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Heat Exposure Measurements in Fire Resistance Wall and Floor Test Furnaces

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ABSTRACT

This paper presents the results of 12 heat exposure tests: 6 in standard, full-scale wall and floor furnaces, and 6 in non-standard, intermediate-scale wall and floor furnaces. These tests were conducted to investigate the effect of full-scale furnace depth (wall and floor furnaces), furnace size (full-scale and intermediate-scale furnaces) and furnace orientation (intermediate-scale wall and floor furnaces) on the heat exposure.

The results showed that, the difference in heat exposure in full-scale floor and wall as well as in the intermediate-scale floor and wall furnaces is 5% and 4%, respectively. However, the heat exposure in an intermediate-scale wall and floor furnace is higher than in full-scale wall and floor furnaces by 18% and 15%, respectively.

KEYWORDS: fire resistance, furnace, wall, floor, full-scale, intermediate-scale, heat exposure

INTRODUCTION

Fire-rated floor and wall building systems formed with new materials and designs have been increasingly used in residential and non-residential buildings. To determine the fire resistance performance of these systems, full-scale tests are required. However, these tests are expensive and time consuming and there is a need by building designers and architects, at least in the initial design stage, to find an alternative solution. To satisfy this need, the National Research Council of Canada (NRC) has been developing simpler and less expensive tests and models to assess the fire resistance of building systems such as walls and floors. Along with these efforts, NRC has completed the construction of an intermediate-scale furnace, 1.2 m wide by 1.8 m long by 0.5 m deep, that can be used for testing loaded and unloaded wall and floor systems. However, to ensure that the intermediate-scale furnace can be used to reflect full-scale test results, it must be characterized in relation to a full-scale furnace. Heat exposure in fire resistance test furnaces is one of the critical parameters in determining the fire resistance performance of building systems. A number of investigations of fire exposure in standard fire resistance test furnaces were carried out by Sultan et al[1] and by Cooke[2]. To characterize the heat exposure for an intermediate-scale furnace in relation to a full-scale furnace, a number of parameters need to be investigated such as the effect of full-scale furnace depth (wall and floor), furnace size (full-scale and intermediate-scale) and intermediate-scale furnace orientation (vertical or horizontal) on the heat exposure. This paper presents the results of heat exposure conducted at the NRC on 6 full-scale and 6 intermediate-scale specimens to investigate the heat exposure in an intermediate-scale and full-scale furnaces.

Comparisons of heat exposure in a full-scale and intermediate-scale fire resistance test furnace were conducted to address the effect of furnace size on the heat exposure to wall and floor surfaces. In addition, comparisons of heat exposure in full-scale and intermediate-scale for both wall and floor furnaces were conducted to address the effect of furnace depth and orientation on heat exposure. The results reported in this paper can also be used as data for the development of fire resistance models for floor and wall assemblies.

EXPERIMENTAL WORK

This experimental study was carried out at the National Research Council of Canada using full- and intermediate-scale wall and floor fire resistance furnaces. Heat exposure experiments include: 3 repeat tests using the full-scale floor furnace, 3 repeat tests using the full-scale wall furnace, 3 repeat tests using the intermediate-scale floor furnace and 3 repeat tests using the intermediate-scale wall furnace. The duration of each test was two hours and measurements were recorded every minute.

The descriptions of the heat flux sensors used to measure the fire exposure in furnaces are given below.

Heat Flux Sensor

Heat exposure to the test specimen was measured by two water-cooled Gardon Gauge heat flux sensors (see Figure 1) in the intermediate-scale furnace and by 5 water-cooled Gardon Gauge heat flux sensors in the full-scale wall and floor furnaces. These gauges are 2.5 mm diameter and 2.5 mm long copper cylinder and has a stated accuracy of 63%. The water flow temperature was maintained during the entire test within the temperature range specified by the manufacturer for the sensors.

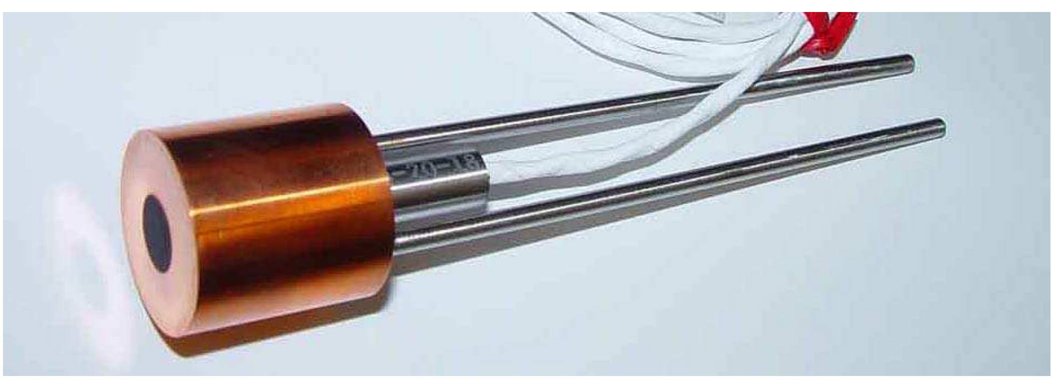

Figure 1 Water Cooled Gardon Gauge Heat Flux Sensor

Standard Full-scale Wall and Floor Test Furnaces

Full-scale fire resistance floor furnace is approximately 4 m wide by 5 m long by 3 m deep (see Figure 2) and the wall furnace is 3.6 m wide by 3 m high by 0.5 m deep (see Figure 3). In both furnaces, the walls were made of insulated fire-brick. Thermal properties of the brick and test specimens are given in Table 1.

Tests were carried out by exposing castable refractory specimens to heat using the propane-fired horizontal and vertical furnaces. The specimens were instrumented with 2 heat flux meters in the intermediate-scale wall and floor furnaces and 5 heat flux meters in the full-scale wall and floor furnaces. These meters were installed flush to the specimen surface to measure the heat exposure in the furnaces. Each specimen was sealed at the edges against the furnace using ceramic fibre blankets. The furnace temperature was measured by 9 (20 gauge) shielded thermocouples in accordance with CAN/ULC-S101-M89[3]. The average of the 9-thermocouple temperatures was used to control the furnace. These thermocouples were located 0.3 m below the fire-exposed surface of the sample, following, as closely as possible, the CAN/ULC-S101-M89 standard time-temperature curve. This curve is similar to the ASTM E119[4] time-temperature curve.

Non-standard Intermediate-scale Wall and Floor Test Furnaces

Intermediate-scale fire resistance floor furnace is approximately 1.2 m wide by 1.8 m long by 0.5 m deep as shown in Figure 4. The furnace walls were also made of insulated fire-brick as in full-scale furnaces. The intermediate-scale furnace can be oriented vertically to become a wall furnace or oriented horizontally to become a floor furnace.

Wall and floor heat exposure tests were carried out by exposing the castable refractory specimens to heat using the propane-fired vertical or horizontal intermediate-scale furnace. The specimen was sealed at the edges against the furnace using ceramic fibre blankets. The furnace temperature was measured by 3 (20 gauge) shielded thermocouples in accordance with CAN/ULC-S101-M89. The average of the 3 thermocouple temperatures was used to control the furnace. These thermocouples were located 0.3 m below the exposed surface of the sample, following, as closely as possible, the CAN/ULC-S101-M89 standard time-temperature curve.

Full-scale Test Specimen

Test specimen used in floor furnace was a castable refractory slab, marketed as KS-4, composed of 20 rectangular slabs, 0.8 m wide by 1.2 m long by 0.15 m thick, suspended on a steel beam. The slabs were tightly butted with ceramic sheet along their perimeters to form a 4 m by 5 m unite. The properties of these slabs are given in Table 1. Five heat flux meters were installed flush with the specimen surface: one at the centre of the furnace and one at the centre of each quarter section of the furnace to measure the receiving heat exposure to the specimen surface.

Full-scale wall furnace test specimen, composed of five so-called measuring specimens, blocks of KS-4 castable refractory brick, 600 mm square by 150 mm thick, were inserted in the simulated block brick wall, one at its centre and four at the centres of its quarter sections as shown in Figure 5. One water-cooled Gardon Gauge heat flux sensor was installed flush with the specimen surface in the centre of each measuring specimen. The location of these sensors is also shown in Figure 5.

Intermediate-scale Test Specimen

In intermediate-scale floor furnace, the test specimen was also a castable refractory slab the same as those used in the full-scale specimen and composed of one rectangular slab 0.8 m wide by 1.2 m long by 0.15 m thick. It was mounted in the centre of a concrete frame 1.2 m wide by 1.8 m long around the specimen.

Table 1 Thermal Properties of Furnace Lining and Specimen Materials

	Furnace Lining Material Fire-brick	Specimen Material Castable Refractory Slab
Thermal Conductivity ($W\ m^{-1}K^{-1}$)	1.15	0.9
Specific Heat ($J\ kg^{-1}\ K^{-1}$)	900	1000
Density ($kg\ m^{-3}$)	2600	2085

Figure 2 NRC Full-scale Floor Furnace

Figure 3 NRC Full-scale Wall Furnace

Figure 4 NRC Intermediate-scale wall and floor Furnace

Figure 5 Full-scale Wall Furnace Test Specime

RESULTS AND DISCUSSION

The effects of furnace depth (full-scale wall and floor furnaces), furnace size (full-scale and intermediate-scale and intermediate-scale orientation on the heat exposure in fire resistance test furnaces are given below.

Effect of furnace depth (full-scale wall and floor furnaces)

Results of average of heat exposure for the 3 tests using the full-scale floor furnace and the other average of 3 tests using the full-scale wall furnace are presented in Figures 6 and 7, respectively. The heat exposure increases with the increase in furnace temperature and it follows a similar trend as the furnace temperature. A comparison of the heat exposure in full-scale wall and floor furnaces of different depths is shown in Figure 10. Heat exposure in a full-scale floor furnace with a larger depth (3 m) is slightly higher (5%) than in a wall furnace with a smaller depth (0.5 m). This slight increase in heat exposure in the case of a floor furnace could be caused by the presence of a thicker hot layer gas facing the specimen fire exposed surface. This increase in heat exposure is considered insignificant.

Effect of Furnace Size (full-scale vs intermediate-scale for wall and floor furnaces)

Average heat exposure results for full-scale floor and wall furnace are shown in Figures 6 and 7, respectively. The average heat exposure results for the intermediate-scale floor and wall furnace are shown in Figures 8 and 9, respectively. Comparisons of the average heat exposure in full- and intermediate-scale floor and wall furnaces are shown in Figures 12 and 13, respectively. The results in Figure 12 indicate that, when either the full-scale or the intermediate-scale fire resistance floor furnace is heated up using the CAN/ULC-S101-89 or ASTM E119 time-temperature curve, the heat exposure in the intermediate-scale floor furnace is approximately 15% higher than in the full-scale floor furnace. Similarly, the results in Figure 13 indicate that, when either the full-scale or the intermediate-scale fire resistance wall furnace is heated up using the CAN/ULC-S101-89 or ASTM E119 time-temperature curve, the heat exposure in the intermediate-scale wall furnace is approximately 18% higher than in the full-scale wall furnace. These results suggest that the effect of furnace size on heat exposure is somewhat significant. Generally, the heat received by a test specimen in a fire resistance test furnaces is by radiation and convection. The radiative part is much greater than the convective part. In the full-scale furnaces, convective heat occurs by natural convection while, in the smaller size furnaces, it occurs by forced convection. Heat transfer by forced convection is greater than by natural convection. As the furnace size increases, the convective heat to the specimen decreases and this may explain why the heat exposure in an intermediate-scale furnace is higher than in a full-scale furnace. For a fire exposure parameter, testing an assembly in an intermediate-scale furnace will provide a conservative performance compared to a full-scale furnace.

Effect of Furnace Orientation (Vertical vs Horizontal)

The average heat exposure results for the furnace in the horizontal position and in the vertical position are shown in Figures 8 and 9, respectively. A comparison of the average heat exposure to a test specimen for the furnace in the horizontal and in the vertical position is shown in Figure 11. The results showed that, when an intermediate-scale fire resistance furnace (1.2 m wide by 1.8 m long by 0.5 m deep) is heated up using the CAN/ULC-S101-89 or ASTM E119 time-temperature curve, the heat exposure to a test specimen in a floor furnace oriented horizontally is slightly higher (4%) than in a wall furnace oriented vertically. A similar comparison is shown in Figure 10 for a full-scale floor furnace and a wall furnace. The difference in heat exposure is considered to be insignificant.

CONCLUSIONS

This paper discussed the effect of furnace depth (full-scale), furnace size (full-scale vs. intermediate-scale) and furnace orientation (intermediate-scale) on the heat exposure in fire resistance test furnaces. Based on the results mentioned above, the following key trends can be highlighted:

1. The effect of full-scale furnace depth on the heat exposure is insignificant.
2. The heat exposure in either intermediate-scale wall or floor furnace, 1.2 wide by 1.8 m long by 0.5 m deep, is 15% and 18% higher than in the full-scale wall or floor furnace, respectively.
3. For the intermediate-scale furnace, 1.2 m wide by 1.8 long by 0.5 m deep, the effect of furnace orientation, whether vertical (wall) or horizontal (floor), on the heat exposure to the test specimen is insignificant.

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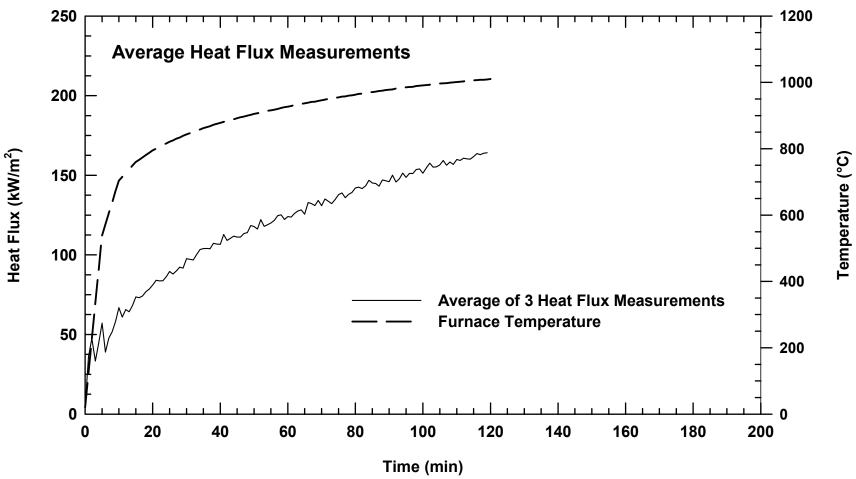

Figure 6 Heat Exposure in Full-scale Floor Furnace

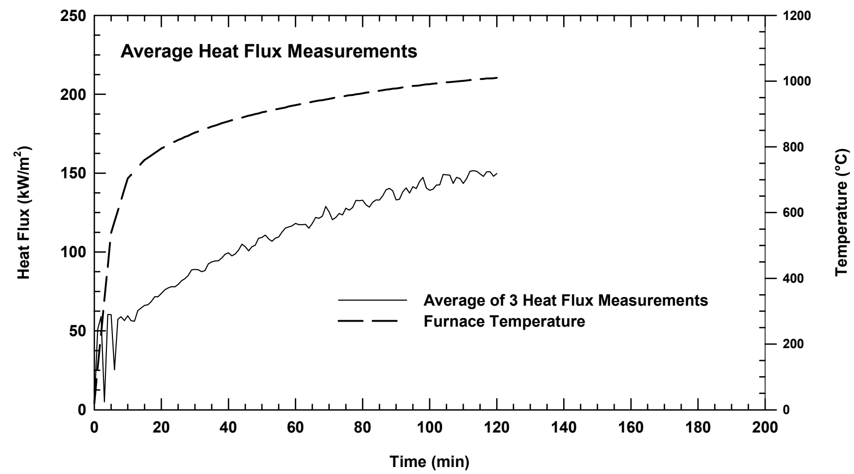

Figure 7 Heat Exposure in Full-scale wall Furnace

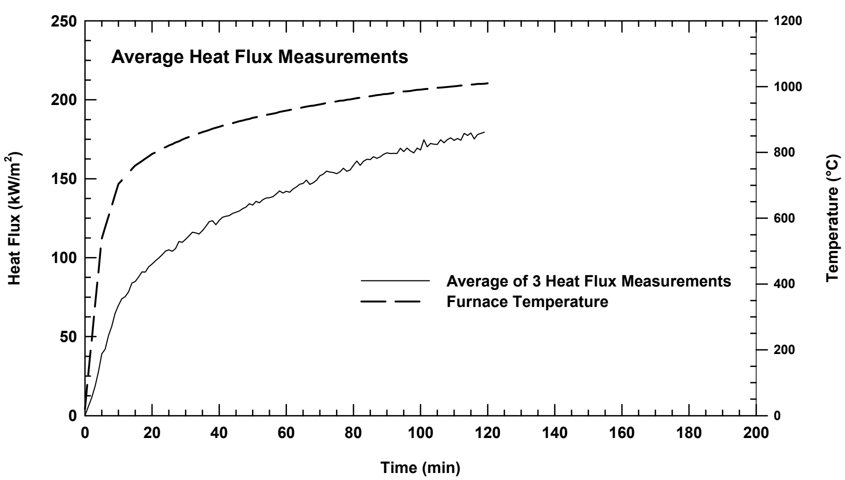

Figure 8 Heat Exposure in Intermediate-scale Floor Furnace

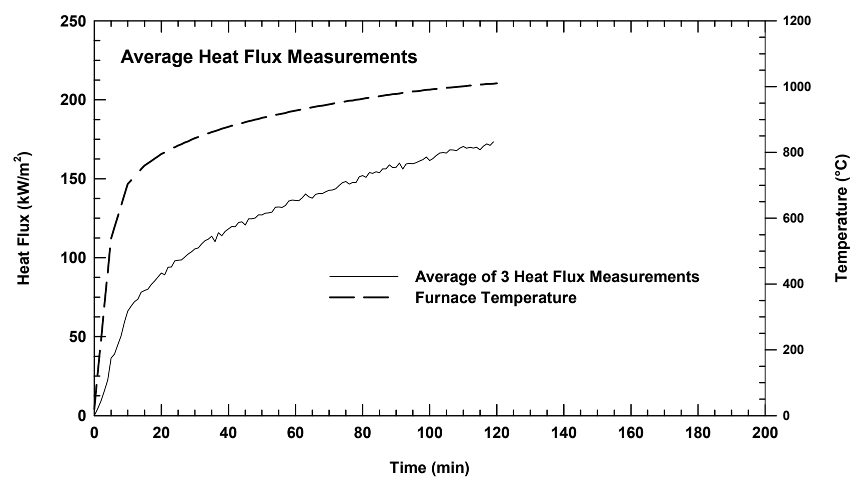

Figure 9 Heat Exposure in Intermediate-scale Wall Furnace

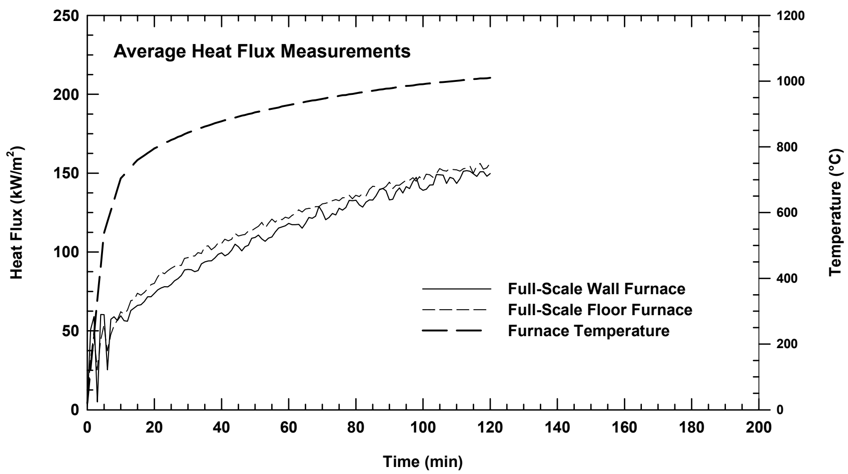

Figure 10 Comparison of Heat Exposure in Full-scale Furnaces (Floor Furnace vs Wall Furnace)

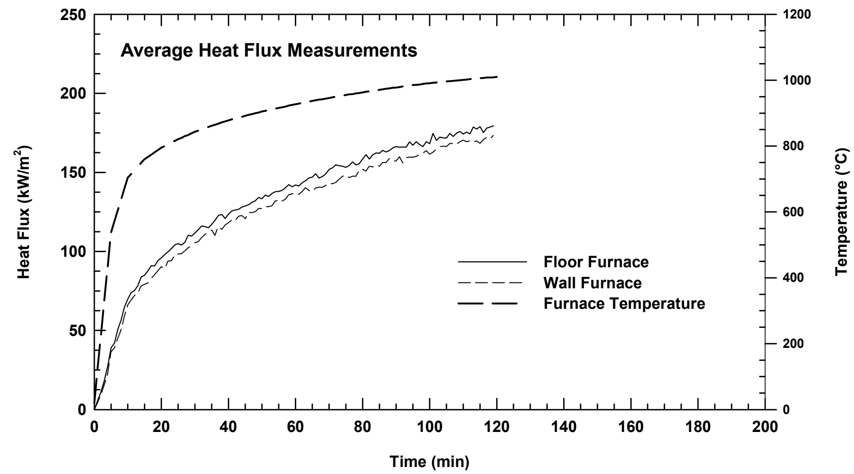

Figure 11 Comparison of Heat Exposure in Intermediate-scale Furnaces (Floor Furnace vs Wall Furnace)

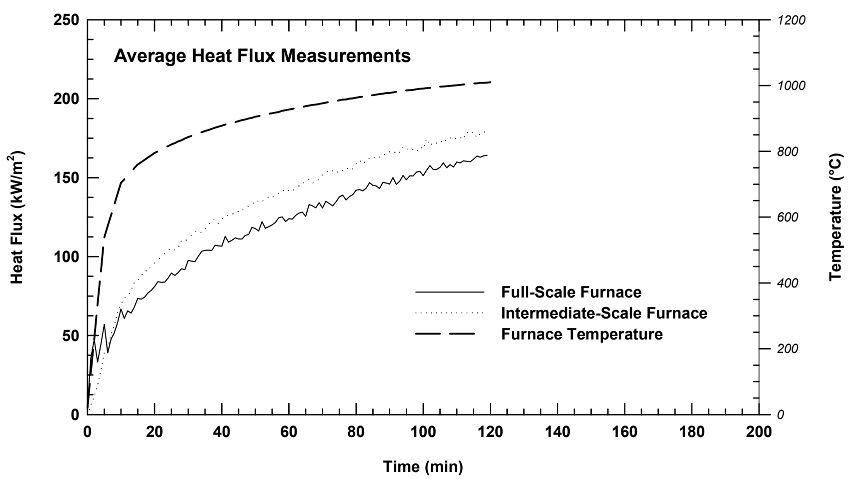

Figure 12 Comparison of Heat Exposure in Floor Furnaces (Full-scale vs Intermediate-scale)

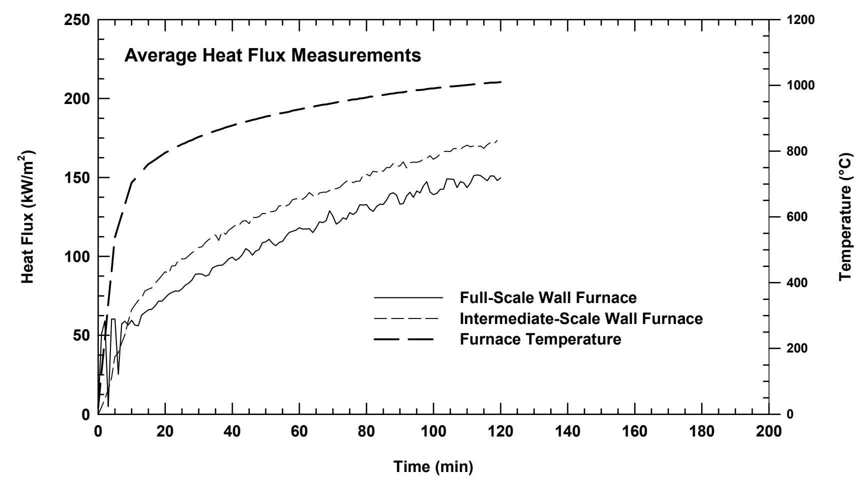

Figure 13 Comparison of Heat Exposure in Wall Furnaces (Full-scale vs Intermediate-scale)