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Comparison of Fire Hazards in Passive and Conventional Houses

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The concept of Passive House or Passivhaus (PH) refers to the current highest energy standard for buildings, with a promise to spare up to 90 % of heating, or cooling, energy compared to common buildings. In order to be certified, a PH must meet tough requirements for air tightness and thermal insulation, so that energy losses are kept as low as possible. The difficulty to achieve the required level of performance in part explains the limited number of PH so far. However, while the member states are implementing the European Directive on Energy Performance of Building, it is expected for instance that by 2015, 100 % of the new buildings in Brussels will be PH!
The fire hazards possibly associated with PHs have recently raised questions amongst the fire community in Belgium (chiefly the fire brigades) reported by the press. In an attempt to answer those questions, ISSeP and University of Mons have conducted a study funded by the SPF Interior whose main objective was to determine to which extent the characteristics of PHs (mainly the forced / controlled ventilation and the thermal insulation) affect the fire spread and fumes propagation. The project "Passive House and fire = Inferno?" compares a PH and a conventional house in terms of fire hazards for the dwellers. It has been shown that the time available for escape of the dwellers calculated according to ISO 13571 is approximately the same for the two houses for identical interior wall lining and fire scenario.

1. Introduction

The first passive houses have been built in Germany and are inhabited since 1991 (Feist, 2006). Two countries are ahead in terms of realizations (Lang, 2009): Germany (>10000 PH) and Austria (> 5000 PH). Then follow Switzerland and Belgium with a few hundred PHs and only a few built in different countries.
The PH standard is defined only in terms of energy performances. The way to achieve these performances matters little. In central Europe, for housing, the criteria for being passive are:

- The annual heating requirements must be less or equal to 15 kWh/(m².year)
- Air leakage measure at a ΔP of 50 Pa – n_{50} - must be less or equal to 0.6 ACH (Air Changes per Hour) according to (EN 13829, 2000).
- Primary energy must be less than 120 kWh/m².
- Overheating within the building (> 25 °C) must be less or equal to 5 % of time.

For non-residential buildings, there is also a criterion related to the annual cooling requirements which must be less or equal to 15 kWh/(m².year). Then one must pay attention to effective sun protection,

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management of heat generated by electric installations and alternative cooling strategies such as free cooling and night cooling for summer thermal comfort while avoiding the need for an expensive conventional air-conditioning system (Gavernik et al, 2009).
So, for the construction, one can find masonry, wood frame, steel frame… or any combination of these. For insulation, any material can be used. Amongst them: polyurethane, wood concrete, hemp concrete, cellulose, straw, cork, mineral wool, polystyrene and any combination of them. Also different packaging is encountered, e.g. panels, injected foam, projected wool.
We can have on the one hand, an entirely "combustible house", e.g. a wood frame house with an external cladding in wood, cellulosic material for insulation, internal cladding in wood. And, on the other hand an entirely non combustible house, e.g. bricks, mineral wool, and gypsum plasterboard.
The fire hazards possibly associated with PHs have recently raised questions amongst the fire community in Belgium. However the very low number of existing PHs shows that the probability of having a fire in such building is presently very low. Currently no fire in a PH has been reported by Fire brigades, either there has been none so far, or firemen have not recognised it was a passive house burning, or the information has not been forwarded. Yet, some investigations of fire in PHs have been carried out in Germany on behalf of insurance companies (Drews, 2010). Besides, in terms of the risks firemen can encounter during fire fighting, whereas these risks are known (Hume, 2005), the phenomena causing death or serious injuries are not always identified correctly. The complexity of the phenomena and their transient aspect make it difficult to distinguish between flashover, backdraft, or any other rapid fire growth behaviour (Gorbett and Hopkins, 2007).
A first study has been funded by the Ministry of Interior in order to determine to which extent the characteristics of the PHs (mainly the air tightness, thermal insulation and forced / controlled ventilation) affect the fire spread and smoke propagation. The project “Passive House and fire = Inferno?” (its acronym PHI suggests that ventilation is a key factor) compares PH and conventional house in terms of fire hazards for the dwellers, with some emphasis on possible occurrence of back draft or flashover. CFAST (Peacock et al., 2008), a two-zone fire model, has been used to calculate the evolving distribution of smoke, fire gases and temperatures throughout the rooms of the dwellings.

2. Fire modeling - Data

2.1 Geometry of the dwelling

The objective of the study was a comparison of a traditional house with a PH in terms of fire development and consequent fire hazards/threats.

Figure 1: The passive house modelled in CFAST

We have chosen a recently built passive house in Belgium (Figure 1). This PH is a single family house with two floors. The ground area garage excluded is ca 100 m². On the ground floor, there is an entrance hall, an office, a living room, a dining room, a kitchen and a laundry room. The living room, the dining room, and the kitchen form one single open space. The stairs connecting the 1st floor are situated in this open space. On the 1st floor there are 4 bedrooms, a bathroom, a shower and a toilet.

2.2 Materials

The construction materials used for the PH are given in Table 1. To calculate conduction heat transfer through the ceiling, walls, and floor of a compartment, the properties of the bounding surfaces must be specified. However there can only exist a single layer specified per boundary in CFAST 6.1.

Table 1: Materials used for the external walls in the passive house (interior insulation)

Materials	λ (W/(m·°C))	ρ (kg/m³)	c_p (kJ/kg·°C)	Thickness (mm)
Brick	0.39	650	1	90
Air	0.18	1.2	1	30
Moisture barrier (fibre)	0.046	130	2.3	22
Cellulose (isofloc)	0.042	23	1.9	360
Plasterboard	0.25	825	1	13

In order to define surface boundaries equivalent to the actual dwelling, the Fourier-Kirchhoff equation was solved to find the temperature profile in the different layers of the boundaries. The temperature profile as function of time has been calculated in case of an interior insulation exposed to a 10 kW/m^2 step heat flux for a simulation time of 300 s. For the duration of the simulation, the insulation layer is hardly affected by the heat front (as this study focused on the fire hazards for the inhabitants of a PH, only the first minutes of the fire development were simulated). Uniform thermo physical properties for the boundaries (equivalent to plaster board of 13 mm and insulation of 0.3 mm) were calculated and set in CFAST in order to obtain an inner surface temperature identical to the one calculated in the actual case after a duration of 300 s for the heat flux step. According to EN 1991-1-2, only the first layer of plasterboard could have been considered in this analysis.

2.3 Openings - Ventilation

In the construction of PHs, a great deal of attention must be paid to air tightness of the building envelope, especially at connections between different elements. Through a blower-door-test, the air leakage of a house at 50 Pa can be measured. This relative pressure would represent leakages of a house subject to a wind of Beaufort 5 (Guerriat, 2008). The Passive House standard n50 is 0.6 h^{-1}.

In order to take into account the leakages in the simulations, two openings of identical area have been assumed in the dwellings, one per floor. The openings toward outside have been fixed in order to obtain Air Changes in an Hour (ACH) respectively of 0.6 and 7 for the passive house and the traditional house with a wind speed of 13 m/s at a reference height of 10 m. This wind speed leads to an overpressure of 50 Pa (at maximum) inside the dwellings. Leakage area obtained for the two configurations are 0.019 m^2 and 0.235 m^2.

Due to the extreme air tightness of the PHs, mechanical venting 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. Used, odorous and moist air is extracted from kitchens, bathrooms and WC's. During the cold seasons the energy contained in this air is used in a heat exchanger to heat the supply air and save valuable heating energy. In CFAST two additional compartments were added to represent the ventilation networks: one for incoming air with an opening in each bedroom, in the living room, and in the office, and another one for exhaust air with opening in the kitchen, in the laundry, and in the bathroom. In Belgium the ventilation rates are prescribed in the (NBN D 50-001, 1991) standard. The characteristics of the two fans are as follows: a constant flow rate of 350 m^3/h, a drop off in flow beginning at a pressure of 200 Pa and a zero flow for a pressure of 300 Pa (from technical data from the manufacturer).

For the "traditional house", the geometry was kept identical but the two compartments representing the ventilation networks were discarded. Insulation and air tightness were modified to represent a common house.

2.4 Heat release rate

One major difficulty in zone models is that heat and chemical species release rates in relation with a given fire source term are usually to be provided as input data. In this project the fire scenario is a sofa burning in the living room. As fire source we have chosen the standard sofa fire which is included in the CFAST database (NIST, 2010).

In order to evaluate the toxic gas generation in the houses it was necessary to correct the data included in CFAST as they correspond to the sofa burning in open air, i.e. to a well ventilated fire. From the development of the fire, we have first estimated the equivalence ratio (Φ = the actual air fuel ratio /the air fuel ratio for complete combustion). Then, using the results of (Purser, 2009) for yields of toxic gas as a function of Φ, we have calculated CO and HCN yields needed as input data for the CFAST simulations in order to take into account the effect of ventilation on the calculation of CO and HCN concentrations. In order to simplify the analysis, the sofa was assumed to be completely constituted of polyurethane foam.

3. Fire modeling - Results

Figure 2 shows that the fire growth in the same way for the PH and the traditional house during the first five minutes (it is not surprising since the heat release rate is an input data of the model). However at ca 315 s, the fire in the passive house cease to grow because of lack of oxygen. After 400 s the fire stabilizes at a mere 0.2 MW. The starvation of oxygen in the traditional house is slightly delayed but the decrease is less important.

3.1 ACH effect

The initial ACH has little effect on the fumes temperature (Figure 3) and concentrations of CO and HCN during the growth of the fire (as the oxygen concentration does not become the limiting factor). In this first phase of the fire, the house is a slight overpressure (overpressure which is particularly important that the house is airtight) and the fire consumes a part of the oxygen initially present in it (Figure 4). In a second phase, the power of the fire decreases because of a lack of oxygen, the house is slightly depressed and the air can re-enter the house and feed the fire. The air flow will be even more important that the openings are important; the air tightness will have an important role in this second phase. The largest tightness (passive house) will lead to a partial extinction of the fire. The power of fire is then smaller; the fumes temperature will decrease faster in the case of the passive house. There will be currently a greater production of unburned gas (resulting in higher probability of backdraft during fire fighting.), carbon monoxide and HCN.

The tightness of the passive house should be affected by the increase in pressure and by elevating the temperature walls but simulations suggest that this will not much influence on the results obtained during the growth phase of the fire (for the period of evacuation of occupants).

3.2 Insulation effect

For the same interior lining (i.e. plasterboard for the walls) and the same type of furniture, similar results for PH and traditional house are obtained for fumes temperature during the fire growth (until oxygen does not become the limiting factor). Indeed, whether the insulation is located just behind the finish coat plaster (internal insulation), the heat front has barely had time to reach this layer. The thickness of this layer has no impact on simulation results, at least in the first minutes of the fire. These conclusions are even more obvious for an external insulation (which is also recommended from an energy point of view).

Conclusions would be different if the insulation was placed directly inside facing (Skujans et al., 2010) and this, regardless of the type of house. In this case, the heat flux transmitted to the surface of the inner walls are smaller and the fumes temperature rise faster (simulation results lead to a peak temperature of 560 °C instead of 350 °C for plasterboards). In general, regardless of the building, the use of an insulating inner face should be avoided, especially when it is a combustible material (see for example the fire on 20 February 2003 Station Nightclub whose walls were covered with an acoustic insulation that was combustible, Rhode Island, United States).

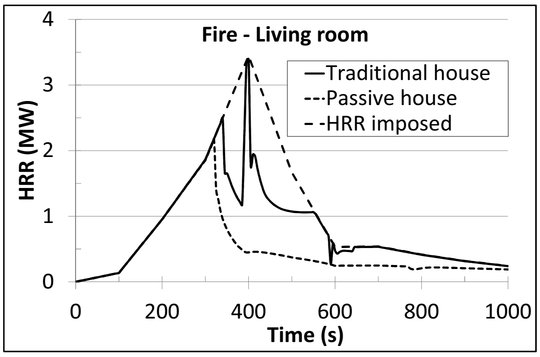

Figure: 2 Fire development

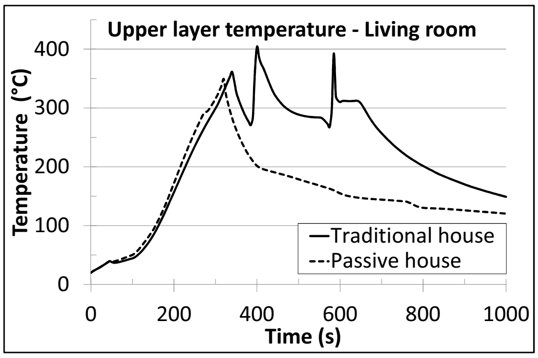

Figure 3: Upper layer temperatures

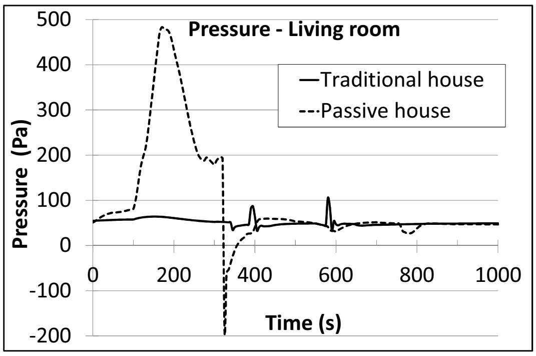

Figure 4: Pressure inside the living room.

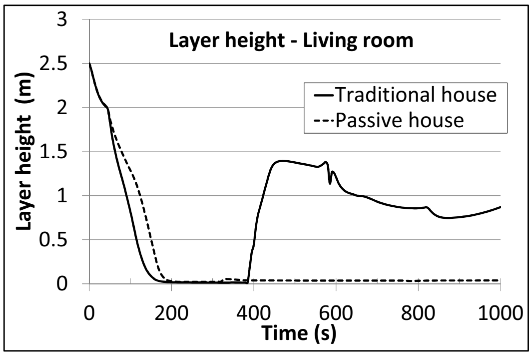

Figure 5: Layer height in the living room

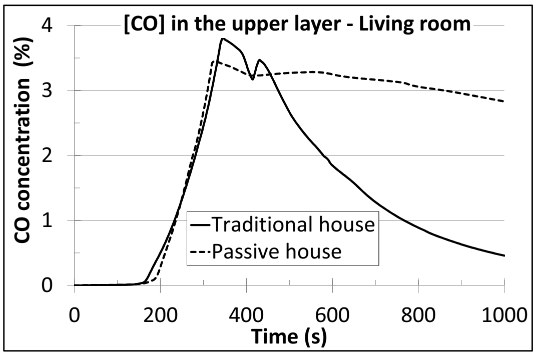

Figure 6: CO Concentration

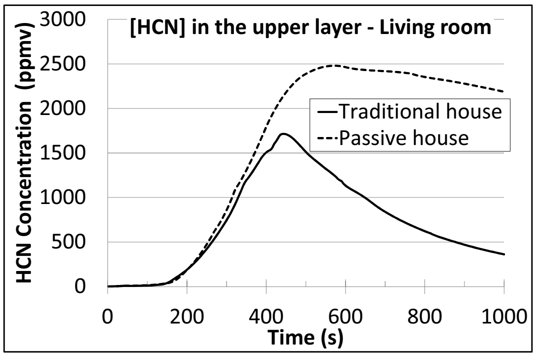

Figure 7: HCN Concentration

3.3 Mechanical ventilation

The design of PHs requires the establishment of a mechanical ventilation system to ensure good air quality for occupants. During the fire growth, thermal expansion leads to an increase in pressure in the house (Figure 4). The flow of the fan supplying fresh air could be reversed if it is unable to overcome the pressure in the PH. Smoke can then go up the ventilation system and pollute other living areas. The (ISO 13571, 2007) standard has been used to estimate the time at which the occupants are no longer able to take effective action to accomplish their own escape. For the fire scenario and interior lining considered in this study, times to escape are approximately the same for the PH and the traditional house (220 and 245 s respectively for the fire-effluent toxicity and heat life treat).

4. Conclusions

A comparison of the fire hazards has been carried out for the dwellers of a PH and a traditional house. Only one fire scenario has been presented in this paper, however many others scenarios were simulated (fire glass breakage, opening the door by the fire-fighters, shut off of the mechanical ventilation, fire in a bedroom).

For the same fire scenario (sofa assumed to be constituted of polyurethane foam) and the same interior lining in the two houses, similar results are obtained in terms of fumes temperatures and CO and HCN concentrations in the room where the fire ignited during the fire growth period. Indeed, the insulation has no effect on the fumes temperatures since the heat front has barely had time to reach this layer (located behind plasterboard) in the first minutes of the simulation. Moreover, leakage areas have no effect on the results since the fire consumes a part of the oxygen initially present in the house and no extra air can enter the houses due to the overpressure during this growth period.

In a second phase, the lack of oxygen leads to a decrease of the heat release rate. The air tightness plays here an important role; extra air can enter the houses since they are submitted to an under pressure. Higher productions of unburned gas, CO and HCN are calculated in the PH.

Times to escape are approximately the same for the PH and the traditional house.

Let us noticed that CFAST does not included a pyrolysis model and consequently does not take into account the increased pyrolysis due to radiative feedback from the flame or compartment.

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