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Thermal characteristics of externally venting flames and their effect on the exposed façade surface

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A B S T R A C T

In a compartment fire, Externally Venting Flames (EVF) may significantly increase the risk of fire spreading to adjacent floors or buildings, especially when combustible insulation materials are installed on the building façade. An increasing number of recent reports suggest that existing fire engineering design methodologies cannot describe with sufficient accuracy the characteristics of EVF under realistic fire load conditions. In this context, a series of fire safety engineering design correlations used to describe the main EVF thermal characteristics, namely EVF centreline temperature and EVF-induced heat flux on the exposed façade surface, are comparatively assessed. Towards this end, measurements obtained in a medium- and a large-scale compartment-façade fire test are employed; aiming to broaden the scope of the validation study, predictions of the investigated correlations are further compared to measurements obtained in 6 large-scale fire tests found in the literature. It is found that the correlation proposed in EN1991-1–2 (Eurocode 1) for the estimation of the EVF centreline temperature is under-predicting the measured values in large-scale fire tests. In addition, it is concluded that estimation of the local flame emissivity should take into account the specific fuel type used in each case.

1. Introduction

When a building fire is fully developed, flames may spill out of external openings, forming Externally Venting Flames (EVF), also known as façade fires. It is well established that EVF may significantly increase the risk of fire spreading to higher floors or adjacent buildings [1]. EVF may occur under both over-ventilated (OV) and under-ventilated (UV) fire conditions. During the initial stages of a compartment fire (pre-flashover stage), combustion is usually limited at the interior of the compartment. When the fire is further evolved, flames in the ceiling jet may become long enough to eject from the compartment openings; in this case, EVF can be observed when the fire is still fuel-controlled. If the fire becomes ventilation-controlled (post-flashover stage), unburnt volatiles may eject from the opening; they can also be mixed with ambient air and ignite, forming EVF.

In case a fire erupts at the interior space of a building, it is possible for glass panes in windows to fail, thus forming compartment openings which increase the risk of EVF occurrence. Hazards associated with EVF are even greater in high-rise buildings. It is widely recognized that the fire behaviour of high-rise buildings is rather challenging in terms of fire safety as they involve some additional features compared to "conventional" low-rise buildings [1]. For example, combustible façade systems may pose an increased fire hazard during installation and construction prior to complete finishing and protection of such systems (e.g. Beijing Television Cultural Centre fire in 2009 and the Residential Building fire in 2010). Evacuation strategies in high-rise buildings are also a major safety issue. In addition, in high-rise buildings, as a part of energy efficient building techniques, there is an extensive use of external façade insulation wall systems such as Structural Insulation Panel Systems (SIPS), External Thermal Insulating Composite Systems (ETICS), Aluminium Composite Panels (ACP) and Metal Composite Material (MCM) claddings. Even though these systems may show superior energy-saving performance, in case they ignite it is possible to promote flame spread very fast and produce large amounts of gaseous toxic products. Table 1 reports a number of indicative recent high-rise building fires around the world, involving external fire spread via the building façade; this has also been the case in numerous other high rise building fires, highlighting the importance of understanding the mechanisms of fire spread due to EVF. In fire events where EVF are observed, external wall claddings are usually ignited, thus increasing

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Nomenclature

A_o	Opening area (m^2)
A_v	Area of vertical openings (m^2)
c	Empirical factor (valued 4.67)
C_p	Specific heat capacity (J/kg. K)
d_{eq}	Characteristic length scale of an external structural element (m)
g	Gravitational acceleration (9.81 m/s^2)
H_v	Opening height (m)
k	Extinction coefficient (m^{-1})
l_x	Length along the EVF centerline, originating at the opening (m)
m_f	Fuel mass (kg)
$\dot{Q}$	Heat Release Rate (kW)
q''	Heat flux to the façade (kW/m^2)
Q_f	Fire load density (MJ/m^2)
RH	Relative humidity (%)
T_{amb}	Ambient temperature (K)
T_f	Temperature of the flame (K)
T_o	Temperature at the centre of the opening (K)
T_z	EVF centreline temperature, related to the height from the opening lintel (K)
T_{wall}	Wall temperature (K)
t_{dur}	Total fire duration (s)
U	External wind speed (m/s)
w_f	EVF width (m)
W_v	Opening width (m)
z	Height from the opening lintel (m)
Z_n	Height of neutral plane (m)

Greek

α_c	Convective heat transfer coefficient (W/m^2K)
λ	Flame thickness (m)
ε_z	Local emissivity of the flame (-)
ρ_{amb}	Air density at ambient conditions (kg/m^3)
$\rho_{500\ oC}$	Air density at 500 °C (kg/m^3)
σ	Stefan Boltzmann constant ($5.67\times10^{-8}\ W/m^2K^4$)
φ_z	Configuration factor (radiation from EVF)
φ_f	Configuration factor (radiation from fire through windows)

Table 1
Indicative cases of recent high-rise façade fires.

Building	Location	Year	Type of façade system	Details
Ajman One residential cluster	Ajman, United Arab Emirates (UAE)	2016	Highly combustible plastic filled ACP	The fire erupted at a building in the Ajman One residential cluster of 12 towers and spread to at least one other tower, 1 injury, external fire spread [7]
Address Hotel	Dubai, UAE	2016	Highly combustible plastic filled ACP	Fire started on the 20th floor of the building and only affected the exterior of the structure, 16 injuries, external fire spread [8]
Docklands Apartment Tower	Melbourne, Australia	2015	ACP	Fire started from an unextinguished cigarette on the sixth-floor balcony, no deaths or injuries, external fire spread [9]
Marina Torch Tower	Dubai, UAE	2015	Highly combustible plastic filled ACP	Fire started in the middle of the tower before spreading downwards, no deaths or injuries, external fire spread [3]
Residential Building	Grosny, Russia	2013	Ventilated façade	Fire started from a short circuit in an air-condition, no deaths or injuries, external fire spread [10]
Polat Tower	Istanbul, Turkey	2012	Ventilated façade	Fire burned through the building's external insulation, no deaths or injuries, external fire spread [10]
Al Baker Tower 4	Sharjah, UAE	2012	Highly combustible plastic filled ACP	Fire started at by a lit cigarette thrown on a balcony, no deaths or injuries, external fire spread [11]
Mermoz Tower	Roubaix, France	2012	Ventilated façade	Fire initiated at the second floor and spread rapidly upwards, 1 fatality, 10 injuries, external fire spread [10]
Wanxin Complex Fire	Shenyang, China	2011	ACP	Fire caused from explosive fireworks, external fire spread [12]
Residential Building	Dijon, France	2010	ETICS (EPS insulation, mineral wool fire barriers)	Arson fire started at the basis of the building from waste containers, 7 fatalities [10]
Residential Building	Shanghai, China	2010	ETICS (under construction)	Fire during renovation for installing exterior wall insulations, 58 fatalities, 71 injuries, external fire spread [12]
Television Cultural Centre (CCTV)	Beijing, China	2009	Ventilated façade (polystyrene insulation)	Fire caused from highly explosive fireworks at construction site on the roof - fire spread, 1 fatality, 7 injuries, external fire spread [2]