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COMPUTER-SIMULATION RESEARCH ON BUILDING-FACADE GEOMETRY FOR FIRE SPREAD CONTROL IN BUILDINGS WITH WOOD CLADDINGS.

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ABSTRACT: Wood is a unique material with respect to fire. Despite being combustible, it is a stable structural element when confronted with flame due to its low thermal conductivity and characteristics of its chemical degradation (Pyrolysis). The level of fire resistance is determined by the mass, size, and configuration of the constructive elements used.

When wood is used as a cladding material, takes the form of boards, plates, or other thin strips, therefore its behavior is subject to its combustibility. This risk is why building fire-safety codes and regulations in many countries have been increasingly restricting the use of combustible claddings.

In this study we used modeling techniques and computer fire simulations to evaluate the influence of facade configuration on fire trajectory and the level of protection it can offer at the facade surfaces. Based on our results, it is possible to consider the use of horizontal projections, provided that they are of sufficient size (greater than 1.2m), to control the spread of fire and heat flow on the building's facade.

The study was performed using field models of computational fluid-dynamics. Particularly through the software: Fire Dynamics Simulator (*FDS*) to solve numerically the mathematical integration models, *PyroSim* for the graphical interface, and *Smokeview* for viewing the results.

KEYWORDS: Flame spread, fire performance on facade, combustible cladding, facade geometry, fire dynamics simulator.

1 INTRODUCTION

When there is a fire in a building, the facade can be one of the quickest spreading pathways. The fire could affect not just the building where the ignition is produced but also the nearby structures. The risk may increase with the use of combustible claddings like wood. In this situation the spread of fire can be faster and radiation heat flux can be very intense. Due to the risk for material and human losses, the use of combustible materials in exterior wall has been restricted by buildings codes in most countries to low buildings.

This research used computer-simulation techniques to study the facade geometry effect to control the spread of fire outside.

Computer simulation of fires is a powerful tool for studying the phenomenon of fire considering different variables and assumptions.

This instrument have been increasingly used to evaluate buildings fire protection strategies in countries like USA, Canada and Australia, where the fire protection standards have been evolving towards the *PBD* (*Performance Based Design*) concept.

2 BACKGROUND

During the last decade, the social awareness of the deterioration of the planet and global warming has become increasingly important. The construction sector is one of the economic activities that generate major environmental impact because their processes include both resource exploitation and use of the building over the years. In recent years wood has experienced a revival in the construction industry. Timber resources management and its wider application in construction are seen, among other measures, as an effective alternative to meet the challenges of achieving a more sustainable planet.

Wood has an ecological value because it is renewable and has low environmental impact on its transformation. It also is a versatile material with large constructional properties. However, one of the major obstacles of

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timber to be more used in buildings is its combustibility and the negative perception people have of their behavior in case of fire. In general, this idea has taken hold because the lack of knowledge about their thermal properties.

Although being a combustible material, timber has a high resistance to fire when used in structural elements with sufficient transverse measure. This fire resistance is due mainly to the low thermal conductivity of the material and degradation by pyrolysis processes that occur when a timber element comes into contact with a heat source. During the development of these processes generates a carbonization layer which slows the loss of mass of the material and the advance of the fire inside the element. The resistance of the elements varies in function of their mass, size and configuration.

Usually, wooden facades are made up of thin boards or small elements arranged in strips, ribbons, tiles, etc.; therefore, the fire behavior of the claddings is mainly defined by its combustibility. The carbonization of the pieces that make up the lining does not have a significant effect in limiting the spread of fire.

Most of the building regulations in European countries limit the use of wood and its products to low buildings, with no more than two or three stories. In most cases the use of wooden claddings is limited to a small percentage of the total surface of the facade. According to the European harmonized classification, requirement to the use of cladding materials is Class B-s3, d2, while the wood-based panels are mostly classified as D-s2, d0.

During the last twenty years it has carried out several investigations in different countries, aimed at providing basic information and data on the safe use of wood in building. Within the European context, the most important goals to achieve focus, on one hand, ensure that the results from research have an impact in a tangible way in building standards, and otherwise achieving greater harmonization of standards for wooden buildings in different countries of the region.

Provide greater knowledge and assurance about the safety of using wood in construction is now an indisputable premise and research is an essential tool to achieve this goal.

In the European context, these challenges have been addressed through research projects that integrate research teams from different European countries such as FireIn Timber project [1]. The research and development efforts have also led to major advances in fire safety in buildings of wood in countries like Switzerland, Sweden and Finland which are characterized by a long tradition of building with this material.

In the case of Switzerland, a series of investigations and large scale tests have led in 2005 to a new regulation for wooden buildings, which nowadays serves as a model for other countries in the region. This legislation includes the construction of wooden buildings for up to six floors. The Swiss regulation also allows the construction of wooden facades for buildings up to eight floors [2].

2.2 SPREAD OF FIRE THROUGH THE FACADES

The spread through the facades is one of the quickest routes of spread of fires in buildings.
There are three situations that can lead to the spread of fire through the facades:

(a) Fire from the outside through hot coals, either by a fire in a nearby building or a wooded area in flames.
(b) Fire because of an element that burns in the front of the facade (garbage container, furniture, etc.).
(c) Fire originated in a compartment of the building, which spreads outwards through the windows.
In this study we focus only on this last case, which is perceived as the most dangerous and is statistically the most frequently occurring.

The facade is the interface between the inside and outside the building, therefore it is an area in which converge many factors that facilitate the dynamics of fire, such as: the unlimited amount of oxygen, the verticality of the surface, the pressure difference between inside and outside of building, the wind, etc. for this reason, the vertical spread of fire occurs even when the cladding materials of the facade are non combustible.
In the case of the facades with combustible materials cladding, the risk increases [3]. The heat flux intensity and speed of fire spread may be higher. Moreover the fire spreads not only vertically, as normally occurs, but may also spread horizontally due to the flammability of the cladding.

According to some studies it is known that the burning rate also depends on the species of wood, its density and moisture level [4], as well as the type and arrangements of the elements of the facade [2].

To limit the risk of spread of fire through wooden facades, two options of passive fire protection could be considered:

(1) Flame retardant treatments to improve the reaction to fire performance of the cladding material.
(2) Through the design and geometry of the facade. To use construction elements capable to avoid the contact between the fire plume and the combustible cladding. Providing deflector elements with the ability to change the trajectory of the flames and prevent its passage into other compartments.
The focus of this study concerns this last option.

2.3 EFFECT OF THE DESIGN AND GEOMETRY OF THE FACADES ON THE SPREAD OF FIRE

Fire is a complex phenomenon; their behaviour can change due to different factors such as: the fire load, the thermal properties of materials, the ventilation factor, the temperature and humidity, the geometrical factor, among other aspects. This research focuses on the geometrical factor because it can be controlled from the architectural design.

Several authors have highlighted in their studies the influence of the geometric factor in the evolution of fire and its spread. Yokoi [5] conducted the earlier studies about the fire plume projecting from building windows. He indicated the need to provide vertical fringes (spandrels) of noncombustible material to separate the windows from one floor to another, or projection horizontal elements with at least 74 cm to control the vertical spread of fire.

Harmathy [6] proposed providing mobile devices on top of the windows. In case of fire, the device acts as a deflector of flames and also prevents the likelihood of spread to another floor. The projection elements may have a significant effect on the trajectory of flames, these can reduce the incidence of flames and heat flux on the facade surface.

M. Law [7], based on Yokoi's researches provided information about the effect of size and shape of the windows on the flames projecting to outside. The geometry of the windows is a key factor in fire behavior, this one not only affects the growth of fire due to the amount of oxygen entering the enclosure of fire, also influences the amount and velocity of hot gases projecting through the windows. This factor commonly is known as: opening factor or ventilation parameter and it describes as: $A\sqrt{H}$, Where A is the area of the window and H is the height.

Subsequently, Oleszkiewicz [8] conducted several studies in which he demonstrated that projection elements of the facade could positively or negatively affect the spread of fire, according to their location respect to windows. For example vertical outgoing elements can channel the fire facilitating its spread, while the horizontal projections (eaves) deflect heat flow path, minimizing its effects on the surface. Mammoser & Battaglia [9] studied the influence of the size of the balconies in reducing heat flow on the upper floors of the building, they used in its studies computational fire modeling.

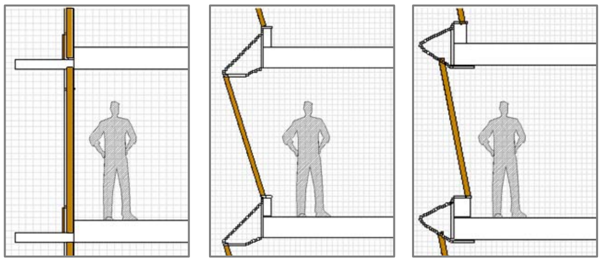
3 OBJECTIVES

Given the influence of the geometric factor in fire dynamics and its spread, this research focuses in the design of the facades as a means of passive protection capable to reduce the risk of external fire spread.

The study aims to assess the influence of some geometric factors of the facade on the fire propagation through the whole structure. Moreover we analyze the level of protection provided by horizontal projection elements and "singular" sloped elements. We focus our study on two aspects (Fig.1):

A. Comparison of four horizontal projections sizes (non combustible material).

B. Assessment of sloping surfaces in two singular designs of facade
Additionally the influence of windows size in the development of fire and its external spread has been considered in each study case.



(A) (B1) (B2)

Fig. 1 Description of the geometric variables of study.
(A) Different size of horizontal projections (eaves).
(B1 and B2) Two singular facade geometry.
(See Table 2)

4 METHODOLOGY

This research has been performed using field models of computational fluid-dynamics to evaluate some aspects of the geometry of the facades and their contribution to controlling the external spread of fire. Particularly through the software: Fire Dynamics Simulator (FDS) [10] to solve the models and Smokeview to visualize the results.

Computer-simulation is a useful tool that allows an approach to the problem of fires taking into account different variables and scenarios. These techniques are used increasingly in different professional fields. During the past ten years, due to the development of more powerful computers, the simulation modeling has advanced significantly. Currently the computer simulation of fire provides a description of the phenomenon of fire with an acceptable degree of approximation to reality.

In this research has made a scenario representing a fire in a room (living room of a house) once the fire reaches the stage of flashover, the fire spreads to outside through the windows. The models show a simplified representation analyzed cases.

Twelve cases have been evaluated based on a common computational domain and a fire scenario. The table 2 describes the variables considered in each study cases.
The characteristics of the computational domain and the scenarios are described below.

4.1 COMPUTATIONAL DOMAIN

The computational domain size is 6.50 m x 4.90 m x 8.25 m. This consists of 241,920 cells. Each cell has uniform size (0.10 m x 0.10 m x 0.10 m). The total number of cells in each domain is units. The general parameters of the simulation are described in Table 1.
There are two different areas to be considered in the domain (Fig.2):

A. Enclosure (Living room)

B. Open (external conditions)

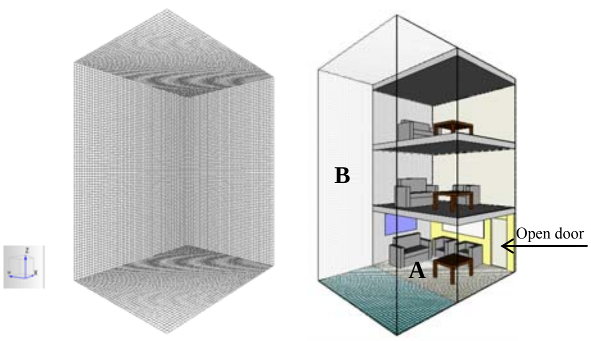


Fig. 2 Computational domain and contents of the fire scenario.

Table 1

Parameters of simulation			
Temperature	Moisture	Ventilation conditions	Simulation time
10ºC	60%	Moderate wind 2,0 m/s (7,2km/h)	900 seconds

4.2 GEOMETRIC CONFIGURATION AND CONTENTS OF THE SCENARIOS

The fire scenario consists of a three-storey living space of 4.00 m x 4.90 m. Each floor is 2.50 m high and is separated by concrete floors (noncombustible material). The facade cladding material is combustible (Wood). This scenario is representative of a typical living space with a fire load density of 600 MJ/m^2. The characterization of the materials that constitute this furniture is based on some parameters that have been extracted from the database of Ref. [10].

Table 2

Study Cases				
Horizontal projections sizes (A)				Windows size
60 cm	80 cm	120 cm	150 cm	Small 1.20x1.80 m
60 cm	80 cm	120 cm	150 cm	Large 4.90x1.80 m
Singular geometry (B)				
Singular design (B1)		Singular design (B2)		Small 2.0x1.80 m
Singular design (B1)		Singular design (B2)		Large 3.90x1.80 m

4.3 MESUREMENTS DEVICES

The data on the evolution of the temperatures were recorded through thermocouples located at the height of the parapet of the first floor. (Fig.4). In order to observe the distribution of temperatures in certain areas of scenario were used chromatic planes of two dimensions as seen in Fig.7 and 10.

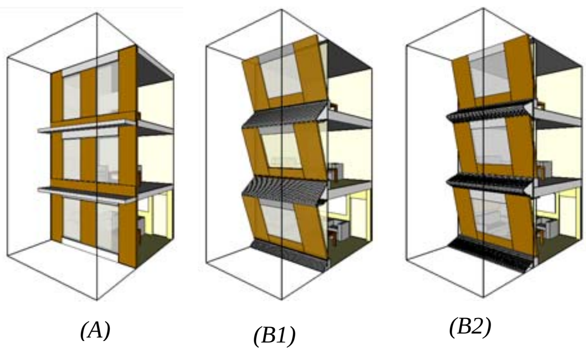


Fig.3 Geometric description of the scenarios
(A) Horizontal projection of 80 cm depth.
(B1and B2) Two singular facade designs.

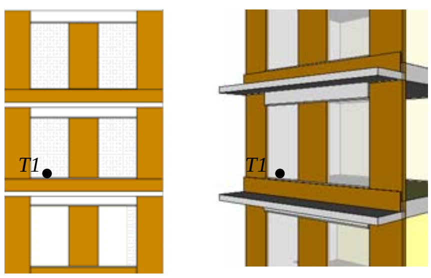


Fig.4 Location of the thermocouple T1 for all study cases.

4.4 FACADE DETAILS

The facade consists of an exterior cladding yellow pine and an interior wall covered with plasterboard.
As indicated in the research objectives, the purpose of the study is to explore the ability of some elements (non

combustible material) that are incorporated into the facade to control the vertical spread of fire. Specifically, it aims to determine the level of protection provided by elements as:

A. Horizontal projections or aprons
B. Singular design of facade. Configurations that combine outgoing elements and sloping surfaces
C. Lintels of the windows

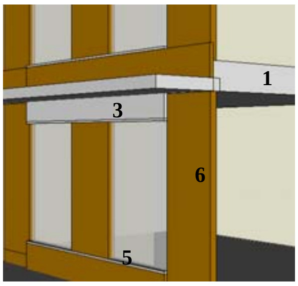
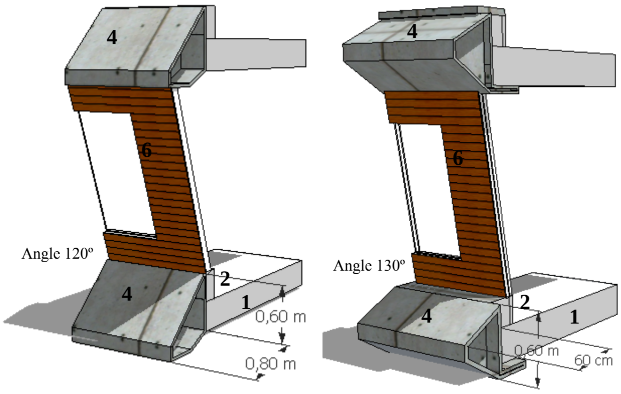


Fig.5 ***Detail 1****. Lintel and horizontal projection (eave).*



1. *Structural floor*
2. *Inner support wall*
3. *Lintel concrete (precast)*
4. *Singular concrete element*
5. *Sill concrete*
6. *Exterior timber cladding*

Fig.6 ***Details 2and 3****. Singular design elements.*

The graphics of the details 1 and 2 show the constructive characteristics of the cases to evaluate. The detail 1 consists of a concrete lintel (prefabricated) whose depth is variable depending on each study case.

This element prevents the passage of fire into the ventilated chamber (in the case of ventilated facades) and also acts as a deflector that changes the vertical trajectory of flames that projecting through the windows. The sill is also a concrete element, but its size is the same in all the cases. The intended is to determine the proper depth of the horizontal projections.

Details 2 and 3 are based on a similar approach which consists of combination of two sloped elements. First is an outgoing concrete element (prefabricated) compound of sloped surfaces. Secondly, the facade surfaces formed by the wooden cladding and windows are sloped too but in the opposite. The intent of this combination of sloped surfaces is to divert the path of the flames and prevent its proximity to the most vulnerable surfaces.

In order to ensure that the protection element considered is sufficiently stable against the fire, has been defined the precast concrete as material for the control fire elements. Usually, lintel and sill are the more affected elements in this type of fire spread.

5 RESULTS

The results show the great influence of the geometric factor of the facade on external fire spread.

A. Depth of horizontal projections

The temperature distribution graphs show that the horizontal projection elements deflect the trajectory of the flames outwards, preventing the incidence of heat flux on the facade surface. A comparison of the four horizontal projections sizes shows that the larger the horizontal extension, the less is the probability of vertical fire propagation (Fig.7). This is also observed in the graphs of temperature distribution on the walls Fig. 8.

The horizontal projections of 60 cm are capable to divert the trajectory of the flames, but might not be enough to avoid a high incidence of heat flux on the facade. The temperature-distribution graphics (Fig.7) show that heat flux in the cases with 60 cm size of horizontal projection could take a curvilinear shape, allowing high thermal exposure on the claddings surface. It is important to note that the wood has its ignition point around 320°C and a high calorific power. Therefore, we can consider that the horizontal projections should be 80 cm or more in order to reduce the heat flux on the cladding facade on the upper floors and prevent the possible vertical spread of fire. The temperature graph of Fig. 9 (bottom) makes clear the protective role exerted by outgoing elements. The facade without protection elements is fully exposed to heat flux and flames.

B. Facade elements with singular design

The two singular design cases: B1 and B2 show favourable results. The singular design B1 is a projecting element of 80 cm which also separates vertically the windows from one floor to another (60 cm). As a whole, offers a level of protection equivalent to an eave or balcony of 120 cm (Fig.7 and 10).

The singular design B2 is slightly less effective than B1, but reduces properly the heat flux on facade surface. Even though the projecting element is 60 cm depth, the heat flux on the facade surface is considerably reduced. The temperature curves show a low incidence of heat flow on the upper floor. In this case the level of protection provided is equivalent to an eave or balcony of 80 cm.

The inclination angle of the surface of the facade has an important role. In both cases can be observed that the sloped angle of the surface increases the distance between the facade and the heat flux and flames projecting from the window, so complements the protection role of the projecting element.

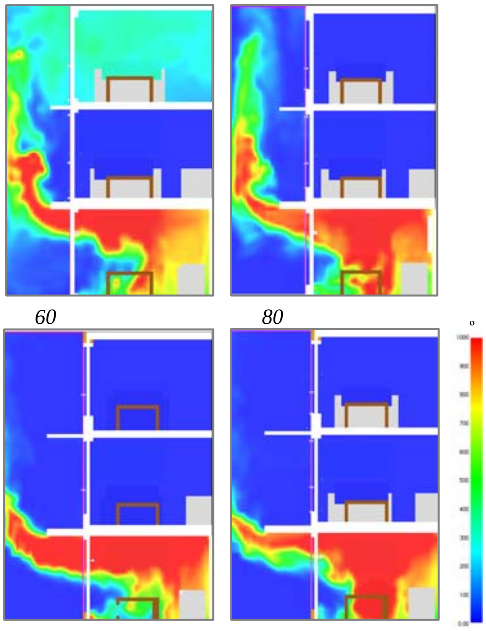


Fig.7 Temperature distribution graphics. Side view. Different horizontal projection sizes.

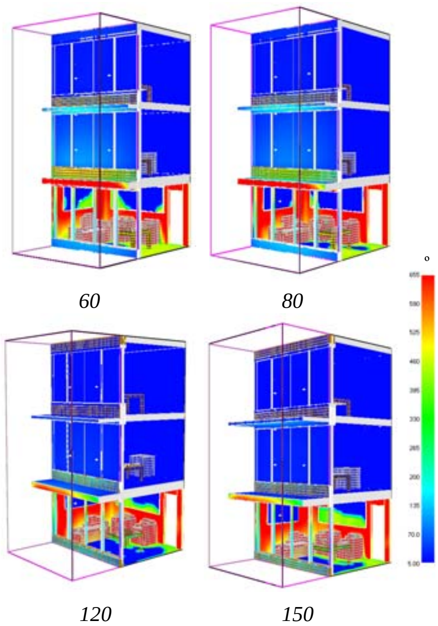


Fig.8 Temperature distribution graphics. On walls. *Different horizontal projection sizes.*

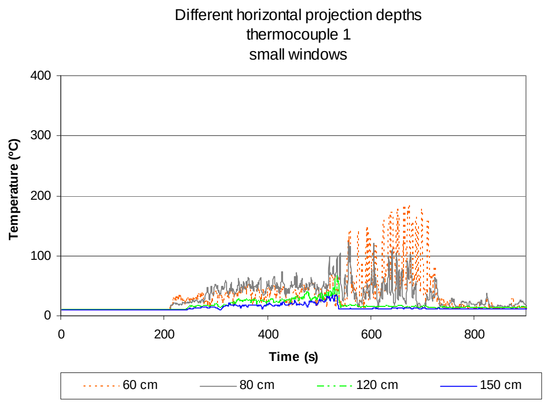
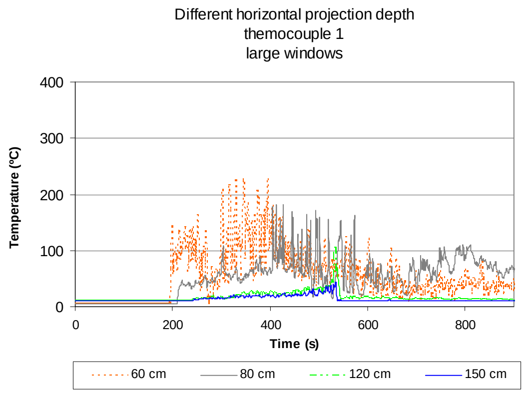


Fig.8 Comparative charts of temperature in thermocouple 1. Cases with small windows.



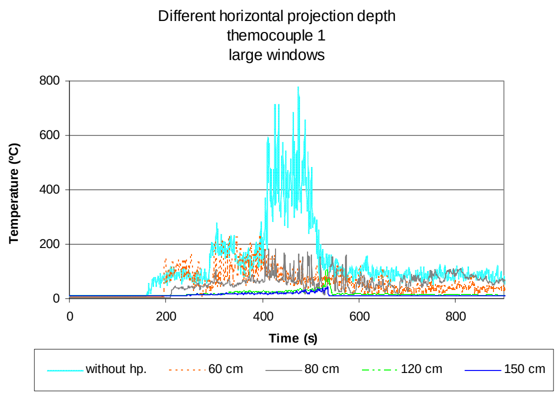


Fig.9 Comparative charts of temperature in thermocouple 1. Cases with large Window.
(Top) comparative sizes of the four horizontal projection.
(bottom) comparative between the four sizes of projections and option without outgoing element.

- **Size of windows**

According to results the size of windows is an important factor to consider in controlling fire spread through the facade. The size of the flames and the amount of heat flux emitted is proportional to sizes of windows through which are projected (Fig.11 and 12).

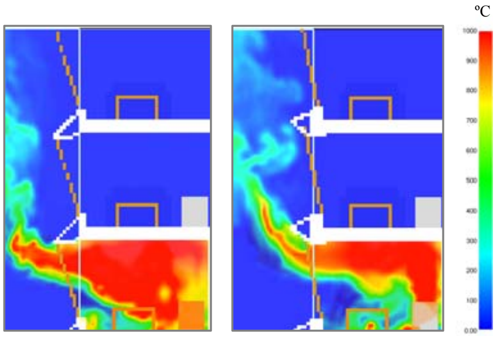
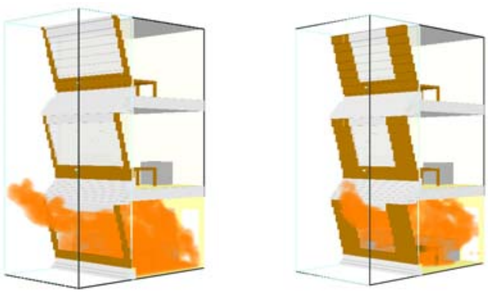
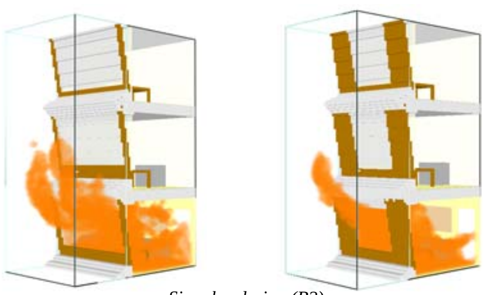


Fig.10 Temperature distribution graphics. Side view. Singular designs of facade

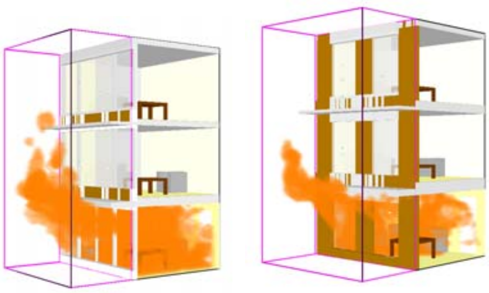
All cases were studied considering small and large windows to assess the influence of the opening factor. The evolution curves of *HRR* (Fig.12) show a large difference in the evolution of fire if the windows are small or large. In the temperature curves of the thermocouple 1 shows a higher incidence of heat flux with large windows (Fig.8 and 9). Thus the level of protection of the horizontal projections can change depending on this factor. The eaves of 80 cm may be insufficient when the windows are very large, it would be necessary to provide eaves or balconies of 120 cm or more.



Singular design (B1)



Singular design (B2)



Horizontal projection of 80 cm

Fig.11 Graphics of fire spread through large windows (right) and through small windows (left).

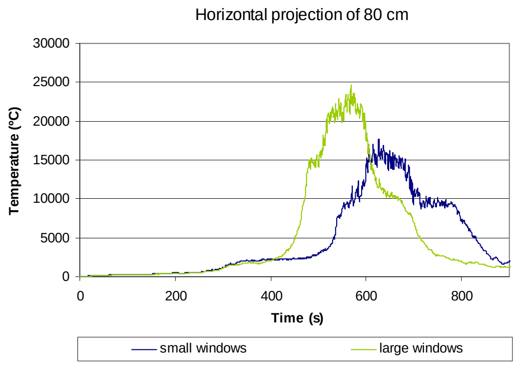


Fig.12Comparative chart of HRR of the two windows sizes.

C. Lintels

Perhaps the most affected architectural elements in this type of fire spread are the lintels of windows. For this reason, in all cases has been considered lintels of concrete, to assume a high level of stability against fire in this area.

In the study cases (A) the lintels are also related to the ability to control the passage of fire through the ventilated chambers (in the case of ventilated facades) and the ability to deflect the trajectory of the flames depending on their depth.

6 CONCLUSIONS

This study has examined a particular geometry of facades with combustible claddings. The results are limited to the examined geometry.

1. This research shows that the facade geometry of buildings can influence greatly on the behaviour of fire and its propagation.

2. The horizontal projection acts as a flames deflector. Therefore this type of projections can contribute to prevent the spread of fire through combustible materials cladding such as wood.

3. Horizontal projections of more than 60 cm are required to deflect the trajectory of the fire plume. However, horizontal projections greater than 80 cm are appropriate to reduce the heat flow on the surface of the facade. When the risk is greatest, for example due to the size of the windows may be necessary to increase to 120 cm depth in order to minimize the incidence of heat flux on the facade.

4. The windows size is an important issue in the fire spread control through the facades. Small windows reduce the risk of spread because the emitted heat flux is lower in comparison to large windows.

5. The combination of horizontal projections and sloped surfaces could be a good option of facade design to minimize the risk of vertical fire spread. This type of configurations deserves to be further explored.

7 ACKNOWLEDGEMENTS

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