concrete decks. The ability of a roof system to store heat rather than transmit it with little time delay results in a time lag between temperature difference and the resulting heat flow. This factor can be described as the thermal capacitance of a roof.

The technique utilized in this study for assessing the thermal resistance of BUR systems consists of a combination of thermographic imaging and local measurements using heat-flow meters and thermopiles.

Infrared (IR) thermography is based on the principle that all surfaces emit energy in the form of electromagnetic radiation, in proportion to their surface emittance and the fourth power of their absolute temperature. The principal components of a thermographic imaging system are the infrared camera, black-and-white monitor, color monitor and temperature profile display monitor (See figure 1) [12]. Upon sensing the radiation intensity from a surface, the IR camera produces a video signal which is internally processed by the black-and-white monitor and displayed as a thermal picture in which the gray tones in the picture correspond to local "apparent surface temperature." The term apparent surface temperature is used here because the thermographic camera is sensing radiation emitted and reflected from a surface. Without knowing the emittance of the surface, the actual surface temperature is not established and the apparent surface temperature is that which would correspond to a black body emitting an equivalent level of IR radiation. Video signals are also fed into the color monitor, where different apparent surface temperatures are displayed as individual colors.

The actual surface temperature of an object may differ from its apparent surface temperature, due to the emittance of the surface and consequently the amount of reflected radiation from the surface. The brightness of the image of a surface on the black-and white monitor, or its color on the color monitor, is dependent upon the intensity of electromagnetic radiation sensed from the surface. This intensity of radiation is a function of the temperature and emittance of a surface. Two objects with identical surface temperatures but different emittances could appear to have different surface temperatures, due to reflected radiation from surrounding surfaces which are at different temperatures. On the thermal picture, or thermogram, the color temperature reference scale is displayed at the bottom with colder to warmer levels running left to right, or black to white.

In following the technique proposed in this study, an initial thermographic scan is performed on the roof surface to obtain an apparent temperature profile map of the top of the BUR system. This scan must be performed during non-daylight periods, allowing enough time to elapse following sundown to enable residual solar radiation effects to dissipate. At this time of day, the outdoor temperature is more steady than at other times, and variations in surface temperature will predominantly be due to differences in thermal resistance of the BUR system, and surface convection effects if wind conditions vary at different roof locations. In addition, sufficient interior-to-exterior temperature difference must be present, approximately 20°F (11°C) minimum, to obtain accurate results. Regions of the roof surface whose temperature appears to vary from the majority of the roof surface are marked with spray paint or otherwise identified for subsequent examination. Apparent temperature variation of some portions of the roof surface may actually be due to differences in emittance or special conditions (such as water, ice patches or metal surfaces). Variations in surface temperature can also be due to hot air exhausting onto a roof from a vent, hot rooms directly below a roof, differences in the amount of roof insulation, difference in exposure conditions, differences in underlying construction, or wet or otherwise defective insulation. Close examination of suspect regions usually enables an accurate assessment of the cause of the apparent temperature variation.

Those areas which are identified as regions of hotter or colder surface temperatures are instrumented for thermal resistance measurements. This is accomplished through the use of heat flow meters and thermopiles. An actual measurement system is described in Section 4. A heat-flow meter produces a millivolt signal proportional to the heat flux passing through its body. When attached flush with a surface, the heat flowing through that surface can be measured. A thermopile is a series of pairs of thermocouple junctions which are attached to opposite surfaces of a roof or wall to measure the temperature difference between the two surfaces. The thermopile will develop a voltage proportional to the temperature difference being measured.

The heat flow meters are attached to either the interior or exterior roof surface, and the thermopile is attached to the interior and exterior surfaces of the roof. Heat flow meters should not be attached directly to a metal deck because the metal deck will act as a fin, possibly disrupting the accuracy of the measurement due to the effect of two-dimensional heat flow. For metal decks, the heat flow meters should be installed on the exterior roof surface, rather than on the interior metal surface. For concrete or wood decks, the heat flow meters can be attached directly to the interior surface of the deck.

The thermal resistance value for a particular area of the roof is determined by dividing the integrated temperature difference, as measured by the thermopile, by the integrated heat flow, as measured by the heat flow meter.

Areas of low thermal resistance can be examined for moisture content through coring of roof samples followed by an oven-drying procedure, or by a non-destructive moisture detection procedure.

## 4. THERMAL RESISTANCE MEASUREMENTS

Measurements were made on the roof of Building 226 at the National Bureau of Standards. The building was constructed in 1963 with a 40,000 $ft^2$ (2716 $m^2$) BUR system consisting of a concrete deck, glass fiber insulation and built-up roofing. A photograph of the roof surface is shown in figure 2. Details of the construction design of the BUR system were utilized to compute its thermal resistance. The components of the BUR system and their thermal resistances are listed in table 1.

Table 1. Computed Thermal Resistance of Test Roof

| Component | Thermal Resistance $h \cdot ft^2 \cdot F/Btu$ | $(m^2 \cdot K/W)$ |
|---|---|---|
| 5-in. (12.7 cm) Concrete Deck* | 0.40 | 0.07 |
| Glass Fiber Insulation ~ 1 1/16 in. (27 mm) (Conductance < 0.24 $\frac{Btu}{(h \cdot ft^2 \cdot F)}$** or 1.36 $\frac{W}{m^2 \cdot K}$) | 4.17 | 0.73 |
| Built-Up Roofing* ° Asphalt Primer ° 4 Plies of Felt ° 3 Layers Asphalt ° Asphalt Flood Coat ° Slag | 0.33 | 0.06 |
| Total Thermal Resistance | 4.90 | .86 |

* From ASHRAE Handbook [13].

** From Design Specification.

The actual thermal resistance of the roof may vary from the computed thermal resistance if different insulation thickness is used instead of the design thickness, or if the thermal properties of the actual materials differ from handbook values. Variations may also occur due to local irregularities in construction materials, assembly techniques, workmanship, or the presence of moisture.

## 4.1 THERMOGRAPHIC SURVEY

A thermographic scan of the roof surface was performed to obtain an apparent temperature map. The scan was performed on a cold night, 29°F (-1.6°C) during December under partially overcast sky conditions. Wind speed was less than 5 mph (8 kh) and the average roof surface temperature was 25°F (-4°C). The major portion of the roof surface appeared to be fairly uniform in temperature, varying by less than 0.9°F (0.5°C) (See figure 3). Roof surface areas surrounding the large central vents are seen to be warmer than the majority of the roof. This is more apparent in figure 4. In the color thermograms, the warmest area of the roof surface appears to be 1.8°F (1°C) warmer than the remaining areas. Visual inspection of the warmer portions of the roof surface did not reveal any obvious differences in roof construction materials from the majority of the roof surface, and no differences in emittance were believed to be present which might be causing warmer apparent surface temperature. One of the warmer areas of the roof surface was chosen as the location for the installation of the heat flow meter and thermopile. This location is shown in figure 5. The cylindrical object in the center of the thermogram is a liquid nitrogen Dewar flask being used as a marker.

## 4.2 SENSOR INSTALLATION

A heat-flow meter was spot-glued to the interior surface of the concrete roof deck. The meter consisted of a thin cylindrical wafer containing an imbedded thermopile. The millivolt signal generated from this imbedded thermopile is proportional to the heat flow passing through the wafer. The heat-flow meter was connected to an analog integrator, for the purpose of recording hourly averaged values of heat flow, and a data logger which recorded instantaneous values at adjustable time intervals. The temperature difference between the interior and exterior roof surfaces was measured with a copper-constantan thermopile consisting of three pairs of junctions attached to the surfaces. The three exterior thermopile junctions were attached to the outer surface of the roof with a room-temperature vulcanizing silicone adhesive. The corresponding interior thermopile junctions were attached to the inner roof surface (concrete deck) with tape. The thermopile was connected to an analog integrator and to the data logger.

## 4.3 MEASUREMENTS

The thermal resistance value for the instrumented location of the roof was determined by dividing the hourly integrated temperature difference by the hourly integrated heat flow, as measured by the heat-flow meter. Measurements were made for several weeks to obtain an average value for the thermal resistance. Figure 6 shows the data obtained during a typical nine day measurement period.

The hourly average thermal resistance of the roof, RI, was determined by dividing the hourly average temperature difference by the hourly average heat flow in discrete hourly increments. The values ΔT (temperature difference), Q (heat flow) and RI (hourly thermal resistance), are plotted in figure 6 at hourly intervals. RAV, noted in figure 6, is the cumulative average of RI or:

$$RAV = \frac{\sum_{i=1}^{t} RI_i}{t} = \frac{RI_1 + RI_2 + \ldots RI_t}{t} \tag{2}$$

where t = elapsed time (hours) or number of readings.

The instantaneous hourly value of the thermal resistance is seen to vary strongly with the temperature difference across the roof. Maximum heat flow is seen to lag behind maximum temperature difference by approximately 12 hours, due to the thermal capacitance of the roof.

The measured overall thermal resistance at this location of the roof was found to be 5.06 $\frac{h \cdot ft^2 \cdot F}{Btu}$ $(0.89\ \frac{m^2 \cdot K}{W})$, based on the nine days of measurement. This is 3.3% higher than the design value of 4.90 (.86). The RAV line gives a good example of how long measurements must be made to negate the effect of random daily temperature fluctuations on the average thermal resistance value. After 67 hours of measurement the cumulative average thermal resistance, RAV, stayed within 10% of the final value (5.06 ± .506). After 133 hours, RAV stayed within 5% of the final value (5.06 ± .253). These time factors would vary according to roof type and temperature conditions, but for roof of this type, three to six days of data collection would be necessary to obtain a representative value for the thermal resistance. The time required for cumulative averaging will vary from one roof to another depending on the thermal capacitance (thermal mass) of the roof. Shortening this time span could result in inaccuracies due to random fluctuations or variable daily temperature cycles.

The close agreement between measured and calculated thermal resistances for the roof indicates that the thermal performance of the BUR system was as would be expected based on design parameters. Moisture intrusion or other factors affecting thermal conductance were not believed to be present, since the roof thermograms indicate fairly uniform surface temperatures, and since the measured thermal resistance at the warmest spot on the roof showed no reduction from design value.

To investigate the actual moisture content of the roof, samples of insulation and membrane were taken from a location near that of the thermopile. The insulation was fiberglass and was about one inch thick. An exact measurement of its thickness could not be made since it was damaged when cut from the roof. Since the roofing specification called for insulation to have a conductance of 0.24 $Btu/h \cdot ft^2 \cdot F$ (1.36 $W/m^2 \cdot K$), it is assumed that the insulation was 1 1/16 in (27 mm) thick. The moisture content of the insulation was determined gravimetrically and was found to be very low, only 0.2 percent.

From the sample taken from the roof it was found that the membrane consisted of four plies of asphalt saturated organic felt with a surfacing of slag embedded in an asphalt flood coat. The moisture content of the membrane was also determined gravimetrically and was found to be 3 g of water per $ft^2$ of area (.09 $m^2$). The average amount of interply asphalt in the sample was about 10 lb/100$ft^2$ (4.5 kg/9 $m^2$). The interply asphalt thickness was measured using a machinist's microscope.

## 5. COMPUTER SIMULATION OF BUR SYSTEMS

A computer simulation procedure [14] was utilized to examine the effect of the thermal mass of the roof on the time period required for accurate measurement of thermal resistance using the technique described in the previous sections of this report. In the case of the BUR system used for the field test, the thermal mass of the concrete deck contributed to a long thermal response time. If the deck had been constructed of steel, response time would have been much shorter, due to the reduction in roof thermal mass.

A mathematical model was used to calculate heat flow through the roof system, using the measured hourly indoor and outdoor surface and air temperatures observed during the field test as input parameters. A response factor technique was employed to first compute surface heat transfer coefficients and subsequently calculate heat flow through the roof system. To validate the model the BUR system used for the field test was modeled, and heat flow through the roof was calculated and compared to actual measured values. A typical four-day period is shown in figure 7. Computed heat-flow is plotted beginning with the ninth hour, to allow start-up time for the model (since heat flow lags behind the driving force, temperature differential).

Agreement between measured and calculated heat flow is satisfactory, considering that the input temperature parameters were in hourly increments, thus imparting some scatter to the calculated heat flow.

Next, the concrete deck was replaced with a steel deck in the model, and heat flow through that roof system was calculated for the same temperature parameters. Figure 8 presents the inside-to-outside temperature difference conditions used for the simulation period, as well as calculated heat flow through the roof system with steel deck. Very little time lag is seen for this roof system, as maximum heat flow follows maximum temperature difference within one hour.

As previously discussed, hourly values of thermal resistance (RI) were computed based on the ratio of the measured hourly temperature difference and the calculated hourly heat flow. The cumulative average of the thermal resistance (RAV) was also calculated. RI and RAV for the BUR system with steel deck are also plotted in figure 8.

Since the steel roof deck provides negligible thermal resistance [13], the thermal resistance of the BUR system modeled with the steel deck would be expected to be the value for the BUR system with concrete deck less the thermal resistance of the concrete deck, or 4.90 minus 0.40 equals 4.50 $\frac{°F \cdot ft^2 \cdot h}{Btu}$ (.79 $m^2 \cdot K/W$).

At the end of the four-day simulation period the cumulative average for the thermal resistance of the steel deck BUR system is seen to be 4.58 $\frac{h \cdot ft^2 \cdot F}{Btu}$ (0.81 $m^2 \cdot K/W$), or 2 percent higher than the design value.

RAV stays within 10% of its final value (4.58 ± .46) after 5 hours elapsed measurement time, and within 5% (4.58 ± .23) after only 7 hours elapsed measurement time. RI is seen to approach RAV for long periods of time during night hours, and in general RI varies much less for the BUR system with steel deck as compared with the concrete deck. This indicates that temperature conditions were fairly near steady-state relative to the thermal response time of the BUR system with steel deck, during night hours. RI variation for the steel deck is less than for the concrete deck since the short thermal response time of the roof means that heat flow will fluctuate more closely in response to temperature conditions, therefore hourly values of heat flow and temperature difference are more closely related, causing their ratio to more accurately reflect the actual thermal resistance. RI deviates from RAV the greatest amounts during periods in which the temperature difference is changing rapidly.

This analysis indicates that the thermal resistance of BUR systems with metal decks could be accurately measured using this technique in a fairly short time period, and probably within one day, depending on weather conditions.

Based on the thermal resistance measurements performed on the BUR system with a concrete deck, and the results of the simulation of a BUR system with a steel deck, the required elapsed measurement time is presented in figure 9 as a function of roof system time lag. Time lag for the steel deck system was estimated to be 3/4 of an hour, although an exact determination was difficult due to the fact that measurements were stepped in hourly increments.

The thermal time lag of a BUR system would be dependent upon the materials constituting the roof, especially heavy-weight decks or large amounts of insulation, as well as weather conditions.

Most BUR systems would probably fall somewhere between the two types examined here with respect to thermal mass and consequently, thermal time lag. Additional information is needed concerning the thermal time lag of various different BUR constructions to enable more complete criteria for required elapsed measurement time to be developed.

## 6. CONCLUSION

Many factors can influence the thermal performance of a built-up roofing system, including design, materials, workmanship, exposure conditions and moisture.

Thermally inefficient roofs can be identified through the utilization of roof thermal asssessment procedures. A procedure utilizing a thermographic imaging system, in conjunction with local measurements using heat flow meters and thermopiles, can be valuable in determining the thermal resistance of BUR systems. The thermal resistance can be calculated using the measured integrated temperature difference across the roof and the measured integrated heat flow through the roof, provided data are obtained over a sufficiently long time period to negate inaccuracies due to the thermal capacitance of the roof. A field test of the measurement procedure yielded a measured thermal resistance value for a BUR system within 3.3 percent of the design thermal resistance for that roof. The 1 1/16 in (27 mm) thick glass fiber insulation contained 0.2 percent moisture by weight.

The thermal mass of a BUR system strongly affects the amount of elapsed measurement time required to determine its thermal resistance accurately. Analysis indicates that a typical BUR system with a concrete deck will require 3 to 6 days of measurement time, while a similar BUR system with a steel deck would require less than one day.

REFERENCES


1. Seidel, M., Plotkin, S., Reck, R., Energy Conservation Strategies, Environmental Protection Agency Report, EPA-R5-73-021, p. 12 (July 1973).

2. Busching, H., Mathey, R., Rossiter, W., Cullen, W., Effects of Moisture in Built-Up Roofing: a State-of-the Art Literature Survey, NBS Technical Note 965 (July 1978).

3. "Project Pinpoint," National Roofing Contractors Association, (1977).

4. Tobiasson, W., Korhonen, C., Dudley, T., Roof Moisture Survey, Cold Regions Research and Engineering Laboratory Report 77-31, (Dec. 1977).

5. McCurdy, C., The Importance of Design Criteria for Built-Up Roof Flashings, NBS Thermally Efficient Roofing Systems Workshop, (May 1978).

6. Perrine, E., Problems Associated with Thermally Efficient Roofs, NBS Thermally Efficient Roofing Systems Workshop, (May 1978).

7. Garden, G. Fundamentals of Roof Design, Canadian Building Digest 67, Div. of Build. Res., Nat. Res. Council, Ottawa, Canada (July 1965).

8. Dupuis, R., Attachment Characteristics of Field Applied Asphalt, NBS Thermally Efficient Roofing Systems Workshop, (May 1978).

9. Powell, F., Robinson, H., The Effect of Moisture on the Heat Transfer Performance of Insulated Flat-Roof Constructions, NBS Building Science Series 37, (Oct. 1971).

10. Tobiasson, W., Korhonen, C., VandenBerg, A., Hand-Held Infrared Systems for Detecting Roof Moisture, Symposium on Roofing Technology, NBS/NRCA, (Sept. 1977).

11. Hedlin, C., Orr, H., Tao, S., Thermal Resistances of Experimental Flat Roof Systems Measured with Heat Flow Meters, ASTM C-16 Thermal Insulation Conference, (Oct. 1978).

12. Burch, D., Hunt, C., Retrofitting an Existing Wood-Frame Residence for Energy Conservation - An Experimental Study, NBS Building Science Series 105, (July 1978).

13. ASHRAE, 1977 Fundamentals Vol., New York (1977).

14. Peavy, B., Determination and Verification of Thermal Response Factors for Thermal Conduction Applications, NBSIR 77-1405, April 1978.

SI CONVERSION CHART

| Physical Quantity | From | To | Multiply by |
|---|---|---|---|
| Area | $ft^2$ | $m^2$ | $9.29\ (10^{-2})$ |
| Thermal Resistance | $h \cdot ft^2 \cdot F/Btu$ | $K \cdot m^2/W$ | $1.76\ (10^{-1})$ |
| Temperature | F | C | $t_C = (T_F - 32)/1.8$ |
| Length | in | m | $2.54\ (10^{-2})$ |
| Length | ft | m | $3.05\ (10^{-1})$ |
| Heat or Energy Flow | $Btu/h \cdot ft^2$ | $W/m^2$ | 3.15 |
| Thermal Conductance | $Btu/h \cdot ft^2 \cdot F$ | $W/m^2 \cdot K$ | 5.68 |

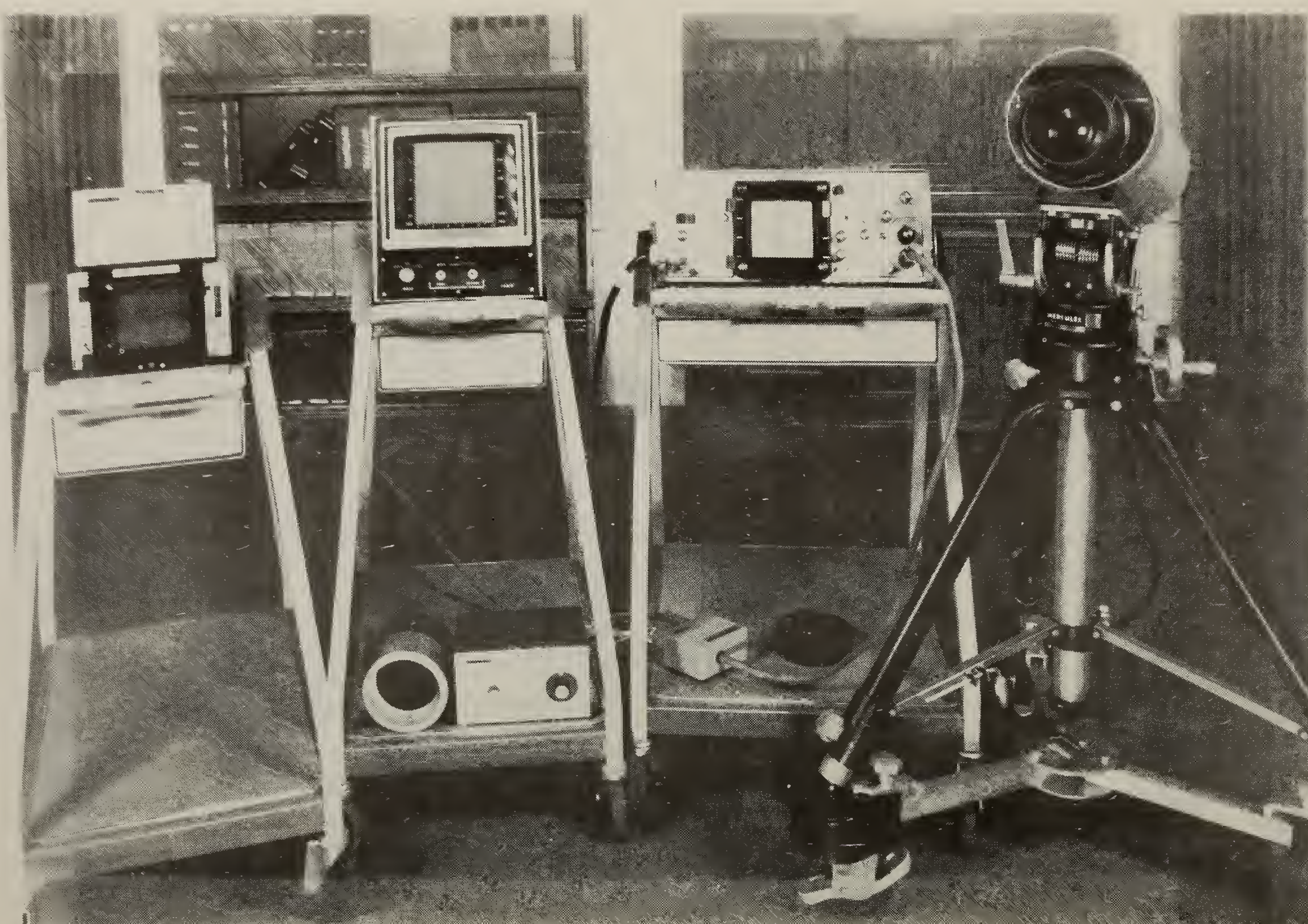

Figure 1. Thermographic Imaging System


Figure 2. Photograph of roof surface


Figure 3. Roof thermogram

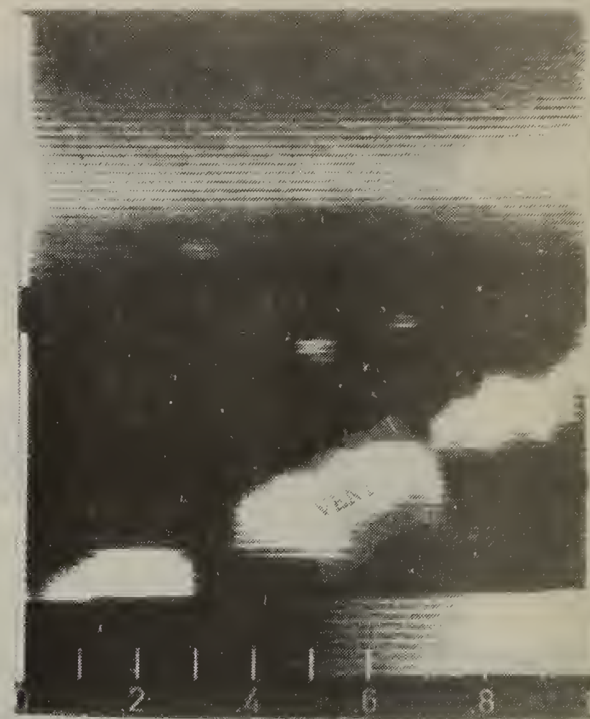


Figure 4. Roof thermogram near vents

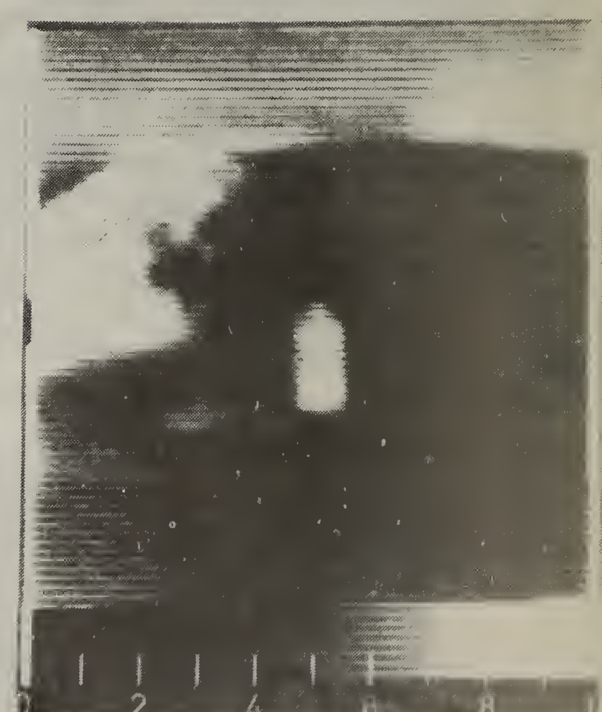


**Figure** 5. Roof Thermogram at Measurement Location (Location Marked by Cylinder)

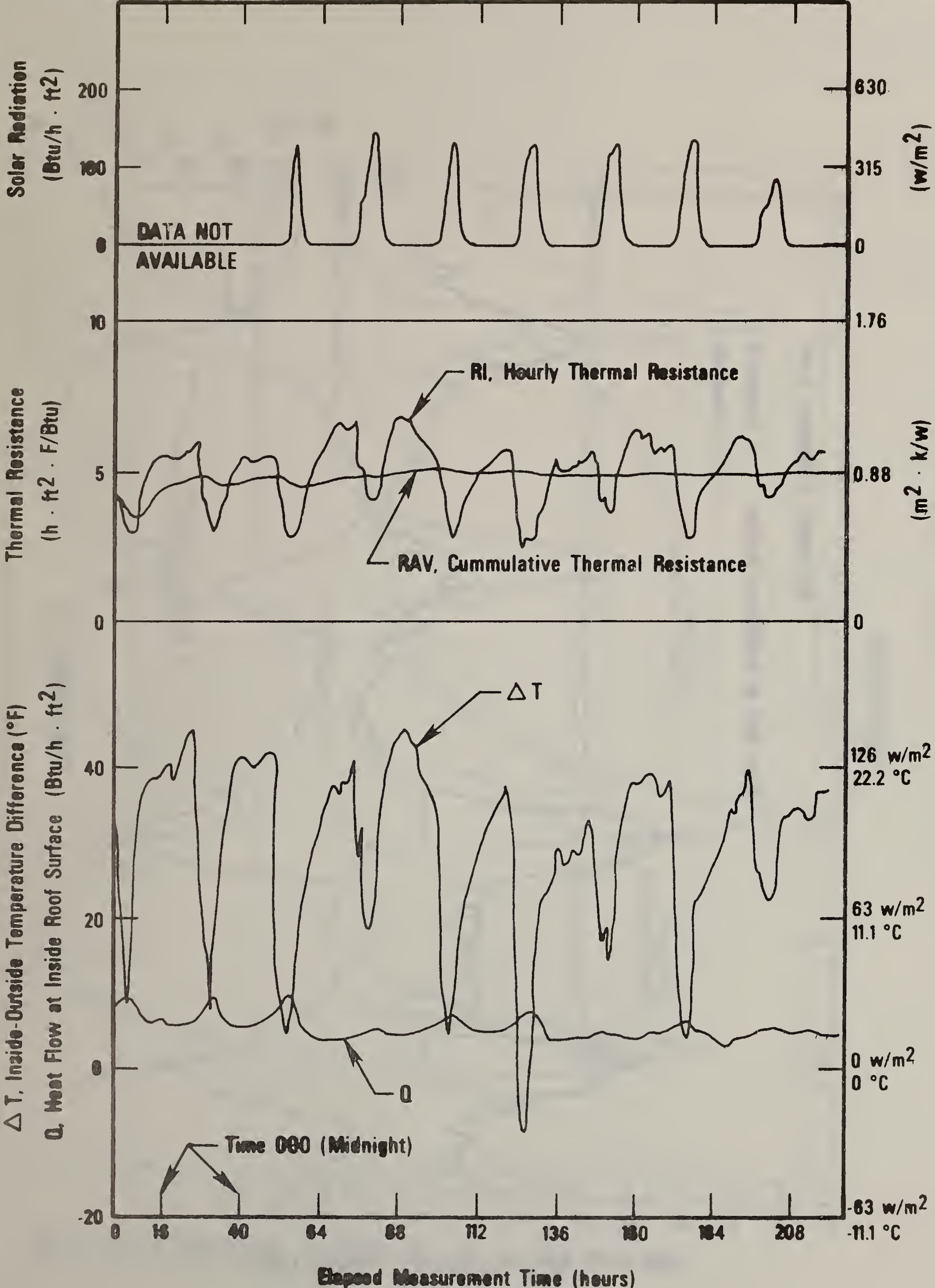


Figure 6. Thermal resistance measurement of BUR system with concrete deck

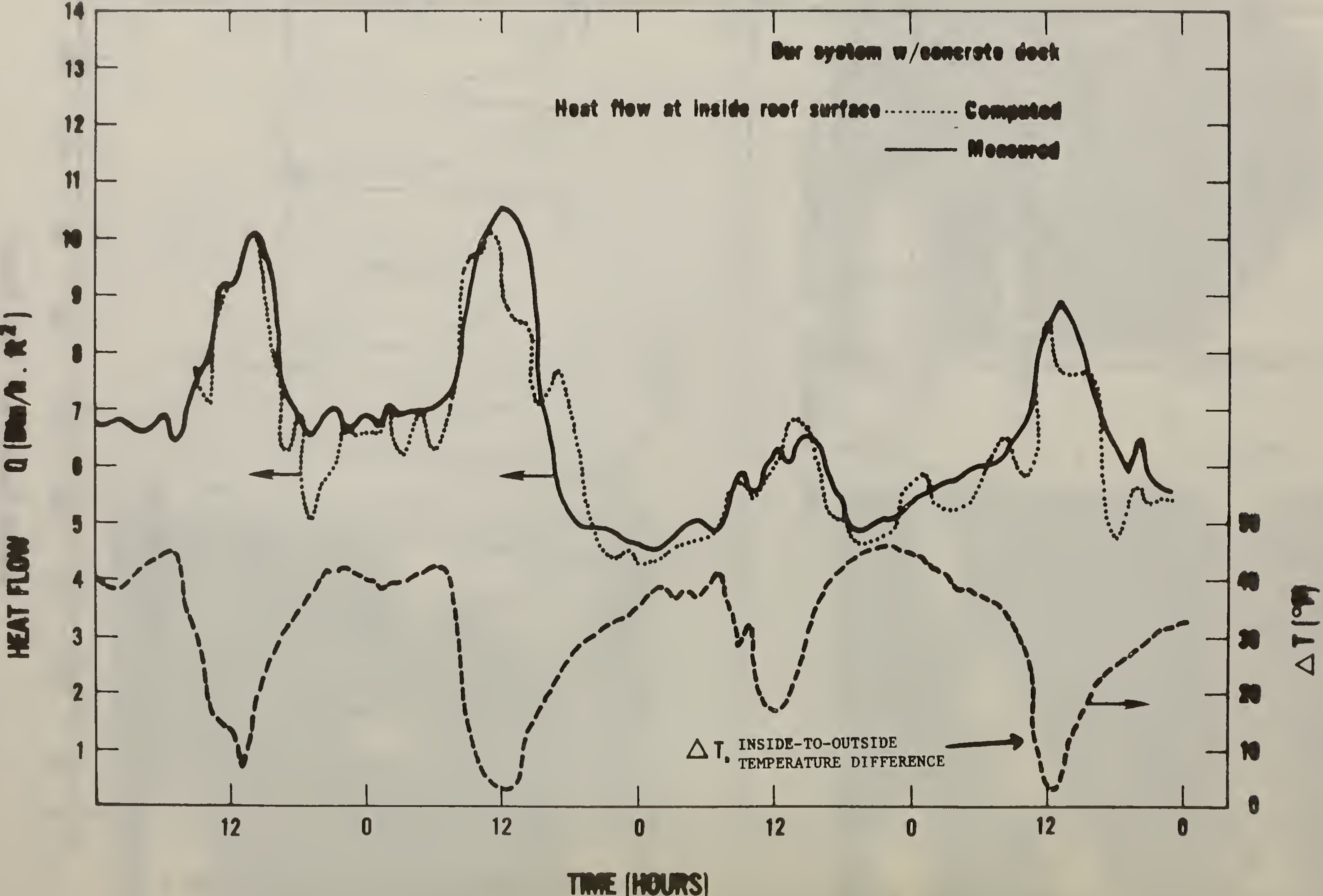


Figure 7. Computed versus measured heat flow for BUR system with concrete deck

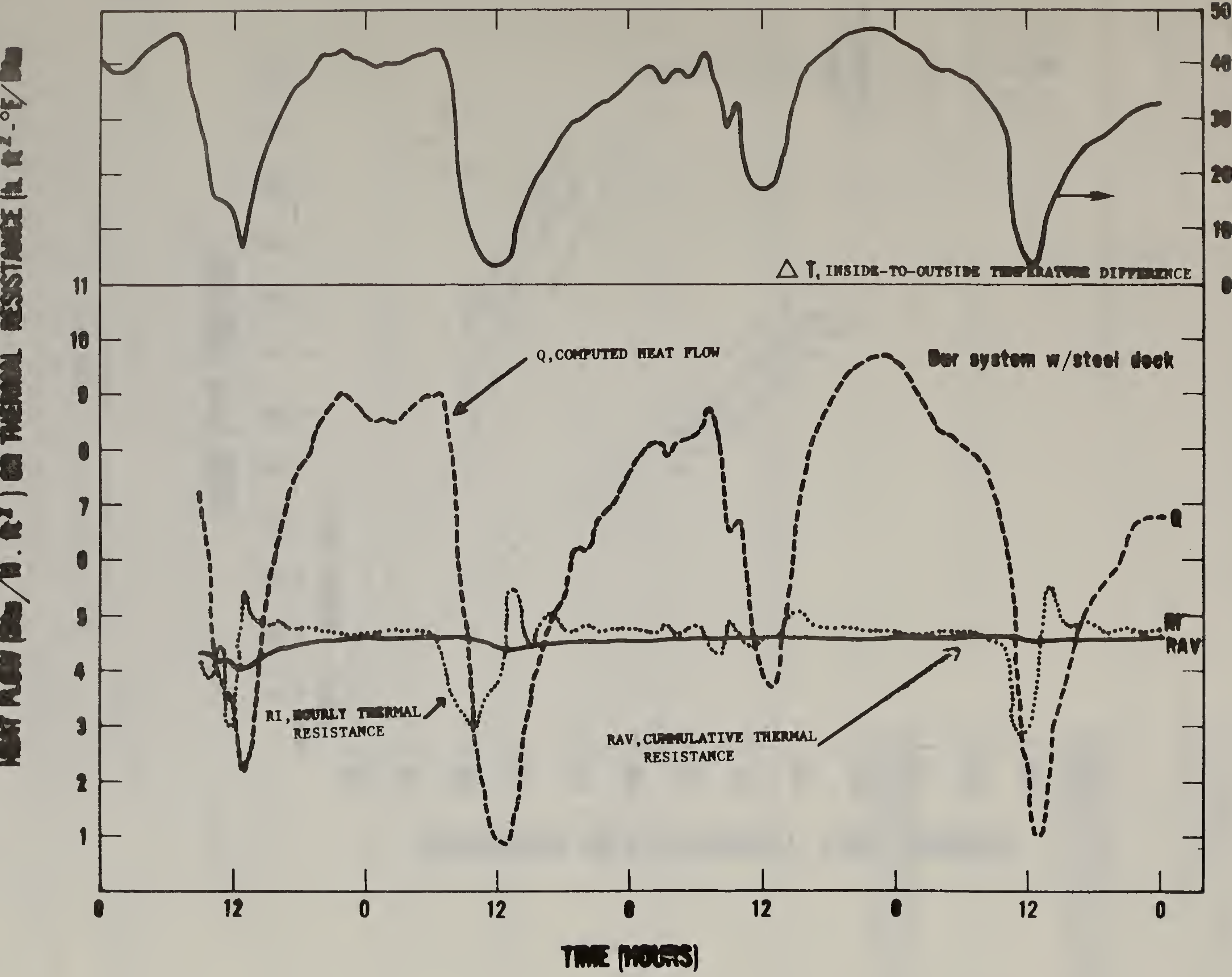


Fig. 8. Computed heat flow and thermal resistance for BUR system with steel deck

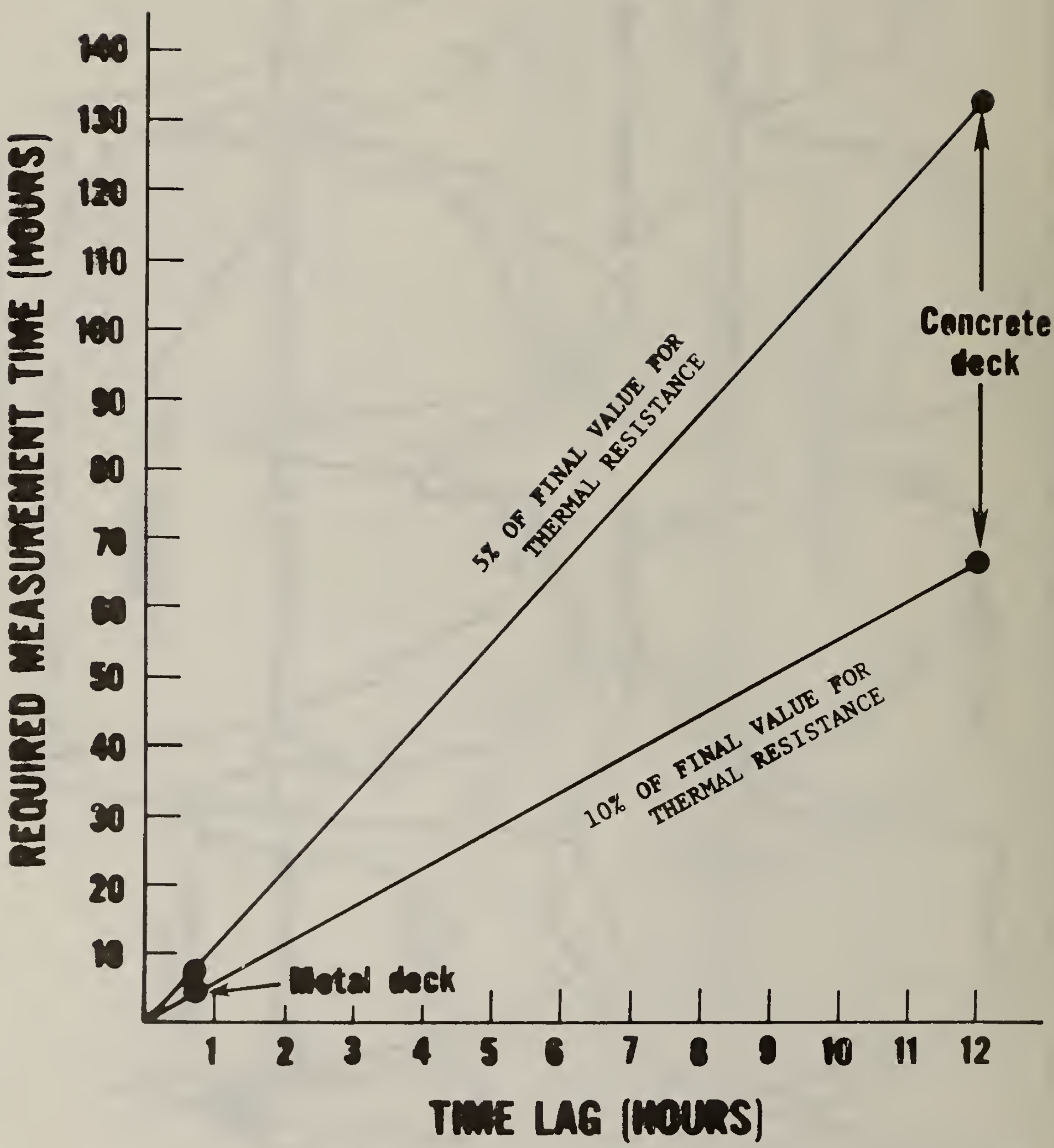


Figure 9. Required elapsed measurement time as a function of BUR system thermal time lag

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM.
BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NO. NBSIR 80-2100
2. Gov't. Accession No.
3. Recipient's Accession No.
4. TITLE AND SUBTITLE

   THERMAL RESISTANCE OF BUILT-UP ROOFING SYSTEMS

5. Publication Date: October 1980
6. Performing Organization Code: 742.01
7. AUTHOR(S): S. J. Treado
8. Performing Organ. Report No.: NBSIR 80-2100
9. PERFORMING ORGANIZATION NAME AND ADDRESS

   NATIONAL BUREAU OF STANDARDS
   DEPARTMENT OF COMMERCE
   WASHINGTON, DC 20234

10. Project/Task/Work Unit No.: 742-6541
11. Contract/Grant No.
12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

    Department of Energy
    Washington, D.C. 20585

13. Type of Report & Period Covered: Final
14. Sponsoring Agency Code
15. SUPPLEMENTARY NOTES

    [ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*


This report describes factors which affect the thermal performance of built-up roof systems, and a technique for making in-place measurements of thermal resistance. This measurement technique utilizes a combination of infrared thermographic imaging, surface heat-flow meters, and surface thermopiles. The thermal resistance of the roof system is computed based on temperature differences across the roof and the measured heat flow through the roof.

A field test of the measurement procedure is detailed, along with an examination of the time period required to perform a roof thermal resistance measurement, as related to the thermal time lag for heat flow through the roof due to the effect of the thermal mass of the roof.

Roof thermal resistance determinations performed according to this measurement procedure are found to be very accurate, if measurements are performed over a sufficient time interval, the minimum interval being dependent upon the thermal mass of the roof system.


17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

    Built-up roofs, measurement technology; moisture accumulation; nondestructive tests; thermal resistance

18. AVAILABILITY [X] Unlimited

    [ ] For Official Distribution. Do Not Release to NTIS

    [ ] Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

    [X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT): UNCLASSIFIED
20. SECURITY CLASS (THIS PAGE): UNCLASSIFIED
21. NO. OF PRINTED PAGES: 27
22. Price: $6.00

USCOMM-DC