WIND DRIVEN (FORCED DRAUGHT) IMPACT ON ENCLOSURE FIRES

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Abstract

Wind-driven, or forced draught, fires are usually caused by high velocity airflows entering the compartment of fire origin under numerous circumstances, e.g. external winds; failure of windows, façade components or erroneous PPV application. Their effects are more evident in modern energy efficient or high-rise building fires resulting in increased firefighter operational injuries and influencing tactical decision making of incident commanders, choice of equipment, and firefighting and evacuation procedures. In the current work, relevant data from wind driven fires encountered in various types of buildings including bio-based, historical and buildings of specific use are collected and analysed. It is revealed that wind-driven fires can inflict complex fire behaviour which can create difficulties in extinguishing, evacuation or have a negative impact on the structure. The hazards and risks associated with the health and wellbeing of occupants and firefighters are also highlighted and analysed.

Keywords: fire, wind, wind-driven, forced drought, high-rise buildings, fire dynamics.

1 INTRODUCTION

In the history, many big fires of cities were strongly influenced by wind, examples being a series of fires in USA, October 1871: Peshtigo Fire (ca. 1500 fatalities), Great Michigan Fire (482 fatalities), Great Chicago Fire (290 fatalities). Wind-driven fires in structures, especially in high-rise buildings, are due to external conditions (e.g. wind) or building features (e.g. orientation and geometry of vent or façade elements). Additional effects creating both positive or negative pressure differentials and forced air movements can also influence fire development due to stack-effects frequently encountered in high elevators, stair shafts or air conditioning systems. Another reason for the occurrence of forced draught conditions is the misuse of positive pressure ventilation (PPV) application during firefighting intervention (Grimwood, 2017; Fishlock, 1996; Kerber and Madrzykowski, 2009). Urban landscape constantly evolves globally, as high-rise residential and commercial buildings with new façade construction techniques continue to grow in height and number. Furthermore, due to stricter requirements for building energy performance, there is a growing trend of installing combustible thermal insulation materials, that are usually flammable such as polystyrene-based, on building façades. Although, wind-driven fires may affect all types of buildings, evidence highlight that modern energy efficient buildings with complex designs and increased sizes may have increased vulnerability. Recently, there has been an alarming occurrence of façade fires in high-rise buildings where the effect of external wind is significant, resulting in high numbers of casualties, structural damage and property loss. Currently, there is limited research on the understanding of the physical phenomena associated with wind-driven fires, design guidelines and firefighting procedures in modern combustible buildings. To fill this knowledge gap, in the current work relevant data from wind driven fires encountered in various types of buildings including bio-based, historical and buildings of specific use are collected and analysed. Data collected from a number of wind-driven fires occurred in the past two decades, indicate that hazardous conditions and aftermath are particularly important in flammable structures as they can impact health and wellbeing of occupants, firefighters and compromise the building safety.

2 WIND DRIVEN FIRES

Wind driven fires are also referred to as Forced Draught (EN 1991-1-2, 2002), Force Draft, Blow Torch and Wind Fed fire. Wind-driven fire conditions can occur in specific conditions and can therefore rapidly change fire dynamics and fire development in building with a significant impact, leading in some cases to serious injuries or death of victims and firefighters. Wind driven fires can significantly change fire dynamics and flow path in a fire compartment. Main causes of wind-driven (forced draught) fires are identified and listed below (Fishlock, 1996):

- **External wind**, e.g. direction of vents, weather conditions or area
- **Mechanical ventilation**, e.g. appliance of PPV, air conditioning systems
- **Stack-effect**, e.g., elevators shafts, high buildings, geometry of the structure
- **Additional reasons,** e.g. inappropriate use of PPV or stack effect in structure.

A thorough investigation of wind-driven fire in non-flammable structures, conducted by National Institute of Standards and Technology (NIST), revealed its effect on prevailing conditions and firefighting approaches. In a series of large-scale experiments, structures were exposed to increased wind conditions, 9-11 m/s; experimental results indicate that increased temperatures can be observed in the flow-path of the bulkhead door exceeding 400°C. Just before window failure heat release rate (HRR) was 1 MW and after its failure during the post-flashover stage HRR suddenly increased from 15 MW to 20 MW. In case fire would involve part of the construction that would be combustible, the increase in HRR would be even higher (Kerber and Madrzykowski, 2009).

2.1 Repository of recent wind-driven fires

To investigate wind-driven fire development, its implication to intervention and impact on buildings and environment, a repository of recent high impact wind-driven fires is presented in Tab. 1. Cases are categorised as confined to a single structure (single-structure) and widely spreading into several adjacent structures (community-scale fire spread). They all have resulted in serious injuries or causalities of firefighters, limiting firefighting attacks and causing serious damages (in some cases even collapse) on structures and environment.

Tab. 1 –Repository of recent wind-driven fires.

Single-structure wind driven fires				
Location, year	**Storeys**	**Consequences**	**Average/max wind speed [m/s]**	**Reference**
Ottawa, Canada, 2007	4	Rapid (in a few minutes) fire development and spreading	-/ 16	(Ottawa Fire Services, 2007)
Houston, USA, 2009	1	Breaking large window changed flow-path of fire against firefighters	9/ 11	(Harlow and Hobbs, 2009)
Brownstone, USA, 2014	4	Changed of flow-path from basement, sudden fire development caused hose damage and trap of firefighters	20/ 31	(Cdc.gov, 2016)
Virginia, USA, 2008	2	Wind limited firefighting efficiency with combination of low pressure in hose line caused serious impact to firefighting intervention	11/ 21	(Bowyer, 2008)
Community-scale wind driven fires				
	Buildings			
Lærdal, Norway, 2014	40 (60 damaged)	Strong wind causes fast fire spreading between non-adjacent buildings	12/ 15	(Steen-Hansen et al., 2016)
Cohoe, USA, 2017	3 (29 damaged)	Strong wind caused fire spreading to adjacent buildings from external fire source. Intensive fire caused fast spreading in structure and premature collapse of building.	21/ 31	(Fahd, 2017)
Mati, Greece, 2018	2,500	In this WUI fire strong wind caused spread from vegetation to buildings and then to the whole community. Firebrands generated from vegetation and structure fuel were identified as the main mechanism of fire spread due to strong wind.	16/ 23	(Lagouvardos, 2019)

Tab. 1 provides evidence of the negative impact of rapid wind-driven fire spread in structures but also how it may evolve community-scale fires that affect numerous buildings or objects. It is worth indicating the two most significant fires on community scale, those are the Lærdal Fire in Norway or the most tragic fire in Europe in 21st century Mati Fire in Greece. These fires represent high risk of possible fire spread between buildings in windy conditions, caused mainly by lofted firebrands from vegetation or structure fuel. High speed wind can bend flames, affecting preheating of fuel influencing the rate of spread as happened in Mati Fire, according to victims' testimonies and records. Under strong wind conditions and lofted firebrands, as demonstrated in Lærdal (Fig. 1), it is observed that dire spread can extend up to tens or hundreds of metres.

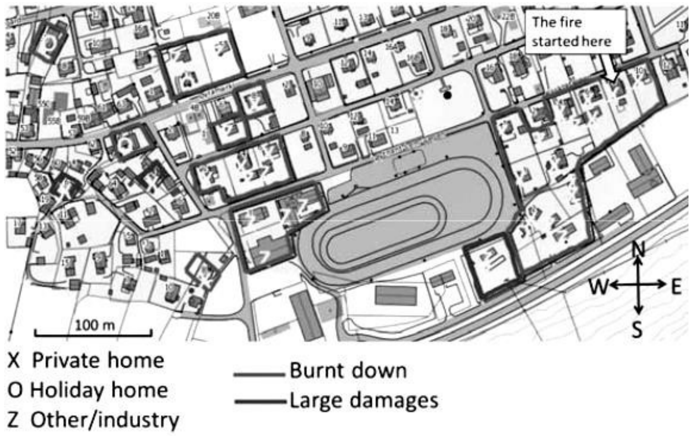

Fig. 1 – Map of area with damages and burnt buildings in Lærdal caused by strong wind (Steen-Hansen et al., 2016).

2.2 Fire Hazard of Flammable Structures

Additional findings from post-fire images in single-structure buildings are exhibited in the case of dormitories fire in Luleå (Björkman, 2013) and in Houston (Harlow, Sr. and Hobbs, 2009). During those cases, fire spreading in void spaces and negative impact of firefighting intervention to structures led to destruction of the buildings, Fig. 2.

Fig.2 – Buildings after Houston fire (left) and Luleå dormitories fire (right) (Björkman, 2013; Harlow, Sr. and Hobbs, 2009)

The above examples along with findings from research, interviews with firefighters and investigation reports provide further evidence on the extreme impacts that wind driven fires may have on structures with combustible components. Under such circumstances, it can be expected that forced draught conditions influence fire spread and may cause more intensive fire behaviour (Grimwood, 2017; Smolka et al., 2018). Also associated fire hazards include a more rapid growth of fire, the creation of natural flow-paths for fire, difficulty in observing hidden fire spread within the structure, premature collapse of buildings, building parts falling e.g., encapsulation as gypsum, repeated occurrence of flashover (in context with CLT (Karuse and Just, 2018)), repeated ignition of fire after extinguishing (hydrophobic materials), cracking of wood may pose hidden fire spreading paths, unknown materials fire behaviour under real conditions and its reaction to extinguishing.

2.3 Wind Impact to Fire

Experimental investigation in wind-driven fires conducted by NIST (Kerber and Madrzykowski, 2009) highlight a fire that could not develop to its flashover stage due to excess of fuel pyrolysis and lack of ventilation in the room until windows fail, allowing a sudden delivery of fresh air into the compartment and increasing oxygen available to the fire. Under conditions without windows failing, the fire during the experiments did not spread outside the apartment of the fire origin. Circumstances however changed when a flow-path appeared despite absent external wind inducing increase of temperature and velocities profiles in corridors and fire spreading throughout the building. A forced draught therefore may support fire spreading within a building as well as between buildings. The wind driven fire spreading mechanism in a building can be divided into internal and external (including cladding, void spaces, combustible facades and floor to floor) fire spread. The serious impact of a forced draught to fire spreading in buildings and adjacent building is shown in Fig. 3, the Cohoe fire in New York (USA) (Fahd, 2017), where the wind that day approached to 31 m/s in gusts, fire damaged 29 buildings and 3 buildings were totally burned.

Fig. 3 – Development of Cohoe fire scene in 30 mins (OneShot, 2017).

The forced draught effect to fire conditions may result to dangerous conditions for firefighters and may further complicate firefighting attack. These conditions can change dramatically within a few seconds or minutes as described in investigation reports (Ottawa Fire Services, 2007; Harlow, Sr. and Hobbs, 2009; Bowyer, 2008; Cdc.gov, 2016; Madrzykowski and Kerber, 2009). Among them, the most common conditions occurred during wind driven fires are: initiation of extreme fire behaviour (flashover, backdraft, smoke-explosion, etc.), decrease / increase of fire intensity, flame deflection, change in flow-path, change in temperature profile in compartment and fire spread.

Parameters of a compartment relevant to vulnerabilities due to wind-driven fires can be based on the evidence summarised in Fig. 4 and in principle it follows and is complementary to Fire Behaviour Indicators (FBI) being used during Compartment Fire Behaviour Training (CFBT) of firefighters (Hartin, 2018). These parameters include construction, airflow, and oxygen access by openings and compartment fire load.

The significant effect of wind-driven fires is also observed in wildland urban interface (WUI) fires. During WUI, firebrands can ignite not only surrounding buildings but also buildings which are not adjacent. Example of dangerous if this kind of fire spread in community with flammable wood-based structures is Lærdal Fire (Norway) in 2014. The fire started in private home in the municipality and strong wind-driven fire caused 40 buildings burnt out and required evacuation of 681 people (Steen-Hansen et al., 2016).

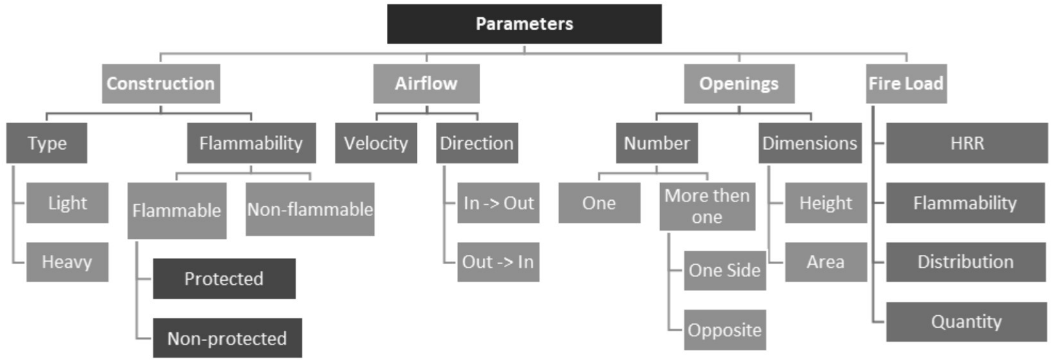

Fig. 4 Fire compartment parameters vulnerable to wind-drive fire conditions

3 EXTINGUISHING IMPACT TO STRUCTURE

Fire spreading under encapsulation or in void spaces are difficult for localization and may require disassembling construction for extinguishing of hidden fire. An important factor differencing between required amounts of water for extinguishing of compartment fire is a non-combustible and combustible structure. This factor also influences structural fire resistance. Extinguishing a combustible structure may require increased amount of water due to the increased fire load of the structure and to prevent its smouldering and repeated ignition.

Evidence from Luleå fire (Björkman, 2013) demonstrate how damages to encapsulation of the structure can be caused by fire and water during intervention caused falling of gypsum board which may cause injury of firefighters present in building. Extinguishing of hidden spread fire may require forced opening up of the construction for extinguishing and exclusion of repeated fire ignition or fire development. This ‘cutting in’ procedure can decrease structural stability and may require calling out firefighters from inside and lead firefighting attack from outside for safety reasons (Björkman, 2013). Strong wind may prevent aerial platform fire truck from involvement in fire and rescue activities, too. Wind-driven conditions in compartment, where failure of windows cause flow-path from outside causing an increase of air velocity and fire intensity in compartment and its spreading inside the corridor of building, resulting in hazardous conditions for firefighters leading intervention (Madrzykowski and Kerber, 2009; Harlow, Sr. and Hobbs, 2009). In a wind-driven fire the water delivery by water mist and spray may be impacted and ineffective.. This may prevent fast and effective extinguishing. In this situation it is required to apply a solid stream or a combination of solid and spray stream which increases efficiency in approaching the fire (Fishlock, 1996). Based on described conditions, wind-driven fire may cause increased requirements on water used for extinguishing a fire and increasing damage to structure of buildings. The safety of firefighters during firefighting interventions needs to be considered, especially in high-rise buildings with combustible components.

4 FIRE SAFETY DESIGN CONCERNING FORCED DRAUGHT CONDITIONS

Building codes and regulations include methods and measures to ensure maximum safety against fire events. In the EU, the structural Eurocodes in combination with each member state’s regulations are applied in order to determine a wide range of analytical procedures and design rules concerning the construction of structures; in this context, a set of minimum requirements for the design and construction of buildings is proposed. There are two ways of demonstrating compliance with EN 1991-1-2 (EN1991-1-2, 2002), either following the prescriptive or the performance-based approach. The effects of wind, ventilation conditions and existence of balconies in the Externally Venting Flames (EVF)’s characteristics are also considered. According to EN 1991-1-2 if there are windows on opposite sides of the compartment or air flow from another source, then Forced Draught (FD) conditions apply. Otherwise, No Forced Draught (NoFD) conditions are used for the calculations. Estimation of the EVF shape dimensions and its thermal characteristics is mainly based on the conservation laws of mass, momentum and energy of upwards flowing jets or, in the case of FD conditions, on temperature distribution patterns of jets without considering buoyancy and heat transfer effects (Asimakopoulou et al., 2017). Nevertheless, there is still lack of evidence on how EVF shape can be correlated in flammable façades.

5 DISCUSSION AND CONCLUSIONS

In the current work, relevant data from single-structure and community-scale wind driven fires in various types of buildings were collected and analysed. Relevant date indicate that wind-driven fires can inflict complex fire behaviour which can create difficulties in extinguishing, evacuation or have a negative impact on the structure. As demonstrated in this research work, it is imperative to update the scientific data regarding façade fires under external wind conditions, if one were to make direct suggestions for improving the existing fire safety design of buildings, regulations, evacuation strategies, firefighter operational decisions and strategies.

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