REPORT

# A REVIEW OF THE IMPACT OF FIRE EXTINGUISHERS IN REDUCING THE CARBON FOOTPRINT OF BUILDING FIRES

PREPARED FOR

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## *Executive Summary*

A building's carbon footprint throughout its life cycle is a combination of carbon emissions during construction, operation, its deconstruction, and - importantly - fire related emissions. This report analyzes the amount of carbon emitted by unwanted fires and the reduction that can be achieved through the use of portable fire extinguishers and sprinklers. Reference 10 finds that sprinklers can reduce fire related carbon emissions by 90%. Portable extinguishers can reduce the remaining carbon emissions by another 93.6%, resulting in a total reduction of fire related carbon emissions of 99% in buildings equipped by sprinklers and portable extinguishers.

The benefits associated with installing this equipment and thereby reducing the carbon footprint from unwanted fires can be realized by evaluating emergency response to a fire. Emergency fire response can be generalized as: 1) early use of a portable extinguisher to extinguish a fire during its incipient stage, 2) possible water discharge from heat-actuated automatic fire sprinklers if the fire has not already been extinguished with a fire extinguisher, and finally, 3) response by the local fire department or industrial fire brigade that will extinguish a fire with fire hoses if not already accomplished with a fire extinguisher or a sprinkler system. There is an increase in carbon emissions each time there is a delay in applying water or other extinguishing agents onto an active fire. Therefore, using portable fire extinguishers early has the potential of providing the highest reduction of carbon emissions of any emergency fire response.

This study provides an assessment of the value of installing and using portable fire extinguishers with respect to the reduction of carbon emissions from accidental fires over the life cycle of buildings. Effectiveness was evaluated from the perspective of two factors: 1) the ability of fire extinguishers to quickly extinguish incipient fires, and 2) the potential for extinguishers to reduce the carbon footprint associated with unwanted (accidental) fires. For both factors, this study finds advantages of using fire extinguishers in the early stages of fire development, extinguishing those fires quickly, and thereby significantly reducing carbon emissions.

Estimates on both reported and unreported fires show that portable fire extinguishers are effective in extinguishing hundreds of thousands of fire events every year. Specifically, the literature review conducted as part of this study found that portable fire extinguishers were used in 4.5% of unreported residential fires between June 2004 and September 2005. This results in approximately 323,000 fire events where portable fire extinguishers were used during this period. In addition, portable fire extinguishers were used in approximately 20% of the reported fires during this period.

In practice, facility personnel and building occupants use portable fire extinguishers before the activation of automatic suppression systems or the intervention of a fire brigade or fire department. Therefore, fire extinguishment that is accomplished by using portable fire extinguishers during this early stage of fire development was used in this study to determine the potential reduction in carbon emissions.

When portable fire extinguishers are used in buildings with automatic sprinklers, carbon emissions during a fire are further reduced from the estimates reported in the FM Global Study [10]. That is because portable fire extinguishers extinguish fires quickly, during the early phase of a fire, when automatic sprinklers have not yet operated and therefore significantly reduce the amount of carbon emissions during a fire event. It is also noted that by early extinguishment, portable fire extinguishers not only reduce the carbon footprint during a fire event, but also result in a reduction in carbon emission during reconstruction activities, since there is less property damage than if a fire had progressed to the point of generating sufficient heat to actuate a fire sprinkler system.

To quantitatively understand the potential reduction in carbon emissions associated with portable fire extinguisher usage, this study built on existing research conducted by FM Global for commercial buildings equipped with sprinkler systems and evaluated the additional benefits of potential fire extinguisher usage. In doing so, this study concludes that carbon emissions from unwanted fires can potentially be reduced from an estimated range of 33 to 90 kg/$m^2$ over the facilities life cycle in buildings not equipped with automatic sprinklers and portable fire extinguishers to less than 1kg/$m^2$ of carbon emissions where both portable fire extinguishers and an automatic fire sprinkler are installed in accordance with fire codes. This level of reduction also highlights the potential for carbon emissions reduction from using portable fire extinguishers in buildings without automatic sprinklers. A large percentage of these emissions can be prevented by extinguishment during the early stages of a fire event by increasing the availability and use of portable fire extinguishers.

# 1.0 Introduction

A building's carbon footprint throughout its life cycle is a combination of carbon emissions during construction, operation, its deconstruction, and - importantly - fire related emissions. Therefore, fire protection is part of the global efforts to improve sustainability and reduce carbon emissions from day-to-day routine operations and potential accidents associated with those operations. Among the key elements in a fire protection strategy, namely, fire prevention, detection, suppression, and life safety, suppression plays an essential role in reducing fire risk. Suppression efforts can be generalized in three categories: 1) early efforts by nearby personnel for controlling small fires which may range from using makeshift strategies to the use of portable extinguishers, 2) fire control and suppression capabilities by fixed systems (e.g., automatic sprinkler systems), and 3) the local fire department or industrial fire brigade.

In this context, this study provides a general overview on the use and effectiveness of portable fire extinguishers, including an assessment of their impact potential of carbon emissions from unwanted fires (also referred to as "carbon footprint"). "Carbon footprint" is the term used when referring to the total amount of greenhouse gases released in the course of specific operations or activities. The study focuses on assessing the value of the use of portable fire extinguishers as related to reduction of the carbon release resulting from unwanted fire events that can happen throughout the life cycle of a building, from construction to demolition and cleanup activities.

Much of the data used for this research is available in the public domain. For example, existing data from various sources is available to determine how often portable extinguishers are used to extinguish fires at the incipient stage, how often sprinklers activate to suppress building fires, and the impact of fire on the environment.

Therefore, the research consisted of reviewing available data from the perspective of portable fire extinguisher usage. In addition, this study builds on prior work conducted by Factory Mutual, specifically, "Environmental Impact of Fire Sprinklers" by Wieczorek et al., 2010 (Reference 11) and "The Influence of Risk Factors on Sustainable Development" by Gritzo et al, 2009 (Reference 10). In this later study, Gritzo et al. found that fire risk increases the carbon footprint of a building by 1% - 2% over the life of a typical office building.

The benefits of portable fire extinguishers are broadly characterized in terms of their use in various occupancies, their effectiveness, and the potential for reducing the carbon footprint associated with the fire risk.

# 2.0 Purpose

The purpose of this research is to summarize an assessment on the extent of use and effectiveness of portable fire extinguishers considering their effects in reducing the carbon footprint associated with accidental fires in order to characterize the value of maintaining portable fire extinguishers in buildings operating under standard fire prevention, detection, suppression and life safety practices.

# 3.0 Use and Effectiveness of Fire Extinguishers

A fire extinguisher is a handheld active fire protection device filled with a suppression agent used to extinguish or control small fires. Typically, it consists of a hand-held cylindrical pressure vessel that can be discharged to extinguish a fire. The device, designed to be used by people who are not fire safety professionals, is not intended for use on relatively large or out-of-control fires, such as propagating fires, explosions, etc. or otherwise requiring the equipment, personnel, resources, and training of a fire brigade or fire department.

Fire extinguishers are routinely provided in a wide range of occupancies, including residential, commercial and industrial. However, since they are designed to control and extinguish small fires, and available for a wide range of applications and occupancies, many instances in which they are used are not reported. In this context the term “reported” refers to fire events that are large enough to trigger a response from emergency services. In contrast, “unreported” fires are those that were not reported to emergency services because they did not grow and either self-extinguished or were controlled or extinguished before posing any hazard to property and life.

A publication by the National Association of Fire Equipment Distributors (NAFED) (Reference 4) reports the following general conclusions:

+ Fire extinguishers are more than 90% effective when used as intended to extinguish or control small fires, and
+ Most uses of fire extinguishers are never reported because users do not want or need the authorities (fire departments and insurance companies) to know that there was a fire.

The latter conclusion is consistent with the intended use of extinguishers as it is expected that their safe and effective use will lead to small or negligible fire damage or loss. At the same time, this is a complicating factor in the development of an accurate characterization of the use and effectiveness of fire extinguishers in occupancies where reporting is not required or not available due to its proprietary nature.

A general assessment of the potential impact of unreported fires in the characterization of the effective use of fire extinguishers can be obtained by considering the number of reported and unreported fires. The National Fire Protection Association (NFPA) documents the findings of fire events based on fires reported to local fire departments at the NFPA annual fire experience survey [1, 2]. The data for 2021 documents the following results:

+ Total fire incidents: 1,353,500
+ Structure fires: 486,500 (36% to all fires), including,
    - Residential fires: 361,000 (27%), and
    - Non-residential fires: 125,500 (9%)
+ Vehicle fires: 208,500 (15%)
+ Outside and other fires: 658,000 (49%).

In addition, the US Consumer Product Safety Commission (CPSC) describes a National Sample Survey of Unreported Residential Fires between 2004 and 2005 (See Reference 3). The study estimates that 96.6% of residential fires were not attended by fire departments. There was reportedly an estimated total of 7,175,628 events that were not attended by fire departments. The remaining residential fires, a total of 254,441, were attended by the fire department.

Of the total number of unreported fires, 82.4%, or 5,912,717 were extinguished by residents or bystanders using various methods (e.g., 17.6% of the fires self-extinguished without any intervention).

It is noted that no insights are offered in Reference 3 on the effects of residential sprinklers in unreported fires. Reference 3 also estimates that fire extinguishers are used in 4.5% of unreported residential fires. This results in approximately 323,000 events where extinguishers were used to suppress a fire (i.e., 7,175,628 x 0.045 = 322,903 fires). The same reference reports that fire extinguishers were used in 17.7% of the reported fires (254,441 x 0.177 = 45,036 fires) with or without a follow up by other suppression capabilities such as a fire department.

The discussion above related to reported and unreported fires suggests that people will attempt to intervene in fire events when possible, including in residential occupancies. This considers that many households do not have fire extinguishers, and that people will utilize makeshift means where extinguishers are unavailable or inconvenient.

The general tendency for intervening in fire events is also observed in operating experience available from industries with strict fire protection program practices and regulations requiring documentation of all events, including "near miss" situations such as fires that were detected and quickly controlled by trained facility personnel.

As an example, the commercial nuclear industry published NUREG -2169 (References 5, 6), which is a statistical study of fire events reported in nuclear power plants in the United States. These reported events include small fires/ignition events that would have gone unreported in many occupancies. Specifically, a total of 509 fire events from this database are selected for developing statistics to be used in performance based/risk informed applications in the commercial nuclear industry. This selection is primarily based on fires that "if left alone" could have developed and presented a challenge to the facility. Prevalent reasons for not using fire extinguishers included: 1) fire extinguishers not being appropriate for the type of fire event (e.g., explosions, arcing faults, etc.) or 2) staff chose other suppression means (e.g., de-energizing equipment, etc.). These cases where fire extinguishers were not used made up 62% of the events, or 314 fires. The remaining events, a total of 195, were controlled effectively by the use of one or more extinguishers (i.e., 38% of the events).

The use and effectiveness of fire extinguishers, as summarized above, is consistent with findings reported in studies focusing on the use of fire extinguishers by the general public. For example, Reference 8 states that there are numerous routine activities with a higher risk of injury than the use of portable fire extinguishers. Although a small and distinct section of the public has specific characteristics that make them vulnerable to fire, leaving them unable to appropriately respond, most people do respond appropriately. In addition, Reference 9, which is a study on the use of fire extinguishers by untrained subjects, indicates that the majority of these untrained subjects used a portable fire extinguisher safely (97%), discharged the suppression agent (98%), and aimed at the base of the fire (74%). The study suggests that although there are certain risks in the use of extinguishers, people may benefit from having them at the time of a fire event. This conclusion was based on testing reported in the study in which the majority of the test trials resulted in successful suppression activities.

In summary, fire extinguishers play an active role in the overall fire protection strategy, specifically in the control and suppression of fires in occupancies ranging from residential to industrial. In all these occupancies, their use ranges from approximately 5% (in residential unreported applications) to 40% (in industrial applications) of the detected fires. In most of those cases, their use results in either extinguishing or controlling the fire.

# 4.0 Impact of Fire Extinguishers on Carbon Emissions

A study by FM Global [10] developed a method for estimating both the total carbon emission (TCE) of a facility over its lifetime and risk of increased carbon emissions due to fire. This study also explored the reduction in the risk of carbon emissions when the fire risk is moderated though the use of automatic sprinkler systems.

As described in the study, the TCE of a facility over its lifetime is the sum of the emissions that occur from construction, normal operation, maintenance, and decommissioning. This is shown in Equation 1:

$$TCE = CE_{const} + LCE_{oper} + LCE_{mnt} + CE_{decom} \qquad \textit{[Equation 1]}$$

Where,

- $CE_{const}$: Carbon emissions from construction. This includes the emissions associated with materials, transportation, and the use of equipment. This is considered to be a one-time event.
- $LCE_{oper}$: Carbon emissions from operation. Operations include power consumption and utilities. This value may be calculated as a function of the years of service, *LT*, and the annual rate of emissions, *ACE*, as shown in Equation 2:

$$LCE_{oper} = LT \times ACE_{oper} \qquad \textit{[Equation 2]}$$

- $LCE_{mnt}$: Carbon emissions from maintenance. This is determined in a manner similar to the carbon emissions due to operations as shown in Equation 3:

$$LCE_{mnt} = LT \times ACE_{mnt} \qquad \textit{[Equation 3]}$$

- $CE_{decom}$: Carbon emissions from decommission. Emissions from decommissioning include those due to equipment used for demolition and transportation for disposal. This is considered to be a one-time event.

The following are average TCE estimates for one commercial/office building from various countries:

- Japan 1976-1989: 111.25 kg $CO_2/m^2$ annually (Considering 40-year life cycle)
- Finland: 66 kg $CO_2/m^2$ annually (Considering 50-year life cycle)
- UK: 34 kg $CO_2/m^2$ annually (Considering a 50-year life cycle)

Reference 10 also indicates that the values in Japan and Finland are similar to estimates in the mid-west of the United States. Based on the above estimates, Table 4-1 summarizes a range of the total (i.e., life cycle) carbon emission values for selected facilities.

***Table 4-1 – Total Life Cycle Carbon Emissions[10],[11]***

| Occupancy Type | Office Building Current Standard | Office Building Reduced Operating Emissions (Green Buildings) | High Hazard Facility | Residential Building |
|---|---|---|---|---|
| **Total life cycle carbon emissions, TCE (kg CO2/m$^2$)** | 3300-4500* | 2000* | 4000* (estimated) | 1695** |

* Values in Table 1 of Reference 11.
** This value is derived as 278,000 kg-$CO_2$ divided by the average area of residential structures of 164 m$^2$ (From Reference 12, page 8).

The risk of abnormal events such as fires, floods, or wind damage should also be considered and added to the TCE. This comprehensive life cycle emission, LCE, is determined as shown in Equation 4:

$$LCE = TCE + LCE_{risk} \quad \text{[Equation 4]}$$

Where $LCE_{risk}$ represents the increase in risk factors posed to the sustainability of the facility over its lifetime. In addition, a risk fraction (RF) can be developed to assess the relevance of risks to the overall carbon emissions of a facility. This risk fraction is described in Equation 5:

$$RF = LCE_{risk}/TCE \quad \text{[Equation 5]}$$

The total carbon emission risk fraction posed by fires hazards is expressed by equation 6, which considers the contribution of both fire events and remediation in a life cycle:

$$RF_{fire} = f_f \times LT \times \left(\frac{F_b \times m_f \times e_{CO_2}}{TCE} + \frac{F_r \times CE_{emb}}{TCE}\right) \quad \text{[Equation 6]}$$

Where:

+ $f_f$ = *annual frequency, fires/year*
+ $LT$ = *Years of service*
+ $F_b$ = *Fraction of combustible material burned, upper bound of 1.0*
+ $m_f$ = *Combustible material (i.e., fuel) density, kg fuel/m²*
+ $e_{CO2}$ = *$CO_2$ released per unit material burned, kg $CO_2$/kg fuel*
+ *TCE = Total Life cycle $CO_2$ emissions per unit area, kg $CO_2/m^2$*
+ $F_r$ = *Fraction of material to be replaced during reconstruction. This value may exceed a value of 1.0 as the carbon associated with disposal and reconstruction associated with reconstruction may exceed the embodied carbon associated with the fraction of carbon emitted due to a fire*
+ $CE_{emb}$= *Total Embodied $CO_2$ emissions per unit area, kg $CO_2/m^2$*

For various building cases (i.e., building types listed below in Table 4-2), the risk fraction for fires can be determined using Equation 6 as:

$$RF_{fire} = (0.001\sim0.016) * (40\sim60) * \left(\frac{(0.5\sim1.0) * (38\sim115) * 3}{(3300\sim4500)} + \frac{(0.8\sim1.0) * \big((0.15\sim0.6) * (3300\sim4500)\big)}{(3300\sim4500)}\right)$$

The study determined the increase due to fires in a standard office building will increase carbon emissions by approximately 30-90 kg/m$^2$ of $CO_2/m^2$ over the life cycle of the building – an increase of around 1-2%. This fire risk fraction is larger for office buildings with reduced operating emissions (i.e., “green buildings”) and high hazard facilities to approximately 4% and 14% respectively as shown in Table 4-2. That is, the carbon emissions from fire accidents over the life cycle of the building represent a 1-2% in the profile of emissions during the life cycle. This value is higher, 4-14% (80 kg/m$^2$ to 560 kg/m$^2$) in office buildings with reduced operating emissions and high hazard facilities.

***Table 4-2 - Fire Fraction of Carbon Emission Due to Fire Risk***

| Occupancy Type | Office Building Current Standard | Office Building Reduced Operating Emissions | High Hazard Facility | Residential Building |
|---|---|---|---|---|
| **Fire Fraction of Carbon Emission, $RF_{fire}$** | <1% ~2%[10] | ≈4%[10] | ≈14%[10] | 0.4% ~3.7%[11] |

Using the results in Table 4-2, the summarized TCE value in Table 4-1, and Equation 5, the carbon emissions from fires over the life cycle emission of an office building can be estimated as shown in Equation 7:

$$RF = \frac{LCE_{risk}}{TCE} \rightarrow LCE_{fire} = RF_{fire} \times TCE = (1\sim 2\%) \times (3300\sim 4500) \qquad \textit{[Equation 7]}$$

This resulting estimation of the life cycle emissions for various facilities are presented in Table 4-3.

*Table 4-3 – Carbon Emissions by Fire Over the Facility Life Cycle*

| Occupancy Type | Office Building Current Standard | Office Building Reduced Operating Emissions | High Hazard Facility | Residential Building |
|---|---|---|---|---|
| **Carbon Emission Due to Fire, $LCE_{fire}$** | <33 kg/m$^2$ ~90 kg/m$^2$ | ≈ 80 kg/m$^2$ | ≈560 kg/m$^2$ | 6.78 kg/m$^2$ ~ 62.72 kg/m$^2$ |

## 4.1 IMPACT OF AUTOMATIC SPRINKLERS

The risk factor reduction, $F_{AFS}$, of automatic fire sprinklers (AFS) is given by:

$$F_{AFS} = \frac{[f_f \times F_b]}{[f_f \times F_b]_{AFS}}, \qquad \textit{[Equation 8]}$$

and

$$RF_{AFS} = \frac{RF_{fire}}{F_{AFS}} \qquad \textit{[Equation 9]}$$

Therefore, the risk factor reduction due to an automatic sprinkler can be estimated as shown in Equation 10:

$$F_{AFS} = \frac{RF_{fire}}{RF_{AFS}} \qquad \textit{[Equation 10]}$$

Reference 10 estimates that reduction in carbon emissions over the life of a facility due to accidental fires is in the order of 90% when a sprinkler system is credited (33 kg as reported in Table 4-3 above to about 3.3 kg as reported in Table 4-4 below). Recall that the carbon emissions due to fire accidents in buildings was estimated as 33-90 kg of $CO_2$/m$^2$. Sprinkler protection would reduce that to 3-9 kg $CO_2$/m$^2$ (i.e., a 90% reduction).

Using equation 5, the results from Table 4-1 (i.e., total life cycle carbon emissions from office buildings) and the reported risk factor reduction value of 0.1% (see Table 1 in Reference 10) for a standard operation office building, the $LCE_{AFS}$ is determined as shown in Equation 11:

$$LCE_{AFS} = F_{AFS} \times RF_{fire} \times TCE = 0.1\% \times (3300\sim4500) \quad \textit{[Equation 11]}$$

That is, the carbon emissions mass in fires controlled by an automatic sprinkler is estimated as the risk fraction of carbon emissions due to fire, times the total cycle carbon emissions times the fraction of the emissions controlled by the automatic sprinkler system. The resulting carbon emission due to a fire controlled with automatic sprinklers for the different building reviewed in the study are shown in Table 4-4.

*Table 4-4 – Carbon Emission From a Fire Controlled by Sprinklers*

| **Occupancy Type** | **Office Building Current Standard** | **Office Building Reduced Operating Emissions** | **High Hazard Facility** | **Residential Building** |
|---|---|---|---|---|
| **Carbon Emission Impact by Sprinkler Control Fire, $LCE_{ASF}$** | 3.3 $kg/m^2$ ~4.5 $kg/m^2$ | ≈ 2 $kg/m^2$ | ≈ 16 $kg/m^2$ | 3.39 $kg/m^2$ |

## 4.2 IMPACT OF FIRE EXTINGUISHERS

This section describes an assessment of the risk factor reduction due to crediting fire extinguishers following the same methodology as summarized in the previous section for automatic sprinklers. The following assumptions are made in this analysis:

- A fire extinguisher may suppress fires up to approximately 100 kW of the peak heat release rates. This assumption considers that the suppression and control capabilities of fire extinguishers vary due to a number of factors. Therefore, although extinguishers can control larger size fires, this limit is intended to conservatively account for extinguishing capabilities, personnel operating the devices, etc.
- In sprinklered buildings, fire sizes are assumed to continue developing up to the time of suppression by an automatic sprinkler system. In this context, the activation of an automatic sprinkler system is interpreted as the limiting condition in which a fire extinguisher would be safely used by building occupants. As such, this captures the early stages of accidental fires in which the fire is small enough so that it can be controlled by fire extinguishers.
- Fires are assumed to follow a t-squared growth profile (see Reference 7).

The practical implication of these assumptions is that an extinguisher can control or suppress fire growth for fire sizes of at least 100 kW within the early stages of the development, which is generally before the operation of an automatic sprinkler system.

The total heat ($\Delta H$) from a fire with an average t-squared growth profile as shown in Figure 4-1 can be determined by integrating for the area under the profile for a period of time as shown in Equation 11 as a function of time. Since there is uncertainty in the fire growth profile and the specific time at which fire extinguishers would be used before an automatic sprinkler system would activate, the integration is performed for a range of intervals (i.e., 5 to 15 min) in the format of a sensitivity analysis.

$$\Delta H(t) = \int_0^t \partial t^2 = 0.02041 \int_0^t t^2 \partial t = 0.02041 * \left(\frac{1}{3}\right)(t^3 - 0)\ kJ \qquad \textit{[Equation 12]}$$

Based on Equation 12, the heat release values of 5 minutes, 10 minutes, and 15 minutes are calculated in the below,

$$For\ 5\ minutes:\quad \Delta H(5mins) = \int_0^t \partial t^2 = 0.02041 \int_0^t t^2 \partial t = 0.0241\left(\frac{1}{3}\right)(t^3 - 0) = 0.02041 * \left(\frac{1}{3}\right) * (300)^3 = 183690\ kJ$$

$$For\ 10\ minutes:\quad \Delta H(10mins) = \int_0^t \partial t^2 = 0.02041 \int_0^t t^2 \partial t = 0.0241\left(\frac{1}{3}\right)(t^3 - 0) = 0.02041 * \left(\frac{1}{3}\right) * (600)^3 = 1469520\ kJ$$

$$For\ 15\ minutes:\quad \Delta H(15mins) = \int_0^t \partial t^2 = 0.02041 \int_0^t t^2 \partial t = 0.0241\left(\frac{1}{3}\right)(t^3 - 0) = 0.02041 * \left(\frac{1}{3}\right) * (900)^3 = 4959630\ kJ$$

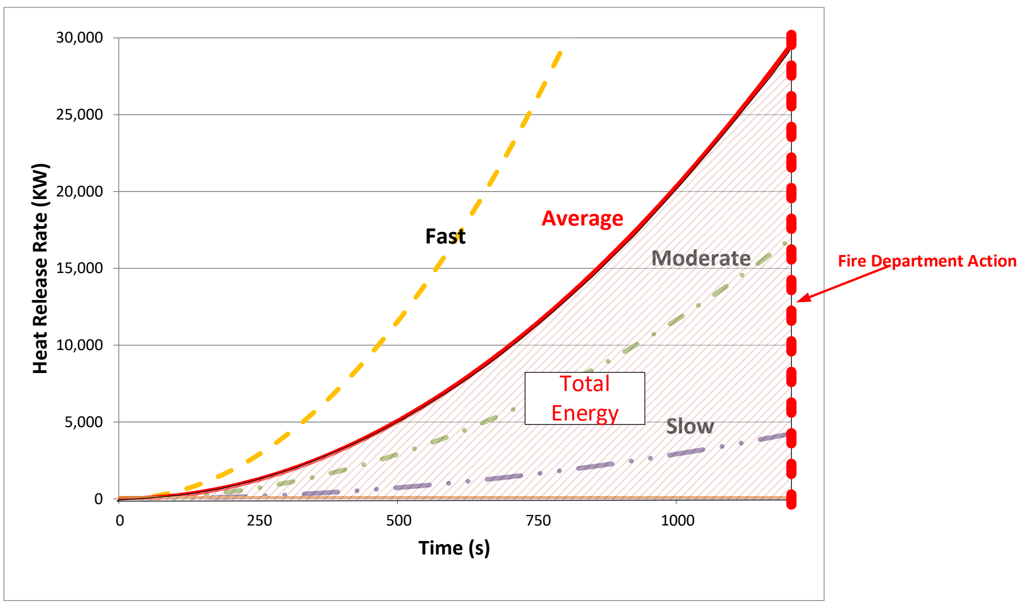


*Figure 4-1 – t-squared fire growth profiles*

Therefore, the total expected energy that a fire extinguisher will control, limiting the fire to 100 kW is expressed as Equation 13 below and presented in Figure 4-2. Notice that total energy calculation is done first for the period of average fire growth to 100 kW (average time of 70 seconds). Subsequently, it is assumed that the fire will burn at 100 kW for some time following suppression by extinguishers and before an activation of an automatic sprinkler system. For the growth portion of the fire, the energy is calculated as:

$$\Delta H_{100kW} = \int_0^{70seconds} \partial t^2 + (t - 70second) * 100kW \qquad \textit{[Equation 13]}$$

Where:

$t$ the time of the other fire suppression system activation or fire department action.

The remaining of the total energy of a fire that grows up to 100kW and is suppressed by extinguishers at various possible times (i.e., 5minutes, 10minutes, and 15 minutes) is calculated as:

5 minutes:

$$\Delta H_{100kW,5mins} = \int_0^{70} 0.02041(70)^2 + (300 - 70) * 100 = 2.53MJ$$

10 minutes:

$$\Delta H_{100kW,10mins} = \int_0^{70} 0.02041(70)^2 + (600 - 70) * 100 = 5.53MJ$$

15 minutes:

$$\Delta H_{100kW,15mins} = \int_0^{70} 0.02041(70)^2 + (900 - 70) * 100 = 8.53MJ$$

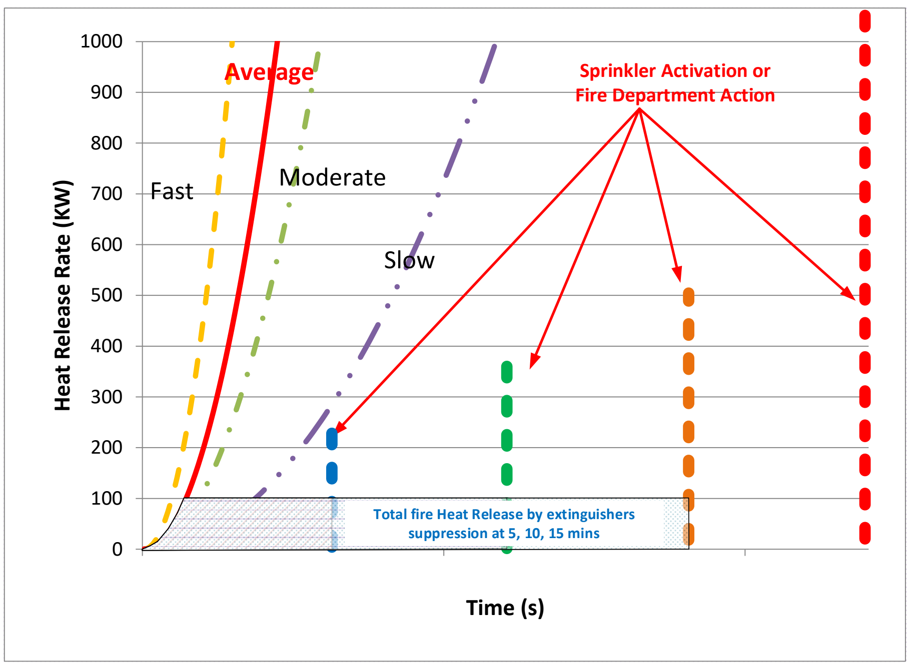


*Figure 4-2 – Energy Controlled by a Fire Extinguisher*

Using Equations 12 and 13, the resulting ratios of heat release rate an extinguisher could control is estimated using Equation 14 for different potential fire durations before sprinkler activation:

15 minutes: $\frac{H_{100kW,15mins}}{\Delta H} = \frac{85333.5}{4959630} = 1.7\%$ *[Equation 14]*

10 minutes: $\frac{H_{100kW,10mins}}{\Delta H} = \frac{55333.5}{1469520} = 3.8\%$

5 minutes: $\frac{H_{100kW,5mins}}{\Delta H} = \frac{25333.5}{183690} = 13.8\%$

On average, the resulting ratio is 6.4%. Assuming a linear relationship between the carbon emission of fire and the total heat released, and assuming the same relationship between extinguishers and automatic sprinklers as in Equation 10, the fraction of risk an extinguisher can control is determined as shown in Equation 15:

$$F_{extinguisher} = \frac{RF_{extinguishers}}{RF_{fire}} = \frac{H_{100kW,15mins}}{\Delta H} = 1.7\%$$
$$F_{extinguisher} = \frac{RF_{extinguishers}}{RF_{fire}} = \frac{H_{100kW,10mins}}{\Delta H} = 3.8\%$$
$$F_{extinguisher} = \frac{RF_{extinguishers}}{RF_{fire}} = \frac{H_{100kW,5mins}}{\Delta H} = 13.8\%$$
*[Equation 15]*

To estimate the carbon emissions that can be controlled with a fire extinguisher and automatic sprinklers, the results from Equation 14 will be used with the results for an office building from Table 4-1 and Equation 5:

$$LCE_{extinguisher} = F_{extinguisher} \times RF_{fire} \times TCE = 6.4\% \times 0.1\% \times (3300\sim4500)$$
*[Equation 16]*

The results are presented in Table 4-5.

*Table 4-5 – Carbon Emission Controlled by Fire Extinguishers*

| Occupancy Type | Office Building Current Standard | Office Building Reduced Operating Emissions | High Hazard Facility | Residential Building |
|---|---|---|---|---|
| **Carbon Emission Impact by Extinguisher Control Fire, $LCE_{extinguisher}$** | <0.21 kg/m² ~0.288 kg/m² | ≈ 0.128 kg/m² | ≈ 0.41 kg/m² | 0.43 kg/m² |

Therefore, assuming commercial buildings equipped with both a sprinkler system and fire extinguishers, the reduction in carbon emissions due to accidental fires resulting from the use of portable fire extinguishers has the potential to be in the order of less than 1 kg/m² (i.e., from a range of 33 to 90 kg/m² to less than 1 kg/m²). That is:

+ The increase in carbon emissions due to fires for commercial standard buildings is approximately 33 – 90 kg/m² (See Table 4-3)
+ Automatic sprinklers reduce the carbon emissions by approximately 90%, for a total of 3.3 – 4.5 kg/m² (See Table 4-4)
+ Additional reduction by fire extinguishers of 93.6% (i.e., 6.4% of the remaining value after the reduction provided by automatic sprinklers) results in a total 0.21 to 0.288 kg/m² (see Table 4-5).

To illustrate the effects of the results summarized above, assume an office building of 1,115 m² (12,000 ft²). This building is estimated to produce 33 kg/m² x 1,115 m² = 36,795 kg of $CO_2$ if there is a fire. If the building is equipped with automatic sprinklers, this estimate is reduced to 36,795 kg x 0.1 = 3,670 kg. Further reductions provided by fire extinguishers will result in an estimate of 3,670 kg x 0.064 = 235.5 kg of carbon emissions. In total, these reductions represent a 99% reduction in carbon emissions due to fire accidents.

The conceptual example described in the paragraph above can be extended considering the number of structure fires mentioned earlier in this report of 486,500 including 361,000 residential fires, and 125,500 nonresidential fires. Since approximately ten percent of the structures are sprinklered (see Figure 1 in Reference 12), the use of fire extinguishers in controlling fires at the early stages provides the first line of defense for the relatively large number of non-sprinklered buildings. At the same time, when used in combination with automatic sprinklered systems, 486,500 x 10% x 36,795 kg = 1.79E9 kg of carbon emissions during a lifetime of operation can be significantly reduced (i.e., up to a 99% reduction).

## *5.0 Conclusions*

This study provides a general overview of the effectiveness of portable fire extinguishers relating to their ability to control or extinguish fires in a wide range of occupancies, and the potential for reducing the carbon footprint associated with accidental fires. For both factors, the study finds advantages in the use of portable fire extinguishers.

Based upon work by the U. S. Consumer Product Safety Commission [3] and others, this report finds portable fire extinguishers are effective in extinguishing fires in hundreds of thousands of fire events per year. In practice, portable fire extinguishers are used by building occupants, facility personnel, etc. before the activation of automatic suppression systems or the intervention of a fire brigade or fire department. Therefore, an early stage of fire development was used in this study to determine the potential reduction in carbon emissions given the use of portable fire extinguishers. When used in buildings also equipped with automatic fire sprinklers, carbon emissions during accidental fires is significantly reduced. It is also noted that by extinguishing the fires and stopping fire growth, portable fire extinguishers not only reduce the carbon footprint associated with carbon emissions due to a fire event, but also from the reconstruction activities.

To quantitatively understand the potential reduction in carbon emissions associated with portable fire extinguisher usage, this study built upon existing research conducted by FM Global for commercial buildings equipped with both sprinkler systems and fire extinguishers. In doing so, this study concludes that carbon emissions from unwanted fires (accidental fires) can potentially be reduced from an estimated range of 33 to 90 $kg/m^2$ over the facilities life cycle in buildings not equipped with automatic sprinklers and portable fire extinguishers to less than 1 $kg/m^2$ of carbon emissions where both portable fire extinguishers and an automatic fire sprinkler are installed in accordance with fire codes. This level of reduction highlights the potential for carbon emissions reduction from installing and using portable fire extinguishers whether fire sprinklers are present or not. This study finds that a relatively large proportion of a building's carbon emissions can be prevented by extinguishing fires in their early stages.

To clearly illustrate the benefits of layering fire protection, in this case fire sprinklers and portable extinguishers, consider the following:

In a sample office building fire, if no sprinklers or extinguishers are used, and the fire department assumes responsibility for extinguishment, we can expect the release of 81,119 lbs. (36,795 kg) of carbon emissions – over 40 tons.

If the building is equipped with automatic sprinklers, we can expect the same accidental fire to release about 8,112 lbs. (3,679 kg) of carbon emissions, for a reduction of 90%.

If the building is equipped with portable fire extinguishers, and they are effectively used, we can expect the same accidental fire to release about 811 lbs. (368 kg.) of carbon emissions, for a reduction of 99% when respectively compared with extinguishment by a fire department.

# 6.0 References

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