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Experimental investigation of Externally Venting Flames using a medium-scale compartment-façade configuration

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Abstract

The main scope of this work is to investigate the fundamental physical phenomena associated with Externally Venting Flames (EVF) and the factors influencing their development. In this context, a series of fire experiments is conducted in a medium-scale compartment-façade configuration; an n-hexane liquid pool fire is utilized, aiming to realistically simulate an "expendable" fire source. A parametric study is performed by varying the fire load and opening geometry. Emphasis is given to the characterization of the temperature environment adjacent to the façade wall. Experimental results suggest that the flame geometry and EVF duration are mainly affected by the opening dimensions, whereas the fuel load has a significant impact on the heat flux to the façade.

1. Introduction

In a compartment fire, Externally Venting Flames (EVF) may significantly increase the risk of fire spreading to adjacent floors or buildings, especially today that there is an ever-increasing trend of using combustible insulation materials in building facades for energy performance purposes [1]. In a fully developed, under-ventilated compartment fire, flames may spill out of external openings (e.g. windows), in case the glazing fails. The transient nature of EVF requires the use of advanced modeling methodologies, capable of describing the relevant physical phenomena in sufficient detail; the commonly used prescriptive methodologies are based on a phenomenological approach that exhibits certain limitations, especially when unusual structures are considered. CFD tools and fire design engineering correlations may provide significant assistance to the fire safety analysis of EVF, by offering the opportunity to obtain an in-depth view of the spatial and temporal distribution of important physical parameters such as velocity, gas temperatures, wall temperatures etc.

Research on EVF during the past years mainly focused on identifying the main physical parameters governing internal fire dynamics and consequent EVF; the pioneering work of Yokoi [2] in the early 1960's has been further expanded by others [3-5]. Some findings of the respective research regarding EVF description and its impact on façades have been gradually incorporated in fire safety codes and design guidelines. The Eurocode design guidelines [6], currently implemented in the E.U., provide general principles and rules regarding thermal and mechanical actions on structures exposed to fire; fire actions for designing load-bearing structures are prescribed in EN 1991 (Eurocode 1) [6]. However, fire spreading due to combustible façade materials is not directly addressed in the Eurocode guidelines and there is only a coincidental reference to risks associated with EVF (i.e. protection of steel and timber building elements).

1.1 Physical parameters affecting EVF

EVF can be loosely described as a vertical rising turbulent volume of hot unburnt gases and flames ejecting from a compartment fire through a vent/opening [7]. The EVF plume, widely considered as fairly incompressible, is principally buoyant driven and its trajectory is not truly vertical, as has been recently demonstrated by Himoto [8]. Supplementary research on medium scale compartment-façade configurations [8, 9] has established the association of the EVF envelope shape to excess HRR and distance from the façade; new length scales to describe the EVF centerline distance as a function of buoyancy have been recently introduced. In an EVF plume, it is not straightforward to identify the involvement of flammable gases on combustion at the exterior of the fire compartment [2, 9, 10], especially in cases where the ventilation in the main fire compartment is restricted (under-ventilated) and combustion cannot be completed inside the compartment [9]. In the latter case, a larger amount of ejected gases may eventually continue to burn when in contact with the oxygen-rich ambient air.

Though significant research has been conducted focusing on the impact of EVF on the façade and the parameters affecting its development [4, 9, 11-13], there are scarce reports focusing on the transient nature of EVF. Recently, Hu et al. [14] have emphasized, for the first time, the transient nature of EVF and have identified the necessity to clarify the conditions that permit the EVF to be sustained at the exterior of the fire compartment. Nevertheless, with the exception of a few experiments [e.g. 8, 11-13,] that have used "realistic" fire sources, most researchers conduct EVF experiments using constant Heat Release Rates, e.g. gaseous burners, aiming to provide steady-state conditions [4, 9, 14].

The main scope of this work is to investigate the fundamental physical phenomena governing the transient development of EVF. A range of realistic fire scenarios is developed by performing a series of medium-scale compartment-façade fire experiments, employing a ¼ scale model of the ISO 9705 room, equipped with an extended façade. An "expendable" fuel source, i.e. n-hexane liquid pool fire, is utilized to effectively simulate realistic building fire conditions and a parametric study is performed by varying the total fire load and opening dimensions.

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2 Experimental Setup

2.1 Geometry

A series of fire tests were conducted in a medium-scale compartment-façade fire configuration. The compartment was a ¼ scale model of an ISO 9705 compartment [15]. The internal compartment dimensions were 0.60 m x 0.90 m x 0.60 m; the additional external façade wall measured 0.658 m x 1.8 m. A double layer of 0.0125 m thick fire-resistant gypsum plasterboards was used as an internal and external lining material. The fire compartment opening, located in the middle of the north wall, measured 0.20 m x 0.50 m. A schematic (top section and side view) of the experimental apparatus and the locations of the measuring devices is shown in Figure 1.

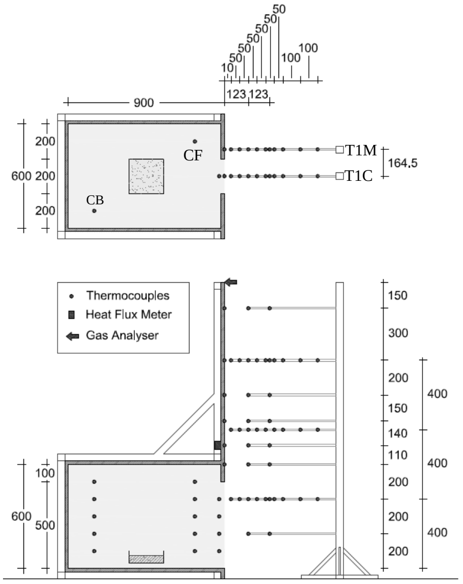

Figure 1: General layout of the compartment-façade configuration; top section (top) and side view (bottom).

2.2 Expandable Fuel Source

Gaseous burners are commonly used in relevant fire compartment experiments [4, 5], aiming to provide a constant fire power (steady-state conditions). However, in order to achieve more “realistic” fire conditions, relevant to actual building fires, an “expendable” fuel source was used (transient conditions). A stainless steel rectangular pan, measuring 0.25 m x 0.25 m x 0.10 m, was installed at the geometrical centre of the compartment’s floor; n-hexane was used as the liquid fuel of choice. The mass of the fuel source was continuously monitored using a load cell, installed under the pan. The fuel pan size was selected in order to create under-ventilated conditions and thus EVF.

2.3 Sensors and Data Acquisition System

Analysis of the flame behaviour in the façade-compartment configuration was investigated using temperature and heat flux measurements. More specifically, 10 K-type 1.5 mm diameter thermocouples located in the front and rear corner of the compartment and 4 thermocouples vertically distributed at the centerline of the opening were used for the estimation of the temperature profile in the interior of the fire-compartment. Emphasis was given to the characterization of the thermal environment near the façade, along its height, both in centerline and peripheral positions; 14 thermocouples were placed in various heights and widths across the façade. Aiming to monitor the gas temperature of the fire plume, 27 additional thermocouples were installed, using two thermocouple trees, located at a distance of 123 mm and 246 mm from the façade wall, respectively (Figure 1). A water-cooled, 25 mm diameter, Schmidt-Boelter heat flux sensor was placed at the centreline of the exposed façade surface, 110 mm above the opening.

All thermocouples and heat flux measurements were recorded using a Universal Data Logging Interface designed in LabView software; the sampling frequency was 1 s. An infrared (thermal) camera was positioned 6.0 m away from the compartment, facing the façade, to record additional information regarding the thermal response of the façade surface. Two digital video cameras were positioned in two locations, opposite and at a right angle to the opening, recording the developing EVF envelope, at 30 frames per second. Time series of video frames were obtained and processed using an in-house developed MATLAB code, aiming to determine the geometric characteristics of the EVF envelope [16]. To ensure consistent results, experiments were conducted in a controlled laboratory environment in order to eliminate potential adverse weather effects.

2.4 Parametric Study

A parametric study was performed, by varying the total fuel load and the opening dimensions. In test cases D-1.00L, D-2.35L and D-4.70L the fire load was gradually increased; in these test cases the opening corresponded to a door, measuring 0.2 m x 0.5 m. In test case W-2.35L, the opening corresponded to a window, measuring 0.2 m x 0.3 m; however, the fire load was identical to the fire load used in test case D-2.35L. A summary of the main operational parameters, i.e. opening height (H_v), opening width (W_v), ambient temperature (T_∞) and relative humidity (RH_∞), total fire duration (t_{dur}), fuel volume (V_f) and mass (m_f), global equivalence ratio (GER) [10] and total heat release rate (Q) for the examined test cases, is given in Table 1.

Table 1. Summary of main operational parameters for the examined test cases.

Test Case	**D-1.00L**	**D-2.35L**	**D-4.70L**	**W-2.35L**
H_v (m)	0.5	0.5	0.5	0.3
W_v (m)	0.2	0.2	0.2	0.2
T_∞ (^{o}C)	25.8	25.5	26.5	26.4
RH_∞ (%)	42.0	40.0	47.0	36.0
t_{dur} (s)	372	335	595	659
V_f (lt)	1.00	2.35	4.70	2.35
m_f (kg)	0.655	1.539	6.078	1.539
Q (kW)	79	207	233	105

3 Results and Discussion

3.1 Fuel Consumption Rate

The fuel consumption rate (or combustion rate) of a pool fire in an enclosure is influenced by a variety of parameters, such as ventilation, radiation from the surrounding walls and thermal characteristics of the exposed rim above the fuel [1, 10]. These effects are demonstrated in Figure 2, where measurements of the instantaneous fuel mass consumption rate for all the examined test cases are depicted. A 5 point Savitzky-Golay moving average smoothing methodology has been used in order to obtain the fuel consumption rate from the initial fuel mass loss signal. The free burning rate, as calculated using the widely used empirical correlation of Zabetakis and Burgess [17, 10], is also depicted. Peak experimental values are significantly higher than the free burning fuel consumption rate.

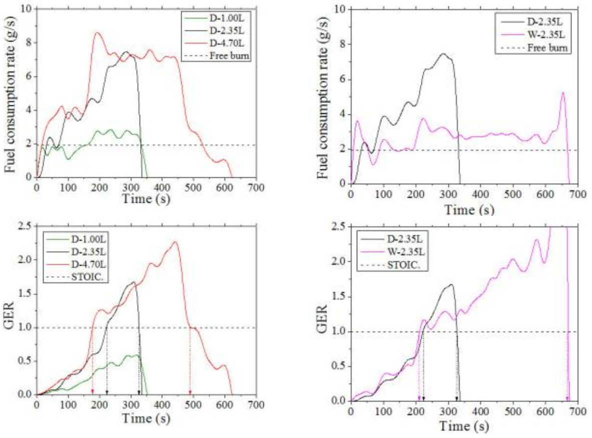

Figure 2: Measurements of instantaneous fuel mass consumption rate (top) and estimated GER (bottom); effect of fire load (left) and opening factor (right).

It is evident that a higher initial fuel mass results in enhanced fuel combustion rates, (Figure 2, left). In addition, as time advances, the gradual lowering of the liquid fuel level results in a slight increase of the instantaneous fuel combustion rate. The size of the opening mainly affects the duration of the fire event (Figure 2, right); the burning period in test case W-2.35L is prolonged due to the decreased ventilation factor. The poor ventilation conditions result in increased mixing between the exiting plume and the incoming air, thus reducing oxygen flow to the pool fire [18]. As a result, the fuel consumption rate in test case W-2.35L is significantly reduced compared to D-4.70L. The pool fire is observed to burn almost steadily in the W-2.35L test case until it enters the decay stage after approximately 650 s.

In order to establish a relationship between ventilation conditions and fuel mass loss rate, the theoretical Global Equivalence Ratio (GER) has been calculated using Equation (1). Based on the methodology for the assessment of the overall combustion process of compartment fires with an opening, initially proposed by Kawagoe [19] and applied by Babrauskas [20], the theoretical GER has been estimated using values for the fuel mass loss rate (m_{fuel}), upper layer gas temperature (T_g), ambient temperature (T_a) and density (ρ_0), fuel stoichiometric ratio (r), discharge coefficient of the opening (C_d) and the opening dimensions (H_v, W_v).

$$GER(t)=\frac{\dot{m}_{fuel}\left[1+\left(\frac{T_g(t)}{T_a}\right)^{1/3}\right]^{3/2}}{\frac{2}{3}H_v^{3/2}W_vC_d\sqrt{2g}\,\rho_0\left(1-\frac{T_a}{T_g(t)}\right)^{1/2}r} \tag{1}$$

The time history of the GER for each test case is depicted in Figure 2 (bottom). When the value of GER exceeds unity (labeled STOIC) then the fire is considered to be “well-ventilated” (fuel controlled) whereas in the opposite occasion the fire is assumed to be “under-ventilated” (ventilation controlled). Test cases D-2.35L, D-4.70L and W-2.35L correspond to under-ventilated fire conditions, although in all test cases GER is below unity during the initial fire development, when flames are mainly restricted to the interior of the fire compartment. In test case D-1.00L well-ventilated fire conditions prevail for the entire duration of the experiment; this is attributed to the low fire load used. Using data from video footage, it was observed that external fire flashes, typically emerging during the initial transient fire stage, occurred at an average GER of 0.2-0.5, whereas Consistent External Flaming [13] conditions prevailed at an average GER of 0.5.

3.2 Indoor Thermal Field

A fire behaviour that is characterized by three distinct phases (stages) appearing in succession, typical for an under-ventilated compartment fire [5, 17], can be observed in all test cases. Initially, combustion is constrained at the interior of the fire compartment (“internal flaming” stage); an advection stream is formed in the vicinity of the fuel pan. Gradually, the flame front moves away from the fuel pan, expanding radially and horizontally towards the opening. In that phase, external flame jets and quick flashes appear at the exterior of the fire compartment, signifying the beginning of the “intermittent flame ejection” stage. As time advances, the “consistent external flaming” stage [11] is observed, owed to the sustained external combustion of unburnt volatile gases, during the quasi-steady phase of the fully developed fire. Throughout the latter phase, the EVF consistently covers the region above the opening resulting in higher values of heat flux in the façade surface.

The vertical distribution of the gas temperature in the front side of the compartment, near the opening (location CF), is notably higher in test cases D-2.35L and D-4.70L, indicating that combustion still occurs further away from the fuel pan (Figure 3, left). The increased fuel load results in flames shifting to the rear of the compartment, creating a recirculating flow pattern inside the compartment, resulting in a larger EVF ejecting from the opening (Figure 3, left). In test case W-2.35L, the decreased opening area results in elevated temperatures at the front side of the fire compartment (location CF), compared to D-2.35L; in addition, temperature variations along the height of the compartment are more modest in W-2.35L (Figure 3, right). The opening area acts as an exhaust for the hot gases; in D-2.35L, the unrestricted outflow results in an decreased residence time of the high temperature combustion products at the back of the compartment, that contribute to the observed high gas temperatures at position CB.

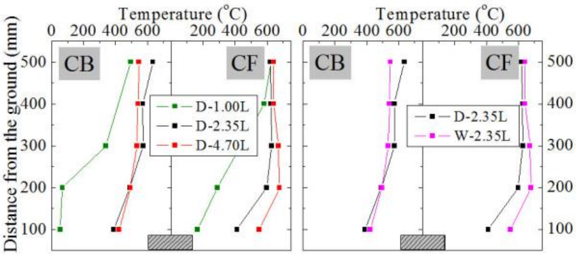

Figure 3: Vertical distribution of averaged gas temperature at the interior of the fire compartment; effect of fire load (left) and opening factor (right).

3.3 EVF Thermal Characterization

The spatial temperature distribution throughout the EVF can be inferred from the time-averaged temperature contour plots presented in Figures 4-7. The residence time of the flames at the interior of the fire compartment varies according to the prevailing ventilation conditions. Therefore, contour plots are presented for two characteristic time regimes. Time regime I corresponds to the period that flames are mainly contained inside the interior of the fire compartment (Figures 4 and 6), whereas time regime II corresponds to the time period that flames (EVF) are consistently ejecting through the opening (Figures 5 and 7). Time regime II essentially covers both the “continuous flame” and the “intermittent flame” regions. The respective time periods for all the considered test cases are given in Table 2. The duration of time regime I tends to decrease with the increase of the fire load. When the opening area is decreased, time regime I tends to last longer.

There is currently no consensus regarding the definition of the origin of the EVF, since the exit flow is usually a horizontally moving jet driven by buoyancy and momentum [3]; this has been initially pointed out by Yokoi [2], who was the first to study plumes and flames venting out of windows. The depicted contour plots comprise data from best fit lines for all thermocouples located at the exterior of the fire compartment. This representation, similar to previous studies [12], allows the EVF averaged temperature field to be determined with respect to the distance away from the façade and the height above the opening. The presented temperature contour plots correspond to measurements obtained on a plane vertical to the façade, either on the centreline (T1C), Figures 4 and 5, or the quarter-width line (T1M), Figures 6 and 7.

Table 2. Characteristic time regimes for all test cases.

Test Case	Time Regime I	Time Regime II
D-1.00L	0s – 137s	137s – 372s
D-2.35L	0s – 84s	84s – 335s
D-4.70L	0s – 28s	28s – 595s
W-2.35L	0s – 92s	92s – 659s

The EVF temperatures observed at the centreline plane for test cases D-1.00L and D-4.70L during time regime I are comparatively low (Figure 4). Peak values are observed at the vicinity of the opening with temperatures reaching 280°C and 150°C respectively just outside the opening. This is not the case for test cases D-2.35L and W-2.35L, where hot volatile gases tend to escape via the opening.

During time regime II, in all test cases, with the exception of case D-1.00L, EVF temperatures remain practically constant, with core temperatures reaching up to 400°C at a distance of 0.15 m away from the façade (Figure 5). EVF temperatures gradually decrease with height in the vicinity of the façade and the EVF shape depends on both the fire load and the opening geometry. The EVF volume is increased with increasing fire load and decreased with decreasing opening area.

At the quarter line plane, Figures 6 and 7, lower temperature values indicate that the EVF dimensions are maximized towards the centreline of the façade. When the fuel load is increased the flame becomes wider, whereas the EVF is narrowed when the opening area is decreased.

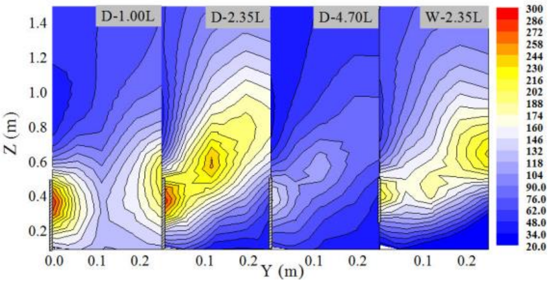

Figure 4: Averaged temperature contours at the centreline plane perpendicular to the façade (regime I).

3.4 Thermal Effects on the Façade

The temporal variation of the EVF temperature and heat flux at the façade is depicted in Figure 8. Initially, combustion is limited at the interior of the fire compartment (“internal flaming” stage). This time period corresponds to the shaded areas in Figure 8 (time regime I). As the flame front moves away from the fuel pan and external flame jets and quick flashes appear at the exterior of the fire compartment (“intermittent flame ejection” stage), the heat flux reaches its maximum and maintains an almost constant value for a prolonged time period, until the fire decay phase is reached. This time period corresponds essentially to the steady-state fully developed fire stage.

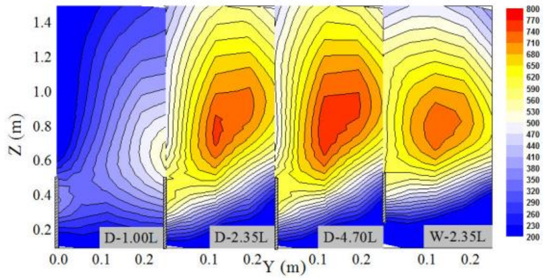

Figure 5: Averaged temperature contours at the centreline plane perpendicular to the façade (regime II).

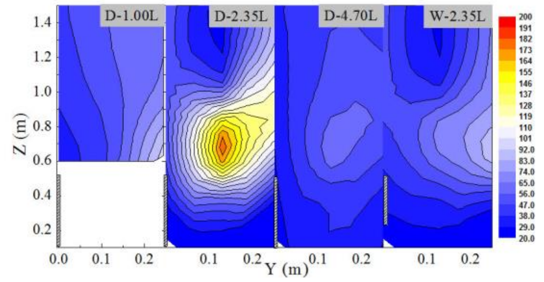

Figure 6: Averaged temperature contours at the quarter width plane perpendicular to the façade (regime I).

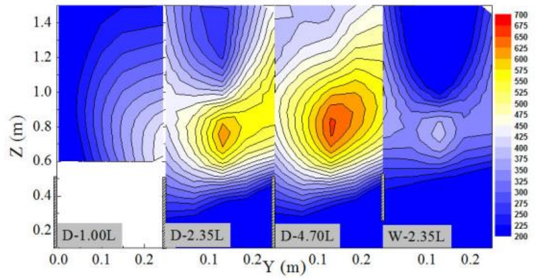

Figure 7: Averaged temperature contours at the quarter width plane perpendicular to the façade (regime II).

Throughout the latter phase, EVF consistently covers the region above the opening resulting in higher values of heat flux in the façade surface. During "consistent external flaming" period, heat flux values measured clearly indicate that fuel load has a significant impact on the heat flux to the façade. The EVF plume development, as demonstrated by the temporal evolution of EVF temperatures at two characteristic heights from the ground (Figure 8), is critical as it can be considered a first indication for the façade heat exposure. Temporal variations of heat flux depend on the EVF flame thickness at particular locations; areas that are constantly exposed to flame receive more heat flux than those that are intermittently covered. As a result, during time regime II, the increase in heat flux for all test cases can be attributed to the façade's exposure on EVF plume in the exterior of the fire compartment.

Heat flux values during test case D-2.35L were more than doubled compared to measured values in test case D-1.00L. In under-ventilated conditions, e.g. test cases D-2.35L, D-4.70L and W-2.35L, turbulence around the central axes of the EVF plume causes increased ambient air entrainment that contributes to good mixing and combustion eventually leading to the formation of areas with higher gas temperatures that re-radiate heat flux back to the façade surface.

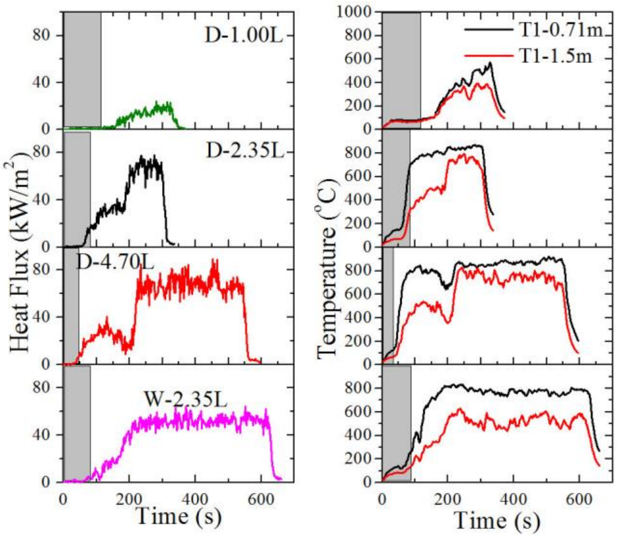

Figure 8: Temporal variation of heat flux at the façade (left) and temperatures at a distance of 123 mm (T1C) from the façade, at a height of 0.71m and 1.5m (right).

The overall thermal effect on the façade is depicted in Figure 9, where faced surface temperature measurements (via both thermal camera and thermocouples) are depicted for test cases D-2.35L and W-2.35L. It is evident that a larger opening (D-2.35L) results in a more severe thermal exposure of the façade.

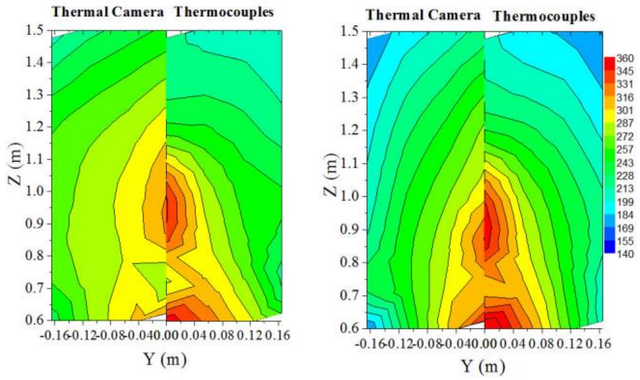

Figure 9: Façade surface temperatures at the end time of test cases D-2.35L (left) and W-2.35L (right).

4 Conclusions and Outlook

A series of medium-scale fire compartment experiments was performed, employing a ¼ scale model of the ISO 9705 compartment, equipped with an extended façade. An "expendable" fuel source (n-hexane liquid pool fire) was utilized to effectively simulate realistic building fire conditions. A range of realistic fire scenarios, relevant to building fires, was developed. A series of 4 fire tests was conducted by modifying the total fuel load and the opening dimensions; the fire load was kept constant when the opening area was modified. In the majority of the examined test cases under-ventilated fire conditions were developed; a slightly over-ventilated fire was established only in the case of the lower fire load. Experimental results suggested that the flame geometry and EVF duration are mainly affected by the opening dimensions, whereas the fuel load has a significant impact on the heat flux to the façade. The obtained extensive set of experimental data, pertinent to both the interior and exterior of the fire compartment, can be used to validate CFD models or evaluate the accuracy of other available fire engineering design correlations.

Using medium- and full-scale compartment-façade fire configurations, a range of realistic fire scenarios will be investigated in the future, by varying a number of significant operational parameters such as ventilation conditions, fire load, opening dimensions and the relative height of the fuel package. Emphasis will be given in evaluating the accuracy of available semi-empirical correlations and methodologies used for the calculation of the EVF envelope dimensions, centreline temperatures and heat flux on the façade surface.

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References

[1] N. White and M. Delichatsios, Fire hazards of exterior wall assemblies containing combustible components, Final Report, Fire Protection Research Foundation, June 2014.

[2] S. Yokoi, Study on the prevention of fire spread caused by hot upward current, Building Research Institute, Report No 34, Tokyo, Japan, 1960.

[3] P.H. Thomas, Fire, flames and dimensional analysis, Fire Safety Science, Proceedings of the 3rd International Symposium, 3-26, 1991.

[4] I. Oleszkiewicz, Heat transfer from a window fire plume to a building facade, reprinted from collected papers in heat transfer, HTD-Vol. 123, Editors: Marner W.J., Chen T.C., Faghri M., Peterson G.P., Kuehn T.H., Pate M.B., Mahajan R.L. and Lavine A.S., Book No. H00526, 1989.

[5] F. Tang, L.H. Hu, M.A. Delichatsios, K.H. Lu and W. Zhu, Experimental study on flame height and temperature profile of buoyant window spill plume from an under-ventilated compartment fire, Int. J. Heat Mass Tran 55 (2012) 93-101.

[6] Eurocode 1 (EN 1991-1-2), Actions on structures, Part 1-2 – General Actions – Actions on Structures Exposed to Fire, Brussels, 2002.

[7] J.G. Quintiere, Fundamentals of Fire Phenomena, Wiley, March 2006.

[8] K. Himoto, T. Tsuchihashi, Y. Tanaka and T. Tanaka, Modeling the trajectory of window flames with regard to flow attachment to the adjacent wall, Fire Safety J. 44 (2009) 250-258.

[9] M. Delichatsios, Y. Lee, P. Tofilo, A new correlation for gas temperature inside a burning enclosure, Fire Safety J. 44 (2009) 1003-1009.

[10] P.J. DiNenno, D. Drysdale, C.L. Beyler, W.D. Walton, R.L.P. Custer, J.R. Hall and J.M. Watts, SFPE Handbook of fire protection engineering, Tien C.L., Lee K.Y. and Stretton A.J., Chapter 4: Radiation Heat Transfer, Third Edition, SFPE, Quincy, Massachusetts, 2002.

[11] S. Klopovic and O.F. Turan, A comprehensive study of externally venting flames, Part I: Experimental plume characteristics for through-draft and no through-draft ventilation conditions and repeatability, Fire Safety J. 36 (2001) 99-133.

[12] S. Klopovic and O.F. Turan, A comprehensive study of externally venting flames, Part II: Plume envelope and center-line temperature comparisons, secondary fires, wind effects and smoke management system, Fire Safety J. 36 (2001) 135-172.

[13] A. Empis, Analysis of the compartment fire parameters influencing the heat flux incident on the structural façade, PhD Thesis, 2010.

[14] L. Hu, K. Lu, M. Delichatsios, L. He, F. Tang, An experimental investigation and statistical characterization of intermittent flame ejecting behavior of enclosure fires with an opening, Combust Flame 159 (2012) 1178-1184.

[15] ISO 9705, International Organization for Standardization: Geneva, Switzerland, ISO 9705, Fire Tests: Full-Scale Room Test for Surface Products, First Edition, 1993.

[16] E.K. Asimakopoulou, D.I. Kolaitis and M.A. Founti, Evaluation of fire engineering design correlations for externally venting flames using a medium-scale compartment façade fire experiment, 9th Mediterranean Combustion Symposium, Rhodes, Greece, 7-11 June 2015.

[17] D. Drysdale, An Introduction to Fire Dynamics, Wiley, August 2011.

[18] Y.P. Utiskul and J.G. Quintiere, An application of mass loss rate model with fuel response effects in fully-developed compartment fires, Fire Safety Science 9 (2008) 827-838.

[19] K. Kawagoe, Fire Behavior in Rooms, Report of the Building Research Institute of Japan, No 27, 1958.

[20] V. Babrauskas, Fire Endurance in a Building, Report No. UBC FRG-76-16. Berkley, 1976.