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Fire in residence in the City of Recife: An experimental study

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ABSTRACT

This article presents the results of an experimental test of a fire in a bedroom of typicalbuilding burned in Recife city – Brazil. A room in the Pernambuco Fire Department training facility, a structure of reinforced concrete with a ceramic bricks' wall, has been used. The room has been renovated and adapted for the test. This compartment has been prepared with furniture and household appliances generally found in a typical firethat occurs in the city during three-year period of 2011-2013. The test was setup with 24 type K thermocouples to monitor the thermal behavior of the gas layer of the dormitory, as well as the temperature on the furniture and walls, both internal and external sides. The experiment has been monitored through hi-resolution camera and thermal image camera, in other to show an effective cooling down of the walls using atomized waterapplied by the firefighting crew.

Keywords: fire in dormitory; fire in building; real fire; safety for fire.

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Incendio en compartimiento de residencia en la ciudad de Recife: Un estudio experimental

RESUMEN

Este artículo presenta los resultados de un estudio experimental, de un incendio en dormitorio de edificaciones típicamente incendiadas en la ciudad de Recife – Brasil. Se ha utilizado una habitación en estructura de hormigón armado y sello en blocs cerámicos, del taller de entrenamiento del Cuerpo de Bomberos, que ha sido remodelado y adecuado para el experimento. Este compartimiento ha sido preparado con mueblería y objetos encontrados en incendios ocurridos en la ciudad en el trienio 2011-2013. Se ha realizado 24 mediciones térmicas con termopares tipo K, en la búsqueda del comportamiento térmico del dormitorio, en la mueblería y paredes, en la faz interna y externa. El experimento ha sido seguido por medio de imágenes VHS y cámara térmica, mostrando un eficaz enfriamiento en las paredes con el uso del jacto atomizado, aplicado por el equipo de combate a incendio.

Palabras clave: incendio en dormitorio; incendio en edificaciones; incendio real; seguridad contra incendio.

Incêndio em compartimento de residência na Cidade do Recife: Um estudo experimental

RESUMO

Este artigo apresenta resultados de um estudo experimental, de um incêndio em dormitório de edificações tipicamente incendiadas na cidade de Recife – Brasil. Utilizou-se um cômodo em estrutura de concreto armado e vedação de tijolos cerâmicos da oficina de treinamento do Corpo de Bombeiros, que foi reformado e adequado para o experimento. Este compartimento foi preparado com mobiliário e objetos encontrados em incêndios ocorridos na cidade no triênio 2011-2013. Realizou-se 24 aferições térmicas com termopares tipo K, buscando-se o comportamento térmico no dormitório, no mobiliário e paredes nas faces interna e externa. O experimento foi monitorado através de imagens VHS e câmara térmica mostrando um eficaz resfriamento nas paredes com uso do jato atomizado aplicado pela equipe de combate a incêndio.

Palavras chaves: incêndio em dormitório; incêndio em edificações; incêndio real; segurança contra incêndio.

1. INTRODUCTION

The building fires in Brazil, in spite of the high frequency, still not fully understood (RODRIGUES *et al*., 2017). The buildings most susceptible to the fire, their occupancy, the ability for a building to resist the effects of fire capacity and mainly protection of life of building occupants, are information not yet consolidated in Brazil (HAHNEMANN *et al.*, 2017).

In order to propose an easy and feasible method for this mapping, based on the recommendation of ABNT NBR 14023 (1997), the fires of the city of Recife, State of Pernambuco, was studied during the triennium of 2011-2013. It was possible to verify the predominance of fires in residences, almost all of them built with a single floor and destined as a single-family housing (CORRÊA *et al*, 2015). Later, a representative model of the damaged buildings was established, which was called the 'Modal Building', with its layout represented by the furniture and household appliances found most frequently in the mapped fires (CORRÊA *et al.*,2016).

It is presented in this paper a real fire experiment in one of the bedrooms of this Modal Building. The bedroom was chosen based on the high frequency of fire origin in this room verified by Corrêa *et al* (2015).

In order to represent this bedroom, it was used a room of the Pernambuco Fire Department training facility. The room has been renovated and adapted for the test. The fire load was compatible with the furniture in the Modal Building's bedroom. Finally, the compartment was subjected to a real fire, which was monitored by hi-resolution camera, thermal image camera and 24 type K thermocouples placed at different heights in the center of the bedroom, in all furniture, and on the internal and external faces of the walls.

As result, it was observed that:

1. among the objects, the highest temperatures were observed in the bunk bed (main element of the fire load consumed);
2. comparing the walls, the highest temperatures were measured on the wall of the compartment door; and
3. the maximum temperatures reached by the gas layer (sensors at the middle of the compartment) occurred at 2,10 m height.

At the final stage of the fire, around 40 minutes from the beginning, a fire fighters team extinguished the remaining flames and cooled down the walls using the 3D firefighting technique.

2. LITERATURE REVIEW

Many studies use structural components subjected to high temperatures with the use of furnaces and radiant panels in order to understand the behavior of these structures in a fire situation (ZAGO *et al*., 2016; PIRES *et al.*, 2012; LAIM *et al*., 2014). But the interaction and dynamics of the objects, the thermal behavior, and the flow and effects of flammable gases impose greater difficulty to be simulated precisely in ovens or bench scale equipment, making the construction of specific experiments necessary.

Real fire experiments are still rare events in Brazil and Latin America. Considering risks and costs, some studies use buildings that have suffered fires to through the testimonies and analysis of the scenario estimate the event (Silva et al., 2007). In these cases, the fire dynamics monitoring is perspective, most of the time using a computer fire simulation.

However, some initiatives of real fire experiments are worth mentioning, such as the experiment carried out by Lorenzi *et al.* (2013). They studied the fire in a furnished house built in steel sheets with polyurethane filling. It is noteworthy that the beginning of the fire occurred in the living room of the house and sought to validate the fire safety of an expanding construction technology in the south of Brazil.

In North America and Western Europe, where fire safety is handled with higher investments, it is interesting to note that the great experiment carried out by the National Institute of Standards and Technology (NIST), with the support of the New York Fire Department (FDNY) and the Federal Emergency Management Agency (FEMA). A series of 14 real fire experiments were conducted in a 7-storey building, where various development and fire-fighting dynamics were tested, all 14 events started with a fire in the respective furnished room. (NIST, 2009).

Cardington, in the United Kingdom, was a highly visible initiative where a multidisciplinary team analyzed the natural fire in eight pre-prepared compartments with different cladding, fire loads and ventilation conditions, with the main objective being the refinement of Eurocodes (LENNON and MOORE, 2003). In all these studies, the temperature curve has the classical characteristics presented in Figure 1.

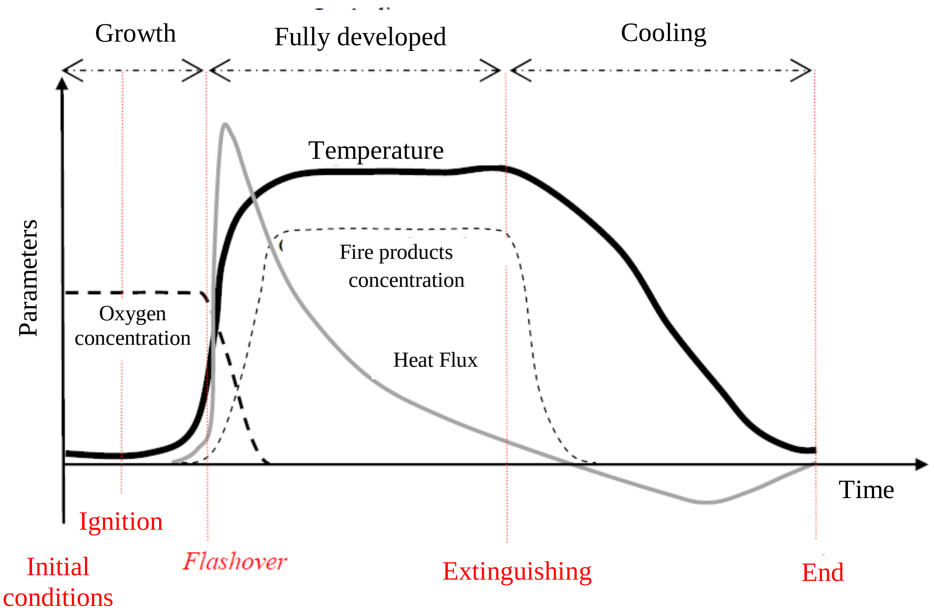


Figure 1. Temperature curve associated with the different parameters of a compartmentalized fire (Torero, 2011).

3. METHOD AND EXECUTION OF THE EXPERIMENT

During the three-year period of 2011-13, a study was carried out to create a modal construction to represents the set of more than a thousand buildings burned in this period in the city of Recife-PE (CORRÊA et al., 2015). This study presents the Modal Building as a single-family residence, built primarily on masonry, with 97 square meters and a fire load inspired by the objects most found in fires.

A reproduction of one of the Modal Building’s bedroom in an experimental environment in a a room of the Pernambuco Fire Department training facility, built in reinforced concrete structure and non-structural ceramic block wall, in addition to the pre-cast slab celling. This room, very similar in size to that found in the model determined by Corrêa *et al*. (2016), was renovated and the four walls were prepared in a different way: two with Roughcast, one with cement mortar and one with plaster mortar. Thermocouples were installed on the internal and external sides of the walls in order to compare the different coatings.

The fire load of the bedroom was the furniture and household appliances determined in the research of Corrêa *et al*. (2016): 01 (one) wooden bunk bed, 01 (one) single wooden bed, 03 (three) foam mattresses, 02 (two)large and 01 (one) small Medium Density Particleboard night stands, 01 (one) Medium Density Particleboard wardrobe, 02 (two) fans and 01 (one) small tube television, plus 20 kg of clothes and 4 kg of paper, all purchased in a used furniture store, so the objects would be compared to the fire load found in the city of Recife houses. Figure 2 reproduces the place and objects.

Figure 2. Rehearsed Compartment (Sketch)

After the room was renovated, it was properly prepared with the described furniture and the measuring instrumentation. The Figure 3 below shows the bedroom just before the test.

Figure 3. Bedroom setup before the fire.

The fire load used, represented by the furniture and appliances in the dormitory, can be observed in Table 1. The value was calculated based on the weight of the pieces and the measurements provided in fire codes used in Brazil (CBMSC, 2014).

Table 1. Bedroom's Fire load.

Object	**Material type**	**Quant.**	**Dimensions**			**weight (kg)**	**density (kg/m³)**	**Calorific value (MJ/kg)**	**Fire load (MJ)**
			length (m)	**depth (m)**	**height (m)**				
Tubo TV 18"	Polypropylene, glass, electronic components, etc.	1.00	0.36	0.40	0.34	9.90	910.00	43.00	425.70
Fan, 40 cm, 6 blades	Polypropylene, electronic components, etc.	1.00	0.50	0.35	0.68	2.86	910.00	43.00	122.98
Fan, 40 cm, 3 blades	Polypropylene, electronic components, etc.	1.00	0.45	0.32	0.63	2.40	910.00	43.00	103.20
Clothes	Fabric	1.00	-	-	-	20.00	390.00	21.00	420.00
Papers	Paper	1.00	-	-	-	4.00	770.00	17.00	68.00
Wardrobe	MDP (Medium Density Particleboard), Plastic, etc.	1.00	1.35	0.47	2.25	90.00	658.52	21.00	1890.00
Small night stand	MDP (Medium Density Particleboard), Plastic, etc.	1.00	0.37	0.32	0.49	5.60	658.52	21.00	117.60
Large night stand	MDF (Medium Density Particleboard), Plastic, etc.	2.00	0.52	0.41	0.45	12.90	750.00	21.00	541.80
Bed	Wood, plywood	1.00	0.95	2.04	0.97	33.40	588.46	21.00	701.40
Bunk Bed	Madeira	1.00	0.85	1.95	1.57	48.00	588.46	21.00	1008.00
Mattress (Bed)	Polyurethane foam	1.00	0.80	1.87	0.15	5.20	23.97	23.00	119.60
Mattress (Bunk bed)	Polyurethane foam	2.00	0.71	1.91	0.16	7.10	33.78	23.00	326.60
								Total fire load (MJ)	5,844.88

The 11.70 m² dormitory was filled with a total load of 5,844.88 MJ, giving a fire load of 499.56 MJ/m², well above the 300 MJ/m² foreseen in recent Brazilian standards (CBMMG, 2013, CBMGO, 2014).

For the temperature measurements during the test, 24 (twenty-four) type K thermocouples were installed in the compartment as shown in Figure 4.

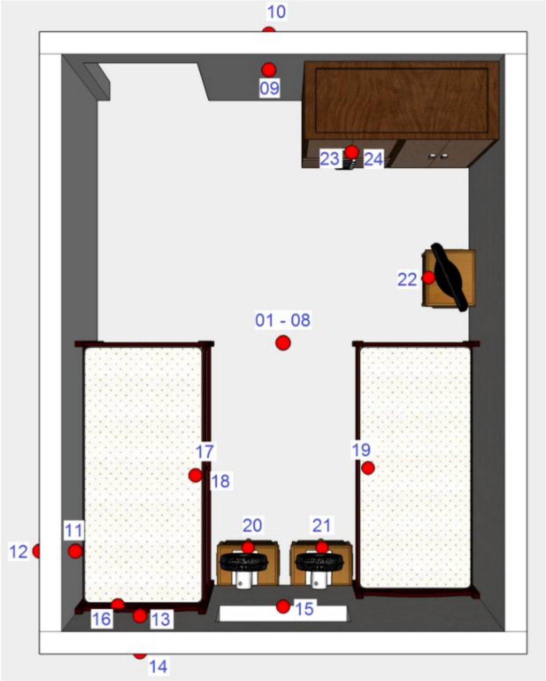


Figure 4. Thermocouple position in the bedroom.

The positioning of the thermocouples had the following correspondence with the numbers shown in Figure 4: 01 to 08, arranged on the stem shown in the figure, installed at 0.3, 0.6, 0.9, 1,2, 1.5,1.8, 2.1 and 2.4 meters; 09 and 10, internal and external sides of the walls with cement mortar coating; 11 and 12, internal and external sides of the walls with plaster coating; 13 and 14, internal and external sides of the walls with Roughcast; 15, window; 16, collection of gases; 17 and 18, bunk bed, upper and lower bed respectively; 19, single bed; 20 and 21, large nightstand (positioned next to bunk bed and single bed respectively); 22, small nightstand with the TV set; 23 and 24, wardrobe, positioned at the door and on the hangers respectively.

The 01 to 08 thermocouples allow observing the temperature at several heights, making possible to investigate the different position of a man standing, crouching, and crawling or the gas layer temperature near a furniture. The installation of the thermocouples on the walls was made 2.1 m high and 0.5 m from the vertices, except for the wall with cementitious plaster where the thermocouples were the same height and 0.5 m from the entrance portal.

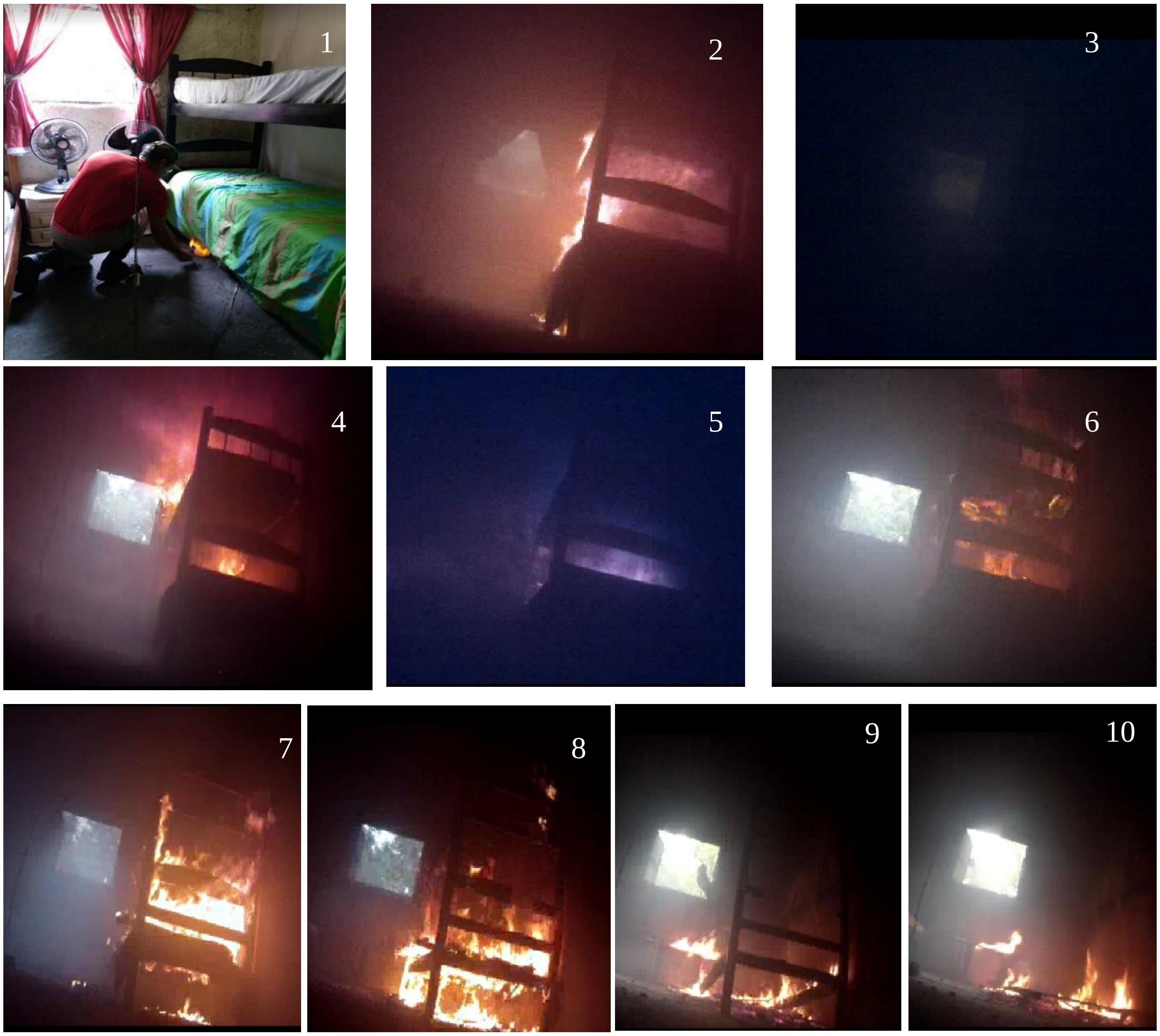
In addition, the experiment was recorded for the complementation of the analysis, using hi-resolution camera and thermal image camera. That way it was possible to have a better understanding of the fire behavior during the whole test. The hi-resolution camera remained in a 3 cm diameter hole located in the wall near the door, while the thermal image camera was placed outside of the room, taking the pictures and recording the video from the window that remained open during the whole experiment.

The experiment was carried out in the morning on March 9, 2017 and lasted a little over 45 minutes, after that it was extinguished by the firefighters. The fire was initiated using a paraffin device used ignite fireplaces. The substance (paraffin) and the location of the ignition point were also inspired by the occurrences verified by Corrêa *et al*. (2015).

Initially, the door of the room remained closed. It was opened after 18 minutes of the test, allowing the cross ventilation in the compartment. It wasn’t used any ventilation or exhaustion equipment during the test.

4. RESULTS

Some results are highlighted below, showing the time line, temperature analysis and image representation. Figure 5 shows the chain of the events of the experiment:



1 - 00min35sec–Fire was started using the paraffin device;
2 - 03min56sec–Start to ignite the upper mattress of the bunk bed;
3 - 06min22sec - Saturation of combustion gases;
4 - 07min38sec - End of the saturation by natural exhaust of the gases and air intake with return of the flames;
5 -10min36sec - New Saturation of combustion gases;
6 -11min49sec - End of the second saturation by natural exhaust of the gases and air intake with return of the flames;
7 -18min02sec - Opening doors allowing cross air circulation;
8 - 19min04sec–fire propagation to a different material;
9 - 21min29sec–The plastic fan over the nightstand start to ignite;
10 -41min43sec - Total collapsed of the bunk bed;

Figure 5. Timeline of the experiment

The thermocouples were used to measure the temperatures during the test. It was used the National Instruments 4 modules USB CompactDAQ, with NI 9213 measuring module, which has sensitivity up to 0,02ºC. The uncertainty inherent in the thermocouple is in the order of 2.2 ° C below 293 ° C, and +/- 0.75% above that (OMEGA, 2004). Example of the data can be seen in the Figure 6 below.

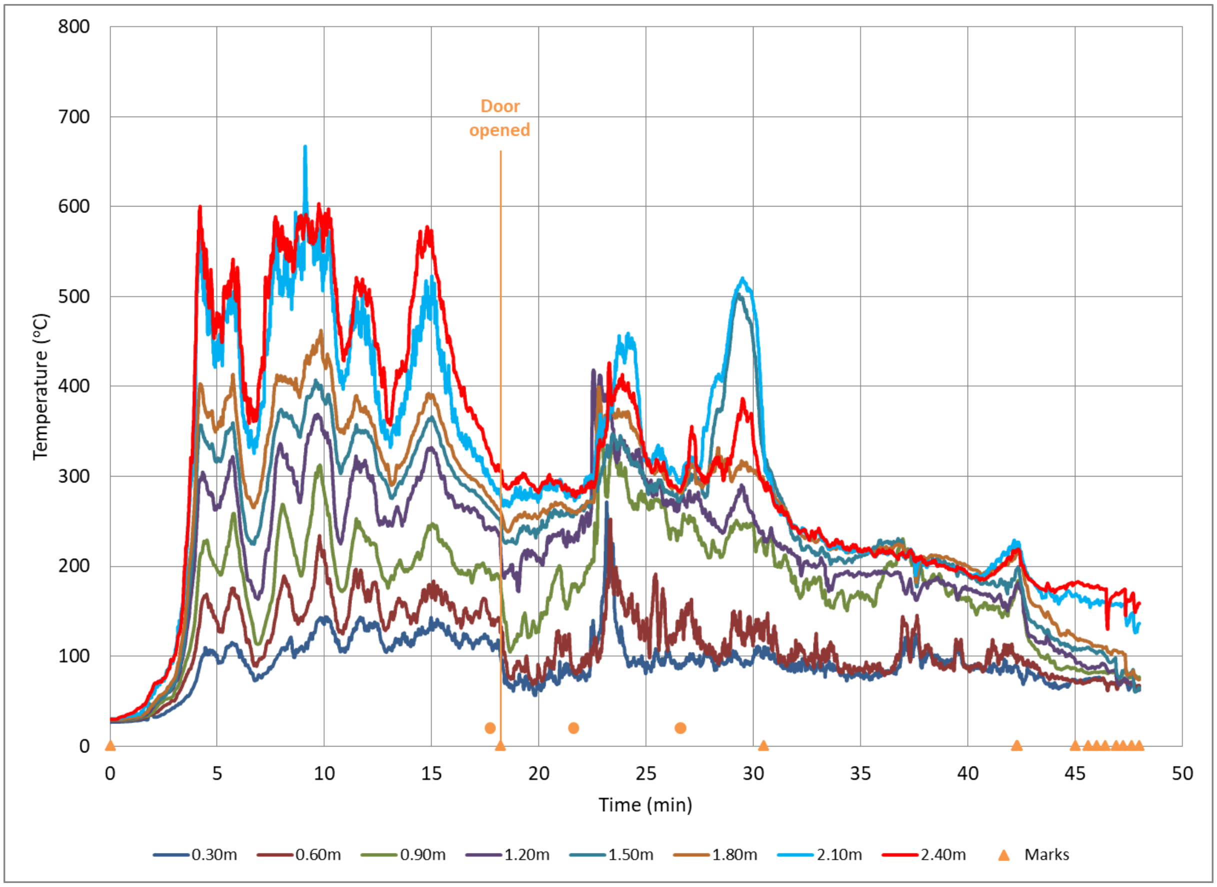


Figure 6. Temperature at different heights at the center of the bedroom.

It was observed a temperature rise in all eight thermocouples at the center of the bedroom during the first 4 minutes. It happened until the gas saturation occurs, where the internal pressure is higher than the external one, preventing the ingress of the atmospheric air and, consequently, the ingress of the oxygen. The thermocouple at 2.40m reached 600ºC in 3 minutes and 40 seconds.

The high internal pressure promotes a slow exhaustion of the gases, followed by a gradual decrease of the temperatures until, approximately, the seventh minute, when a new entrance of the atmospheric air, rich in oxygen, makes the fire alive again (with presence of intense flames and luminosity). The temperature increases, reaching667ºC at 2.10m from the florin 8 minutes and 35 seconds. Once again, the large production of combustion gases follows a decreasing of the air / oxygen intake, making the temperature decrease more than 100° C at the highest level.

These cycles will repeat a few more times until the fifteenth minute, when the temperatures begin a progressive decline. The highest temperature reports 300ºC and the lower ones less than 100ºC, showing the classic cooling phase described by Torero (2011).

It should be noted that, with rare exceptions, the thermocouples in the center of the room showed a certain compatibility with temperatures increasing and decreasing at the same time in all different height until the opening of the door at 18 minutes. With the opening of the door and the establishment of cross ventilation in the room, the temperature in the center of the bedroom changed the previews behavior, without presenting a common pattern. Cross-ventilation allowed the hot gases to circulate from one side to the other. After 23 minutes, the temperature of the thermocouple at 0.60 m is higher than that of the thermocouples at 2.10 m and 2.40 m. Without cross-ventilation, such situation would be unlikely by the convection principle demonstrated by Janssens (2016).

After 30 minutes, the temperatures were divided into two patterns: the five thermocouples closest to the ceiling (2.4m, 2.1m, 1.8m, 1.5m and 1.2m) present temperatures close to 200ºC and the three thermocouples closest to the floor (0,9m, 0,6m and 0,3m) present temperatures close to 100ºC, but both patterns present an almost linear decrease, characterizing cooling phase of the fire.

It is noteworthy that the flashover never occurs in this experiment. It is also observed that time-temperature curve of this fire differs from the classical one presented in Figure 1, mostly by the cyclic movement of Flame Combustion - Gas Saturation - Natural Exhaustion - Oxygen Intake - Flame Combustion, creating valleys and peaks in the time-temperature curve.

The objects temperature can be seen in the Figure 7 below.

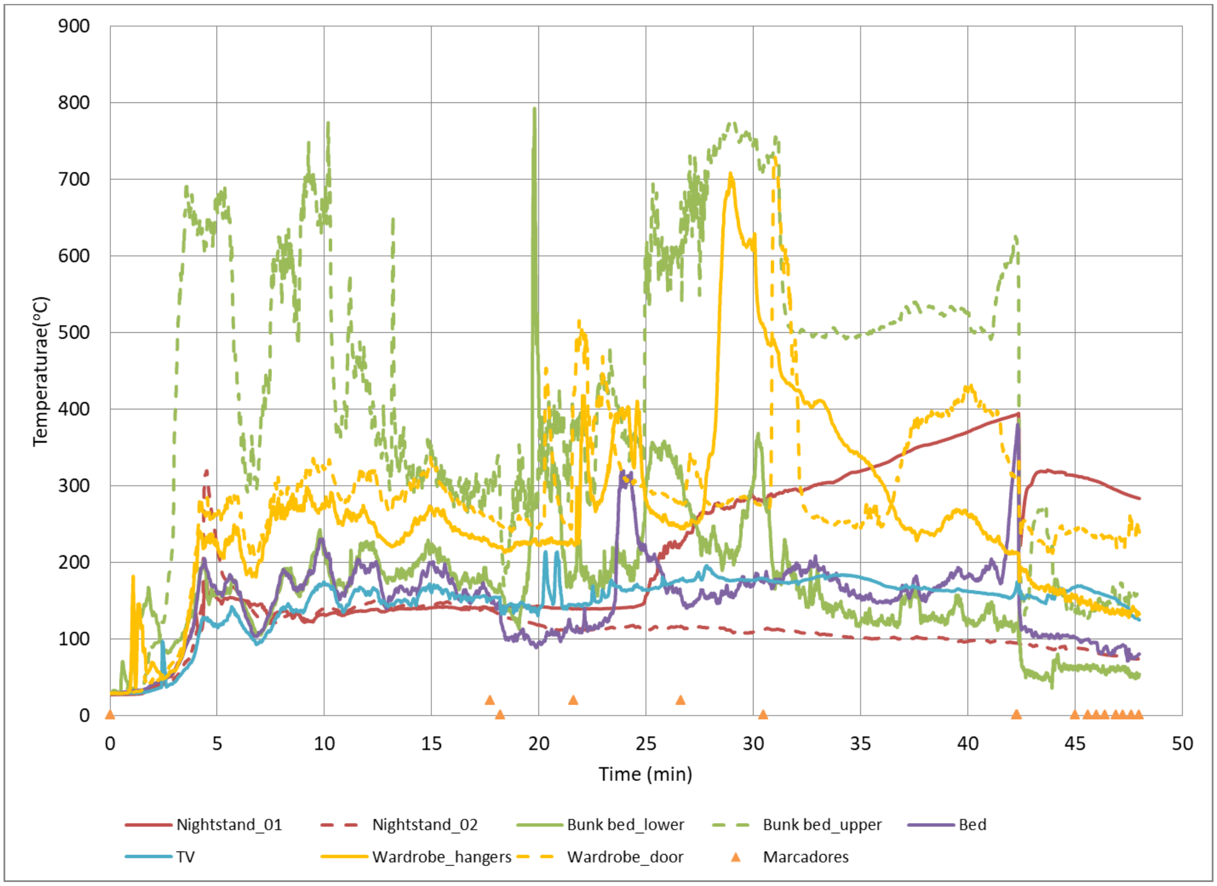


Figure 7. Temperature of the objects.

It is seen that the highest temperatures were measured in the lower bed of the bunk, getting close to 800ºC in several moments (10, 19, 27 and 31 minutes). This is compatible with the fact the fire was started there and the object had consistent flames for more time. It is also noteworthy, especially after the first 25 minutes of firing and with the door opened (18 minutes), the increase in temperature in the wardrobe's door and hangers, with both reaching temperatures above 700ºC. This temperature can be explained, in part, by the convection of the gases into the wardrobe, which was facilitated by its geometry. In addition, some clothes went into combustion, increasing the heat.

The inside and outside temperature of the walls were also measured. All of them had cement mortar facing externally, but there were three different types of internal lining: cement mortar, roughcast and plaster mortar. The two walls closed to the bunk bed were those with roughcast and plaster mortar. Figure 8 below shows the graph representing the temperatures measured on the walls during the experiment.

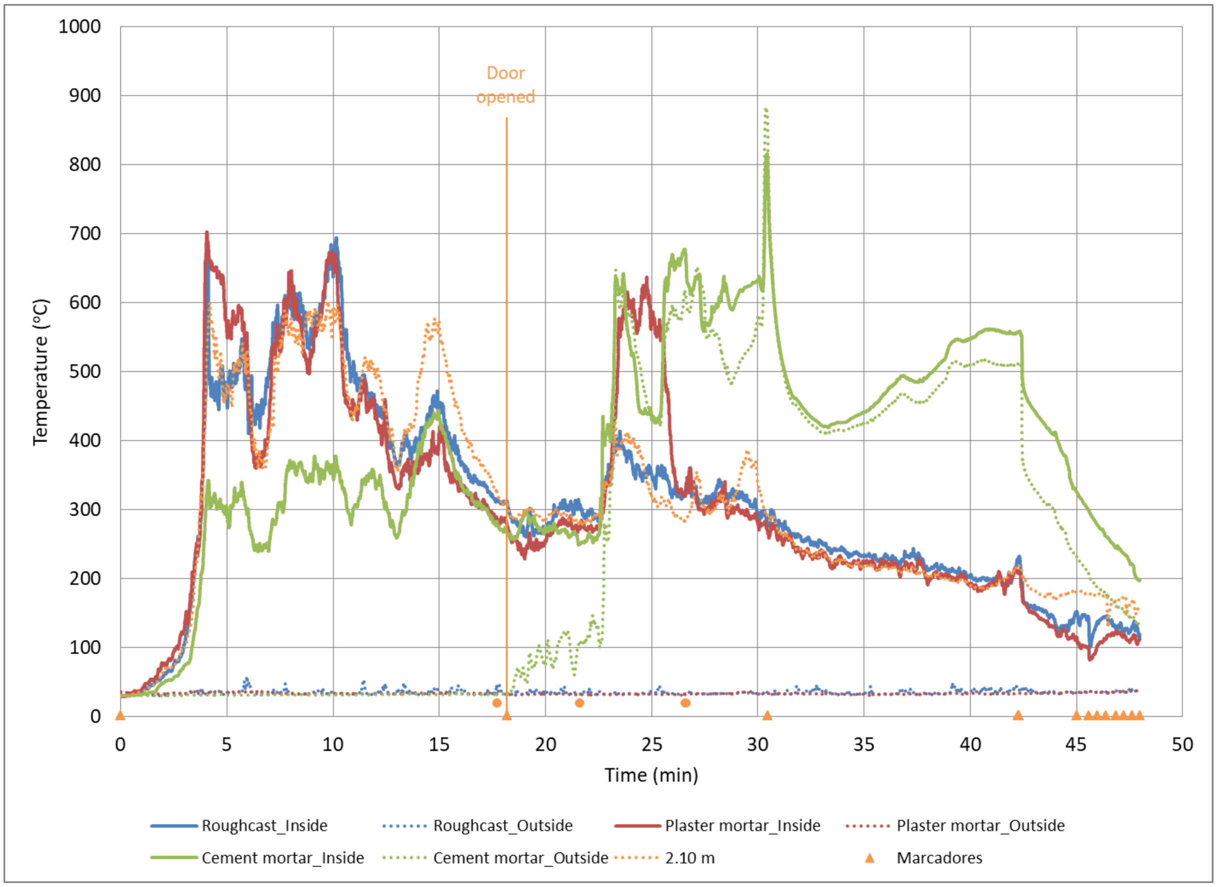


Figure 8. Temperaturas aferidas nas paredes interna e externamente

The temperatures in the internal walls, especially those with roughcast and plaster mortar (closer to the initial fire ignition point) followed the temperature behavior of the gas layer, measured in the center of the bedroom, until the door is opened. It can be seen from the comparison of these two thermocouples with the one located at 2.10 m of floor height in the Figure 8 above.

After 4 minutes, the wall with plaster mortar reached 702ºC on its internal face, while the roughcast wall reached 641ºC. At 9 minutes and 54 seconds the roughcast wall was subjected to 684ºC and the plaster mortar at 662ºC, these being the highest recorded temperature. It is worth mentioning that both have a very close temperature until the door was opened.

The cement mortar wall (further away from the initial fire ignition) had temperatures below 400°C until 14 minutes and 12 seconds, when it reached the highest temperature before the door was opened.

The temperatures of all the inner walls after the door opening were close up to the 22 minutes, when the plaster wall temperature increases substantially, reaching values higher than 600°C.

In the exterior wall temperatures, there is little variation until the door is opened, with values not exceeding 60ºC. There was a significant increase in the temperature of the external face on the wall with cement mortar after opening the door and consequent cross ventilation, reaching more than 645°C in just over five minutes. There were peaks and valleys above 400°C in this wall, reaching 878°C at 30 minutes and 24 seconds.

To examine in more detail the thermal conduction from the masonry walls, internally lined with plaster mortar, roughcast and cement mortar, it can be used the Figure 9 below.

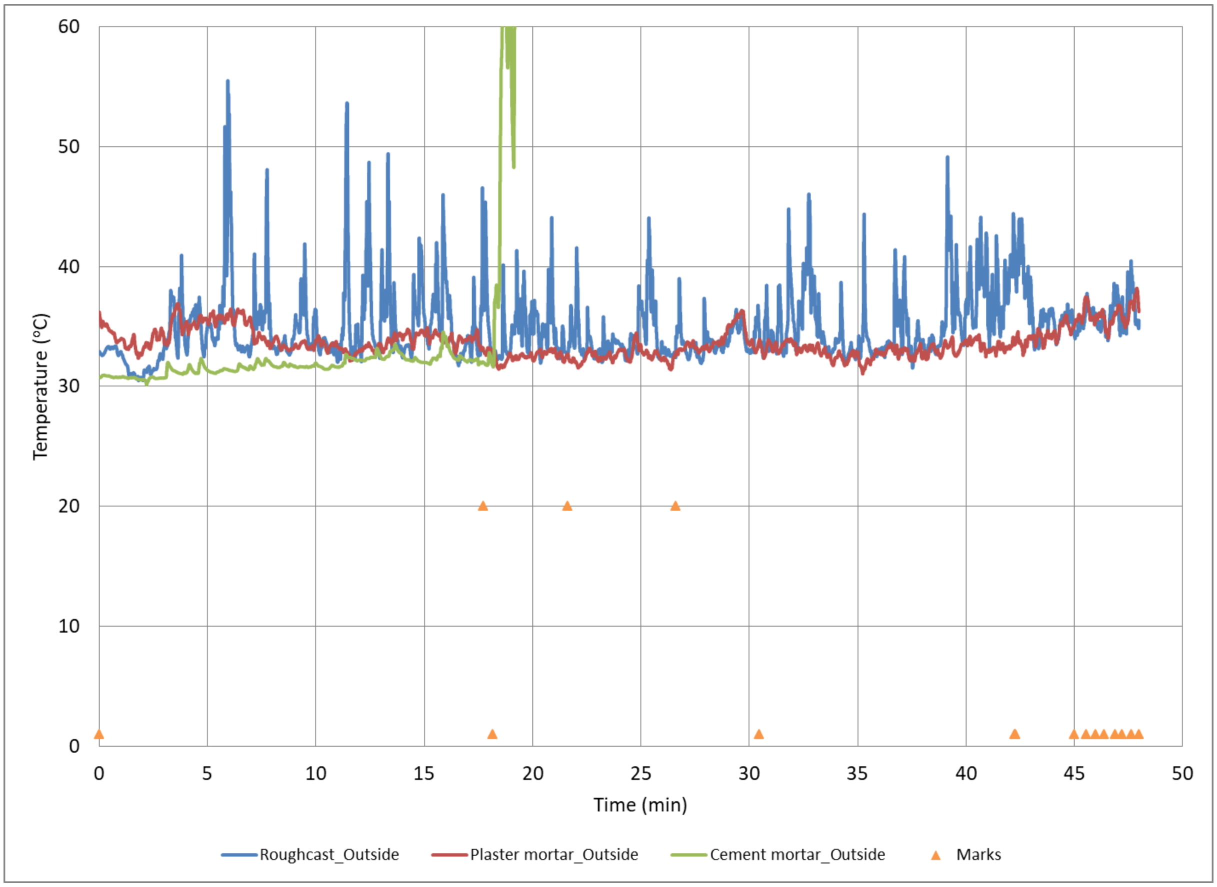


Figure 9. External wall temperatures.

It was observed that the high internal temperatures were not conducted to the outer face of the walls, even those walls closer to the fire ignition point. The abrupt rise of the external temperature of the cement mortar wall is associated with the opening of the door and the beginning of the cross ventilation, showing that the opening of a fired compartment can increase substantially the temperature of the contiguous rooms and, consequently, helping the fire propagation.

When it was analyzed only the walls with roughcast and plaster mortar, there was a good thermal insulation for both. Even with internal temperatures exceeding 680ºC, the external face did not reach temperatures higher than60ºC. However, comparing the performance, the roughcast was less effective than that of plaster mortar. The first one reached 54.38°C at 5 minutes and 58 seconds and the second reached a maximum temperature of 38.19°C at 47 minutes and 49 seconds of experiment.

Thermal images were taken by a technician in thermography provided by the company 'FLIR Thermal Camera'. Figure 10 shows some comparative images between those captured by conventional and thermal image cameras.

Figure 10. Thermal images of the firefighter's entry.

Using thermal image cameras can provide a large amount of information for the firefighters. It can help to locate the fire through the smoke layer, as well as pointing out different structural components such as ceramic bricks hidden beneath the coating, or even give indications of structural failure not perceived by the naked eye, leading to the evacuation of the affected and adjacent areas.

Another factor highlighted by the thermal imaging is the process of structural cooling, as seen in Figure 11.

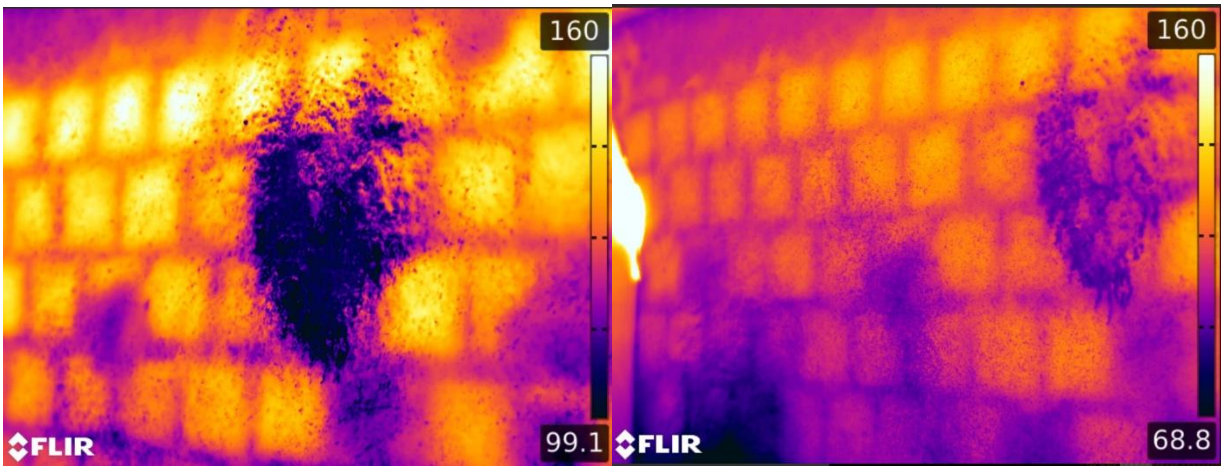


Figure 11. Thermal Imaging of Structural Cooling.

In the thermal images above, the efficiency of the application of the 3D firefighting technique, water spray applied using 1 ½-inch fire hose, with a working pressure of 8 Kf /cm^2 (PSI) at a flow rate of 30 gallons per minute, with 60º opening and pulses of 1 to 2 seconds, on the walls.

In the first image, a single jet provides almost instantaneous reduction from 160°C to 99.1°C, while in the second image a set of a few jets lowered the wall temperature to 68.8°C in many spots of its area.

It is worth mentioning that one of the night stands was painted with wood-specific paint from CKC Brazil, applied according to the manufacturer's instructions. The study of the behavior of this piece during a natural fire will occur in another paper.

After the experiment, it was observed some furniture completely consumed (bunk bed, mattresses, fans) or partially consumed (cabinet and television). The walls were completely charred, but without any sign of visible pathologies. Figure 12 shows the images of the room after the fire.

Figura 12. Imagens do cômodo após o incêndio.

5. CONCLUSIONS

It is concluded initially that this kind of experimental study (based on a statistic of more than 1,000 fires and with well monitored) is still scarce in Latin America.

The fire load of the bedroom analyzed is much higher than that specified in the Brazilian standards, which, as a general rule, indicate 300 MJ / m² for this type of building, in contrast to the 499.56 MJ/m² calculated from the appliances and furniture indicated by Corrêa *et al*. (2016).

It was observed a time-temperature curve quite different from the “classical” curve, associated to the oscillation mainly due by the cyclic process of Combustion - Gas Production - Gas Saturation - Natural Exhaustion - Oxygen Intake - Flame Combustion. It could be expected, since the “classical” curve is qualitative and presents temperature average.

Among the furniture, the highest temperatures were observed in the bunk bed, the main element of the fire load consumed, and in the wardrobe. Even though it was not fully evolved, it showed temperatures above 700ºC. The geometry of the objects can facilitate the concentration of hot gases and thermal flow, this being one more factor to be evaluated by the Fire Safety Codes.

The internal walls near the ignition point (plaster mortar and roughcast) had similar temperatures, reaching peaks of temperature up to 700ºC during the growth and fully development phases.

Thermal conduction of masonry walls was low in this experiment, with outside temperatures below 60°C. However, when compared with the conductivity of the walls covered with plaster mortar and roughcast, there is a difference in favor of the first one, which had a maximum temperature of 38.19°C, while the second was 54.38°C.

The opening of a door in a room, such as the one set up for the experiment, changes the dynamics of the fire, allowing cross-ventilation. It can bring the heat flow quickly to adjacent compartments, as measured by the thermocouple external face of the wall with cement mortar, propagating the fire if there is combustible material in this compartment.

The cooling of the walls in masonry by 3D firefighting technique proved to be quite effective, as seen in the thermal images. These images can also be used for optimization of the firefighting technique, as well as the examination of the structures during and after the fire.

Finally, the use of a compartment with dimensions, structural characteristics, fire load, and dynamics similar to those found in statistical survey, generates relevant results. However, the repetition of experiments based on fires data must be pursued in order to get more general conclusions.

6. AKNOWLEDGMENTS

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