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Autor: Fiorato, A.E. / Corley, W.G.

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Tests of Heat Transfer through Walls

Essais de transfert de chaleur au travers de murs

Versuche über Wärmeübertragung durch Wände

A.E. FIORATO
Manager
Portland Cement Association
Skokie, IL, USA

W.G. CORLEY
Divisional Director
Portland Cement Association
Skokie, IL, USA

SUMMARY

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. Steady-state tests were used to obtain average thermal conductance (C) and thermal resistance (R) values. Dynamic tests provided a comparative measure of thermal response under a diurnal outdoor temperature cycle.

RESUME

Une étude des caractéristiques de transmission thermique de murs en maçonnerie et cadres en bois est présentée. Des essais statiques et dynamiques ont été entrepris dans une chambre chaude calibrée. Les essais statiques ont été utilisés pour obtenir les valeurs moyennes de conductance thermique (C) et résistance thermique (R). Les essais dynamiques ont permis une mesure comparative du comportement thermique durant un cycle diurne de température extérieure.

ZUSAMMENFASSUNG

Eine Untersuchung der Wärmenutzungseigenschaften von Mauerwerks- und Holztafelkonstruktionen wird beschrieben. Stationäre und instationäre Messungen werden durchgeführt nach der Heizkostenmethode. Für die Messung der mittleren Wärmeleitfähigkeit und des Wärmedurchlaufswiderstandes werden stationäre Verfahren angewendet. Instationäre Verfahren wurden für Vergleichsmessungen vorgesehen über die thermische Reaktion auf tägliche Aussentemperaturschwankungen.

1. 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. Tests in this program provide data to quantify the relationship between dynamic energy requirements and steady-state thermal coefficients.

2. TEST FACILITY

Tests were conducted in the Calibrated Hot Box facility of the Portland Cement Association's Construction Technology Laboratories. This facility is unique in that it is specifically designed to evalute thermal performance of large wall assemblies under dynamic as well as steady-state temperature conditions. Dynamic tests provide a means to realistically evaluate thermal response under laboratory simulated sol-air temperature conditions. A standard test method for the Calibrated Hot Box is being developed by the American Society for Testing and Materials.(1)

The Calibrated Hot Box Test facility, shown in Fig. 1, consists of two highly insulated chambers separated by a test wall. The test wall has nominal overall dimensions of 103x103 in. (2.62x2.62 m). During a test, temperatures in the outdoor chamber can be held constant or cycled between -20 and 120F (-29 and 49C). Temperature cycles can be programmed to simulate desired outdoor sol-air conditions. Indoor chamber air is maintained at constant room temperature between 65 and 80F (18 and 27C). A highly sensitive watt-hour meter is used to measure energy expended for heating and cooling the indoor chamber. This measurement, in combination with temperatures measured on the wall and in the chamber air, is used to determine heat transfer characteristics of the test wall.

Steady-state tests are conducted by maintaining both chambers at constant but different temperature levels. This provides a predetermined temperature differential between chambers. Temperatures are maintained until conditions of equilibrium are established. Under these conditions, heat flow through the test wall is essentially constant. Results of energy and temperature measurements are used to determine average thermal properties such as conductance (C), resistance (R), transmittance (U), and overall resistance (R_u).

Dynamic tests are conducted by maintaining the indoor chamber at constant temperature while outdoor chamber temperatures are cycled. Total energy required to maintain constant indoor temperature is used to evaluate performance of the test wall.

3. EXPERIMENTAL INVESTIGATION

The first major program utilizing the Calibrated Hot Box was jointly sponsored by the Portland Cement Association, the Brick Institute of America, and the National Concrete Masonry Association. Detailed information is reported in Reference 2.

Six wall assemblies were evaluated. These were:

1. 8-in. (200-mm) Hollow Concrete Block Wall
2. 8-in. (200-mm) Hollow Concrete Block Wall Insulated with Perlite Loose Fill
3. 10-in. (250-mm) Concrete Block-Clay Brick Cavity Wall
4. 10-in. (250-mm) Concrete Block-Clay Brick Cavity Wall Insulated with Perlite Loose Fill
5. Wood Frame Wall with 3-1/2-in. (90-mm) Blanket Insulation
6. Wood Frame Wall with 4-in. (100-mm) Clay Brick Veneer

Conditions established for the dynamic test are shown in Fig. 2. The outdoor sol-air temperature cycle is based on a diurnal cycle used by the National Bureau of Standards in their evaluation of a concrete masonry building.[3] The measured energy response curve, shown in Fig. 2(b), represents heating and cooling energy required to maintain an essentially constant indoor chamber temperature.

To compare energy requirements of each test wall for nominally identical test conditions, a measure of total energy demand was selected. This is defined in Fig. 2(b) as the shaded areas of the energy response curve. Results were normalized to represent one 24-hour cycle.

4. EXPERIMENTAL RESULTS

The relationship between steady-state and dynamic test results is summarized in Fig. 3. For each specimen, total energy demand for a 24-hr dynamic test cycle is plotted as a function of overall thermal resistance, R_u, obtained from steady-state tests.

Results indicate that increases in overall thermal resistance beyond an R_u-value of about 8 $hr \cdot ft^2 \cdot F/Btu$ ($1.41 K \cdot m^2/W$) did not result in corresponding decreases in energy demand.*

A significant decrease in energy demand was obtained by addition of loose fill insulation to the hollow block wall. This wall had a relatively low initial R_u-value. In this range, increasing insulation resulted in a considerable reduction in energy requirements.

*Note that experimental results are for an isolated wall subjected to one diurnal temperature cycle.

The reduction in energy demand obtained by addition of insulation to the cavity wall was also significant. However, it was not as large as that for the hollow block wall considering the relative increase in R_u that was obtained by adding loose fill. Thus, energy savings tended to decrease with increasing thermal resistance.

A major finding was that the insulated cavity wall had approximately the same energy demand as the wood frame wall even though the resistance of the frame wall was nearly twice that of the cavity wall.

Addition of brick veneer to the wood frame wall indicated the influence of mass. Reduction in energy demand was substantial considering the small increase in resistance.

Results of dynamic tests were also used to evaluate thermal lag. Lag is defined as the time required for peak cooling or heating load to be reached after maximum or minimum sol-air temperature is reached. Thermal lag is important because it is a measure of heat capacity or thermal inertia. The greater the lag, the greater the potential to "smooth out" and reduce peak heating and cooling energy demands. This can lead to greater efficiencies in equipment operation, smaller equipment, and lower peak utility demands.

Measured thermal lag is plotted as a function of wall weight in Fig. 4. Thermal lag increased significantly with wall weight. This is most apparent in the comparison of results for wood frame and wood frame-brick veneer walls. Addition of brick veneer increased wall weight from 5.2 to 45.1 psf (25 to 220 kg/m^2), and increased thermal lag from 2.0 to 6.5 hr.

It is also evident that loose fill insulation was more effective in increasing lag in the cavity wall than in the hollow block wall. It is probable that absence of thermal bridges in the cavity wall provided a more effective mechanism of insulation between the masses of the block and brick wythes.

5. CONCLUSIONS

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

1. Dynamic tests indicated that increasing thermal resistance from 2.8 to 8.5 $hr \cdot ft^2 \cdot F/Btu$ (0.49 to 1.50 $K \cdot m^2/W$) resulted in a significant decrease in energy requirements under dynamic conditions. Further increases in resistance were not as effective in reducing energy requirements.

2. Dynamic tests indicated that energy requirements for an insulated block-brick cavity wall with a thermal resistance of 8.5 $hr \cdot ft^2 \cdot F/Btu$ (1.50 $K \cdot m^2W$) were essentially equivalent to that of a wood frame wall with a thermal resistance of 14.8 $hr \cdot ft^2 \cdot F/Btu$ (2.61 $K \cdot m^2W$).

3. 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.

4. Thermal lag between cycles of outdoor temperature and energy response increase 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.

6. REFERENCES

(1) "Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box," Draft No. 5, Committee C-16: Thermal and Cryogenic Insulating Materials, American Society for Testing and Materials (ASTM), May 1979.

(2) Fiorato, A.E. and Cruz, C.R., "Thermal Performance of Masonry Walls," Proc. of the Fifth International Brick Masonry Conference, Washington, D.C., October 1979 (to be published).

(3) Peavy, B.A., Powell, F.J. and Burch, D.M., "Dynamic Thermal Performance of an Experimental Masonry Building," Building Science Series 45, U.S. Department of Commerce, National Bureau of Standards, July 1973, 98 pp.

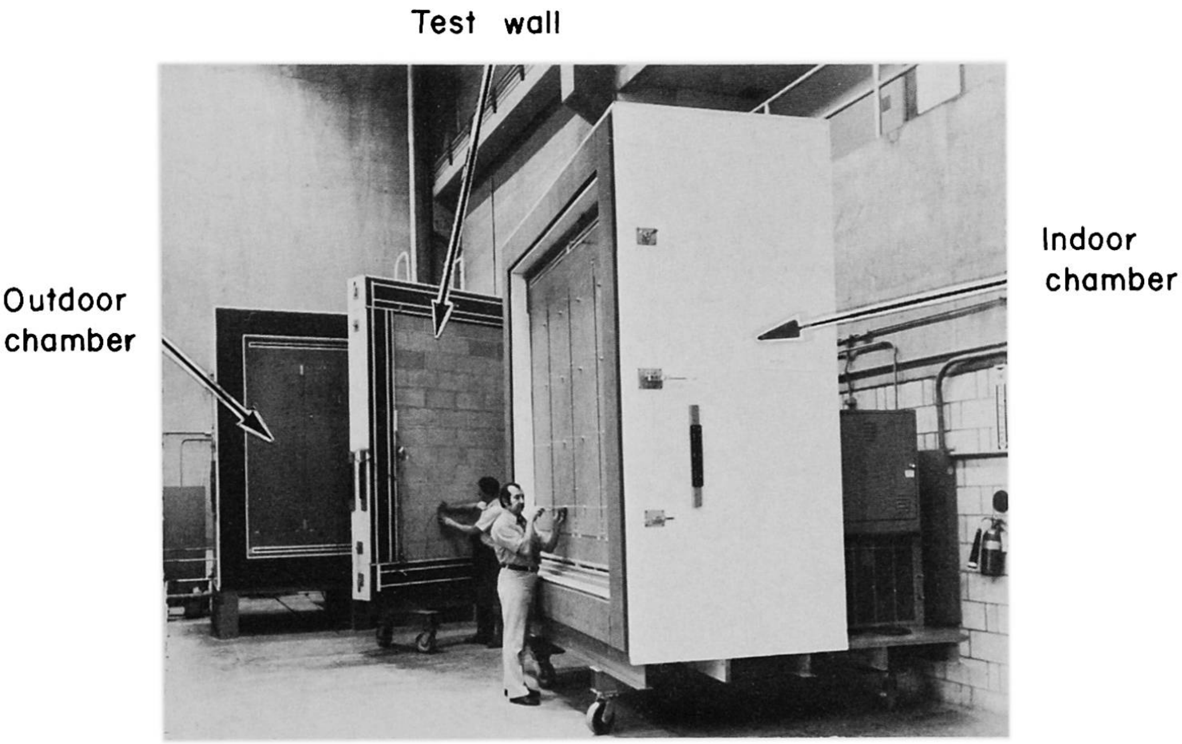

FIG. 1 CALIBRATED HOT BOX TEST FACILITY

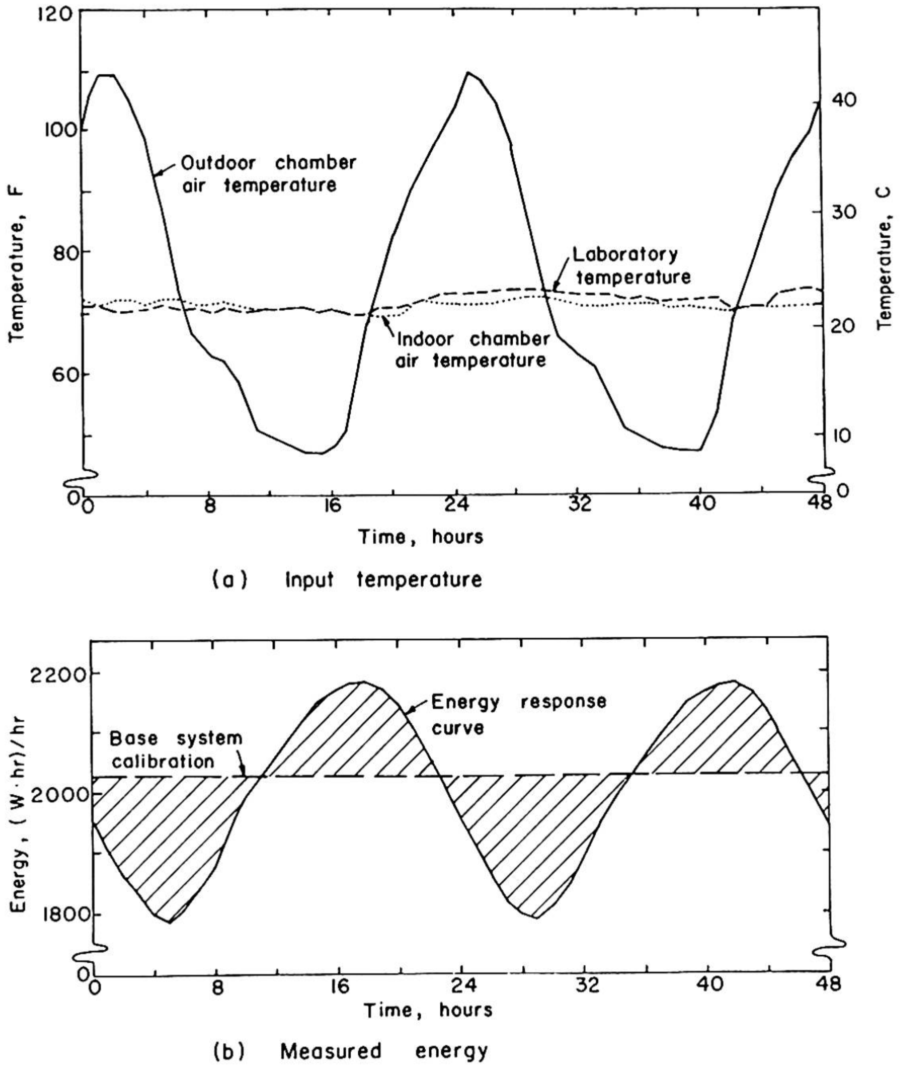

FIG. 2 DYNAMIC TEST OF HOLLOW BLOCK WALL

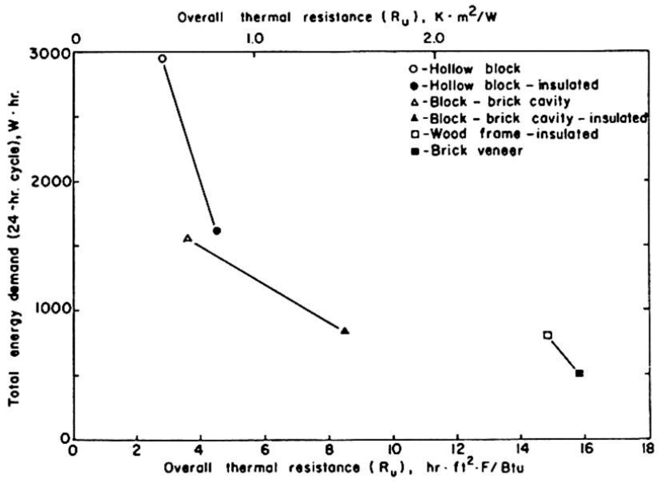

FIG. 3 HEATING AND COOLING ENERGY VS. OVERALL THERMAL RESISTANCE

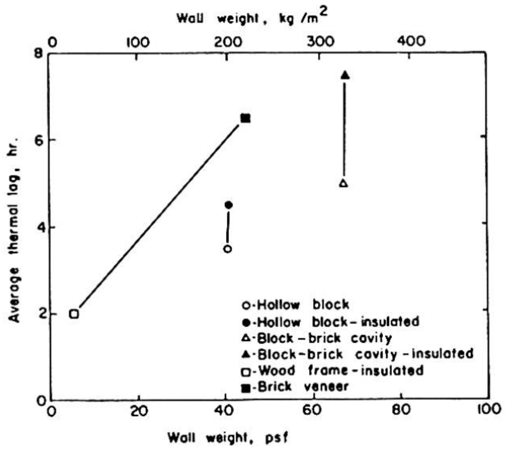

FIG. 4 EFFECT OF WALL WEIGHT ON THERMAL LAG