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TOWARDS THE DEVELOPMENT OF DESIGN FIRES FOR RESIDENTIAL BUILDINGS: LITERATURE REVIEW AND SURVEY RESULTS OF FIRE LOADS IN CANADIAN HOMES

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ABSTRACT

This literature review was carried out to determine the range of methods used to characterize design fires. The current methods were found to be largely empirical in nature. The two main quantities used to describe design fires are the heat release rate and temperature-time profiles. The most widely used pre-flashover design fires are t^2 fires, whereas a host of empirical correlations are available for post-flashover design fires. The paper also presents a summary of the results of a fire load survey of living rooms in Canadian homes, which was conducted using an internet-based questionnaire. The fire load densities were found to be in the range of 100 MJ/m^2 to 1300 MJ/m^2.

INTRODUCTION

A performance-based approach to fire safety assessment and design of buildings is an elaborate process consisting of many steps and requires the use of decision making tools based on analytical and computational methods. The selection of a suitable fire of assumed characteristics, which is referred to as the "design fire", is an important element of the process. A design fire is generally considered to be a quantitative description of the main time-varying properties of a fire based on reasonable assumptions about the type and quantity of combustibles, ignition method, growth of the fire and its spread from the first item ignited to subsequent items, and the decay and extinction of the fire [1]. The main time-varying properties that define a fire are the heat release rate (HRR), gaseous combustion products (smoke and combustion gases, such as carbon dioxide (CO_2), carbon monoxide (CO)) and temperature.

A rational assessment of fire safety in buildings demands that design fires are based on realistic fire scenarios. A fire scenario is a qualitative description of the course of a specific fire with time, identifying key events that characterize the fire and differentiate it from other possible fires[1]. Ideally, the process of determining a design fire should begin with the establishment of the objectives of the fire safety assessment task [1], which could be, for example, to evaluate a smoke management system or smoke detector response, assure life safety, protect property and prevent the spread of fire beyond the room of fire origin. The design fire required for each of these tasks could be different. Following the establishment of objectives, an appropriate fire load density (in MJ/m^2) is selected and the nature of the combustibles likely to be involved in the fire and ventilation conditions are specified by considering the building category. A well-documented account of the initial steps that are usually undertaken early in the fire safety assessment process, before a design fire is specified, is given in the engineering guide [2] published by the Society of Fire Protection Engineers (SFPE) and the technical reports [1, 3] published by the International Organization for Standardization (ISO).

This paper presents a brief literature review of design fires and the results of a pilot fire load survey of living rooms in Canadian homes. The paper focuses on fires, which normally begin with a single item burning in a room. Therefore, there will be no discussion about design fires for extreme events such as blasts, as they are unusual situations that cannot reasonably be expected to occur in the vast majority of residential, public and commercial buildings without inherent explosive hazards.

PRE-FLASHOVER DESIGN FIRES

The life safety of occupants takes precedence during the pre-flashover stage. The HRR and quantity of combustion gases produced are important attributes of pre-flashover fires. During the growth stage, the HRR is commonly approximated by power law correlations of the form:

$$\dot{Q} = \alpha\, t^{p} \qquad (1)$$

Where: $\dot{Q}$ is HRR (kW), p is a positive exponent, t is time after effective ignition (s), and α is a fire growth coefficient (kW/s^2). The exponent is usually given a value of 2 and the resulting curves are popularly known as t^2 fires. The growth coefficient is sometimes determined using experimental data, as demonstrated by Kim and Lilley [4].

A common form of Equation (1) has the growth coefficient, α, expressed as [5]:

$$\alpha = \frac{\dot{Q}_o}{t_o^2} \qquad (2)$$

Where $\dot{Q}_o$ is the reference HRR, usually taken to be 1055 kW, and the growth time, t_o (s), is the time to reach $\dot{Q}_o$. The recommended broad categories of fire growth are: ultra-fast, fast, medium, and slow. These are illustrated graphically in Figure 1 along with the growth constants, α and t_o.

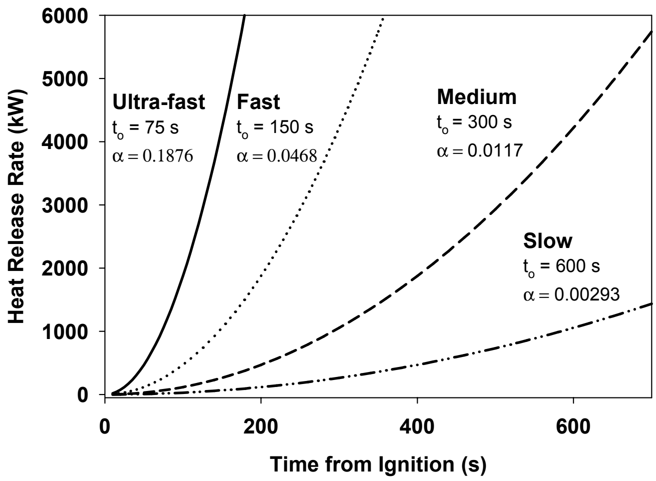

Figure 1. Rates of Energy Release of t^2 Fires

The decay phase of a fire can also be represented by a t^2 curve with appropriate decay constants[4,6]. The t^2 fires given by Equation (1) are typically for a single burning item [5]. If other combustibles are close to the fire source, the size of the design fire should be increased appropriately.

When sufficient experimental data is available, other empirical correlations for HRR can be developed for specific combustibles, as demonstrated by Hertzberg et al. [7], Hoglander and Sundstrom [8], and Barnett [6].

Two software modules, MAKEFIRE and FREEBURN, are available from the National Institute of Standards and Technology (NIST) [9], which can be used to generate HRR curves for design fires.

POST-FLASHOVER DESIGN FIRES

The structural integrity of the building is the primary concern during the later post-flashover stage of a fire. The temperature profile is required in order to determine the destructive impact of the fire on the structural elements. Many empirical correlations[10 - 12] are available for predicting temperatures in post-flashover fires. The EUROCODE parametric equations[10, 13] are illustrative of the approach used for estimating temperatures in post-flashover fires. The equations produce a temperature-time relationship for a given combination of fire load, ventilation conditions and materials forming the boundaries of the compartment.

HEAT RELEASE RATE DATA`

The HRR is an important variable that quantitatively defines a design fire. It largely controls the main characteristics of the fire, such as plume flows, hot gas temperatures, and the rate of descent of the hot gas layer. Heat release rates of combustibles are measured in facilities such as the furniture calorimeter [14] and the cone calorimeter [15] under fully-ventilated conditions. Test standards and guides[16-18] are also available that enable HRRs to be measured in large-scale room tests.

HRR data are available from many sources [9, 19 - 31], especially for upholstered furniture. Upholstered furniture has been studied in fire tests much more than any other household furniture because it is the major combustible associated with fatalities in house fires [8, 32].

The concept of heat release density (kW/m^2), which is the HRR of a fire divided by the base area of the fuel package, is important in estimating the peak HRR of similar fuel packages occupying different base areas. Gemeny and Wittasek [33] gave examples of the use of HRR density obtained from the cone calorimeter tests to specify design fires.

Small- and large-scale fire experiments to obtain HRR data are expensive to conduct. Therefore, there have been many attempts to predict the HRR of full-size combustibles from information obtained from less-costly bench-scale tests, such as the Cone Calorimeter. However, many efforts have been met with limited success mainly because of the difficulty of scaling complex phenomena from bench-scale to full-scale items [34].

FIRE LOAD

The fire load density is usually expressed as the total fire load per unit internal surface area (MJ/m^2) or floor area and it largely depends on the occupancy. It is recommended that both fixed and moveable fire loads (including transient fire loads) should be taken into consideration[35], and that if data from representative surveys are available, the 90 percentile value should be selected [34] to represent a worst-credible case. Transient fire loads are items that are in a space temporarily, for example; Christmas decorations [35]. Klote [35] suggested a method of accounting for transient fuels in which a fixed HRR density or HRR is assigned to these fuels. Bwalya et al. [36] conducted a literature review of fire load data for residential occupancies and found that a great quantity of fire load data has been published over the last two decades, but due to regional differences in lifestyles and the subjective manner in which fire loads are quantified, there are large variations in values. The fire load enables the duration of a fire to be estimated. Examples of the type of calculations performed are given in a design guide published in New Zealand [37].

SURVEY RESULTS OF FIRE LOADS IN CANADIAN HOMES

A survey [38] was conducted due to the lack of recent fire load data for Canadian residential buildings. It was conducted using a carefully designed internet-based questionnaire and primarily focused on movable fire loads in living rooms situated on the main floor and the basement level, because of the high probability of a fire originating in these areas [32]. A web-based questionnaire was used in order to take advantage of the widespread use of Internet communication (electronic mail and the world-wide web) in homes and places of work.

Questionnaire Structure

The questionnaire had a predetermined list of household items, which are commonly found in living rooms. Drop-down boxes were placed beside each item, from which quantities, sizes, materials and other pertinent attributes could be selected. In addition, there were questions concerning the type and size of the home, the number of exits, and the number of windows in a specified living room. The fire loads were calculated using the highest values of weight and heat of combustion found for each grouping of furniture.

Results

Seventy-four homes, ranging from apartments to single family detached homes, were surveyed. The average floor area for the main floor and basement living rooms was 22 m^2 and 28 m^2, with standard deviations of 10 m^2 and 9 m^2, respectively.

The frequency distribution of the fire load density in main floor and basement living rooms is shown in Figures 2 and 3, respectively. The mean for main floor and basement living rooms is 600 MJ/m^2 and 500 MJ/m^2, with standard deviations of 200 MJ/m^2 and 300 MJ/m^2, respectively. The mean fire load density is slightly lower in basements because the average floor area is greater than that for main floor living rooms.

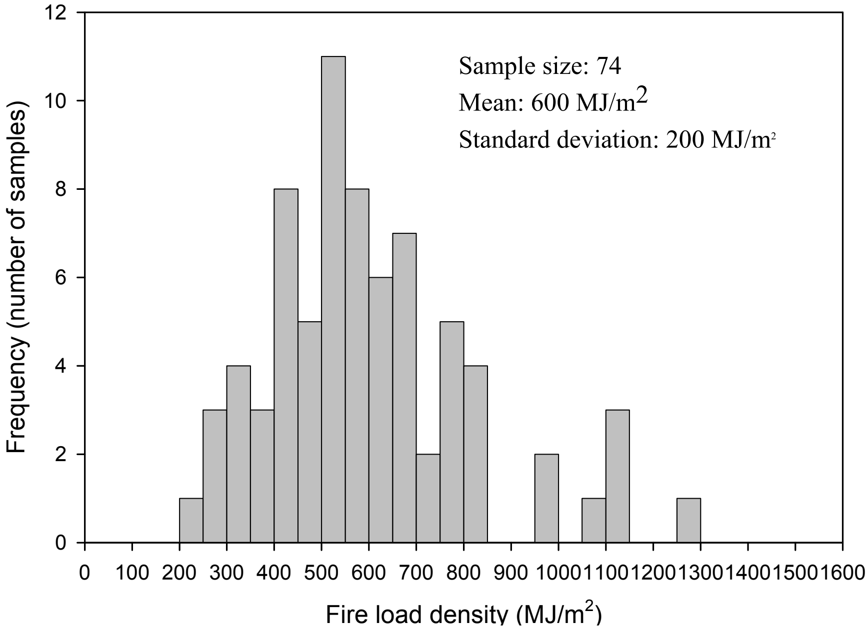

Figure 2. Frequency distribution of fire load density for living rooms.

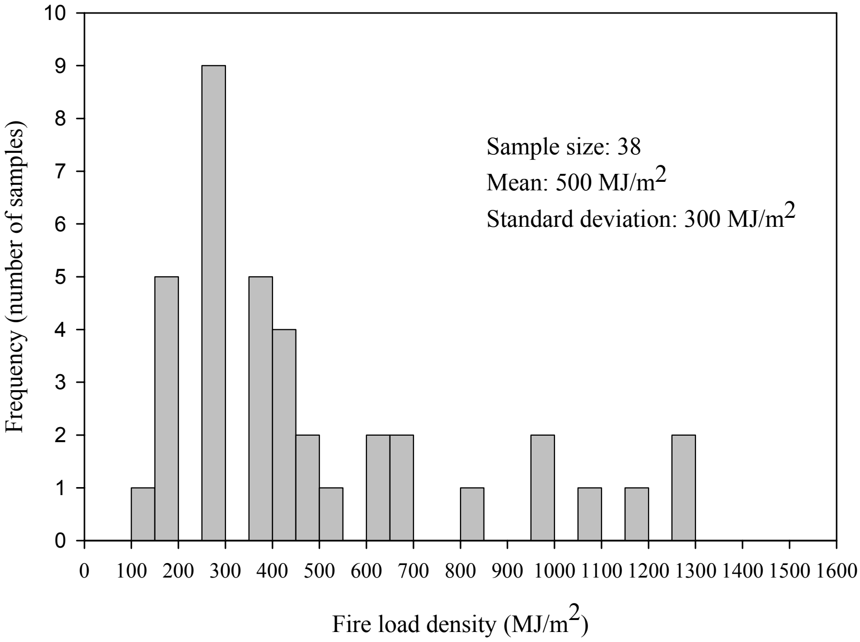

Figure 3. Frequency distribution of fire load density for basement living rooms.

The typical living room contents were found to be: upholstered furniture (2 to 3 pieces), a television set, a bookcase, an entertainment unit, a coffee table, side tables and synthetic floor coverings (carpets and area rugs). Many published fire load surveys have shown that fire loads in houses vary greatly, even within the same geographical location. The values obtained in this survey compare favourably with values of around 500 MJ/m^2 reported [39] for the US.

DISCUSSION AND CONCLUSION

The choice of a design fire is influenced by the nature of the fire safety assessment or design tasks being undertaken. Many parameters must be taken into consideration and many assumptions made in order to select an appropriate design fire. The ISO and SFPE publications[1-3] are essentially the state-of-the-art in the approach to specifying design fires . It is essential to have information on fire load data for the occupancy under consideration, combustion data for the combustibles expected to be present in the compartment, and the specific characteristics of the building, including ventilation conditions, in order to specify HRR, fire effluent, and the temperature history of a fire. HRR data for many combustibles is available from the various sources cited in this paper.

The guiding principle in selecting a design fire is that the assumptions about the type and quantity of combustible materials, ignition method, growth of the fire and its spread from the first item ignited to subsequent items, and the decay and extinction of the fire ought to be reasonable. In addition, there is a requirement for the design fire to represent a fire that presents a challenge to whichever fire safety feature or aspect of a building is being evaluated.

At present, the calculation schemes available for design fires are largely empirical in nature. The two main quantities used to describe design fires are usually the HRR and temperature-time profiles. The most widely used pre-flashover design fires are t^2 fires, whereas a host of empirical correlations are available for calculating temperatures in the post-flashover stage.

The results of a pilot survey of combustibles in Canadian homes show that the mean fire load density for main floor and basement living rooms is 600 MJ/m^2 and 500 MJ/m^2, with standard deviations of 200 MJ/m^2 and 300 MJ/m^2, respectively. Although a fire load survey conducted using a questionnaire has limitations when it comes to determining accurate room dimensions and weights of combustibles, the combustibles were identified and relevant information was collected about room sizes and ventilation conditions, which will be used in a planned experimental study of design fires. In light of the positive outcome, work is underway to extend the survey to a larger number of homes drawn from many Canadian provinces in order to enhance the scientific validity of the results.

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