

Natural fire tests in a dormitory with fire protected furniture

Cristiano Corrêa,^{1,2}

George Cajaty Braga,³

Roberto Rianne Ferraz de Menezes,^{1,2}

José Jéferson Rêgo e Silva,²

Roberta Tabaczewski,²

José do Carmo Bezerra Junior,^{1,2}

Tiago Ancelmo Pires de Oliveira²

¹Fire Department of Pernambuco;

²Federal University of Pernambuco;

³Fire Department of Distrito Federal, Brazil

Abstract

This article presents a full-scale fire experiment carried out in a dormitory bedroom in the city of Recife, Pernambuco, Brazil. The experiment was recorded by thermal and conventional cameras, and temperatures were measured at 24 different points within the environment, making it possible to observe the dynamics and behavior of the fire in detail. Among the objects in the dormitory were two identical bedside tables, one of which was coated with intumescent paint. Particular attention was paid to the behavior of this piece of furniture, which, despite being in direct contact with the flames for more than 20 minutes, did not completely burn. Similar experiments are rare in Brazil and in Latin America as a whole, especially with the use of furniture and locally built structures. Understanding the dynamics of this fire, which very closely resembles many local cases, is therefore important to generate data on thermal behavior and overall understanding of the phenomenon. Regarding the specially-treated piece of furniture, its performance was found to be satisfactory, suggesting that such a protective process for furniture may help inhibit the spread of similar fires.

Introduction

The coating of structures, building elements, and objects of furniture with intumescent paint is a passive fire protection alternative that has seen growing interest in recent years. This strategy, as well as others such as compartmentalization, aims to fortify and increase the structural resilience of a building during a fire, so that its occupants will be able to evacuate in a timely and safe manner, and so that its impacts are lessened.

The term *intumescence*, when used in the context of fire safety, transcends the narrow definition merely representing an increase in volume or swelling. An object coated with paint or another intumescent substance will react to heat by forming an air bubble between the outer layer and the surface of the object or structure. This swelling can also cause other reactions that make the object much more resistant to pyrolysis in a fire scenario.

Destructive trials in real-world fire scenarios are relatively common worldwide.¹⁻³ In Brazil, these experiments are rarer, this being an important branch of research that still lacks national regulations and standards.

In 2017, a fire test in a fully-furnished dormitory was carried out in the city of Recife, Pernambuco, Brazil, based on a statistical survey of fires that occurred during the three-year period 2011-2013,⁴ establishing a building type, rooms, and furniture components of typical fires that occur in this city.⁵

The experiment was carried out in a building at the Military Fire Brigade Instruction Center of Pernambuco, and lasted for 48 minutes, with temperatures measured throughout the duration.⁶ In the test bedroom, in addition to other objects of furniture, were two similar bedside tables made of wood chipboard. One of the tables was coated with intumescent paint, provided by the CKC company of Brazil, Ltd., under the trade name CKC 268, specific for wood.

Materials and Methods

The experimental test was carried out in a building belonging to the Fire Brigade Instruction Center of Pernambuco. The test room was adapted to represent a dormitory belonging to the type of houses that most commonly experience fires in the city of Recife.⁴ Various objects of furniture were placed inside, including two identical bedside tables made of wood agglomerate.

For the experiment, one of the bedside tables was coated with intumescent paint, following the standards recommended in Technical Data Sheet CKC 268.^{7,8} The Technical Data Sheet describes CKC 268 as a non-toxic, water-based, indoor paint that delays the spread of flame and inhibits the emission of smoke. In addition, it has a high-quality finish and is recommended for use on natural or painted wood surfaces, partitions, and woods of any nature.

The surfaces were dried and cleaned prior to application of the product and the paint was thoroughly mixed to provide a

Correspondence: Cristiano Corrêa, Fire Department of Pernambuco, Street Itaenga 104, Tejipió, Recife, CEP 50.930.380, PE, Brazil.
Tel.: 055.81.984943353 – Fax: 055.81.31829117.
E-mail: cristianocorreacbmpe@gmail.com

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homogeneous texture. The manufacturer does not recommend applying the product when the temperature is below 10°C or when the relative humidity is above 80%, and these parameters were respected.

Breathing masks, goggles, and latex gloves were used during the application of the product, according to the manufacturer's recommendation. In addition, a brush, roller, paint tray, and sandpaper were used. Five coats were applied with a 6-hour interval between each coat.

The first coat of the product was applied at 5:00 p.m. on 06/03/17 at a temperature of 29°C and 79% humidity. The second coat was applied at 8:00 a.m. on 07/03/17, at a temperature of 29°C and humidity of 71%. The third coat was applied at 3:00 p.m. on 07/03/17 at a temperature and humidity of 30°C and 77%, respectively. The fourth coat was applied on 08/03/17 at 10 a.m. On that day, the temperature during application was 31°C and the humidity was 63%. The fifth

and final coat was applied at 5:00 pm on 08/03/17. The temperature was 30°C and the relative humidity was 60%. During the application of all coats, the temperature and relative humidity of the air were in accordance with the recommendations stated on the product data sheet (Appendix Figures).

Days before the experiment, the sample room was assembled. In addition to the furniture present, a thermocouple was installed in each of the two bedside tables, in order to verify the temperature variation throughout the test (Figure 1).

This study is based on the hypothetical deductive logic proposed by Lakatos *et al.*,⁹ which suggests that the research hypothesis should collect evidence to arrive at a proof, starting from the premise that it is possible to establish a relationship between the intumescent material and resistance to the propagation of fire.

The distribution of the 24 thermocouples is shown in Figure 1.

The positioning of the thermocouples had the following correspondence with the numbers shown in Figure 1: i) 01 to 08, arranged on the stem shown in the Figure 1, installed at 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1 and 2.4 meters; ii) 09 and 10, internal and external sides of the wall with cement mortar coating; iii) 11 and 12, internal and external sides of the wall with plaster coating; iv) 13 and 14, internal and external sides of the walls with Roughcast; v) 15, window; vi) 16, collection of gases; vii) 17 and 18, bunk bed, upper and lower bed respectively; viii) 19, single bed; ix) 20 and 21, large nightstand (positioned next to bunk bed and single bed respectively); x) 22, small nightstand with the TV set; xi) 23 and 24, wardrobe, positioned at the door and on the hangers respectively.

Results and Discussion

The basic chronology, as evidenced by Corrêa *et al.*,¹⁰ is shown below and details the events of the experiment itself: i) 00min35sec - Fire was started using the paraffin device; ii) 03min56sec - Start to ignite the upper mattress of the bunk bed; iii) 06min22sec - Saturation of combustion gases; iv) 07min38sec - End of the saturation by natural exhaust of the gases and air intake with return of the flames; v) 10min36sec - New Saturation of combustion gases; vi) 11min49sec - End of the second saturation by natural exhaust of the gases and air intake with return of the flames; vii) 18min02sec - Opening doors allowing cross air circulation; viii) 19min04sec - fire propagation to a different material; ix) 21min29sec - The plastic fan

over the nightstand start to ignite; x) 41min43sec - Total collapsed of the bunk bed (Figure 2). The entire experiment was measured using temperature-transmitting thermocouples connected to a National Instruments CompactDAQ USB module, with an NI 9213 measuring tool having a sensitivity of 0.02°C. It should be noted that the uncertainty of the thermocouple is approximately 2.2°C for temperatures below 293°C, and +/- 0.75% for higher temperatures (OMEGA, 2004).¹¹ An example of this data can be seen in Figure 3 below.

Table 1 summarizes the observations measured during the test.^{12,13}

It is important to note that, in this experiment, the generalization of the fire, or *flashover*, was not observed in its expected and typical manner. It should also be noted that the curve of this fire differs from the classic qualitative fire curve, mainly due to the cyclical movement of Combustion - Gas Saturation - Natural Exhaustion - Oxygen Injection - Combustion, which causes the appearance of temperature peaks and valleys.

Temperatures of objects of furniture are shown in Appendix Figure A8.

In the experiment, the fire was started at a point on the upper surface of the lower bunk bed. It was found that in the region close to this point, the temperature reached its highest level, nearly 800°C, at various times (10, 19, 27, and 31 minutes). This piece of furniture is the object most enveloped by the flames. It is also important to note the significant increase in temperature in the cabinet (another piece of furniture, not as close to the bunk) that, after the first 25 minutes of burning and following the opening of the door (18 minutes), exceeded the expressive value of 700°C, even without fully combusting. This heating can be explained by the radiation of the temperature in the direction of the cabinet and the convection of gases into the cabinet. Its geometry even facilitated the accumulation of hot gases. In addition, some clothing inside the cabinet burned, producing more heat.

A more precise analysis of the behavior of the bedside tables during the fire pro-

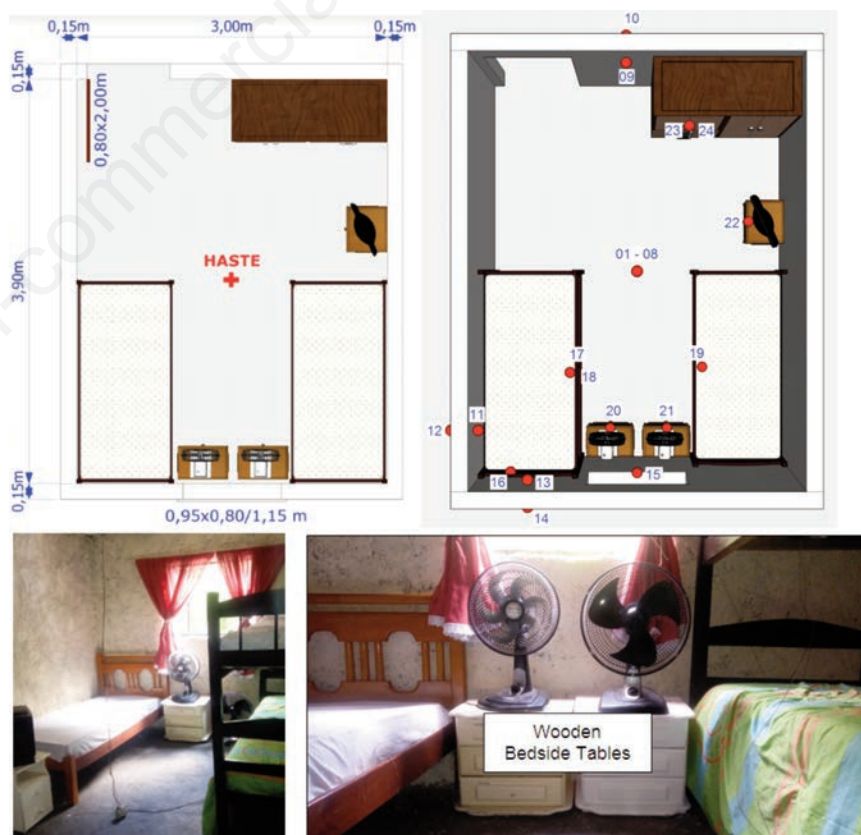


Figure 1. Thermocouple positions in the bedroom,⁷ and image of the test room and the two bedside tables used for the experiment. The table on the right is painted with intumescent paint CKC 268.

duces the following graph (Figure 4).

By analyzing the time lag between the occurrence of events and comparing it with the graph in Figure 4, important relationships between the furniture with intumescent paint and the environment are observed. Comparing the behavioral characteristics indicated in the chart, which deals specifically with the bedside tables, will provide a more accurate observation of what happened.

In Figure 4, three lines are seen, which represent the temperatures of the furniture tested and the environment. The blue and red lines represent, respectively, the thermocouples installed on the untreated bedside table and on the table with intumescent paint. The orange dotted line represents the temperature recorded by the thermocouple at a height of 60 cm, the same height as the upper outer face of the furniture.

It can be seen that during the initial five minutes, the untreated bedside table reached a temperature as much as two times that of the treated table. This is possibly due to the fact that, according to the CKC 268 technical data sheet, after application of the product and when exposed to fire, the paint will be activated by heat, causing the protective



Figure 2. Timeline of the experiment. Reproduced with permission from Corrêa *et al.*⁷

Table 1. Observations measured during the test.

Interval	Observations
0-4 min.	Shortly after the ignition of the fuel material (start of the fire, ambient temperature), the temperatures at the eight measuring points on rods in the center of the dormitory room rose exponentially. At 3 min. and 40 sec., the thermocouple 2.4 m from the floor recorded a temperature of 600°C. The formation of a cloud of combustion gases, dense and saturated, caused an increase in internal pressure (superior to external), preventing the entrance of atmospheric air and, consequently, of oxygen.
4-7 min.	Gradual decrease in temperature with the slow and natural exhaustion of the cloud of combustion gases, due to the natural reduction of oxidizing material.
7 min.	Injection of atmospheric air (increase in oxygen) due to natural ventilation, feeding combustion and reactivating the fire.
7-8 min.	Intense flames (more pronounced luminosity), with rapid increase in temperature.
8 min., 35 sec.	Maximum recorded temperature: 667°C, in the thermocouple at a height of 2.1 m.
8-10 min.	Again, high production of combustion gases reduces the availability of oxygen. In the upper thermocouples, a temperature reduction of more than 100°C is observed. Natural exhaustion.
10-15 min.	Repetition of the cycles of increase in natural ventilation, with rapid increase in temperature with the entrance of air, and subsequently, a gradual reduction in temperature. In this interval, it was verified that the temperatures (in the thermocouples along the vertical rod) displayed values compatible with the cycles of increase and decrease of fire intensity.
15-18 min.	Progressive temperature decline due to significant reduction of combustible material. The measured temperature values were around 300°C (maximum, in the highest thermocouples) and 100°C or less in the lower thermocouples. Behavior was consistent with the final cooling of the fire, observed by Torero. ¹²
18 min.	Beginning of sharp decline in fire intensity. Opening of the bedroom door to provoke cross-ventilation.
18-30 min.	Following the opening of the door, temperatures measured in the center of the dormitory room (along the vertical rod of thermocouples) lost their correlation, i.e., they oscillated individually without presenting a common pattern. It was concluded that cross-ventilation created a circulation of hot gases at various heights/levels. At the 23-min. mark of the test, the temperature of the thermocouple at 0.60 m was higher than that of the thermocouples at 2.10 m and 2.40 m. Without cross-ventilation, such a situation would be unlikely because of convection, as demonstrated by Janssens. ¹³
30 min.	The fire is out. At this point, with a significant decrease in the amount of combustible material, the fire is about to be completely extinguished. The temperatures measured by the five highest thermocouples (2.4 m, 2.1 m, 1.8 m, 1.5 m, and 1.2 m) are close to 200°C and those measure by the three thermocouples nearest the floor (0.9 m, 0.6 m, and 0.3 m) are around 100°C. In both groups of thermocouples, the temperature drop is nearly linear. This characterizes the cooling phase of the fire.

layer to expand in thickness.⁸ After the initial five minutes, in which the ambient and furniture temperatures were higher, we see a reduction due to the saturation of gases present in the environment, reducing the flames and, consequently, the heat radiated to the other areas in the test bedroom.

Appendix Figure A9 shows the effects caused by fire on the bedside table that was coated with intumescent paint.

With the reduction in temperature, following the initial five minutes, the ambient temperature at 60 cm remained between 100°C and 250°C until the 18-minute mark. In this same time span, the temperature of the treated furniture varied minimally, maintaining an almost continuous line, while the non-treated furniture showed a higher degree of variation over the same time interval. It is important to note that the treated bedside table was nearer to the bunk where the flame was ignited, as shown in the image.

After the 18-minute mark of the test, the ambient temperature declined due to the opening of the door by the monitoring team, allowing air to pass between the window and the door and creating cross-ventilation.¹⁴ From that point on, the formation of a column of air passing through the room formed a barrier that prevented the propagation of the flames by irradiation to the furniture located on the opposite side of the dormitory.

As the test approached 23 minutes, the air column, along with the gradual destruction of the bunk, causes the flames to be concentrated near the treated bedside table. The partially destroyed bunk had burning fragments in direct contact with the furniture. Thus, the intake of air that initially caused a decrease in temperature provided, over time, oxygen for the flames and allowed the fire to come back to life.¹⁴ The furniture on which the intumescent paint was applied increased in temperature to almost 400°C until the 43-minute mark of the test, when the team of fire fighters entered the room to quench the flames. The bedside table without intumescent paint maintained a temperature of around 100°C until the same 43-minute point.

That the furniture remained in flames throughout this time (23 to 43 minutes) at an elevated temperature, is supported by two pillars. The first is that the burning of wood occurs through a combination of pyrolytic, oxidative, and hydrolytic reactions, which, with the increase in temperature, generate flammable gases that feed the combustion process. That is, the material does not combust directly. First, the wood decomposes by pyrolysis into volatile products and fuels, which then ignite.¹⁴ Second

is the nature of intumescence, which inhibits the propagation of the flames, allowing them to burn for a long time.

With the entrance of the firemen to extinguish the fire by means of a combined attack, releasing pulses of sprayed water along with directly smothering the burning material, the temperatures fell rapidly. Soon afterwards, without the presence of flame and without the possibility of propagation and reignition of the fire, the temperature of

the room declined due to the ventilation provided by the open door.

The test dormitory was then opened for the study team to enter and verify the damage that occurred, finding the two bedside tables in the following condition (Figure 5).

After the experiment, the bedside tables were removed from the site and weighed to check the damage they suffered during the fire. Because they had the same layout and composition of wood agglomerate, each

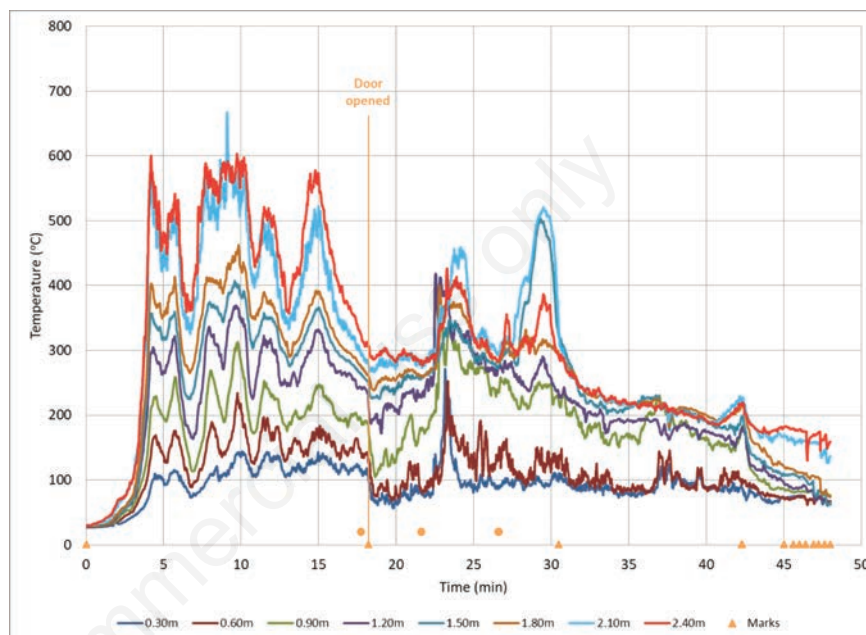


Figure 3. Temperature at different heights at the center of the bedroom. Reproduced with permission from Corrêa *et al.*⁷

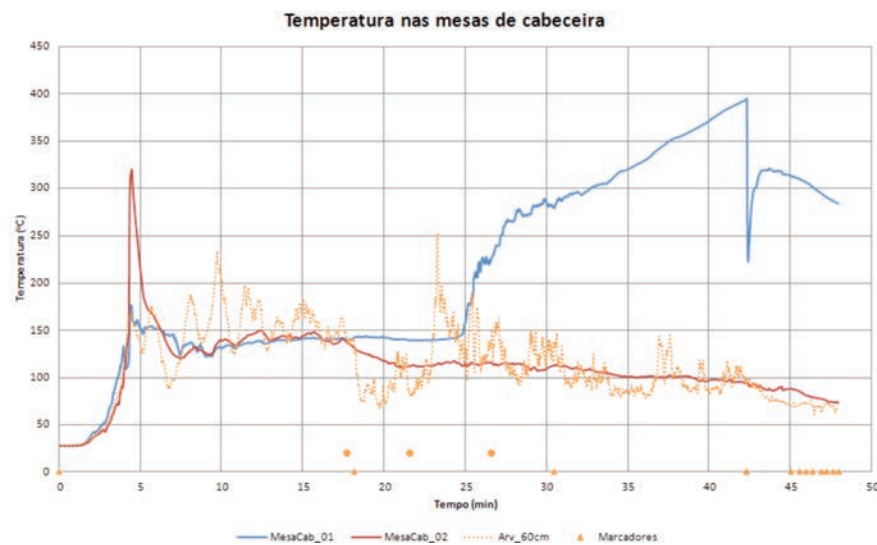


Figure 4. Temperature reached by the bedside tables during the event.

weighed 12.9 kg before the experiment. At the end of the test, the non-treated bedside table had a weight of 14.1 kg, while the treated table weighed 12.1 kg. The increased weight of the non-treated furniture was likely due to the barrier made by the treated furniture, which prevented the propagation of the flames and, consequently, the consumption of the wood by the fire, as well as the use of water to extinguish the flames that was partly absorbed by the wood, increasing its weight. Days after the experiment, the two now completely dry bedside tables were re-weighed, with the non-treated and treated tables weighing, respectively, 12,7 Kg and 11,9 kg. The treated table showed a higher degree of damage because it was in direct contact with the flames for a long period of time and was located immediately next to the bunk that was completely consumed by the flames.

For Lepage *et al.*,⁹ when the temperature is in the range between 280 and 350°C, as was the case of the treated furniture, the wood will lose a considerable amount of mass (around 68%), and in the range between 350 and 370°C, the remaining mass will be only about 20% of its initial value. Given this context, the treated furniture performed considerably well, both avoiding the spread of flames and also

maintaining a significant part of its structure undamaged.

Conclusions

After the 48-minute fire test, the bedside table coated with CKC 268 intumescent paint was observed to have prolonged durability due to the ability of the paint to expand after contact with heat. On the other hand, the wooden bunk, which had not been treated with CKC 268 paint, and from where the fire originated, was not only damaged by pyrolysis, but was completely destroyed. Observations showed that propagation of the fire to the furniture on the opposite side of the dormitory was avoided for two reasons: the direction of the flames by virtue of the air column created by cross-ventilation, which reduced the radiated heat to the untreated table and other furniture, as well as because of the characteristic of the intumescent paint to prevent the propagation of the flames. There is a need for continued experimental studies with intumescence in Brazil, which is important to validate the effectiveness of the coatings in situations similar to the fire scenarios, which are experienced daily across the country.

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Figure 5. Air column formed between the window and the door, keeping the flames to one side.