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Nielsen, Jess Grotum ; Sørensen, Lars Schiøtt; Husted, Bjarne

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NUMERICAL INVESTIGATION OF PRESSURE DEVELOPMENT IN ENCLOSURES DURING FIRE

Jess Grotum Nielsen, Søren Jensen Consulting Engineers, Aaboulevarden 70, 8000 Aarhus C, Denmark
Lars Schiøtt Sørensen, DTU, Brovej, Building 118, 2800 Kgs. Lyngby, Denmark
Bjarne Paulsen Husted, Lund University, Box 118, SE 22100 Lund, Sweden

ABSTRACT

Previous studies have shown that the pressure development during fires in modern air tightened buildings can be critical. This high pressure can hinder the opening of doors and thereby block the evacuation route. Furthermore, an overpressure can give rise to increased smoke spread to adjacent fire compartments through the ventilation systems.

The pressure development in an apartment building with a balanced ventilation system has been analysed utilizing the Fire Dynamic Simulator (FDS). The parameter study showed that both fire growth rate, heat release rate and the ventilation system as expected had an impact on the pressure build up in the enclosures. A faster fire growth rate leads to that the magnitude of the peak overpressure increased. However, a reduction in the leakage area of the building, together with a balanced ventilation system, revealed that the change in overpressure was small. The main reason is that the relief of overpressure happens through the ventilation system.

The parameter study results also showed a risk of smoke spread with a running smoke ventilation system and 50 Pa overpressure. This is for a fire growth rate faster than the medium rate, according to NFPA 204M (0.012 kW/s^2) and a leakage area according to the Danish BR 2015.

Keywords FDS, pressure development, smoke spread, modern air tightened buildings

1. INTRODUCTION

In the past the fire protection community has not considered the overpressure from enclosure fires as a potential safety risk for the occupants in the building. The phenomenon of fire-induced pressure increase in domestic buildings is limited, because the leakage areas in these building often are fairly large.

This assumption is not valid anymore because of the social and political awareness on energy consumptions of buildings. The latest building regulations in Denmark has been focusing on reducing the energy consumptions. This is achieved by both introducing multilayer windows (energy efficient windows), increased insulation demands and the reduction of the allowable leakage area in the building envelope [1]. The decrease in leakage area in the building envelope, has from the 2010 to 2015 building regulation decreased from 1.5 L/s per m^2 (of heated floor area at 50 Pa) to 1.0 L/s per m^2 [1]. Furthermore, it is expected that this will be further decreased to 0.5 L/s per m^2 in the 2020 building regulation [1].

The use of energy efficient windows which today can consist of up to three layers of glass has also impact on the fire dynamics in enclosures. For double and triple glass windows, data from full-scale experiments reported in the literature states that windows consisting of 6 mm double glazing doesn't break before temperatures of around 600 °C [2].

This paper investigates the consequence of these changes with relation to leakage area, fire growth rate and ventilation conditions by the use of CFD. This paper is based on a thesis from the Technical University of Denmark by Jess Grotum Nielsen [3].

The method has been to first validate the CFD code, before using the code on a typical modern apartment setup with a balanced ventilation system.

2. LITTERATURE STUDY AND VALIDATION

The Fire Dynamic Simulator (FDS 6.5.3) [4] was chosen as the tool for carrying out the study after a literature study on the performance of FDS for the actual use. The main findings from this study is summarised below.

The US Nuclear Regulatory Commission did in 2007 publish the "Verification and Validation of Selected Fire Models for Nuclear Power Plant Application, Volume 7: Fire Dynamics Simulator" [5]. Several parameters were validated and the results marked by a colour code as seen in Table 1. A green code indicates that the model can be used with confidence to calculate the specific attribute, whereas a yellow classification indicates that the validation process indicates that the numerical results are outside the experimental uncertainty, and furthermore, there is no consistent pattern of the over- or under-predictions [6]. The results of the validation study for each parameter is given in Table 1.

Parameter	Validation – Comments	Validation – Color code
Hot gas layer temperature	Both in room of origin and adjacent room	OK
Hot gas layer height		OK
Ceiling jet temperature		OK
Plume temperature		Caution
Flame height		Caution
Oxygen and Carbon dioxide concentration		OK
Smoke Concentration		Caution
Compartment pressure		OK
Radiation and total heat flux and target temperature		Caution
Wall heat flux and surface temperature		Caution

Table 1: Overview of different FDS parameters validation obtained from US Nuclear Regulatory Commission (2007) [5]

The validation of the compartment pressure has been given a green code, which implies that the relative difference between the experimental and numerical results are within the experimental uncertainty. If the validation results are investigated in further details, the predicted pressures are within 50% of the measured pressures, but this is consistent with the reported uncertainties for the leakage area and the ventilation rate [6]. A relative difference of 50 % is considerable, compared to the size of the actual over-pressure ranging between 50-300 Pa in the experiments [7].

Based on the relatively high experimental uncertainty from the experiments used above it is necessary to review more validation works regarding FDS's capability of predicting the compartment pressure. In modern buildings, a HVAC system is an integrated part for ensuring a good indoor environment. Therefore, it is also important for FDS to be able to predict the impact from the HVAC system in case of a fire in the enclosure. The following validation works has shown good agreement between the experimental and FDS results:

- Validation of FDS for large-scale well-confined mechanically ventilated fire scenarios with emphasis on predicting ventilation system behaviour, (Wahlqvist & Van Hees 2013) [8]
- CFD modelling of pressure rise in a room fire, (Li 2015) [9]
- Fire Induced Flow in Building Ventilation Systems, (Janardhan 2016) [10]
- NIST/NRC Experiments – FDS Validation, (Hamins et al. 2005) [11] and (McGrattan et al. 2017) [12]

The validation works given above are presented in further details in the thesis of Nielsen to highlight the FDS setting used to obtain the results. Based on the findings in these validations works it is possible to conclude that FDS can be used to perform the desired parameter study.

3. SIMULATION SETUP

The basic layout of the model setup is inspired from the parameter study performed by (Hostikka & Janardhan in 2017) [13] . The geometry of the floor plan, surface and material properties, the fire size and fire growth are similar to model setup by Hostikka & Janardhan. But because of lack of information regarding the HVAC setup and the actual fire base and burning material, this has been adjusted according to the Danish building regulation regarding the HVAC setup values.

The floor of the modeling area is estimated on the basis of (Hostikka & Janardhan 2017) [13] and (Hostikka et al. 2017) [14]. The floor is illustrated in Figure 1 including the primary dimension, which is given in mm. Only apartment 2 is sketched in details with all rooms, since the fire is located in the kitchen. For the other apartments the subdivision into rooms can be ignored since they are just single pressure zones.

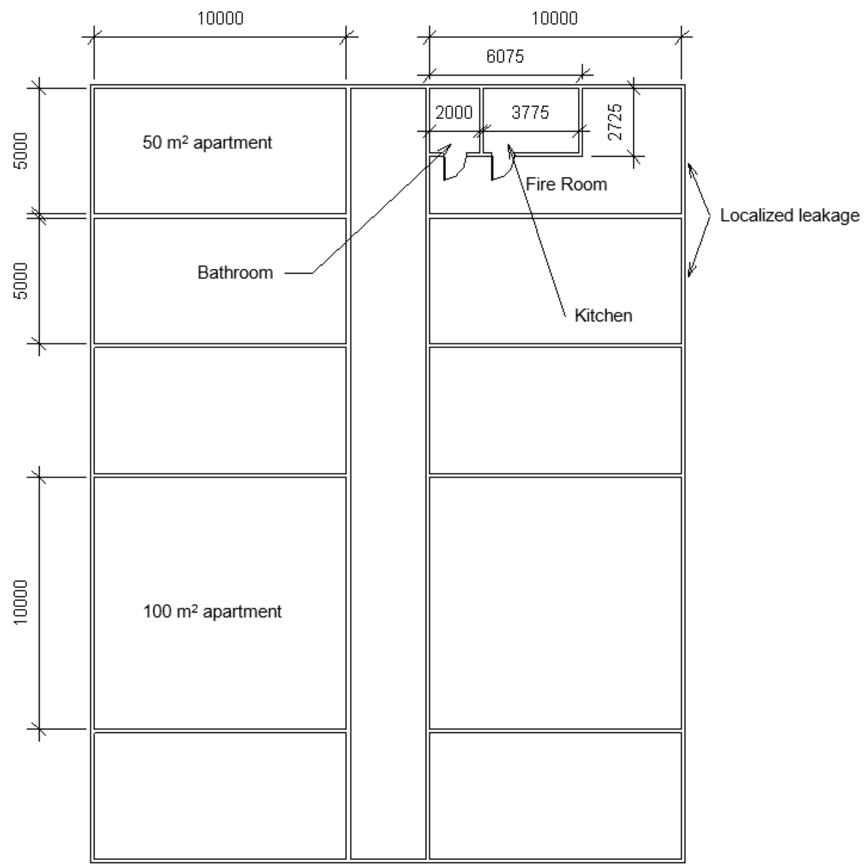

Figure 1: Illustration of the apartment layout used for the parameter study. All measurement is given in mm.

Table 2 shows the fire leakage area in the two sizes of apartment. The allowed leakage area has been halved in the proposed changes of the 2015 regulations to the 2020 regulations.

BR2015	Volume flow [m^3/s]	Δρ [Pa]	A_{leak} [m^2]
50 m^2 apartment	0.05	50	0.0055
100 m^2 apartment	0.10	50	0.0110
BR2020	**Volume flow [m^3/s]**	**Δρ [Pa]**	**A_{leak} [m^2]**
50 m^2 apartment	0.025	50	0.0027
100 m^2 apartment	0.050	50	0.0055

Table 2: Overview of the leakage areas for both the 50 m^2 and 100 m^2 apartment, with respect for the volume flow demand given in the 2015 and 2020 building regulation.

A mesh sensitivity study was conducted. It proved that a mesh size of 125 mm in the fire room and a mesh size of 250 mm in the rest of building was sufficient to get a mesh independent solution. A total of 16 simulation were done subsequent to investigate the combination of fire growth rate, leakage area and ventilation system (on/off).

4. RESULTS

The results presented in Figure 2 reveal that a faster fire growth leads to a higher pressure in the fire room. The results are also consistent for both settings of the HVAC system. The reason why the peak overpressure increases with a faster fire growth is due to the fact that for a faster fire growth the heat release rate can reach a higher value within the same timeframe.

Also, the results in Figure 2 reveals that the pressure increase in the fire room is larger with a running HVAC system compared to a non-running system. A reason for this could be the difference in the amount of pressure relief the fire compartment can have through the HVAC ducts. For a non-running HVAC system the fire compartment can use both the inlet and outlet ducts a pressure relief paths, whereas with at running HVAC system only the outlet HVAC duct can function as a pressure relief path. For a running HVAC system the inlet duct will have a dynamic pressure resistance that the fire would have to overcome in order to use it as a pressure relief path.

At the same time a running ventilation system is beneficial for the visibility in the rooms as will prevent smoke from being leaked from the fire room to other rooms. This was confirmed by the simulation results. The smoke spread to other apartments with a running ventilation system is lower comparted to the situation with a stopped ventilation system.

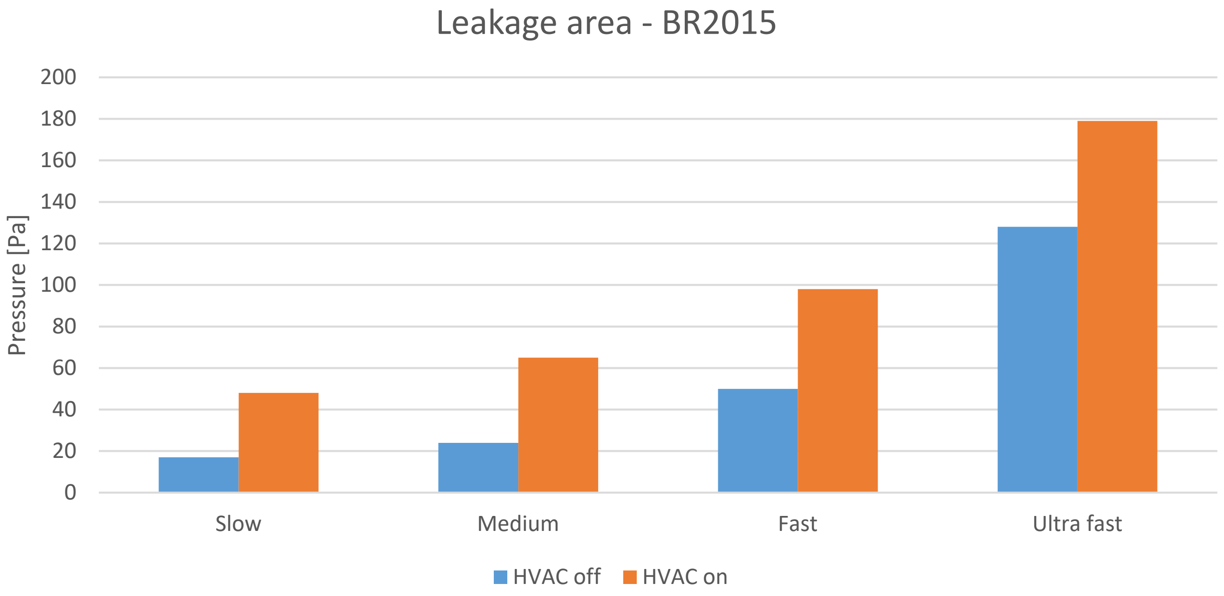

Figure 2: Results for the pressure peak with the heat release rate growth as the parameters investigated for the leakage areas given in building regulation 2015

As the results indicate, the critical condition with respect to the 100 Pa peak overpressure, is a function of the fire growth rate and the ventilation system setting. For ultra fast fires the threshold of 100 Pa, is achieved within the first 50 seconds and for the fast fires, it happens shortly around ~175 seconds. This shows that a ultra fast fire development can hinder the opening of doors, even when the ventilation system is stopped.

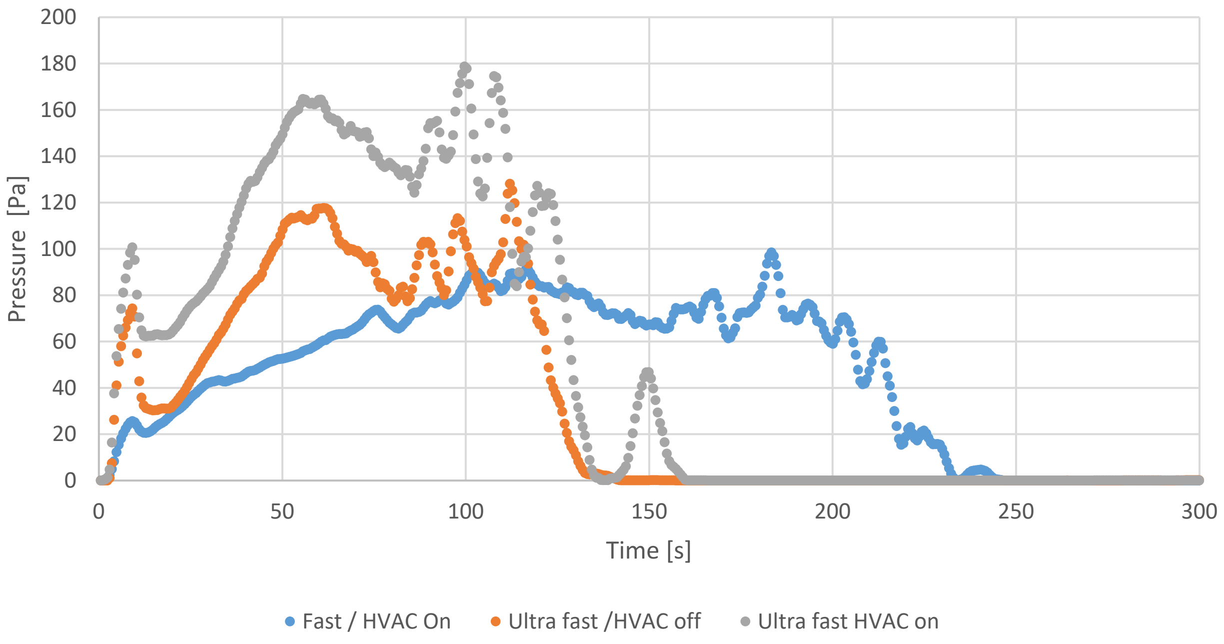

Figure 3: Illustration of the peak overpressure as a function of time for parameter study 10 (Fast / HVAC on), parameter study 13 (ultra fast / HVAC off) and parameter study 14 (ultra fast / HVAC on).

Further analysis revealed that most of the pressure relieve happens through the ventilation. With today's regulation the buildings are so tight that even if the leakage area is halved it has only limited effect on the pressure relieve.

5. CONCLUSION

The results of this study revealed that both the fire growth, heat release rate and the ventilation system as expected had an impact on the pressure build up in enclosures. The results showed that with faster fire growth the magnitude of the peak overpressure increased. The results for the change in the proposed leakage area, revealed that the change in overpressure was insignificant.

The interpretation of the parameter study results showed a risk of smoke spread in a smoke ventilated system with only 50 Pa overpressures for all fires faster than a medium fire growth, with a leakage area of BR2015 and a running ventilation system. The findings in the parameter study also revealed that many parameters have an influence on the results, including some parameters, which was not possible to investigate in this study. Therefore, more studies are needed in order to clarify these subject.

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