A WALL AND EDGE GUARDED HOT BOX FOR FENESTRATION TESTING

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EXTENDED ABSTRACT

General Description

A unique guarded hot box that incorporates several new design concepts from guarded hot plates, namely wall and edge guards, is described in detail. This new approach to the guarded hot box, originally developed by the National Physical Laboratory in the United Kingdom (Williams 1992), operates in a manner similar to a conventional guarded hot box, but with improved temperature and power control. The wall and edge guarded hot box was built to meet the test methodologies specified in the American Society for Testing and Materials' (ASTM) Standard Test Methods C 236-89, "Standard Test Method for Measuring the Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box" and C 1199-91, "Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods." The new hot box is used to determine the thermal performance of fenestration systems (windows, doors, skylights, etc.) according to National Fenestration Rating Council (NFRC) Standard 100-91, "Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values)." The wall and edge guarded hot box improves the heat transfer measurement accuracy using three systems: a wall plate heater system, a wall heat flowmeter (heat flux transducer) system, and a linear temperature gradient edge guard system.

The test facility is rotatable, with the ability to provide upward or horizontal heat flow. Both the climatic and metering chambers provide variable air velocities parallel to the specimen surface. An external refrigeration system is used to condition the climatic chamber, which is capable of maintaining a minimum air temperature of -10°F. The following is a summary of the operating characteristics of the test facility.

Test specimen area dimensions: 8 ft by 8 ft (maximum)
Test specimen thickness: 1.5 ft (maximum)
Metering area: 8 ft by 8 ft
Climatic Chamber:
- *air temperature range: 100 to -10°F*
- *air velocity: 0.5 to 15 mph*

Metering Chamber:
- *air temperature range: 35 to 120°F*
- *air velocity: 0.5 to 5 mph*

Chamber Construction

The climatic and metering chambers have interior and exterior surface dimensions of 34 in. by 96 in. by 96 in. and 48 in. by 110 in. by 110 in., respectively. Each chamber is structurally supported by an internal aluminum angle frame. All corner joints were mitered and welded to maintain tolerances of ± 1/16 in. Poplar hardwood strips, through-bolted to the outside surface of the framing members with stainless steel fasteners, provide a mounting surface for the exterior plywood cladding. The 3/4-in. plywood is attached to the hardwood with adhesive and screws. All potential thermal bridges are thermally isolated from the aluminum frame with bolt sleeves with a nonstick coating and nylon washers. Additionally, all joints and penetrations are sealed internally and externally with a silicon caulk. Exterior metal stiffeners and the plywood cladding maintain the chambers' structural rigidity.

The chamber walls are insulated with approximately 3 in. of rigid, aluminum-foil-faced polyisocyanurate thermal insulation board placed inside the aluminum frame. The enclosure formed between the plywood and the aluminum frames are insulated with 11/2-in.-thick, 3-pcf fiberglass batt. Flat black painted aluminum sheet is adhered to the insulation boards to complete the chamber's interior surfaces. All joints and penetrations are sealed both internally and externally with a silicon caulk. Medium-density, closed-cell rubber covers the chamber and test section mating surfaces to provide an air-sealing mechanism.

Climatic Chamber Design

Three connected plenums were created with an aluminum frame assembly and a movable, insulated baffle in the climatic chamber. The climatic chamber is conditioned by circulating air through an external refrigeration system with a 2.5-ton cooling capacity. The system is optimized by using hot gas by pass valves to maintain constant air temperature control. The chilled air is supplied to the central plenum and returned from the upper plenum through two flexible, insulated ducts. A 4.5-kW electric air reheat system, mounted at the supply entrance orifice, also may be used to control the chamber air temperature. Air is returned to the refrigeration system mixing chamber through a slotted, circular, plastic duct located in the upper plenum,

mounted to the chamber exit orifice. The duct extends the length of the plenum to ensure uniform air removal from the chamber.

Forced parallel airflow is supplied to the space between the baffle and the test specimen by a controlled blower located in the central plenum and rated at 3,800 cfm with 1 in. of static pressure. Air is circulated from the central plenum by the blower, through a duct, to the lower plenum. Deflector plates and a perforated aluminum sheet mix and distribute the air throughout the lower plenum. The air supply, now uniform, exits the lower plenum through the lower baffle exit orifice and enters the space between the baffle and the test specimen. Air is returned to the upper plenum through the upper baffle entrance orifice and enters the central plenum through openings at each end of the chamber width to complete the closed flow path.

Metering Chamber Design

The metering chamber was designed to maximize power and temperature control, while minimizing extraneous heat transfer losses between the metering area and the conditioned laboratory space. The unique use of various DC power supplies with a wall plate heater system, a wall heat flowmeter system, a resistance wire air heater system, and circulating air blowers accomplishes this task.

The metering chamber's wall plate heater system consists of 12 1/4-in.-thick aluminum plates bolted to the chamber's internal aluminum frame, each uniformly covered with thin-film heaters. Four plates are located on the back wall and two plates are located on each of the four sidewalls. Power is supplied to the heater plates by two 100-W DC power supplies, with control divided between the top half and bottom half six plates.

The wall guard plates are insulated with approximately 3 in. of rigid, aluminum-foil-faced polyisocyanurate thermal insulation board placed on the face of the heater plates. Twenty-gauge aluminum sheet, with 1/8-in.-thick rubber material adhered to one surface, is attached to the exposed interior insulation board surface.

Twelve heat flux transducer boards were fabricated with 1-in.-thick, 3-pcf expanded polystyrene insulation material and type-T, 30-gauge thermocouple wire. The temperature sensors were symmetrically arranged and adhered to the boards at an average density of 1.6 sensors per square foot. The boards were placed against all interior chamber wall surfaces. Voltage signals produced by each board are connected in series to generate the heat flowmeter system's voltage output. The boards are protected by a second layer of 1/8-in.-thick rubber material backed by the interior aluminum sheet. The assembly is secured in place with nylon bolts through-fastened to the opposing aluminum sheet.

Blower and air heater assemblies were mounted on a removable aluminum frame that is positioned inside the metering chamber. The frame is secured in place with threaded nylon rods through-fastened to the back aluminum plates. Both the resistance wire air heater system and the five blowers span the entire width of the chamber to provide uniform airflow and temperature across the test specimen surface. The blowers and the resistance wire heater system are supplied with 100-W and 1,800-W controllable DC power supplies, respectively. A series of baffles, attached to the frame, direct the airflow from top to bottom to create uniform, natural convection conditions.

Test Section Design

The test sections were designed to maximize the metering surface area while minimizing specimen flanking heat transfer through the utilization of the linear edge guard system. Frames were constructed using 3/4-in. plywood assembled in a U-channel configuration. The channels were filled with aluminum-foil-faced polyisocyanurate thermal insulation board and enclosed with stainless steel plates, screwed into the plywood. This construction is identical for test sections of both the 6-in. and 12-in. widths.

Four 96-in.-long, 1/8-in.-thick stainless steel plates were required for each test section. Resistance wire heating elements, encased in insulating electrical tape, were adhered to the underside metering chamber edge of the stainless steel plates. One resistance strip heater is utilized for the horizontal plates and two are used for the vertical plates, separated at the midpoint. Power is supplied to the edge guard heaters by two 100-W DC power supplies, with control divided between the top half and the bottom half resistance wire heating elements.

Chamber Instrumentation and Control

Measurements of air and surface temperatures, velocity, humidity, pressure, and baffle surface temperatures are incorporated into both chamber designs. Proportional-integral-derivative (PID) temperature controllers with resistance temperature detector (RTD) sensors are used to control air temperatures. Graphically displayed, real-time temperature measurements, generated by the personal-computer-based data-acquisition system, are used to fine tune the controller settings.

The metering chamber wall plate heater system's control is accomplished by two PID controllers. An RTD sensor placed at the center of the back, bottom, right heater plate generates the signal used to set the bottom half heater plate temperature controller. A differential thermopile, placed at the centerline between the top and bottom half heater plates, generates the signal used to set the top half heater plate differential millivolt controller. Identical symmetric arrays of type-T, 24-gauge thermocouple sensors are permanently attached to both the aluminum plate and interior aluminum sheet surfaces. The information from the above sensors and the output voltage signal from the heat flowmeter system, graphically displayed in real time by the personal-computer-based data-acquisition system, are used to fine tune the controller settings. The system is set up to minimize and account for any extraneous metering chamber wall heat transfer that may exist.

The test section linear edge guard heater system is controlled by two PID differential millivolt controllers. Two thermopiles generate the signals used to set the top and bottom half resistance wire heater element controllers. Differential thermocouple pairs are placed on the stainless steel plate's top surface, directly above the heating element, and the test specimen surface, perpendicularly four inches above the plate. The plate edge temperature is *controlled to match the test specimen surface. The opposing climatic chamber air conditions cause the exposed stainless steel plate to closely match the test specimen surface. Since both chamber test specimen surface temperatures are closely matched by the stainless steel plate, the linear temperature gradient through the test specimen is also matched, minimizing the specimen flanking heat transfer losses.*

REFERENCES

Willisms, R.G. 1992. A new approach to the measurement of thermal transmittance; the NPL wall guarded hot box. Teddington, U.K.: National Physical Laboratory, Division of Quantum Metrology.

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