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Influence of the built environment on design fires

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ABSTRACT

Design fires are often used to the evaluate performance based designs by fire protection engineers all over the world and can be an invaluable tool if used properly. One potential big issue however is the fact that the exact same design fire is recommended by authorities in similar building types despite the fact that some building characteristics, such as building material, can differ greatly. This paper focused on investigating several key characteristics of a building (building material, openings, room floor area size and ceiling height) and its effect on the design fire using computational fluid dynamics. When well to moderately insulating materials was used the design fire growth rate and maximum heat release rate was in many cases significantly increased, especially if the room was well ventilated, the ceiling height was relatively low and the room floor area was moderate. However, using thermally thin materials (steel sheet) or materials with large heat storing capacity (concrete) very little change was seen on the growth rate or maximum heat release rate. In conclusion it was recommended that one should take precaution when using recommended design fires in buildings with certain characteristics since it potentially can overestimate the safety in such case.

1. Introduction

The simple design fire concept has been used extensively to evaluate performance based designs all over the world and is an invaluable tool for many fire protection engineers. However, the design fire is a rough simplification of the real world and using it in applications outside the boundaries of its original intent might result in erroneous conclusions in regard to fire safety. E.g., the Swedish National Board of Housing, Building and Planning (Boverket in Swedish) recommends different fire growth rates depending on the type of activity in a building [1], but one problem that can arise from directly using proposed growth rates is that the characteristics of the fire compartment is never accounted for; e.g. will a heavily insulated building behave the same as a steel sheet building or does the radiative feedback increase the fire growth and maximum heat release rate? Does a smaller room behave different from a big room? How much does the amount of openings (both normal openings and those caused by evacuating people, as in doors being opened) to the fire room affect the development of a fire? Some studies has been made on this topic, e.g. an experimental study done by Evegren et al. that indicates that the effects of using highly insulated compartments will influence the mass loss rate [2] to some degree, but the scope of different scenarios was rather limited in that work. This work focuses on investigating typical building materials, the amount of door openings supplying air to the fire room, fire room floor area and ceiling height and how they affect the fire growth and maximum heat release rate using the computer software Fire Dynamics Simulator [3] doing so called numerical experiments [4].

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2. The design fire

Design fires are often used when doing performance based design of the fire safety in buildings. The time to critical conditions (for example visibility, toxicity, temperature and radiative heat flux levels) inside the building or compartment in case of a fire is compared to the time it takes for the occupancies to safely egress; if occupants are not exposed to critical conditions prior to leaving the building it is often presumed to be as safe as needed. The approach to design fires is divided into three parts; the growth phase, the steady phase and the decay phase. In this work the primary phase of interest is the growth phase, but some discussion is also focusing on the steady phase, specifically the maximum heat release rate.

2.1. The growth phase

The most common way to describe the growth phase is to use the following mathematical formulation:

$$\dot{Q} = \alpha \cdot t^2 \tag{1}$$

what this means is that the heat release rate $\dot{Q}$ at a certain moment determined by a number α and the time t since the fire started. A larger α value would mean that the heat release rate would increase more quickly than a smaller number, and a common classification of this number has been done by the National Fire Protection Association (NFPA), which can be seen in Table 1. This standard classification will be used throughout this paper by using references to both the name of the growth rate classification as well as the given α-value. A visual representation (with a given maximum heat release rate of 5 MW) of the different classifications can be seen in Fig. 1.

When selecting the growth rate for a design fire it is most often depending on the building type and building content (e.g. office, school, shopping mall) and sometimes the national authorities give recommendations on which value to use, as the example from Sweden seen in Table 2. The heat release rate is then allowed to increase over time up until a pre-set maximum value, which initiates the steady phase. As can be seen in the Swedish example in Table 2, all buildings within the same activity group will be treated exactly the same even though their building construction and building materials can differ greatly.

2.2. The steady phase

If oxygen depletion does not occur during the growth phase a maximum prescribed heat release value is reached and sustained until the decay phase (unless oxygen depletion once again interferes). This phase is called the steady phase. The magnitude of the maximum heat release value and the duration of the steady phase is often determined by the building type and building content, similar to the growth phase. And as with the growth phase, the national authorities often give recommendations on which value to use (see Table 2 for example), and once again all buildings within the same activity group will be treated the same even though their building construction and building materials can differ greatly.

3. Specification of the numerical experiments

To investigate the influence of the building material and opening factor on the design fire a simple room was created with the following dimensions; $10 \times 10 \times 3$ m (width × length × height), see Fig. 2. The $10 \times 10 \times 3$ m compartment was selected as the "default" room to represent a reasonable "normal" case, but also adapted to be able to see a clear distinction for each material. If the ceiling would have been very high the radiation from the ceiling and hot gasses might potentially be relatively low which in turn would mean that the growth rate probably would never be changed. The same thing would probably happen if the room floor area was relatively large, since there would be very little build-up of a hot gas layer and there would probably be very little radiative heat flux feedback from the walls. To further analyze these assumptions additional simulations were done to investigate the influence of the room floor area size and the room ceiling height.

3.1. Wall materials

The main goal was to investigate the influence of the building materials used in the walls, ceiling and floor. Four different materials were selected, each having different properties and responses (thermal properties and thickness/heat storing

Table 1
Standard classification of different growth rates according to NFPA 204M [5].

Growth rate	$\alpha\,[kW/s^2]$	Time to reach 1055 kW
Ultra fast	0.19	75
Fast	0.047	150
Medium	0.012	300
Slow	0.003	600