Design of a Calibrated Hot-Box for Measuring the Heat, Air, and Moisture Transfer of Composite Building Walls

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ABSTRACT

A large calibrated hot-box is to be constructed at the National Bureau of Standards to support the development of standard procedures for measuring the heat, air and moisture transfer of room-size (3.0 by 4.5 m) exterior-wall specimens under a range of simulated climatic conditions. The apparatus will be used for research in both steady-state and dynamic thermal performance in support of standard test methods; for study of the processes of heat transfer, air leakage and moisture transfer in building walls as aids to the design and construction of buildings for energy conservation; and to provide traceability in measurement to NBS through calibration services, Standard Reference Materials or the National Voluntary Laboratory Accreditation Program. The facility is being designed, constructed and operated under the joint sponsorship of the Department of Energy and the National Bureau of Standards as part of the National Program Plan for Building Thermal Envelope Systems and Insulating Materials, issued by the Department of Energy in January 1979.

The apparatus is being built to measure the performance of homogeneous or composite walls having a range of thermal resistance from 0.35 to 8.8 $\frac{m^2 \cdot °C}{W}$ (2 to 50 $\frac{ft^2 \cdot °F \cdot hr}{Btu}$), air leakage rates up to 255 m^3/hr (150 cfm) and moisture transfer rates up to 1.4 kg/hr (3 lb/hr). It will accommodate wall specimens up to 0.6 m (24 in.) in thickness and up to 700 kg/m^2 in weight per unit area. Construction should be completed in the summer of 1980.

1.0 Introduction

Early in the 1970s it became evident that the United States must begin to design more efficient buildings to conserve energy. This country passed its peak production of domestic petroleum in 1970. Foreign suppliers imposed a sharp price rise in late 1973 and the price has continued to rise rapidly ever since. The use of energy for heating and cooling buildings represents about one fifth of the annual national consumption.

The need to increase the thermal resistance of building envelopes was first made the subject of a Presidential order in 1971. This policy was further emphasized in 1977 when the President set a goal of having 90% of the houses in the country "weatherized" by 1985.

Key Words: Building heat transfer, Calibrated Hot-Box, Heat transfer measurements, Standard test methods, Wall air leakage, Wall heat transfer, Wall moisture transfer.

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In addition to several ASTM Standard Test Methods for measuring the thermal transmission and other related properties of insulation as a material, the only existing U.S. standard test method for measuring the heat transfer properties of walls, floors and ceilings is the American Society for Testing and Materials (ASTM) C236, entitled a Standard Method of Test for Thermal Conductance and Transmittance of Built-Up Sections by Means of a Guarded Hot-Box. However, this test method is not well suited for measuring the heat transmission properties of room-size envelope specimens containing windows or doors or other composite features. ASTM subcommittee C 16.30 has prepared a Draft Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot-Box, which is under review.

The development of standards and regulations for limiting the energy requirements of whole buildings at the Federal and State level and in the private sector has created the need for test apparatuses that would more nearly simulate actual usage, by accounting for air and moisture transfer as well as heat transmission, through large-scale building elements.

Solvason[1] at the National Research Council in Canada built the first calibrated hot-box in 1959 to meter the heat flow through representative sections of large building walls. The first calibrated hot-box[2] in the U.S. was built by Owens-Corning Fiberglas Corporation in 1974. Since that time four others have been put into operation in the U.S., one of which was made rotatable and another was designed for research for floor and ceiling/roof constructions.

A calibrated hot-box apparatus basically consists of two large, five-sided, boxes with highly insulated sides plus an equally well-insulated frame which supports a test wall clamped between the open sides of the two boxes. One of the boxes is equipped with conditioning and control equipment suitable for maintaining a range of indoor temperature conditions and the other box is provided with similar equipment for maintaining a range of outdoor conditions. Instrumentation is provided to measure the heat release on the indoor side and the indoor box heat loss is determined by calibrating the box with a wall panel of known thermal resistance. Most of the existing calibrated hot-boxes also provide for simulating air leakage through the test wall by maintaining a measured static pressure difference across the specimen.

A series of tests[3] on the thermal and acoustical performance of 2.7 x 4.3 m (9 x 14 ft) insulated wood frame walls, some fitted with windows and doors, was conducted for the National Bureau of Standards in the calibrated hot-box built by the Owens-Corning Fiberglas Corporation. The results of these tests showed that the measured heat transfer of insulated walls, without doors or windows, agreed reasonably well with values calculated from handbook data. However, the overall heat transmission was approximately doubled under still-air conditions when the wall contained a window or door, and was approximately quadrupled under the static pressure difference corresponding to an 11 m/sec (25 mph) wind. Studies of different types of wall constructions at the National Bureau of Standards for the Federal Housing Administration showed that the air leakage under still-air and wind conditions varied among the specimens over a range of 40 to 1.

Considering the highly diversified nature of the building industry and the wide range of materials used as insulation and as building components, the insulation industry, ASTM, the Building Research Advisory Board and several Federal agencies have all expressed a strong need for the National Bureau of Standards to build a calibrated hot-box wall tester to assist in the development of suitable test procedures and standards.

2.0 Purpose of the NBS Facility

The purposes for which the NBS facility was designed are as follows:

a) Conducting research on steady-state and dynamic heat, air and moisture transfer, either as single or multi-modal processes, through large homogeneous or composite wall systems.

b) Cooperation with other Federal agencies and with the building industry in developing test procedures for calibrated hot-boxes for use in consensus standards.

c) Providing a mechanism for traceability to NBS in measurement of the thermal properties of wall specimens through a Standard Reference System concept.

d) Providing the methodology for accrediting testing laboratories in calibrated hot-box measurements.

e) Generating technical data on the thermal transmission properties of full-scale wall systems to support special requirements of Federal and State governments and to contribute to more economical and functional building envelope design and construction.

3.0 Design Concept

The NBS facility was designed to expose a wall specimen to a wide range of environmental conditions which simulate actual use conditions with respect to temperature, humidity and wind effects. The two chambers, one of which would simulate indoor conditions and the other outdoor conditions, were designed to limit the heat exchange with the laboratory ambient in which the facility is to be located.

Accurate measurements of heat input, moisture supply, air supply, temperature, pressure and humidity will be made in the chamber representing indoor conditions, hence it has been called the Metering Chamber. Equally accurate control of conditions will be provided in the chamber simulating outdoor conditions, but less accurate measurement of the gain or loss of heat, air and moisture will be made in this chamber, called the Environmental Chamber.

The Environmental Chamber was designed to simulate summer or winter temperatures in a steady-state or dynamic pattern. The temperatures in the Metering Chamber will simulate steady-state comfort conditions, or a nighttime setback cycle, or elevated steady-state temperatures to increase the temperature difference, and consequently the measuring accuracy, across well insulated walls during test.

A metered air supply will be provided to either chamber so that air leakage through the test wall can be simulated in either direction. The air will be supplied at any of several selected constant rates. Likewise, measured amounts of moisture will be supplied to the Metering Chamber to maintain selected relative humidity levels under winter conditions in order to study condensation conditions in the wall specimens. Summertime condensation in walls will not be simulated since the current recommended summer indoor temperature levels almost entirely avoid internal condensation in the walls of air-conditioned buildings in the United States.

Moisture accumulation tests normally require long periods of exposure to produce measurable results, especially if diffusion is the principal mechanism of moisture transport. In combination with air leakage, the rate of moisture accumulation is usually increased significantly. Not every wall specimen will be subjected to a vapor pressure difference, but it is considered important to be able to study moisture transport phenomena in combination with measured heat transfer and measured air leakage for selected well-instrumented wall constructions.

Table 1 lists the principal climatic conditions which the NBS apparatus was designed to simulate. Fig. 1 is an axonometric view of the calibrated hot-box and the conditioning equipment for the Environmental Chamber.

The NBS facility will be used to test vertical wall assemblies only. Another facility is being planned for testing floor and roof/ceiling assemblies, including the joints between these two elements and wall sections.

4.0 Description of Major Components

The walls of the Metering Chamber will be comprised of foamed polyurethane board insulation about 38 cm (15 in.) thick surrounded on all sides with a water jacket of integral-wall construction, which in turn is covered on the outside with about 6 cm (2½ in.) of glass fiber insulation and a plywood exterior envelope. The interior surfaces of the chamber will be covered with 3 mm (1/8 in.) thick glass-fiber-reinforced polyester (FRP) resin sheets. The exterior surface of the plywood is to be covered with a 1.5 mm (1/16 in.) layer of a similar material. The thick insulation in the walls of the Metering Chamber and the exterior water jacket is needed to meet the design requirement that the reverse heat loss through the Metering Chamber should not exceed 5% of the heat transfer through a wall specimen with a thermal resistance, R, of 8.8 $\frac{m^2 \cdot °C}{W}$ ($\frac{50\ ft^2 \cdot F \cdot hr}{Btu}$).

The conditioned-air circuit of the Metering Chamber will incorporate a variable speed vaneaxial fan, flowmeter, cooling coil, humidifier and electric resistance heater. Dampers and air diffusers in the air circuit are designed to distribute air uniformly over the face of the test wall in either an upward or downward direction. A movable baffle, containing the diffusers, will confine and direct the airstream across the face of the wall. The baffle will expose the test wall to a high emissivity surface and also allow some additional adjustment in the velocity of the airstream. The cooling coil will be used to remove a selected fixed quantity of heat from the airstream when the electric energy required to operate the fan and humidifier produces more heat than the wall specimen can transfer. The interior volume is divided into an upper and lower plenum by means of a sliding separator assembly. Fig. 2 is a vertical section of the Metering Chamber showing the arrangement of most of the internal conditioning system.

The walls of the Environmental Chamber will be comprised of polyurethane board insulation 48 cm (18 in.) thick covered internally with sheets of 3 mm (1/8 in) thick FRP and enclosed externally in a plywood/FRP casing. The conditioning equipment for this chamber is outside the chamber. The interior of the Environmental Chamber is also divided into upper and lower plenums connected to a supply and return duct system and direction dampers which allow the air to flow either upward or downward over the test wall. This chamber is also fitted with a movable baffle, with attached air diffusers, serving the same functions previously described for the Metering Chamber. Fig. 3 shows some of the details of the air circuit in the Environmental Chamber.

The external conditioning equipment consists of a refrigerating unit, absorption type humidifier and dehumidifier unit, a fan and two electric resistance heaters in an insulated duct system which also contains a flowmeter. This system supplies the conditioned air to the Environmental Chamber for an air curtain velocity of approximately 0.4 m/sec (80 ft/min). When higher air curtain velocities are required, a second, larger variable-speed fan will recirculate air from the return to the supply duct, while the conditioning equipment described above removes heat and moisture from the recirculated air stream for winter conditions and adds heat for summer conditions.

Performance specifications will be used for instruments and equipment where-ever possible. When a specific proprietary product is required to attain the required performance, some source justification will be prepared. Tolerances for all of the measuring equipment and for the chamber design have been selected, but these have not been presented in this paper because of space limitations.

Two test frames are to be furnished, 0.3 m and 0.6 m (12 in. and 24 in.) thick to accommodate different wall constructions. The frames will be polyurethane board built up to 0.45 m (18 in.) thickness at top and bottom and 1.07 m (42 in) thickness on the sides so that the frames will match the exterior dimensions of the two chambers. The inner surfaces of the frames will be covered with FRP sheets 3 mm (1/8 in.) thick and neoprene sponge-rubber gaskets 13 mm (½ in thick. The frames can be disassembled to facilitate fitting of wall specimens into the frames. This feature is discussed later.

The calibrated hot-box apparatus has been designed for walls of the size, weight, thickness and thermal resistance shown in Table 2. The Table also shows the maximum air leakage and moisture transfer rates and the static-pressure difference which has been provided for in the design of the auxiliary equipment.

5.0 Range of Operating Conditions for the Two Chambers

Table 3 summarizes the ranges of dry-bulb and dew point temperatures, diurnal temperature amplitudes, rates of temperature change, velocity of the air in contact with the wall specimen and the maximum heat input and removal rates for both chambers.

6.0 Special Design Features

Several special features were designed for the NBS calibrated hot-box so as to permit more accurate measurement of the heat energy passing through a test specimen and to increase the range and versatility of the apparatus. Some of the more important features are briefly described below.

6.1 Reverse Heat Loss Through the Metering Chamber

As previously mentioned, the five sides of the Metering Chamber will be water-jacketed. The temperature in the water jacket will be controlled at approximately the same temperature as the air temperature within the Metering Chamber so as to minimize the reverse heat loss of the chamber.

When testing a wall specimen of maximum thermal resistance, $R = 8.8 \frac{m^2 \cdot °C}{W}$ ($R = 50\ ft^2 \cdot °F \cdot hr$), it will be necessary to operate the Metering Chamber at a temperature appreciably above the laboratory ambient for some tests to augment the total heat flow through the specimen. By circulating a relatively large volume of water through the water jacket, the temperature of the water can be kept within a degree or two of the mean air temperature in the Metering Chamber, thus reducing the heat transfer through the Metering Chamber insulation to a small percentage of that passing through the test specimen.

Arrays of matched heat flow meters are to be affixed to the inner wall surfaces of the Metering Chamber and the Environmental Chamber and arranged so each meter represents approximately an equal surface area. By connecting the heat flow meters in series, the total output of each array should correlate well with the total heat flow rate into the five sides of the corresponding chamber even if they do not provide an absolute measurement of the total heat flow during steady state tests. This feature will be especially important for night setback tests when the temperature of the Metering Chamber is operated in a dynamic mode.

6.2 Flanking Heat Loss

The test frame which surrounds the wall specimen during a test must be sufficiently strong to prevent excessive deflection for the heaviest specimen. The bottom section of the frame must not be stressed sufficiently to damage the FRP facing or to permanently deform the foamed polyurethane insulation underneath. Since testing of dense concrete walls is contemplated, suitable small wooden compression members will be embedded in the polyurethane insulation in the bottom member of the frame to carry the major part of the weight loading. However, these wooden columns have insulation placed on both the hot and cold sides to limit the flanking effect for heat flow.

The FRP facing which serves as an inner wearing surface on all faces of the specimen frame has a relatively high thermal conductivity and thus serves as a flanking path for heat transfer relative to the test specimen. By limiting this facing material to 3 mm (1/8 in.) thickness, the total heat flow through the aggregated area of the FRP facing material is reduced to approximately one to two percent of the heat transfer through a highly insulated wall specimen.

Fitting a wall specimen into a one-piece test frame at the sides and top of the frame presents an additional opportunity for flanking heat loss through the small air gaps between the wall specimen and the faces of the frame. Air leakage can be prevented by a surface sealant at this joint on each side of the test specimen; however, it is difficult to completely fill air gaps for some types of constuction.

The NBS frames have been designed in four pieces and are to be fitted with thin neoprene sponge-rubber gaskets on the inner face to reduce the variable character of this flanking heat path. After building a wall specimen on the base of the frame, the sides and top of the frame will be placed in contact with the edges and top of the wall. The gaskets will be compressed slightly by the use of tension banding around the entire frame plus additional compression members. The total flanking heat loss due to the FRP facing and the neoprene gaskets is expected to be on the order of 4% to 5% of the heat transfer through the well-insulated test wall.

The absolute value of the flanking heat transfer and its percentage relationship to the heat transfer through the test specimen will vary with the thickness, composition,and thermal resistance of the test wall and also with the temperature differences between Metering Chamber, Environmental Chamber and laboratory ambient. A finite difference model of this flanking heat transfer region is needed to guide the experimental evaluation of this flanking heat loss and to provide a basis for calculating such losses which are not amenable to good experimental verification.

6.3 Air Flow Pattern at Wall Surfaces

Discussion with the operators of other calibrated hot-boxes indicates that the direction and velocity of the air approaching a test wall will be of importance when studying composite walls containing doors or windows. The NBS apparatus was designed so the direction of flow will be compatible with the direction of natural convection, i.e., downward in the winter and upward in the summer at the interior wall surface and just the opposite at the exterior wall surface.

Sectionalized and adjustable diffusers will be built into the top and bottom of the movable baffles located near the wall on both exposures. The multiple sections will allow adjustment to attain approximately a uniform velocity laterally across the wall. Adjustable vanes within the diffuser frames will permit the airstream to be directed downward at the top of the wall or upward at the bottom of the wall with limited impingement on the surface. In the Metering Chamber the air velocity at the diffuser openings will be adjustable from 0.25 to 0.81 m/sec (50 to 160 ft/min) by varying the fan speed. The velocity will be reduced to about one half these values as the air stream expands into the entire space between the test wall and the baffle. The range of air velocities at the wall surface in the Environmental Chamber will be from 0.41 to 4.1 m/sec (80 to 800 ft/min), equivalent to about 1 to 10 miles/hr.

This is one of several areas in which further effort toward standardization of test procedures is needed in the use of calibrated hot-boxes.

6.4 Air Infiltration

A separate conditioner is provided for the infiltration air for the NBS calibrated hot-box. When infiltration air is supplied to the Metering Chamber it will be conditioned as nearly as possible to the same temperature and humidity as that of the air supplied to the test wall. It will be introduced into the Metering Chamber ahead of the fan, flowmeter and the electric heater which is used to trim the supply air temperature to assure that the supply air is well mixed.

When the infiltration air is to be supplied to the Environmental Chamber, it is preconditioned to a dry-bulb temperature of about 10°C (50 F) in the infiltration air conditioner and then delivered to the inlet of the principal air conditioner to lower its temperature and moisture content to the selected conditions being maintained in the Environmental Chamber. When winter infiltration of cold dry air from the Environmental Chamber through the test wall into the Metering Chamber is being simulated, the humidifier in the Metering Chamber will have to be operated to maintain the desired relative humidity in the Metering Chamber.

In either case, the infiltration air is metered by a separate flowmeter before it is introduced into the hot-box. If the external duct system serving the Environmental Chamber cannot be made sufficiently airtight, the infiltration air passing from that chamber through the test wall can be measured where it is exhausted from the Metering Chamber.

When no static pressure difference is to be imposed on the test wall the infiltration air supply duct is disconnected and the Metering Chamber is made airtight. For some types of walls, especially those containing windows and/or doors, there will still be an exchange of air between the two chambers because of the temperature difference maintained across the test specimen. This exchange of air will be measured in the two chambers using a tracer-gas technique. By measuring the decrease in tracer-gas concentration in one chamber and the increase in concentration in the other chamber, the rate of air recirculation can be calculated. When the Metering Chamber is sealed for this type of test, a separate internal humidifier, designed to deliver measured amounts of moisture, will be used to maintain the selected levels of relative humidity.

7.0 Systems Control

The principal variables requiring control in the Metering Chamber are: (a) the dry-bulb temperature, dew point temperature, volume and velocity distribution of the air supplied at the face of the wall under tests; (b) the dry-bulb temperature, dew point temperature and flow rate of the infiltration air; (c) the pressure difference across the wall specimen; and (d) the supply temperature and flow rate of the water entering the cooling coil.

The volume of air circulated over the wall will be manually adjusted to provide a selected velocity, and the direction of vertical flow will simulate either winter or summer natural convection.

The dry-bulb temperature of the supply air will be controlled by a platinum resistance element, centrally positioned in the air stream approaching the wall. It will control the electric resistance heater in the supply duct and reset the temperature of the chilled water supplied to the cooling coil in sequence. The flow rate of chilled water will be determined by manually adjusting the speed of the metering pump in the chilled water circuit. The dew point temperature of the supply air will be controlled by a precision dew point hygrometer located in the air-supply duct downstream from the electric heater used to control the dry-bulb temperature. The dew point hygrometer will cycle delivery of moist air from the internal humidifier and modulate the pan temperature in the humidifier.

The flow of infiltration air will be measured by a positive displacement gas meter at the outlet of the infiltration air conditioner. The pressure difference between the Metering Chamber and the Environmental Chamber will be sensed by a differential-pressure transmitter through multiple ports in the baffles facing the wall. This device will modulate the pressure control valves in the house air supply lines.

The dry-bulb temperature of the infiltration air will be controlled by a platinum resistance element located at the outlet of the conditioner. It will control an electric resistance heater in the conditioner so as to deliver infiltration air to the Metering Chamber at the same temperature as the air supplied to the face of the wall under test. A dew point controller will be located at the outlet of the infiltration air conditioner. It will modulate the delivery of moist air into the airstream to provide the selected relative humidity of the supply air in the Metering Chamber.

The variables to be controlled in the Environmental Chamber are similar to those in the Metering Chamber, with a few exceptions. When summer dry-bulb temperatures are being simulated in the Environmental Chamber, the dew point temperature in the Environmental Chamber will be maintained at a value corresponding to approximately 50% relative humidity at the temperature of the Metering Chamber. This will preclude any possibility of condensation in the wall or in the Metering Chamber, and will permit the wall materials to come to an equilibrium moisture condition more promptly.

When the air circulation rate over the test wall in the Environmental Chamber exceeds about 0.52 m^3/sec (1100 cfm), the larger recirculation fan will be used and the offset between the dry-bulb temperature at the outlet of the air conditioner and the air supplied to the test wall will have to be increased to compensate for the mixing ratio while still permitting the electric resistance heater at the inlet to the chamber to provide the precision control of dry-bulb temperature.

8.0 Measurement Systems

The following physical parameters in three groups must be measured with known accuracy as a basis for evaluation of a wall specimen. The measurements in Group A are necessary if thermal transfer through an air impermeable specimen is the only transfer mode being studied; those in Group B are additionally necessary if thermal transmission and air leakage are both involved and no condensation nor evaporation of moisture is occurring in the hot-box or test specimen; and Group C must also be measured if humidity conditions are being controlled and moisture transfer and condensation are being investigated.

Group A

Average surface temperature and surface temperature distribution on both sides of the wall specimen.
Average air temperature adjacent to the test wall on both sides.
Average supply and exhaust temperature of air curtain, on both sides of the test wall.
Temperature of the chilled water entering and leaving the cooling coil in the Metering Chamber.
Water temperature at inlet and outlet of the water jacket of Metering Chamber.
Average temperature of the inside wall surface of the Metering Chamber.
Average Laboratory air temperature around the hot-box.
Distribution of velocity in air curtain in both chambers.
Integrated heat-transfer rate indicated by the heat flow meters on the walls of both chambers.
Air flow rate at entrance to supply plenum in both chambers.
Chilled water flow rate to the cooling coil in the Metering Chamber.
Air exchange rate between chambers due to stack effect.
Average electric power consumption of reheater in the Metering Chamber.
Average electric power consumption of the vaneaxial fan in the Metering Chamber.

Group B

Infiltration air temperature at entry to either chamber.
Infiltration air temperature at the exhaust from either chamber.
Infiltration air flow rate to either chamber.
Static pressure difference across test wall.

Group C

Dew point temperature of air at supply and exhaust of both chambers.
Dew point temperature of infiltration air at entry to either chamber.
Dew point temperature of infiltration air at exhaust from either chamber.
Electric power supplied to humidifier in Metering Chamber.
Average water evaporation rate from humidifier in the Metering Chamber.
Change in moisture content of elements of the wall specimen.

Calibrated thermocouples and thermistors will be used for measuring air and water temperature, and calibrated thermocouples will be used to measure surface temperatures. Apparatus for measuring the dew point temperature with a thermoelectrically cooled mirror will be used to measure the dew point temperature of supply and return air in both chambers and of the infiltration air. The electric energy used by fans, blowers and resistance heaters will be measured with watt-hour meters equipped with impulse generators. Variable speed metering pumps will be used to measure water flow rates. The air flow rates in the two chambers will be measured using commercial flowmeters employing manifolded pitot tubes with symmetrical averaging. The infiltration air flow rate will be measured with a positive displacement gas meter. High-resolution pressure transducers will be used to measure the static pressure difference across the test wall and the air flow meters. The heat flow meters will be of the high sensitivity type and will be calibrated. The velocity distribution in the air curtain will be measured with a traversing hot-wire anemometer. The air exchange between the two chambers caused by stack effect will be determined by a tracer-gas technique using sulfur hexafluoride as the tracer gas. The moisture content of the wooden components of wall specimens will be monitored by the electric resistance of a wood moisture meter. The moisture content of other materials will be determined by coring at selected stations after controlled exposure to conditions that might cause condensation. The total moisture gain of a test wall will be determined by the difference in the moisture given up by the air on the high humidity exposure and that absorbed by the air on the low humidity side. The fractions of the total moisture gain represented by condensation and by change in the absorbed moisture in the materials can only be approximated.

A 300-channel data acquistion system which can accommodate voltage signals various ranges and dry contact closures, which can perform selected data reductions, and provide hard copy documentation, has been procured for the apparatus. The data acquistion system is capable of producing printed paper tape from an onboard printer, and will also interface with incremental magnetic tape and a minicomputer.

At least eleven of the measurements in Group A, identified above, will be involved in determining the accuracy of the thermal resistance reported for a given wall specimen. Since the flanking heat loss around the test specimen cannot be measured directly, the value determined by difference will tend to include the uncertainty in all of the other energy measurements. At least twenty measured parameters will be involved in evaluating the results of any test that includes heat, air and moisture transfer. This suggests the importance of developing a good error analysis procedure, a good mathematical model for the flanking heat transfer and the best practicable procedure for calibrating this type of hot-box.

The NBS specifications will be ready for request of a construction contract during the spring of 1980. The experience of others suggests that construction will require six to eight months after finalizing a contract.

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ACKNOWLEDGMENTS

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Table 1

Climatic Conditions to be Simulated

SEASON	Transmission Phenomena					
	Thermal		Air		Moisture	
	Direction[a]	SS or Dyn[b]	Direction[a]	SS or Dyn[b]	Direction[a]	SS or Dyn[b]
Winter	Out	S.S	None[c]		None[d]	
Winter	Out	Dyn	None		None	
Summer	In	S.S.	None		None	
Summer	In	Dyn	None		None	
Winter	Out	S.S	Recirc[e]	S.S	None	
Summer	In	S.S	Recirc	S.S	None	
Winter	Out	S.S	Recirc	S.S	Out	S.S
Winter	Out	Dyn	Recirc	Dyn	None	
Summer	In	Dyn	Recirc	Dyn	None	
Winter	Out	S.S	In	S.S	None	
Winter	Out	S.S	Out	S.S	None	
Summer	In	S.S	In	S.S	None	
Summer	In	S.S	Out	S.S	None	
Winter	Out	Dyn	In	S.S	None	
Summer	In	Dyn	In	S.S	None	
Winter	Out	Dyn	Out	S.S	None	
Summer	In	Dyn	Out	S.S	None	
Winter	Out	S.S	Out	S.S	Out	S.S
Winter	Out	Dyn	Out	S.S	Out	S.S

a. "In" and "Out" refer to the direction of heat, air, or moisture transfer as viewed from the Metering Chamber.

b. "S.S" stands for steady-state. "Dyn" means dynamic or variable.

c. "None" means no static pressure difference across the specimen

d. "None" means that no vapor pressure difference will be maintained across the specimen.

e. "Recirc" means two-way flow of air can take place through some wall specimens due to stack effect.

Table 2

Physical Characteristics of Hot-Box Wall-Tester

Wall Specimen Size	3.0 x 4.5 m	(10 x 15 ft)
Thermal Resistance Range	0.35 to 8.8 $\frac{m^2 \cdot {}^\circ C}{W}$	(2 to 50 $\frac{hr \cdot ft^2 \cdot {}^\circ F}{Btu}$)
Specimen Weight per unit area (max)	700 kg/m^2	(150 lb/ft^2)
Specimen Thickness (max)	0.6 m	(24 in.)
Air Leakage Rate (max)	255 m^3/hr	(150 cfm)
Moisture Transfer Rate (max)	1.4 kg/hr	(3 lb/hr)
Static Pressure Difference (max)	125 Pa	(0.5 in W.G.)

Table 3

Range of Operating Conditions for Hot-Box Wall-Tester

Parameter		Metering Chamber	Environmental Chamber
D.B. Temperature Range	°C F	10 to 65 (50 to 150)	-40 to 65 (-40 to 150)
D.P. Temperature Range	°C C °F F	4.4 at 10 DB 20 at 24 DB and above (40 at 50 DB) (68 at 75 DB and above)	-43 at -40 DB 20 at 24 DB and above (-45 at -40 DB) (68 at 75 DB and above)
Diurnal Temperature Amplitude (max)	°C F	17 (30)	56 (100)
Rate of Temperature Rise at 27 °C (min)	°C/hr F/hr	11 (20)	11 (20)
Rate of Temperature Decrease at -7 °C (min)	°C/hr F/hr	8 (15)	8 (15)
Heat Input Rate (max)	kW Btu/hr	7.3 (25,000)	12.3 (42,000)
Heat Removal Rate (max)	kW Btu/hr	6.4 (22,000)	12.3 (42,000)
Velocity of Air Curtain	m/sec ft/min	0.25 to 0.75 (50 to 150)	0.41 to 4.1 (80 to 800)

AXONOMETRIC VIEW OF CALIBRATED HOT-BOX

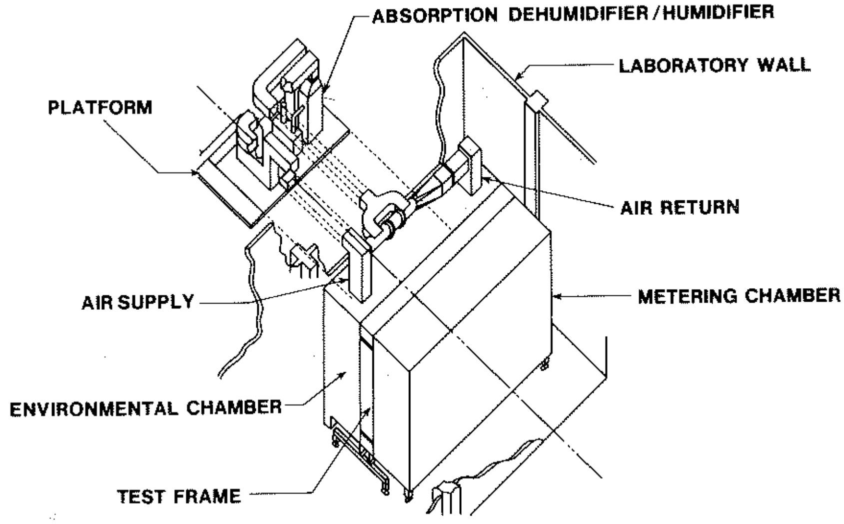

Fig. 1

METERING CHAMBER SECTION

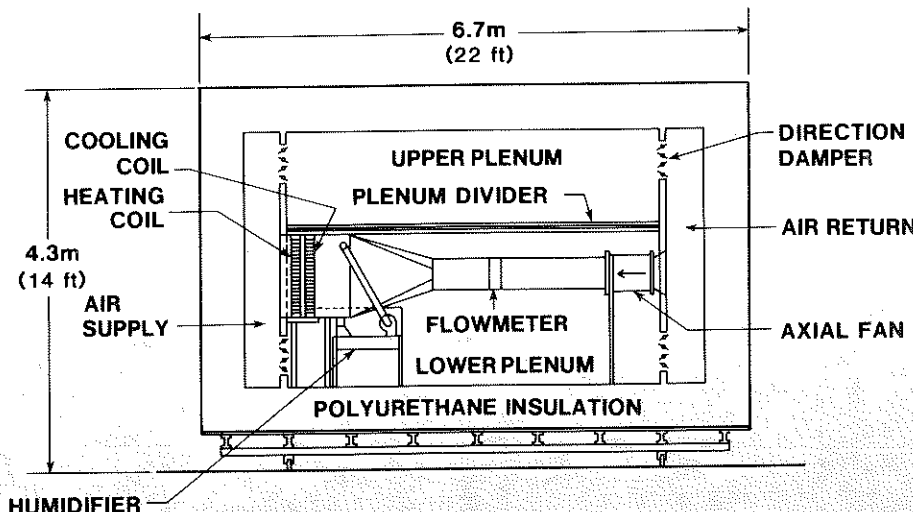

Fig. 2

ENVIRONMENTAL CHAMBER SECTION

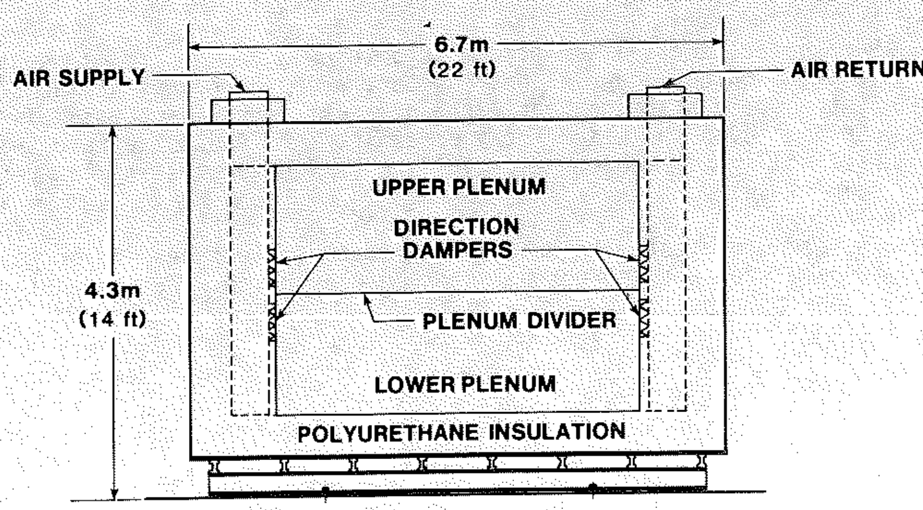

Fig. 3

Session III - Question and/or Comment

Fiorato and Cruz

a. Harry W. Fowler, Thermtron Products

Q. Have any tests been done to show the affects of air infiltration through an insulated stud wall on the "R" Value composite of that wall? Also, if these tests have been done, have they ever compared various types of insulating materials? For example, 3½" F.G. Batt vs. 3½" cellulose fiber in regards to comparative "R" Value loss due to infiltration.

A. We have not conducted tests to evaluate effects of air infiltration. However, tests have been conducted by Owens-Corning Fiberglas on Wood Frame Walls. Pressure differentials between chambers were used to induce air leakage. Results are published in the following reference:

"Acoustical and Thermal Performance of Exterior Residential Walls, Doors, and Windows," by H.J. Sabine and M.B. Lacher, NBS Building Science Series 77, U.S. Department of Commerce, National Bureau of Standards, November, 1975.

b. Morton Sherman, Jim Walter Research Corporation

Q. Has the calibration sample used in your program been validated over the entire design R-Value range for your facility, and if so, was this accuracy and precision/reproducibility validation accomplished in the guarded hot box test mode? What are the results of this full R-Value range validation?

A. We are in agreement with concern for calibration over the entire R-Value range. Work on the high R-value range (15 _ R _ 20) is planned. However, one problem with calibration in this range has been the development and characterization of a suitable sample material. Work on this problem is currently in progress with the ASTM/NBS/DOE round robin program on calibrated hot boxes.

c. A. Arranz Lopex, INCE-MOPU

Q. We'd much appreciate to receive as soon as possible full and detailed information of the equipment described in your conference as well as measurements monitored with a digital data acquisition system interfaced with a mini-computer. Thank you very much in advance.

A. A preprint of the paper has been sent to Mr. Lopez.

d. Uyttebrueck, CSTC

Q. Due to the parallel air stream in both cold and hot rooms the thickness of the boundary layer is not constant over the height of the sample. By that fact also the heat exchange coefficients (superficial) are not constant over the height of the sample. Are you not afraid that this fact will give problems especially when you are testing low resistance samples (windows)?

A. In specimens tested to date, significant differences in air-to-surface temperatures with height have not been observed. We have not evaluated window samples.

e. Achenbach, NBS

Q. Did your calibration procedure take into account flanking heat loss from hot to cold side around the test specimen? Your slide showing equal temperatures on the two sides of the specimen suggests that flanking heat loss was not included in Qo.

A. Flanking heat loss may contribute to part of the discrepancy between results obtained by the calibrated hot box and those obtained by the guarded hot plate and heat flow meter as shown in Figure 7 of the paper. We have not yet attempted to quantify this contribution.

f. Lewis, Florida Power Corporation

Q. Have you done any study of the effectiveness of filling core of block with insulation material? What results to additional R-value for total wall assembly were attained?

A. We have some data on block walls and block-brick cavity walls filled with perlite loosefill insulation. These are in the following reference:

" Thermal Performance of Masonry Walls," by A.E. Fiorato and C.R. Cruz, Proceedings of the Fifth International Brick Masonry Conference, Washington, D.C., October 1979.

A preprint of this publication has been sent to Mr. Lewis. Additional material is available in the following publications:

" Heat Transmission Coefficients of Concrete Block Walls with Core Insulation," by L.S. Shu, A.E. Fiorato and J.W. Howanski, Proceedings of the DOE/ASHRAE Conference on Thermal Performance of Exterior Envelopes of Buildings, Orlando, Florida, December 1979.

" Calculation of U-Values of Hollow Concrete Masonry," by R.C. Valore, Journal of the American Concrete Institute, February, 1980.

J.L. Rucker and J.R. Mumaw

a. Morton Sherman, Jim Walter Research Corporation

Q. We have found reason for concern that low R Value calibration standards may not be adequate for calibrated hot box tests run on very large R Value test specimens.

A. Your concern about the application of high R calibration samples is currently being discussed in ASTM C-16 which is struggling to develop a test method for this type of apparatus. The complexity of the problem emphasizes the need to understand the mechanisms of heat flow before construction and calibration of a calibrated hot box facility is undertaken. Choosing the proper calibration specimen and procedures is very important and I feel these must be tailored to each specific test device being operated. Unfortunately the need for high R calibration specimens is not the only answer and proper calibration must be coupled with detailed analysis before accurate calibration is obtained.

Q. Has the calibration sample used in your program been validated over the entire design R value range for your new horizontal mode facility, and if so how was this accuracy and precision/reproducability validation accomplished? What are the results of this validation?"

A. The Calibration Hot Box design used in the construction of OCF's Horizontal Facility is quite different from the design used in most vertical heat flow devices. This difference was caused by the requirement to test samples such as an entire attic which has construction details extending beyond the 14 X 20 defined dimensions of the metering chambers. In OCF's device, the sample boundary is defined as the top of the pit walls which supports the sample. By design, the boundaries at the samples are identical for all tests independent of R value or thickness to be run in the facility. The calibration for this facility easily can be performed once the flanking loss is independent of sample thickness as opposed to the more typical box where this loss is dependent on sample thickness. Once the thickness effect was eliminated, the calibration is performed as a function of the thermal flux level rather than the thermal resistance of the calibration sample. Thus by performing many tests at different temperature differences and mean temperatures, an accurate calibration can be performed with one sample using regression analysis of the data.

Q. Has this sort of validation also been accomplished on your original vertical mode calibrated hot box facility? If so, how was this done and what are the results of this validation?

A. Flanking loss in the standard configuration calibrated hot box can cause significant errors in test results and therefore a correction term must be developed for the data analysis. The magnitude of these losses is a function of the hot box design and thus each facility must be treated differently. In the OCF hot box, the analysis and calibration tests performed thus far have confirmed this error to be on the order of tests 3-5 percent for an R-11 frame test wall. Fortunately, in our facility this error is on the conservative side and correction will increase the reported R value for the wall. To date we have completed the calibration work for the initial thickness calibration sample. In this facility, as opposed to our vertical heat flow facility, the modeling indicates a thickness dependency of this flanking correction. We are therefore relying on the modeling analysis to extroplate our data on the single calibration sample to thicker walls until such time later this year when we can construct and schedule a thicker wall calibration sample. Based upon our model estimates, the error induced by using this interim procedure will be small (less than 2%) for the test samples which we will be testing in the next 12 months.

Brown & Schuyler

a. Yuill, UNIES, Ltd.

Q. Did you consider the possibility of direct radiative transfer from the heater to the wall? How do you assure that the free convection is similar to that on the rest of the surface?

A. The heat transfer through an opaque wall is governed by the temperature at the warm and cold surfaces. The three modes of heat transfer (conduction, convection and radiation) are only important within the calorimeter in that the combination must produce a temperature on the wall inside the calorimeter which matches that on the rest of the surface. Thus, there is no need to assume that the free convection inside the calorimeter is the same as that outside as long as the surface temperatures match. In the case of the heater in this calorimeter, it is a low temperature one and the direct radiative transfer is relatively small.

b. Burch, NBS

Q. How was the calorimeter sealed to the wall?

A. In attaching the calorimeter to the wall, it was first strapped to the wall and then the contact edges were taped.

Bryson

a. R.P. Tye, Dynatech R/D Company

Q. The results of measurements on proficiency samples are extremely important to ASTM Committee C-16 for developing accuracy and precision statements in their Specification. Will these results be released and discussed with members of ASTM C16.30 in order to assist with the development of such accuracy and precision statements relating to the different standard test methods?

A. Yes. We regard the development of accuracy and precision statements for test methods where they do not now exist as extremely important to our program and to the testing laboratory community in general. Our project leader for the Thermal Insulation Laboratory Accreditation Program is Dr. Diana Kirkpatrick, who is a member of ASTM Committee C16. The results of measurements on proficiency samples will be made available to this committee by Dr. Kirkpatrick.

b. R.W. Gerrish, Pittsburgh Corning

Q. Since the ASTM Standards are continually being revised, what mechanism is there to insure that the accredited laboratories are conforming to the newly revised standards?

A. Laboratories are required by NVLAP to follow the procedures of most current standard test methods for which they have been accredited, and to make all changes necessitated by the revision of the standard test method within 45 days of the official notice date or by the effective date, whichever is later. The scheduled on-site inspections coupled with unannounced on-site inspections for as many as 1/3 of the laboratories randomly selected is the principal means for determining whether the laboratories are conforming to the most recent standards.

c. A.Arranz Lopez, INCE-MOPU

Q. Information on requirements that must comply. Labs on Thermal Insulation would be most valuable for the accreditation program we have in our country. The area on Thermal characteristics at lab level, is still in its beginnings in Spain. We have developed safety requirements and acoustics mainly. Thus, our interest in thermal for qualifying Accredited Lab. is most essential.

A. The criteria against which the labs are judged for accreditation under this program falls into two categories - general criteria and specific criteria. The general criteria includes characteristics that should be found in reputable testing laboratories, they include general information about a laboratory (such as name, address, ownership, management structure); conditions that must be met for accreditation (such as agreement to adopt certain policies); and the maintenance of a quality control or a laboratory operating manual (such as written procedures and information addressing the control of staff, physical plant operational processess, testing control procedures and quality assurance) for use by laboratory staff in the laboratory.

The specific criteria are those requirements for accreditation which relate specifically to individual test methods. Even so, universal language is used and some portions of the specific criteria may not be applicable to all test methods. For the particular test methods for which accreditation is sought, "Supplemental Information" will be sent to each applicant laboratory showing how the specific criteria relates to each of the test methods. The general and specific criteria for the thermal insulation laboratory accreditation program was just recently published, and I will be most happy to send you a copy.

B. Rennex

a. B.V. Karlekar, Rochester Institute of Technology

Q. What kinds of commercial insulations belong to the type investigated and up to what thickness?

A. The theoretical study applies to any commercial insulation for which there is a significant radiation and conduction heat transfer component and a negligible convection heat transfer component.

Q. If for a porous insulation such as fiberglas, the effective k-value is determined experimentally, what is the need for differentiating between real k-effect and radiation effect?

A. In order to make predictions of the combined k as the conductive or radiative parameters are indepently varied, one must describe the two heat flow modes separately.

Perrin, Linehaw, Howanski, and Shu

a. Vyttenbrueck, CSTC

Q. Are you measuring U-values or thermal resistance between the inside and outside face of the sample. If you are measuring U-values, how do you come to the real U-value which you can use in the building? Instead, in the laboratory test, the air velocity on the inside is much higher than in normal room. If you are measuring Thermal Resistance you need to know the surface temperatures. This can be relatively easy with a homogeneous sample. But how are you doing it with a sample with thermal bridges (for instance, in the case of a window)?

A: The equipment utilized in all of the units Wiss, Janney, Elstner and Associates, Inc. (WJE) has built can be used to record both air and surface temperatures. When air to air temperatures are recorded, it frequently is necessary to process the data to determine the performance which would be obtained with air velocities beyond the limits of the equipment supplied. For specimens with plane surfaces, the calculations can be quite precise. When specimens contain doors, windows or other irregularities, the method is less satisfactory.

When surface temperature measurements are utilized, similar problems are generated by thermal bridges. The non-uniform surface temperatures are frequently too complicated to be completely analyzed even if tens of thermocouples are employed.

As you point out, a window presents a difficult problem. It has thermal bridges, and it does not have a flat surface. It would be possible to build equipment which would be especially suited for window heat loss testing. By increasing the fan capacity for the "outside" air the effects of the non-plane surface in higher wind velocities could be more closely duplicated. Also, air flow on the inside might be modified. A lower air flow would result in a higher temperature gradient from top to bottom, but the "still air" condition would be more closely duplicated.