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**EVALUATION OF FOAMSEAL CEILING PANELS
IN THE LARGE SCALE CLIMATE SIMULATOR
UNDER WINTER CONDITIONS PHASE I**

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Letter Report
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Energy Division

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Prepared for
Foamseal Urethane Technology, Inc.

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EVALUATION OF FOAMSEAL CEILING PANELS IN THE LARGE SCALE CLIMATE SIMULATOR UNDER WINTER CONDITIONS PHASE I

This report serves to document Phase I of tests on ceiling panels fabricated by Foamseal Urethane Technology, Inc. in the Large Scale Climate Simulator (LSCS). The work reported here was accomplished during August, 1991.

TEST SETUP

Large Scale Climate Simulator

The tests reported here were performed using the Large Scale Climate Simulator located in the Roof Research Center at the Oak Ridge National Laboratory.¹ As shown in Figure 1, the upper portion of the LSCS is the environmental chamber which simulates a wide range of climatic conditions in either a steady-state or dynamic (simulating diurnal conditions) mode. Temperatures in the environmental chamber can range from 150 to -40°F. Roof surface temperatures can be controlled with infrared heating up to 200°F. The lower portion of the LSCS contains both a guard and a metering chamber each of which can be controlled independently from 45 to 150°F. Both upper and lower chambers have controlled humidity and other capabilities which were not utilized in this set of experiments.

The LSCS can be operated in two modes. In the heat flux transducer mode, the metering chamber hot box is kept in a lowered position (see Fig. 1), and the lower chamber is used only to provide simulation of indoor conditions. Heat flows through the roof panel are measured with heat flux transducers attached to the panel. The guarded hot box mode uses the metering chamber as a guarded hot box. The metering chamber is raised so that it seals against the underside of the roof panel, and provides a measurement of the total heat flow through the 8 feet by 8 feet central area of the panel. The surrounding guard chamber is maintained at the same temperature as the metering chamber to minimize heat flows across the metering chamber walls.

Because of the complex heat flow paths in the ceiling panels, it is necessary to use the LSCS in the guarded hot box mode. In the guarded hot box mode, the heat flow through the panel is calculated from an energy balance on the metering chamber. Elements in this heat balance include energy supplied by the direct current circulation fans, energy supplied by an electric resistance heater, energy removed by a chilled-water coil, heat losses or gains through the walls of the metering chamber, and the heat flow through the roof panel. Fan and heater energies are obtained from DC current and voltage measurements. The energy removed by the chilled-water coil is obtained from a flow rate measured by a turbine flowmeter and from a temperature rise measured with a differential platinum resistance temperature device. (Note: for all the tests reported here, the chilled water coil was turned off so that it did not enter into the heat balances.) Heat flows through the metering chamber walls are estimated using 32 differential thermocouples across the walls.

Test Panels

The test panels were fabricated at ORNL by Bob Snyder of Foamseal Urethane Technology, Inc. on July 10, 1991. Panel 1 was constructed with 2X4 wood joists spaced 24 inches on centers, with sheets of 5/16 inch thick gypsum board on both the top and bottom. The bottom sheet was attached to the joists using staples, and the top layer was attached with drywall screws. The cavities were left empty.

Panel 2 was of similar construction, with the following differences. The wood joists were 2X4s that had been trimmed to a thickness of about 3-1/8 inch, leaving a gap of 3/8 inch between the joists and the bottom sheet of gypsum board. The bottom sheet was attached to the joists using foamed-in-place urethane foam with a CFC-11 foaming agent. The foam filled in the gap between the wood joists and the gypsum board, and also covered part of the bottom sheet of gypsum board. No mechanical fasteners were used on the bottom sheet in the metering area.

Each panel was instrumented with 48 thermocouples, with 24 thermocouples on the outer surface of each of the sheets of gypsum board. The thermocouples were taped in place using two inch wide masking tape. Locations of the thermocouples are shown in Figure 2. Of the 24 thermocouples, 20 were placed over the empty cavities and four were placed over the joists. Arrays of thermocouples were also placed in the air above and below the panels. All thermocouples were made from 26 gauge Type T special limits of error wire, and all thermocouples were taken from the same spool of wire, resulting in individual temperature measurements accurate to within $\pm 1^\circ\text{F}$.

DATA ANALYSIS

Surface-to-surface R-values for the panels were obtained from the following equation:

$$R = \frac{A \Delta T}{Q} \quad (1)$$

where A is the area of the ceiling contained between the centerlines of the guarded hot box walls (69.4 square feet), ΔT is the temperature difference between the bottom surface of the bottom layer of gypsum board and the top surface of top layer of gypsum board, and Q is the heat flow through the metered area of the ceiling. The temperatures of these two surfaces are obtained by averaging readings of the 24 thermocouples on each surface, with the readings from the framing and cavity areas being weighted by their respective areas.

The heat flow is obtained from a heat balance on the guarded hot box. Terms in this heat balance include heat supplied by the air circulation fans, heat supplied by an electric resistance heater, heat losses or gains through the walls of the metering chamber, and the heat flow through the ceiling. Fan and heater energies are obtained from DC current and voltage measurements. Heat flows through the metering chamber walls are estimated using differential thermocouples across the walls.

The duration of each individual test was about 24 hours, with data being collected every four minutes. Data from the first several hours were ignored in the data analysis. Whenever possible, a continuous time segment of 8 hours was selected for analysis, during which the temperatures and heat flows were most stable. Temperatures and heat flows were averaged over this time period and the averages were used with Equation 1 to calculate an R-value.

ACCURACY OF DATA

The overall accuracy of the measured R-values has been assessed through LSCS measurements on samples constructed from expanded polystyrene foam insulation for which the thermal conductivity is accurately known from independent measurements in the ORNL Unguarded Screen Heater Apparatus.²

The first set of LSCS measurements was performed on a 4.0 inch thick monolithic panel of the foam. Under a wide range of simulated winter conditions, measured R-values were within about 3.5 percent of the known values (on average), and the precision of the measurements was about 1.5 percent.

For the second set of LSCS measurements, pieces of foam were cut and fitted into the Attic Test Module. The first layer fit between the 2X4 joists with a thickness equal to that of the joists. The second layer was applied perpendicular to the joists, such that the total thickness of foam between the joists was 5.0 inches. The second layer of foam also covered the joists. Under simulated winter conditions, measured overall R-values (i.e., between the bottom of the gypsum board and the top of the insulation) were within ± 2.8 percent of R-values obtained from a detailed finite difference analysis using the known thermal conductivity of the foam and estimates for the thermal conductivity of the wood joists and the gypsum board.

Immediately after the tests on the Foamseal panels, the 4.0 inch thick monolithic foam panel was replaced in the LSCS and another set of tests was performed. For these tests, the measured R-values were within about 4.0 percent of the known values (on average), and in addition were within 1.5 percent of the values measured in the first set of tests on this panel.

These results indicate that under simulated winter conditions, with no cooling in the metering chamber, the accuracy of thermal resistances measured with the LSCS is about ± 4.0 percent, and the precision is about ± 1.5 percent.

TEST RESULTS

The results of tests on the two panels are given in Tables 1 and 2, and in Figures 3 and 4. For all tests, the metering chamber was maintained at 70°F. For each panel, three tests were run, with the climate chamber at 40°F, 20°F, and 0°F.

Figure 3 shows a plot of the measured heat flow through the metered area of the ceiling as a function of the climate chamber temperature. For both panels, the heat flow is linearly related to the climate chamber temperature, and is nearly proportional to the difference in temperature between the metering and climate chambers. This figure clearly shows that the heat flow measured on the panel with the joists attached with urethane foam is about 10 to 11 percent lower than that for the panel with the joists attached with staples.

Figure 4 shows a plot of the measured thermal resistance of the panel versus the mean temperature of the panel. For Panel 1, with the joists attached with staples, the R-value is about 1.47 hr-ft²·°F/Btu, while for Panel 2, with the joists attached with urethane foam, the R-value is about 1.66 hr-ft²·°F/Btu, or about 13 percent higher. For both panels, the R-value is relatively independent of the mean temperature. In general, it is expected that the R-value should be a

function of both the mean temperature and the temperature difference. For the particular conditions used in these tests, the mean temperature and the temperature difference are correlated, and their effects appear to cancel.

CONCLUSIONS

The following general conclusions may be drawn from the testing performed in this project:

1. The heat flow measured on the panel with joists attached with urethane foam was about 10 to 11 percent lower than that measured on the panel with joists attached with staples.
2. The measured thermal resistance of the panel with joists attached with urethane foam was 13.3 ± 0.4 percent higher than that measured on the panel with joists attached with staples.
3. For the particular conditions under which the tests were run, the R-value was independent of mean temperature.

REFERENCES

1. W. R. Huntley, Design Description of the Large Scale Climate Simulator, ORNL/TM-10675, Oak Ridge National Laboratory, Oak Ridge, TN, 1989.
2. D. L. McElroy, R. S. Graves, D. W. Yarbrough, and J. P. Moore, "A Flat Insulation Tester that uses an Unguarded Nichrome Screen Wire Heater," Guarded Hot Plate and Heat Flow Meter Methodology, ASTM STP 879, pp. 121-129 (1985).

Figure 1. Cross section of the Large Scale Climate Simulator.

FOAMSEAL PANELS THERMOCOUPLE LAYOUT DAS CHANNEL NUMBERS

T=TOP OF PANEL SURFACE (GYPSUM)
B=BOTTOM OF PANEL SURFACE (GYPSUM)

Figure 2. Location of thermocouple arrays on the top and bottom sheets of gypsum board and above and below the test panel.

LSCS RESULTS FOR FOAMSEAL PANELS

WINTER CONDITIONS

Figure 3. Heat flow through metered area versus climate chamber temperature for FoamSeal panels. The metering chamber was maintained at 70°F for all tests. Joists in Panel 1 were attached to bottom sheet of gypsum board with staples. Joists in Panel 2 were attached to bottom sheet of gypsum board with urethane foam

LSCS RESULTS FOR FOAMSEAL PANELS

WINTER CONDITIONS

Figure 4. Thermal resistance versus mean temperature for Foamseal panels. The metering chamber was maintained at 70°F for all tests. Joists in Panel 1 were attached to bottom sheet of gypsum board with staples. Joists in Panel 2 were attached to bottom sheet of gypsum board with urethane foam.

Table 1. Foamseal Panel No. 1, Joists Attached with Staples

Temperatures, °F		Heat Flow, Btu/hr	Temperature Difference, °F	Mean Temperature, °F	R-Value, hr-ft ² -°F/Btu
Metering Chamber	Climate Chamber				
70	40	782	16.4	54.1	1.46
70	20	1293	27.3	44.2	1.47
70	0	1820	38.5	34.1	1.47

Table 2. Foamseal Panel No. 2, Joists Attached with Foam

Temperatures, °F		Heat Flow, Btu/hr	Temperature Difference, °F	Mean Temperature, °F	R-Value, hr-ft ² -°F/Btu
Metering Chamber	Climate Chamber				
70	40	700	16.8	54.2	1.66
70	20	1155	27.8	44.2	1.67
70	0	1644	39.3	34.1	1.66