Ignition Sources in Room Fire Tests and Some Implications for Flame Spread Evaluation

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ABSTRACT Large scale room/corner fire test methods permit evaluation of the reaction to fire of wall and ceiling finish materials in configurations and under exposure conditions representative of end use. The response of a lining material depends directly on the exposure conditions imposed on the material, so selection of an appropriate ignition source intensity and location is essential for realistic appraisal of fire performance. A number of experiments have been conducted to evaluate the effects of heat release rate and ignition source location on the heat flux distribution imposed on lining materials in room/corner fire tests. Results of these experiments are reported and some implications for room/corner fire test methods and for flame spread prediction are discussed.

KEYWORDS: fire tests, flame spread, heat flux, ignition source, wall coverings

INTRODUCTION

Enclosure fire scenarios frequently involve the ignition of a furnishing such as a wastebasket, an upholstered chair, a curtain, or some other easily ignitable object that can continue to burn in the absence of an external heat flux. Such a fire alone may constitute a threat, depending on the combustion characteristics of the object. For many fire scenarios, however, the significant hazard arises because the incipient furnishing fire exposes a combustible wall or ceiling finish material, which then may ignite and extend the fire. This type of scenario has been the implicit subject of interior finish flammability regulations.

Traditional flammability test methods such as the ASTM E84 Tunnel Test[1] used widely in the United States to regulate interior finishes, rank materials based on performance in small- to medium-scale fire tests. These tests do not necessarily use configurations or exposure conditions representative of end use. Such test methods have produced anomalous and inconsistent flammability ratings for many lining materials[2], notably foam plastics and textile wall coverings[3]. These index-based test methods no longer should be considered adequate for product qualification purposes because they do not evaluate the fire hazard of a product in end use. They can, however, continue to serve as screening tests. Products that perform poorly by screening tests can be disregarded from further consideration, but products that pass the screening process should be required to demonstrate suitable performance under representative conditions of use.

Internationally, a number of large scale room/corner fire test methods[4],[5],[6] have been developed to permit evaluation of the performance of wall and ceiling finish materials in configurations and under exposure conditions representative of end use. While these room test methods are much more representative than the traditional index-based test methods, any one test still can be used only to evaluate a single ignition source/configuration scenario. Given the expense of large-scale fire tests, selection of a single scenario for evaluation is desirable. A corner geometry is typically used to represent the most severe configuration plausible, but a wide range of ignition scenarios is equally acceptable. The ignition scenario that is selected should subject the test material to a severe, yet realistic, exposure condition, but it should not mask the performance of the product being evaluated.

Wood cribs, trash bags, and wastepaper baskets have been used as ignition sources for room/corner fire tests. Within the past decade, however, the use of gas burners has become prevalent because their heat release rate histories can be programmed and controlled. Typically, gas burners used as ignition sources in corner tests have been placed in contact with both walls of a corner. Thus, when the burner is ignited there is immediate flame impingement on the surface of both walls. When wood cribs are used as the ignition source in corner tests, a space usually exists between the sides of the crib and the walls in the corner to allow air to enter the crib from all sides. Direct flame impingement on the wall does not occur until flames spread to the outside of the crib, some time following ignition. "Real world" ignition sources such as upholstered furniture fires, liquid spill fires or burning piles or bags of trash may produce rapid flame impingement or they may produce flames detached from the wall surface.

The history of the exposure fire can play an important role in the response of a specimen. For instance, for a wall covered with a thermoplastic foam polymer, rapid flame impingement can cause ignition and flame spread in the corner. If the ignition source is at some distance from the wall, the same thermoplastic foam polymer will often melt and never ignite. However, for materials that do not recede or melt under an imposed heat flux, an ignition source that is initially detached from the wall surface may preheat the lining material and thereby accelerate flame spread once ignition does occur. For relatively thin materials such as textile wall coverings adhered to noncombustible substrates, this preheating may make the difference between localized burnout and rapid flame propagation to flashover. The choice of ignition source intensity and location is thus not obvious.

This paper focuses on the effects of ignition source strength and location on the heat flux distribution at the wall surface in a room/corner fire test. Ignition source strengths include heat release rates of 40 and 150 kW, values representative of those used in the United States for standardized room/corner tests[4],[5]. Heat flux and temperature measurements are presented for three burner "standoff" distances: 0 cm, 5 cm and 10 cm.

EXPERIMENTAL PROCEDURE

A room/corner test method (UBC 42-2)[5] has been adopted for the regulation of textile wall coverings by all the model building codes in the United

States. These products have yielded anomalous test results when evaluated in the ASTM E84 Tunnel Test [3]. In the UBC 42-2 test method, the side and rear walls of a 2.4 m x 3.6 m x 2.4 m high test compartment are lined with the product to be evaluated. The front wall and ceiling are lined with gypsum wall-board. The front wall, which is 2.4 m x 2.4 m, contains a 0.76 m wide x 2.03 m tall opening. A 0.3 m x 0.3 m propane-fired diffusion flame burner is located 5 cm from one of the side walls and the rear wall. The top of the burner is located 0.3 m above the floor. The test configuration is illustrated in Fig. 1.

For the experiments reported here, all the walls and the ceiling of the test compartment were lined with gypsum wallboard (GWB). For each experiment a fresh piece of GWB was placed in the corner behind the ignition source so the "burn pattern" on the paper facer of the GWB could be recorded. A 0.25 m grid was marked on these sheets of GWB for visual reference. A schematic diagram of one of the burn patterns resulting from a 5 cm "standoff" is shown in Fig. 1 to lend a sense of scale to these experiments.

The ignition source in these experiments was programmed to follow a Rate of Heat Release (RHR) protocol similar to that specified in the UBC 42-2 test procedure. It started, for each of the three standoff distances, at 40 kW for 5 minutes, followed by 0 kW for 5 minutes, then 150 kW for 10 minutes. In the UBC 42-2 test protocol there is no pause between 40 and 150 kW RHR. However, to permit the taking of photographs of the char pattern produced by the 40 kW RHR, an intermediate period of flame extinguishment was included.

Two types of measurements were made during these experiments. First, the standard temperature and RHR measurements, including oxygen depletion,

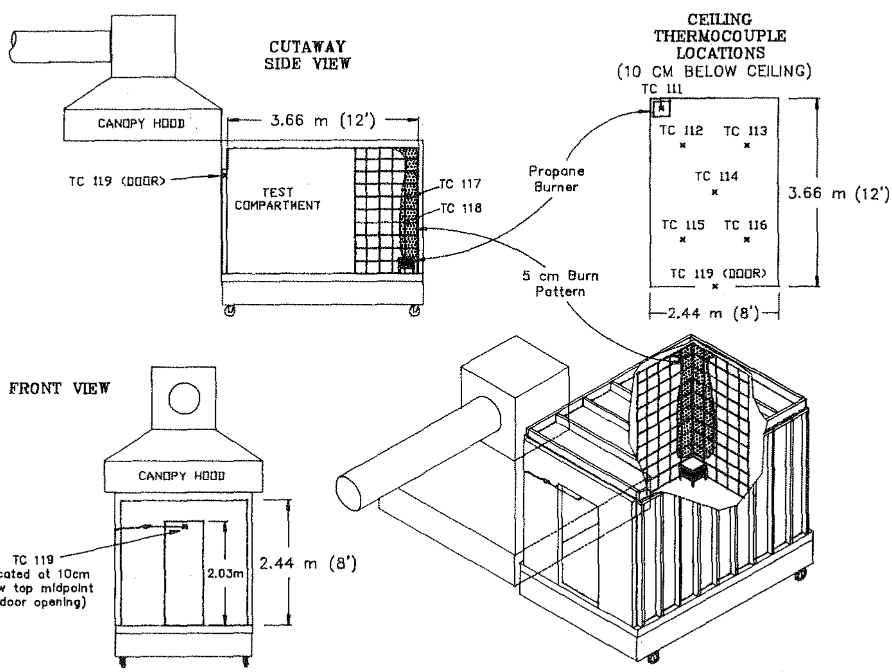


Figure 1 Schematic Drawing of Test Compartment and Placement of Thermocouples.

which are normally a part of modern room/corner fire tests. Second, a number of special measurements were made to better understand the differences between the three exposure conditions represented by the three standoff distances.

The locations of thermocouples are indicated in Fig. 1 on the side and front views of the test compartment, and on the ceiling thermocouple plan. Except for Thermocouples 117 and 118 (TC 117 and TC 118), they are the standard thermocouple locations in both the UBC 42-2 and the proposed ASTM test standards. All the thermocouples were fabricated from 24 A.W.G. (0.5mm diameter) chromel-alumel wire with approximately 1.7 mm diameter beads.

In addition, heat flux measurements were taken at the wall surfaces. Calorimeters were placed at nine different locations on the side wall, adjacent to the ignition source, as shown in Fig. 2. Two "Schmidt-Boelter" type of heat flux gauges were placed in two locations and recorded on CH: 143 and CH: 149. The remainder were "Gardon" type heat flux gauges.

EXPERIMENTAL RESULTS and DISCUSSION

The ultimate burn patterns on the GWB for the three standoff distances are shown in Fig. 2. The outer boundary of the char patterns shown in Fig. 2 are the result of the full ten minute exposure at 150 kW. The approximate char pattern after a one minute exposure at 150 kW is also shown in Fig. 2.

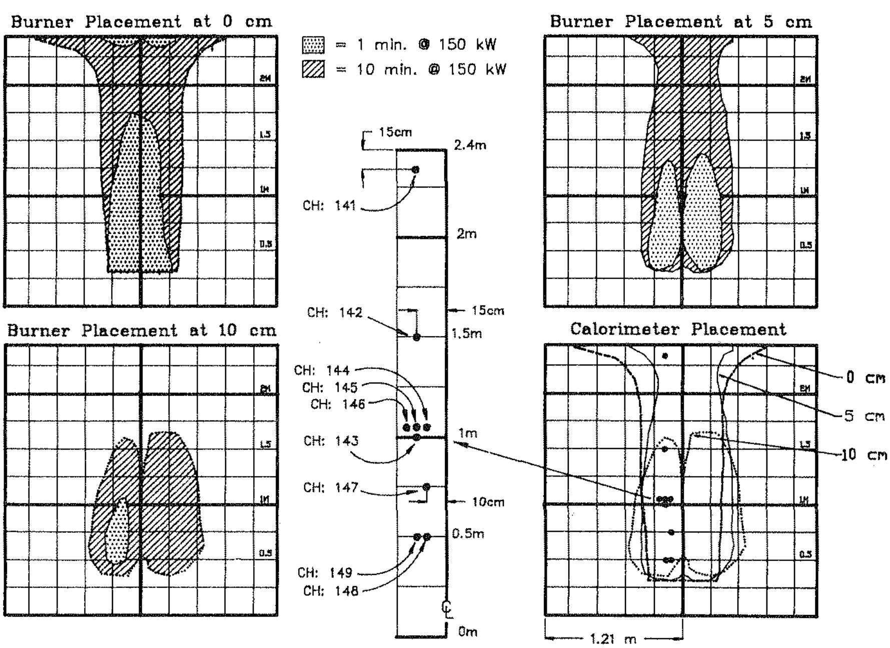


Figure 2 Burn Patterns on the GWB for the Three Standoff Distances. In addition, the location of the heat flux gauges are shown.

The heat flux measurements at the three standoff distances are shown in Fig. 3. Some implications of these measurements are discussed below. Representative photographs of the flames at the three standoff distances are shown for a RHR of 40kW in Figs. 4 (a-c) and for a RHR of 150kW in Figs. 4(d-f).

The RHR histories for two of the experiments are shown in Fig. 5. This data provides a sense of the reproducibility of the experiments and the accuracy of the RHR measurements taken in the University of California, Berkeley, room fire test facility. The gas temperatures in the test compartment are shown in Figs. 6 and 7 for each standoff distance. Fig. 6 shows the temperatures 10 cm below the ceiling in the corner of the test compartment, directly above the ignition source. Fig. 7 shows the average gas temperatures measured 10 cm below the ceiling at the center and quarter points of the compartment.

Figure 1 illustrates in an isometric drawing of the standard test compartment and the final burn pattern of GWB at the end of the complete 40 and 150 kW exposure period for a standoff distance of 5 cm. The char pattern on the GWB paper provides a representation of the effective exposure of this ignition source. The char patterns in Figs. 1 and 2 show differences between the exposure conditions developed by the three standoff distances. These differences are a combination of direct ignition and self-propagation of flames on the paper on the surface of the GWB under the influence of the ignition source.

The burn patterns in Fig. 2 show that the fire propagation potential of GWB with the UBC 42-2 ignition program at any of the standoff distances is

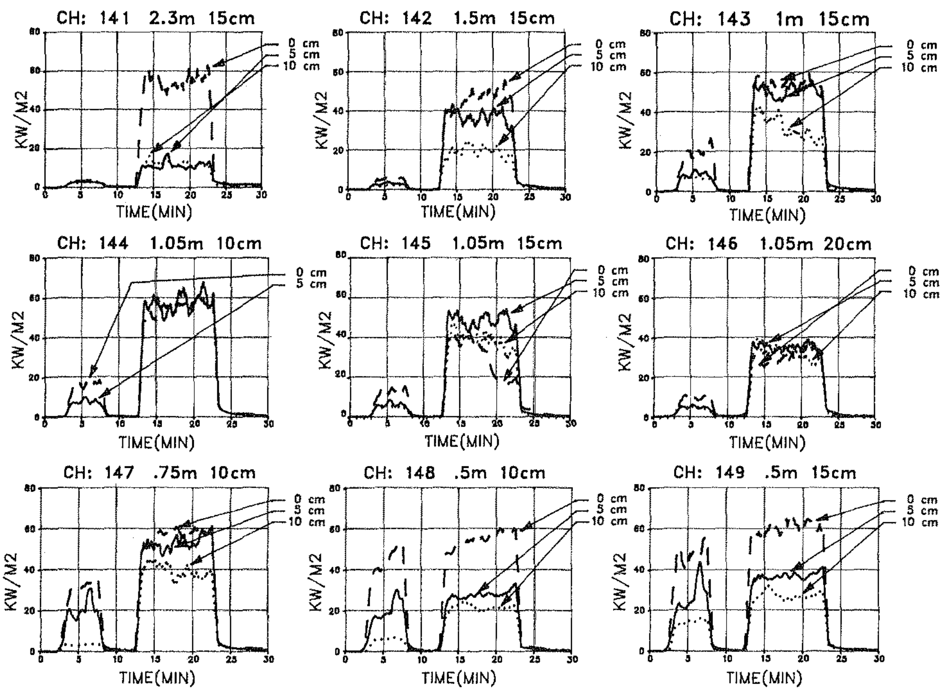
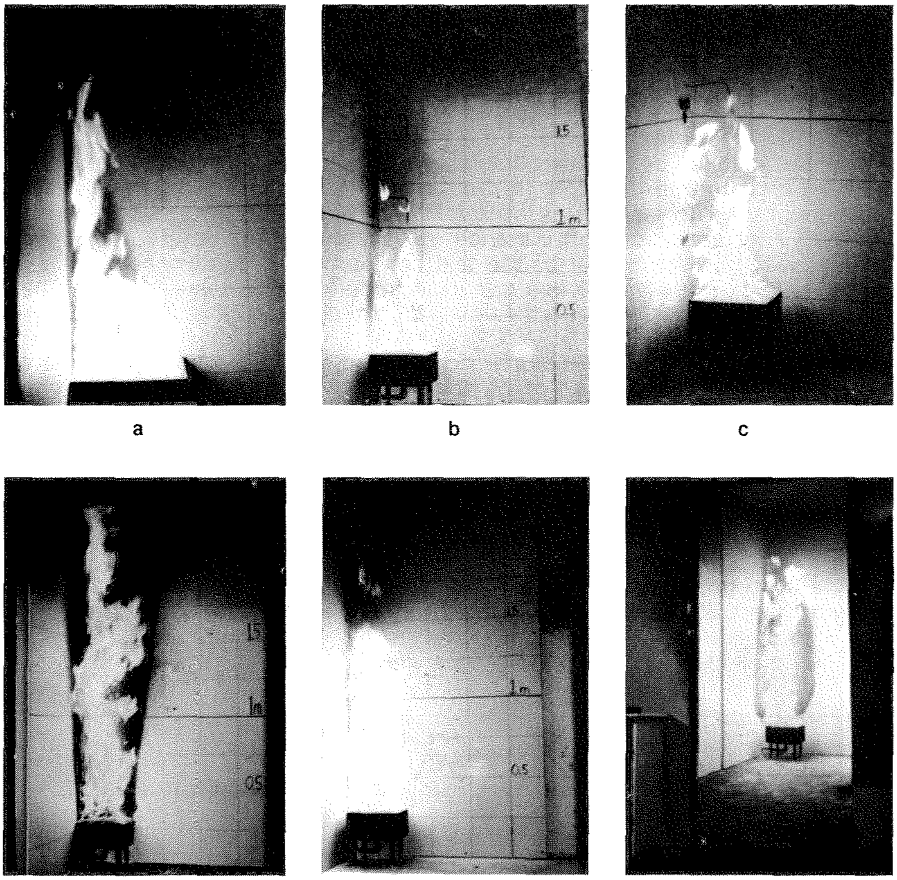


Figure 3 Heat Flux Measurements for the Three Standoff Distances.



a b c

d e f

Figure 4 Photographs of the Flames at the Three Standoff Distances.

limited to a single 1.2 m x 2.4 m sheet of GWB in the ignition corner. The performance of other materials can be considered qualitatively in terms of this performance for GWB, which is generally regarded as a reasonably "safe" material for walls and ceilings.

The GWB burn patterns shown in Fig. 2 show little propensity for lateral flame spread on this material under these exposure conditions. The ultimate burn patterns show virtually vertical boundaries, unlike the V-shaped pattern frequently used by fire investigators, albeit incorrectly in some cases, to identify areas of fire origin. Materials with a greater propensity for lateral flame spread develop more pronounced V-patterns. Quintiere[7] notes that lateral flame spread is much slower than vertical spread, but the propensity for lateral spread can have a significant influence on hazard development because of the increased area of surface involvement that results from this lateral spread.

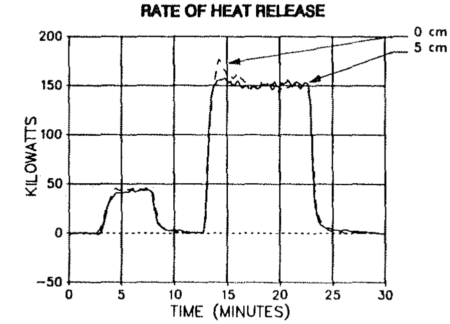


Figure 5 Rate of Heat Release Measurements for Two Experiments

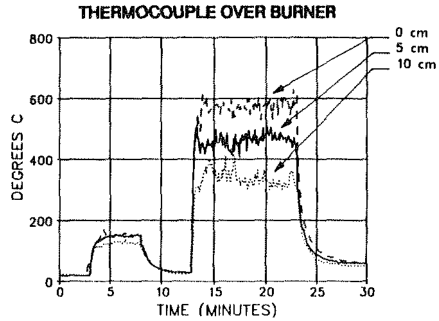


Figure 6 Gas Temperatures in the Corner Above the Ignition Source

The char patterns produced by a five minute exposure at 40 kW followed by a one minute exposure at 150 kW are superimposed for each standoff distance in Fig. 2, where they are labeled "one-minute". At the 0 cm standoff distance there is substantial charring of the paper up to the 1.5 m height as well as some charring of the paper at the ceiling level. For the 5 cm standoff distance the charring of the paper on the GWB is limited to approximately the lower 1.25 m height. After 5 to 7 minutes of exposure the upper paper ignites in the 5 cm standoff experiments and the char pattern goes to the shape shown in Fig. 2. At the 10 cm standoff distance, the back wall (i.e., right hand wall in Fig. 2) never ignited in the experiment used to generate the "one-minute" patterns. Thus, there is no char pattern shown for this location. The paper was heavily browned on the back wall in that experiment, but it did not ignite within one minute.

The final char patterns for the three standoff distances are virtually symmetrical about the corner. The slight asymmetries illustrated in Fig. 2 are likely due to differences in the flow field within the room caused by the relative locations of the doorway and the burner.

Comparison of the heat fluxes at the 5 cm standoff distance, shown in Fig. 3, indicates general agreement between similar heat flux gauges when used in nominally the same experiment conducted 114 days apart. Some of the differences are probably due to minor variations of the ignition source between the experiments as well as variation in the response of the burning paper on the GWB. Figure 3 provides a sense of the reproducibility for these corner fire tests. The Channel 141 data shows the largest differences, but it should be recognized that this is the most complex fluid dynamic region in the experiment.

As illustrated in Fig. 3, significant differences in wall heat flux exist for the 40

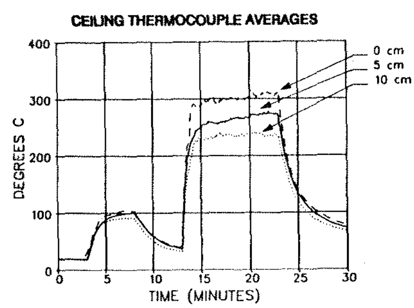


Figure 7 Average Gas Temperatures 10 cm Below the Ceiling for 3 Standoff Distances.

kW RHR to the 1 m level. These differences are most pronounced at the 0.5 m elevation, where the heat fluxes are in excess of 40 kW/m^2 for the 0 cm, around 20 kW/m^2 for the 5 cm, and between about 5 and 15 kW/m^2 for the 10 cm standoff. The spike in the 5 cm standoff heat flux data at approximately 3 minutes after ignition is associated with ignition of the paper facer on the GWB

The heat flux data at the 150 kW RHR demonstrates large differences based on standoff distance at the lower and higher elevations and more uniform values at the middle elevations. At the 0.5 m elevation, the heat fluxes range from 50 to 60 kW/m^2 for the 0 cm standoff, from about 30 to 40 kW/m^2 for the 5 cm standoff, and from about 20 to 30 kW/m^2 for the 10 cm standoff. Some of these differences can be attributed to reduced radiant flux as a function of standoff distance, but it is also likely that the lower portion of the wall is cooled convectively by air entrained between the burner and the walls for the 5 and 10 cm standoff distances. At the 0.75 m elevation, these differences diminish considerably, and at the 1.05 m elevation, the heat fluxes for all three standoff distances become virtually the same, but as indicated in Fig. 3, the magnitude of the heat flux depends on the lateral location. At the 1.5 m and 2.3 m elevations, differences in measured heat fluxes based on standoff distance again become apparent. The 0 cm standoff fluxes remain highest, with values typically between 50 and 60 kW/m^2 at both elevations. At the 1.5 m elevation, the 5 and 10 cm standoff heat fluxes remain virtually constant at 40 kW/m^2 and 20 kW/m^2, respectively. At the 2.3 m elevation, the fluxes at both standoff distances become virtually the same, with values between 10 and 15 kW/m^2.

The heat flux for the 0 cm standoff experiment remained virtually uniform, at approximately 50-60 kW/M^2, from the bottom to the top of the wall. At the mid-height of the wall, the heat flux for both the 5 and 10 cm standoff distances can be characterized as at the same general level as in the 0 cm standoff experiment, but this peak value diminishes above and below the mid-height for these two standoff distances.

Representative photographs of the flames in Fig. 4 (a-f) show several important features not evident in the char patterns or heat flux data. In Fig. 4a) flames at 0 cm standoff distance are shown at the 40 kW RHR level. At this standoff there is "flame attachment" to the wall. A combustible wall surface will ignite rapidly at the 40 kW RHR level, as shown in Fig. 4(a), with the paper on the GWB. At the 5 cm standoff distance, the flames shown in Fig. 4(b) do not directly impinge on the surface of the wall and ignition of the paper on GWB does not always occur. At the 10 cm standoff distance there is almost no possibility of ignition of any wall surface material at the 40 kW exposure level. The flame shown in Fig. 4(c) is representative of flames observed at this standoff distance.

When the RHR of the ignition source is increased to 150 kW, the flame attaches to the walls for some periods of time at all three standoff distances. The flame shown in Fig. 4(d) for the 0 cm standoff is shown after the paper on the GWB has been charred to its fullest extent. There is still attachment visible on the left wall. On the other hand, the flame shown in Fig. 4(e) for the 5 cm standoff distance is at an early stage in which the paper on the left wall is just igniting and there is flame attachment for a distance of approximately one meter above the ignition source. The flame shown in Fig. 4(f) shows how there is generally less flame attachment with the 10 cm standoff, although there are some detached flame "packets" near the wall in that photograph. Figures 4 (a-f) provide some visual indication that the three standoff distances give quite different flame exposures to the surface of the wall.

Figures 6 and 7 illustrate the relatively small differences that standoff distances make on upper layer temperatures. These differences are most pronounced for the 150 kW RHR. They most likely can be attributed primarily to differences in plume entrainment that result from the presence of the solid corner boundary[8],[9],[10]. The temperatures above the ignition source, shown in Fig. 6, illustrate that there is much more flame impingement on the ceiling with the 0 cm standoff distance during the 150 kW exposure, and the temperature remains above 550°C for the entire ten minute exposure. The temperature during the 5 cm standoff exposure remains below 500°C for the same period of time. Finally, there is much less flame impingement with the 10 cm standoff distance and, for the most part, the temperature remains below 400°C for the entire 150 kW exposure. The temperatures shown in Fig. 7 demonstrate that the effects of the standoff distance on reducing the entrainment of fresh air into the fire plume remain within the ceiling jet. Due to preheating of the ceiling surface, these differences could spell the difference between fire propagation and burnout for some ceiling materials.

SUMMARY AND CONCLUSIONS

The intensity and location of an ignition source for room fire tests depends on the purpose of the test. For the UBC 42-2 test of textile wallcoverings, the primary purpose is to evaluate the flame spread potential of wall lining materials under a range of exposure conditions. This also permits evaluation of the total contribution of the wallcovering for these exposure conditions.

The 0 standoff distance produces the most severe exposure conditions at the surface of the walls and ceiling. At this standoff, a virtually constant heat flux of 50 to 60 kW/m^2 is imposed for the entire height of the walls in the corner at the 150 kW RHR. Flames reach the ceiling within one minute and the paper on the GWB has already begun to burn within this time. Consequently, the 0 cm standoff exposure is in many respects too severe to assess the fire spread potential of wallcovering materials. Conversely, the heat flux at the 10 cm standoff exposure is not sufficiently intense to challenge the wallcovering material at either 40 kW or 150 kW.

The 5 cm standoff distance produces a range of exposure conditions that can be used to evaluate the fire propagation potential of various wall lining materials. At the 40 kW RHR, this standoff produces peak heat fluxes at the wall surface of approximately 20 kW/m^2 over a fairly small area permitting an evaluation of the flame propagation potential under moderate exposure conditions. At the 150 kW RHR, the peak heat fluxes produced by the 0 and 5 cm standoffs are almost the same at the mid-height of the walls, allowing an evaluation of the performance of a material under more severe exposure conditions.

Another factor favors use of the 5 cm standoff. With no standoff, flames attach immediately to the wall surface, causing rapid ignition of the wall covering at the 40 kW exposure level. Flames may propagate some distance up the wall, but then burn out due to fuel consumption and a subcritical heat flux. When the RHR is increased to 150 kW, this burned out region is no longer available to help propagate the flame. At the 5 cm standoff, the potential for ignition and propagation at lower heat fluxes can be evaluated. If ignition does not occur at the 40 kW, preheating of the walls and ceiling will occur under the subcritical exposure conditions. This preheating can lead to more rapid flame spread when the RHR is increased to 150 kW.

These experiments have implications for flame spread prediction and for the small-scale RHR tests, such as the Cone Calorimeter[11], used to acquire data for these predictions. Qualitatively, these experiments show how relatively small differences of 5 cm in ignition source location can have relatively large effects on the exposure conditions in a room fire. Quantitatively, these experiments show that representative ignition sources commonly produce incident heat fluxes near 60 kW/m^2 at wall surfaces. This is approximately double the values previously cited[12],[13] for wall flames and line burners. Since ignition times vary approximately as the square of incident heat flux[12] this difference is important and warrants further consideration.

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