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FIRES IN ENVIRONMENTS WITH BRAZILIAN AND FOREIGN MATERIAL: A COMPARATIVE STUDY [1]

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ABSTRACT
The actual article presents an experimental study that aims to compare the development of a fire full scale of a furnished environment with Brazilian materials, and another analog experiment with foreign furniture (England and The United States of America). Assessing the temperatures reached, the heat fluxes, the emanated gases and the thermic and conventional images. Verifying that, for environments containing a sofa and a TV each, being made in Brazil in the first experiment, and with an English sofa and an American TV in the second. It comes out from the presented data that the environment furnished with foreign materials presented a longer delay reaching the maximum values of temperature and heat flux. In general, the maximum values in the same environment were always lower on the foreign one, about both temperature and heat flux, when compared to the environment with Brazilian furniture. It came out also that both the carbon monoxide and carbon dioxide in the environment furnished with Brazilian furniture would be lethal to 50% of the population after three minutes from the beginning of the combustion process if the inmate kept standing behind the sofa (gas collection point).

Keywords: Safety fire; Full size essay, Fire experiment, Fire gases.

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1. INTRODUCTION

Carrying out full-scale fire tests is of great importance for gauging fire behavior, especially for improving fire prevention, fighting and investigation (Corrêa, *et al*., 2017).

It is possible to observe an increasingly aggressive behavior in the fires that happen in Brazil (Peres, 2019). Factors such as the type of material on site, the size of the room and ventilation can have a significant impact on the development of the fire, aggravating the consequences for people and secondarily increasing material losses (Braga, Neto & Salazar, 2016).

In Brazil, unlike countries in Europe and North America, there is little use of materials in the manufacture of furniture and household appliances that are flame retardant or even less igneous in their composition (in this study, furniture with a retardant material was not used).

It is therefore important to carry out studies to check fire behavior in similar settings, containing Brazilian furniture and furniture from other countries with more careful legislations and cultures in terms of Fire Safety – FS. This study used pieces of furniture and household appliances with very similar dimensions and specifications, manufactured in Brazil (room 1) and abroad (room 2).

The most widely discussed full-scale fire tests in the world have been carried out outside Latin America, with a special focus on the experiments conducted by the National Institute of Standards and Technology / NIST – USA, with the support of the Fire Department of New York (FDNY) and other bodies. An experiment with 14 real fire events was carried out in a 7-storey building, testing various scenarios for developing and fighting the flames. All of these events started with a fire in the respective furnished room (NIST, 2009).

In the UK, Cardington was a high-profile initiative, where a multidisciplinary team analyzed natural fire in eight previously prepared compartments, with different cladding, fire load and ventilation conditions, with the overall objective of seeking to refine the Eurocodes (Lennow & Moore, 2003).

Reports of full-scale fire research and analysis started to emerge only in the last decade (Corrêa, *et al*., 2017; Lorenzi, *et al*., 2013; Corrêa, *et al*., 2018), but still none comparing Brazilian furniture with furniture manufactured outside the country. An important aspect of understanding the lethality of fires lies in the gases emanating from them. These are the biggest cause of death in these tragic events (David, *et al*., 2017).

One example is exogenous intoxication, which comes from inhaling combustion gases. Nevertheless, surveys collecting and analyzing these gases are rare, especially in the Latin American context (Corrêa, *et al.,* 2017). For this reason, tests were carried out to compare the development of a fire in an average compartmentalized setting, where there was no difference in terms of geometry, construction material and ventilation, but only in terms of the combustible material present in the room, i.e. the furniture.

Accordingly, the aim of these experiments was to check the influence of the composition of Brazilian (first experiment) and foreign (second experiment) furniture and household appliances, manufactured under a different FS regulatory framework. With the concern arising from the gases emanating from the fire, during the experiment, the collection and subsequent analysis was carried out using an experimental protocol (not standardized), since there is no standard in the subcontinent (Latin America) for the collection of fire gases on a real scale.

2. METHODOLOGY

In order to check the difference in fire behavior resulting from the burning of materials manufactured in Brazil and abroad, two similar experiments were carried out using two rooms with a light steel structure (Stell Frame) and drywall walls and ceiling with dimensions of 2.4 meters wide, 3.6 meters long and 2.4 meters high (see Figure 1 below).

In this setting, an opening 0.8 meters wide and 2.1 meters high was placed, representing an open door in a room. This was designed on the premises of the Training Center of the Federal District Military Fire Brigade – CBMDF (as per its Portuguese acronym).

Figure 1 – Setting designed for fire tests.

These rooms were furnished with televisions – TV and sofa manufactured in Brazil (room 1) and TV manufactured in the USA and sofa manufactured in the UK (room 2), respectively. The sofas were slightly different, as it was not possible to buy two identical sofas, but the TVs were similar (same manufacturer and model, only one was bought in Brazil and the other in the USA). The sofas can be seen below in Figure 2. There is only one photo of the TV model, as they are visually identical, see Figure 3.

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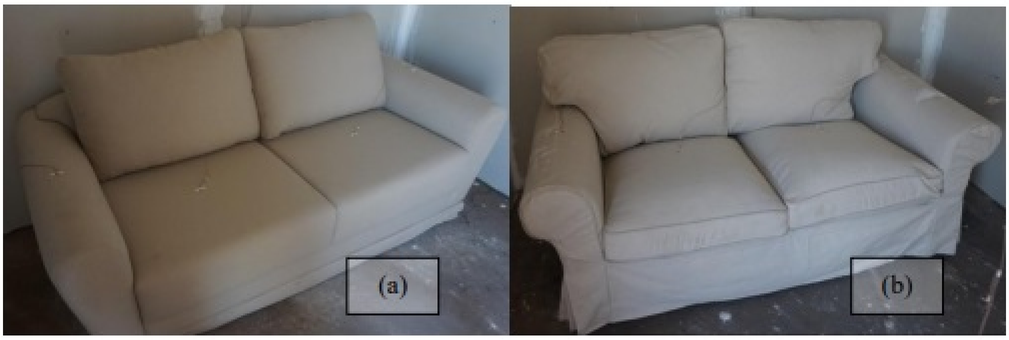
Figure 2 – Photo of the Brazilian (a) and English (b) sofas.



The sofa was placed at the back of the room, away from the door, and the TV was placed on the opposite wall to the sofa, near the door. The layout of the furniture and TV can be seen in the picture below.

Figure 3 - Photo of the position of the sofa (a), the TV (b) and the external view of the TV in the room.

The entire test was monitored using high-definition cameras (yellow arrow), one to monitor the sofa and the other to monitor the TV, as well as a thermal camera (red arrow) also pointed at the sofa (see Figure 4).

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Figure 4 - Positioning of the high-definition (yellow arrow) and thermal (red arrow) cameras.

In order to better assess the fire behavior, k-type thermocouples and Schmidt-Boelter heat flow sensors were used. In total, nine thermocouple sensors were placed in the center of the room, six on the sofa, three on the TV, three on the door and a further six to monitor the temperature of the plasterboard walls (see Figure 2 and Figure 3 above). In addition, a heat flow sensor was placed pointed at the sofa inside the room and another outside, which was pointed at the opening that represented the door (green arrows in Figure 5).

The meters were connected to a cooling system to ensure that the internal temperature of the meter was in its calibration range (white box in the figure below). Throughout the experiment, the thermocouples measured the temperatures, highlighting that the uncertainty in these measurements is in the order of 2.2 °C below 293 ºC and +/- 0.75% above that (Omega Engineering, 2004).

For the case of heat flow, the uncertainty of the calibration component for Schmidt-Boelter type devices is, according to the manufacturer, in the order of ± 3 % (Medtherm, 2003). Results of a study on the response and calibration of heat flow meters show that the expanded uncertainty for Schmidt-Boelter gauge type meters is in the order of ± 8% (Pitte, *et al.*, 2006).

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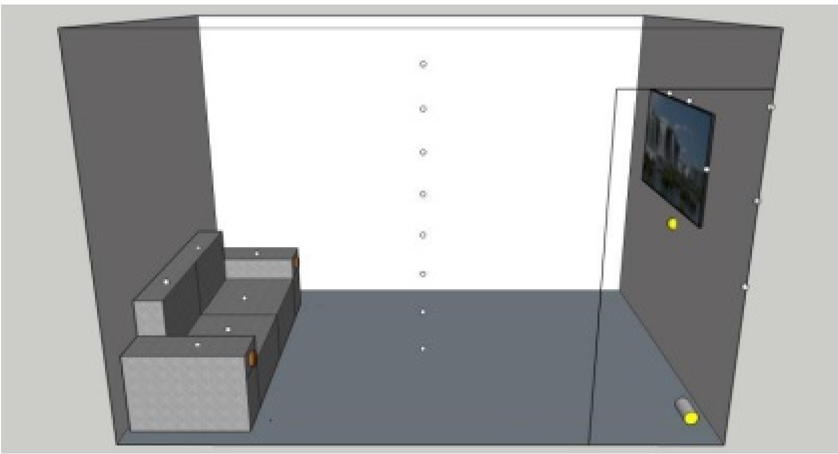
Figure 5 – Location of the heat flow sensors.

The figure below displays the general layout of the room and the furniture and TV. It shows an outline of the devices (white dots for the thermocouples and yellow for the heat flow

Figure 6 – Outline of the test site and its instrumentation.



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All the data was collected on a CompactDAQ chassis with temperature and voltage measurement modules from National Instruments and stored on a computer using a program developed especially for the experiment in LabView.

Figure 7 – Data acquisition system.

The candle was lit and placed on the left side of the sofa, at the junction between the seat and the side armrest and with the wick facing the backrest (see arrow in Figure 8), and the development of the fire was monitored until the sofa combusted. The candle was always placed in the same way and was not moved once it had been placed.

Figure 8 – Position of the ignition source (candle) on the sofa.

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Cylindrical glass ampoules with two taps at the ends and a capacity of 125 ml were used to collect the gases. A semi-vacuum was applied with a 10 ml syringe, which was aspirated ten times in sequence into each ampoule, seeking a standard negative pressure in all collections.

These ampoules were labeled and placed on a bench and used to aspirate the gases in the two experiments, as displayed in Figure 9. For collection, the ampoules were positioned in a small hole in the wall next to the sofa, at a height of 1.6m, approximately where the mouth and nose (aspiration) of a man of average heightare located, according to Brazilian parameters (Figueiroa, 2012).

Figure 9 – Ampoules being prepared and arranged on the bench.

3. RESULTS

The two burnings were carried out on the same day, with a 30-minute difference between them. The weather conditions were favorable (see Figure 10), with no rain, an average temperature of around 23 ºC and relative humidity of 80% (source: INMET).

Figure 10 – Environmental conditions during burning.

Some results obtained are presented below, in particular the temperatures observed in the room, using thermocouples placed in the center of the room, the temperature of the objects (sofa and TV) and the heat flow observed within the room and one meter away from the door. 4.1 – Temperature measurement. The charts below show the temperatures at different heights in the rooms with Brazilian furniture (Figure 11) and foreign furniture (Figure 12). From these charts, it can be seen that the temperatures in the gaseous layer reached higher values, as well as developing more quickly, within the room with Brazilian furniture.

Figure 11 – Temperature chart at different heights in the center of the room with Brazilian furniture.

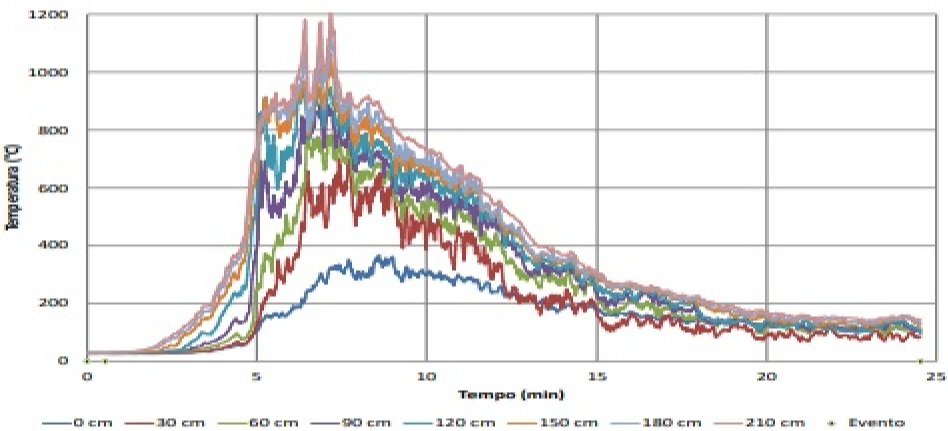

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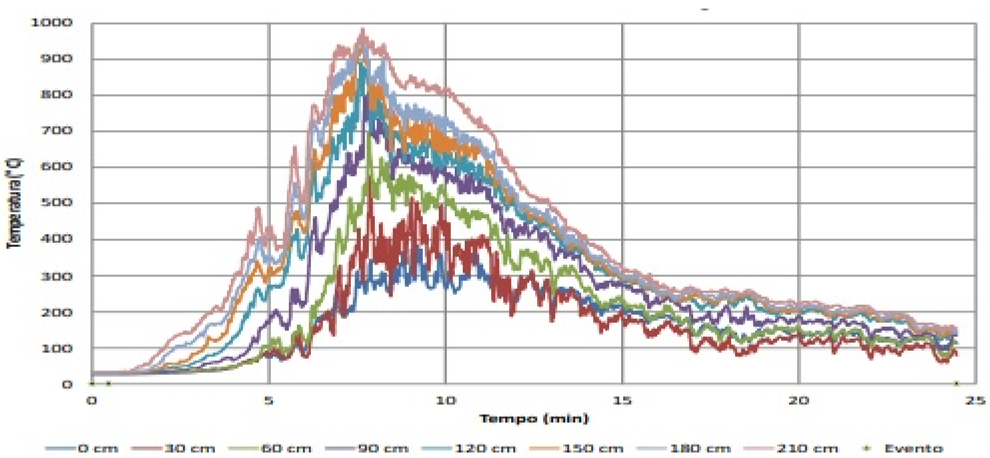
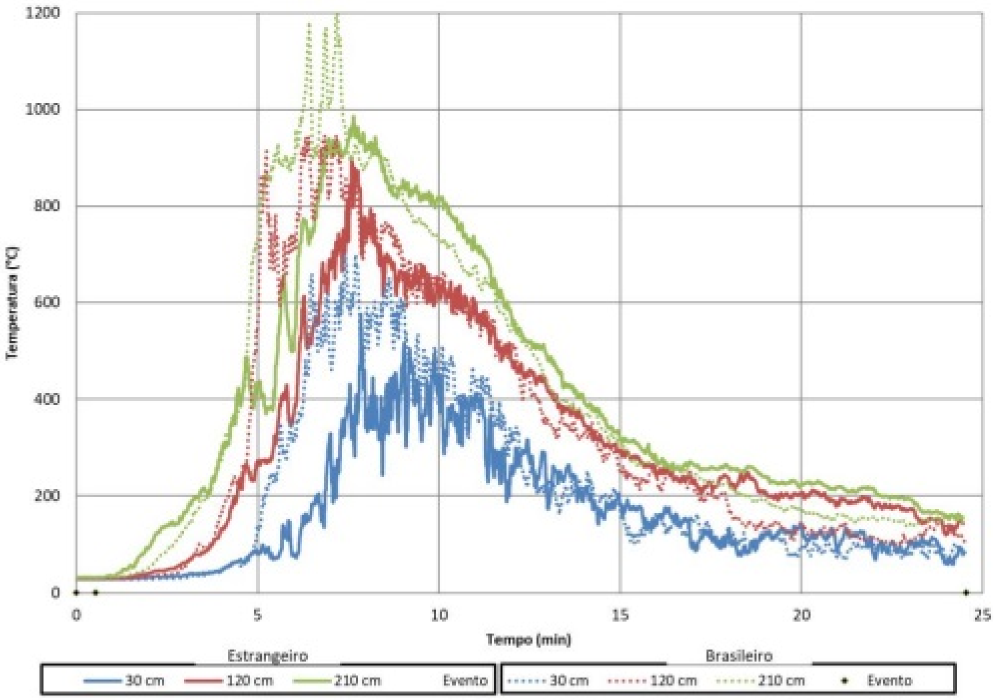
Figure 12 – Temperature chart at different heights in the center of the room with foreign furniture.



The difference in the speed at which the fire temperature develops can be better seen when we compare some curves (30, 120 and 210 cm high) on the same chart (Figure 13).

One can note the difference in speed and temperature increase between the experiments with foreign furniture (solid line) and Brazilian furniture (dotted line). In addition, one cannote that the room with Brazilian furniture, after a quicker start and with higher temperatures, has a temperature decay with time close to the room with North American furniture (see time over 10 minutes), indicating that it not only evolves more quickly, but also remains at high temperatures for longer.

Figure 13 – Comparative temperature chart in the center of the room with foreign (solid line) and Brazilian (dotted line) furniture.



In addition, it was possible to measure the temperature in the sofas and TVs. In the case of the sofas, it can be seen that the Brazilian sofa (Figure 14) has a very close temperature increase in all its parts, showing that the piece as a whole quickly contributes to the magnitude of the fire. In the case of the foreign sofa (English), there was a more gradual temperature evolution, with a difference in temperature evolution between the left and right sides of the sofa.

Figure 14 – Temperature evolution on the Brazilian sofa.

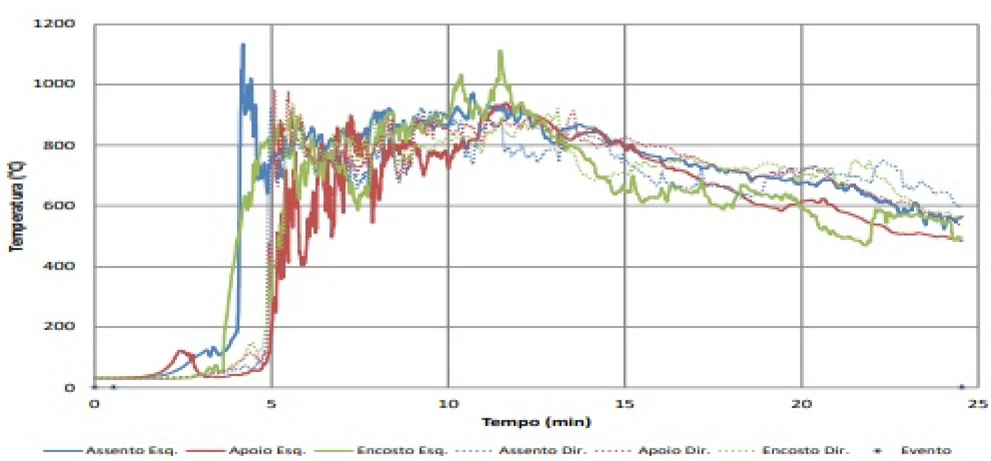
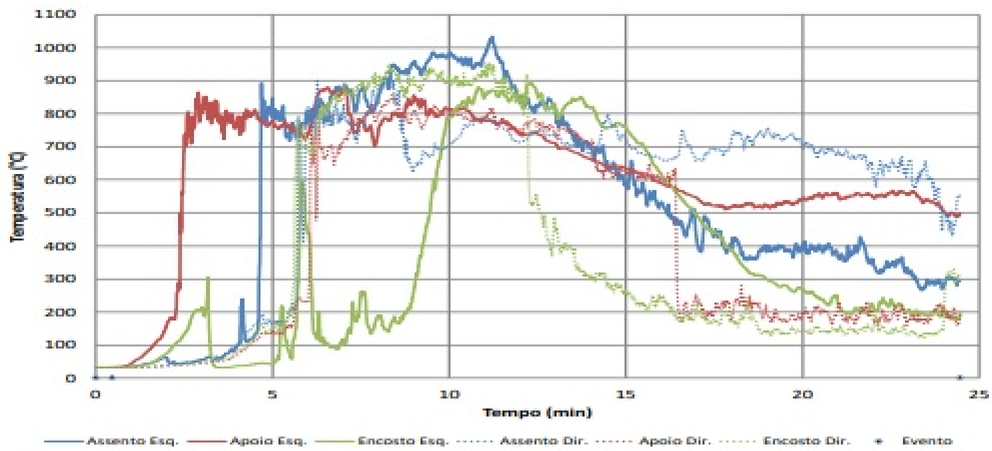


Figure 15 – Temperature evolution on the foreign sofa (English).



In the case of the Brazilian and foreign (USA) TVs, the behavior was similar, but a small difference can be seen in favor of the foreign TV. The chart below shows a comparison of the temperature at the top of the TVs.

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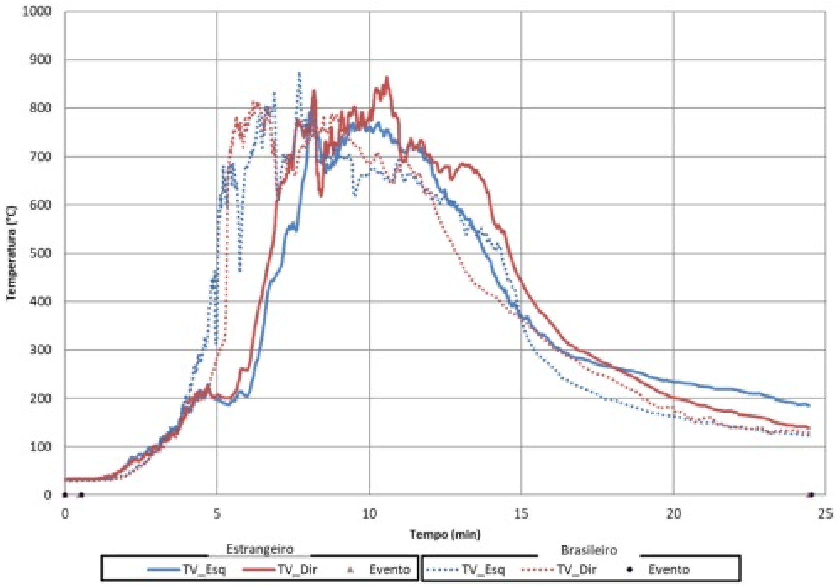
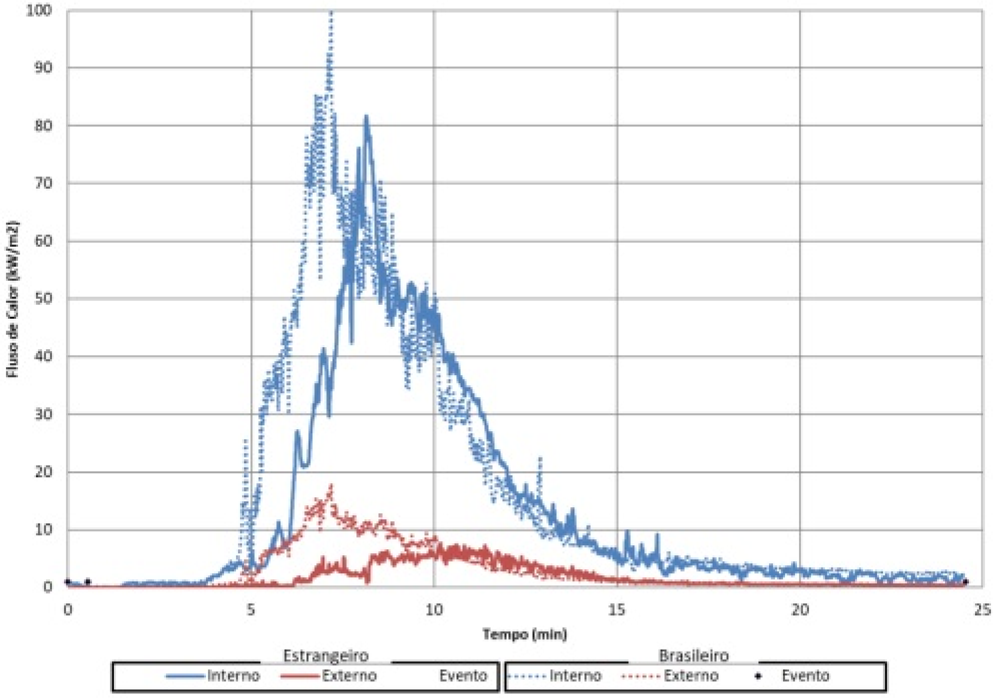
Figure 16 – Comparative temperature chart at the top of the foreign (solid line) and Brazilian (dotted line) TVs.



3.2. Measuring heat flow.

More important than checking the behavior of temperatures in a fire is measuring the heat flow released by it, as this is a direct measure of its magnitude. The chart below (Figure 17) shows that there was a big difference between the two types of furniture. In the case of the room with Brazilian furniture, the heat flow reached peaks of 100kW/m2 inside.When evaluated by the meter placed outside, it reached peaks of around 18kW/m2. For the room with foreign furniture, the internal sensor showed peaks of around 80kW/m2 inside, while it showed peaks of 7.7kW/m2 outside. In addition, one can see that there was a quicker increase in heat flow in much shorter times in the room with Brazilian furniture.

Figure 17 –Chart of internal and external heat flow (1 meter from the door) for the two tested settings (USA solid line and Brazilian dotted line).



3.3. Thermal images – Using the thermal camera images, it can be seen that there is a difference in the visual spread of the fire on the Brazilian (Figure 17) and American (Figure 18) sofas, which is consistent with what was checked by means of the temperature and heat flow sensors.

Figure 18 – Thermal camera image of the Brazilian sofa.

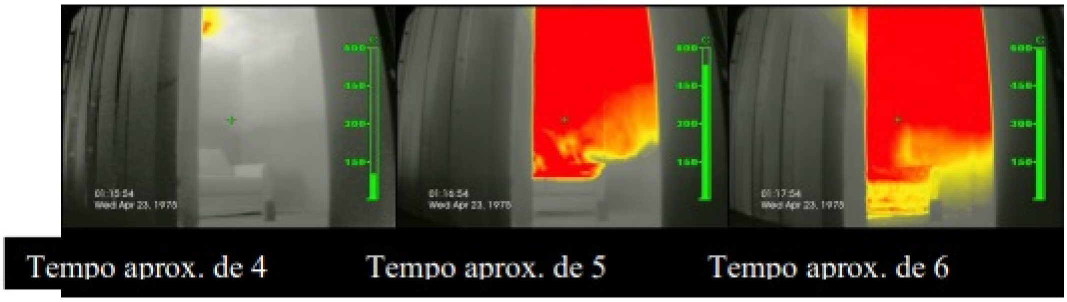


Figure 19 – Thermal camera image of the foreign sofa.

After each gas collection, the small hole used to fit the ampoule was sealed with a plug made of aluminized material, as can be seen in Figure 20.

Figure 20 – Gas preparation and collection.

The samples were analyzed using gas chromatography in a laboratory at the Federal University of Pernambuco. In this analysis, 200 microliters were injected in splitless mode, at a temperature of 40°C for 2.5 minutes, with heating at 20°C/min up to 80°C, maintained for a further 5 min. Porapak-N column, nitrogen as a carrier gas, flow rate of 30 mL/min. It was carried out on an HP 5890 chromatograph with a thermal conductivity detector, recently calibrated and inspected. The first results in terms of CO (carbon monoxide) and CO_2 (carbon dioxide) are displayed in the table below:

Table 1 – Full-Scale Fire Gas Results.

Time (minutes)	Carbon Monoxe (%)	Carbon Dioxide (%)
3	1,60	5,87
5	1,67	5,22
7	1,65	5,33
11	1,70	5,36
13	1,71	5,75

It should be highlighted that the preliminary data refers to the room containing the Brazilian furniture, since there is already a good knowledge of the toxicity of furniture and household appliances manufactured there in the USA and England.

4. CONCLUSIONS

The fire was started with a candle placed horizontally in the left-hand corner of each of the sofas. Once the flame was lit, data collection took place. The starting point was the moment when the sofa material started to catch fire, and the end point of the experiment was the end of the burning of the combustible materials in the compartment.

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In much of the measured data, it was possible to see that the room made up of foreign materials took longer to reach the maximum temperature and heat flow values. Besides that, in general, the maximum values in this setting were always lower, both in terms of temperature and heat flow, when compared to the setting with Brazilian furniture.

Furthermore, the thermal and high-resolution images showed a visible difference in the burning behaviors of these settings, especially in terms of the production of flames and even smoke, as well as the burning time of the TV. Carbon monoxide has a high affinity with hemoglobin, making it a competitor (with much greater chemical attraction) for oxygen (David, *et al*., 2017).

Thus, the monoxide spreads quickly through the blood to all the organs and tissues of the human body (Inacio and Brandão, 2016). However, the main harm from this intoxication is the anoxia resulting from the conversion of oxyhemoglobin into carboxyhemoglobin (COHb), since the affinity of carbon monoxide is around 200 to 250 times greater for hemoglobin than oxygen (Lacerda, Leroux & Morata, 2005).

Exposure to carbon monoxide for a certain period of time at a concentration of 10 ppm will produce signs of poisoning, while it is lethal at 100 ppm for 50% of the population subjected to such an environment for a few minutes (Jachid and Jachid, 2001). Carbon dioxide or carbon dioxide gas is found in atmospheric air in average percentages of 0.03% (Jachid and Jachid, 2001), but this rate was 191 times higher in the experiment at stake.

With regard to the collection of gases, it was found that the rates of carbon monoxide and carbon dioxidecould be lethal for an occupant standing in the burning setting from the third minute after the start of combustion at a height of 1.6m, revealing the possibility of using the experimental protocol as another parameter for measurements made in full-scale fire experiments.

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