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A New Method for Selecting the Design Fire for Safety Provision

Walter Wah Yuen[1] and Wan Ki Chow[2]

[1] *Department of Mechanical & Environmental Engineering, University of California at Santa Barbara, California, USA*

[2] *Areas of Strength: Fire Safety Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China*

ABSTRACT

It can be difficult to come to agreement on a design fire for designing safety provisions, especially for smoke exhaust systems, while applying engineering performance-based fire codes. A new method is proposed for selecting the design fire for a typical building use. In addition to the common approach widely adopted in many places in the Far East, uncertainties in fire statistics and fire physics are considered by this new method. The Monte Carlo method is used to estimate such uncertainties. The approach is recommended for the Authority to work out design fires for buildings of different use.

keywords: Fire safety provisions, design fire, heat release rate, statistical analysis.

1. INTRODUCTION

In the determination of the safety provisions for buildings under fire, there is a need to specify a "design fire". This is important in hazard assessment while implementing engineering performance-based fire codes (EPBFC) [e.g. 1-4]. In essence, the key question [e.g. 5] is:

How big is the fire?

The size of a fire is related to the heat release rate. To determine a design fire, a database on heat release rate should thus be developed [6]. The size of the fire and its heat release rate are the first and most important elements among the following list of parameters commonly used to characterize an unwanted fire [5,7]:

- An indication of the size of the fire.
- The rate of fire growth, and consequently the release of smoke and toxic gases.
- The time available for escape or fire suppression.
- The type of suppressive action employed.
- Other attributes that define the fire hazard.
- Whether flashover occurs.

Designers have used different values of heat release rate for different types of building in the past. In a prescriptive code regulating the design of a smoke management system (SMS), a design fire should be agreed [8-10]. Typical values used in local projects in Asia are [11]:

- Airport and train terminal hall: up to 7 MW
- Shopping mall: 5 MW
- Atrium: up to 7 MW
- Train compartment: 1 MW

Even with the above prescriptive values, however, designers must still exercise "engineering judgment" for a specific situation. For example, in the sizing of natural vents for a static smoke extraction system, the heat release rate for the design fire must not be too high. If 7 MW is chosen as the design value, a natural vent of certain size will be designed. On the opening of the vent due to an accidental fire with a much lower heat release rate, cool air above the vent, might enter. This would stop smoke that does not have adequate buoyancy from moving up. On the other hand, the heat release rate of the design fire in a mechanical ventilation system (dynamic smoke extraction) must not be too small. A fire with a much higher heat release rate can lead to a smoke production rate higher than the operating flow rate of the fan. In general, the heat release rate of a design fire must thus be specified carefully [12].

Currently, apart from developing a database based on full-scale burning tests [e.g. 3,6,13-15], the practical method developed by Morgan and Hansell [12] can be used for determining the heat release rate for a design fire. This method and the results have been widely used in many places in the Far East, especially in those under British Administration (either currently or previously) such as Hong Kong and adjacent areas with rapid economic growth.

Based partially on the UK Fire Statistics Data Base and some limited consideration of fire physics, the approach determines, for a building with a given ventilation area and geometry, a heat release rate, Q, such that the cumulative probability of fire causing greater damage occurred in the building is less than x. A correlation is generated to express the heat release rate in terms of the area A_w and height H of the opening; and the desired cumulative probability x as:

$$Q = F(A_w, H, x) \tag{1}$$

While the current approach is useful in generating a quantitative estimate of the heat release rate, particularly in relation to a cumulative probability of damage, it is based on data which are more than twenty years old and can have significant uncertainty. In addition to the inherent statistical uncertainty associated with the data, these data do not reflect the change in design and construction practices occurred over the past twenty years. It is important to develop a design approach to account for the uncertainty.

The objective of the present work is to develop a methodology which can account for the uncertainty of the fire statistic data and fire physics. Changes in building design and construction practices occurred over the past twenty year will not be included in the current study because these changes can, in principle, be accounted for by the collection of a new set of fire statistics data. The current work focuses only on how to deal with the uncertainty in the statistical data and the uncertainty in fire physics. The Monte Carlo approach [16], widely used in risk analysis [17-19], is shown to be an effective probabilistic approach in determining the heat release rate for a design fire. Within the probabilistic framework, both the heat release rate and its associated uncertainty can be determined for a specific cumulative probability of damage, accounting for the uncertainty of both the fire statistics and fire physics.

2. THE DESIGN METHOD BY MORGAN AND HANSELL [12]

As a basis to illustrate the probabilistic based design approach, the design process recommended by Morgan and Hansell [12] is described in this section. It should be noted that from the perspective of a deterministic design approach, there are other approaches with different (and perhaps "better") physical models. The design approach of Morgan and Hansell is chosen here because this approach is still used by many practicing fire engineers and accepted by the Authority in Hong Kong and other Asian countries. This model is sufficient for the purpose of the present work which is to illustrate the effectiveness of the probabilistic based design approach.

Specifically, the process of determining the design fire recommended by Morgan and Hansell [12] is done in 2 steps.

- First, the 1978-79 U.K. Fire Statistics Data Base for fire damage area, plotted both as the number of reported fire and a discrete probability in *Figure 1*, is used to find a relation between a cumulative probability x and the fire damage area, A_{FD}:

$$A_{FD} = f_1(x) \tag{2}$$

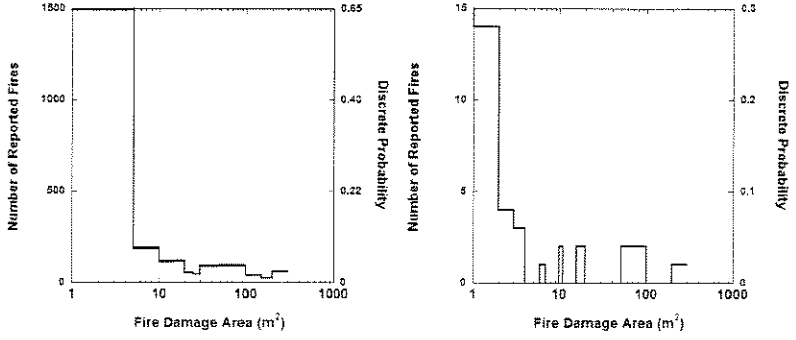

Figure 1 Number distributions and the corresponding discrete probability Distributions of reported fires for office premises with and without sprinklers

The function $f_1(x)$ is the fire damage area at which the cumulative probability that a fire will have a fire damage area greater than or equal to A_{FD} is x.

The cumulative probability distributions for the cases with and without sprinklers are shown in *Figures 2*. By taking a linear interpolation of the lower limit of the cumulative probability distribution, $f_1(x)$ is generated and shown as the broken line in the same figure.

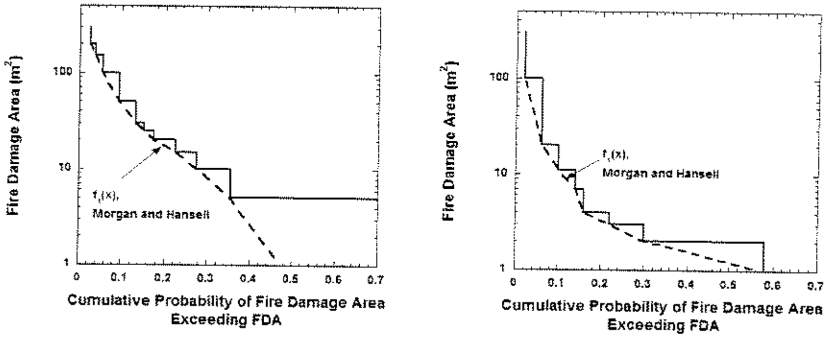

Figure 2 Cumulative probability distributions for reported fires for office premises with and without sprinklers (The broken line represents the cumulative probability function, $f_1(x)$, as utilized by Morgan and Hansell [12]

- Once x (and therefore A_{FD}) is chosen, fire physics is then used to determine the appropriate heat release rate for a design fire as in *Equation 2*:

$$Q = f_2\,(A_w, H, A_{FD}) \tag{3}$$

The deterministic and/or probabilistic behavior of the two functions, f_1 and f_2, will thus affect the validity of the selection of Q in meeting the design goal.

To determine Q, the "best" available correlations from fire physics at the time were used [12]. Specifically, the function $f_2(x)$ is represented by the flow chart shown in *Figure 3*. Whether a fire is fuel-controlled or ventilation-controlled can be determined by examining whether the ratio of $A_w\sqrt{H}$ (also known as ventilation the factor) to A_{FD} is greater than 0.317.

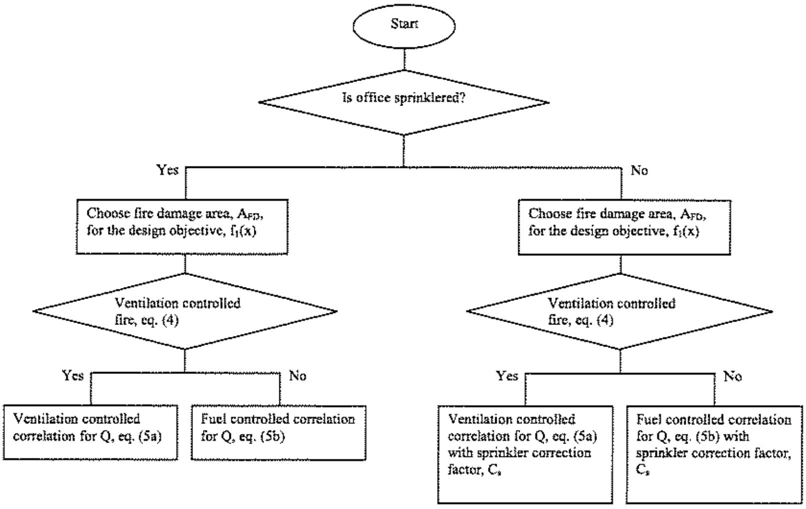

Figure 3 Sechmatics of the procedure used by Morgan and Hansell in the selection of the design fire [12]

$$\frac{A_w\sqrt{H}}{A_{FD}} > 0.317 \qquad \text{fuel - bed controlled}$$
$$\frac{A_w\sqrt{H}}{A_{FD}} < 0.317 \qquad \text{ventilation controlled} \tag{4}$$

For a ventilation controlled fire, the heat output is determined by:

$$Q_f = 456 C_s A_w \sqrt{H} \tag{5a}$$

C_s is a correction factor used to account for the effect of sprinklers, and is taken to be 0.5 by Morgan and Hansell.

For a fuel-bed controlled fire, the heat output is given by:

$$Q_f = 260\, C_h C_s A_{FD} \tag{5b}$$

C_h is a factor used to account for the heat loss to the compartment boundary, and is recommended to be 1/3 by Morgan and Hansell.

Equations 4, *5a* and *5b* were determined based on their "best" judgement on the validity of both the functional expressions and the associated constants for design purposes. There was no consideration of uncertainty related to either the choice of the models or the associated constants.

For a particular set of ventilation parameters, *Equations 4, 5a* and *5b* will generate a functional relation between the design fire, Q_f, and the fire damage area, A_{FD}. A numerical example (with H = 3 m, A_w = 9 m^2) of the relation is shown in *Figure 4*. Note that the fire damage area is a monotically increasing function of the design fire only in the region of a fuel-bed controlled fire. At the transition to a ventilation controlled fire, the design fire takes a step change to the value given by *Equation 5a* and becomes insensitive to the fire damage area. This model is thus not quantitatively useful for design purposes after the transition to a ventilation controlled fire.

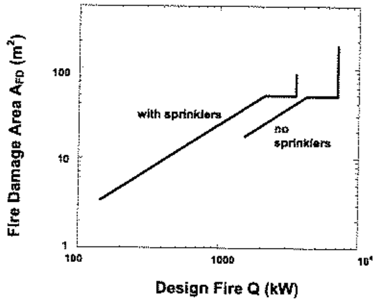

Figure 4 Relation between fire damage area and design fire according to equations (4), (5a) and (5b) with H = 3 m, A_w = 9 m²

In essense, *Figure 2* and *4* contain all the basic information needed for the design method of Morgan and Hansell [12]. For a design objective of x = 0.1 (i.e. the selection of a design fire accounting for 90% of the fire damage cases), for example, the utilization of f_1(x) in *Figure 2* leads to a fire damage area of 11 m² and 47 m² for the sprinkler and unsprinklered case respectively. From *Figure 4*, a design fire of 4.1 MW for an unsprinklered office and 0.48 MW for a sprinklered office is determined.

To illustrate the general behavior of the design process, the design fire estimated by the flow chart in *Figure 3* for an office with ventilation parameters of A_w = 9 m² and H = 3 m is tabulated and shown in *Figure 5*. Results show that the transition from a fuel-bed controlled fire to a ventilation controlled fire occurs at x = 0.05 for the sprinklered case and 0.1 for the unsprinklered case. Even though a design fire value is assumed for the ventilation case, it has a limited design application. For example, the utlization of a design fire value of 7.1 MW (the value for a ventilation fire) for the unsprinklered case can only assure that the design accounts for 90% of the expected fire (x = 0.1, assuming that f_1(x) is totally valid). The model cannot generate a design fire value for a design goal of x < 0.1. This illustrates the importance of *Equation (4)*. Its applicability to the specific offices/buildings under consideration must be carefully assessed. The relative accuracy of *Equations (5a)* and *(5b)* must also be considered to assure the reliability of the predicted design fire.

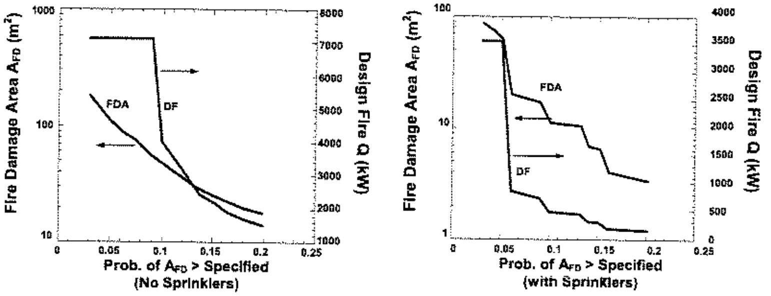

Figure 5 Fire damage area and design fire for an example ventilation setting (A_w = 9 m², H = 3 m) using the design approach of Figure 3.

3. IMPROVEMENT OF THE DESIGN METHOD

Even with a deterministic approach, the uncertainty in the selection of a design fire is well known. Indeed, a systematic and rigorous assessment of the uncertainty is expected by the Authority in approving a design fire. The lack of a systematic approach, however, has led to arbitrary adjustment of the design value; for example, adding of a "safety" factor based on "expert" opinion. Additional risk might thus be introduced into the design.

There are uncertainties associated both with the determination of the fire damage area from the UK Fire Statistic Data Base, $f_1(x)$, and the equations used to describe the relevant fire physics (*Figure 2, Equations 4, 5a* and *5b* and *Figure 6*). Since the data base is never complete and is subjected to update from new data, the interpretation of the data base must be done statistically with appropriate conservatism. Similarly, the understanding of various important mechanisms in fire physics can also be uncertain as most of them relied on experimental data. Identifying those uncertainties and their effect on the predicted design is extremely important in convincing the Authority of the validity of the design, particularly those without good understanding of advanced fire dynamics.

In the following sections, an approach to address these uncertainties is demonstrated. The fundamental philosophy of the approach is to identify uncertainty in each step of the design process (interpretation of data, utilization of a mathematical correlation to describe a particular physical process, etc.) and to provide a statistical characterization of its effect on the design. As an illustration, a Monte Carlo approach [16] will be used to provide a numerical example. Specifically, the approach will yield a best-estimate of the design parameter (for example, the design fire, Q_f) corresponding to a specific design objective (x, the cumulative probability to have a larger FDA). Since the uncertainty of the model is identified, the current approach will also provide an estimate of the statistical uncertainty of the design. This statistical information can be useful for other decisions such as system improvement and the identification of research areas to eliminate uncertainties in physical models.

4. THE UNCERTAINTY IN FIRE STATISTICS $f_1(x)$

Even if the uncertainty of the reported fire damage area can be ignored (they are difficult to assess), there is inherent uncertainty in the relation between the cumulative probability x and the fire damage area since data are reported over discrete ranges of fire damage area (for example, 24 fires were reported with a range of fire damaged area between 151 and 200 m^2 for unsprinklered offices). This leads to the "step function" behavior of the cumulative probability as shown in *Figure 2*. In view of the possible transition from a fuel-bed controlled fire to a ventillation controlled fire which can occur over a small change in the fire-damage area at some critical value of x (assuming the modelling of fire physics using *Figure 2, Equations 4, 5a* and *5b* is accurate), the approach of

Morgan and Hansell can thus be "unconservative" and can underpredict the design fire.

Statistically, an approach which can account for the uncertainty is to consider the "upper" and "lower" bound of the cumulative probability function as shown in *Figure 6*. Using *Figure 2*, *Equations (4)*, *(5a)* and *(5b)* and *Figure 3*, the corresponding bounding value for the fire damage area and design fire (again for the case with A_w = 9 m^2, H = 3 m) is shown in *Figure 7*.

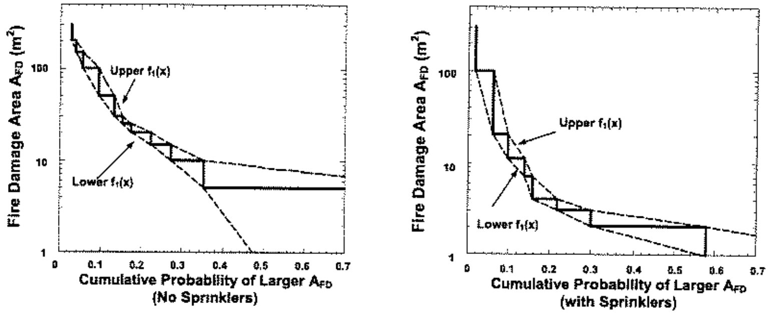

Figure 6 The upper bound and lower bound of the cumulative probability distribution, $f_1(x)$ for the sprinklered and unsprinklered cases

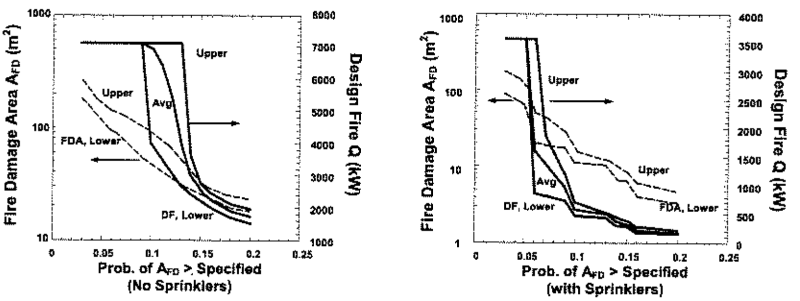

Figure 7 The upper bound, lower bound and average fire damage area and design fire for an example ventilation setting (A_w = 9 m^2, H = 3 m) using the design approach of Figure 3.

It is interesting to note that the spread between the upper and lower bound of the design fire, for a particular design objective x, can be quite large due to the transition from a fuel-bed controlled fire to a ventillation controlled fire. In *Figure 7*, the average design fire is calculated assuming that the fire damage area has a uniform probablity to have any value between the lower and upper bound. Note that the average design fire is not the average of the upper and lower limit of the design fire. This is due to the highly nonlinear relation between fire damage area and design fire.

Note that if the "upper" bound of the cumulative probability function is used, a design fire of 4.1 MW for an unsprinklered office would correspond to a fire damage area of 42 m^2 and a cumulative probability of x = 0.14. The uncertainty of the cumulative probability density function thus suggests that a design fire of 4.1 MW for an unsprinklered office accounts for 86% to 90% of the fire damage cases. Similarly, from *Figure 7b*, a design fire of 0.48 MW for a sprinkler office accounts for 87.5 % to 90%

of the fire damage case. By choosing to use only the "lower" bound of the cumulative probability function, the approach of Morgan and Hansell is thus "unconservative" and overpredicts the percentage of fire damage cases accounted for by a design fire.

Independent of the uncertainty of the fire model used in the determination of the design fire (*Figure 2*, *Equations 4*, *5a* and *5b*) which will be discussed in the next section, the effect of the uncertainty in the selection of the fire damage area for design is clearly significant. The effect is particularly important in the region where the transition from a fuel-bed controlled fire to ventilation-controlled fire might occur. This uncertainty, which is due largely to the uncertainty of the Fire Statistics Data Base, should be improved as the quantity and quality of the data base is improved (e.g. number of data points, the size of the discretized interval over which data are collected, etc.). It is also important to ensure that the data account for any changes in building design and construction practices. In summary, the result of this section illustrates that if the concept of design fire is to be used as the principle factor for the fire safety design of a building, it is important to maintain and update the statistical data base and to account for its uncertainty in the design.

5. THE UNCERTAINTY IN FIRE PHYSICS

Even with the significant amount of research which has been conducted on the many physical phenomena which are important for the understanding of fire, a significant amount of uncertainty still exists and will continue to exist in the modeling of fire in practical situations. The appropriate consideration of these uncertainties is thus extremely important for any design process involving fire.

The current discussion will focus only on the relations and phenomena considered by Morgan and Hansell [12] in their approach in selecting a design fire. While this limits the scope of the present discussion, it is sufficient for the current objective, which is to illustrate the appropriate consideration of uncertainty in fire design. Expansion to account for other phenomena is quite straightforward and can be considered in the future.

- Correlation for transition between fuel-bed controlled and ventilation controlled fire

As shown by results in *Figures 4* and *6*, the transition between a fuel-bed controlled fire to a ventilation-controlled fire is extremely important in the prediction of the design fire. Physically, however, this transition depends on a large number of factors such as fuel type and room geometry. A typical representation [20] of the transition data for different fuels is shown in *Figure 8*. *Equation 4* is clearly not an adequate representation of the actual observation. A more appropriate correlation would be

$$
\begin{aligned}
&\rho_a g^{1/2} \frac{A_w H^{1/2}}{A_{FD}} > C_t + \delta \qquad \text{fuel - bed controlled} \\
&\rho_a g^{1/2} \frac{A_w H^{1/2}}{A_{FD}} < C_t \qquad \text{ventilation controlled}
\end{aligned}
\tag{6}
$$

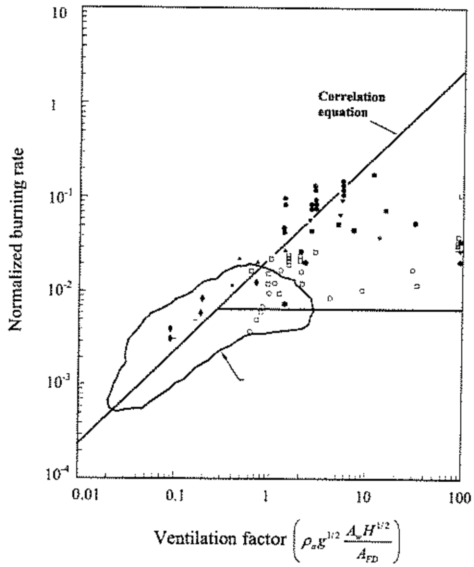

Figure 8 Data for transition from a ventilation-controlled fire to a fuel-bed controlled fire for various fuels (e.g. [20])

The identification of two transition constants, C_t and δ, is to account for the behavior that the transition not only occurs at different values of the transition constant (depending on materials and other fire parameters), it also occurs smoothly over a range of the dimensionless parameter $\rho_a g^{1/2}(A_w H^{1/2} / A_{FD})$. In general, the value of the transitional constants, C_t and δ, their ranges and the relative probabilistic distribution within the range, can be determined by the designer based on the specifics of an application and data such as those [e.g. 20] shown in *Figure 8*. For example, if materials in the office/building are limited to a certain type, C_t and δ can be selected based only on combustion data for the specific materials. If no restriction on materials can be made, a reasonable approach will be to assume that C_t and δ are bounded by a minimum and maximum value with some probability distribution of having any intermediate value. Mathematically, using only data from *Figure 8*, one can assume the following discrete probability distribution for C_t:

$$P(C_t) = \begin{cases} 1 \quad \text{for} \quad 0.3 < C_t < 5.0 \\ \\ 0 \qquad \text{otherwise} \end{cases} \tag{7}$$

and δ can be assumed to a constant with a value of about 0.1.

Note that the selection of the bounding values and the exact probabilistic distribution is part of the decisions made by the designer based on the "best" information available. Indeed, *Equation 4* can be considered as a special case of *Equation 7* in which the probabilistic distribution is assumed to be a "delta" function at $C_t = 1.19$ and $\delta = 0$.

- Correlation for the heat output from a ventilation controlled fire

The development of *Equation 5a* is based on the assumption that the heat output from a ventilation-controlled fire can be written as

$$Q_f = mC_p\theta \tag{8}$$

where m is the mass flow rate of the hot gas generated by the fire, C_p the specific heat and θ the temperature rise of the hot gases above the ambient. To obtain *Equation 5a*, the following correlation for mass flow rate (based on experimental data for wood crib fires) is utilized,

$$m = 0.5A_w\sqrt{H} \tag{9}$$

together with the assumption of C_p = 1.0 kJ/kg-K and a temperature rise of 1200 K.

The utilization of wood crib fires data for the determination of the mass flow rate is clearly too restrictive. Indeed, the data for polyethylene shown in *Figure 8*, for example, show a higher burning rate than wood in the ventilation-controlled regime. To account for the presence of different fuel, *Equation 9* is replaced with a more general correlation

$$m = C_vA_w\sqrt{H} \tag{10}$$

and C_v is given by the following discrete probability distribution

$$P(C_v) = \begin{cases} 1 & \text{for} \quad 0.4 < C_v < 0.6 \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

Equation 11 assumes that there is a 20% variation of the constant C_v around the wood crib value (and also theoretical value) of 0.5. For simplicity, no statistical variation of the temperature rise is implemented.

- Correlation for the heat output from a fuel-bed controlled fire

Equation 5b is based on the burning rate data [12] presented *Figure 9*. Assuming a fire load per unit floor area of 57 kg/m² and using the wood cribs curve, a burning rate per unit area was determined from *Figure 11* to be 14.4 x 10^{-3} kg/m²/s. Taking the calorific value of wood to be 18 MJ/kg, the ratio of heat output to fuel area is determined to be 260 kW/m², which is the basis of *Equation 5b*. Since there is uncertainty associated with the fire load per unit area and also with the form of the fuel, the ratio of heat output to the fire damage area has significant uncertainty. Taking the limit between the curves with normal and high ratio of fuel surface to fuel mass and assuming the same fire load per unit floor area of 57 kg/m³, the burning rate per unit area will vary between 5 and 20 × 10^3 kg/m²/s. Assuming that the calorific value of fuel remains approximately the same at 18 MJ/kg, *Equation 5b* is replaced by the following expression.

$$Q_f = C_{fb}C_hC_sA_{FD} \tag{12}$$

where

$$P(C_{fb}) = \begin{cases} 1 & \text{for} \quad 90 < C_{fb} < 360 \\ 0 & \text{otherwise} \end{cases} \tag{13}$$

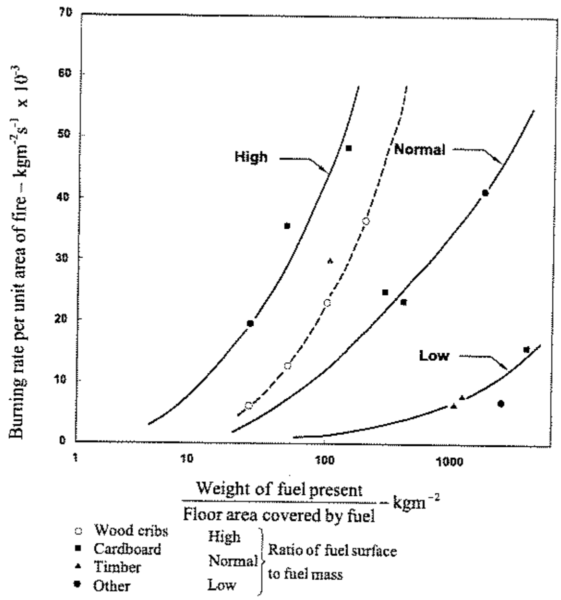

Figure 9 Rate of burning for fuels in various forms, Morgan and Hansell [12]

- Effect of sprinkler and convective heat loss

Morgan and Hansell estimated that the energy lost to the sprinkler spray is between 40% to 60% of the heat carried by the gas. They use a value of 0.5 for C_s for their deterministic model. In the present illustration, C_s will be assumed to have the following discrete probability distribution

$$P(C_s) = \begin{cases} 1 & \text{for} \quad 0.4 < C_s < 0.6 \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

For fuel-bed controlled fire, two-third of the heat generated by the fire is assumed to be lost to the compartment boundary. This lead to a value of 1/3 for the constant C_h. No statistical variation is assumed for C_h in the present consideration since its effect can be partially included in the statistical variation of C_s.

6. PREDICTION BY THE MONTE CARLO METHOD

Using the Monte Carlo method, a modified relation between the design fire and fire damage area, including the effect of some uncertainty, can be generated to replace *Figure 4*. Specifically, for a given value of the design fire, the probabilistic distributions as represented by *Equations 7, 11, 13* and *14* can be simulated by random sampling. Numerical results for the simulation of the 4 parameters (C_r, C_v, C_{fb}, C_s) with 50,000 samples are shown in *Figure 10*. The probability distribution of A_{FB} with Q = 800 kW is shown in *Figure 11*.

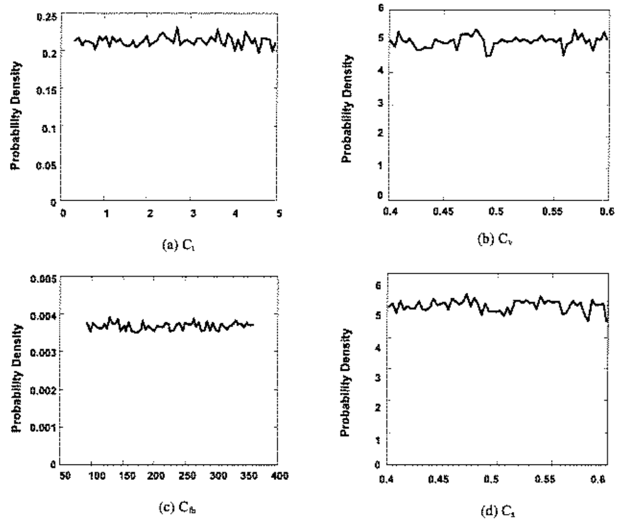

Figure 10 Probability density distribution of the four parameters in the model after 50,000 samplings

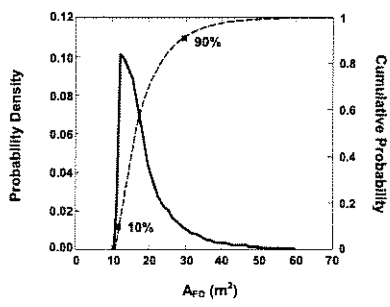

Figure 11 Probability density and cumulative probability distribution of the fire damage area for a case with sprinkler and Qf = 800 kW

The points labeled 90% and 10% are values at which the cumulative probability of the fire damages area below those values are 90% and 10% respectively. Statistically, 80% of the expected values of fire damage area are bounded between these two figures. For a building with the venting dimension of A_w = 9 m^2 and H = 3 m, the fire damge area for different design fire generated by the Monte Carlo method, together with results generated from Morgan's deterministic model (*Figure 5*) are shown in *Figure 12*.

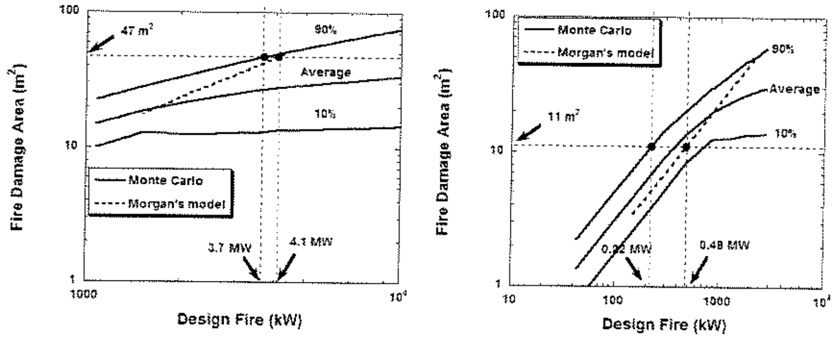

Figure 12 The variation of fire damage area with design fires accounting for the variation of parameters as represented by equations (7), (11), (13) and (14)

As expected, the model of Morgan and Hansell is bounded by the 10% and 90% lines of the current model since it is essentially a special case of the current statistical model. It is interesting to note that if one accepts the fire damage area predicted by the 90% line for a given design fire Q, the required design fire for a given fire damage area is lower than that predicted by the deterministic model of Morgan and Hansell. For example, with a design objective of 0.1 and a fire damage area of 11 m^2 and 47 m^2 for the sprinklered and no-sprinklered case, the 90% line leads to a heat output of 0.22 MW and 3.5 MW for the two cases respectively. The Morgan's approach, on the other hand, which would lead to values of 0.48 and 4.1 MW. These design points are shown in *Figure 12*. From a practical perspective, this means that if a designer chooses a design fire of 0.2 MW for the sprinklered case, there is only a 10% probability that the fire damage area would exceed 11 m^2 according to the current probabilistic model. If a designer chooses a design fire of 0.48 MW for the sprinklered case based on the Morgan's approach, the probability for the fire damage area to exceed 11 m^2 is higher than 10%.

Using a deterministic relation for $f_1(x)$ as shown in *Figure 4*, together with the 90% curves shown in *Figure 12*, the design fires for different design objective, x, can be calculated. For the same ventilation setting as that in *Figure 5*, numerical data are generated and they are shown in Figure 13 (along with results from *Figure 5* as a comparison).

As an illustration of application of these data, three specific cumulative probabilities of fire damages (0.1, 0.12, 0.14) are considered. The fire damage area predicted by *Figure 4* (shown as a line marked FDA in *Figure 13*) and the corresponding design fire generated by the Morgan model (shown as a line marked DF(Morgan) in *Figure 13*) and current probabilistic model (shown as a line marked DF(90%) are tabulated in Table 1. It is clear that, by accounting some uncertainty effects, the Monte Carlo results will lead a reduction in the design fire.

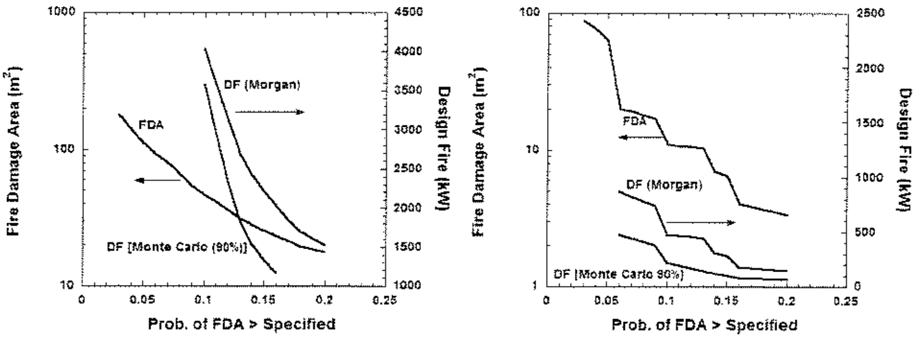

Figure 13 Fire damage area and design fire using the Morgan's approach and the Monte Carlo approach

Table 1 Numerical examples illustrating the design fire generated by the model of Morgan and Mansell and the current probabilistic model.

	x	FDA, m²	DF (Morgan), MW	DF (90%), MW
No sprinklers	0.1	46.52	4.031	3.582
	0.12	36.23	3.140	2.336
	0.14	28.03	2.430	1.537
With sprinklers	0.1	11.0	0.478	0.220
	0.12	10.5	0.455	0.208
	0.14	7.0	0.303	0.124

7. CONCLUSION

The approach by Morgan and Hansell [12] in the selection of a design fire to meet particular design criteria is assessed. If the uncertainty of the U.K. Fire Statistics Data Base (which is used as the basis of the approach) is accounted for, the percentage of fire damage cases accounted for by a design fire has large uncertainty. The uncertainty in fire physics is also shown to have a significant effect on the relation between a design fire and the fire damage area. A Monte Carlo approach is used to demonstrate the effect of the fire physics uncertainty. Results from the Monte Carlo simulation show that when the uncertainty in fire physics is accounted for only, the fire damage area associated with a particular design fire is greater than that predicted by the approach of Morgan and Hansell.

A simultaneous consideration of the uncertainty of U.K. Fire Statistics Data Base and the uncertainty in fire physics is needed to develop an effective approach to select a design fire. The Monte Carlo approach is an effective method for this task. This effort is currently underway and applied to design fire detection system [19]. Other results will be presented in future publications.

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