International Journal of Emerging Engineering Research and Technology
Volume 7, Issue 1, 2019, PP 38-46
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Full Scale Testing of Fire Performance on A House Construction System Assembled With Sandwich Steel and Polyurethane Structural Panels

Luciani Somensi Lorenzi; Kássio Joe Stein; Luiz Carlos Pinto da Silva Filho.

Universidade Federal do Rio Grande do Sul, Laboratório de Ensaios e Modelos Estruturais (LEME), Avenida Bento Gonçalves, CEP 91509-900 - Porto Alegre, RS, Brasil.

***Corresponding Author:** Luciani Somensi Lorenzi, Universidade Federal do Rio Grande do Sul, Laboratório de Ensaios e Modelos Estruturais (LEME), Avenida Bento Gonçalves, CEP 91509-900 - Porto Alegre, RS, Brasil. luciani.lorenzi@gmail.com*

ABSTRACT

This paper contains the test results of a fire behavior test performed in a full scale house prototype built with 60 mm thick steel sandwich panels. Each panel was composed of two 6mm galvalume steel plates and a core of expanded polyurethane (PU) or expanded polystyrene (EPS), depending on the intended use of the panel. This configuration is an innovative construction system used in Brazil. The study was conducted by a multidisciplinary team including civil engineers, thermography experts, gas collection and analysis experts, and fire control experts. The purpose of this test was to increase the knowledge about the behavior of these construction systems on fire situations using the results obtained. Actual scale tests are extremely rare in Brazil due to their costs and complexity, and no national standards for conducing these tests are available, although they are the best alternative to gather information about the dynamics of fire evolution and for building system responses. This study enabled us to analyze the user's ability to escape the incident, the potential extent of the damage, and the resistance of the fire system.

Keywords: *Fire Resistance, Steel Sandwich Plates, Polyurethane.*

INTRODUCTION

Civil construction in Brazil is undergoing a major transformation pertaining the performance standards of residential buildings. This is a time to consolidate practices, discuss test methods and their parameters to ensure the performance of buildings in accordance to the NBR 15.575/2013 [1] building standard.

The new approach to the performance of residential buildings promoted by the implementation of the NBR 15.575 brings to this sector a more rational vision of building techniques, representing a promising research scenario to the Brazilian academy and its civil construction industry.

This approach transforms the industry and directs its focus to the discovery of new techniques to enhance the performance of future buildings.

This study is based on an innovative system of modular construction. This system represents the development of new concepts, with unusual material and uncommon structural elements. Despite the actual regulations, Brazilian civil construction community still needs to establish minimum performance standards for these new systems in order to make this type of building safe.

MATERIALS AND METHOD

The testing of full-scale buildings in fire situations is a never seen practice in Brazil. There is no Brazilian standard that specifies or regulates these types of testing procedures. The procedure used during this study was developed by researchers at the Laboratory of Testing and Structural Models (LEME) located at Universidade Federal do Rio Grande do Sul (UFRGS).

It was based on several national standards ([1], [2], [3], [4], [5] and [6]) and technical instructions from the Fire Department of São Paulo and Minas Gerais ([7] and [8]). International studies performed at NIST [9] and the international standards [10] and [11] also guided the present study.

The test was designed to obtain sufficient experimental data to support a consistent analysis of the fire dynamics of the building system. It was intended to evaluate the possibility of users to escape the building on fire and the effect that a fire situation on such kind of building would have on the vicinity.

The behavior of this new assembly system during a fire, especially the behavior of PU and EPS was also analyzed. Three requirements and criteria related to the performance evaluation of the constructive system [12] were defined, as follow:

- Requirement1:possibility for users to escape from the casualty; Criterion: quality of indoor air and escape time;
- Requirement 2: potential damage for the neighborhood;
  Criterion: analysis of temperature and air quality of nearby buildings;
- Requirement 3: fire resistance; Criterion: ruin of the building.

The strategy adopted was to build a prototype in real scale and instrument it to observe its behavior during an induced fire.

Prototype Description

The test was conducted in a 39.42 m² prototype, built using this new constructive system composed of sandwich panels made of dual galvalume steel plates with a core of expanded PU weighing 11.13 kg/m².

The panels were embedded into the system and the joints were sealed with PU tape.

The walls were stiffened by steel tensioning cables crossing the panels on the top and bottom regions, giving them structural capacity.

The roof of the prototype was composed of sandwich tiles made of galvalume steel plates and EPS core, without lining.

The frames were made of aluminum with 3 mm thick glass. The doors were made with the same sandwich panels as the walls and finished with metallic profiles.

Three barriers were built 3 m away from the outside walls of the prototype, with the objective of providing protection to the team collecting data, and to simulate the presence of neighboring buildings.

The barriers were constructed with the same material of the prototypes and instrumented to collect data about the levels of temperature at the surface of neighboring buildings as illustrated in Figure 1.

Fig1. *General view of the prototype.*

The prototype fit Class A-1 according to the Table B.1 of ABNT NBR 14432 [2] and required a fire load of 300 MJ/m² according to Table C.1 of the same Brazilian code. The furniture placed in the prototype resulted in a fire load of 306.37 MJ/m². This fire load was chosen according to the Table 1 and distributed according to the Figure 2.

It is relevant to point out that the actual load of 306.37 MJ/m² is relative to the main room of the prototype; the other rooms were furnished according to the usage expectancy and the actual loads were not estimated since they would not influence the test by increasing fire load.

The choice of using ordinary furniture for this prototype was made with the intention of simulating a real fire situation with a similar fire load that such an inhabitation would contain. The material characterization was performed based on Table C3 of ABNT NBR 14432/2001. [2]

The starting point of the fire was chosen with the help of the Fire Department, which experience indicated that most unintentional fires in Brazil start in the common areas of the houses or in the bedrooms, and not in the kitchen area as many assume. The statistics of the Fire Department [13] indicate that one of the most common causes of fire in Brazil are candles left unattended. Based on this information, the ignition point was positioned in the living room area and it was defined as a lit candle on the couch, as shown Figure 2.

This situation was also convenient to simulate the worst circumstances for the user’s perception of the fire. Someone asleep in the bedroom would need more time to notice the danger.

Table1. *Furniture employed to simulate the fire load.*

Description	Quantity	Calorific Potential (MJ)
Couch	01	434,00
Sofa	01	233,70
Pillows	04	31,00
Blanket	02	138,00
Ottoman	01	190,00
Stereo	01	19,00
Side Table	01	380,00
Table Ornament	04	28,00
Dinner Table	01	923,40
Chair	04	570,00
Rug	01	372,00
Curtains	02	54,00
Book Shelf	01	1.100,00
	Total (MJ)	**4.473,1**
	Room Area	**10,60**
	Room Fire Load (MJ/m²)	**306,37**

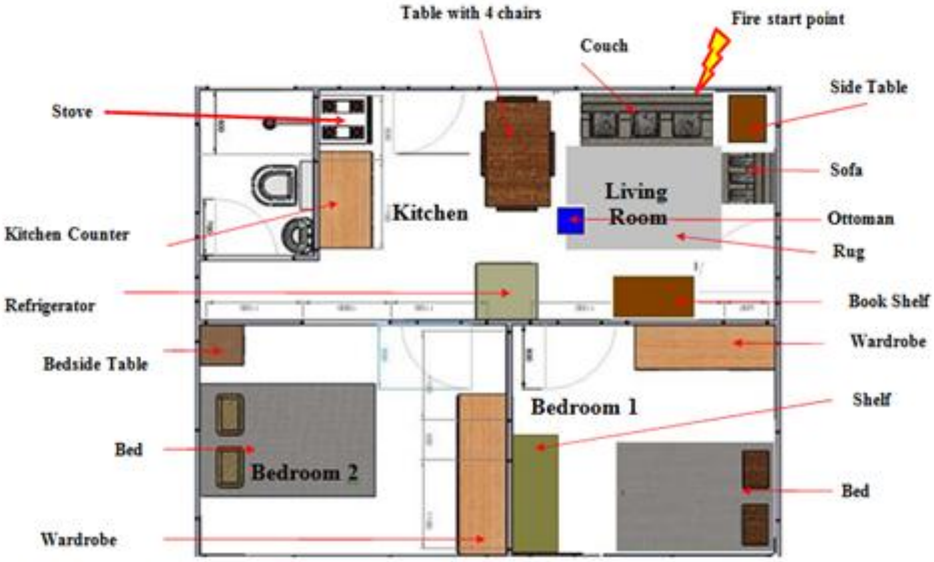


Fig2. *Fire load distribution in the prototype and fire start point location.*

Instrumentation

The experiment was monitored with sensors and specific equipment used to collect gas originating from the fire. The internal and external wall temperature was measured in several rooms with thermocouples. The prototype was instrumented with:

- 23 K-type thermocouples with a precision of 13°C and maximum temperature measurement of 1370°C – 5 located outside the prototype and 18 located inside the prototype;
- 1 PT100 thermocouple with a precision of 0.1°C and maximum temperature measurement of 300°C – located on the surface of the B1 barrier;
- 8 gas collectors with suction bombs – 5 internal and 3 external;
- 16 video cameras – 8 internal and 8 external;
- 2 thermographs – one fixed and one transportable.

Twelve thermocouples were positioned as three trees that measured the heat in different heights; one tree located in each of the prototype's extended-stay rooms (kitchen and bedrooms).

The heights of each thermocouple located in each tree were 0.6, 1.20, 1.80, and 2.20m, and each tree was able to record 12 temperature measurements. The other thermocouples were placed on the internal and external surfaces of the wall and one was placed at the window closer to the start point of the fire. An accurate scheme of the placement of each thermocouple can be seen in Figure 3.

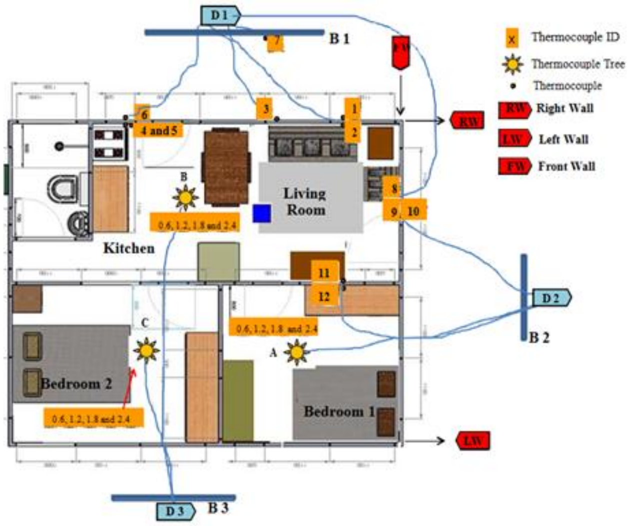


Fig3. *Thermocouple and measuring station locations.*

An example of the thermocouple trees can be seen in Figure 4b, which shows an internal view of the prototype with the thermocouple trees C (front) and B (back) in display.

Fig4. *Instrumentation* - *(a) gas collectors located close to the B2 barrier;(b) thermocouple trees inside the prototype.*

The five internal gas collectors were metallic or ceramic tubes connected to suction bombs used for aspirating the gases, the locations of these collectors is shown in Figure 5 and an example of them can be seen in Figure 4a. Three external gas collections were also placed near the B1, B2 and B3 barriers.

Fig5. *Distribution and location of gas collectors.*

Eight external camcorders were placed approximately 5.0 m away from the prototype to avoid the need for thermal protection.

Eight internal high resolution webcams were protected with double metal boxes covered internally and externally with ceramic blankets. Their lenses were protected by refractory glass.

RESULTS AND DISCUSSION

The fire simulation test on the prototype started at 09:37 a.m, when a candle placed on the living room couch was lit. At this point, the first samples of gases were collected and the first temperature measurements were performed.

(a) (b)

Fig6. *Prototype after collapse: (a) camcorder view e (b) thermograph view.*

The time of the end of the test was 10:08 a.m. and it was characterized by the collapse of the structure, 31 minutes after starting the test. Images of this moment are shown in Figure 6. During the test, some important events that occurred must be described. The wind registered on the day of the test was from north and northeast with speeds ranging from 4.0 to 6.0 m/s. The wind affected directly the results of the test, since the smoke generated by the fire was carried to the south side of the prototype (close to theB3 barrier). Visible flames decreased and the fire seemed too died out 6 minutes after the beginning of the test. The data indicates that at this moment the PU of the roof tiles started to volatilize, generating a very hot gas that caused the self-ignition of the roof tiles and spread of the fire.

Internal Data

Internal temperatures were also monitored throughout the test, with data collected at every second from the start of the test until 28 minutes later, when the data loggers and computers were removed to prevent damage. The temperatures in each of the thermocouple trees during the test can be observed in Figures 7, 8, and 9.

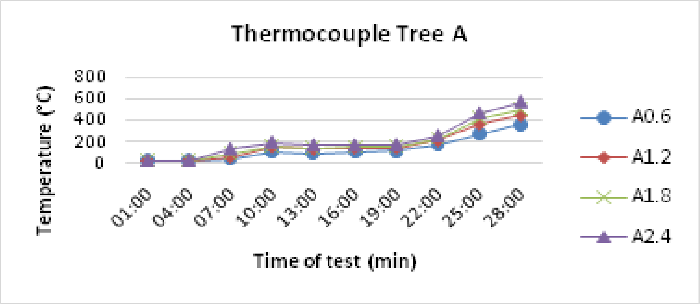


Fig7. *Temperatures collected by the thermocouple tree A.*

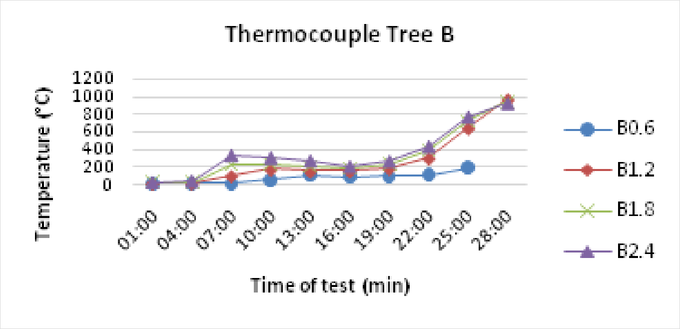


Fig8. *Temperatures collected by the thermocouple tree B.*

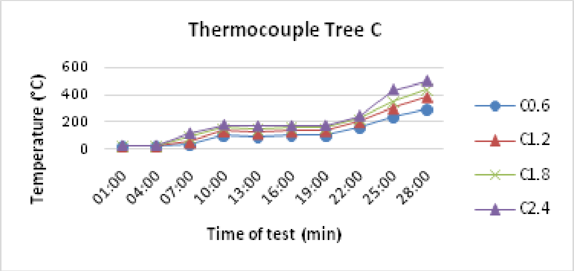


Fig9. *Temperatures collected by the thermocouple tree C.*

At the beginning of the test, the average temperature assessed from the twelve thermocouples positioned at the center of each of the extended-stay rooms was 22ºC. Approximately seven minutes after the start of the ignition process, the temperature in the living room/kitchen (tree B) was about 230% higher than the average temperatures measured in bedrooms 1 and 2, located 1.20 m away. Throughout the test, the higher the thermocouple was positioned, the higher was the temperature recorded, as expected. The temperatures recorded by the thermocouple tree B, located in the kitchen/living room showed that the temperature of 900°C was reached by every functional thermocouple by the end of the test, regardless of the height of the sensors. The internal thermocouples, located in different rooms, showed considerably different temperatures, and their measurements are shown in Figure 10. The thermocouple T11, located on the side of the panel that faced the fire, 7 minutes after the start of the test, registered 79°C. At the same time, the temperature of the thermocouple T12, located on the side of the panel that faced the bedroom 1, was only 27°C, showing a difference of 48°C between the two sides of the panel. The highest temperature difference between the two sides of this panel was registered 24min22sec after the start of the test. It happened at the moment when the side of the panel that was exposed to the fire was at 612° C and the non-exposed side of it was at 113°C. At this point, the furniture inside bedroom 1 started to ignite, and increased the temperature even more.

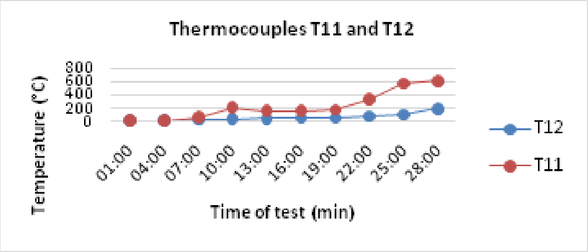
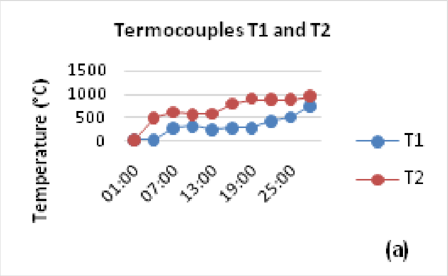


Fig10. *Different temperatures on each side of the sandwich panel for the living room and bedroom 1.*

The difference of temperatures between external wall tiles was measured by the thermocouples T1 and T2 located on the kitchen door, and showed a considerably lower temperature on the external side of the wall panel, as can be observed in Figure 10. The same behavior was noticed near the fire source by the thermocouples T1 and T2, as shown in Figure 11.



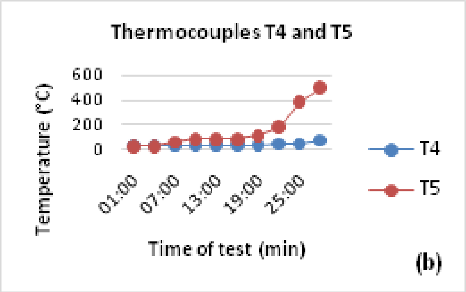
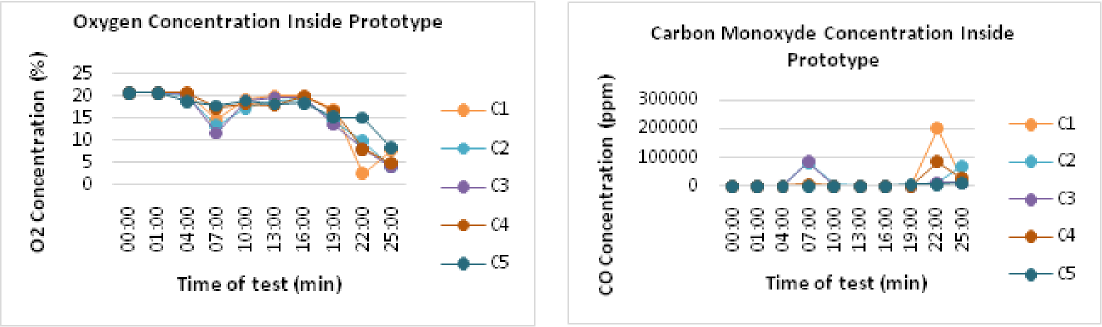


Fig11. *Different temperatures on each side of the sandwich panel for: (a) the living room and external area; (b) the kitchen and external area.*

The last location chosen for this type of measurement was close to the fire source with the thermocouples T9 and T10. This reading point was lost, since the thermocouple T9 malfunctioned at the beginning of the test.

Images collected by the internal web cams were not conclusive due to the low visibility caused by smoke. Only the first four minutes produced visible images that could be used for consistent conclusions. In the period between 00:00 minutes and 27:00 minutes of the test, ten samples of gas from inside the prototype were collected and analyzed. Figure 12 shows carbon monoxide and oxygen concentrations for each environment: C1 (Kitchen), C2 (Bedroom 1), C3 (Bedroom 2), C4 (Living Room), C5 (Living Room).



(a) (b)

Fig12. *(a) Oxygen concentration decrease inside prototype; (b) Carbon Monoxide concentration increase inside prototype.*

Due to budget constraints, data collection focused on concentration of CO and O^2 gases (HCN concentration analyses were not performed). For the first two samples, the temperatures were mild and the gas concentrations were very low, compatible with human survival. From the 3rd collection (4 minutes from the start of the test) onwards, we observed that carbon monoxide (CO) concentration increased significantly. The concentrations of remaining oxygen (O^2) were above 20%, and the temperatures remained mild. The temperature at collection point C5, which increased to 49ºC, was an exception of it. After 7 minutes (4th data collection), high concentrations of CO were detected, especially in C2 (Bedroom 1) and C3 (Bedroom 2), with peaks of 83,500 ppm and 84,000 ppm, respectively. The concentration of O^2 dropped significantly to 17.8%, and the temperatures increased significantly, with a record of400°C on C5. These conditions threaten human survival and can be explained by the volatilization of PU from the roof panels that occurred at 06:30 minutes of the test. This fact was crucial for the quick auto-ignition process of the furniture inside the prototype, since the high temperature of the gases released caused a generalized increase in temperature.

External Data

The temperatures recorded on the B1 barrier, used to simulate a neighboring building, were around 36ºC at the beginning of the test, and progressed to 46°C after 29:18 minutes of test (time of last reading, since the measuring device was removed before collapse to prevent damage). Thermographic records of B1 barrier are shown in Figure 13. These thermographic readings indicate the existence of radiating temperatures higher than those measured by the thermocouple T7, located on the surface of the B1 barrier.

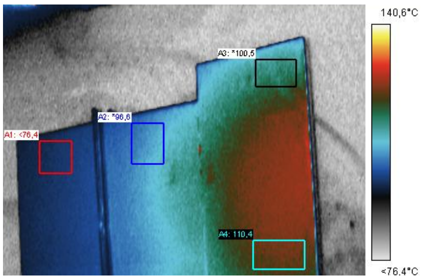


Fig13. *Thermographic image of barrier B1 18min after test start.*

Nine minutes after the collapse of the prototype, the temperature registered by the thermograph near the B1 barrier was around 246°C, while the debris of the prototype measured 1120°C.

Gas collection outside the prototype was performed via suction devices, and used to evaluate the effect on the neighborhood. The collection was performed by technicians protected by the barriers in 6-minute intervals, as shown in Figure 14.

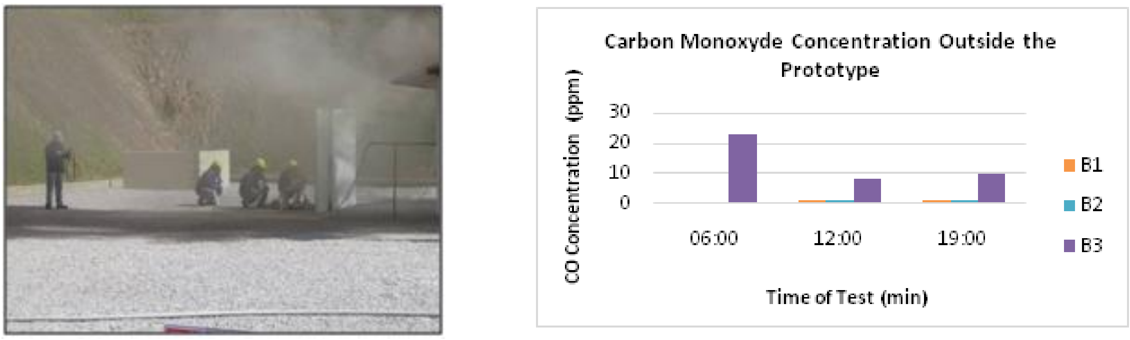


Fig14. *(a) Collection of external gases near the barrier B3; (b) Concentration of carbon monoxide at external environment.*

In the three samples, the oxygen concentration remained relatively stable and above 20%. Carbon monoxide presented a small variation and its maximum concentration was recorded during the third collection at the B1 barrier (23 ppm). These concentrations do not endanger the neighborhood.

CONCLUSION

It is possible to observe a direct correlation between air quality and temperature behavior in the prototype. Low temperatures and low concentrations of CO were reported in the first 4 minutes of the test. These concentrations maintained oxygen levels above 20%. During the interval between four and seven minutes, air quality changed abruptly inside the prototype, with the concentration of CO rising to levels that are highly harmful for humans [14].

The main factor that explains the increase of CO within 6min30s of the test was the ignition of the EPS, used as a filling for the sandwich tiles of the roof. The PU sandwich panels had a better performance under fire. After the EPS was consumed by the fire, the temperatures and gas concentrations decreased considerably.

The analysis of the dynamic evolution of gases and temperatures indicates that the time available for humans to flee the prototype on a fire situation is, at this studied scenario, 6min30s from the start of the fire. It is relevant to notice that this period could be shorter due to HCN gas concentrations that could not be measured in this study. Based on the Technical Instruction [8] it can be concluded that this 6min30s would be an appropriate time period for the occupants to escape. This Technical Instruction considers the minimum exit time for buildings with high risk of fire and smoke propagation should be 2min30s.

The data collected indicates the prototype behaves appropriately in regards to the safety of the neighborhood during fire situations. This happens because the side walls and roof do not release sparks or glowing pieces that could ignite neighbor residences. This test represented a worst-case scenario, when there are no firefighting operations.

The temperatures generated within 3 meters of the prototype were elevated, though not enough to cause auto ignition of materials in nearby buildings. Air quality in the vicinity was not significantly diminished. Concentration of CO remained less than 20 ppm, and the percentage levels of oxygen never fell below satisfactory levels (20%). The maximum radiance temperatures developed during the test and recorded by thermographs were of approximately 240°C, below the critical threshold that would cause the auto ignition of most materials. The prototype collapsed 31 minutes after the ignition started and 24 minutes after full fire development. The Technical Instruction [7] defines the Fire Resistance Time Required for a structure to resist before collapsing due to fire action. For this type of building the Instructions defines a minimum fire resistance time of 15 minutes. The evaluated structure resisted 16 minutes beyond the required time.

Finally, it is possible to state that this innovative constructive system behaves in accordance with the current Brazilian Fire Requirements and Regulations for this type of building. This new system can be used with caution as an alternative to combat housing deficit, improving construction time and accuracy. Nonetheless, further studies are still necessary to define the exact influence the gases released by these sandwich panels on the propagation of flames and the user's evacuation. Furthermore, it is highly recommended that the current Brazilian regulations are reviewed, so that the performance requirements for the innovative construction materials in fire situations are properly and more specifically defined.

REFERENCES

[1] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (2010) NBR 15.575 – "Edifícios habitacionais de até cinco pavimentos – Desempenho".

[2] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (2001) NBR 14.432 – "Exigências de resistência ao fogo de elementos construtivos de edificações – Procedimento".

[3] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (1989) NBR 10.636 – "Paredes divisórias sem função estrutural – determinação da resistência ao fogo";

[4] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (1986) NBR 9442 – "Materiais de construção – determinação do índice de propagação superficial de chama pelo método do painel radiante".

[5] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (2006) NBR 15.366 – "Painéis industrializados com espuma rígida de poliuretano – Parte 2: Classificação quanto à reação ao fogo".

[6] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, ABNT. (2001) NBR 5628: Componentes Construtivos Estruturais – Determinação da resistência ao fogo.

[7] INSTRUÇÃO TÉCNICA IT 08/2004–SP – "Segurança Estrutural nas Edificações: Resistência ao fogo dos elementos de construção".

[8] INSTRUÇÃO TÉCNICA IT 37/2010–MG – "Centros Esportivos e de Exposição: Requisitos de Segurança Contra Incêndio".

[9] NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY. NIST (2003). Smoke Component Yields From Room-Scale Fire Tests. Technology administration, Department of Commerce, USA. NIST 1453.

[10] AMERICAN SOCIETY FOR TESTING AND MATERIALS, ASTM. (2010). 1678: Standard Test Method for measuring Smoke Toxicity for Use in Fire Hazard Analysis, USA.

[11] AMERICAN SOCIETY FOR TESTING AND MATERIALS, ASTM. (2007). E 800: Standard Guide for Measurement of Gases Present or Generated During Fires. USA.

[12] KIRK, P. L., DEHANN, J. D., (2007). Kirk's Fire Investigation. The Nature and Behavior of Fire (6th Edition).

[13] BRIGADA MILITAR. (2010). Estatística de Incêndio. Corpo de Bombeiros da Brigada Militar de Porto Alegre/RS.

[14] AMBIENTEC. (2010). Análises Ambientais: qualidade do ar inalável. Laboratório de emissões atmosféricas, análises químicas e ambientais.

Citation: *Luciani Somensi Lorenzi; Kássio Joe Stein; Luiz Carlos Pinto da Silva Filho., "Full Scale Testing of Fire Performance on A House Construction System Assembled With Sandwich Steel and Polyurethane Structural Panels", International Journal of Emerging Engineering Research and Technology, 7(1), pp.38-46*