EXPERIMENTAL METHODS FOR DETERMINING THE THERMAL PERFORMANCE OF CELLULAR PLASTIC INSULATION MATERIALS USED IN ROOFS

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The use of thermal insulation for energy conservation purposes in buildings has increased significantly during the past 15 years and the use of cellular plastics is extensive for most building envelope applications.[1,2] However, the question of thermal performance changes and its long-term effects has still not been answered totally. It is a well-established and documented fact that the thermal performance of fluorocarbon-blown cellular plastic foams change with time and/or environmental conditions. This phenomenon is due to the gradual change in the composition and pressure of the entrapped gases in the cells of the foam. The thermal conductivity of the original gas mixture is increased as higher thermal conductivity gases diffuse into the cellular structure. This manifests itself as a reduction in the thermal resistance of the cellular plastic foam. The extent and rate of this change depends on the material, the board size and thickness, the facer type and its integrity, the environment, and the type of construction. This subject has been covered both analytically[3-6] and experimentally.[7-10] To design energy conserving buildings and predict energy performance behavior over the lifetime of the building, the extent of the aging effect needs to be evaluated within realistic levels.

These concerns are not new. In 1978, the Urethane Division of The Society of the Plastics Industry outlined goals pertaining to this subject.[11] The major item of the proposed program was to develop and verify a "theoretically sound base for the determination of the long-term insulation efficiency of urethane foams." An update was provided in 1981.[12] In this, brief details were included on the scope and progress of an experimental program to study the long-term thermal efficiency (up to three years) of various commercial cellular plastic materials with different facings in order to validate and refine the proposed stabilized R-values document first published in 1979.[13] A final report and paper discussing this program is presently being prepared. Since 1980, the imposition of federal and state regulations, such as the FTC Trade Regulation Rule[14] relating to building insulation, requires that the manufacturer provide accurate and reliable R-values for products. For fluorocarbon-blown foams, the rule mandates the publication of "aged" R-values obtained after specified specimen conditioning. The Roof Insulation Committee of the Thermal Insulation Manufacturers Association (RIC/TIMA) has addressed this issue by recommending the conditioning of cellular plastic foams prior to testing for thermal performance.[15]

While much information is available, there are still some issues and controversies[16] dealing with the long-term installed thermal performance of cellular plastic foams. There are instances where such reported values are clearly open to question.

This paper summarizes two different experimental methods designed to address the questions relating to the long-term thermal performance of insulation materials. The first method involves the laboratory evaluation of the insulation products after their exposure to artificial environments for various periods of time while the second experimental method measures the thermal performance of the insulation products *in-situ* in an actual roof assembly.

LABORATORY TEST METHOD

The most widely used experimental method for evaluating the "aged" or "stabilized" R-value of a cellular plastic insulation product is to analyze its thermal performance under steady-state conditions in a laboratory utilizing standardized experimental procedures such as ASTM C518, ASTM C177, or ASTM C236.[17] Small specimens of the insulation products are artificially conditioned over a period of time by one or more of several prescribed procedures[14,15,18] prior to testing for thermal performance. The results of these tests are then used to promote the thermal performance of these products. These results are indicative of the product's thermal performance at the prescribed test time but do not necessarily reflect "life-time" thermal performance. The laboratory test method used in this study was similar to the Society of the Plastics Industries study[12] but included some significant changes. Although the same laboratory test procedures were followed, the mechanisms for sample selection and the size of the aging samples were modified to better represent commercially available products and to conservatize the experimental findings.

SAMPLING AND TESTING PROCEDURES

Nine different roofing insulation materials were purchased by laboratory personnel from various wholesale sources. The material selection process attempted to generically cover all major material types used in roofing applications. Typically, two pallets of each product were obtained by the wholesaler by adding this quantity to a much larger contractor order. In effect, these products could have been purchased by a contractor and installed on a roof. Where possible, two different thicknesses of each product (1 1/2 and 3 inches) were obtained. Descriptions of the products used in this study are given in Table 1. The perlite board, the expanded polystyrene beadboard, and all of the polyisocyanurate products did not have date codes. One of the glass-faced polyisocyanurates did have a package code which could not readily be deciphered. Twenty full-size boards were randomly selected from the purchased materials, coded, and placed in the appropriate conditioning environment. The selected conditioning environments were:

1. 75 +/− 3°F and 50 +/− 5 percent relative humidity. Seventeen full-size boards of each product were placed in an environmentally controlled room, standing on edge, with a minimum of 1/2 inch between each board.

2. 140 +/− 3°F with unregulated humidity. A 4-foot-square section was cut from the center of two boards of each product and similarly placed in a specially designed temperature-controlled chamber. If the board size was smaller than 4 by 4 feet, the entire board was conditioned.

Each product was evaluated for thermal resistance upon receipt, after conditioning at 140°F for 90 days, and after 90, 180, and 360 days at 75°F. It is presently planned to continue this program until all products have been conditioned at 75°F for at least 720 days. These conditioning periods were selected to align with trade association and major code agency requirements. The longer conditioning periods were chosen to determine if the present requirements adequately reflected stabilized thermal performance. Typically, two or three test specimens were prepared for each testing period. A single test specimen approximately 24 inches square by thickness was cut from the exact center of each board and immediately tested for thermal resistance in accordance with ASTM C 518-76, Standard Test Method for "Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter" utilizing commercially available heat flow meter instruments.[19] The remainder of the board was discarded. All testing was performed at a mean temperature of 75°F with a temperature difference of approximately 50°F. The instrument is calibrated with 1- and 6-inch-thick NBS Transfer Standards having thermal resistances of 3.12 and 18.2 hr ft^2 F/Btu respectively.

The importance of predefining the board location to be sampled cannot be overstated. The R-value retention of some fluorocarbon-blown cellular plastic foams is a strong function of facer integrity and its adhesion to the foam core. By predefining the sampling location, the possibility of selective sampling based on visual inspection is minimized. Additionally, the selected sampling location was deemed conservative from a manufacturer's perspective because a test specimen removed from this location would probably yield the highest R-value of the board. However, the sampling procedure used in this test method has the disadvantage of testing a different specimen for each test period. While this sampling procedure increases the square footage of product being tested, material variability in the form of thickness and sample differences is added to the test uncertainty when the test data are analyzed.

TEST RESULTS AND DISCUSSION

The experimental results are summarized in Table 2 and are shown graphically in Figs. 1 and 2. The property "thermal resistance" was chosen for comparing the insulation products even though the product's thickness impacts this parameter. The insulation user purchases these products to control the energy consumption of his building. Since the insulation thickness affects energy usage, it should be included into any analysis regarding insulation products performance. Table 2 lists the actual test results while Figures 1 and 2 depict the deviation in thermal resistance between label R-value and the present series of experiments. A positive deviation indicates that the tested product's thermal resistance is higher than the label or advertised R-value. The following comments and conclusions were drawn from the experimental work.

1. This test program did not include sufficient experimentation in order for statistically significant "life-time" thermal resistance values to be obtained for generic types of products. However, the test results for the individual products can be used qualitatively to observe trends.
2. None of the products analyzed by this test method were seriously deficient in thickness. Each product averaged not less than 95 percent of its advertised thickness.
3. Initially, the lack of manufacturing dates for a number of the products was of concern. However, the pallets of boards used for this program were purchased through an insulation wholesaler and would have been installed in a roof at approximately the same time this program was initiated.
4. The phenolic foam (Code 1 in Table 1), perlite board (7), expanded polystyrene beadboard (8), and the fiber glass board (9) products stayed within manufacturing tolerances and exhibited no consistent drift in thermal resistance. The thermal resistance of the extruded polystyrene (2) product drifted downward slightly but was the only product which tested at higher than label R-value for every test period.
5. All of the polyisocyanurates exhibited thermal drift. Five of the seven product/thickness combinations tested below label R-value on receipt. After 180 days of conditioning at 75°F, all polyisocyanurate test results were more than 10 percent and averaged 20 percent below label R-value.
6. In six of the seven polyisocyanurate product/thickness combinations studied in this program, additional thermal drift was noted beyond the two most widely accepted conditioning periods for preparing specimens for thermal performance testing.

The thermal resistance test results were integrated for the one-year test period. With periodic data for the first year, the one-year integration provides a better method of comparing different types of roofing insulation products (i.e.,perlite board to polyisocyanurate foam) than an arbitrarily selected single conditioning period. The results of this analysis are shown in Fig.3. Since a typical roof assembly has a life expectancy of much more than one year, the "life-time" thermal resistance of those products exhibiting thermal drift will be lower than the results presented in Fig. 3.

IN-SITU TEST METHOD

The conditioning and experimental procedures described for the Laboratory Test Method bear little resemblance to the environment in which these products will eventually be used. As stated earlier, the extent and rate of the thermal drift for cellular plastic foams is dependent on the material, the board size and thickness, the facer type and its integrity, the environment, and the type of construction. It is unlikely that the thermal performance of a fluorocarbon-blown cellular plastic foam will have similar thermal drifts when conditioned under laboratory isothermal and field conditions. Several researchers, most notably the National Bureau of Standards,[20] U.S. Army Cold Regions Research and Engineering Laboratory,[21] W.R. Grace and Company,[22] the Lawrence Berkley Laboratory,[23] the Oak Ridge National Laboratory (ORNL),[24] and RIC/TIMA[25] have undertaken experiments to determine the *in-situ* thermal performance of building envelope components.

In general, the researchers for these field studies utilize heat flux transducers (HFTs) to monitor heat flow in their field experiments. Confidence in the validity of this measurement technique is sufficiently high that the American Society of Testing and Materials (ASTM) has prepared a standard practice on this subject.[15] This confidence is based primarily on a propagation of errors analysis of the key thermal influences on the accuracy of measurement. However, the principal difficulty encountered by researchers in this field remains the validation of the experimental techniques and the interpretation of the results with respect to the separation of the various parameters affecting thermal performance.

The purposes for this *in-situ* test program were:

1. Develop an instrumentation package for performing *in-situ* thermal resistance tests on new roof constructions.
2. Validate the performance of the instrumentation package by performing concurrent testing with ORNL.
3. Compare *in-situ* and laboratory test results.
4. Evaluate a technique for measuring the thermal resistance of existing roof constructions.
5. Generate long-term *in-situ* thermal resistance data for a phenolic foam roof insulation product.

TEST BUILDING AND PANEL CONSTRUCTION

With the cooperation of the Oak Ridge National Laboratory, a combined field experiment was undertaken on the Roof Thermal Research Apparatus (RTRA) at ORNL. The RTRA has previously been described.[24] Basically, the RTRA is housed in a concrete block building approximately 8 feet wide by 26 feet long by 9 feet high with a concrete slab-on-grade floor. The roof consists of a central fixed BUR roof sandwiched between two 4-foot-by-8 foot test sites on each side. The interior of the RTRA is temperature-and humidity-controlled. The test panel for this study was mounted into one of these test sites.

The present test panel consisted of a metal deck, a 3/4-inch-thick layer of perlite board, a 2-inch (R 16.7)-thick layer of phenolic foam, and a 1/2-inch-thick layer of fiberboard. Wood nailers were mounted around the test panel and the panel was then placed into a steel frame to facilitate handling. A fully adhered EPDM membrane was laid over the entire panel. No vapor retarder was used in the construction. Several spare boards of each material in the test panel were saved for laboratory evaluation.

The test panel was installed on the RTRA on Dec. 10, 1985 and data collection was initiated on Dec. 18, 1985.

INSTRUMENTATION

The most difficult aspect of performing field experimentation on insulated systems is to accurately measure the heat flow in those systems. Historically, most researchers have used small and thick ($2 \times 2 \times$ 1/8 to 1/4 inch) HFTs for their *in-situ* experimental work. Their selection was primarily based on the high sensitivities of these HFTs (approximately 1mV/Btu/hr ft^2 F). The disadvantages of this design are that their active (metering) area is extremely small and that their small aspect ratio (cross-section to thickness) and lack of a guard region increases the possibility of edge effects affecting the heat flux transducer output by distorting the heat flux locally at the transducer.[26,27]

To overcome these disadvantages, special HFTs were used in this program.[28] Specifically, the HFTs are 12 by 12 inches square by 0.032 inches thick and have an active area that is 6 by 6 inches. The sensitivity of this type of HFT is approximately 0.2mV/Btu/ hr ft^2 F at 75°F. The advantages of this type of HFT construction are:

1. The thickness of the HFT and its guard region virtually guarantee that edge effects will be minimized and not perturb into the active area.
2. The large active area reduces the criticality of the HFT mounting location and allows the researcher to measure a significantly larger portion of the test panel.
3. The reduced mass and thickness of this HFT compared to other HFT's historically used for performing *in-situ* testing increases its thermal response.
4. The reduced thickness of the HFT reduces its thermal resistance and therefore the thermal resistance added to the test panel by the instrumentation.
5. The photo-etching process used to fabricate these HFTs is very reproducible, guaranteeing HFTs of similar sensitivity when multiple units are used.

Three HFTs and nine 30-gauge Type K Chromel/Alumel thermocouples were mounted into the test panel. The HFTs were located between the metal deck and the perlite board, between the perlite board and the phenolic foam, and between the phenolic foam and the fiberboard. Small indentations were cut in the perlite board and the fiberboard to accommodate the HFT. When embedded into these indentations, the exposed surface of the HFT was flush with the insulation board surface. Thermocouples were also located at these locations within the test panel and on the interior and exterior surfaces of the roof assembly. The internal thermocouples were mounted into small grooves in the perlite board and fiberboard. Two temperature sensors were installed at each location to verify temperature uniformity and to guarantee the continuance of the experiment should one thermocouple fail. Each thermocouple array was "assigned" to a HFT, effectively allowing for three simultaneous series of independent measurements. Each HFT/ thermocouple array was designated as a "team". Team 1 instrumentation utilized the HFT that was located between the perlite board and the phenolic foam. This HFT location was most desirable because the HFT would be thermally isolated from exterior or interior environmental fluctuations. Teams 2 and 3 utilized the HFTs mounted between the fiberboard and phenolic foam and the metal deck and the perlite board respectively. These locations were deemed less desirable than the central location but represented more typical HFT placements when testing was required on an existing roof assembly.

ORNL has performed a computer simulation of the test panel which indicates that the central 80-by-32-inch portion is free of edge effects. The three instrumentation teams were mounted in a staggered array in half of the test panel such that they were in the isothermal central zone and no two HFTs were in the same vertical plane. ORNL mounted their standard instrumentation package in the second half of the test panel. A comparison between the two instrumentation packages will be the subject of a future paper.

A meteorological station was set up outside the RTRA to monitor local weather conditions. A standard 10-foot-high tower was mounted on the RTRA and was equipped to measure wind speed and direction. A second wind vane and anemometer were installed near the roof to measure local surface conditions. Temperature and dew point sensors were mounted into a motor aspsirated radiation shield and attached to the side of the tower and a barometer was installed inside the RTRA. The outputs of all the meteorological sensors were connected to signal conditioners, which modified their outputs to 0 to 5 VDC.

HEAT FLUX TRANSDUCER CALIBRATION

The ability to perform *in-situ* thermal performance testing is limited by the accuracy of the HFT calibration. This subject still requires further study and ASTM Subcommittee C16.30 on Thermal Measurements has set up a task force to research this matter. Conceptually, the HFTs should be calibrated with similar edge effects and over the anticipated range of temperatures to be encountered in the field.

The calibration technique used for the present utilized test instrumentation designed in accordance with ASTM C518-76. The HFTs that were used in the test panel were embedded into 24-inch-square sections of perlite board and fiberboard in an identical fashion to their test panel installation. Two embedded HFTs were sandwiched around two 1-inch-thick, high-density fiber glass boards and inserted into the C518 tester. Since the surface plates of the tester are at approximately 50° and 100°F, an HFT was at approximately each temperature. When the experiment equilibrated, the sensitivity of each HFT was determined by comparing its output to that of the instrument HFT. The composite assembly was removed from the tester, inverted, and reinserted into the tester such that the HFTs were near the opposite surface plate. After equilibration, the stack was once again removed from the tester and the HFTs were placed between the two fiber glass boards such that, when retested, their temperature would be approximately 75°F. A least-squares linear regression was performed on the HFT sensitivity data as a function of temperature and the coefficients of these regressions were written into the control program.

DATA ACQUISITION SYSTEM

A digital data acquisition system (DDAS) was designed to collect temperature, heat flow, and weather data from the sensors located in, on, or near the test panel. The system consisted of a personal computer with 640K of RAM and 10-megabyte hard drive with a data acquisition/control unit connected through a general purpose interface bus. The function of the personal computer was to initiate data scans at predetermined time intervals, convert the data to engineering units (for example, convert thermocouple EMFs in microvolts to temperature in degress Fahrenheit), and store the data in files which it would set up in the mass storage medium. The data acquisition system served as the termination point of all the sensors. As configured, the data acquisition/control unit would accommodate 20 channels, although it is easily expandable to over 100 channels. On command from the computer, it closes a switch on the selected channel and samples the analog signal, usually a low-level voltage, which is then digitized and sent to the computer through the interface bus. The data acquisition/ control unit used in this program was selected because its voltmeter has a high resolution which was needed with the lower sensitivity HFTs.

DATA ACQUISITION AND ANALYSIS

A control program was written to govern the functions of the DDAS during data accumulation, to create data files, and to reduce and store the collected data. Whenever the program was initiated, a data file was created which was identified by the start date and time. The sensors were scanned four times a minute over an 11-minute period at the hour (44 scans total per hour). This data was converted to engineering units, averaged, and the average stored as the data for that hour. The system would then idle until the next scanning period. The data was written to the file in such a manner that it could then be directly imported into a spreadsheet for further calculations and analysis.

The data was analyzed in five-day or 120-hour blocks. This data array limit was determined by the size that the PC RAM could accommodate. The thermal resistance of the phenolic foam was determined by dividing the integrated temperature difference across the phenolic foam by the integrated heat flux through the phenolic foam. Three different time intervals were integrated: block, month, and program. The program integration is the true measure of an insulation product's life-time thermal performance for the application and environmental conditions under test.

LABORATORY TESTING OF THE TEST PANEL COMPONENTS

Each insulation product used in the fabrication of the test panel was separately analyzed for thermal resistance in accordance with ASTM C518-76. The products were obtained in October 1985 and were stored in an environmental room maintained at 75°F and 50 percent relative humidity. Just prior to testing, specimens 24 inches square were prepared from the spare boards of each product. Testing of the phenolic foam was undertaken in January and April 1986. No apparent thermal drift was noted.

Additional boards were supplied to ORNL for laboratory analysis. As part of their standard procedure, ORNL calibrate their HFTs by building an accurate 3-by-5-foot specimen of the test panel with all the appropriate field instrumentation installed and evaluating this specimen in an unguarded screen tester.[29] From this experiment, HFT sensitivity data and the thermal resistance of the entire test panel are obtained. Using Dynatech's thermal resistance data for the perlite board and the fiberboard, the thermal resistance and apparent thermal conductivity of the phenolic foam was derived. Fig. 4 depicts the apparent thermal conductivity of the phenolic foam as a function of temperature. The nonlinearity in this relationship is probably due to a change of phase in the fluorocarbon blowing agent.

TEST RESULTS AND DISCUSSION

The *in-situ* testing has been underway for eight months. The experiment was designed with several internal consistency checks to determine the quality of the data. Figs. 5, 6, 7, and 8 depict the monthly intergrated mean temperature of the phenolic foam board, the monthly integrated heat flux through the test panel, and the monthly and program integrated thermal resistance of the phenolic foam. The present interpretation of the test results are:

1. Fig. 5, the insulation mean temperature plot, demonstrates the reproducibility of temperature measurements when special-grade thermocouples, effective shielding, and high-resolution electronics are used. The temperature data also verifies the analytical modeling of the test panel by ORNL. Typical agreement between the three teams was better than +/− 0.2°F.

2. For the time period studied, the program average board temperature is approximately 71°F. This result adds credibility to the selection of 75°F as the mean temperature for laboratory analyses.

3. Fig. 6, the monthly integrated heat flux, suggests that the measurement of this parameter remains the critical path for improving the accuracy of field experimentation. Very small integrated heat fluxes during swing temperature months (April and May for the present study) require improved measurement techniques. Improved calibration techniques are also suggested by these results. Note that the heat flux (and therefore integrated thermal resistance) predicted by Teams 2 and 3 agree with each other better than they do with Team 1's prediction. This is probably due to the fact that Team 2 and 3 were calibrated together while the HFT used for Team 1 calibrated with a spare HFT. In addition, it appears that the scanning procedure used for HFTs located outside of the insulation should be modified. Presently, the rapidly changing heat fluxes on

the exterior side of the insulation are not being adequately averaged.

4. Both the monthly and program integrated thermal resistance plots (Figs. 7 and 8) suggest a reduction in the thermal resistance with time, even though all the measured results remain higher than the label R-value of 16.7 hr ft^2 F/Btu. However, a comparison of the *in-situ* and laboratory test results gathered in January and April 1986 (Fig. 9) shows that the *in-situ* experiment measures a higher thermal resistance in the winter months and a lower thermal resistance during the summer months after normalizing the data for mean temperature differences. It has been suggested that moisture may be responsible for this behavior. It is presently planned to continue this experiment for the remainder of the calendar year to determine if this interpretation is correct. Note that there is no vapor retarder in this construction and the effect of the phenolic foam-board mean temperature on thermal resistance for the *in-situ* experiment has been normalized to 75°F so that the *in-situ* to laboratory comparison can be made.

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Product	Code	Label thickness, inches	Board size, feet	Manufacturing date	Initial test date	Test thickness, inches	Test density lbs/ft^3	Label R-value hr ft^2 F/Btu
Phenolic foam	1	1½	3 × 4	08/20/85	10/17/85	1.55	3.60	12.5
		3	3 × 4	08/27/85	10/17/85	3.12	3.08	25.0
Extruded polystyrene	2	1½	2 × 4	10/30/84	01/28/85	1.50	2.20	7.5
		3	2 × 4	06/17/84	01/28/85	3.14	2.16	15.0
Glass-faced polyisocyanurate #1	3	1½	4 × 8	N/A	04/26/85	1.48	2.29	9.4
		3	4 × 8	N/A	04/26/85	3.00	2.09	20.0
Glass-faced Polyisocyanurate #2	4	1½	4 × 8	N/A	02/28/85	1.46	2.70	11.1
		3	4 × 8	N/A	02/28/85	3.08	1.92	22.2
Foil-faced polyisocyanurate #1	5	3	4 × 8	N/A	04/22/85	3.07	2.22	21.6
Foil-faced polyisocyanurate #2	6	1½	4 × 8	N/A	02/11/85	1.57	1.90	11.5
		3	4 × 8	N/A	02/11/85	3.13	2.02	23.3
Perlite board	7	1½	2 × 4	N/A	01/28/85	1.45	11.39	4.2
		2	2 × 4	N/A	01/28/85	2.01	9.39	5.6
Expanded polystyrene beadboard (1.5 PCF)	8	1½	4 × 8	N/A	01/31/85	1.47	1.55	6.0
		3	4 × 8	N/A	01/31/85	2.96	1.37	12.0
Fiber glass board	9	1⅝	3 × 4	10/29/84	04/22/85	1.70	10.26	6.4
		3	3 × 4	04/01/85	04/22/85	3.05	9.30	12.3

Table 1 *Description of products analyzed by the laboratory test method*

Product	Code	Thickness	Average thermal resistance, R, hr ft^2 F/Btu @ 75°F after				
		inches	on receipt	90 days @ 75°F	180 days @ 75°F	360 days @ 75°F	90 days @ 140°F
Phenolic foam	1	1½	12.7	13.6	12.0	13.2	11.1
		3	27.0	26.5	24.5	26.8	27.3
Extruded polystyrene	2	1½	8.1	7.7	7.7	7.6	7.8
		3	16.2	15.7	15.7	15.3	15.8
Glass-faced polyisocyanurate #1	3	1½	9.5	8.7	8.2	7.9	6.3
		3	20.8	18.2	17.9	15.7	17.5
Glass-faced polyisocyanurate #2	4	1½	9.0	8.2	7.9	7.7	8.0
		3	20.7	19.1	17.8	19.1	20.7
Foil-faced polyisocyanurate #1	5	3	19.8	19.6	18.2	17.3	18.4
Foil-faced polyisocyanurate #2	6	1½	11.0	9.1	8.5	8.0	8.4
		3	21.0	18.5	17.6	16.9	16.5
Perlite board	7	1½	3.6	3.5	3.6	3.6	3.6
		2	5.3	5.2	5.2	5.3	5.3
Expanded polystyrene beadboard (1.5 PCF)	8	1½	5.8	5.6	5.7	5.6	5.7
		3	11.0	10.8	11.0	11.3	10.5
Fiber glass board	9	1⅝	6.4	6.3	6.9	6.5	6.5
		3	12.0	12.1	12.0	11.6	12.1

Table 2 *Test results derived by the laboratory test method*

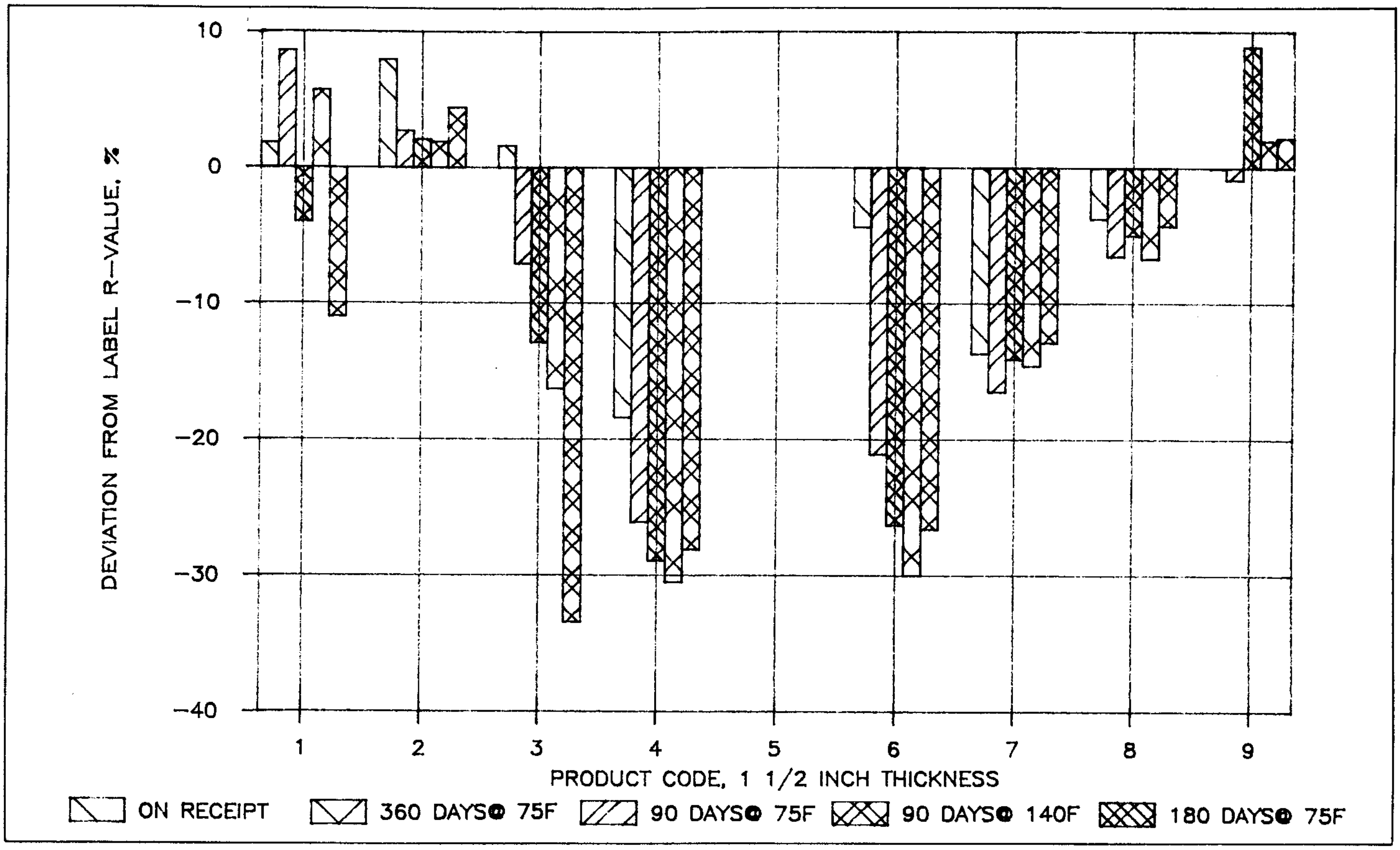

Figure 1 *The difference between label and tested R-values for eight 1½-inch-thick roofing insulation materials*

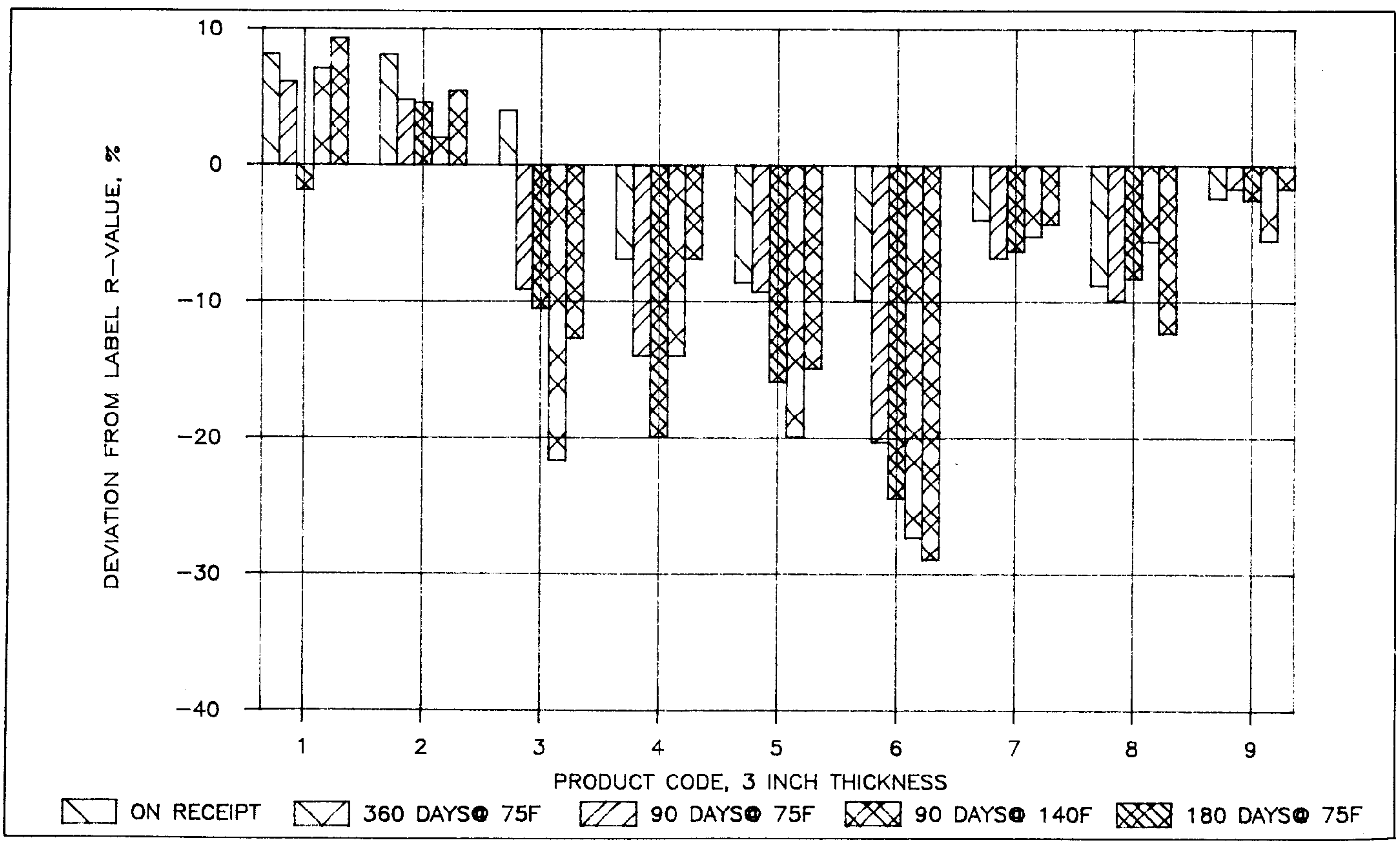

Figure 2 *The difference between label and tested R-values for nine 3-inch-thick roofing insulation materials*

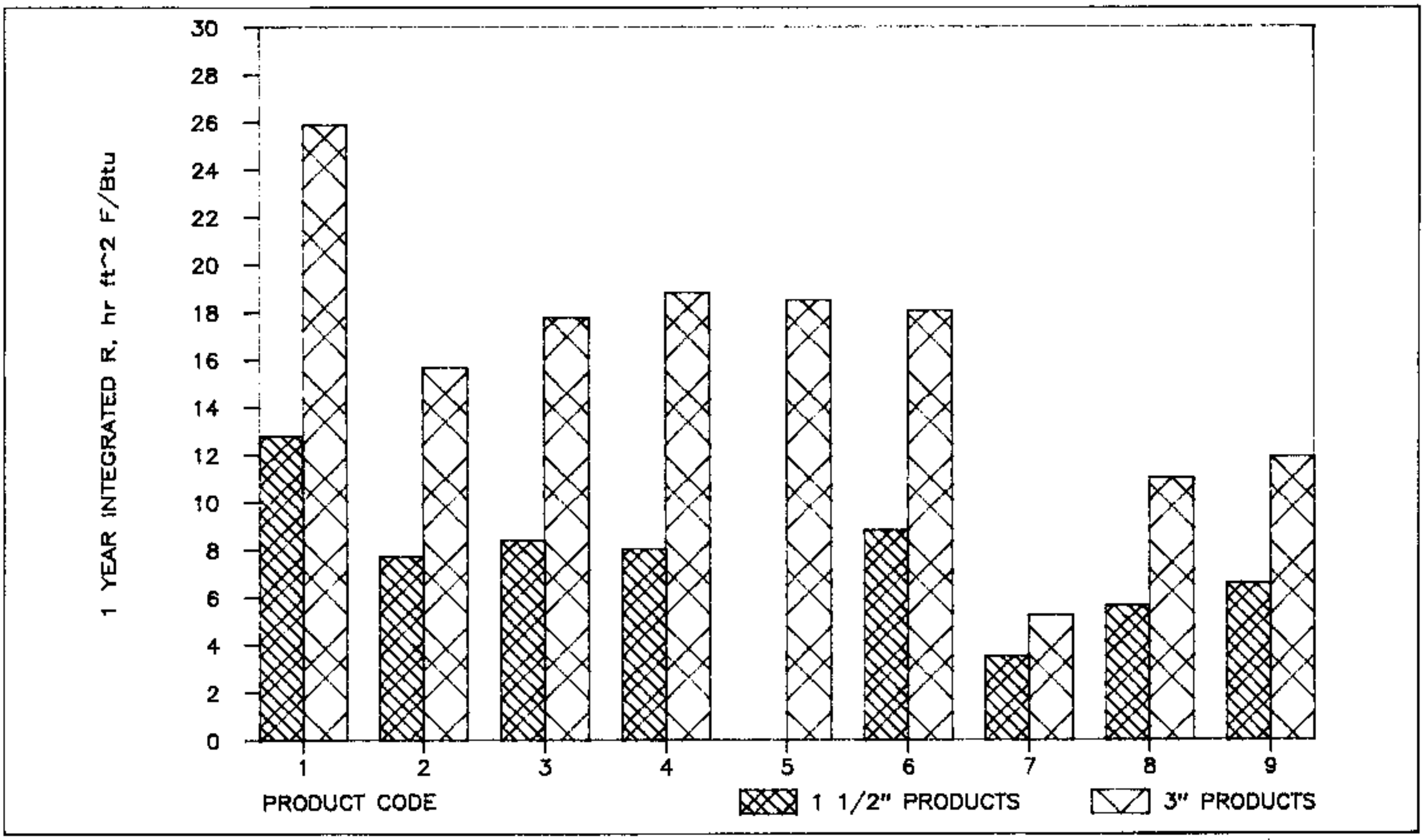

Figure 3 *The one-year integrated thermal resistance of nine roofing insulation materials*

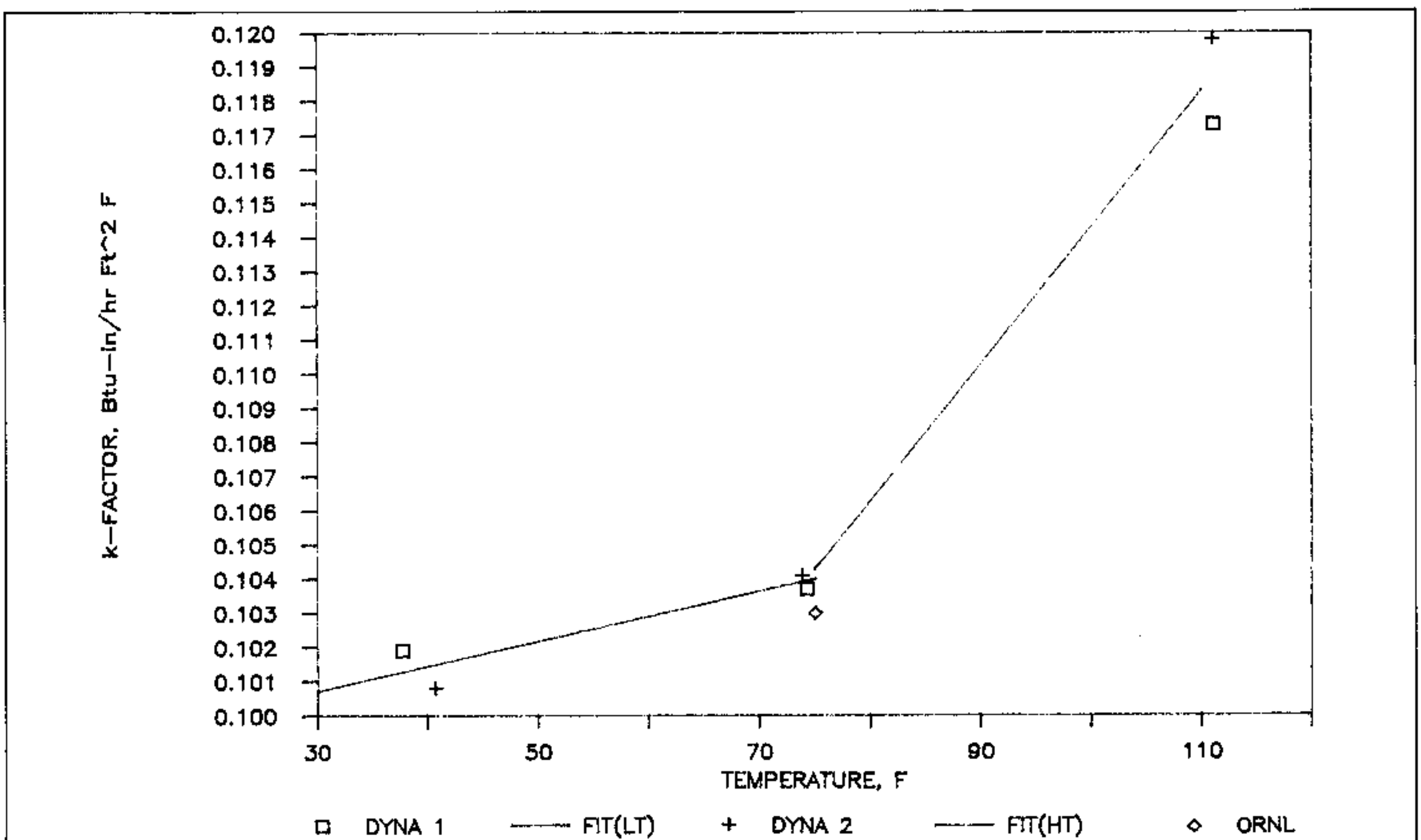

Figure 4 *The apparent thermal conductivity of a phenolic roof board by laboratory analysis*

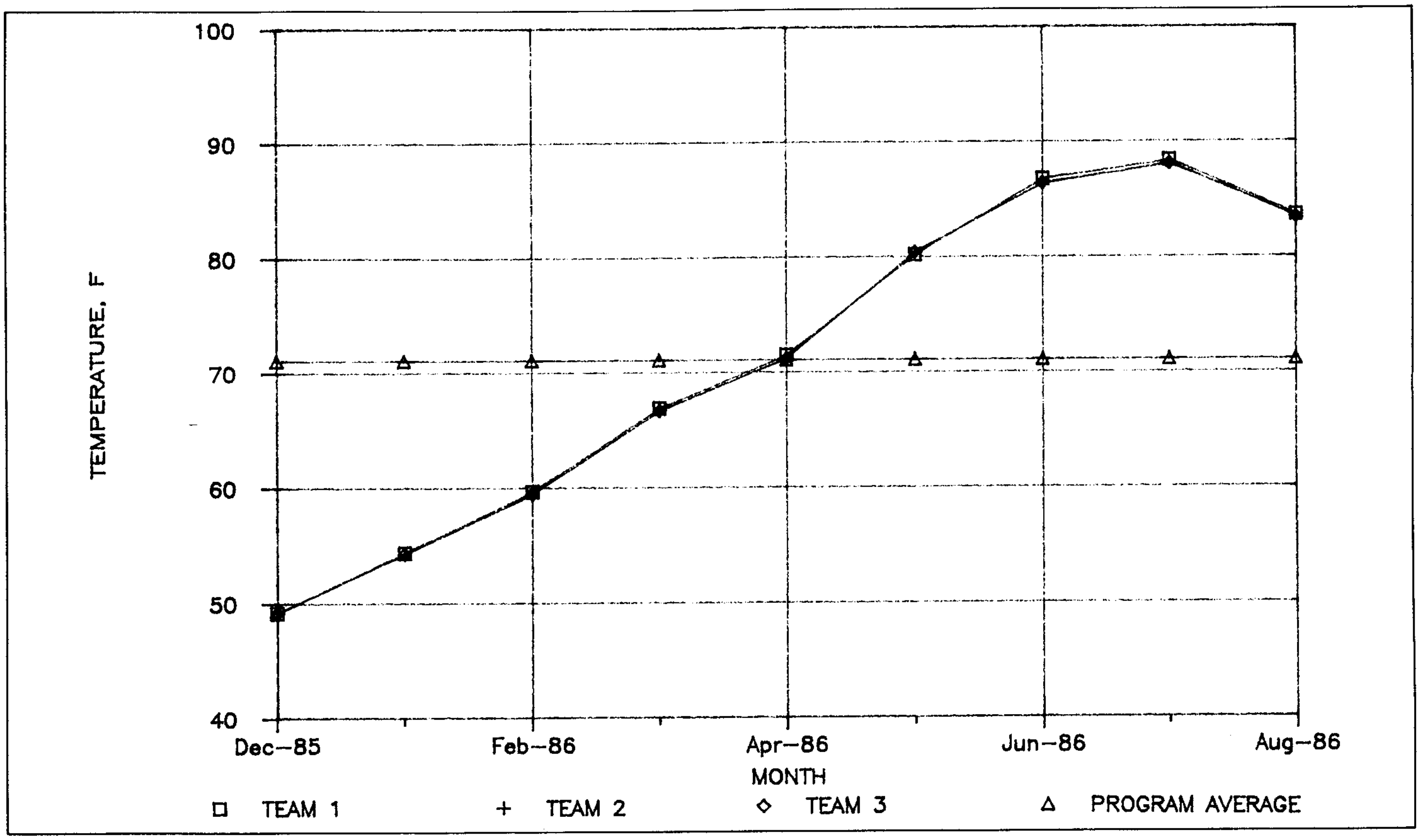

Figure 5 *The monthly integrated mean temperature of a phenolic foam roof board*

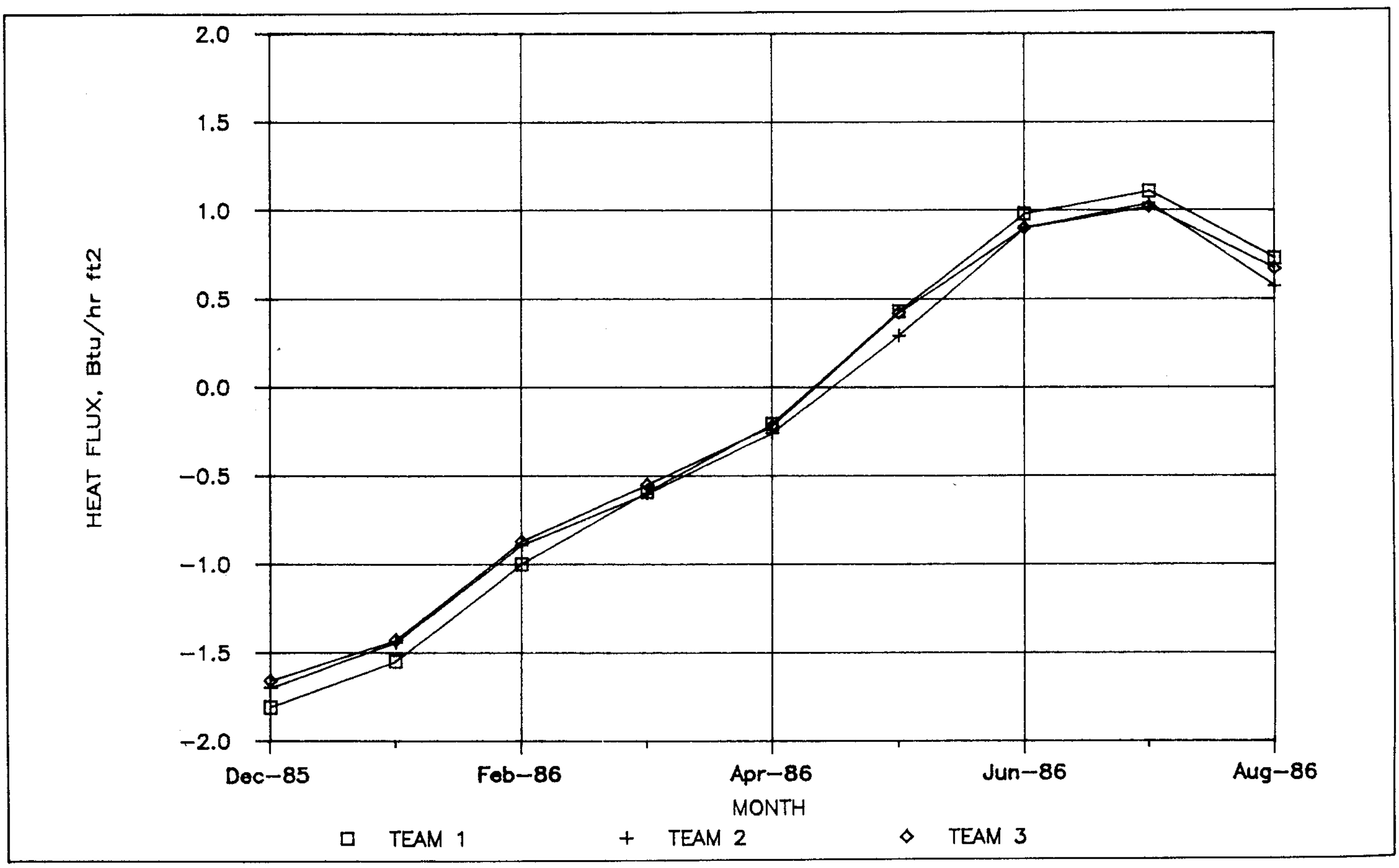

Figure 6 *The monthly integrated heat flux through the test panel*

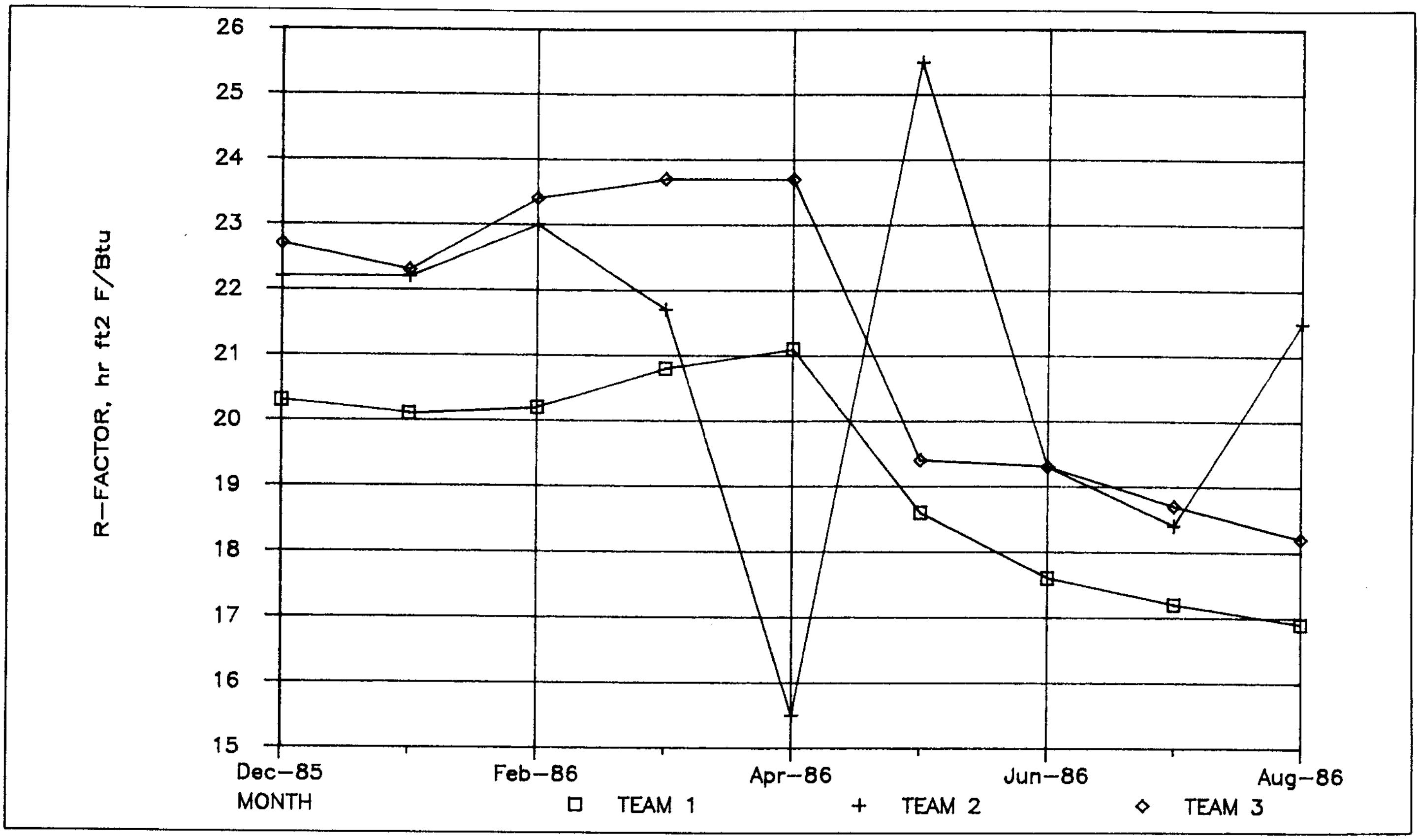

Figure 7 *The monthly integrated thermal resistance of a phenolic foam roof board. See text for discussion of April and May data.*

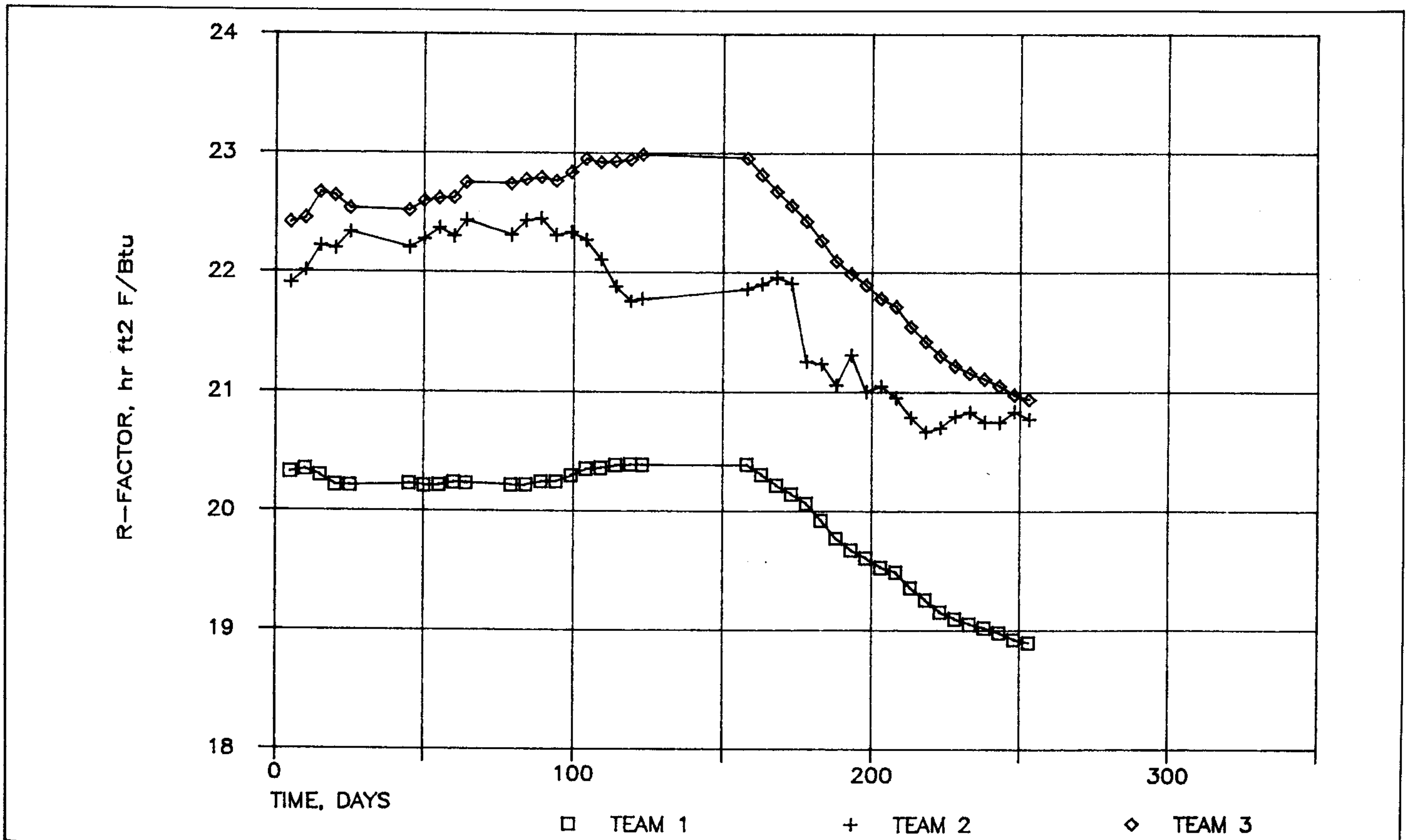

Figure 8 *The program integrated thermal resistance of a phenolic foam roof board. Missing data due to power outages at test site.*

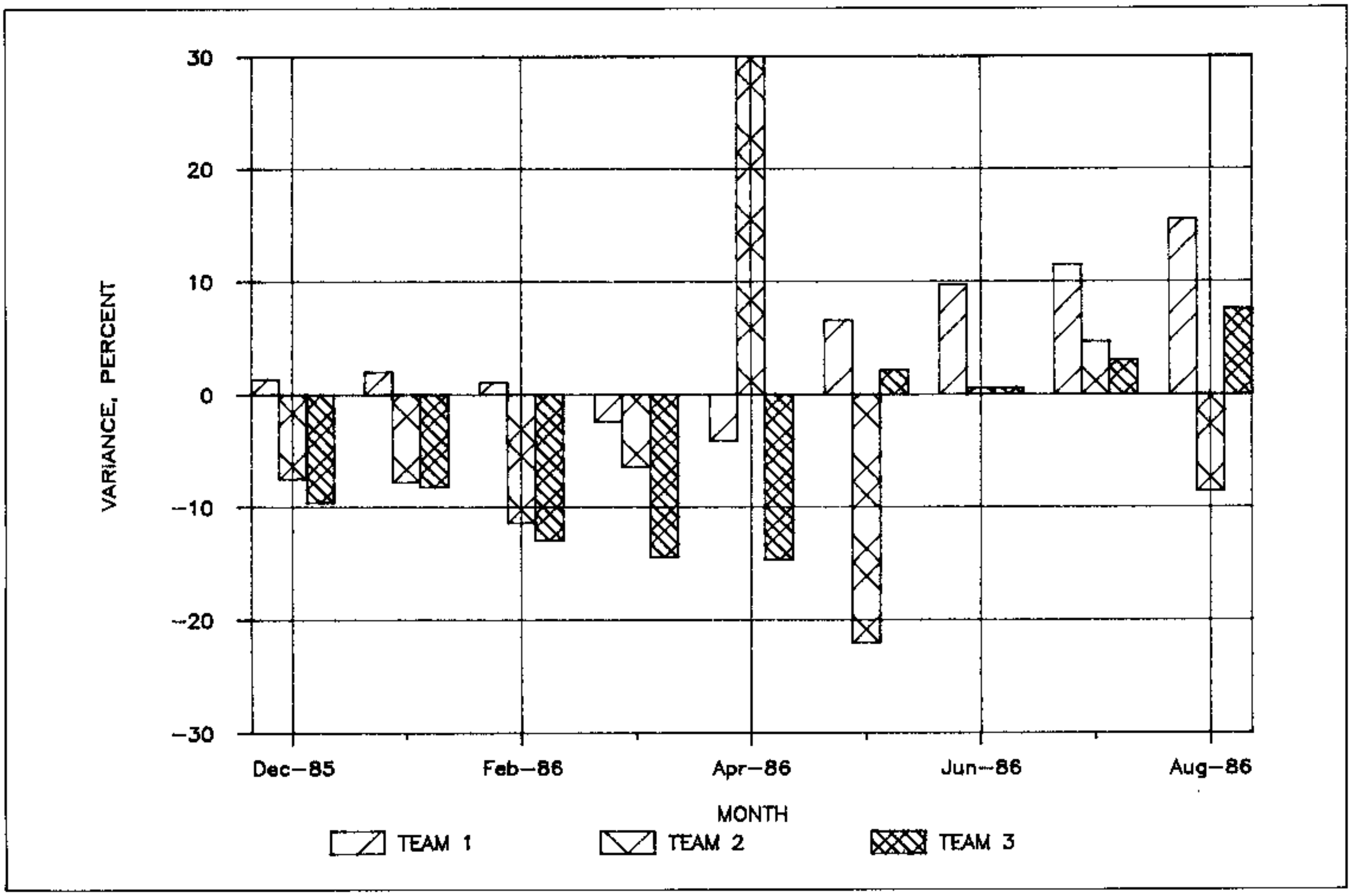

Figure 9 *The monthly variation between laboratory and* in-situ *thermal resistance test results*