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**NUMERICAL STUDY ON THE LIKELIHOOD OF IGNITION OF
MATERIALS NEARBY COLLAPSED COMPARTMENT WALLS DURING
DWELLINGS' FIRES**

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***Abstract.** A full-scale ISO 9705 room was numerically modelled to verify the changes in fire dynamics resulting from the collapse of a compartment wall and its influence on combustible materials close to the structure. The results showed that the wall collapse promoted changes in the dwelling fire regime due to the air inflow and smoke outflow, which stimulated the fire burning for cases of high and medium fire load, and, together with the reduction of the HGL thickness, a decrease in ambient temperature. The incident radiative heat flux has a behaviour inversely proportional to the distance from the compartment, presenting more uniform values as the distance from the compartment increases. Considering different heights, the highest heat flux was measured from the middle to the top of the compartment, according to the characteristics imposed by the fire load. From the comparison between the results of this work and the critical heat flux and distance presented in the literature, it was evident that when considering a medium fire load, the separation distance of 2.14 m presents a high risk of fire spread, and the distance of 3.14 m is still less than necessary.*

***Keywords:** Fire Dynamics Simulator, Fire spread, Compartment fires, Informal settlements dwellings.*

1. INTRODUCTION

The fire spread within a building and to adjacent buildings is of great importance in fire risk assessment and prevention. It is known that compartments made up of combustible materials (structural or cladding) have a greater potential for flammability, which results in an increase in the fire HRR (heat release rate), causing a more severe fire. Additionally, the burning of these combustible elements may cause changes in the compartment fire dynamics, since changes in the compartment ventilation may occur during the fire due to these material thermal degradation.

Several researchers have studied the fire development in ISDs (informal settlements' dwellings), which, due to their characteristics (such as improvised structures, proximity between ISDs, large availability of combustible material, lack of basic services, among others) are susceptible to the risk of large-scale fires. For this reason, the present work aims to model and validate a large-scale ISD fire experiment with wood cribs as the fire source, and based on this model analyse the influence of the collapse of one of the ISD walls on the fire dynamics and on combustible materials placed close to the dwelling.

2. METHODOLOGY

The first objective of this study was to reproduce computationally a fire scenario in a single conventional ISD, using as reference one of the experimental fire scenarios studied by Wang et al., 2021a. The numerical modelling of the experiment was conducted through a computational fluid dynamics (CFD) software namely Fire Dynamics Simulator (FDS), being the obtained numerical results compared to the experimental data described by Wang et al., 2021a, and the numerical results provided by Beshir et al., 2021, to verify the numerical model capability to predict this type of scenario. Subsequently, the collapse of the front wall was modelled to occur at 975s after the fire ignition, the time in which according to Wang et al., 2021a, the structure started to collapse.

Three compartment fire loads were tested to cover the different degrees of fire risk (low, medium and high), following the values specified in Rio Grande do Sul, 2020. In order to verify the changes in the fire behaviour due to the collapse of the dwelling's front wall and its influence on the fire spread to combustible materials placed close to the structure, the radiative heat flux was measured at different distances and heights, to compare the obtained results with the critical heat flux and critical distances presented by Wang et al., 2021b.

FDS is a widely used and well established software in the study of fire dynamics. It is a free and open source CFD software developed by the National Institute of Standards and Technology (NIST) and the VTT Technical Research

Center of Finland. FDS solves numerically a form of the Navier-Stokes equations for low Mach numbers ($Ma < 0.3$), using Large Eddy Simulation (LES) methodology for the turbulence modelling. A more detailed description of the software, equations and models can be found in McGrattan et al., 2022.

2.1 Problem statement and numerical modelling

The dwellings' geometry used in the experiments and simulations had the dimensions of a full-scale ISO 9705 room, with internal dimensions of 3.6 (W) x 2.4 (L) x 2.4 (H) m³. The ISD had two openings on the front wall, a door of 2.0 (H) x 0.8 (W) m² and a window of 0.6 x 0.6 m², positioned 0.7 m and 2 m from the front right corner, respectively. The walls and ceiling of the ISD were built using corrugated galvanized steel sheets 0.51 mm thick, with a specific heat of 0.6 kJ/kg.K, density of 7850 kg/m³ and conductivity of 45 W/m.K (Beshir et al., 2021), which were attached to a wooden structure. The measuring instruments, as well as the other characteristics of the experiment carried out by Wang et al., 2021a, were reproduced in the FDS. The walls and ceiling were defined as having their back surface "EXPOSED", so the 1-D conductive heat transfer through the wall was calculated. Figure 1 shows the position of the radiative heat flux measuring points used in the simulations.

As a fire source, two wood cribs were placed in the centre of the compartment, separated 0.18 m between each other. Each crib had 7 layers of 10 sticks with a dimension of 0.038 x 0.064 x 1.219 m³. In the numerical study, the compartment fire load was varied to cover the different degrees of fire risk, by modifying the number of sticks in each wood crib, which were determined according to Wang et al., 2021a. The approximate fire loads considered were: 260 MJ/m² (low risk, 80 sticks), 780 MJ/m² (medium risk, 240 sticks) and 1230 MJ/m² (high risk, 380 sticks). The wood properties used in the fire source modelling are presented in Table 1, following the parameters suggested by Beshir et al., 2021, as a baseline for this study. The numerical model ignition was based on the HRR experimental curve, being carried out through 8 'VENT's' (FDS command) of 0.0036 m² each, with MLRPUA (mass loss rate per unit area) of 0.055 kg/m²s (Babrauskas, 2016), placed in the same places where the experiment was ignited. This procedure was performed only because there was not enough information to model the ignition as performed experimentally.

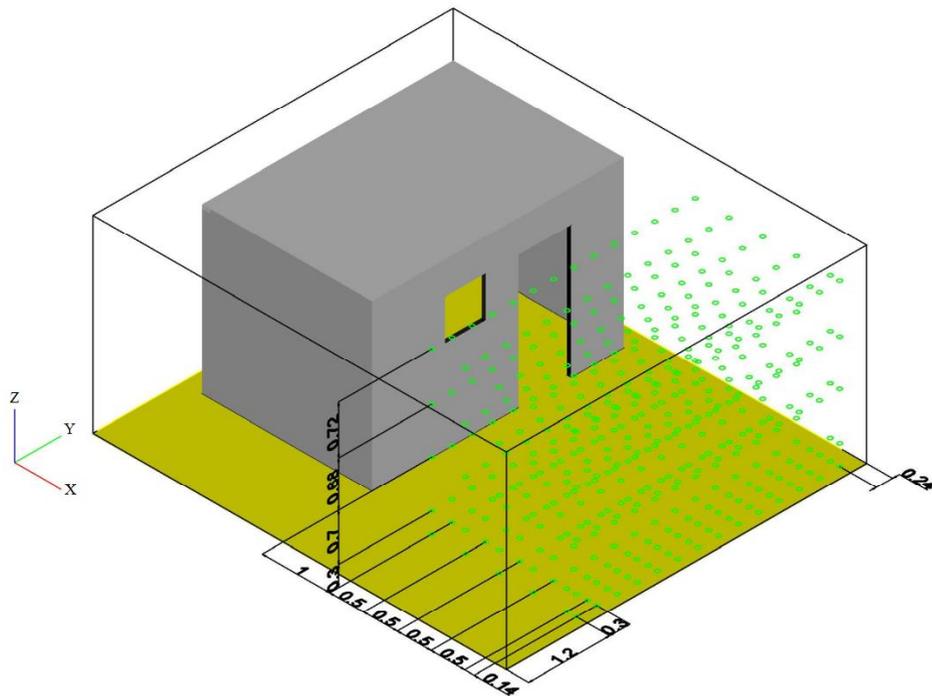


Figure 1. The position of the radiative heat flux measuring points.

As in the present work, we are interested in analyzing the fully developed fire phase, to reduce the computational effort required to carry out the simulations, the "Time Shrink Factor" command was applied. This factor was previously applied by Beshir et al., 2021, who evaluated its influence in the numerical results by evaluating the "Time Shrink Factor" of 2, 5 and 10, finding results with an acceptable variation, around 5 and 10% using a factor equal to 5. For this reason, all the simulations were run until 1100s, using a Time Shrink Factor equal to 5.

Table 1. Wood properties applied in fire modelling.

Density	535 kg/m ³
Bulk density	455 kg/m ³
Heat of combustion	20 MJ/kg
Soot yield	0.015
Ignition temperature	250°C
Specific heat	1.3 kJ/kg.K
Conductivity	0.2 W/m.K
Heat release rate per unit area (HHRPUA)	111 kW/m ²
Chemical composition	C _{3.4} H _{6.2} O _{2.5}

2.2 Domain and Mesh resolution

It is known that the computational domain extension beyond the compartment openings has an influence in the fire model results. The literature (He et al., 2008, and Zhang et al., 2010) suggests that an extended computational domain equivalent to one hydraulic diameter of the opening, in the perpendicular direction to the opening, produces a better agreement with the experimental data. Thus, the domain size in this study was defined as 6.12 (X) x 5.34 (Y) x 2.82 (Z) m³, which provides an extension greater than the recommended one. The lateral and the top boundaries of the domain were defined as “OPEN”, allowing the fluid to enter and/or leave the domain based on pressure gradients.

One method widely used by the fire community to estimate the adequate mesh cell size is based on the analysis of the non-dimensional parameter $D^*/\delta x$. This method provides a measure of how well the flow field is resolved, being a good way to determine a suitable mesh for simulations involving fire plumes. The characteristic fire diameter, D^* is obtained by equation 1 and the δx is the nominal size of a mesh cell (McGrattan et al., 2022).

$$D^* = (HRR/\rho_\infty T_\infty c_p \sqrt{g})^{(2/5)} \quad (1)$$

where HRR is the heat release rate (kW), ρ_∞ is the density of the ambient fluid (kg/m³), T_∞ is the ambient fluid temperature (K), c_p is the fluid specific heat (kJ/kg.K) and g is the acceleration of gravity (m/s²).

The literature establishes the values of the non-dimensional parameter $D^*/\delta x$ that provide an adequate mesh resolution. Values ranging from 4 to 16 have been suggested by Salley and Kassawara, 2007, and values of the order of 10 by McDermonnt et al., 2010. Table 2 presents the values of D^* and $D^*/\delta x$ for the four mesh sizes evaluated in this study, considering the maximum HRR of 4339 kW provided by Wang et al., 2021a.

Table 2. Non-dimensional mesh resolution criterion analysis.

HRR (kW)	D^* (m)	$D^*/\delta x$			
		$\delta x = 12$ cm	$\delta x = 9$ cm	$\delta x = 6$ cm	$\delta x = 3$ cm
4339	1.72	14.33	19.11	28.66	57.32

As can be seen in Table 2, all considered mesh sizes are in accordance to the established criteria.

Several works carried out by the fire community (Beshir et al., 2021, Cicione et al., 2020, Cicione and Walls, 2020), among others) applied a mesh resolution lower than 0.1 D^* , showing good results for the modelling of fire spread on wood cribs. So, considering the maximum HRR of 4339 kW provided by Wang et al., 2021a, the control volume dimensions for the simulations should be less than 17.2 cm, a criterion attended by all tested meshes. Since a traditional mesh sensitivity analysis was impracticable due to domain size and computational limitations, the mesh size was chosen based on the geometry of the wood crib`s sticks, as proposed by Kallada and Hostikka, 2019. Initially, a 3 cm mesh was considered, however, given the domain size and the high computational effort required to carry out the simulation, it was decided to use a 6 cm mesh, which, considering the presented criteria, provides an adequate mesh resolution for this study.

2.3 Numerical model validation

The FDS numerical model for a single informal settlement dwelling in still air condition was validated comparing the numerical results to the experimental results of Wang et al., 2021a, and the numerical results of Beshir et al., 2021. This validation focused on the fire dynamics aspects considered relevant for this work, namely: the total HRR and the radiative heat fluxes through the openings.

2.3.1 Total heat release rate

The comparison between the experimental total HRR, the numerical results from Beshir et al., 2021, and those obtained in the present study (numerical) are presented in Figure 2.

As can be seen in Figure 2, the numerical model captured the HRR fully-developed stage (post-flashover) accurately, considering the data from Wang et al., 2021a, and Beshir et al., 2021. As discussed previously, the initial stages (ignition and growth phases) could not be accurately reproduced, which was expected due to the lack of information available and the complexity involving the fire spread within the wood crib, therefore, these stages will not be taken into account in this analysis. The variation between experimental and numerical data was obtained through a time average between 500 and 900s, resulting in a variation of ~2% for the values obtained in this work (numerical) in relation to the available experimental data Wang et al., 2021a.

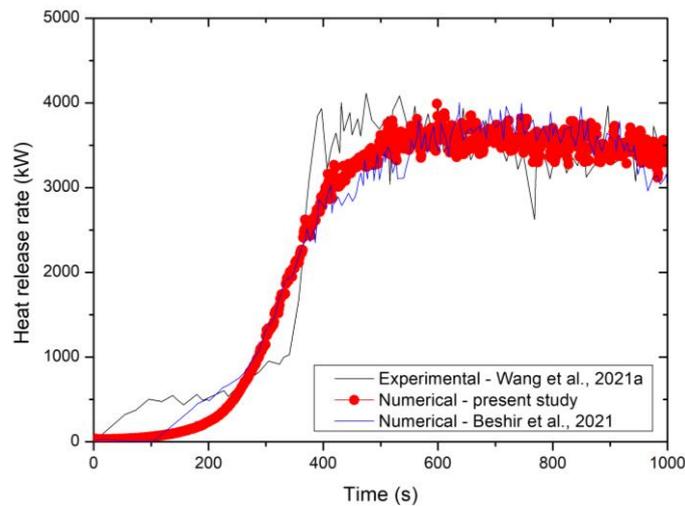


Figure 2. Comparison between numerical results (this work, Beshir et al., 2021, and experimental data from Wang et al., 2021a, for the total HRR.

2.3.2 Radiative heat fluxes to the surroundings

The heat fluxes from the compartment to the surroundings were evaluated in two points: (i) in the middle of the door width, 1.6m above the floor, 2.0 m away from the compartment front wall and (ii) in the middle of the window, 2.0 m away from the compartment front wall. Figure 3 presents the comparison of heat flux values, measured at the door (Fig. 3 a) and at the window (Fig. 3 b), for the experimental data Wang et al., 2021a, the results from Beshir et al., 2021, and those obtained in this study (numerical).

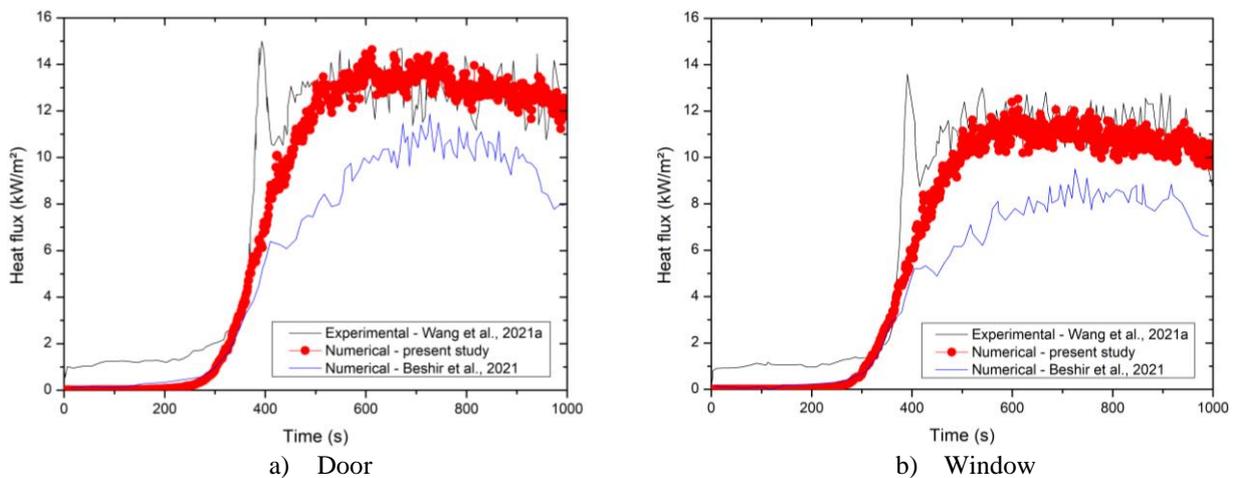


Figure 3. Heat flux measured 2m away from the compartment front wall.

As can be seen in Figure 3, the results of the present work present a good agreement with the experimental data Wang et al., 2021a, showing the behaviour accurately of the heat flux measured at the door and at the window, with a variation of approximately 2% and -6%, respectively. These deviations are obtained through a time average between 500 and 900s, during the fully-developed stage (post-flashover). Thus, it can be considered that the numerical model was capable of representing the experimental behaviour adequately during the fully-developed stage (post-flashover), providing reliable results for the accomplishment of this study.

3. PRELIMINARY RESULTS AND DISCUSSIONS

In this work, the fire dynamics after the collapse of the compartment's front wall was investigated. For this purpose, the dwelling's gas temperatures and the incident radiative heat fluxes in front of the dwelling were evaluated. The results measured before and after the collapse of the compartment's front wall were compared, additionally, the measured radiative heat fluxes were compared to the critical heat fluxes and critical distances reported by Wang et al., 2021b, to assess the possibility of fire spread.

3.1 The fire dynamics after the front wall collapse

During a fire, the presence of obstructions (ceiling and walls) differentiates a free burning fire from a compartment fire, as the obstructions trap smoke and heat within the structure, preventing its dispersion, and consequently, creating a highly dangerous environment.

A compartment fire starts with the fuel ignition. After the ignition, the fire grows, producing energy (heat and light) and combustion products (smoke). The hot smoke is surrounded by ambient air, so being less dense than the ambient air, it rises upwards due to buoyancy, forming a fire plume. The fire plume laterally entrains the surrounding cold air, which decreases its temperature and the concentration of the combustion products, but increases its volume. This mixture of gases (smoke + air) reaches the ceiling and spreads through it until it reaches the structure's walls, forming two distinct layers, a layer of hot gases and a layer of cold gases. The hot gases layer (HGL) will continue to increase as the fire develops due to the injection of smoke from the combustion process. The smoke will accumulate inside the compartment (below the ceiling) until it reaches the top of the openings and starts to flow to the external area.

In a traditional compartment fire, generally, the fire growth stage is fuel-controlled, which means that there is plenty of oxygen available for the fire to grow, being its growth a function of the fuel available. If there is sufficient fuel and oxygen, the fire will keep growing, and the high temperatures reached inside the compartment will lead to a stage known as flashover, when all combustible materials inside the compartment will ignite. The flashover stage frequently defines the transition from the growth stage, to a fully developed fire, where more fuel is pyrolyzed that it can be burned with the oxygen available inside the compartment, so, this stage is called ventilation controlled.

After the front wall collapse (during the fully developed fire stage), some changes in the compartment fire dynamics are observed. Basically, the removal of the obstruction (front wall), due to its collapse, allows a greater amount of smoke to flow out of the dwelling to the external environment, while a greater air inflow to the structure is observed. The amount of air available in the compartment influences the fire behavior. The wall collapse during the developed stage, change the fire scenario from a ventilation-controlled fire to a fuel-controlled fire, leading to the complete combustion of the fuel (due to the increase on the oxygen availability) and/or to a reduction in the pyrolysis rate by reducing the compartment temperature and the heat feedback to the fuel surfaces. This behaviour can be observed through the total HRR presented in Figure 4 for low, medium and high fire loads evaluated in this study.

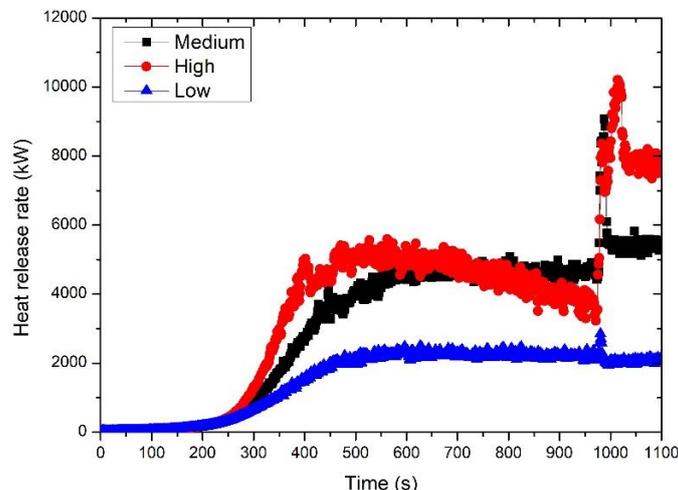


Figure 4. Total HRR for low, medium and high fire loads.

Analyzing the results shown in Figure 4, it is noticed that after the wall collapse there is a small reduction in the HRR for the low fire load case, this happens since in these case, as the fuel load was very low and there were no flames being ejected from the structure, the compartment fire did not reach the ventilation-controlled stage, so the sudden change in ventilation do not increased the burning rate, instead, by allowing the hot gas flow out the compartment, it reduced the thermal feedback to the wood crib, and consequently reduced the HRR. For the high fire load case, before the wall collapse, there is a fast increase in the HRR, which reaches a peak and after reaching the ventilation-controlled stage, start to reduction until the moment of the wall collapse, after that, there is a rapid and large HRR increase (due to the sudden inflow of air). For the medium fire load, before the wall collapse, there is an increase in the HRR, which reaches a peak and starts burning in a steady rate. Again an increase in the HRR after the wall collapse was observed (due to the sudden air inflow), but with a more stable behaviour, just slightly increasing the HRR after the wall collapse, since there is the smaller amount of fuel inside the compartment, so the amount of oxygen required for the complete combustion was smaller, and the burning rate was less affected by the change in ventilation.

One way to assess the scenario's ventilation is through the stoichiometric HRR (HRR_{stoich}), which represents the maximum amount of fuel that can be completely burned with the available air through the openings (Walton et al., 2016). The following values for the HRR_{stoich} were obtained: 3745 kW before the front wall's collapse and 20078 kW after. When comparing these values with those presented in Figure 4, it can be noted that, before the wall collapse, only the low fire load case is in the fuel-controlled stage ($2250 \text{ kW} < HRR_{stoich}$), while the medium and high fire loads are in the ventilation-controlled stage (4651 kW and $4184 \text{ kW} > HRR_{stoich}$, respectively). After the wall collapse, all fire scenarios are in the fuel-controlled stage (all HRR's $< HRR_{stoich}$). Therefore, the results corroborate the described and expected behaviour of the problem.

3.2 The dwelling temperatures

To understand the influence of the wall collapse on the fire dynamics, the dwelling temperatures were analyzed. As mentioned earlier, before the wall collapse, the HGL formed inside the dwelling was limited to flow out of the compartment to the external environment through the vertical openings (door and window), which influences its thickness and also the amount of air entrained through the openings. From the moment the front wall collapses, there is an increase in the ventilation factor, allowing more air inflow and smoke outflow, which leads to a reduction in the HGL thickness and, consequently, a reduction in temperature within the compartment. Figure 5 presents the transient temperature measured at the top and lower thermocouple of the thermocouple tree positioned in the middle of the door, for medium fire load.

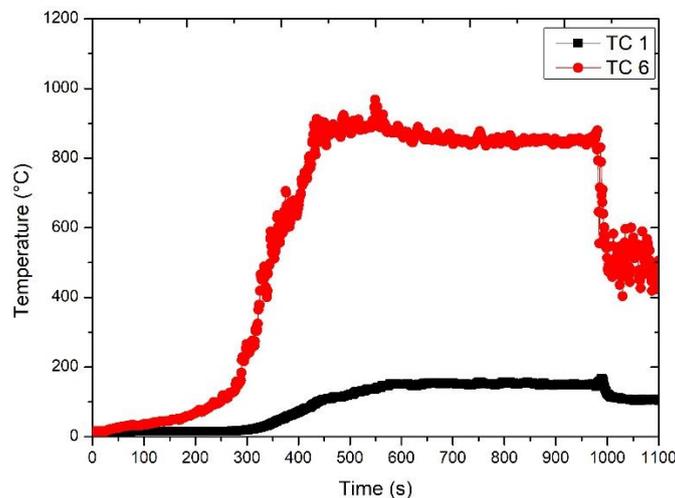


Figure 5. Transient temperature measured at the top and lower thermocouple positioned in the middle of the door.

Observing the results of the lower thermocouple reading (TC 1), presented in Figure 5, which represents the compartment cold gas layer (CGL), it can be noticed that after the wall collapse, there is a small decrease in its temperature. The greater amount of cold air available inside the compartment (after the wall collapse), causes the fire plume to entrain cold air instead of the hot air present inside the compartment before the wall collapse, decreasing the HGL temperature. The higher air entrainment in the fire plume decreases the smoke temperature and concentration and increases the smoke volume, however, the lack of a barrier to the smoke outflow (the absence of the front wall) reduces the HGL thickness, once the smoke does not accumulate as it did before the wall collapse. So a colder and thinner HGL is observed. The described behaviours corroborate with the results presented in Figure 5, through top thermocouple reading (TC 6). The same behavior was observed for the case with a low fire load, and almost the same behavior was

observed for the case with a high fire load. The difference is the increase in the HGL temperature. This increase is believed to occur due to the shift in the fire scenario from being highly ventilation-controlled to fuel-controlled, leading to the complete combustion of the fuel (due to increased oxygen availability).

3.3 Radiative heat flux to the surroundings

The incident radiative heat flux reaching a given material or structure in front of the compartment was measured along the front wall. Measurements were taken considering the following distances from the compartment: 1m, 1.5m, 2m, 2.5m, 3m and 3.14m; based on the critical distances described by Wang et al., 2021b. For each described distance, measurements were performed at different heights (0, 0.3, 1.0, 1.68 and 2.4) to identify the risk of fire spread and verify its behaviour after the front wall collapse. Figure 6 shows the radiative heat flux, before and after the wall collapse, through an average of values obtained in an interval of 800s to 900s and 1000s to 1100s, respectively, considering a medium fire load.

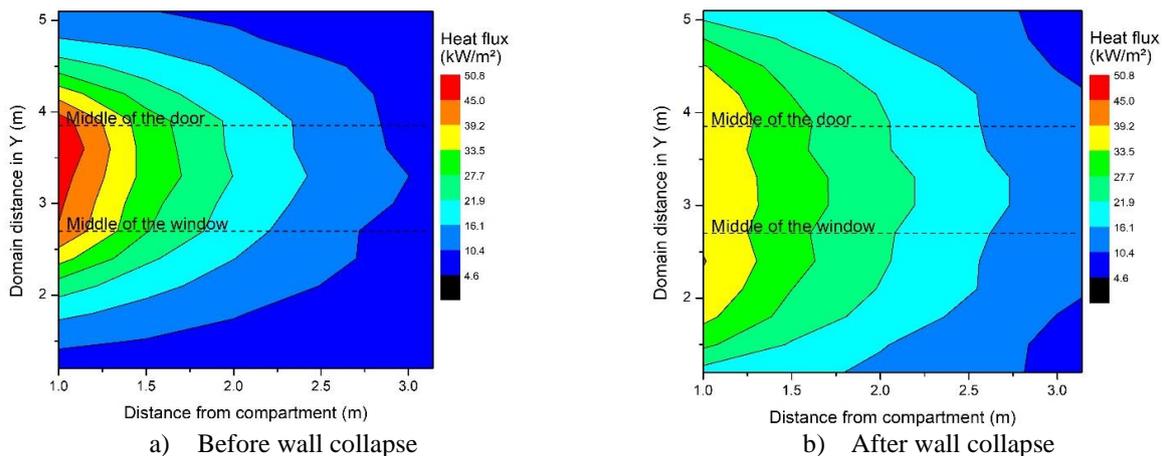


Figure 6. Heat flux measured at the mid-height of the window (1.68 m).

It can be noted from Figure 6a, that before the wall collapse, the highest heat flux measurements were taken at the closest distance to the compartment (1 m), with the peak being observed in the region in front of the door. This behavior was expected, as normally fire spreads by thermal radiation through the compartment openings, having the radiative heat flux peak in front of the largest opening or exposed area, the door in this case. As the distance between the measuring point and the compartment front wall increases, the radiative heat flux decreases, as expected. The radiative heat flux measurements along the Y direction (x axis in the graph) become more uniform when the distance from the front wall increases. In addition, measurements performed in the domain extended region showed the lowest values.

After the wall collapse, Figure 6b, it is evident that there is a scattering of the heat emitted by the fire, which leads to more homogeneous heat flux values as the distance from the fire increases. Before the wall collapse, the thermal energy contained within the structure was directed through the dwelling openings (door and window), after the collapse, this energy was scattered to the entire frontal region, thus obtaining lower values for the maximum heat fluxes, but higher radiative heat fluxes in the measuring points placed further from the domain center (in the y direction). However, higher values were measured along the entire frontal domain extension and at the most distant points from the compartment, as shown in Figure 6b and Figure 7. This can also be observed in the readings taken beyond the compartment (two extreme points), which record higher measurements after the wall collapse. The increase in values is due to the energy scattering, but also to the increase in HRR, as explained in the previous section.

Figure 8 shows the radiative heat flux measurements at different heights, at a distance of 1m from the compartment front wall, before and after the wall collapse, through an average of values obtained in an interval of 800s to 900s and 1000s to 1100s, respectively, considering a low fire load.

Analyzing the results shown in Figure 8a, it can be observed that the lowest heat flux measurements were close to the floor and the top of the compartment, with a peak in front of the opening region, mainly at the door, as described above. The highest heat flux values were measured at the mid-height of the window (1.68 m), followed by the region near the center of the compartment (1 m) and, finally, at the compartment height (2.4m). In this case, there is no presence of flames coming out of the dwelling due to the low fire load, it is assumed that this behaviour occurs due to the heat emitted through the openings, where normally the fire spreads, combined with the presence of HGL, which occupies a large part of the compartment and has a high temperature. When considering cases with medium and high fire load, it is noted that the largest measurements were taken at the maximum analyzed height, 65.4 kW/m² and 89.2 kW/m², respectively. This is due to the flames that are burning part of the pyrolyzed fuel outside the compartment, due to the lack of oxygen inside (ventilation-controlled fires), as mentioned earlier, which had not occurred in the case with low fire load.

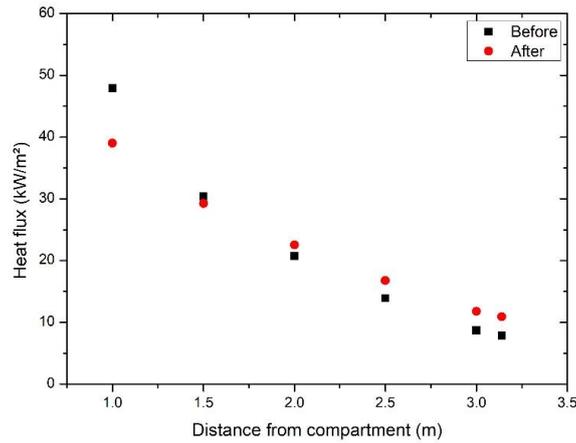


Figure 7. Radiative heat flux measured at the door before and after front wall collapse, measured at the mid-height of the window.

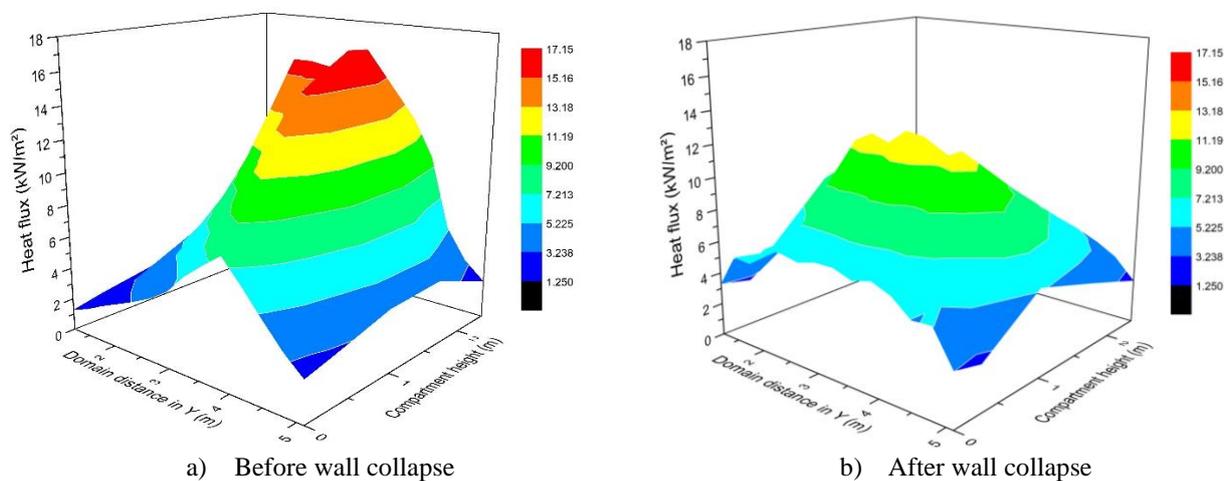


Figure 8. Heat flux measurements for different, 1 m away from the dwelling.

For the low fire load case, after the wall collapse, the maximum heat flux was measured near the mid-height of the compartment (1 m above the floor), furthermore, due to the heat scattering more uniform radiative heat flux values were measured at all heights, as shown in Figure 8b. Thus, it is evident that the scattering of the heat emitted by the fire also applies to this variation (fuel load), once before the wall collapse the energy was also directed through the openings, and after was emitted (scattered) by the entire compartment front region. From Figure 8b, it was found that the highest measurements were taken near the half height of the compartment, which may have occurred due to the absence of flames coming out of the structure and the reduction of the HGL thickness, as explained above. Increasing the fire load, the heights at which the maximum radiative heat fluxes were measured were also different, after the wall collapse. It happened at the mid-height of the window (1.68 m) for medium fire load and at the compartment height (2.4m) for high fire load. It is assumed that this occurs due to the flames coming out of the dwelling and the increase in the HGL thickness, factors resulting from the fire load increase.

3.4 Influence on the radiative heat flux to combustible materials close to the dwelling

Several flammable materials commonly found in ISD were presented in Wang et al., 2021b, which were analyzed to determine the critical heat flux for ignition and the critical distance, distance beyond which the material will not be ignited in an informal settlement fire. A total of 32 different materials were subjected to a series of cone calorimeter tests. The results showed that if all the materials considered were 3.14 m away, the risk of fire spread for the adjacent dwelling would be insignificant and that a distance of 2.14 m, more realistic practicable distance, would prevent the ignition of 75% of the materials considered. It is emphasized that these experimental and theoretical results are based on laboratory conditions and require further verification considering the complexity of the informal settlement

It is known that the fire load density within ISDs varies highly, however, according to research carried out in South Africa, the average fuel load in an ISD is 410 MJ/m² with a standard deviation of 140 MJ/m² (Wang et al., 2021a). Therefore, a comparison will be made, considering the low and medium fire load used in this study, between the experimental and theoretical values presented by Wang et al., 2021b, and the distances and the critical heat flux measured at the door. Values measured at 1.68 m from the floor will be considered, as this is a height that includes clotheslines, curtains, finishing wood, between others, in other words, combustible materials that can lead to the fire spreading. Table 3 presents the measurements of heat fluxes at some distances for low and medium fire load, which were obtained by averaging the values obtained in an interval of 800s to 900s and 1000s to 1100s, before and after the wall collapse, respectively.

Table 3. Average radiative heat flux measurements at different distances from the dwelling.

Fire load	CHF, 3.14m (kW/m ²)	CHF, 2.5 m (kW/m ²)	CHF, 2.0 m (kW/m ²)	CHF, 1.5 m (kW/m ²)	CHF, 1.0 m (kW/m ²)	Wall fall
Low	2.6	4.2	6.3	9.8	16.9	Before
Medium	8.4	14.0	20.9	31.3	50.7	
Low	4.2	4.8	5.4	6.4	8.6	After
Medium	11.4	17.1	22.6	28.9	38.0	

Comparing the present work values for the low fire load and the results of Wang et al., 2021b, it can be noted that, if the established critical distance is respected, none of the listed materials would be ignited before or after the wall collapse. For a medium fire load considered in this study, all listed materials would be ignited, before or after the wall collapse, when respecting the minimum established critical distance, if they are subjected to a heat flux for the necessary time to ignition.

In a second analysis, the heat flux measured at a fixed distance of 2 m was considered, closest value to the distance indicated as a practicable separation distance by Wang et al., 2021b, (2.14 m), to verify the possibility of fire spreading to adjacent materials or dwellings. For this analysis, the medium fire load was considered, therefore, the heat fluxes measured at 2 m were 20.9 kW/m² and 22.6 kW/m², before and after the wall collapse, respectively. Both results, taking into account the critical distance needed to ignite the material, would propagate the fire to the adjacent structure, as mentioned earlier. If we assume that the materials presented in Wang et al., 2021b, are positioned at a distance of 2 m from the front wall (1.68m high) and that the materials would be subjected to the heat flux for enough time for ignition to occur, it would be possible to ignite 71.9% to 78.1% of the materials mentioned in Wang et al., 2021b. It should also be noted that the heat flux is inversely proportional to the distance from the fire, which means that, the closer is the measuring point to the fire dwelling, the higher are the radiative heat flux measured values. Thus, it is evident that for the medium fire load applied to this work, the separation distance of 2.14 m presents a high risk of fire spread, and the distance of 3.14 m is still less than the required. It is important to emphasize that the medium fire load used in this study is slightly higher than that presented in Wang et al., 2021a, in addition, adverse weather conditions, such as wind, were not considered in this work, conditions that may increase the chance of fire spreading, due to the increase in the severity (Lemmertz et al., 2023, and Beshir et al., 2023) of the fire or by directing the flames toward combustible materials.

4. CONCLUSIONS

A numerical model of a full-scale ISO 9705 room (representative of an ISD) was used to verify the changes in fire dynamics resulting from the collapse of one of the compartment wall and its influence on the ignition of combustible materials close to the structure. The Fire Dynamics Simulator (FDS) was used to predict the fire dynamics and potential fire spread from a ISD burning wood cribs. This kind of simulation requires a high computational effort, so several modelling methods were applied in order to increase the model efficiency, always seeking to reproduce the main fire characteristics and trends with good accuracy.

It was found that the wall collapse promoted changes in the dwelling fire regime due to the sudden change in the ventilation, which stimulated the fire burning for cases of high and medium fire load (ventilation-controlled cases), and led to a reduction in the pyrolysis process for low fire load (fuel-controlled case), due to the reduction of the compartment temperature and the heat feedback to the fuel surfaces.

The incident radiative heat flux has a behaviour inversely proportional to the distance from the compartment, presenting more uniform values as the distance from the compartment increases, a behaviour that did not change with the wall collapse. Before the wall collapsed, the maximum heat flux was observed in front of the door (the largest exposure area), 1 m from the compartment (the closest measurement points to the compartment front wall). After the wall collapse, there was a scatter of the radiative heat flux emitted by the fire, which led to more homogeneous heat flux values in the entire compartment frontal area (at each distance from the front wall). The heat flux was also evaluated for different heights, with its highest value being measured at different heights according to the fire load, because, in addition to the scattered energy (after the wall collapse), the HGL thickness and the ejected flames influenced the results of the regions

closest to the compartment. From the comparison between the results of this work and from Wang et al., 2021b, it was evident that when considering a medium fire load, the separation distance of 2.14 m presents a high risk of fire spread, and the distance of 3.14 m is still less than the required to avoid fire spread.

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