The Dutch Approach to the Escape from Large Compartments

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ABSTRACT

In the Netherlands, the building regulations have no design rules for large fire compartments (over 1000 m^2). With respect to the ability of people to escape from a fire in such large spaces, the Centre for Fire Research of TNO Building and Construction Research has developed a guideline that integrates the calculation of the available safe escape time (ASET) and the required safe escape time (RSET).

The ASET is calculated using traditional zone models which were extended modelling several aspects relevant for large spaces, such as the cooling of smoke on ceiling and walls as well as the effects of unstratified smoke spread in the room. A calculation model for the RSET using the flow capacity of exits was extended by taking into account the travel distance inside large fire compartments and the moment people start to escape. These extensions for modelling both aspects, ASET and RSET for large compartments, may also be useful outside the scope of the proposed Dutch guideline.

KEYWORDS: ASET, RSET, zone model, large fire compartments.

INTRODUCTION

Current building regulations in the Netherlands [1] contain fire safety rules limiting the size of fire compartments. In offices for example, the area of compartments has to be 1000 m^2 or less, while in hotels this area is 500 m^2 maximum. The regulations contain the provision that for a safe escape from the building once they have left the fire room, people must not be forced to go through smoke for a distance larger than 30 m in general. In an experiment performed at our laboratory, it was confirmed that able-bodied people are able to walk over such a distance even in the presence of a low smoke density of 0.08 m^{-1} [2].

However, for some building types such as large assembly rooms, these rules are considered too severe. Not only the practical reason that not all such rooms can be divided in several smaller spaces, but also the fact that life threatening conditions in such buildings can occur much later due to slower smoke filling, have motivated the responsible Ministries to commission work on guidelines regarding the safety level in such 'large compartments'. That work can be divided in two components, one describing fire growth and smoke spread, and another describing escape. Referring to this last component, TNO developed a model to judge fire safety in large compartments. The most important aspects of this model are presented in this paper.

The model essentially consists of a comparison of the time to fill a large room with smoke and hot gases with the time it takes to leave that room (ASET/RSET, i.e. available and required safe escape time). The model is based on calculation methods from literature that have been used traditionally in the Netherlands in neighbouring areas, such as the design of smoke venting systems. For the purpose of developing a usable guideline for large fire compartments, to be introduced in the building regulations, these methods were extended in scope and at the same time reduced in complexity. The work has resulted in a guideline described in [3]. The design guideline will go through a series of trials and discussions with designers and architects, before it will be implemented in the Dutch Building Decree.

In this paper attention is given to both parts of the model. First the method to calculate the ASET is presented, which is the smoke filling process of the fire compartment, thereafter the calculation of RSET (escape from the compartment) is presented.

SMOKE FILLING PROCESS OF THE COMPARTMENT

Normally, the design of smoke and heat ventilation systems in the Netherlands [4,5] is based on the calculation method of the work of Thomas, Morgan and Hansell [6,7]. With that method the smoke spread is calculated from a fire in a large room as well as from a fire in an adjacent room using a zone model. To make the method better suited as a guideline to evaluate large compartments, some extensions had to be made to this model. The most important are the assumed fire scenario, the cooling of smoke along ceiling and walls and the effects of unstratified smoke. Besides these, the calculations are performed stepwise in time ($\Delta t = 0.1$ sec) resulting in a smoke filling time of the compartment, contrary to the design of smoke and heat ventilation systems where a steady state situation is calculated (in which the smoke flow into the smoke layer balances the outflow of smoke from the layer through the vents).

Only the first stage of a fire, while the fire is growing in size, is important for judging the possibility of escape. The fire scenarios are classified in 3 types of t^2 fires, mainly because the classification with only three fire types simplifies the use of the guideline for judgement. The growth rate of these fires - slow, fast and ultra-fast - were taken from literature [8]. The radius of a circular fire grows linearly in time. The heat output per area is taken as a constant value, depending on the type as well. The fire load and the height of combustibles in the fire room determine the type. Combustibles piled higher than 3 meters are treated differently, depending on the reaction to fire of the goods and the packing (analogous to [8]).[9]). Sprinkler installations are assumed to stop the growth of the fire once the area is 9 m^2, and the heat output is reduced by 50% from that moment on.

In large spaces the smoke and hot gases will cool down while flowing under the ceiling and along the walls. In practice the effect of cooling is not very important for the thickness of the smoke layer, but it is important for the stratification as discussed below. Therefore, the existing method to calculate the smoke flow rate [5] was extended, taking into account the energy flux that flows from the smoke layer through the ceiling and walls of the building. The calculation of the flux is based on the penetration theory of a semi-infinite slab with the surface suddenly raised to a higher temperature, included in many textbooks on heat transfer [10]. The flux depends on the level of the temperature rise ΔT itself, the time t that has passed since the stepwise temperature rise and the thermal inertia of the slab $\lambda.\rho.\ C_p$.

Ceilings or walls exposed to smoke differ in two aspects from the above mentioned semi-infinite slab case. The first aspect is the slow temperature rise instead of the stepwise change, and the second aspect is that convective heating of the ceiling and walls by the hot gases is limited compared to the temperature rise of the surface of the slab. These two differences are taken into account by including an additional factor 2 for the penetrating energy flux ϕ, and a maximum convective heat transfer coefficient of 20 W/m^2K; the lowest value determines the flux.

$$\Phi = \min(20 \bullet \Delta T, 2 \bullet \Delta T \bullet \sqrt{\frac{\lambda \bullet \rho \bullet C_p}{\pi \bullet t}}) \tag{1}$$

The additional factor 2 was calculated from numerical simulations for cases in which the surface temperature of the semi-infinite slab rises linearly instead of stepwise. However, the exact value is not very important since in all practical work performed with the model until now, the maximum heat transfer coefficient of 20 was the lowest value and determined all energy losses. Note that the assumed value 20 W/m^2K of the heat transfer coefficient is based on small temperature differences in the first phase of smoke spread in a large room.

In large compartments the smoke temperature can be high so that a stratified situation arises with a smoke layer under the ceiling (with increasing thickness) and a clear layer below it. But in case the calculated temperature of the smoke layer is less than e.g. 5 K above ambient, it cannot be guaranteed that a clear layer will appear under a smoke layer. To some degree, mixing of smoke in the compartment will appear. The model distinguishes two situations that must be evaluated in that case: situations with a clear layer as well as with a homogenous mixing of smoke in the compartment are considered. A problem that is subject to further study is when exactly to evaluate against this 5 K criterion. If the first smoke reaches the ceiling and the layer starts to form, then even the ultra fast fires with high heat release rates will result in small temperature differences. If one looks at a certain thickness of the smoke layer (e.g. 10 % of the height of the compartment, or 1 metre [3]) then the time to evaluate against the criterion depends on the size of the compartment.

ESCAPE FROM THE COMPARTMENT

Traditionally, calculation methods of the required safe escape time (RSET) are based on the calculation of the flow capacity of exits, using 90 persons/metre-width/minute for doors and corridors, 45 persons/metre-width/minute for stairs broader than 1.1 m and 25 persons/metre-width/minute for smaller stairs. These relationships for walking velocity are based on the data from the London Underground [11]. The current building regulations [1] are based on 5 classes for the population density inside buildings. A normal walking velocity of 1.6 m/s is used for the four classes, while only for the class with the highest density of 1.25 m^2/person a velocity of 1.1 m/s is used.

Referring the scope of the model as an easy to use guideline, the model for large compartments uses these methods neglecting the more complex approach of models like Simulex [12]. This implies that care must be given to the assembly of people in one room escaping from several other rooms [13]: to limit such effects it is required that such rooms are large enough to contain all people escaping through that room.

The time required for escape is calculated as the minimum of a) the time needed for all people to pass the exits (flow capacity time) and b) the time for people to cross the large compartment (travel time). For the travel time, it is assumed that people are going from any point to an exit which gets blocked by radiation, after which people have to reach the next nearest exit. This is approximated by the sum of the distances from a point to the two nearest exits, see figure 1 [3]. This overestimates the length of the route taken., and thus constitutes a conservative approach. In practice, large assembly rooms are designed such that there is no large over capacity for the exits, so the RSET is dominated by the flow capacity time. Next we focus on the moment the people start to evacuate. This moment depends on the moment people become aware of the fire and the subsequent delay before they start to escape (pre-movement time).

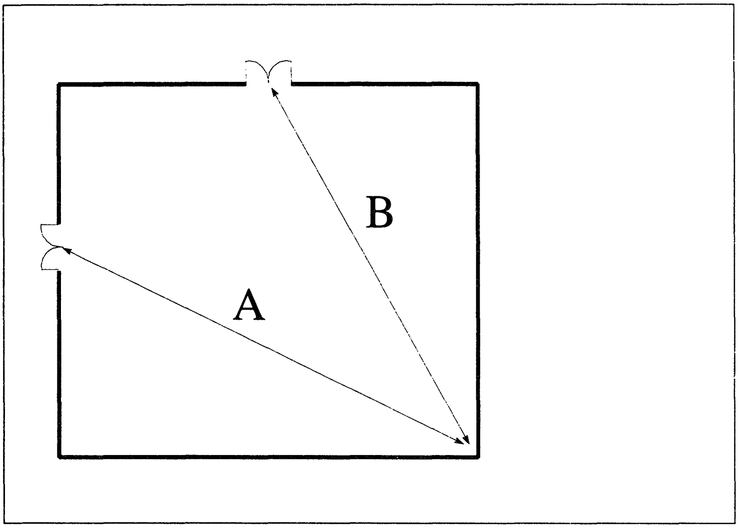

FIGURE 1 Large fire compartment with two exits. The travel distance is the sum of distances A and B from the 'worst case' point to the two nearest exits.

The model can only be applied to buildings where people present are awake. The moment people become aware of the fire is calculated depending on the presence of smoke detectors.

The smoke density under the ceiling which should be at least equal to the threshold value of the detector, and an assumed delay time of 60 seconds, derived from standard detector sensitivity tests, define the moment when detection occurs.

In the absence of automatic detectors however, some crude assumptions were made on the moment of detection by smelling since no general criterion for smelling the smoke was found in literature. The concentration and the nature of the chemicals produced in the smoke determine that moment. Above that, the zone model approach as described above does not include a calculation of the smoke concentration at floor (nose) level.

The assumptions are based on the smoke concentration in the 'clear' layer under the smoke layer, taken from CFD calculations of small fires in comparable spaces. The smoke density $SD_{1.7m}$ is calculated at a relative distance x (the distance from 1.7 m above a floor where people are present divided by the distance from the lowest floor in the compartment to the bottom of the layer) under the smoke layer and the smoke density in the smoke layer SD. $SD_{1.7m}$ is approximated by a third order polynomial, see figure 2:

$$SD_{1.7m} = SD \bullet (a + bx + cx^2 + dx^3) \qquad (2)$$

with the following constants:

a = 0.102676
b = -0.327093
c = 0.34895
d = -0.124485.

Once this smoke density is higher than $1/15{,}000\ m^{-1}$, people become aware of the fire at that floor. For modern buildings with large compartments however, the uncertainties in these assumptions are expected to be not of much practical interest since automatic smoke detection is normal.

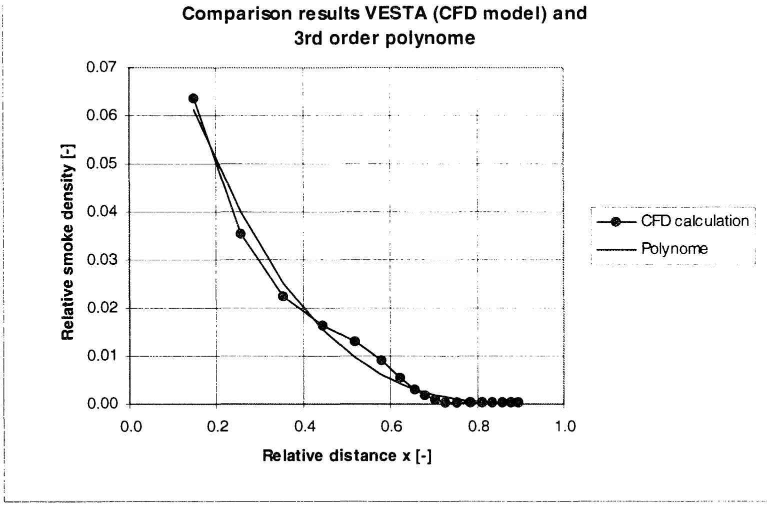

FIGURE 2 Relative smoke density as a function of relative distance.

For the case of a fire occurring in an adjacent room with smoke flowing into the large room, it is assumed that people become aware of the fire (hear or see) when flash-over occurs in the small room (assumed when the smoke temperature in the adjacent room reaches 600 °C) or when construction elements (e.g. glass) between the two rooms fail. Construction elements such as normal float glass (and, as suggested by the regulators, all other construction elements with a fire resistance lower than 20 minutes) are assumed to fail when the average temperature (smoke layer and clear layer) in the adjacent room reaches 150 °C.
Currently there are insufficient simple engineering tools to estimate the duration of the "pre movement period" that starts after people become aware of the fire. One can expect differences in behaviour between people who do and who do not know the building very well. In the Netherlands however, in large buildings the internal organisation could help people in deciding to leave the building and so diminish pre movement time. In large buildings such organisations are required for some years now. Experience in practice is not yet available. In work from others, commissioned by the Ministry, the proposed pre-movement time in our guideline [3] was changed to a fixed period of 2 minutes [14].

The model takes into account the blocking of an exit by a fire. The worst case regarding the location of the fire must be taken into account. Given the radius of the fire calculated at a certain moment, people cannot pass exits that are nearer than four times this radius. This is based on the radiation from a square surface, an emissivity of 1 and a temperature of 750 K; the radiant flux is less than 2.2 kW/m^2 at these distances, which can be withstood without pain for 30 seconds [15]. It is assumed that no exits are blocked within 30 seconds from the start of the fire.

EVALUATION OF THE MODEL FOR SAFE ESCAPE FROM LARGE COMPARTMENTS

The following criteria are taken to judge the situation. A route for escape is available if:

1. there is a clear layer of 2.5 m and the temperature of the smoke above is less than 200 °C, or
2. there is no clear layer of 2.5 m but the visibility for light emitting objects is 30 m or higher.

With the model described briefly here, large fire compartments (maximum area 15,000 m^2, height 5 to 50 metres) can be evaluated regarding the ability for people to escape safely: the calculation of RSET and ASET according to this model form a complete and easy approach. Especially the aspects of cooling of the smoke on ceiling and walls, unstratified smoke spread and the blocking of an exit could also be used outside the scope of the Dutch guideline.

Work was and will be commissioned by the Ministry to develop the proposed guideline from TNO as presented here [3] further. The guideline is and will also be reviewed by other organisations [14]. Apart from some assumptions that were needed by the Ministry and where better solutions were not available, the comparison of the results from this model for new designs of large fire compartments and the common building practice must be performed to finalise the guideline for building regulations.

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