AIR INFILTRATION EFFECTS ON THE THERMAL TRANSMITTANCE OF CONCRETE BUILDING SYSTEMS

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FOREWORD

Field measurements of thermal transmittance have been performed on two types of concrete buildings using portable guarded hotbox equipment. Air infiltration measurements of these same two types of concrete systems were made in the laboratory. It is the primary purpose of this paper to present the effects of the air infiltration on the over-all heat transfer coefficients.

BUILDING SYSTEMS IDENTIFICATION

The two types of concrete building systems evaluated in this study are identified by the following:

12-in. (0.305 m) thick sandwich panel - This system consisted of an 8-in. (0.203 m) thick hollow core concrete plank, faced on the exterior side with a nominal 2-in. (50.8 mm) thick expanded polystyrene board (molded beads), and a 2-in. (50.8 mm) thick concrete face shell. The exterior face shell was secured to the plank with 1/4-in. (6.35 mm) diameter "U" shaped anchors which pierced the board insulation. The concrete used in construction of this system was of a heavy weight sand and gravel mix. The cores were void of any insulation material. The wall evaluated in the field for thermal transmittance was painted on the exterior surfaces only, and the sample evaluated in the laboratory for air infiltration was unfinished on both sides.

12-in. (0.305 m) thick lightweight concrete block wall - The concrete blocks were of a lightweight aggregate and nominally 12-in. x 8-in. x 16-in. (0.305 m x 0.203 m x 0.406 m). The two core blocks were constructed into a wall using running bond and standard mortar joints. The cores were filled with a beaded expanded polystyrene insulation. Both walls were painted on the exterior, unfinished on the interior. The wall tested for air infiltration was painted with two coats of an exterior, white latex paint. When dried, the paint did contain some drying cracks. A typical block used in construction of the air infiltration test wall weighed 37.2 lbs (16.9 kg).

BACKGROUND

Air leakage into and out of buildings is of concern because it increases the thermal transmittance, and the cost of heating and cooling the building. This

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effect can vary greatly with the resistance of the building components to air infiltration. Some elements offer a great resistance to the flow of air, while others are less resistant and are highly effected by the air infiltration. For example, a 3 ft x 5 ft (0.914 m x 1.52 m) double hung wood window with insulated glazing and in the locked position may have a thermal transmittance of 0.45 Btu/hr-sq ft-F (2.56 W/sq m-C) when tested with minimum air infiltration effects, yet have a thermal transmittance of 3.30 (18.7) when the effects of a 23 mph (37 km/h) are imposed (NBS BSS 77, p. 82).

For those construction materials and systems that allow the air infiltration, the over-all heat transfer coefficient consists of two primary parts:

1. The heat transfer due to conduction through the assembly (U_c).

2. The heat transfer due to the air infiltration (U_i).

For this study, the over-all coefficient (U_o) is equal to the sum of these two parts, or mathematically: $U_o = U_c + U_i$

During winter, the heat required to condition incoming colder outside air would include the following:

1. The sensible heat required to raise the air temperature of the exterior air to the interior temperature.

2. The latent heat of vaporization of the water required to raise the humidity of the exterior air to that of the interior air.

To simplify this presentation, only the sensible heat required to raise the outside air temperature to that of the inside air temperature is included. If humidification of the buildings were to be included in this study, the over-all heat transfer coefficients would be even higher due to air infiltration than are presented herein.

Pressure differences causing air infiltration in a building include those due to wind forces, and those due to differences in temperature between the inside and outside producing a difference in density of the air columns (stack effect). For buildings with a relatively small height, such as 25 ft (7.62 m), the forces due to air density differences are small compared with wind forces and are neglected in this study. Pressure differences produced by mechanical equipment and other external causes are also being neglected. Therefore, only the effects of wind forces are included in this study. For taller buildings where the stack effects become appreciable, or where mechanical equipment contribute to the air infiltration rates, the over-all heat transfer coefficients due to air infiltration would be higher than are presented herein.

Wind forces can be theoretically defined mathematically, but due to variables such as wind direction, shape of the building, presence of trees and ground elevations around the building, it is necessary to make assumptions in order to correlate wind velocity with actual imposed pressure differentials. Published information (ASHRAE Handbook and Product Directory, 1977, p. 21-1 & 21-2) indicates that wind pressures vary from +0.5 to +0.9 of ideal on the windward side, from -0.3 to -0.6 of ideal on the leeward side of a simple square or rectangular building depending upon the angle of the wind, and from -0.1 to -0.9 of ideal static pressure on the sides parallel to or at slight angles to the wind direction. Since the blocks were textured and the sandwich panels contained scored exterior surfaces, the concrete systems evaluated contained greater than a square foot of contact surface for each square foot of wall area. With this information, it was assumed that the wind impinged upon the windward side with full efficiency causing air infiltration to occur, and that the outflow of air occurred through the other three sides.

The over-all heat transfer coefficients are calculated as follows:

$$U_o = U_c + U_i = U_c + Qcp(60)/A(4)$$

Where: Q = air infiltration rate @ velocity V, cfm
c = specific heat of dry air at constant pressure, 0.24
p = density of outside air (density of standard air @ 0.075 pcf used to simplify this presentation) pcf
A = area through which Q is occurring, sq. ft.

TEST METHODS

Field Measurements of Thermal Transmittance

Thermal transmittance tests were performed on two relatively new, warehouse type concrete buildings located about two blocks apart in Minneapolis, Minnesota. The testing was performed during one week in January, 1978 on east facing wall areas selected by this author. One building was constructed of the sandwich panels, and the other of the lightweight concrete blocks.

The testing was performed following the guidelines of ASTM C-236 using specially constructed apparatus. A sketch of the apparatus is shown in Fig. 1. The exterior box contained a grid network of thermocouples for measurement of the exterior air temperatures. The metering box was nominal 4 ft. (1.22 m) wide and 8 ft. (2.44 m) high and was instrumented with differential thermocouples for correction of the net heat flow. Differential thermocouples were placed on the walls at the perimeter of the metered area for control of lateral heat flow. The metering box was equipped with fan, heaters, and variable voltage source for control and adjustment of the electrical heat input to the metering box, with the heat input measured using the General Electric watthour meter standard. The temperature of the air and of the concrete surfaces on both sides were monitored using thermocouples and direct reading digital thermocouple indicator. Data were taken half-hourly during a sufficient period to assure that all conditions were stable. Minor adjustments were made to the heat flow input during the preliminary period to maintain the wall differential at zero. The warehouses were maintained at constant temperature, and used as the guard box.

The exterior box was kept in near contact with the wall, to shield the wall from the effects of varying winds. Data were taken at night when no solar effects were present. A remote refrigeration unit provided additional cooling when required, although the existing cold winter air was used to provide most of the cooling.

Laboratory Measurements of Air Infiltration

The air infiltration testing was performed in conformance with ASTM E-283, except the differential pressures used were many. The testing was performed on specimens approximately 4 ft. (1.22 m) wide and 6 ft. (1.83 m) high. The concrete block wall was constructed by a professional block layer using Sakkrete mortar mix, running bond, and standard 3/8 in. (0.95 cm) wide mortar joints. The joints were tight and were tooled. Painting of the concrete block wall was accomplished using a roller. The paint was allowed to thoroughly dry prior to testing, but fissures did develop during the air drying period. Both walls were thoroughly dried prior to air infiltration testing.

The apparatus consisted of a five sided, open-faced chamber, adjustable air supply, and manometer. A schematic of the apparatus is shown in Fig. 2. Each specimen was sealed to the opening in the air tight chamber, and the perimeter edges of each panel sealed so all airflow had to occur from the exterior side to the interior side through the specimen. A high speed blower forced air into the chamber, and the chamber allowed the build up of pressure equal to the forces created by varying wind velocities. An inclined water column manometer was used to measure the static pressure within the chamber, and the differential pressure across the specimen. A valve in the air supply line allowed the adjustment of airflow to achieve the desired chamber pressure. The airflow rate was measured using the EMCO low pressure flow prover equipment, which consisted of an approach tube, thermometer well, straightening vanes, orifice plate flange and orifice plates, discharge tube and manometer to measure the pressure differential across the orifice plate in use. The orifice plates used were calibrated by the manufacturer.

The relationship between chamber static pressure and simulated wind velocity is given by the following formula (Handbook and Product Directory, 1977, p. 21-1):

$$P = 0.000482\ V^2$$

Where: P = differential pressure, inches of water column (249 pascals)
V = simulated wind velocity, miles per hour (0.447 m/s)

Note: The coefficient 0.000482 becomes 0.601 when SI unit are used.

TEST RESULTS

Field Thermal Transmittance Measurements

The test results are summarized by the following:

Item Wall System	Test Results Sandwich Panel	 Concrete Blocks
Heat flow rate, Btu/hr-sq ft	5.80	5.99
(W/m^2)	(18.3)	(18.9)
Warm air temperature, F	65.5	67.2
(C)	(18.6)	(19.6)
Cold air temperature, F	16.8	28.5
(C)	(-8.4)	(-0.2)
Thermal transmittance, as tested		
Btu/hr-sq ft-F	0.119	0.155
(W/m^2-C)	(0.676)	(0.880)

Laboratory measurements on a thoroughly dried, specially selected sandwich panel yielded a thermal transmittance of 0.10 Btu/hr-sq ft-F (0.568 W/m^2-C) (Dynatherm Engineering Lab. No. 208). This value was calculated using measured panel conductance, and surface resistances from ASHRAE for still air inside and 15 mph (24.2 km/h) wind outside. Laboratory measurements of a thoroughly dried concrete block wall with block of slightly lower density and comparable core insulation yielded a thermal transmittance corrected to the same surface conditions as above of 0.13 Btu/hr-sq ft-F (0.738 W/m^2-C) (Dynatherm Engineering Lab. No. 038).

Laboratory Measurements of Air Infiltration

The results of air infiltration measurements on the two wall systems are presented in Fig. 3. The air infiltration rates are corrected to standard conditions of 29.92 in. (760 mm) of mercury column, and to 69.4F (20.8C).

At the higher simulated wind velocities, the air infiltration was so obvious that the air jetting out of the wall from the interior side was detectable readily by simply placing the hand adjacent to the wall. Using this technique, differences were detectable in the magnitude of the air infiltration at different blocks within the same test wall.

Expanded polystyrene board insulation (molded beads) does allow some air infiltration. For example, a rate of 0.270 cfm/ sq ft (1.37 $l/s\text{-}m^2$) was measured on a nominal 1-in. (2.54 cm) thick 1 pcf (16 kg/m^3) using a pressure differential of 1.57 psf (75.2 pa) (Dynatherm Engineering Lab. No. 152). It appears that the properties of higher density concrete, board insulation, and lack of mortar joints were factors contributing to the increased resistance to air infiltration through the sandwich panel.

OVER-ALL HEAT TRANSFER COEFFICIENTS (U_o)

The effects of air infiltration on the over-all heat transfer coefficients (U_o) are shown in Fig. 4. The one curve shows the sandwich panel with nil air infiltration effects, with the coefficients corrected only for the wind effects on the outside surface conductance coefficients. For the lightweight concrete block wall panel where air infiltration effects were quite significant, the over-all coefficients are shown for dry air only, where no humidification is taken into account. The over-all coefficients were calculated using the measured value by conduction, and from the measured air infiltration data.

REMARKS

It is not known how typical either wall system was. Deterioration of paint or other surface coatings, repainting or recoating of walls, opening up of mortar joints, variations in materials, and other factors may effect the over-all heat transfer coefficients obtained. Additional research is underway to evaluate other types of concrete building systems for air infiltration effects on the thermal transmittance.

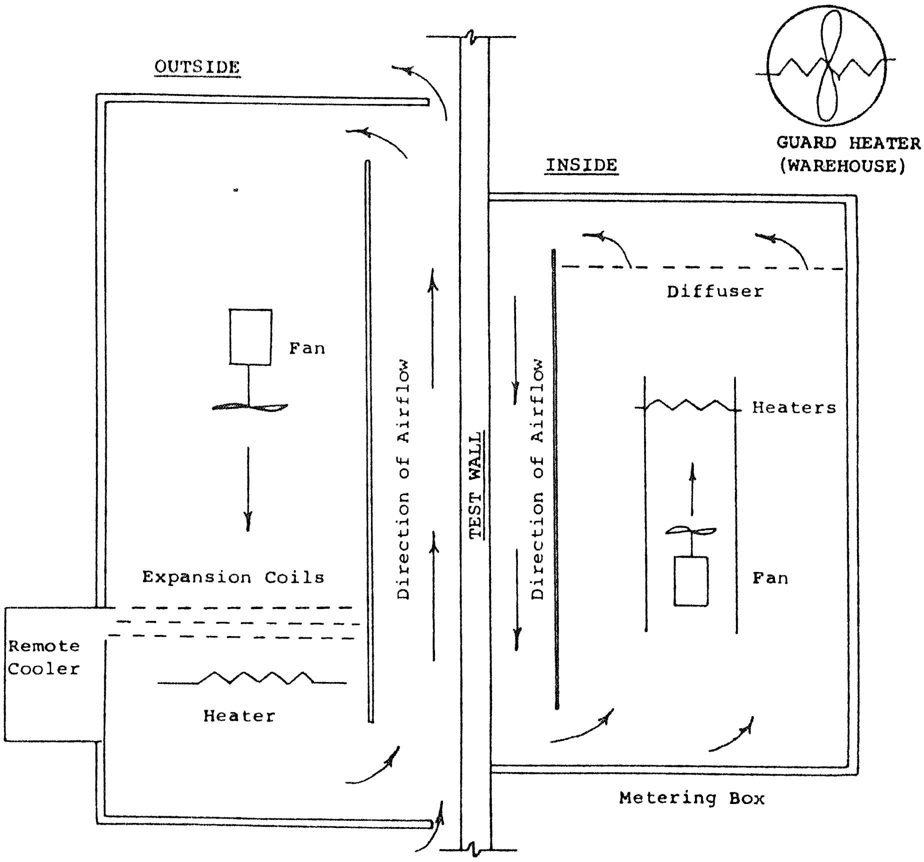

Fig. 1 Schematic diagram of guarded hotbox apparatus

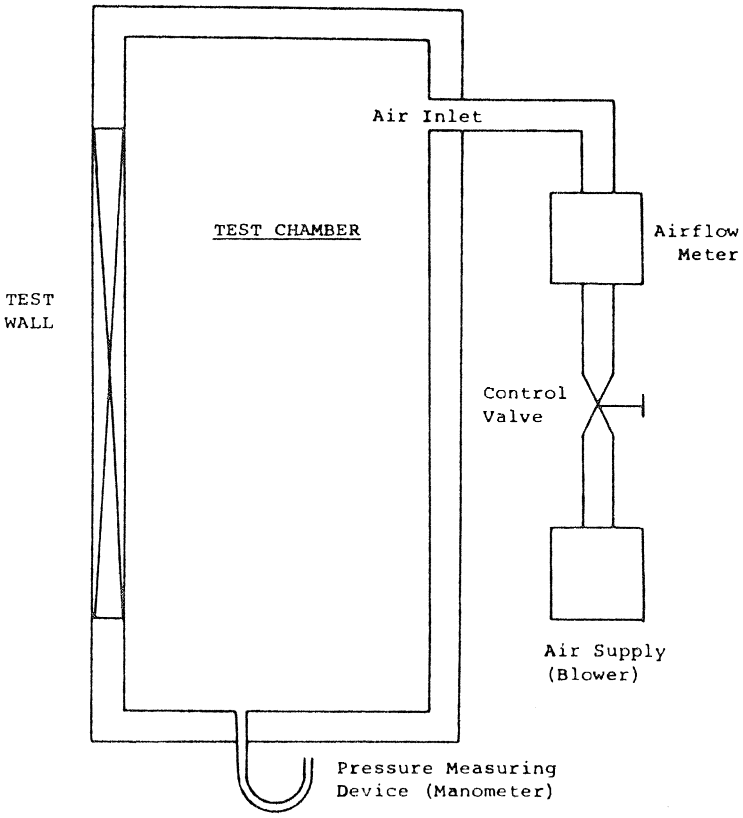

Fig. 2 Air infiltration apparatus

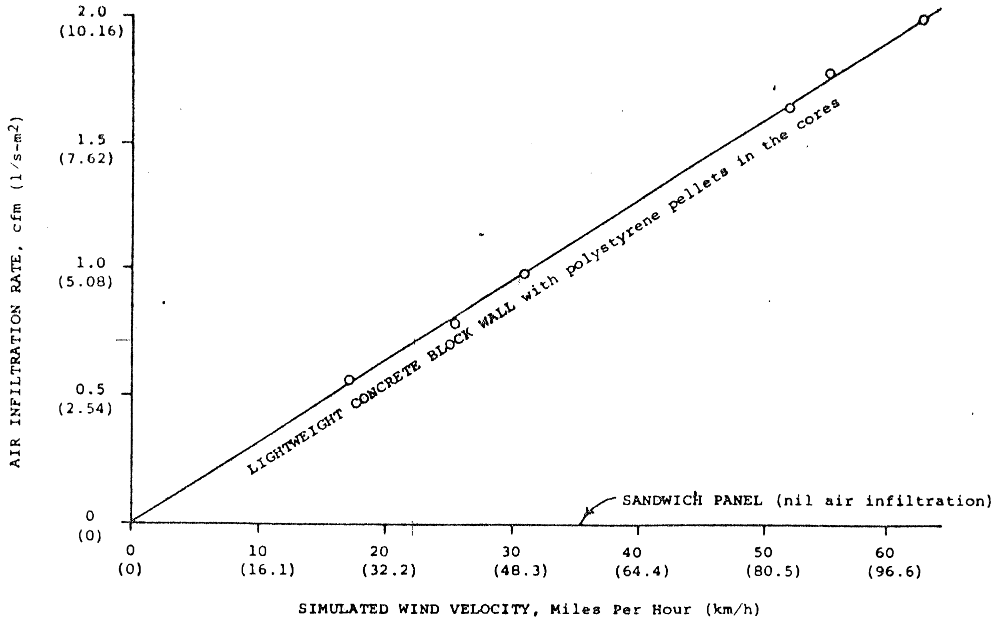

Fig. 3 Air infiltration rates through two types of concrete building systems

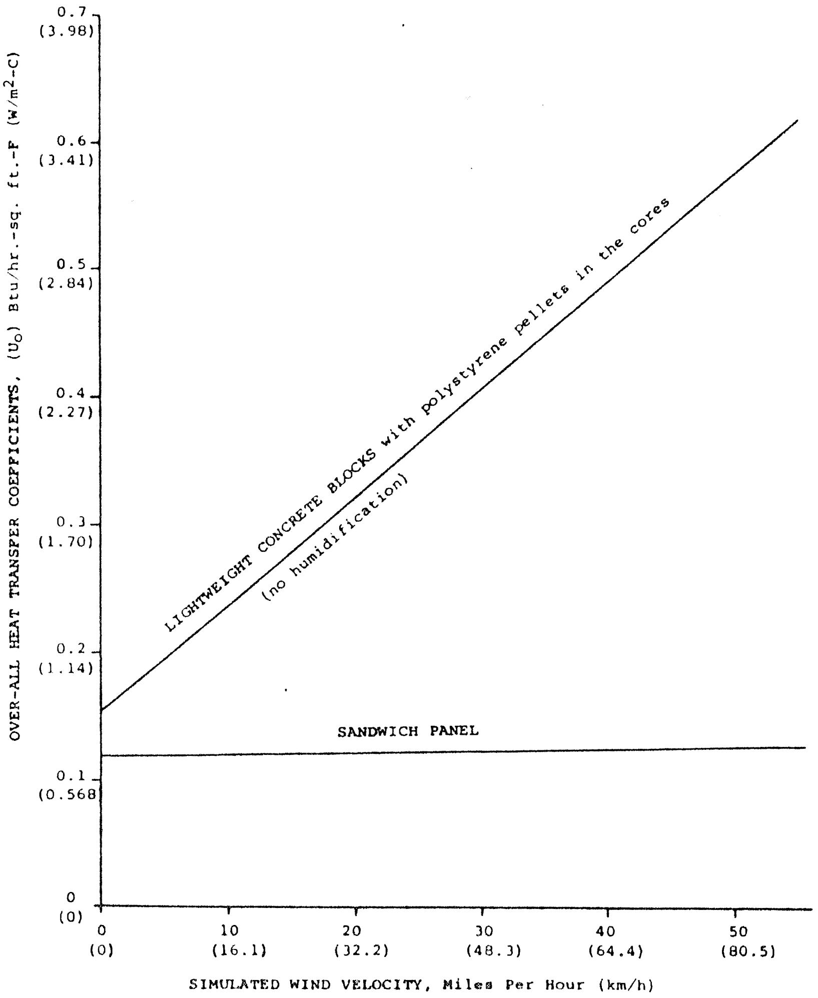

Fig. 4 Over-all heat transfer coefficients for concrete walls