THE EFFECTIVE THERMAL PERFORMANCE OF AN INSULATED STANDARD STUD WALL CONTAINING AIR GAPS

by

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ABSTRACT

An experimental investigation of the effective performance of a cavity wall assembly has been undertaken using the standard guarded hot box procedure. Measurements of the thermal conductance were obtained with the cavities completely filled with a cellular plastic and then partially filled with accurately machined pieces of the same cellular plastic which simulated different sizes, positions and orientations of air gaps, particularly representative of those due to shrinkage.

The results indicate that there is a direct relationship between effective thermal performance and size of air gap of the order to 5% loss for each 1% of shrinkage. The results are both analysed and compared with previous analyses for such systems and discussed with respect to installation, aging and other factors affecting in situ performance. The results have been used to calculate derating factors for the effective thermal resistances. The results confirm the validity of the NBS Derating Analysis for deriving effective resistance of materials which shrink within a cavity.

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INTRODUCTION

Very great emphasis is being placed upon the use of thermal insulation in residental buildings as one means of accomplishing the major conservation goals of the Energy Act. Because of the large numbers of units involved and the relative simplicity of installing one or more of the currently available thermal insulations[1] large short-term savings of energy and hence costs can be anticipated. This is particularly true for the case of existing structures where it has been estimated[2] that there are over 20 million uninsulated buildings which require some type of insulation retrofit action before 1985. As a result many and various government, state and utility programs are in operation or are being planned to either mandate or encourage the installation of thermal insulation in new and existing homes in order to achieve the savings.

PROBLEM DEFINITION

The envisioned energy savings are usually estimated from calculations of the heat losses or gains for the insulated versus uninsulated buildings. Various heat transfer models are in use but in general they make two assumptions.

1. the thermal properties of the various construction and insulating materials are those obtained from laboratory measurements on conditioned samples.

2. that the particular construction is regular, uniform and perfectly insulated and performs as such.

Under actual, real-world conditions neither of these is necessarily achieved. Current construction practices for a typical wood frame dwelling, combined with variations of materials dimensions and their change with time, can often result in significant differences in size and form of the cavities to be insulated. Variations in the dimensions or of the form or behavior of current insulation materials combined with poor insulation practices further compound the problem of trying to install a perfectly insulated system.

Recently results from a number of studies involving field and laboratory tests on various thermal and physical properties of insulation materials taken from retrofit installations[3,4,5] have become available. They show that the materials had not deteriorated with time and that the property values were within the limits given in the various specifications for the respective materials. Furthermore the installation of insulation did not result in any moisture, corrosion or bacterial related degradation of the structure.

However the field examination of the walls and attics did show that there were potential areas where it was likely that the actual thermal performance of the system would not be as good as the expected value based on calculation. The basic reason for the possible degradation of performance was the fact that there were often significant air gaps around the insulation especially in the wall cavities. Such air gaps are the source of additional heat transmission paths within the system which would be even more pronounced if there was air infiltration within the system.

The major air gaps were caused by one or more of the following construction, materials or installation related factors:

1. Shrinkage of urea formaldehyde insulation from most of the cavity surfaces although it sometimes adhered to one of the sheathings. This normally resulted in two equal width gaps close to the vertical framing members, a gap at one sheathing surface and gaps at the top or top and bottom of the cavity. Furthermore these were often horizontal or diagonal within the insulation itself.

2. The actual width of a constructed cavity was greater than either the actual or the nominal width of a mineral fiber batt or blanket. In such cases the insulation was either attached to one frame only with a large gap on the other side. In other cases it had been installed centrally within the cavity and held in place by pressure of the inner and outer sheathings with gaps of variable size on each side.

3. The actual width of a constructed cavity was less than the actual or nominal width of a batt or blanket. In this case the insulation was usually squeezed into the cavity and attached on each side such that there was a significant reduction in thickness close to the two framing members.

4. The length of a batt or blanket had been cut such that it was less than the length of the cavity thus leaving a gap at either the top or the bottom or both.

5. The nominal or actual thickness of a batt blanket was less than the depth of the cavity either because the batt had not recovered fully or had been over compressed when it was installed.

6. An obstruction in the cavity had not allowed retrofit loose fill or urea formaldehyde insulation to fill the cavity completely. This resulted in random air gaps depending on the type and position of the obstruction within the cavity.

7. Pressure relief holes had not been drilled in the cavities below sills or support members when loose fill or urea formaldehyde was being installed creating air gaps at the top of such cavities.

Recently more attention has been paid to the effects of air gaps on the thermal performance of insulated building components. As examples, Burns and Tien[6] and Bankvall[7] have illustrated analytically and experimentally the degrading effects of both natural and forced convection in fiber insulated walls. The work carried out by Verschoor and Vinieratos[8] on various insulation filled walls and ceiling constructions containing flaws, including air gaps, has shown significant reductions in thermal performance due to air gaps.

In addition to these studies there has been considerable discussion concerning the subject of shrinkage of urea based foam insulation and its effect on the thermal performance of wall systems containing such insulation. Two reviews[9,10] have been published outlining the existing state of knowledge of the subject. As a result there is now general agreement that, if the insulation does shrink after installation, some reduction in overall thermal performance will result.

Thus far the effect of shrinkage on thermal performance has been determined only by calculation, using conventional procedures such as those outlined in the ASHRAE Book of Fundamentals[11] or the NBS review[9]. However different assumptions and properties information can produce significantly large differences in calculated thermal performance for the same degree of shrinkage.

Therefore, a need was established to undertake a fundamental and experimental study of the effect of systematically varying air gap size on the heat transmission characteristics of a typical cavity wall. Such a program would fit directly into the insulation material and systems studies of the National Program Plan on Thermal Insulation Materials and Systems for Buildings. The quantitative results would apply specifically to insulation systems where shrinkage of the insulation was known. In addition the results could be applied more generally for any cases where air gaps do or could occur for any reason.

PROGRAM OUTLINE

As a result of the need established above, an investigation of the thermal performance of a series of typical stud wall systems using a guarded hot box according to ASTM C236 was undertaken. A basic wall system, as described below, was established as reference.

1. This system consisted of a very carefully constructed two-cavity stud wall fully insulated with accurately machined, tightly fitting pieces of a polystyrene material with known thermal resistance properties established by an independent test. This material was chosen because it could be machined accurately and because its unit thermal resistance was directly similar to that of urea formaldehyde. The results for this system were used subsequently as the baseline value against which results for any of the following similar but flawed systems could be compared.

2. The basic wall system was modified by inserting blocks of the same polystyrene material accurately machined to dimensions which created different sizes and positions of air gaps. Systemmatic increases in size were

obtained by machining the blocks to dimensions equivalent to shrinkages of 1, 3, 5, 7% which cover the typical range found for urea formaldehyde insulation, i.e., gaps up to 0.5" wide on the width and 1.5" deep on the depth.*

The blocks were machined and positioned within the cavity such that they were

(a) centered with equal gaps at the edges, top and bottom

(b) centered, resting on the bottom with equal gaps on each side

(c) centered with equal gaps at edges, top and bottom and faces

(d) resting on the bottom, touching one face but with equal gaps on each side

The measured values for these systems with different amounts and orientations of air gaps were used to check the validity of the various calculation procedures used for estimating the derating of the performance of such systems.

TEST SYSTEMS AND EXPERIMENTAL DETAILS

The basic stud wall system is shown in Figure 1. It consisted of an outer frame with three internal, vertical supporting members arranged to form equally spaced cavities all having the close tolerances shown. The wood used to construct this frame was kiln dried and specially selected for straightness, squareness and uniformity.

Pieces of 2" polystyrene were cut, fitted and caulked into the central two-cavity sections to form a smaller two-cavity section, 3.5 $\pm$0.01" deep and with the other dimensions as shown. This served to define the actual measurement area for the guarded hot box tests since the metering box was to be centered over this material frame. Additional polystyrene space supports were fitted into the external frames to ensure uniformity of width and depth of all cavities.

One side of the total section was covered with a uniform piece of 0.5" thick top quality plywood. This was then caulked and screwed into place on all of the framing members to ensure that it fitted tightly, thus eliminating any possibility of gas convection paths between the sections. The outer cavities and upper and lower portions of the central cavities were filled with a friction fit R-13 fiberglass product. The two central metering area cavities were each filled completely with an accurately machined piece of a Dow Sytrofoam product cut from a large 4" thick panel. The entire system was completed with a similar piece of plywood consisting of a separate removable inner section some 60" x 45" surrounded by an annular ring with a fine saw cut between them. The narrow gap between the two sections was filled with a loose fill and then taped.

After this fully insulated sample had been measured, the central piece of plywood was removed and the cavity insulation in the metering area taken out. It was replaced by successive pairs of accurately machined pieces of the Styrofoam cut from the original stock, representing different reductions in dimension and oriented as described earlier. The blocks were positioned in the cavities by means of small 1/8" dowel horizontal support pegs in the outer framing members and small machined slices of polystyrene on the inside faces of the inner framing member. In each case the removable plywood section was replaced as described previously.

The wall waa placed in the center of a polystyrene foam/glass composite frame which was then sealed centrally to separate the hot and cold sides within the insulated walk-in chamber of the guarded hot box system. All joints were caulked and taped.

Nine fine-gauge thermocouples were attached carefully by means of tape to each surface of the metering area. They were positioned on the surface in an area weighted array in order to determine the representative average temperature of the surface. Four similar thermocouples were arranged in an area weighted array, some 3" from each surface, to measure air temperatures within the test section. In all cases corresponding thermocouples on the two faces were mounted such that they were opposite one another.

**The authors wish to acknowledge and apologise for the fact that the units and terms used throughout this paper are not in conformance with the accepted ASHRAE practice of using the SI System. Current usage in the thermal insulation and building industries remain in the non-SI System and, unfortunate as it may be, it is recommended that to be of the most practical use at the present time the paper should be given in this latter system.*

A 48" x 32" by 24" deep metering box was pressed against the described metering section of the wall in the hot side of the box. The edges of the metering box were gasketed with thin strips of a polystyrene foam to act as a seal. This box contained both a d.c. resistance heater and a d.c. motor driven fan to mix the air within the box. A 40-junction thermopile connected differentially between the inner and outer walls of the metering box was used to control automatically the power to a heater in the guard area of the box so that the temperature difference between the sections was zero. The temperature conditions in the hot and cold sections of the hot box system were arranged such that the respective surface temperatures were 100 $\pm$1F and 50 $\pm$1F respectively.

At equilibrium conditions, obtained when three successive four-hour interval readings provided results with a difference less than 1% and not changing monotonically, the constant d.c. power supplied to the heater and motor in the metering box was measured with a precision resistor network. All temperatures were measured. The thermal conductance, C, and derived thermal resistance, R, were obtained from

$$C = \frac{q}{(t_i - t_o)A} \quad \text{and} \quad R = \frac{1}{C}$$

where q = total energy passing through metering area

$t_i - t_o$ = average temperature of hot and cold surfaces respectively

A = area of cross-section of metering box

Prior to this investigation measurements by the guarded hot box of panels having a thermal resistance in the range 9 to 13 $h \cdot ft^2 \cdot F/Btu$ had been made. These panels included samples from a round robin series of tests on aged polyisocyanurate material with protective skins(12) completed at several laboratories and an internally maintained calibration panel. The results of these measurements indicated that the overall accuracy of measurement was better than $\pm$3% and that the reproducibility was better than 2%.

The thermal resistance of the cellular plastic used on the cavity insulation was also determined independently. Several pieces, 24" square and 3.5" in thickness, were measured using the heat flow meter method according to ASTM C518-76. The average value of the thermal resistance for these 3.5" thick samples was 18.55 $h \cdot ft^2 F/Btu$, equivalent to an apparent thermal conductivity of 0.187 Btu $in/h \cdot ft^2 F$.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results are shown in Table 1. The following general conclusions can be drawn:

1. The inclusion of air gaps within a typical cavity wall construction leads to an immediate loss in thermal performance due to the additional thermal short circuits formed.

2. The average reduction in performance for the different orientations of any one set of air gaps is proportional to the percentage dimension change up to 7%. A 1% linear reduction in dimension produces an approximate 5% reduction in the thermal performance of the system, as illustrated in Figure 2.

3. The orientation and position of the air gaps within the cavity do not appear to produce significant differences (<6%) in thermal performance as shown in Table 1.

4. For any one set of air gap sizes the best thermal performance is obtained for the situation where the cavity insulation is resting at the bottom of the cavity. This is due presumably to the partial reduction of the convection path from the bottom to the top of the cavity insulation.

5. The addition of a small surface air gap or gaps does not create a large enough thermal resistance to improve the thermal performance. However the additional heat transfer path does not reduce the thermal performance appreciably over that for the comparable situation without the surface air gap or gaps.

The present results have been analysed using two models, the NBS Derating Calculation[9] and the ASHRAE Series/Parallel Calculation[11]. It is expected that the measured resistances would fall between the two sets of calculated results, due to the nature of the actual two-dimensional heat flow within the system as compared to the two one-dimensional approximations. There are several factors, described below, which can cause the base case test results to deviate from analysis:

1. The value of thermal conductivity used in the analytical results for the wood studs was selected from ASHRAE standard tables for pine studs. Wood thermal conductivities are not only variable between samples of the same type, but also non-isotropic, values differing by 30% between cross-grain and tangential-grain measurements.

2. There is a two-dimensional effect introduced at the edge of the test section due to the thickness of the insulated gasket. This effect occurs directly in the high conductivity region introduced by the studs, and thus any deviation introduced by prior cause would be amplified in this geometry as compared to the homogeneous geometries used for system calibration.

3. The studs extend directly to the edge of built-up section. Wood conductivity in this direction (along the grain) is twice that across the grain. This produces an appreciable potential for heat loss from the metering section, even with the careful guarding at center of each guard face.

4. Despite the care taken in the construction of the original wall, there were still some thermal short circuits present. These would be due to the presence of small air gaps, crevices or other flaws which could arise both during the construction and in the initial measurements where the wall was subjected to several days of temperature gradient conditioning before the final result was obtained.

Any such deviations should apply to the flawed cases as well as to the base case, so that the relative results will be completely valid. Table 2 indicates that the NBS derating procedure for establishing the percent decrease in performance is valid, even though the series parallel calculation is more desirable for establishing the base case.

Table 3 contains the results for the effective thermal resistance of the cavity alone neglecting the sheathing, and allowing for the various shrinkages within the cavity. These results show the validity of the NBS model for illustrating the effects of shrinkage within a cavity.

Since the effective thermal resistance and its variation with air gap size are functions of both the thermal resistance of the cavity insulation and the total resistance of the wall, calculation results are presented in Table 4 using the present results with the NBS model to illustrate these factors. A system of particular interest, due to possible shrinkage, is the wall insulated with urea formaldehyde foam. The thermal resistance for the typical urea formaldehyde products has been measured and the results are shown in Figure 3. A value of 14.7 $h \cdot ft^2 F/Btu$ for 3.5" was selected as being typical for this material having a density in the 0.7 to 0.8 $lb \cdot ft^3$ density range normally specified in applications.

Table 4 is a summary of the results both for the UF foam insulated wall and for a wall insulated with a material, such as a fibrous batt, having an R of 11 $h \cdot ft^2 F/Btu$. Also included are results for a wall system having higher resistance in series with the insulation than the test wall but containing insulation of the same resistance as the present measured material. The results are in good agreement with those recommended[14] as a result of the original NBS calculations.

SUMMARY

Measurements have been made of the thermal performance of a typical cavity wall containing insulation to represent different sizes, positions and orientations of air gaps. The air gap sizes have been varied to cover the range equivalent to 7% shrinkage within the cavity. Results indicate that the reduction in thermal performance is directly related to air gap size.

The present study did not include any effects of air infiltration within the insulated structure. Thus the results should be considered as illustrating minimum reductions when considering the real life performance of insulated cavity wall constructions. Further work is necessary in similar conditions in order to provide information on the total effects.

ACKNOWLEDGEMENTS

This work formed part of an overall study on factors affecting cavity wall insulation performance being carried out on behalf of the Department of Energy under Contract Number 72X86993V with Dr. Ted Lundy of Oak Ridge National Laboratory as program manager.

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Table 1

THE MEASURED THERMAL CONDUCTANCE AND THERMAL RESISTANCE OF A STUD WALL STRUCTURE CONTAINING AIR GAPS SIMULATED BY REDUCTION OF THE DIMENSIONS OF CAVITY INSULATION

Reduced Dimensions %	Thermal Conductance $Btu/h \cdot ft^2 \cdot F$	Thermal Resistance $h \cdot ft^2 \cdot F/Btu$	Sample Construction
0	0.0729	13.7	Full cavity
1	0.0765	13.05	Insulation centered in cavity, full thickness
1	0.0763	13.1	Insulation resting on bottom of cavity full thickness
1	0.077	13.0	Insulation centered in cavity, thickness reduced
1	0.077	13.0	Insulation resting on bottom of cavity, thickness reduced
3	0.086	11.65	Insulation centered in cavity, full thickness
3	0.083	12.05	Insulation resting on bottom of cavity, full thickness
3	0.084	11.9	Insulation centered in cavity, thickness reduced
3	0.086	11.65	Insulation resting on bottom of cavity, thickness reduced
5	0.098	10.2	Insulation centered in cavity, full thickness
5	0.095	10.55	Insulation resting on bottom of cavity, full thickness
5	0.099	10.10	Insulation centered in cavity, thickness reduced
5	0.100	10.0	Insulation resting on bottom of cavity, thickness reduced
7	0.108	9.25	Insulation centered in cavity, full thickness
7	0.110	9.09	Insulation resting on bottom of cavity, full thickness
7	0.114	8.75	Insulation centered in cavity, thickness reduced
7	0.112	8.95	Insulation resting on bottom of cavity, thickness reduced

Table 2

COMPARISON OF MEASURED AND CALCULATED RESULTS FOR THE VARIOUS INSULATED WALLS

Percent Reduction in Dimensions	Thermal Resistance, h ft^{2}F/Btu			Reduction in Wall Thermal Performance, Percent		
	NBS Model*	Series/Parallel Model*	Measured	NBS Model	Series/Parallel Model	Measured
0	16.3	15.35	13.7			
1	15.3	13.6	13.05	6.1	11.4	4.7
2	14.45	12.3		11.3	19.9	
3	13.65	11.2	11.65	16.3	27.0	15.0
4	12.95	10.35		20.6	32.6	
5	12.3	9.6	10.2	24.5	37.5	25.5
7	11.2	8.5	9.25	31.3	44.6	32.5

*The thermal resistance of the two air film coefficients (R_{air} = 0.667) are subtracted from the calculated values

Table 3

THE COMPARISON OF MEASURED AND CALCULATED EFFECTIVE THERMAL RESISTANCES OF THE CAVITY INSULATION

Percent Reduction in Dimensions	Effective Thermal Resistance h·ft^2·F/Btu			Reduction in Effective Thermal Resistance,%		
	NBS Model	Series/Parallel Model	Measured	NBS Model	Series/Parameter Model	Measured
0	18.55	18.55	15.6	-	-	-
1	17.0	15.45	14.5	8.4	16.7	7.1
2	15.7	13.25	-	15.4	28.6	-
3	14.5	11.6	12.25	21.8	37.5	21.5
4	13.5	10.35	-	27.2	44.2	-
5	12.65	9.35	10.2	31.8	49.6	34.6
7	11.15	7.85	8.85	39.9	57.7	43.3

Table 4

THE EFFECT OF THERMAL RESISTANCE OF CAVITY INSULATION AND
WALL CONSTRUCTION ON THE REDUCTION OF THERMAL PERFORMANCE (NBS MODEL)

Percent Reduction in Dimensions	Reduction of Effective Thermal Resistance, as a Function of Thermal Resistance of Cavity Fill (R_{wall} = 2.6),%			Reduction in Effective Thermal Resistance, as a Function of Fixed Thermal Resistance of Wall Construction (R_{foam} = 18.55),%	
	R = 11.0	R = 14.7	R = 18.55	R = 2.6	R = 6.6
1	5.3	6.7	8.4	8.4	5.4
2	10.0	12.8	15.4	15.4	10.2
3	14.2	18.0	21.8	21.8	14.6
4	18.3	22.9	27.2	27.2	18.7
5	21.9	27.2	31.8	31.8	22.4
7	28.2	34.5	39.9	39.9	29.3

All values of R are h·ft^2·F/Btu

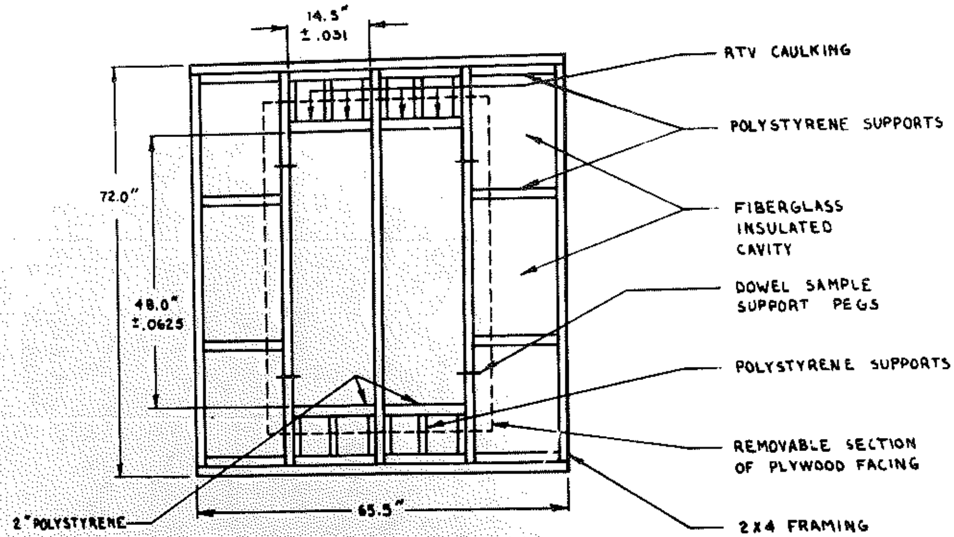

Fig. 1 Schematic of the cavity construction used for the investigation

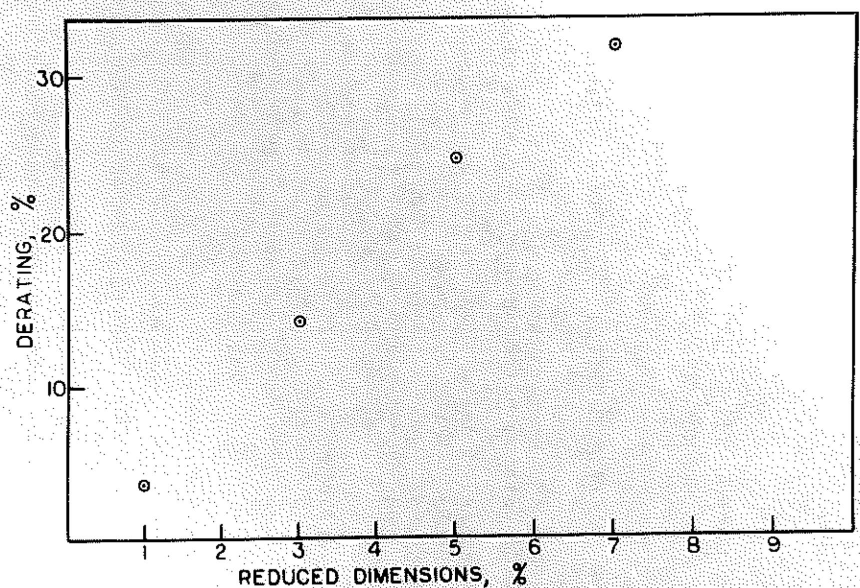

Fig. 2 Derating of a typical insulated cavity wall for increased air gap dimensions

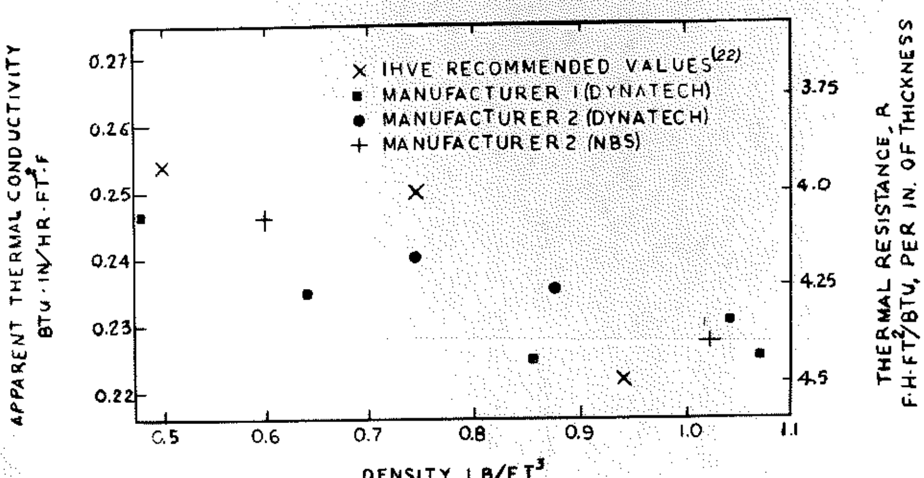

Fig. 3 Thermal resistance of ERA formaldehyde foam insulation

APPENDIX

CALCULATION TECHNIQUES

Two models, namely, the NBS Derating Calculation[9] and the ASHRAE Series Parallel Calculation[11] were used in order to derive thermal performance values of the various wall systems in order to compare results. Subsequently they were used to derive both the effective thermal resistance (derating value) of the cavity insulation and to illustrate its sensitivity to the actual resistance of the insulation and to that of the overall system.

Tables A1 – A3 list details of the materials property values and the respective cross-sectional area used for both. The derived thermal resistances and the overall heat transfer coefficients used in the NBS model are given in Table A4.

Essentially, using a somewhat different terminology, the NBS model derives the overall heat transfer coefficient as:

$$U_{overall} = \frac{A_{stud}}{A_{total}} \cdot U_{stud} + \frac{A_{foam}}{A_{total}} \cdot U_{foam} + \frac{A_{air}}{A_{total}} \cdot U_{air} \qquad (1)$$

With the overall heat transfer coefficient of the foam section being calculated from:

$$U_{foam} = \left(U_{overall} - \frac{A_{stud}}{A_{total}} \cdot U_{stud} \right) \cdot \frac{A_{total}}{A_{foam}} \qquad (2)$$

This equation assumes that the overall heat transfer coefficient of the foam is reduced because of the air gap. The overall thermal resistance of the foam section is calculated from:

$$R'_{foam} = \frac{1}{U_{foam}} \qquad (3)$$

The thermal resistance of the foam is calculated from:

$$R_{foam} = R'_{foam} - R_{wall\ components} \qquad (4)$$

Using the series parallel model the overall heat transfer coefficient is derived from:

$$R_{overall} = 2R_{film} + 2R_{sheath} \left(+ \frac{A_{stud}}{A_{total}\ R_{stud}} + \frac{A_{foam}}{A_{total}\ R_{foam}} + \frac{A_{air}}{A_{total}\ R_{air}} \right)^{-1} \qquad (5)$$

$$U_{overall} = \frac{1}{R_{overall}}$$

In this case R_{foam} is then obtained by assuming the final term is zero and the foam filling the cavity completely. In each case the effective thermal resistance (or derating factor) of the insulation is obtained from:

$$R_{effective} = \frac{R_{foam}\ (0\%) - R_{foam}\ (X\%\ \text{linear reduction})}{R_{foam}(0\%)} \qquad (6)$$

The above models were used to calculate the thermal performance characteristics of the walls for the case of the full cavity and for the reduced sized but full thickness insulation centered within the cavity. These results for the present insulation are shown as an example in Table A5.

Table A1

THERMAL RESISTANCE OF WALL COMPONENTS USED IN CALCULATIONS

Component	Thickness, in	$\lambda_{apparent}$ Btu·in/h·ft^{2}F	R, h·ft^{2}F/Btu
Wood Sheathing	0.5	0.80	0.61
Wood Stud	3.5	0.82	4.27
Polystyrene (measured)	3.5	0.187	18.55
UF Foam (average)	3.5	0.238	14.7
Fiber Batt (average)	3.5	0.318	11.0
Air Space	3.5	-	1.67
Surface Film	-	-	0.67

Table A2

AREA OF CROSS-SECTION OF COMPONENTS

Component	Geometry, in	Number of Sections	Area, ft^2
Stud	48 x 1.5	2	1.0
Foam	$(48 \times 14.5)S^2$	2	
Total	48 x 32	1	10.667

1 - S = Linear reduction in dimension,%

Area Air = Total Area - (Stud Areas + Foam Area)

Table A3

WALL SECTION AREA AS FUNCTION OF REDUCED DIMENSION OF INSULATION

Linear Reduction,%	A_{total}	A_{stud}	A_{foam}	A_{air}
0	10.667	1.000	9.667	0
1	10.667	1.000	9.474	0.193
2	10.667	1.000	9.284	0.383
3	10.667	1.000	9.096	0.571
4	10.667	1.000	8.909	0.758
5	10.667	1.000	8.724	0.943
7	10.667	1.000	8.361	1.306

All areas are ft^2

Table A4

THE CALCULATED THERMAL RESISTANCE AND OVERALL HEAT TRANSFER COEFFICIENTS OF THE WALL SECTION

Wall Construction	Section	Fixed Thermal Resistance $h \cdot ft^2 \cdot F/Btu$	Variable Thermal Resistance $h \cdot ft^2 \cdot F/Btu$	Total Thermal Resistance $h \cdot ft^2 \cdot F/Btu$	Overall Heat Transfer Coefficient $Btu/h \cdot ft^2 \cdot F$
Present wall	Stud	2.56	4.27	6.83	0.1464
	Foam	2.56	18.55	21.11	0.0474
	Air	2.56	1.67	4.23	0.2364
Wall with UF foam	Stud	2.56	4.27	6.85	0.1464
	Foam	2.56	14.70	17.26	0.0579
	Air	2.56	1.67	4.23	0.2364
Wall with fiber batt	Stud	2.56	4.27	6.83	0.1464
	Foam	2.56	11.00	13.56	0.0737
	Air	2.56	1.67	4.23	0.2364
Present wall insulated with additonal 1-inch beadboard sheathing	Stud	6.56	4.27	10.83	0.0923
	Foam	6.56	18.55	25.11	0.0398
	Air	6.56	1.67	8.23	0.1215

Table A5

THE CALCULATED EFFECTIVE THERMAL RESISTANCE AND PERCENT DERATING OF AN EXTRUDED POLYSTYRENE FOAM CAVITY INSULATION

Reduced Dimensions,%	Calculated U-Factor $Btu \cdot hr^{-1} ft^{-2} F^{-1}$	U-Factor of Foam Section $Btu \cdot hr^{-1} ft^{-2} F^{-1}$	R-Factor of Foam Section $Btu^{-1} hr \cdot ft^2 F$	R-Factor of Foam $Btu^{-1} hr \cdot ft^2 F$	% Decrease in R-Factor of Foam
0	0.0567	0.0474	21.10	18.54	-
1	0.0601	0.0512	19.53	16.97	8.5
2	0.0634	0.0548	18.25	15.69	15.4
3	0.0668	0.0585	17.07	14.51	21.7
4	0.0701	0.0622	16.08	13.52	27.1
5	0.0734	0.0658	15.19	12.63	31.9
7	0.0798	0.0729	13.72	11.16	39.8