VI –7. Thermal Performance of Masonry Walls

A. E. Fiorato

Manager, Construction Methods Section, Construction Technology Laboratories, a Division of the Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois

C. R. Cruz

Senior Construction Engineer, Construction Methods Section, Construction Technology Laboratories, a Division of the Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois

ABSTRACT

An investigation of heat transmission characteristics of masonry and wood-frame walls is described. Steady-state and dynamic tests were conducted using a calibrated hot box. Results indicate that thermal inertia has a considerable effect on heat transfer characteristics. Thermal lag increased with increased wall weight. A significant reduction in dynamic energy requirements occurred as thermal resistance was increased to 8 hr•ft²•F/Btu (1.41 K•m²/W). Increases beyond this value did not result in corresponding reductions in energy requirements.

Une étude des charactéristiques de transmission thermique de murs de maçonnerie et de portailles en bois est décrite. Des essais à état-constant et dynamiques ont été entrepris dans une chambre chaude calibrée. Les résultats indiquent que l'inertie thermique a un effet considérable sur les charactéristiques de transfert thermique. Le retard thermique augmente avec l'accroissement du poids du mur. Une réduction significative des demandes d'énergie dynamique a eu lieu quand la résistance thermique a été augmentée à 8 hr•ft²•F/Btu (1.41 K•m²/W). Accroissement au dessus de cette valeur n'ont pas résulté en de correspondantes réductions des demandes d'énergie.

Eine Untersuchung der Wärmeübertragungseigenschaften von Mauerwerk- und Holztafelkonstruktionen ist beschrieben. Gleichmäßige und dynamische Messungen wurden mittels eines geeichten Heizkastens durchgeführt. Ergebnisse haben gezeigt, daß die thermische Trägheit einen bedeutsamen Einfluß auf die Wärmeübertragungseigenschaften hat. Eine zunehmende Wärmeverzögerung hat statt gefunden mit erhöhten Wandgewicht. Die dynamische Energieforderung hat sich erheblich vermindert als die Wämedämmung bis auf 8 hr•ft²•F/Btu (1.41 K•m²/W) erhöt wurde. Eine weitere Erhöhung der Wärmedämmung verursachte keine entsprechende Verminderung der Energieforderung.

INTRODUCTION

Design of building envelopes for energy efficiency has gained considerable importance as awareness and concern for energy and resource conservation have increased. This paper describes tests conducted to evaluate thermal performance of masonry and wood frame walls.

Primary emphasis of this investigation was to compare performance under steady-state and dynamic temperature conditions. Current designs are based primarily on steady-state thermal transmittance (U) values. It has been shown that steady-state coefficients do not adequately reflect actual performance.[1,2,3] Tests in this program provide data to quantify the relationship between dynamic energy requirements and steady-state thermal coefficients.

Six wall assemblies were tested. Objectives were to experimentally determine and compare:

1. Average thermal properties, including conductance (C) and resistance (R), under steady-state temperature conditions.
2. Thermal response under dynamic conditions representative of a diurnal sol-air temperature cycle.

Walls were tested in the Calibrated Hot Box facility of the Portland Cement Association's Construction Technology Laboratories.

TEST SPECIMENS

Six walls selected for testing are illustrated in Figure 1. Specimens, which are representative of assemblies commonly used for exterior walls, were constructed in accordance with common construction practices. Overall nominal dimensions were 103 × 103 in. (2.62 × 2.62 m). Design thermal resistances (R_u) ranged from 2.4 to 12.7 hr • ft² • F/Btu (0.42 to 2.24 K • m²/W). Wall weights ranged from 5.2 to 67.7 psf (25 to 331 kg/m²). Additional data are given in Table 1.

Hollow Block Wall

An uninsulated hollow block wall was made of unreinforced 8 in. concrete masonry units. Aggregate in the units was a combination of expanded shale and carbonate rock. Block properties are summarized in Table 2. Mortar consisted of one part portland cement, one-quarter part lime, and three parts masonry sand by volume. The wall was laid in a running bond pattern with face shell mortar bedding. Interior and exterior surfaces were not coated or finished prior to testing.

After the uninsulated hollow block wall was tested, loose fill insulation was poured into the cores and the wall was retested. Insulation used was silicone treated perlite having a loose unit weight of 6.1 pcf.

Block-Brick Cavity Wall

An uninsulated block-brick cavity wall was constructed of unreinforced 4 in. concrete block and 4 in. clay brick separated by a 2 in. (51 mm) air gap. Properties of masonry units are given in Table 2. Aggregate for the concrete block was a combination of expanded shale, carbonate rock, and siliceous materials. Mortar proportions were the same as used for the hollow block wall. Block and brick were laid in a running bond pattern with metal "Z" ties between wythes.

After initial testing, the cavity wall was retested with perlite loose fill insulation in the gap between the block and brick wythes.

Wood Frame Wall

The wood frame wall was constructed in accordance with specifications of the American Plywood Association for the Sturd-I-Wall Building System.[4] It was made of 2 × 4-in. (51 × 102 mm) studs spaced 16 in. (406 mm) on centers. Insulation between studs consisted of 3-1/2-in. (89 mm) mineral fiber blanket insulation faced with kraft paper. The insulation was labeled to indicate an R-11 thermal resistance rating.

The inside of the wall was 1/2-in. (13 mm) gypsum wallboard painted with two coats of flat white latex paint. The exterior was 5/8-in. (16 mm) plywood cedar siding with a reverse board and batten surface pattern. No sheathing was used.

Wood Frame-Brick Veneer Wall

After testing the wood frame wall it was removed from the test chambers and a 4-in. clay brick veneer was applied to the exterior. A 1-in. (25 mm) air gap was left between the veneer and exterior plywood siding. Corrugated metal ties were used to attach the veneer to the existing siding. Properties of the brick are summarized in Table 2. Mortar was the same as that used for the hollow block wall.

TEST FACILITY

Tests were conducted in the Calibrated Hot Box facility shown in Figure 2. This facility was developed specifically for obtaining a realistic evaluation of thermal performance of large wall assemblies under steady-state or dynamic temperature conditions. It is termed a Calibrated Hot Box by the American Society for Testing and Materials (ASTM). A standard test method for thermal performance of building assemblies by means of the Calibrated Hot Box is currently under development by ASTM Committee C16 "Thermal and Cryogenic Insulating Materials."

Description

The facility consists of two highly insulated chambers as shown in Figure 3. Walls, ceilings, and floors of each chamber were constructed from foamed urethane sheets to attain a final thickness of 12 in. (305 mm). During tests, the chambers are clamped tightly against insulating frames around the test wall. The test wall has nominal overall dimensions of 103 × 103 in. (2.62 × 2.62 m). The facility was designed to accommodate walls with thermal resistance values ranging from 1.5 to 20 hr • ft^2 • F/Btu (0.26 to 3.52 K • m^2/W).

The outdoor chamber can be held at constant temperature or cycled between −20 and 120F (244 and 322 K). Temperature cycles can be programmed to obtain the desired time temperature relationship. The indoor chamber which simulates an indoor environment, can be maintained at constant room temperature between 65 and 80F (291 and 300 K).

Instrumentation

Instrumentation is designed to precisely monitor energy required to maintain constant temperature in the indoor chamber while conditions in the outdoor chamber are varied. Chambers are calibrated to account for thermal losses. By carefully measuring energy expended, heat transfer through the test wall can be determined.

Thermocouples corresponding to ASTM Designation E230/Type T are used to measure temperatures. There are 16 on each face of the test wall, 16 in the air space of each chamber, and 12 outside the chambers. Thermocouples were uniformly distributed on a 20-in. (508 mm) square grid over the wall area. Thermocouples in air were located approximately 3 in. (76 mm) from the face of the test wall.

A watt hour meter with ± 0.1% accuracy is used to measure energy required for heating and cooling the indoor chamber. Supplementary measurements monitor cooling coil and reference temperatures for data acquisition equipment.

All measurements are monitored with a digital data acquisition system capable of sampling and recording up to 160 independent channels of data at preselected time intervals. Interfaced with the data acquisition system is a mini-computer that is programmed to reduce and store data.

STEADY-STATE TESTS

Steady-state tests are conducted by maintaining constant temperature levels to provide a predetermined temperature differential between chambers. Temperatures are maintained until conditions of equilibrium are reached. This provides a constant rate of heat flow through the test wall. Results of energy and temperature measurements are used to calculate average thermal properties including conductance (C) and resistance (R).

Test Procedure

For all but one specimen, steady-state tests were run at five temperature differentials. Three temperature differentials were run for the uninsulated hollow block wall.

For each temperature differential, indoor chamber air was maintained at a nominal 72F. Outdoor chamber air was maintained at constant temperature to provide nominal air-to-air temperature differentials of −50, −20, 0, 35, and 80F (−28, −11, 0, 19, and 44 K). These correspond to nominal mean temperatures of 97, 83, 72, 55, and 33F, (309, 301, 295, 286, and 274 K), respectively.

Figure 4 shows a test of the insulated block-brick cavity wall at a nominal temperature differential of −50F (−28 K). Indoor chamber air, t_h, was maintained at 72F (295 K) while outdoor chamber air, t_c, was maintained at 122F (323 K). Energy expended in maintaining the indoor chamber temperature is denoted in Figure 4 as "Q_t". Energy expended over each four hour sampling interval varied by less than 1% over the 48 hour test duration. This energy is a measure of heat flow through the test wall.

Figure 4 also shows average temperatures on the inside surface, t_1, and outside surface, t_2, of the test wall. Temperature of the laboratory air outside the test chambers is shown as t_l in Fig. 4. This temperature should be close to the air temperature in the indoor chamber to minimize heat losses between the test chambers and laboratory space.

Data shown in Fig. 4 represent a measurement period under essentially steady-state temperature and heat flow conditions. Tests were run such that a period of eight hours or longer produced two or more successive four hour periods in which results agreed within 1%. In calculating final test results, data were averaged over the eight hour interval.

Figure 5 shows the variation in energy with differential temperature for steady-state tests of each specimen. Values of energy have been corrected for the base calibration of each specimen. Base calibration was obtained from the steady-state test at a nominal temperature differential of 0F. This provided a value for the base calibration energy, Q_0. Heat flow through the test specimen for a particular temperature differential is determined from the net input energy $Q = Q_t - Q_0$.

Net energy input to the indoor chamber was essentially a linear function of temperature differential. Once net energy was established for each temperature differential, the average thermal conductance for the test specimen was calculated according to the following equation:

$$C = \frac{Q \times 3.413}{A \times (t_1 - t_2)}$$

where: Q = net energy input to indoor chamber, W•hr/hr

A = area of wall surface normal to heat flow, ft^2

t_1 = average temperature of inside wall surface, F

t_2 = average temperature of outside wall surface, F

3.413 = conversion factor from W•hr/hr to Btu/hr

C = thermal conductance, Btu/hr•ft²•F

Test Results

Results of steady-state tests are summarized in Table 3. Test values represent average conductance and resistance coefficients for a mean temperature of approximately 68F (293K). Because the Calibrated Hot Box method of testing is relatively new and standard test methods have not yet been established, it was considered conservative to express conductance values to two significant figures. Three significant figures were used for wood frame and brick veneer walls to distinguish results in the table.

To compare test results with values currently used for design, data were corrected for surface resistance coefficients. This provided an estimated value for overall thermal resistance R_u. Surface resistances were taken as 0.68 hr • ft² • F/Btu (0.12K•m²/w) for the inside of the wall and 0.17 hr•ft²•F/Btu (0.03 K•m²/w) for the outside. These values are commonly used in design and are considered to represent still air on the inside and an air flow of 15 mph (24 km/hr) on the outside. Thermal transmittance, U, was calculated as the reciprocal of overall thermal resistance.

Design values of overall thermal resistance and transmittance were calculated using resistance values shown in Table 4. Calculations were in accordance with procedures established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers.[5] The last column of Table 3 shows the ratio of test and design transmittance values.

For the hollow block wall without loose fill insulation, measured transmittance was about 86% of the design value. Although lower than the design value, the measured value is within the range of data reported from other tests.[9]

Improvement in thermal resistance of the 8-in. hollow block wall with addition of perlite loose fill insulation was not as large as indicated by the design values. Measured thermal transmittance for the insulated hollow block wall was about 60% of that of the uninsulated wall. Design values indicate a 50% reduction in transmittance for addition of perlite loose fill insulation. The difference between measured and design values may be attributed to thermal bridging that occurs through webs of the block.

The uninsulated and insulated block-brick cavity walls had measured transmittance values in close agreement with design values. Improvement in transmittance attributed to loose fill insulation corresponded to design estimates.

Test results for the wood frame and the wood frame-brick veneer walls did not show as good an agreement with design values as other specimens. The primary reason for this is believed to be the R-11 design value used for resistance of the mineral fiber blanket insulation. This insulation had a measured unit weight of 2 pcf (32 kg/m³) and a measured thickness of 3.56 in. (90 mm). Published conductivity values (k) show a wide range of variation depending on density of material and mean temperature. Industry sources indicate that mineral fiber building insulation of the density and thickness used in this program could have a resistance 20% higher than the rated value.

If the resistance of the insulation is taken as 13 hr•ft² • F/Btu (2.29 K•m²/W), the design transmittance values become 0.080 and 0.072 Btu/hr•ft²•F (0.45 and 0.41 W/m²•K) for the wood frame and wood frame-brick veneer wall, respectively. These values are within 15% of measured transmittance values.

The wood frame-brick veneer wall had a measured transmittance that was approximately 93% of the trans-

mittance of the wood frame alone. Design values indicate that transmittance for the veneer wall would be approximately 90% of that of the frame alone. Since the clay brick used in the veneer wall was considerably denser than normally assumed in establishment of design values, the difference between test and design results is not unusual.

DYNAMIC TESTS

Although thermal properties determined from steady-state tests are commonly used for thermal design of building envelopes, dynamic tests provide more realistic conditions for comparing thermal performance. Under dynamic testing, effects such as wall mass (thermal inertia) are incorporated in the results.

Test Procedure

Figure 6 illustrates the procedure used for dynamic tests. A diurnal sol-air temperature cycle was simulated in the air of the outdoor chamber while the indoor chamber was maintained at constant room temperature. The sol-air temperature cycle shown in Fig. 6(a) was essentially the same as that used by the National Bureau of Standards in their evaluation of dynamic thermal performance of an experimental masonry building.[3]

With temperature conditions established in the indoor and outdoor chambers, energy required to maintain the indoor chamber temperature was monitored. This energy, which is a measure of heat flow through the test wall, is plotted as a function of time in Fig. 6(b).

The 24 hour dynamic cycle was repeated until conditions of equilibrium were attained. Equilibrium conditions were evaluated by consistency of applied temperature and measured energy response. Test results are based on average readings from two consecutive 24 hour cycles.

Test Results

Results of dynamic tests were evaluated using several measures of energy. With regard to energy output, two parameters were derived from response curves as measures of energy expended during dynamic cycles. These are illustrated in Figure 6(b).

To provide a measure of total energy, areas within "loops" of the energy response curves were evaluated. These are denoted as Q'_a in Figure 6(b). The base line for evaluating these areas was taken as the base calibration obtained from steady-state tests at $t_1 - t_2 = 0$. Values of Q'_a obtained were averaged to represent total energy over a 24 hour period.

Double-amplitude limits of energy response curves were also evaluated. A double-amplitude value was determined for each 24 hour cycle. This is denoted as Q_p in Fig. 6(b). It represents the difference between the maximum and minimum limits of the energy response curve.

Results of dynamic tests are summarized in Figures 7 through 10. In Figures 7 and 8 energy response values are plotted as a function of measured average thermal conductance of the test walls. Results for total energy response and double-amplitude response limits are similar. This indicates that response curves are defined by either value.

Energy response values are plotted versus measured thermal resistance values in Figures 9 and 10. Again, results for either measure of response are similar.

Results in Figures 7 through 10 indicate that, for the sol-air temperature cycle used in the tests, a significant reduction in measured energy requirements occurred as wall thermal resistance was increased from 2 to 8 hr•ft²•F/Btu (0.35 to 1.41 K•m²/W). Increases in resistance beyond 8 hr•ft²•F/Btu (1.41 K•m²/W) were not as effective in reducing dynamic energy requirements.

Addition of perlite insulation to hollow block and block-brick cavity walls significantly reduced energy requirements under dynamic test conditions.

The insulated block-brick cavity wall with a thermal resistance of 7.7 hr•ft²•F/Btu (1.36 K•m²/W) had approximately the same energy requirements as that of the wood frame wall with a thermal resistance of 14.0 hr•ft²•F/Btu (2.47 K•m²/W).

Addition of a brick veneer to the wood frame wall, which increased the thermal resistance from 14.0 to 15.0 hr•ft²•F/Btu (2.47 to 2.64 K•m²/W), resulted in a 35% reduction in dynamic energy requirements.

In addition to evaluation of energy requirements, thermal lag under dynamic conditions was investigated. Thermal lag was defined as shown in Figure 11. Values reported are averages of data obtained for each half cycle over the 48 hour test duration.

Figure 12 illustrates the effect of wall weight on measured thermal lag. Thermal lag increased significantly with increasing wall weight. This is most evident in the comparison of results for the wood frame and brick veneer walls. Addition of brick veneer to the wood frame wall increased average thermal lag from 2.0 to 6.5 hours.

Addition of loose fill insulation to block and block-brick cavity walls also resulted in an increase in thermal lag.

SUMMARY AND CONCLUSIONS

This paper presents results of an experimental investigation of heat transmission characteristics of walls under steady-state and dynamic test conditions. Tests were conducted using a Calibrated Hot Box. Hollow concrete block, block-brick cavity, wood frame, and wood frame-brick veneer walls were evaluated.

The following conclusions are based on results obtained in this program:

1. Steady-state test results for an uninsulated hollow block wall indicated that current design values for thermal transmittance may be conservative for block of the unit weight and composition tested.
2. Perlite loose fill insulation added to an 8-in. hollow block wall was not as effective in reducing thermal transmittance as design values indicated. It is possible that thermal bridging that occurs through webs of the block is not adequately represented by design values.
3. Performance of loose fill insulation in a block-brick

cavity wall, where thermal bridges were not present, was adequately predicted by current design values.

4. Dynamic tests indicated that increasing thermal resistance from 2 to 8 hr•ft^2•F/Btu (0.35 to 1.41 K•m^2/W) resulted in a significant decrease in energy requirements under dynamic conditions. Further increases in resistance were not as effective in reducing energy requirements.
5. Dynamic tests indicated that energy requirements for an insulated block-brick cavity wall with a thermal resistance of 7.7 hr•ft^2•F/Btu (1.36 K•m^2/W) were essentially equivalent to that of a wood frame wall with a thermal resistance of 14.0 hr•ft^2•F/Btu (2.47 K•m^{2}W).
6. Addition of brick veneer to a wood frame wall resulted in a 7% increase in thermal resistance and a 35% decrease in dynamic energy requirements.
7. Thermal lag between cycles of outdoor temperature and energy response increased significantly with wall weight.

Results described in this paper represent an initial effort to experimentally evaluate thermal response of building envelopes under dynamic as well as steady-state conditions. Additional tests should be conducted to evaluate effects of different wall configurations and different temperature cycles.

ACKNOWLEDGEMENTS

Tests described in this paper were sponsored jointly by the Portland Cement Association, The Brick Institute of America, and The National Concrete Masonry Association. Work was performed in the Engineering Development Division of the Portland Cement Association's Construction Technology Laboratories under the direction of Dr. W. G. Corley, Divisional Director.

Many helpful comments and suggestions were received from Mr. A. H. Yorkdale of The Brick Institute of America; Mr. T. Redmond and Mr. K. D. Callahan of The National Concrete Masonry Association; and Mr. M. J. Catani, Mr. S. E. Goodwin, Dr. G. B. Barney, and Mr. A. Litvin of the Portland Cement Association.

Construction and preparation of specimens were performed by Mr. E. A. Valko, Mr. J. St. Aubin, Mr. H. A. Hassan, Mr. M. J. Mosser, and Mr. M. J. Pfeiffer. Mr. D. Anstedt was responsible for electronic instrumentation.

Mrs. E. Ringquist, Mrs. R. Harrison, and Mrs. J. Fry prepared and edited the manuscript.

REFERENCES

1. Catani, M.J. and Goodwin, S.E., "Heavy Building Envelopes and Dynamic Thermal Response," *Journal of the American Concrete Institute,* Proc. Vol. 73, No. 2, Feb. 1976, pp 83–86.
2. van der Meer, W.J., "Effective U Values," New Mexico Energy Institute Report No. 76–161A, The University of New Mexico, Albuquerque, July 1977.
3. Peavy, B.A., Powell, F.J., Burch, D.M., "Dynamic Thermal Performance of an Experimental Masonry Building," Building Science Series 45, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., July 1973.
4. *The Wood Book,* Wood Products Publications, Tacoma, Washington, 1978.
5. *ASHRAE Handbook of Fundamentals,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. New York 1977.
6. "Tables of U-Values for Concrete Masonry Walls," NCMA-TEK 67, National Concrete Masonry Association, McLean, Virginia, 1975.
7. "Heat Transmission Coefficients of Brick Masonry Walls," Technical Notes on Brick Construction Number 4, Brick Institute of America, McLean Virginia, August/September 1974.
8. "Perlite Loose Fill Insulation," Catalog Number 7.14d/Per, Perlite Institute, Inc. New York 1978.
9. "Estimating U-Factors for Concrete Masonry Construction," NCMA-TEK 12, National Concrete Masonry Association, McLean, Virginia, 1969.

ABBREVIATIONS AND SYMBOLS

A = area of wall surface normal to heat flow, ft^2
Btu = British thermal unit
C = thermal conductance, Btu/hr•ft^2•F
F = degrees Fahrenheit
ft = feet
hr = hour
in. = inches
K = degrees Kelvin
pcf = pounds per cubic foot
psf = pounds per square foot
$Q = Q_t - Q_o$ = net energy input to indoor chamber,
Q_0 = energy input to indoor chamber with $t_1 - t_2 = 0$, W•hr/hr
Q_p = double-amplitude limit of energy response curve = difference between maximum and minimum energy response during 24 hr diurnal temperature cycle, W•hr/hr
Q_t = energy input to indoor chamber with $t_1 - t_2 \neq 0$, W•hr/hr
Q'_a = total energy input during 24 hr diurnal temperature cycle, W•hr
R = 1/C = thermal resistance, hr•ft^2•F/Btu
R_u = 1/U = overall thermal resistance, hr•ft^2•F/Btu
r = surface thermal resistance, hr•ft^2•F/Btu
t_1 = average temperature of inside wall surface, F
t_2 = average temperature of outside wall surface, F
t_c = average temperature of outdoor chamber air, F
t_h = average temperature of indoor chamber air, F
t_l = average temperature of laboratory air, F
U = thermal transmittance, But/hr•ft^2•F
W = watts

CONVERSION FACTORS

1.0 in. = 0.0254 m
1.0 ft^2 = 0.0929 m^2
1.0 pcf = 16.0184 kg/m^3
1.0 psf = 4.8824 kg/m^2
1.0 Btu = 0.2931 W•hr
1.0 Btu/hr•ft^2•F = 5.6783 W/m^2•K
1.0 hr•ft^2•F/Btu = 0.1761 K•m^2/W
t (K) = {t(F) + 459.67} /1.8
t (c) = t(K) − 273.15

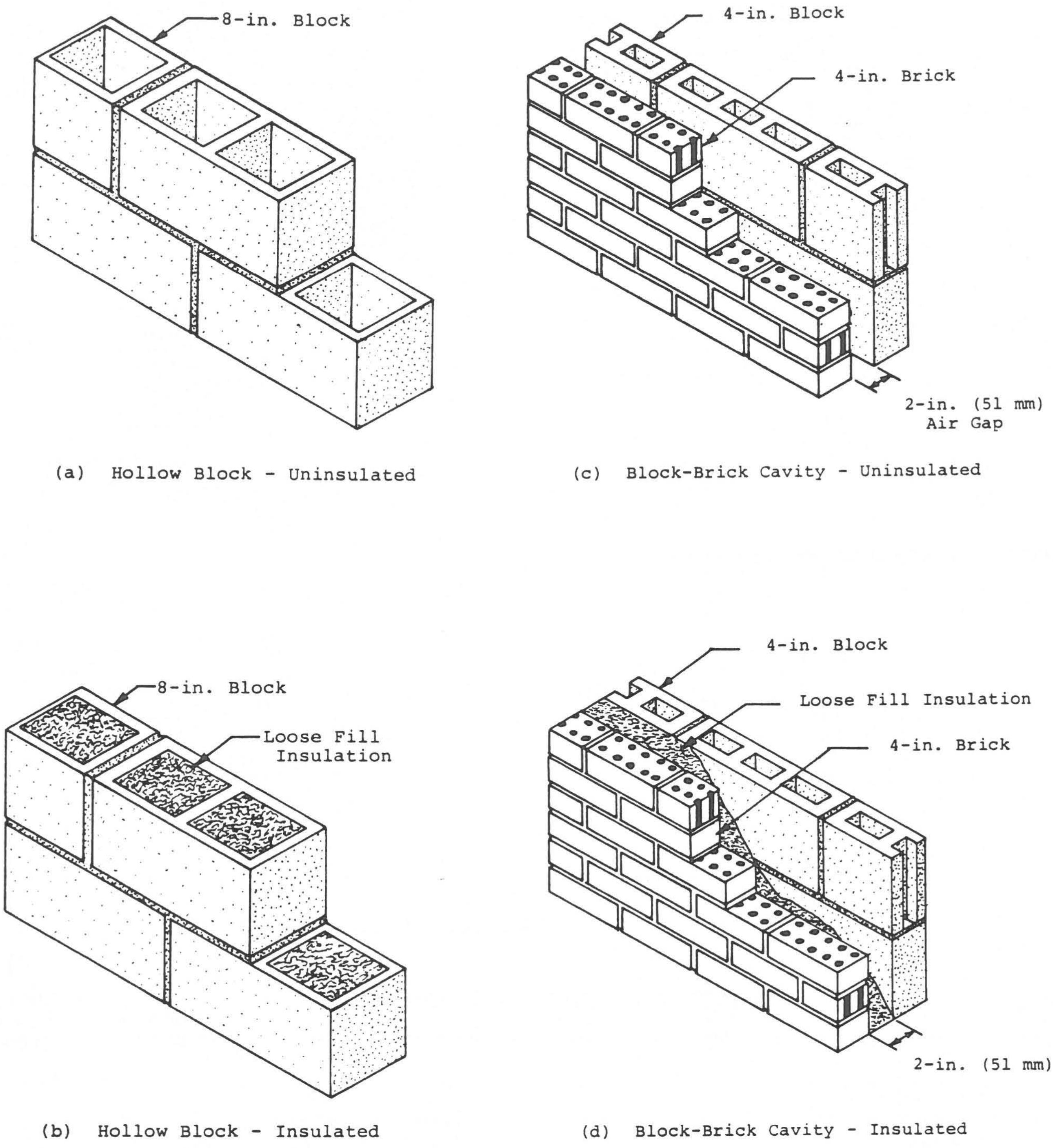
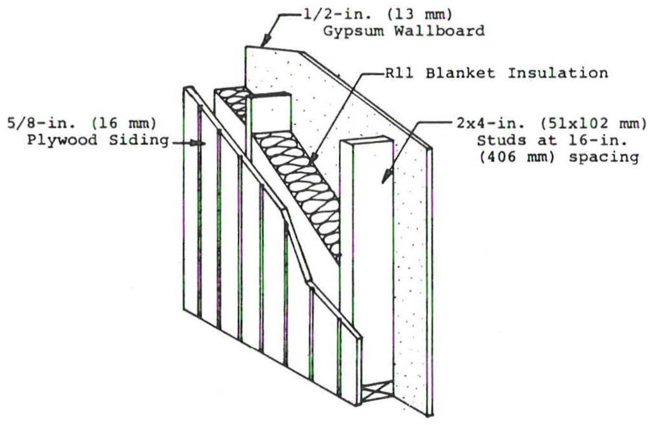
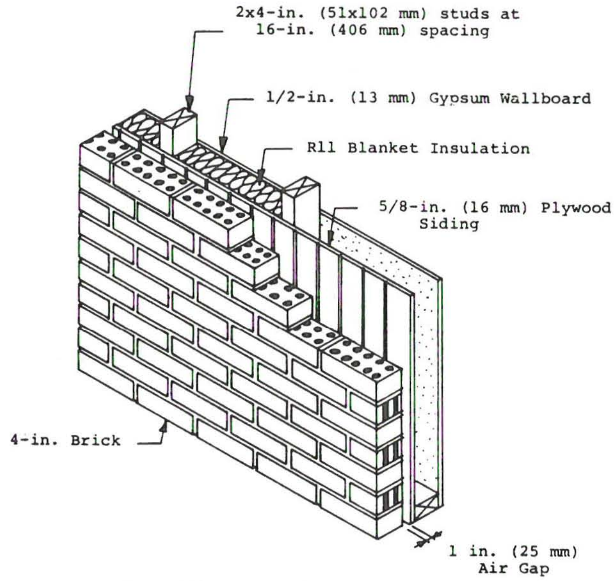


Figure 1. Test Specimen Details



(e) Wood Frame



(f) Wood Frame-Brick Veneer

Figure 1 Test Specimen Details (continued)

TABLE 1 —TEST SPECIMENS [1]

Wall No	Description	Inside Surface Finish	Outside Surface Finish	Measured Weight, psf(kg/m²)	Measured Overall Thickness, in. (mm)	Measured Air Gap Thickness, in. (mm)	Moisture Content, [2] % dry wt.
1	Hollow Block-Uninsulated	None	None	40.1 (196)	7.6	—	Block = 0.6
2	Hollow Block-Insulated	None	None	40.9 (200)	7.6 (193)	—	Block = 0.6
3	Block-Brick Cavity Uninsulated	None	None	66.7 (326)	9.6 (244)	2.0 (51)	Block = 1.5 Brick = 1.1
4	Block-Brick Cavity Insulated	None	None	67.7 (331)	9.6 (244)	2.0 (51)	Block = 1.5 Brick = 1.1
5	Wood Frame	Two Coats Flat White Latex Paint	None	5.2 (25)	4.6 (117)	— —	— —
6	Wood Frame—Brick Veneer	Two Coats Flat White Latex Paint	None	45.1 (220)	9.2 (234)	1.0 (25)	Brick = 1.8

[1] Test area for walls was 73.96 ft² (6.87m²).
[2] Measured on wall section, including mortar joints, after test.

TABLE 2 —PROPERTIES OF MASONRY UNITS

Property	8-in. Hollow Core Concrete Block	4-in. Hollow Core Concrete Block	4-in. Clay Brick
Applicable Specification	ASTM Designation: C90	ASTM Designation: C90	ASTM Designation: C216
Standard Dimensions, in. (mm)	7-5/8 x 7-5/8 x 15-5/8 (194 x 194 x 387)	3-5/8 x 7-5/8 x 15-5/8 (92 x 194 x 397)	3-3/4 x 2-1/4 x 8 (95 x 57 x 203)
No. of Cores	2	3	10
Percent Solid Volume	49	70	75
Oven Dry Unit Weight, pcf, (kg/m³)	115 (1842)	116 (1858)	151 (2419)
Moisture Content, % dry wt.	0.8	1.1	0
Absorption, % dry wt.	10.1	9.1	1.8

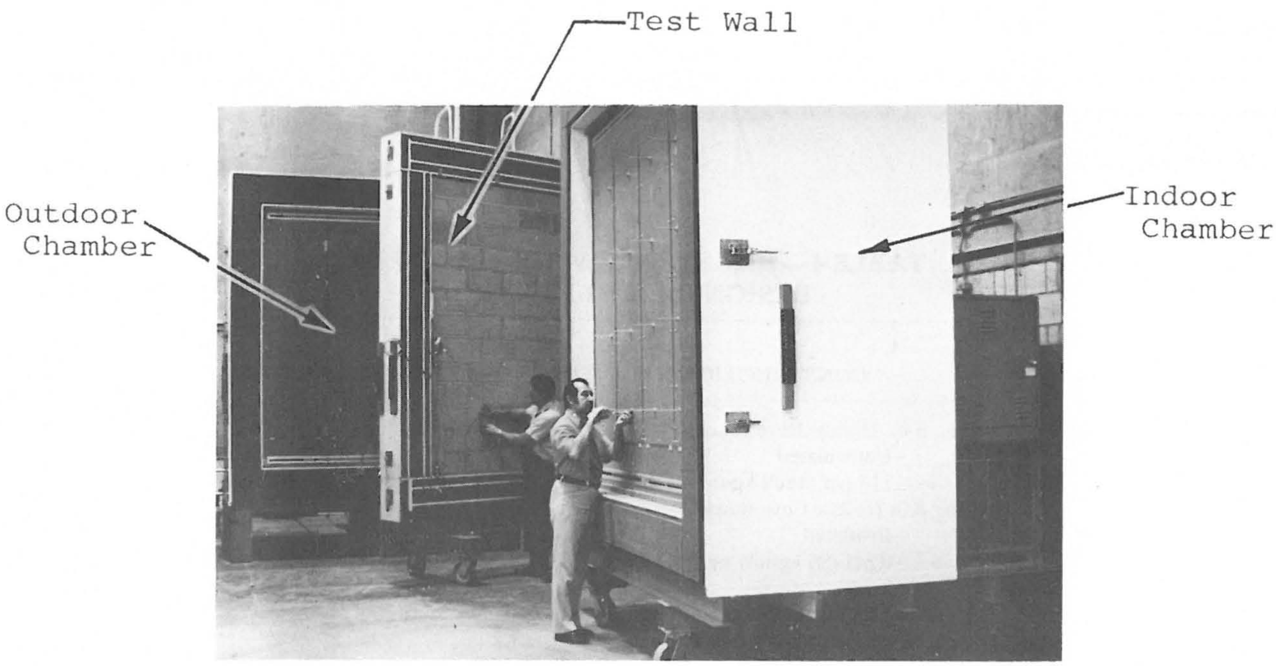


Figure 2. Calibrated Hot Box Test Facility

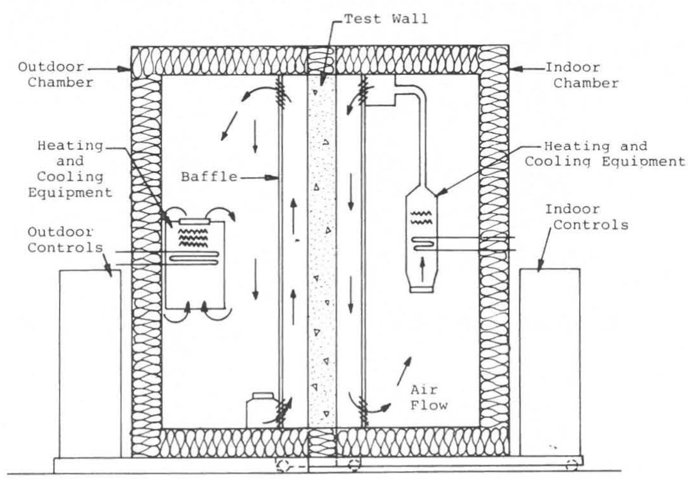


Figure 3. Calibrated Hot Box

TABLE 3—STEADY STATE TEST RESULTS

Specimen	FROM TEST DATA				CALCULATED DESIGN VALUES[2]		
	C Btu/hr•ft^2•F (W/m^2•K)	R hr•ft^2•F/Btu K•m^2/W)	R_u[1] hr•ft^2F/Btu (K•m^2/W)	U[1] Btu/hr•ft^2•F (W/m^2•K)	R_u hr•ft^2•F/btu (K•m^2/W)	U Btu/hr•ft^2•F (W/m^2•^{2}K)	$\frac{U_{Test}}{U_{Design}}$
Hollow Block	0.52	1.9	2.8	0.36	2.4	0.42	0.86
–Uninsulated	(2.95)	(0.33)	(0.49)	(2.04)	(0.42)	(2.38)	
Hollow Block	0.27	3.7	4.5	0.22	4.9	0.21	1.05
–Insulated	(1.53)	(0.65)	(0.79)	(1.25)	(0.86)	(1.19)	
Block-Brick Cavity	0.36	2.8	3.6	0.28	3.4	0.29	0.97
–Uninsulated	(2.04)	(0.49)	(0.63)	(1.59)	(0.60)	(1.65)	
Block-Brick Cavity	0.13	7.7	8.5	0.12	8.6	0.12	1.00
–Insulated	(0.74)	(1.36)	(1.50)	(0.68)	(1.51)	(0.68)	
Wood Frame	0.072	14.0	14.8	0.068	11.4[3]	0.088[3]	0.77
	(0.42)	(2.47)	(2.61)	(0.39)	(2.01)	(0.50)	
Wood Frame	0.067	15.0	15.8	0.063	12.7[3]	0.079[3]	0.80
–Brick Veneer	(0.38)	(2.64)	(2.78)	(0.36)	(2.24)	(0.45)	

[1]Measured values plus design surface resistances (inside = 0.68 and outside = 0.17)
[2]Based on resistance values in Table 4
[3]Adjusted for framing (15% frame area)

TABLE 4—RESISTANCE VALUES USED IN DESIGN CALCULATIONS

CONSTRUCTION	THERMAL RESISTANCE[1]	SOURCE[2]
a. 8-in. Hollow Core Block –Uninsulated –115 pcf (1842 kg/m^3) concrete	1.5 (0.26)	6
b. 8-in Hollow Core Block –Insulated –6 pcf (96 kg/m^3) perlite loose fill –115 pcf (1842 kg/m^3) concrete	4.0 (0.70)	6
c. 4-in. Hollow Core Block –116 pcf (1858) kg/m^3) concrete	1.2 (0.21)	6
d. 4-in. Clay Brick	0.44 (0.08)	7
e. 1 or 2-in. (25 or 51-mm) Air Space	0.97 (0.17)	5
f. 2-in (51-mm) Loose Fill Insulation –6 pcf (96 kg/m^3) perlite	6.1 (1.07)	8
g. 5/8-in. (16 mm) Plywood	0.78 (0.14)	5
h. 3-1/2-in. (89-mm) Mineral Fiber Blanket Insulation	11.0 (1.94)	5
i. 3-1/2-in. (89 mm) Wood Stud	4.4 (0.77)	5
j. 1/2-in. (13mm) Gypsum Board	0.45 (0.08)	5
k. Outside Surface Resistance	0.17 (0.03)	5
l. Inside Surface Resistance	0.68 (0.12)	5

[1]hr•ft^2•F/Btu(K•m^2/W)
[2]Numbers refer to references listed at end of paper

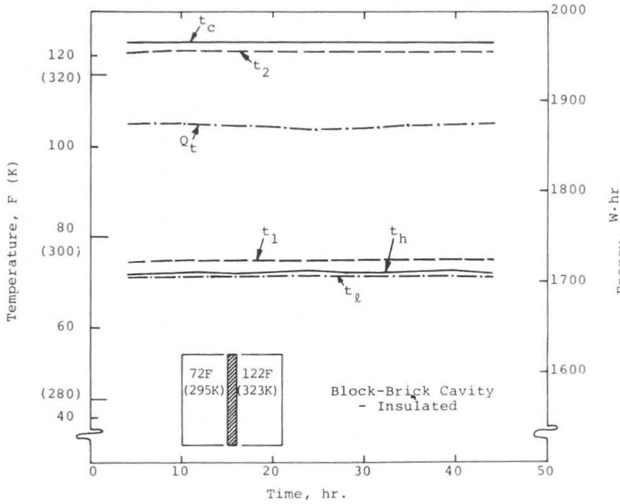


Figure 4. Steady-State Test

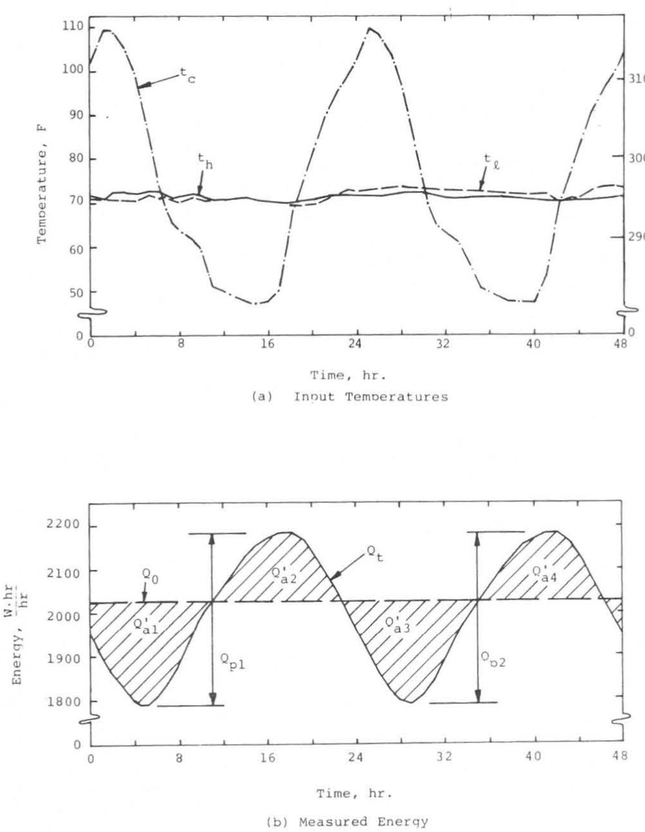


Figure 6. Dynamic Test of Hollow Block Wall

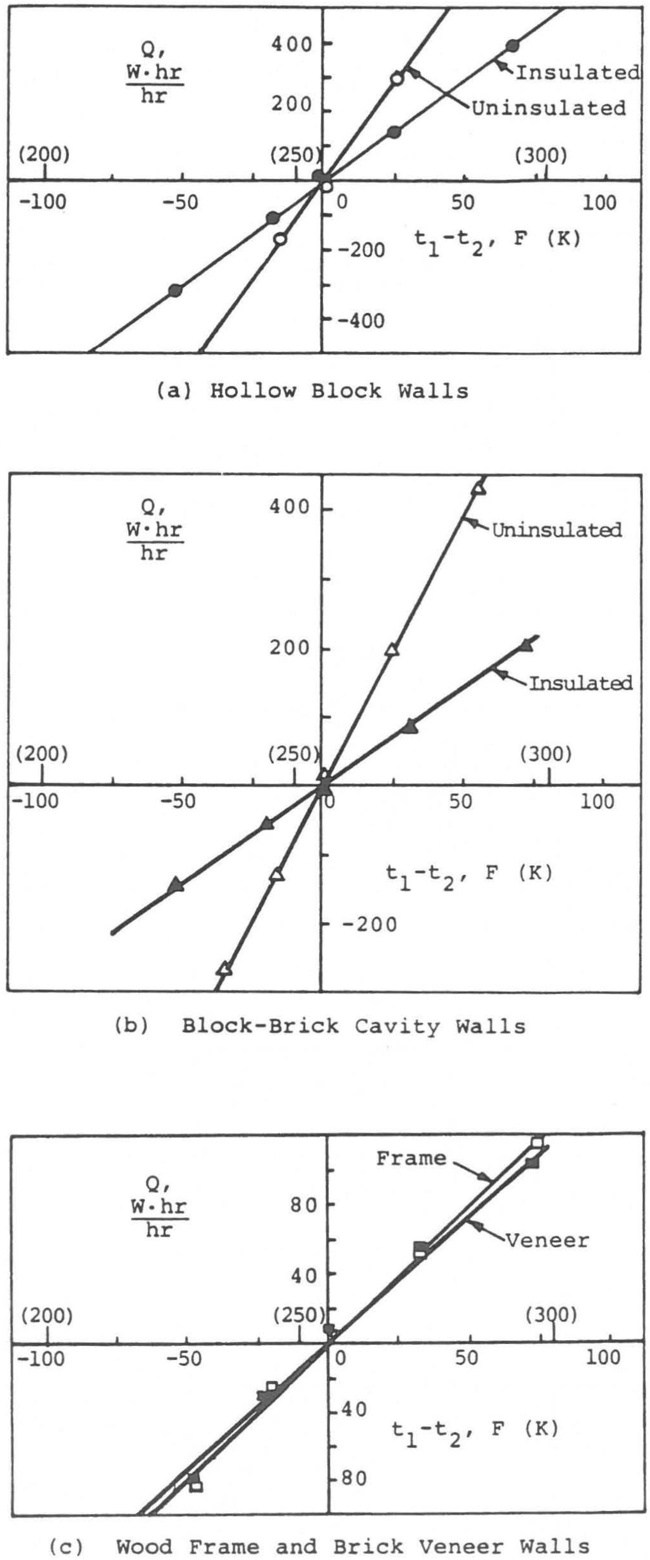


Figure 5. Variation of Energy with Differential Temperature for Steady-State Tests

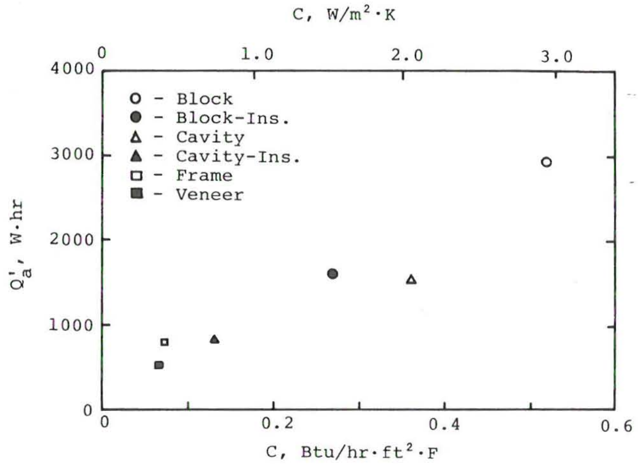


Figure 7. Total Energy vs. Thermal Conductance

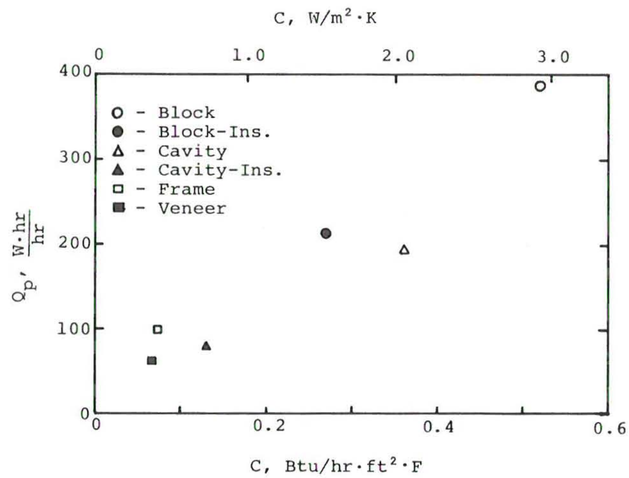


Figure 8. Double-Amplitude Energy Response vs. Thermal Conductance

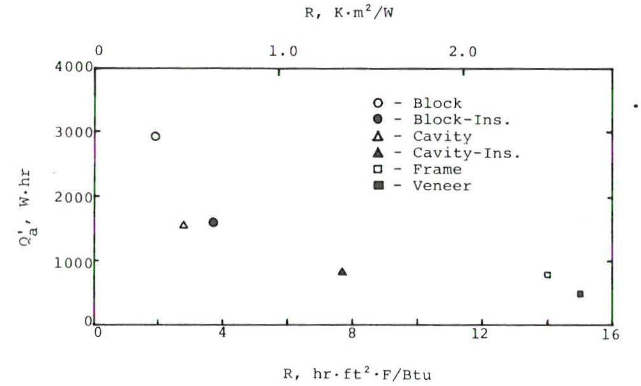


Figure 9. Total Energy vs. Thermal Resistance

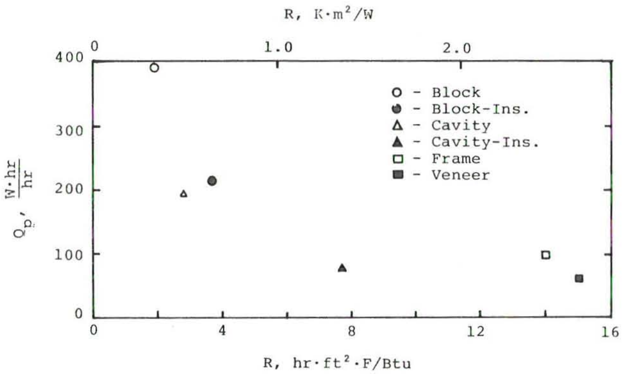


Figure 10. Double-Amplitude Energy Response vs. Thermal Resistance

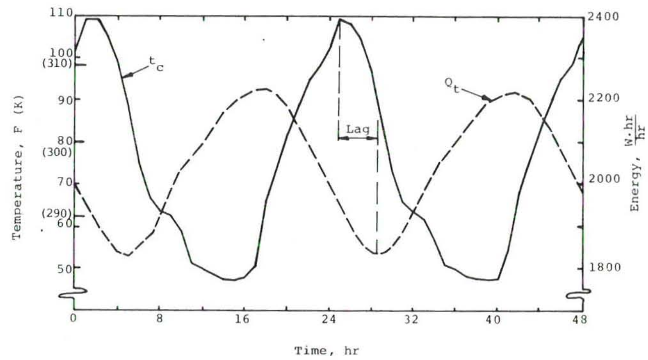


Figure 11. Thermal Lag

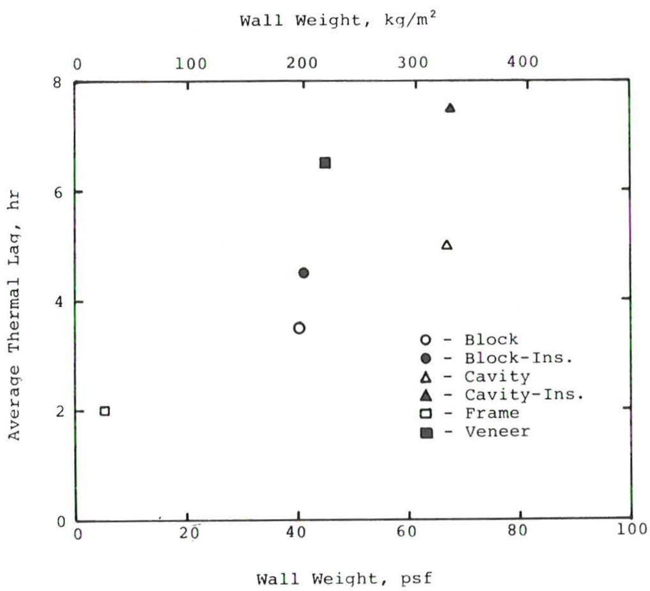


Figure 12. Effect of Wall Weight on Thermal Lag