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Inwards Doors Blocked by Fire Induced Overpressure in Airtight Apartment: a Real Case in Germany

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Nowadays, construction requirements and practices are rapidly moving towards more airtight building envelopes, thermal insulation and energy saving according to the Energy Performance of Buildings Directive. In such structures, one might wonder if there are specific risks in case of fire. Some fatal accidents during the intervention of fire brigades were reported in the past due to a backdraft phenomenon in airtight and insulated renovated apartment. However, the occupants of better insulated and sealed buildings can also be exposed to news kinds of hazards. This paper presents the fire that occurred in an apartment in Germany on the 5 February 2013. This fire broke out during night in an apartment in a newly renovated building to meet the passive standard. Awakened by the noise of the flames, the occupant of the apartment quickly noticed that a fire had just broken out in his living room. After an unsuccessful attempt at fire extinction, he decided to abandon his dwelling. Unfortunately, the inwards-opening door to reach the outside via the corridor turned out to be completely blocked. After an interminable waiting period estimated by the investigators of nearly two minutes the occupant was finally able to open the bedroom door leading to the balcony where he was rescued by the emergency services and escaped with burns. After some investigations and based on fire simulations results from CFAST modeling, it was concluded that the door were blocked due to the fire induced overpressure.
From this real fire case there is no doubt about the capacity of the building structure to withstand high levels of overpressure, the integrity of the sealing of the passive house being not deteriorated in the first moments of the fire. This new fire hazard has to be taken into account in the fire safety design of confined dwellings.

1. Introduction

The need for sustainability and smaller ecological footprint lead to the construction of more airtight building envelopes with better thermal insulation in order to reduce the pollution and increase the energy efficiency, according to the Energy Performance of Buildings Directive (EPBD 2010/31/EU). However, in such structures, one might wonder if there are specific risks in case of fire.
Some fatal accidents were reported in the past due to a fire development in airtight and insulated renovated apartment. On March 28, 1994, at 62 Watts Street in Manhattan, New York City, a fire took place in a three-story apartment that had been renovated by installing new windows and doors, minimizing air infiltration and setting up heavy thermal insulation (Bukowski, 1995). Upon an emergency call, firefighters arrived and saw smoke coming from the chimney but no other signs of fire, so they decided to open the door of the apartment on the first floor where the fire took place leading to a backdraft and killing the team composed by three firefighters. A similar event occurred on September 14, 2002, in Neuilly-sur-Seine, near Paris (Hume, 2004). In this case, a short circuit of an old television took place in a very confined room of 9 m^2 on the sixth floor of a building and triggered a fire. Because of the room size and its airtightness, the fire produced large amounts of unburnt and hot gases and, when firefighters opened the door, fresh air suddenly flew into the room causing a backdraft that killed the team of five young firefighters. On April 14, 2002, the Fire Department of Waterloo in Belgium received a phone call for a fire in a frozen food store called Covée with exiting flames on the floor and the windows covered by a layer of black soot (Lambert, 2013). The fire brigade decided to break a window with a hammer. A hole of about 15 cm was created at the bottom of the window. Then the glass seemed to bend inside and fresh air was sucked in at a very high speed leading to a backdraft. Fortunately, the

firefighters could get safe behind a wall. The likelihood of backdraft is well recognised by fire brigades, new operational procedures were develop in order to take into account this particular hazard.
Thanks to the growing interest to build more airtight and insulated buildings, the specific fire hazards possibly associated with such structures raised questions amongst fire community in Belgium. In 2010, the Belgian Ministry of the Interior funded a study on the hazards that occupants of passive houses might incur compared to traditional houses in case of fire. The University of Mons and ISSeP used zone modelling for investigating how much the characteristics of a passive house such as airtightness, ventilation and thermal insulation could affect the fire development (Fourneau, 2012). During the growing phase of the fire, similar results were obtained in terms of fumes temperatures and CO concentrations in the fire room for the same fire scenario and the same interior cladding. The time available for the escape of the dwellers calculated according to ISO 13571 is approximately the same for both houses for identical interior facing and fire scenario. Indeed, the effective leakage area has no effect since the fire consumes a part of the oxygen initially present in the house and no extra air can enter due to the overpressure during this fire growth period. However, a significant fire-induced overpressure due to thermal expansion of fumes was calculated due to the airtightness in the passive house. Questions raised from the scientific monitoring committee of the project about the integrity of airtightness in case of fire and thus about the ability of passive house to maintain such a level of pressure.
This paper presents the fire that occurred in the night of the 5 February 2013 in Germany in an apartment that meet the passive house standard (Mayer, 2013). This learning from accident is of great interest to highlight specific dangers and take them into account in order not to repeat the accident (Hailwood, 2016).

2. The building

The fire occurred in an apartment located in a seven-story building totally reclaimed in 2008 on a very high energy efficiency level in Cologne (Mayer, 2013). The apartment was located on the third floor. The area of the apartment was about 60 m^2 and had two rooms (an open space for the living room with the kitchen in the front, a bedroom and bathroom) and a balcony. The renovation of the apartment was carried out in accordance of the passive house standard.

In central Europe, for housing, the criteria for being passive are:

- The annual heating requirements must be less or equal to 15 kWh/m² per year;
- The air leakage measured at a 50 Pa pressure difference - n50 - must be less or equal to 0.6 ACH (Air Changes per Hour) according to EN 13829 (2000);
- The primary energy consumption for all domestic applications (heating, hot water, electricity) must be less than 60 kWh/m² per year;
- Overheating within the building (> 25 °C) may not exceed 5 % of time.

Triple-pane insulated glazing with air-seals and specially developed thermal break window frames were used for the renovation of the building. The front door was a special door with fire and smoke protection (T30 RS). Due to the extreme air tighness of the apartment, a comfort ventilation was required in order to guarantee the necessary hygienic fresh air. The rate of air change was optimized and carefully controlled by the mechanical ventilation network with an air change per hour of about 0.4. Fresh air was supplied in dry rooms such as living room and bedrooms while moist air was extracted from kitchen, bathroom and WC's.

3. The incident

In the night of the 5 February 2013, a fire started in the living room of the apartment. The occupant was asleep, woke up because of the fire noise and run into the living room where he saw flames at the end of the room, the sofa was in fire (Figure1). His first idea was to put out the fire by using water. He went to the kitchen and began to fill up a bucket with water but it took too much time. The fire extended very fast and the heat became huge. He decided to get out of the apartment. Although the front door was not locked, he could not open it; the door was like locked (Figure 2). He tried to open it several times, but he had no chance. After several unsuccessful attempts, he ran back in the bedroom to escape through the balcony door (Figure 3). The same effect was observed. He could not open the window door; this door was also like locked. Then, he closed the bedroom door because of incredible smoke coming from the living room (Figure 4) and put some clothes at the bottom of the door to protect himself from fumes. He tried to open the balcony door again. After several times, the occupant was able to open the door. He escaped with injuries but he survived.

Figure 1 : the sofa

Figure 2 : The front door

Figure 3 : The bedroom with the balcony

Figure 4 : The living room

4. Cause and origin

The subsequent investigation revealed that a defective electrical appliance was at the origin of the fire, which spread to the sofa. The damage to the apartment was limited to the living room and more specifically to the sofa and the pictures located in the upper part of the walls. There was no structural damage. The first glass of the window in the living room close to the sofa bursted because of the fire (Figure 5), but the two others glasses of the triple pane glazing were not deteriorated. The occupant confirmed that all doors and windows were closed before the accident.

When he heard about this fire case, the brother of the occupant who is a journalist at the German Television Broadcast ARD tried to understand this misadventure that occurred during this night of the 5 February 2013 (Mayer 2013).

Two weeks after this fire, the occupant of the apartment made a reconstruction of the accident with the help of his brother. They concluded that from the beginning, when he woke up, until his escape on the balcony it took about two minutes.

In the beginning of the journalist investigations, no one could give any satisfactory answer. The fire department in Cologne told him first, that maybe the material of the doors expanded because of the heat and that could be the reason that the occupant was not able to open the doors (the front door and also the balcony door).
A couple of days after the fire accident, the journalist tested both the front door and the balcony door from the bedroom: they were undamaged and worked perfectly. He shoot some photos of the doors and sent them to the fire department in Cologne. They were helpless and had no more idea. Thanks to the advice of the fire department, the journalist called Dieter Brein, the leader of the German institute KIT (Forschungsinstitut für Brandschutztechnik, in Karlsruhe) which is a department of the University of Karlsruhe and told about this fire case. He was totally surprised because he had never heard before about a case like this. The leader of the institut KIT did some investigations and found a study published some months ago about the fire hazard in passive house (Brohez, 2012). This study was about CFAST zone modelling for investigating how much the characteristics of a passive house such as airtightness, ventilation network and thermal insulation could affect the fire development.

Figure 5: First glass of the triple-pan window

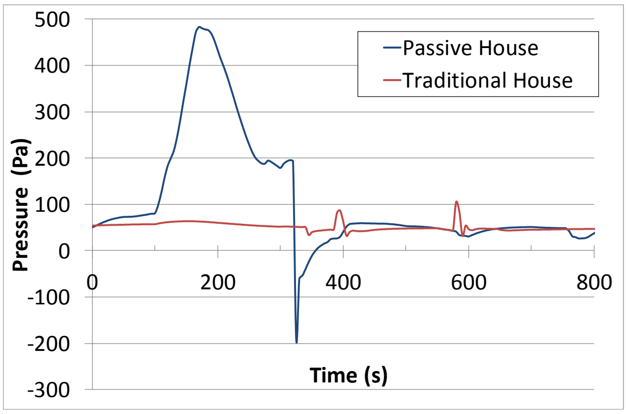

Figure 6: Fire-induced overpressure, (Brohez, 2012)

5. Computer analysis – CFAST Modelling

In 2010 the University of Mons and ISSeP used zone modelling to study the hazards that occupants of passive houses might incur compared to traditional houses in case of fire, taking into account the characteristics of a passive house such as airtightness, ventilation and thermal insulation (Brohez, 2012). The zone model CFAST was used to simulate a sofa fire in a passive house with two floors (each of 100m^2). By default, the standard sofa included in the CFAST database with a 3.5 MW peak HRR was chosen as fire source.
In the passive house modelling, a great deal of attention must be paid to airtightness of the building envelope.
In order to take into account the leakages in the simulations, two openings of identical area were assumed in the dwellings, one per floor. The opening area toward outside were fixed in order to obtain Air Changes per Hour (ACH) of 0.6 with a wind speed of 13m/s at a reference height of 10 m (the air leakage from the 50 Pa overpressure used for the blower door test represents the leakages of a house subject to a wind of 5 Beaufort, Guerriat, 2008). With this wind speed an overpressure of 50 Pa at maximum (depending of the room) inside the dwelling was obtained for a 0.019 m^2 leakage area (for each opening). Due to the extreme air tightness of the passive houses, mechanical ventilation network is required in order to achieve a minimum quality of indoor air. The ventilation system consists of ducts via which some rooms of the house are supplied with fresh air (living room, bedrooms, office…). Used, odorous and moist air is extracted from kitchen, bathrooms and WC's. A value of 350 m^3/h for the nominal flow rate of both fans was calculated (with a drop off in flow beginning at a pressure of 200 Pa and a zero flow for a pressure of 300 Pa).
In this study, for the traditional house, the geometry was kept identical to the one of the passive house but the air tightness was modified to represent a common house. The openings toward outside were fixed in order to obtain 7 ACH with a wind speed of 13m/s at a reference height of 10 m. A 0.235 m^2 leakage area was obtained for each opening in the traditional house.
The fire-induced overpressure is linked to the HRR. When the HRR increases, the pressure rises as well. Then due to a lack of oxygen, the HRR decreases in the fire room and the pressure decreases consequently. From the CFAST simulations, a significant difference in pressure rise (500 Pa) due to the thermal expansion

of fumes was calculated due to the airtightness of the passive house in comparison to the one calculated in a traditional house (10 Pa). Moreover, it can be noticed that the duration during which the fire-induced overpressure is higher than 150 Pa could be as long as 3 minutes; 150 Pa being the threshold below which most people could open an inward door (Voorbij, 2001, Vanhaverbeke, 2015). However, without any fire test validation at large scale during this project, questions raised from the scientific monitoring committee about the integrity of airtightness in case of fire and thus about the ability of passive house to maintain such a level of overpressure induced by the fire.

The results of this study were used by the German institute KIT for the reconstruction of the fire accident of the 5 February 2013 and to confirm that the fire-induced pressure in a passive house could block the occupants during a long period due to inwards-opening doors. The ventilation network in the apartment, which comply with the regulations of an energy-efficient design, was not enough to prevent high overpressure.

A television documentary about this fire case in Cologne was broadcasted at the end of September 2013 on the German Television Broadcast ARD. Nevertheless, in Germany, the competent authorities and architects remained sceptics about the connection between the doors blocked due to the fire-induced overpressure and the airtightness of the building, maybe due to a lack of validation from large-scale experiments or because this is the only fire case with such a problem of evacuation (Mayer 2018).

6. Experimental validations

Since this fire accident, fire tests at large scale in different countries were carried out in order to study the effect of the building skin airtightness and the ventilation network on the fire-induced pressures.

In 2015, full-scale experiments were carried out in the Eindhoven University of Technology to study the effect of the building skin on the fire and the pressure behaviour in well-insulated and airtight dwellings (van den Brink, 2015). A 20.7 m^3 room was used for the test setup. An air change per hour of about 1 h^{-1} was measured at 50 Pa from a blower door test and bioethanol was used as fuel. From the experiments, it appeared that pressures in the order of hundreds of Pa can occur within the first 23 seconds after ignition and may prevent the occupants from escaping.

More recently, a research about fire-induced pressure and smoke spreading in mechanically ventilated buildings with airtight envelopes has been carried out in Aalto University (Kallada Janardhan, 2017). Heptane pool and polyurethane mattress fires were carried out inside a real 150 m^3 apartment. An air change per hour of about 2.9 (h^{-1}) was measured at 50 Pa from a blower door test. Even if the airtightness is not as low as the ones encountered in passive house standard (air change per hour must be lower than 0.6), the pressure ranges encountered were between 100 Pa and 1650 Pa and occurred in less than 50 s from the ignition. During this period of high over-pressure, it was not possible to open an inwards-turning door by pulling from inside of the apartment. This experimental campaign was used for validating FDS predictive capability and gave good results even experimental uncertainties were encountered for the ventilation system configuration, the fan characteristics and the additional leakage due to high overpressures.

In 2015, a full-scale experimental facility, designed with the support of the Ghent University (Vanhaverbeke, 2015), was build up in the region of Mons with the support of the KCC centrum and the Régie Provinciale du Hainaut. Some of the objectives were to study the effects of airtightness of the building, mechanical ventilation network, heat release rate on the fire-induce overpressure in a confined compartment (Brohez, 2018). The volume was divided into two rooms The outer shell of the building is made of 20 cm concrete blocks and has the same inner dimensions of a 40-foot shipping container (12m length, 2.38m width and 2.44m height). An air change per hour of about 1 h^{-1} was measured at 50 Pa from a blower door test. Pallets and wood cribs were used as fire load instead of fuel pan in order to obtain realistic fire scenarios. The order of magnitude of the pressure measured during the experiment without mechanical ventilation (with vent pipes closed) was higher than the one carried out with mechanical ventilation: the mechanical ventilation network succeed in lowering the pressure by helping the fumes going outside. However, overpressure peaks up to 500 Pa were even measured when the ventilation ducts were not closed and both fans working. Both the reverse flow of the fan supplying fresh air and the extra flow rate of fumes extraction due to the overpressure inside the apartment were not sufficient to prevent overpressure, as it was the case with the vent pipes during the fire incident of the 5 February 2013. Moreover, pressure values higher than the 150 Pa threshold could be observed for a long period of 3 minutes which validate the reconstruction of the fire accident. The fire-induced overpressure in closed buildings such as passive houses can block the evacuation of the occupants for a lengthy time due to the impossibility to open inward opening doors. These large-scale results were used for developing and validating a methodology to predict fire-induced pressure in confined compartment by means of CFAST and FDS modeling (Caravita, 2018).

7. Lessons learned - Conclusions

The danger of backdraft in airtight and insulated buildings are well recognized by fire brigade since a long time. Operational procedures were developed to reduce the likelihood of firefighters exposure to such a dangerous phenomenon in case of fire.
However, as buildings become better insulated and confined for the energy efficiency, the occupants can also be exposed to new hazards as it was the case for the fire which occurred in the night of the 5 February 2013 in Cologne. The use of computer fire modeling was of great help in the reconstruction of this fire incident to understand what happened to the occupant during this fire. While in public spaces the doors are open by pushing outward, the doors are classically open by pulling from inside in dwellings. The fire-induced overpressure due to the thermal expansion of fumes in confined buildings such as passive houses can block the evacuation of the occupants for a long time because of the impossibility to open inward opening doors during the growing phase of the fire. The ventilation network in the apartment, which comply with the regulations of an energy-efficient design, was not enough to prevent high overpressure.In the meantime, fire experiments conducted at large scale in different countries confirm the overpressure effects associated to the fire development in such structures. It has been shown than the evacuation of the occupants can be problematic for a lengthy time due to the impossibility to open inward opening doors. Moreover, these experimental results were used to validate capability of computer fire modeling (such as CFAST or FDS) to predict fire-induced overpressure in confined spaces taking into account the leakages and mechanical ventilation network. The use of validated software could be helpful to take into account the fire-induced overpressure in confined dwellings in fire safety design.This learning from accident is of great interest to highlight specific dangers that could be encountered in passive houses in case of fire and to take them into account in the regulatory in order not to repeat the accident.

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