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The development of a real performance-based solution through the use of People Movement Modelling Analysis (PeMMA) combined with fire modelling analysis

Rodrigo Machado Tavares [a,*], Steven Marshall [b]

[a] IPT – Instituto de Pesquisas Tecnológicas (Institute of Technological Research), Laboratório de Segurança ao Fogo – LSF (Laboratory of Fire Safety), Av. Prof. Almeida Prado 532 Cid. Universitária., 05508-901 São Paulo, Brazil

[b] CAPITA SYMONDS Fire Engineering Team, United Kingdom[1,2]

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ABSTRACT

This paper presents a real study case in which fire engineering (i.e., performance-based) solution was developed to address a deviation from a prescriptive fire safety code. The study case, investigated in this paper, consists in a TV Studio (i.e., assembly), which is occupied by a maximum number of 928 people. In this instance the exits provided are 1 × 3920, 3 × 1040, 1 × 1650 and 910 mm clear width and after discounting the largest (in this case a 1040 and the 3920 mm wide exits were discounted because they are close together), the maximum occupant capacity under the Approved Document B (*AD B*) is 806 people. Therefore, in order to address this non-code compliance condition, evacuation and fire modelling analyses were carried out to estimate the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET) for people evacuation from the TV Studio. The results have shown that this methodology addressed satisfactorily the occupants' safety, validating the use of the BS 7974 as an efficient alternative document to the *AD B*. This study shows how the appropriate use of People Movement Modelling Analysis (PeMMA) and fire simulation models can help immensely the development of performance-based designs. The results are presented and discussed in this paper.

1. Introduction

The Approved Document B (*AD B*) is part of a series that has been approved and issued by the Secretary of State in the UK. Its purpose is to provide practical guidance with respect to the requirements for some of the more common building situations (Anon, 2006).

The *AD B* is the main fire safety document for buildings in Wales and England; and is prescriptive in nature. For instance, it defines the minimum number of exits which should be placed within enclosures according to the number of people as well as the type of occupancy. The *AD B* does also require the minimum value for the exit(s) width according to the number of people.

Despite its prescriptive nature, the *AD B* also states clearly that: "The fire safety requirements of the Building Regulations should be satisfied by following the relevant guidance given in this Approved Document. However, Approved Documents are intended to provide guidance for some of the more common building situations and there may well be alternative ways of achieving compliance with the requirements" (Anon, 2006). In fact, it does recommend that fire engineering solutions (i.e., performance-based solutions) can provide alternative ways for achieving the fire safety. Based on that, the *AD B* does mention some British standards, such as the BS 7974, as well as Published Documents (PDs) as alternative guidance to be followed when a more performance-based solution is needed.

Under this perspective, the concepts of ASET and RSET are introduced in the Published Document (PD) 7974 '*The application of fire safety engineering principles to fire safety design of buildings*' (Anon, 2001). In Section 6.7.2 of this document, it states:

"To ensure the safety of the occupants of a building, it is necessary to establish that they are able to reach a place of safety before untenable conditions occur. The time necessary for evacuation of the occupants to a place of safety will depend on a number of factors relating to the occupants, the building and the rate at which the fire gives rise to untenable conditions. The aim is to ensure that all persons can leave a threatened part of a building in reasonable safety without assistance and the aim is generally to ensure that the time available for escape is greater than the time required for escape":

$$ASET > RSET$$

where ASET is the Available Safe Egress Time (before untenable conditions occur) and RSET is the Required Safe Egress Time.

It is possible to get a reasonable good estimation of both parameters by using the hand calculation approach suggested in this document. However, in highly populated enclosures and complex

* Corresponding author. Tel.: +55 11 53542504.
E-mail address: rodrigotmj@gmail.com (R.M. Tavares).

[1] http://www.capitasymonds.co.uk
[2] http://www.ipt.br/EN

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geometries, the interaction between the occupants potentially produces significant areas of congestion. For this reason, alternative methods of calculation should be considered, such as the use of computational models which simulate people's movement and fire dynamics behaviour.

These computational models have been developed largely over the last two decades. The literature on such types of models is already vast; furthermore they will not be discussed in depth in this paper. Those models which represent people's movement under emergency conditions and non-emergency are still commonly known as evacuation (egress) models and/or pedestrian models. Taking an upfront view, these models can be designated as People Movement (PM) Models and the analysis performed based on their results as People Movement Modelling Analysis (PeMMA) (Machado et al., 2010). PeMMA is discussed further in this paper. Those models which simulate fire behaviour based on its dynamics are commonly called simply as fire models. They are typically divided into two main types, namely: zone models and CFD (Computational Fire Dynamics)-based models. Depending on the complexity of the fire scenario to be investigated as well as the level of accuracy to be pursued, it is common practice to use the CFD-based models. Considering the simplicity of the study case investigated in this paper, a zone model was used instead.

In the next section, the study case is discussed. In Section 3, the assumptions considered for the PeMMA and fire modelling analysis are presented. In Section 4, the assumptions and the simulation parameters are described. And in Section 5, some concluding remarks are presented.

2. The study case

The study case investigated in this paper, consists in a TV Studio (i.e., assembly), which is occupied by a maximum number of 928 people. From this figure, 914 people are assumed to be located in the seating area, while 14 people (i.e., the staff/stars) will be standing up, see Fig. 1. The enclosure in its original architectural plan has six exits; nevertheless, for fire safety strategy purposes, two exits are discounted. Having this said; the *AD B* states that for enclosures with more than 600 persons, the minimum number of exits should be three. Therefore, the number of exits does not represent a deviation from the *AD B*. However, in this instance the exits provided are 1×3920, 3×1040, 1×1650 and 910 mm clear width and after discounting the largest (in this case a 1040 and the 3920 mm wide exits were discounted because they are close together) the maximum occupant capacity under *AD B* is 806 people. Therefore, as mentioned previously, in order to address this non-code compliance condition, People Movement Modelling Analysis (PeMMA) and fire modelling analysis were carried out to estimate the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET) for people evacuation from the TV Studio.

The results have shown that this methodology addressed satisfactorily the occupants' safety, validating use of the BS7974 as an efficient alternative document to the *AD B*. This study shows how the appropriate use of evacuation and fire simulations models can help immensely the development of performance-based designs. The results are presented and discussed in this paper.

3. Some considerations about PeMMA

In the next paragraphs, some basic considerations about PeMMA are presented.

3.1. PeMMA – People Movement Modelling Analysis

People Movement (PM) models can be used in a wide field of applications from fire safety engineering (including human behaviour analysis in emergency situations) to circulation of people in open and enclosed spaces (including risk analysis in events involving crowds: crowd management).

There are many PM models available. There is a vast literature on PM models (Galea ER, 2003; Tavares, 2008, 2009, 2010a, 2010b, 2010c; Tavares and Galea, 2009a, 2009b; Cruz et al., 2005) and furthermore, this paper will not discuss about them in depth.

These models take into account not only the physical attributes of the occupants, but also their psychological attributes (i.e., competitive behaviour, response time, etc.) for estimating the RSET. Some well-known PM models, like (STEPS, xxxx), (LEGION, xxxx), (EXODUS, xxxx) and (SIMULEX, xxxx) are continually updated and improved to take into account new research in the field. They are usually capable of taking into account the impact of fire on the occupants' movement.

For this reason, in the fire safety engineering field, these models, when properly used, can produce realistic results and be powerful tools for helping engineers and designers to address deviations from the fire safety codes requirements. In reality, the use of PM models has been enabling the development of fire engineering solutions; allowing performance-based designs to be achieved. For instance, their use can help immensely to address core fire safety issues, such as:

- Evaluation of stairs width based on their capacity in terms of occupants' flow rate for different types of scenarios and occupants' bodies and mobility.
- General investigation of deviations from the building regulation codes (i.e., travel maximum distances; inner room conditions; maximum number of persons permitted, etc.) for developing performance-based solutions.
- Improvements of people's flow rate (elimination and/or reduce of congestions, bottlenecks, queues, etc.).

Despite this, it is extremely important to use the PM models with responsibility and accurately; especially considering that there is neither National nor International organizations to supervise the way these models have been applied. Therefore, the appropriate use of the PM models should follow three main principles, namely: (i) understanding the limitations of these models; (ii) accurate analysis of the results from the simulations; (iii) proposition of feasible and intelligent design solutions based on the modelling analysis (which requires knowledge of fire safety codes).

For this reason, to rely merely on the model visual interface or on the model developers' claims should not be a common practice. This is a relevant point to be discussed, especially within the fire safety engineering, where human lives might depend on the results obtained from the PM models.

Based on that, the concept of PeMMA (People Movement Modelling Analysis) should be considered when using PM models. PeMMA is a sophisticated and flexible methodology which can be performed solely to address fire safety issues in the final fire safety strategy as well as to be incorporated within the whole fire safety management package. PeMMA can also be applied for Fire Risks Analysis (FRA) in conjunction with Quantitative Risks Analysis (QRA) and/or Decision-Making models.

The PM model used in the study case of this paper was STEPS.

4. Results and discussion

The results of the PeMMA and fire modelling analysis are presented in the next paragraph of this section.

4.1. ASET

As mentioned previously, a fire zone model was used for estimating the ASET. In this instance the performance criteria used

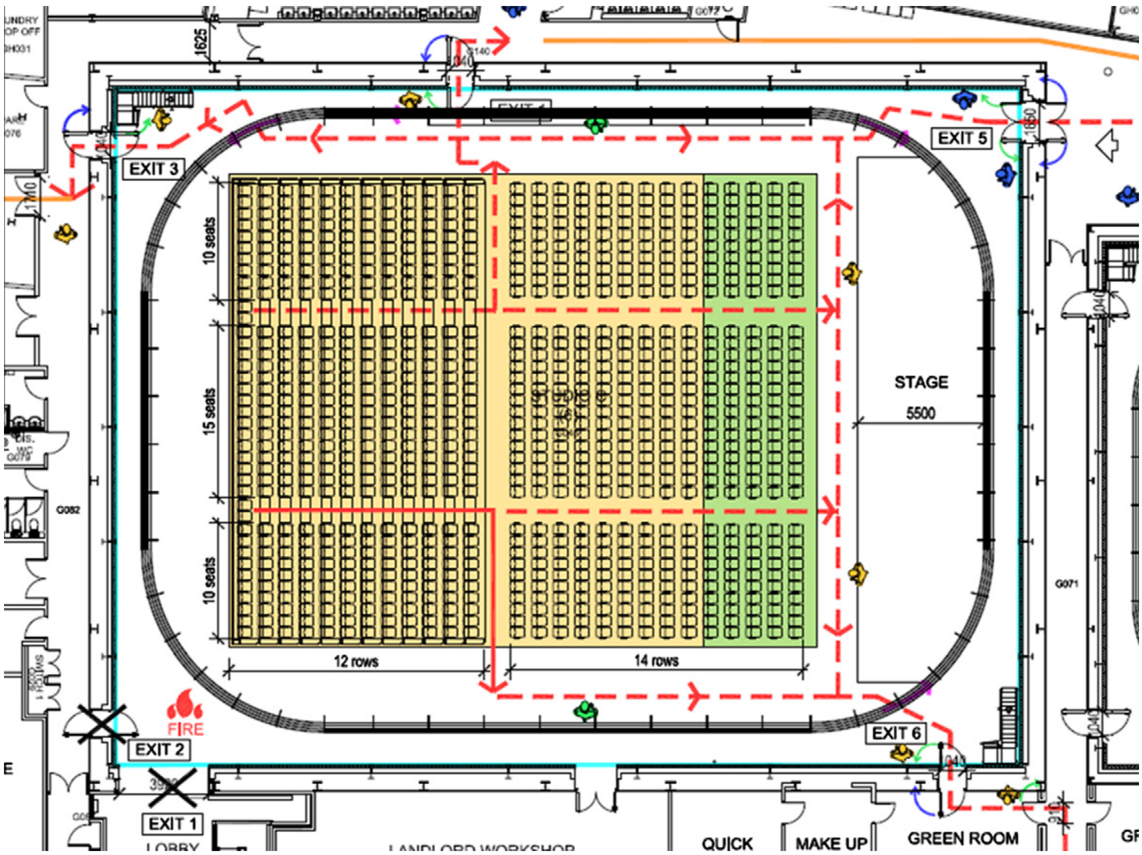

Fig. 1. Study case – a TV Studio.

as critical conditions to evaluate the ASET is the layer height of the smoke produced from the fire.

The zone model calculation used the expressions from the (CIBSE Guide E, xxxx), Section 10.8.

The following parameters, shown in Table 1, were used for the smoke calculation:

The results are shown in Table 2 and Figs. 2 and 3. They identify that the smoke layer height does not descend to around head height (2–2.5 m above ground level) until around 8 and a half minutes. At this point the average temperature of the smoke layer is around 70 °C. For conservatism a figure of 8 min will be used as the ASET criteria.

As identified in Table 2 the room fills completely at around 11 min. However by this time everyone should have evacuated the building and the fire service should be in attendance. Because of the cool temperatures in the smoke layer it would also be feasible for them to use the ventilation system provided for day to day ventilation to extract an amount of smoke to assist in locating the seat of the fire. It is appreciated that the ventilation system will be in no way fire rated or designed for smoke control; however the low temperatures mean that there would be no harm in using it initially.

Table 1
Parameters used for the smoke calculation.

Physical parameters	Assumptions
Room height	$H = 18.5$ m
Floor area	$S = 1116.5$ m^2
Fire modelling parameters	Assumptions
Fire development	The growth rate of the fire was predicted by comparison with typical building fuel densities (MJ/m^2). It was assumed to be 'fast' fire growth as defined in the (CIBSE Guide E, xxxx). This is based on a worst case scenario whereby there may be a large number of plastic seating in the studio and is therefore considered to be conservative. It should also be noted that the calculations put no restriction on the maximum fire size
Characteristic fire growth rate	Fast t^2 relationship [(CIBSE Guide E, xxxx), Eq. (10.1)]
Restricted fire size	No
Heat loss fraction	70% convective [(CIBSE Guide E, xxxx), Eq. (10.43)]
Fire plume	Axi-symmetrical smoke plume
Smoke production relationships	Eq. (10.24) for mass of smoke production
	Eq. (10.35) for conversion to temperature
	Eq. (10.38) for determining smoke volume
Fuel type	Polypropylene

4.2. RSET

As mentioned previously, the STEPS model was used to predict RSET for the occupants of the TV Studio to reach the 'place of relative safety' (i.e., once they pass through the exits, it is assumed that they are safe).

The following assumptions have been applied to model the occupants in both physical and psychological respects, they are described as follow:

- The response time (also known as the pre-movement time, is the time that the occupants take to recognize that there is an emergency for starting to move) was considered to be 0, since trained staff will be managing the evacuation;
- The travel speed (the velocity in which the occupants will have during their escape movement) was considered to be 1.2 m/s;
- Further attributes were also considered in order to represent the actual scenario realistically:

Table 2
Results for the smoke calculation.

Time minutes (s)	Heat output (kW)	Clear layer (m)	Average temp rise of plume (°C)	Smoke vent flow rate (m^3/s)	Visibility in layer (m)
00:00	0	25.0	0.0	0	Clear
01:00	169	23.1	1.0	0	133.9
02:00	675	19.7	2.7	0	47.2
03:00	1520	16.1	5.5	0	23.6
04:00	2701	12.8	9.6	0	13.7
05:00	4221	10.0	15.5	0	8.6
06:00	6078	7.6	23.8	0	5.8
07:00	8273	5.6	35.0	0	4.1
08:00	10,806	3.8	50.0	0	3.0
09:00	13,676	2.1	69.6	0	2.3
10:00	16,884	0.4	94.9	0	1.8
11:00					Room filled

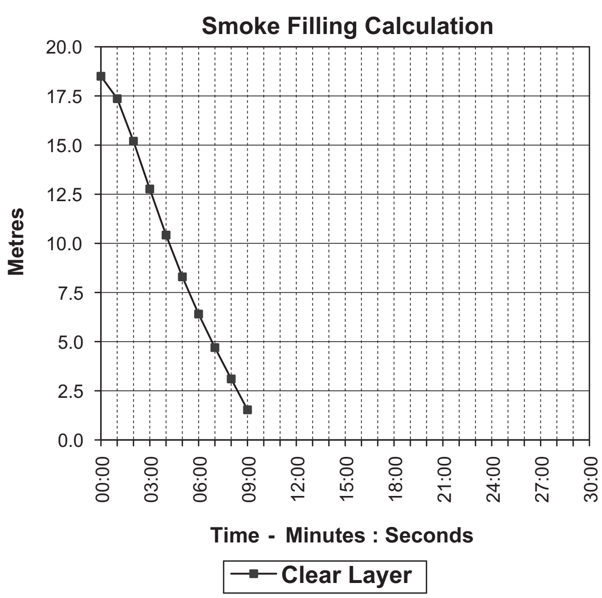

Fig. 2. Smoke filling calculations: time–height curve.

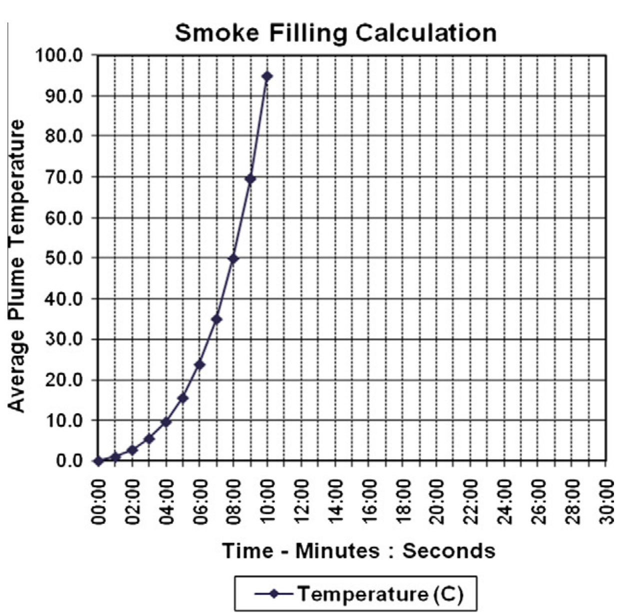

Fig. 3. Smoke filling calculations: time–temperature curve.

Table 3
Results for the evacuation modelling.

Simulation	RSET (min)
Simulation 1	3.98
Simulation 2	3.59
Simulation 3	3.86
Simulation 4	4.03 (worst case scenario)
Simulation 5	3.87

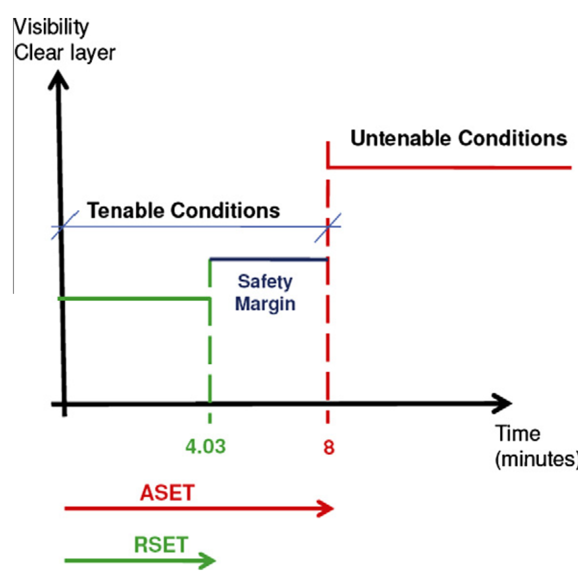

Fig. 4. Evacuation study timeline.

- the occupants are assumed to have competitive behaviour (or "rush behaviour") since they would be prompted by the staff to leave the studio immediately;
- they would chose paths in order to reduce congestion.

It is important to mention that STEPS, as some other models, does take congestion into account; allowing the people's travel speed to be reduced in crowded areas (Yuhaski and Smith, 1989).

The results are shown in Table 3.

A total of five simulations were performed for the same scenario in order to reduce the error due to expected computational modelling limitations. And additionally for assuring that reliable results would be produced, for each simulation, the occupants' locations were randomized within the floor area.

The times obtained for the five simulations runs are shown below:

As identified in Table 3 the RSET is 4.03 min based on the worst value obtained from the simulations.

5. Concluding remarks

Based on the results, the ASET is calculated to be 8 min (480 s) and the RSET is calculated to be 4.03 min (241.8 s). Fig. 4 presents this information. Therefore it can be concluded that, for the worst case scenario (a fire based on polypropylene and with fast growth) will not compromise the occupants' safety; since the safety condition ASET > RSET is satisfied. What is also identified is that there is a substantial margin of safety present, at 238.2 s (approaching 4 min).

This is also supported by the assumption that a good level of management will take place in the TV Studio as well as the occupants will be aware if a fire occurs, based on the current layout.

Based on this study case, it can be said that the application of PeMMA combined with fire modelling analysis can potentially bring the following benefits:

- enhanced life safety;
- avoidance of disruption (i.e., avoidance of business losses);
- building value (i.e., future sale);
- cost savings elsewhere in the building design;
- greater building design freedom.

For this reason, PeMMA and fire modelling analysis should be conducted by professionals who are able to use PM and fire models confidently and also with good knowledge of fire safety codes. This is a core-issue, since the integrated understanding on such types of computational models and fire safety codes is needed for developing reliable performance-based solutions.

It is expected that this paper can bring some additional practical and illustrative example to this issue.

The authors are currently working on different and more complex projects, in which the intelligent integration between PM and fire models (as well as other fire engineering tools and methods, such as QRA techniques) is being aimed.

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