CILASCI

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5º CONGRESSO IBERO-LATINO-AMERICANO EM SEGURANÇA CONTRA INCÊNDIOS

5th IBERIAN-LATIN-AMERICAN CONGRESS ON FIRE SAFETY

15-17 /07/ 2019 - Porto, Portugal

Atas dos Artigos
Proceedings (full papers)

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U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
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PREFACE

The Iberian-Latin American Congress on Fire Safety (CILASCI) is held once every two years, with the aim of disseminating scientific and technical knowledge in the field of fire safety, integrating different players involved in this area of knowledge. The first edition of the Iberian-Latin American Congress on Fire Safety (CILASCI 1), was held in Natal (Brazil) between 10-12 March 2011. The second congress (CILASCI 2) was held in Coimbra (Portugal), between May 29 and June 1, 2013. The 3rd and 4th editions took place on the South American continent. The third congress (CILASCI 3) was held in Porto Alegre (Brazil) from November 3 to 6, 2015, while the fourth congress (CILASCI 4) was held in Recife (Brazil) from 9 to 11 October 2017. The CILASCI 5 will take place in the city of Porto (Portugal) from 15 to 17 July 2019, and presents 5 invited lectures and 78 manuscripts (full papers) from researchers around the world (Algeria, Australia, Belgium, Brazil, China, Czech Republic, France, Hong Kong, Italy, Mozambique, Portugal, Spain, United Kingdom and United States).

the 5th Iberian-Latin-American congress on fire safety reflects the new developments achieved on active and passive fire protection, on evacuation and human behaviour under fire, on computational modelling of structures and materials under fire, on explosion and risk management, on architectural issues for fire safety in buildings, on fire dynamics, on the experimental analysis of materials and structures under fire, on fires in special buildings and spaces, on fire-fighting operations and equipments, and on the behaviour of structures and materials under fire.

The Fire Safety is reaching new developments as a result of new research, development and innovation around the world, based on the excellence level of the research, the support of new skilled professionals and due to the existence of advanced training programmes in fire science technology. This development will increase the safety level of people, buildings, and products, but also is going to produce an impact in the economy of each country, with a positive impact on society.

The organizing committee believe that this congress will address to our delegates a wide forum of discussion about the recent developments in Fire Safety, promoting the exchange of ideas and international cooperation.

The organizing Committee would like to thanks to all authors and delegates.

On the behalf of the Organizing Committe
Paulo A. G. Piloto

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NUMERICAL PREDICTION OF THE INCOMING HEAT FLUXES ON FIREFIGHTER PROTECTIVE CLOTHING

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Abstract: The present study is a numerical attempt for the prediction of the incoming thermal flux on a firefighter protective clothing. The study focuses on ventilation conditions impact on the incident fluxes reaching the external garment's face. A radiative and convective transfer modeling is considered for a 3D geometry compartment, equipped with a door, a window and subject to a localized fire, with stationary heat release rate (HRR) during a prescribed exposure time. An additive constraint on oxygen mass fraction threshold is considered to account for flame extinction. The outer layer of the protective garment is modeled as a solid medium, featuring both front (chest F) and rear (back R) sensors. The baseline case corresponds to a situation where the external temperature of the protective clothing and that of the fresh air adjacent to the firefighter's body are maintained at 25 °C. Despite the importance of mechanical ventilation devices in smoke clearance and temperature attenuation, critical values for ventilation flow rates may lead to tremendous heat fluxes revealing the apparition of backdraft situations.

Keywords: Firefighter clothing; Heat flux; Mechanical ventilation; Flashover.

1. INTRODUCTION

Fire is one of the most destructive risks that threaten people's lives and the durability of structures. Firefighters or occupants trapped in a thermal environment could be at risk, including hazardous chemical liquids, toxic gases and tremendous heat fluxes from burning materials or smoke [1].

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Firefighters should wear protective clothing that provides effective protection against various thermal exposures, i.e. flames as well as smoke. With the commonly used synthetic insulating materials, the thermal loading during a firefighting can exhibit an unexpected behaviour [2]. During fire services, firefighters are subjected to fire conditions with fluctuating levels of heat fluxes. Despite low radiative intensities of incoming fluxes from solid surfaces [3], extended exposure times may lead to the apparition of thermal stress and skin burns [4].

Compartment fire is conducted by complex phenomena which have been the subject of many investigations. Natural ventilation (NV) is of the topics that attract the researchers to deal with experiments and computational fluid dynamics (CFD) studies for both reduced and full-scale benches [5]. In the same direction, experimental investigations have been developed to study horizontal opening effect on pool fire behaviour [6]. In such situations, the equivalence ratio of the compartment has been shown to strongly relate to self-extinction modes of the pool fire.

Studies on flashover have been generally limited to hazard calculations in which presumed temporal curves of the fire heat release rate (HRR) were used [7]. However, there have been few reports of study on the flashover caused by a natural re-ignition of the flammable gases, i.e., backdraft [8]. It is therefore important to highlight the contribution of natural ventilation as well as mechanical ventilation to the thermal fluxes development on a specified solid target over a prescribed exposure time.

The present work aims to numerically predict the incoming convective and radiative fluxes on a firefighter garment. A stationary pool-fire heat release rate is considered over all the exposure time, for a confined, a naturally ventilated (NV) and a mechanically ventilated (MV) compartment. Specific situations related to under-ventilation and backdraft are recovered and discussed with regards to the heat fluxes intensity.

2. HEAT FLUX MODELING

In a fire situation, heat fluxes usually emanate from hot media such as flames, plumes or solid surfaces (walls). The contribution of the radiative part has been proved to be important when a certain level of confinement is provided by the compartment [9]. Moreover, significant convective fluxes can arise in considerations from natural or mechanical ventilation, remaining relatively low when only buoyancy settles, but becoming intense in some critical situations [10].

Figure 1: Basic heat sources for a firefighter [11].

The flame located at a fire pool is the primary source that transmits radiative flux to the firefighter's body, considered as a target. For engineering purposes, simplified models for the prediction of the incoming fluxes are used [10]. For such situations, the corresponding expression of the incoming flux is given as:

$$\phi_{rad} = F \times \tau \times \phi_f \tag{1}$$

where ϕ is the flux received at the target (kW/m²), F is the shape factor, τ stands for the atmospheric transmissivity factor and ϕ_f is the emissive heat flux released at the fire pool, which relates to the chemical heat release (Q_f). In the single solid flame model, the emission power is assumed to be uniform throughout the height of the flame H_f. Therefore, the attenuation factor due to infrared absorption and diffraction, can be expressed according to the correlation of Brzustowski and Sommer [11]:

$$\tau = 0.79 \times (100/d)^{1/16} \times (30.5/RH)^{1/16} \tag{2}$$

d is the distance between the firefighter's body and the source of fire, RH is the relative humidity of the internal air of the compartment, and commonly equal to 70%. For the shape factor, when the flame is seen as a parallelepiped solid surface, it can be expressed as [11]:

$$F_v = 1/2\pi \times \left[X/\sqrt{1+X^2} \times Arctg\,(Y/\sqrt{1+X^2}) + Y/\sqrt{1+Y^2} \times Arctg\,(X/\sqrt{1+Y^2}) \right] \tag{3}$$

with $X=H_f/d$ and $Y=D_f/d$, where D_f refers to the equivalent diameter of the flame.The average height of the flame is expressed via the Heskestad correlation as [11] :

$$H_f / D_f = -1.02 + 0.235 \times Q_f^{2/5} / D_f \tag{4}$$

The fire heat release rate (Q_f) is seemed to be related to the fuel type and the air-fuel mixing rate. Nevertheless, for engineering applications, standard fire heat release rate curves are considered with regards to ventilation conditions [12]. According to the author's knowledge, there are no analytic formulations that allow for incoming convective fluxes prediction, in presence of natural or mechanical ventilation.

3. RESULTS AND DISCUSSIONS

The compartment consists in a 10m×4m×2.9m room, featuring a gate and a window. The fire pool of 2.25 m^2 surface, is located in the vicinity of the window, and provides a stationary heat release rate Q_f = 1125 watts (Fig.2).

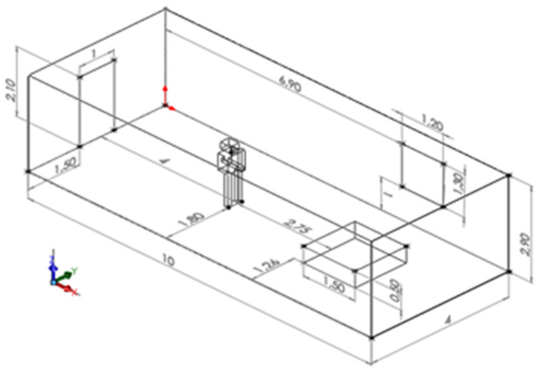


Figure 2: Compartment geometry sketch [11].

The firefighter's body is modelled as a flat plate located at a standard distance (2.75 m) from the fire pool, on which two sensors are placed, respectively on the front (F) and on the back (R).The emitting thermal density Q_f = 500 kW/m^2 of the flame is stationary during the observation period t_{phys} = 15 minutes [13]. The walls as well as the outer face of the fireman's body are maintained at a temperature T = 25°C (Fig.3.a) and the computation domain is mapped with a structured grid containing 100.000 cells (Fig.3.b). Large eddy simulation (LES) technique is used to filter the Navier-Stokes, energy and radiative transfer equations using the Fire Dynamic Simulator FDS® solver.

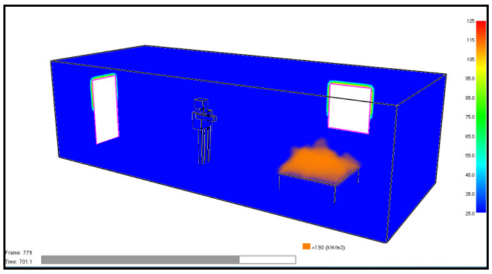


Figure 3.a: Boundary condition for the baseline [14].

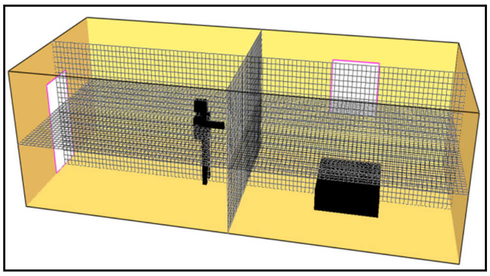


Figure 3.b: Structured mesh for the computational domain.

For a stationary thermal power at the fire focus, the convective and radiative fluxes incident on the firefighter's body are related to the ventilation of the room and more specifically, on the air supply conditions of the base of the flame. Accordingly, there are three possible configurations for the local, namely fully confinement (door closed, window closed), natural ventilation (one or two free openings) and mechanical ventilation (air blowing).

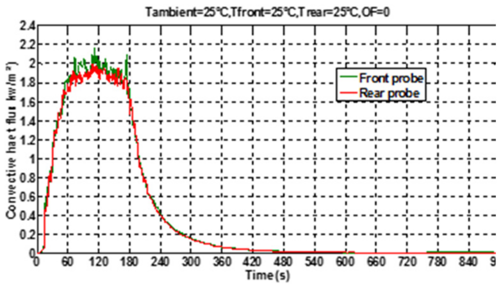


Figure 4.a: Evolution of the incoming convective flux.

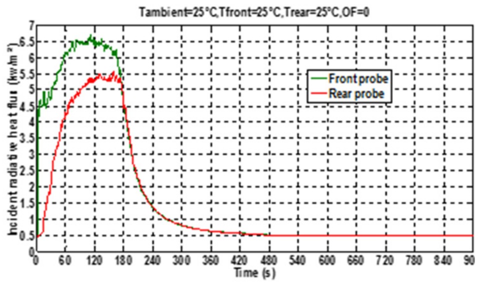


Figure 4.b: Evolution of the incoming radiative flux.

Figure 4 shows the evolution curves of the fluxes received by the firefighter's body, in a fully confinement situation (opening factor *OF* = 0). An abrupt increase in convective flux through the firefighter's body during the first 60 seconds is noticed; which reveals an instantaneous response, with a flux of 2.2 kW/m², received at the front face and a convective flux of 2 kW/m² received at the back (fig.4.a). This increase is explained by a significant variation in the density of air between the fire pool and the firefighter surrounding (∞). However, from 180s, the convective flux is decreasing up to a zero-value (past 540 s), owing to the smothering of the flame and the absence of air circulation around the firefighter.

Regarding the radiative flux, a value of 0.5 kW/m² is recorded at 0s, which corresponds to that of the fire source (fig.4.b). The radiative flux received on the chest, it is more important, with an instantaneous response $q_{rad,inc}$= 4.5 kW/m^2, around 5s. It ranges from 4.5 kW/m² up to a maximum value 6.5 kW/m². However, the incident radiative flux at the back remains constant with a moderate value (5.5 kW/m²) than the flux received at the chest ($q_{front} \approx 1.1\ q_{rear}$), owing to shadowing effect of the firefighter front face. From 180s; the radiative flux received by the firefighter body is decreasing asymptotically towards a limiting value 0.5 kW/m² which corresponds to the flux emitted by the surrounding smoke. Overally, the radiative flux received by the firefighter's body is greater than the convective flux ($q_{rad} \approx 3q_{con}$).

For the case corresponding to a natural ventilation with an open door and window (*OF* = 0.045), the fluxes magnitude seems slightly attenuated. Figure 5.a shows the variation of the convective flux received by the firefighter's body, as a function of the exposure time.

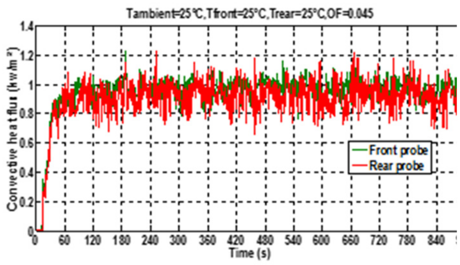


Figure 5.a: Incident convective flux (NV).

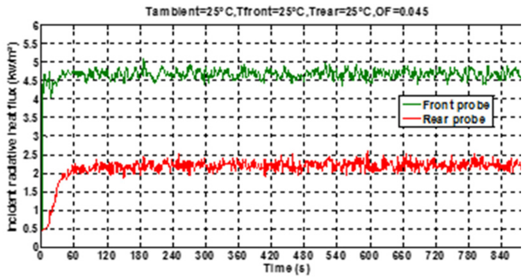


Figure 5.b: Incident radiative flux (NV).

Compared with the confined space case, the fluxes seem more stable (no extinction), varying from 0.7 kW/m² to 1.2 kW/m². These limits are less intense and reveal the effect of natural evacuation of the surrounding smoke, through the openings (Fig.6).

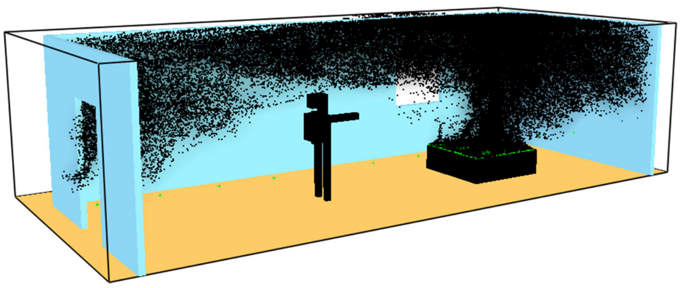


Figure 6: Natural smoke evacuation from the gate (NV).

Curve 5.b represents the variation of the radiative flux received by the firefighter. It varies between 4.5 kW/m² and 5 kW/m² for the front face, and 2 kW/m² to 2.5 kW/m² for the back, with a ratio $q_{front} \approx 2\ q_{rear}$. It is also noted, that the convective flux magnitude is still lower compared to the radiative flux ($q_{rad} \approx 4\ q_{con}$).

Mechanical ventilation involves blowing fresh air through one or more openings to decrease the temperature, while evacuating smokes. The case presented corresponds to a configuration where the door and the window are open (*OF* = 0.045) and the blowing operating via the door with a flow rate of 0.54 m^3/s. Figure 7.a shows the variation of the convective flux received by the firefighter's body in a semi-confined space with a mechanical blowing through the door. It exhibits a slight increase compared to the natural ventilation case. However, the convective flux received at the rear face of the firefighter shows a variation between 1.3 kW/m² and 1.5 kW/m². This is mainly due to the air stream provided by blowing system at the gate entrance, located behind the firefighter.

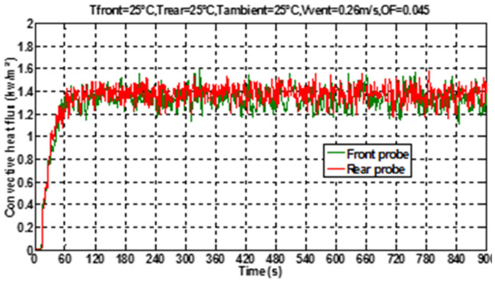


Figure 7.a: Incident convective flux (MV).

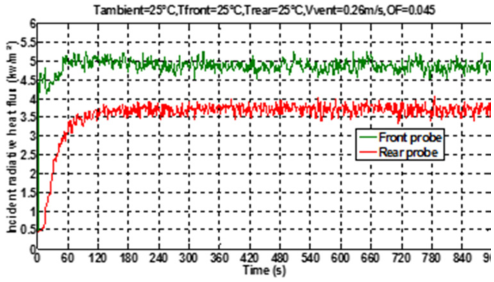


Figure 7.b: Incident radiative flux (MV).

Figure 7.b shows a stable fluctuation of the radiative flux received by the firefighter's front face, with values ranging from 4.5 kW/m² to 5 kW/m². These results are slightly greater than those of the natural ventilation case. Indeed, the ventilation of the room accelerates the combustion, since it supplies the fire pool with oxygen, which increases the quantity of the radiative flux emitted by the focus that fact led to a large flow received at the front of the firefighter body.

The influence of the radiative flux received, is localized at the level of the back of the firefighter. A considerable amount of flux received for the case of mechanical ventilation blowing through the door, it varies between 3.5 kW/m² up to 4 kW/m², which presents a significant increase over the case of a semi-confined space with natural ventilation. The increase of the value can be explained by the fact that a quantity of the radiative flux emitted by the smoke is accumulated at the level of the rear face of the firefighter's body.

In the situation where the window remains closed and one begins to blow through the door (opening factor *OF* = 0.026) with a critical flow rate of 0.42 m^3/s, considered as a very frequent situation with regard to firefighting maneuvers, the incoming fluxes seem temporary attenuated owing to the under ventilation of the compartment. In fact, a backdraft occurs before 15 minutes, inducing a flashover (FOV), and releasing tremendous flux values, that exceed the tenacity thresholds of the garments and the human tissues (Fig.8.a, 8.b).

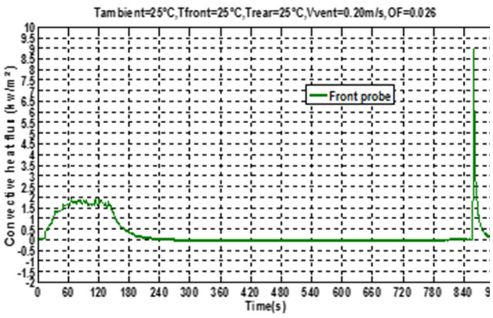


Figure 8.a: Incident convective flux (FOV).

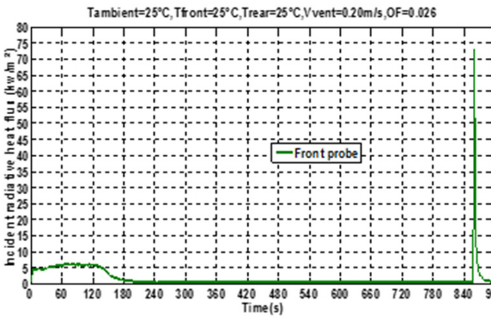


Figure 8.b: Incident radiative flux (FOV).

The same situation occurs in the case of blowing through the window, with a critical flow rate of 0.39 m^3/s, keeping the door closed (*OF* = 0.019). In this situation, a flashover seems to appear right after 15 minutes (Fig 9.a, 9.b).

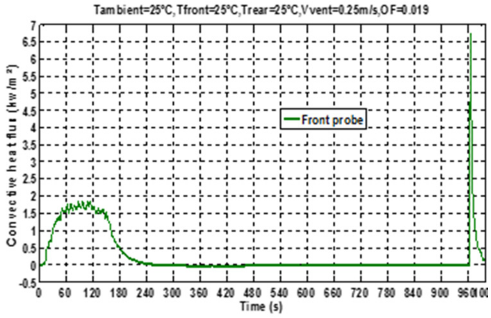


Figure 9.a: Incident convective flux (FOV).

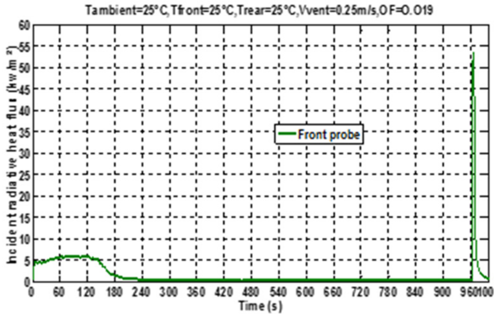
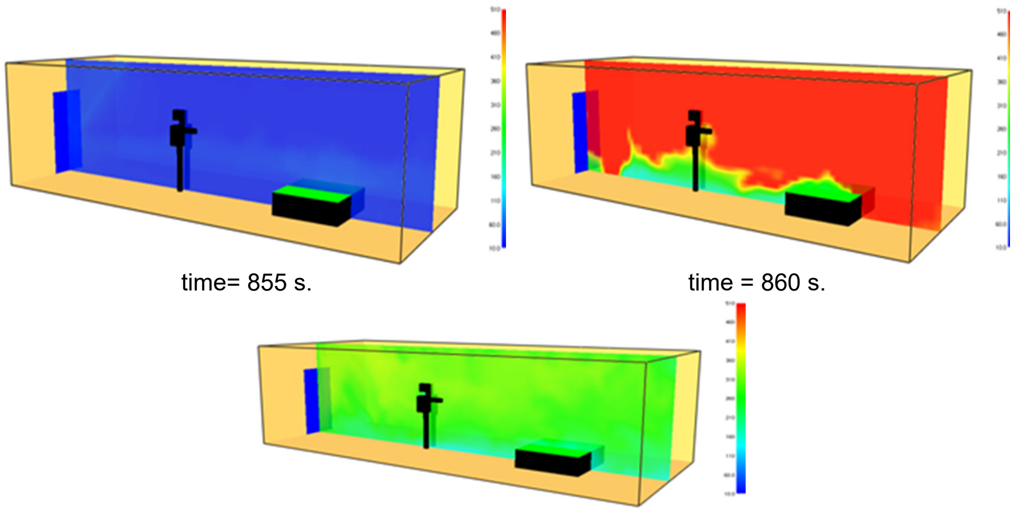


Figure 9.b: Incident radiative flux (FOV).

The thermal thresholds reached in this situation are relatively lower than those of the first flashover and this is due to the low flow rates of the blowing. Consequently, sudden flashover situations provide arise in temperature, in the vicinity of the firefighter (Fig. 10).


time= 855 s.

time = 860 s.

time= 865 s.

Figure 10: Temperature distribution (°C) in the compartment during the flashover (*OF*=0.026)

4. CONCLUSION

The present study represents a numerical prediction of the thermal fluxes received by a firefighter external garment. A descriptive model on the incoming thermal flux from a pool fire is also presented to allow for comparisons. Two modes of heat transfer (radiative and convective) have been considered to generate the simulations. It is shown that in the case of a full confinement, the incident convective flow towards the front and the back of the firefighter's back remains relatively low (< 2.2 kW/m^2) and tends to vanish due to under ventilation considerations. The front face is therefore exposed to high radiative flux (~ 6.8 kW/m^2) which despite the smothering of the flame, decreases towards a limiting value (0.5 kW/m^2), which corresponds to the emitting power of the surrounding smoke. Although the mechanical ventilation attenuates the intensity of the incident flux and consequently the surrounding temperature, it can contribute to generate a secondary ignition at the fire pool source inducing, therefore, the phenomenon of flashover.

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