Department for Communities and Local Government Final Work Stream Report:

BD 2887

Compartment sizes, resistance to fire and fire safety project

Work stream 2 – Maximum fire compartment sizes

286856 (D24V1)

CPD/04/102

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25 February 2015

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FIRE

BD 2887

Compartment sizes, resistance to fire and fire safety project

Final Work Stream Report for Work Stream 2 – Maximum fire compartment sizes

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BRE output ref. 286856 (D24V1)

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Executive Summary

Building Regulations and Standards Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled "Compartment sizes, resistance to fire and fire safety". The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 2 – Maximum fire compartment sizes. The aim of this work stream was to produce robust evidence and data to explore the potential to develop a systematic method for determining maximum compartment sizes based principally on life risk, but taking into account other factors such as environmental impact.

This work has considered the background to the current guidance in relation to maximum compartment sizes. A review of existing fire databases has been undertaken primarily to consider the relationship between compartment size and life safety with particular reference to single-storey industrial and storage buildings. A review has been undertaken of alternative approaches used to derive maximum compartment sizes for single-storey industrial and storage buildings to provide an international perspective in relation to regulatory requirements.

This work stream has also involved the participation of an industry Steering Group.

Note. The statistical analysis presented in this report has been performed by BRE using raw statistical data supplied by DCLG.

The findings of this work stream are as follows:

- Members of the industry Steering Group felt that there was a need to include a limitation on compartment size for single-storey buildings in Approved Document B (AD B)[1]. However, such a limitation would not mean that large compartments could not be constructed, simply that they would not be covered by the simplified guidance within AD B. A designer wishing to go outside the limits would need to carry out a fire engineering design in accordance with British Standards BS 9999[2] or BS 7974[3], as appropriate.

- Steering Group members also felt that where compartment sizes greater than the current limitations in Table 12 of Approved Document B are constructed, it is important to realise that the access and facilities for the Fire and Rescue Service may be inadequate. It is recommended

[1] Department for Communities and Local Government. The Building Regulations 2010 (England). Approved Document B: Fire safety. Volume 2: Buildings other than dwellinghouses (2006 edition incorporating 2010 and 2013 amendments).

[2] British Standards Institution. BS 9999 Code of practice for fire safety in the design, management and use of buildings, London, 2008.

[3] British Standards Institution. BS 7974 Application of fire safety engineering principles to the design of buildings Code of Practice, 2001.

that where large compartments are constructed using alternative fire engineering approaches, the Fire and Rescue Service are consulted at as early a stage as possible.

- Approved Document B, the guidance to the Building Regulations for England and related guidance for other parts of the UK set out limits on the maximum dimensions of fire compartments based on the type of occupancy and the height of the building. Many of the current provisions are based on the recommendations set out in the Post-War Building Studies No. 20 Fire Grading of Buildings[4]. One of the most significant aspects of the current guidance is that there is no limitation on the maximum compartment floor area for single-storey industrial buildings.
- Very large industrial buildings have developed in cases where single-storey industrial buildings are not subject to issues around boundary conditions. In such cases, the structural elements only supporting a roof (not used as a means of escape) do not require any specific level of fire resistance and are not subject to any restrictions in terms of compartmentation.
- Although the regulatory guidance does not specify any limitation in maximum compartment size for such buildings, insurance industry requirements do. For single-storey buildings belonging to the industrial group, where no limit on compartment floor area is specified in AD B, the insurance industry guidance covering property protection requirements limit the maximum compartment floor area to 7,000 m² where there is no automatic sprinkler system installed and 14,000 m² where an automatic sprinkler system is installed.
- A review of the DCLG fire statistics[5] relating to the area of the fire compartment shows that, for rooms smaller than 500 m² in floor area, an increase in floor area increases the probability that a fire will spread beyond the room of origin. As the room size increases above 500 m², the relationship is reversed and there is an increasing tendency for the fire to remain within the room of fire origin. There is no obvious statistical evidence for an increase in risk to life safety as compartment sizes increase.
- An international review of requirements related to maximum compartment sizes in single-storey industrial and storage buildings has indicated that the provisions within the guidance to the England and Wales Building Regulations are the least onerous of all the countries investigated.
- The whole-life costs in warehouses are dominated by the “financial” component, with the life safety, “social” and “environmental” components accounting for a small fraction of the total.

The overall conclusions of this work stream are:

- The review of statistical data has shown no clear correlation between compartment size and life safety for compartments with floor areas larger than 500 m^2 for large-single storey industrial and storage buildings.

[4] Post-War Building Studies No. 20 Fire Grading of Buildings Part 1 General Principles and Structural Precautions by a Joint Committee of the Building Research Board of the Department of Scientific and Industrial Research and of the Fire Offices’ Committee, His Majesty’s Stationery Office, London, 1946.

[5] Department for Communities and Local Government. Fire Statistics, Great Britain.

- The review of international requirements found no systematic method for determining maximum compartment sizes based principally on life risk.

Contents

1 Introduction and Objectives

This Final Work stream Report is delivered as part of the Department for Communities and Local Government (DCLG) project BD 2887, titled “Compartment sizes, resistance to fire and fire safety”, DCLG Contract reference CPD/04/102/010. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing (large and small scale), computer modelling and laboratory testing (where necessary) on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010. The project was broken down into seven specific work streams.

This report describes the findings of the research for Work stream 2 – Maximum fire compartment sizes.

Compartmentation is used to subdivide buildings so as to restrict fire size and fire spread. For non-domestic buildings, Approved Document B (volume 2) (AD B) [1] sets out maximum compartment sizes, which vary with height and use of the building. Compartment size is also used as a trigger to indicate where fire sprinkler systems should be installed in a building. Much of the existing guidance on compartmentation is based on assessments made in the 1940s, which has been amended in a piecemeal fashion.

Currently, there are no recognised engineering methods for establishing the appropriate compartment size for a particular building. Safety campaigners often argue that the limitations should be imposed but some industrial activities prefer the greater flexibility provided by larger spaces.

The principal objective of this work stream was to produce robust evidence and data to explore the potential to develop a systematic method for determining maximum compartment sizes based principally on life risk but taking into account other factors such as environmental impact.

The Work stream 2 Tasks were:

- Task 2.1 Identification and engagement of stakeholders
- Task 2.2 Review of background to existing AD B requirements
- Task 2.3 Review of existing fire database
- Task 2.4 Review of alternative approaches used to derive maximum compartment sizes
- Task 2.5 Reporting.

2 Programme of work

2.1 Stakeholder engagement

This work stream has involved the participation of an industry Steering Group, Satellite Steering Group A. This group provided input during the course of the work, giving feedback on the research methodology as well as key deliverables and milestones. This group met three times.

The organisations represented at the Steering Group are as follows.

Organisations represented at the Steering Group
Building Regulations Division, Department for Communities and Local Government (DCLG)
BRE Project team
British Constructional Steelwork Association (BCSA)
Association of Specialist Fire Protection (ASFP)
Association of Building Engineers (ABE)
British Automatic Fire Sprinkler Association (BAFSA)
Business Sprinkler Alliance (BSA)
Chief Fire Officers Association (CFOA)
The Chartered Institute of Building (CIOB)
The Concrete Centre
Fire Brigades Union (FBU)
Fire Industry Association (FIA)
Institution of Fire Engineers (IFE)
Local Authority Building Control (LABC)
National Register of Access Consultants (NRAC)
Passive Fire Protection Federation (PFPF)
RICS Building Control Professional Group (RICS)
RISCAuthority
Scottish Building Standards (SBS)
Shore Engineering
Structural Timber Association (STA)
Warwickshire FRS
Welsh Government (WG)

At the first Satellite Steering Group A meeting it was agreed that the focus of this work stream would be large single-storey industrial and storage buildings. Although there is currently no limit on compartment sizes for multi-storey office buildings there tends to be a practical limit imposed on inner city developments. This is not the case with large out of town storage or industrial buildings. The design of large open plan compartments within multi-storey office buildings is the subject of a number of new initiatives looking at travelling fires. Members felt that there was a need to include a limitation on compartment size for single-storey buildings in Approved Document B. However, such a limitation would not mean that large compartments could not be constructed, simply that they would not be covered by the simplified guidance within Approved Document B. A designer wishing to go outside the limits would need to carry out a fire engineering design in accordance with British Standards BS 9999 [2] or BS 7974 [3], as appropriate.

Satellite Steering Group members also felt that where compartment sizes greater than the current limitations in Table 12 of Approved Document B are constructed, it is important to realise that the access and facilities for the Fire and Rescue Service may be inadequate. It was also suggested that where large compartments are constructed using alternative fire engineering approaches, the Fire and Rescue Service should be consulted at as early a stage as possible.

The third Steering Group meeting concentrated on presenting and discussing the findings of this work stream. In discussion, the following issues were raised:

- A concern was expressed about the consideration of the link between warehouse compartment size and safe fire fighter access for effecting rescue operations.
- Warehouses are varied and can be retail, storage, industrial and distribution facilities. It was suggested that the definition of warehouses could benefit from being tightened up in AD B. There could perhaps be a new definition, a new explanatory footnote or another separate purpose group for warehouses.
- Compartment size may be an imprecise and not the best metric to address the risks. Could this be replaced with another metric?

2.2 Review of background to existing AD B requirements

The guidance to the Building Regulations in Approved Document B [1] sets out limits on the maximum dimensions of fire compartments based on the type of occupancy and the height of the building. In common with the periods of fire resistance discussed in relation to Work stream 1, many of the current provisions are based on the recommendations set out in Post-War Building Studies No. 20 Fire Grading of Buildings [4]. Tables 7a to 7c in that document specify restrictions in relation to both maximum floor areas and maximum cubic capacities dependent on the nature of the construction and the nature of the fire hazard. From the outset, there was recognition that any recommendations on limiting floor areas, heights or cubic capacity to reduce the extent of loss of contents and reduce the risk of a fire developing into a conflagration should take into account commercial considerations and should account for the potential to impose significant barriers to trade.

Original bye laws were applicable only to buildings constructed in full or in part from combustible materials. For other forms of construction, only in London and Liverpool were there restrictions in relation to the height or cubic capacity of buildings. Subsequent revisions to the guidance have removed the distinction between combustible and non-combustible materials with performance based functional requirements applied to all forms of building.

In the past, there may have been specific issues in relation to both height and cubic capacity in relation to bonded warehouses that led to specific restrictions within certain metropolitan districts. However, it is acknowledged that there was no general demand for greater heights in industrial buildings. If that were true in the immediate post-war period it is even more so now when for industrial and storage facilities the trend has been for increasing floor area rather than increasing height, while for office buildings there has been an increase in the number of very tall buildings within city centres which looks likely to continue for the foreseeable future.

The principal factors that influence the regulations governing the maximum size of fire compartments are:

a) the type of construction

b) the nature of the occupancy

c) the location and particularly the proximity of other buildings and

d) the nature of fire precautions including the provision of an automatic sprinkler system.

Provided “fire proof” [6] construction was used, the recommendations of the Post-War Building Studies report did not propose a restriction on maximum height. Current restrictions on maximum height are addressed by means of performance requirements related to periods of fire resistance, and there does not seem to be any reason to change this approach.

The critical issue is in relation to maximum floor area or maximum cubic capacity, particularly in relation to very large single-storey warehouse or storage buildings which may house very large amounts of combustible material. Many such buildings may incorporate significant amounts of combustible material within the fabric of the building itself in the form of insulated cladding panels forming the external leaf of the building.

One of the most significant aspects of the current guidance is that there is no limitation on compartment floor area for single-storey industrial buildings. The original recommendations of the Post-War Building Studies proposed a similar solution for single-storey buildings of Construction Type 1, 2 or 3 (protected or partially protected) for low fire load occupancies, but did impose restrictions on cubic capacity in relation to other types of construction or higher fire loads. This distinction has been removed. For this class of building, current guidance does not require any restriction on compartment area. Where restrictions are imposed, such as a multi-storey industrial building not more than 18 m high, then the compartment floor areas can be doubled if a suitable sprinkler system is installed. This is in line with the recommendations of the Post-War Building Studies report for incorporating the benefits of a suitable suppression system. However, there does not appear to be any traceable robust scientific basis to underpin the guidance.

Very large industrial and storage buildings have developed in cases where single-storey industrial or storage buildings are not subject to issues around boundary conditions and there are no problems in terms of access for the Fire and Rescue Service. In such cases, structural elements only supporting a roof do not require any specific level of fire resistance and are not subject to any restrictions in terms of compartmentation.

Although the regulatory guidance does not specify any limitation in maximum compartment size for such buildings, insurance industry requirements may specify limits on compartment size. For single-storey buildings belonging to the industrial group where no limit on compartment floor area is specified in AD B, the property protection requirements [5] limit the maximum compartment floor area to 7000 m² where there is no automatic sprinkler system installed and 14,000 m² where an automatic sprinkler system is installed. This is in line with the AD B requirements for multi-storey industrial buildings up to 18 m high. The technical basis for these figures is unknown.

2.3 Review of existing fire database and compartment sizes

The available statistics have been examined to determine the numbers of buildings of different occupancy types, in different size classes. The occupancy types were restricted to industrial, retail and storage (warehousing), as these were expected to include a number of very large buildings. Compartment sizes

[6] Type 1 construction as defined in the Post-War Studies Fire Grading of Buildings Report i.e. the elements of construction have a fire resistance of at least four hours.

were not recorded, but could potentially have been the same as the entire building. This information has been provided by the Valuation Office Agency [6] for buildings in England only, and is presented in Table 1.

Data from the DCLG's Incident Reporting System (IRS) records [7] have been analysed to generate statistics that illustrate the effect of compartment size. The records cover the four year period 1st April 2009 to 31st March 2013.

Table 1 – Number of buildings of different sizes, in different occupancy classes

	Total area (m^2)						
Description	**< 2,000**	**2,000 to 4,999**	**5,000 to 9,999**	**10,000 to 20,000**	**> 20,000**	**Unknown**	**Total**
Factories Workshops and Warehouses (Including Bakeries and Dairies)	296,100	16,750	5,180	1,840	70	230	**320,170**
Factory Shops	1,320	0	0	0	0	0	**1,330**
Food Processing Centres	140	20	20	10	0	0	**200**
Food Stores	510	0	0	0	0	0	**520**
High Tech Warehouses	20	0	0	0	0	0	**20**
Large Distribution Warehouses	20	50	160	370	510	0	**1,120**
Large Food Stores (750 – 2500 m^2)	1,970	220	0	0	0	0	**2,190**
Large Industrials (Over 20 000 m^2)	0	10	30	160	790	30	**1,010**
Large Shops (750 – 1850 m^2)	400	10	0	0	0	0	**410**
Large Shops (Over 1850 m^2)	190	1,300	320	100	20	0	**1,940**
Refuse Destructor Plants/Disposal Sites	0	0	0	0	0	0	**0**
Retail Warehouses and Food Stores	6,190	1,450	180	100	10	10	**7,930**
Shops	406,380	110	0	0	0	260	**406,760**
Storage Depots	1,650	280	80	20	10	10	**2,050**
Stores	68,920	290	50	20	0	60	**69,340**
Waste Incinerator Plants	0	0	0	0	0	30	**30**
Waste Recycling Plants	0	10	0	0	0	120	**130**
Waste Transfer Stations	0	0	0	0	0	620	**630**
Wholesale Warehouses	240	90	80	40	0	0	**450**
Cold Stores (Rental Valuation)	120	80	50	50	20	10	**330**
Warehouses Within/Part of Specialist Property	100	10	0	0	0	0	**110**
Workshops Within/Part of Specialist Property	130	10	0	0	0	0	**130**

2.3.1 Area of fire damage

There is a clear trend for the area of fire damage as defined in the Fire and Rescue Service reports to increase in larger rooms up to a certain size, see Figure 1. The error bars are 1 standard deviation of the error on the mean.

Most of the larger room sizes are in non-residential property types. Figure 2 shows the area of fire damage versus room size, for non-residential buildings only.

Data from the DCLG's Incident Reporting System (IRS) records [7] have been analysed to generate statistics for all building types (not just large single-storey) that illustrate the effect of compartment size. The records cover the four year period 1st April 2009 to 31st March 2013.

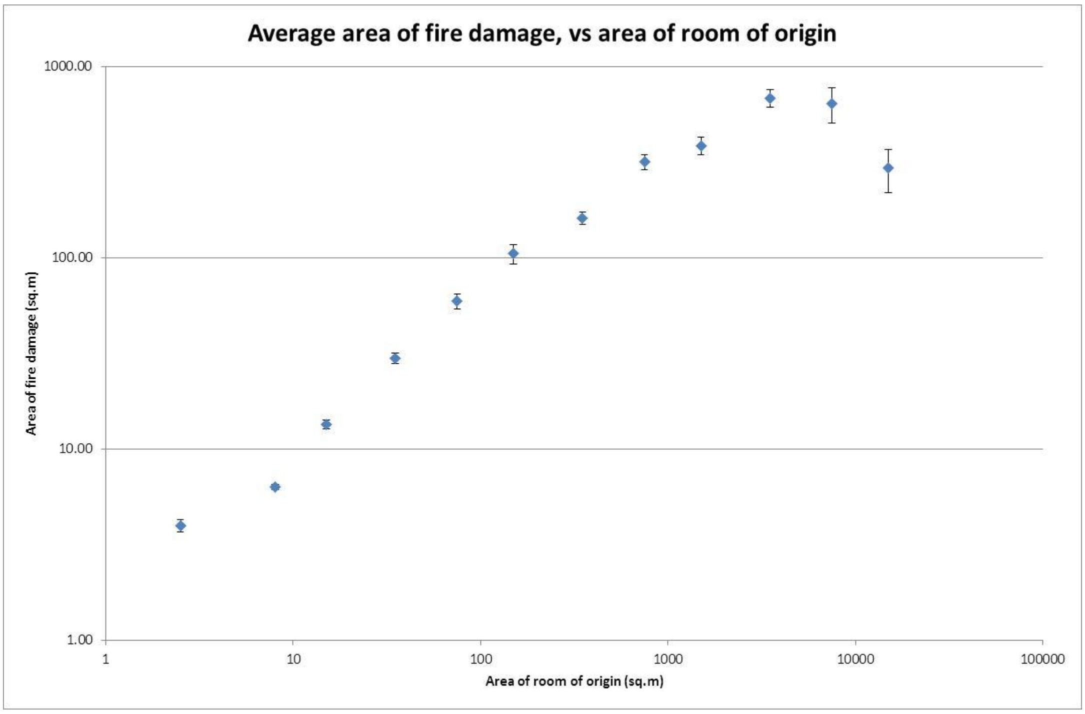

Figure 1 – Graph of average area of fire damage (m^2) versus area of room of fire origin (m^2) (sample size 263,000 fires)

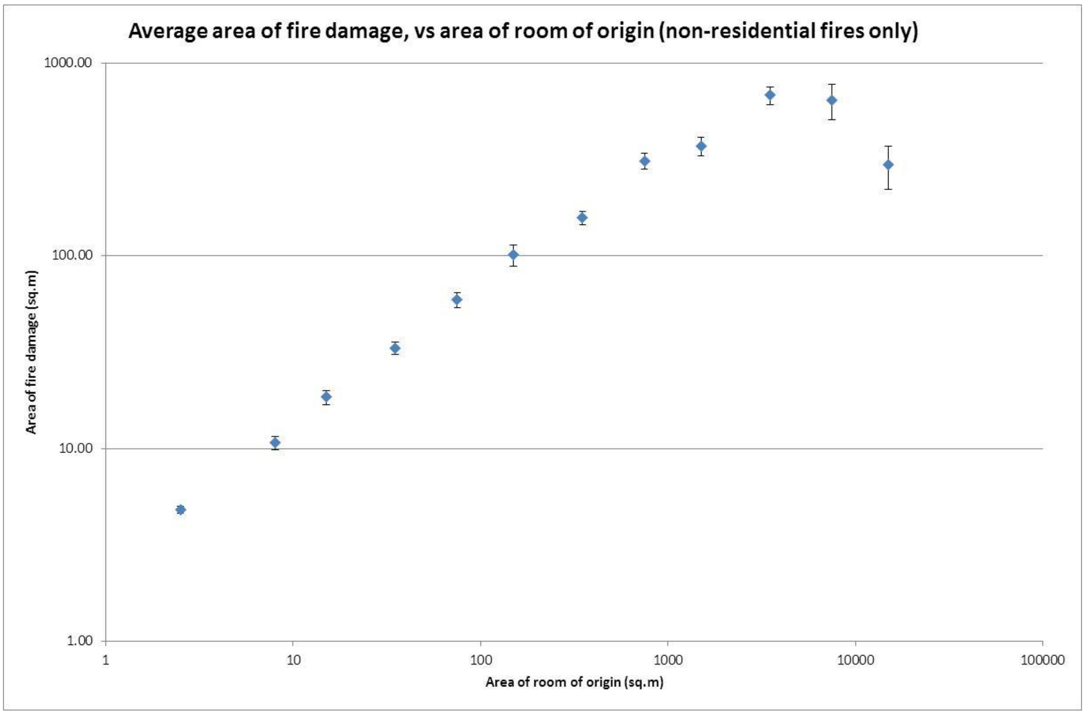

Figure 2 – Graph of average area of fire damage (m^2) versus area of room of fire origin (m^2) for non-residential buildings (sample size 80,000 fires)

There is clear evidence of a power-law relationship between the average area of fire damage, and the area of the room of fire origin. In Figure 2, for room areas up to 5,000 m^2, the relationship is $A_{fire} = 2.79\ A_{room}^{0.69}$. For room areas above 5,000 m^2, the average fire area decreases. The reason for this has not been determined, but may be connected with the fact that larger buildings are more likely to have sprinklers [8] which will control or suppress the growth of the fire.

Inspecting the probability distribution for fire area (rather than just the average value) also reveals some interesting trends, see Figure 3.

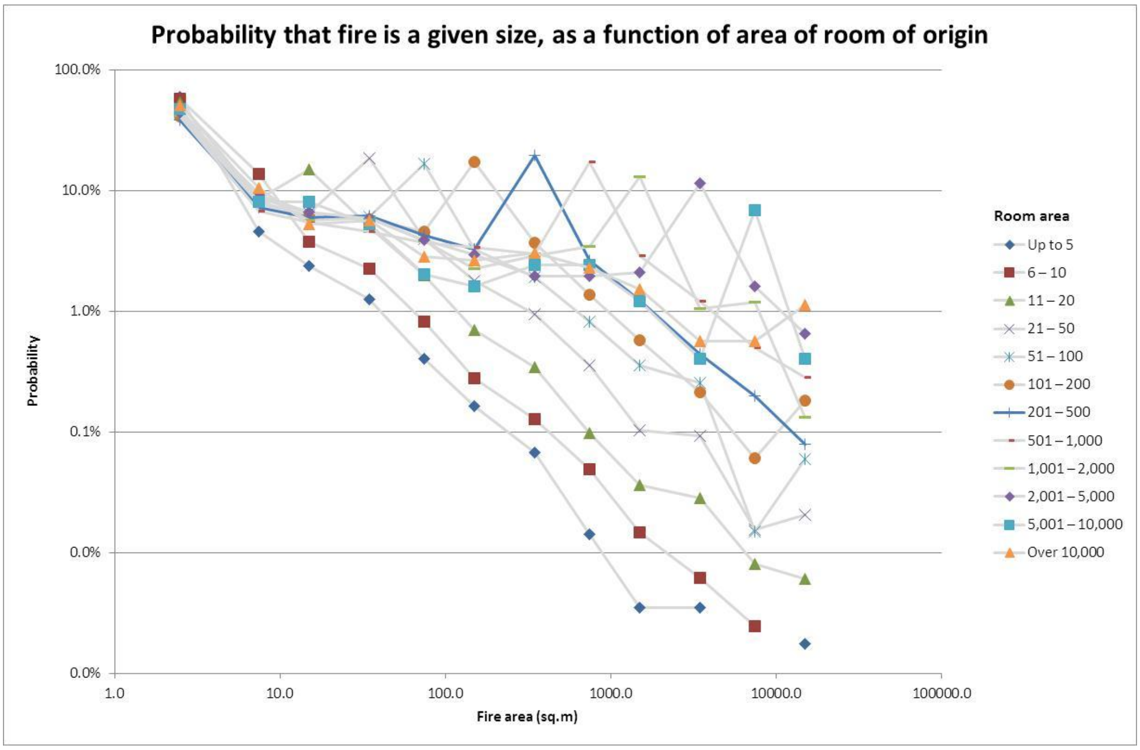

Figure 3 – Graph of probability that fire is a given size as a function of area of room of fire origin based on 224,000 fires

In order to show the trends more clearly, one line (for room sizes in the range 201 m^2 to $500m^2$) has been highlighted. Most fires are small; the graph shows the fire area as $2.5m^2$, but as the smallest fire area that is recorded in the DCLG IRS system is "under 5 m^2", it is likely that the true average area for this category may be smaller. Fires of this size would include a large fraction of fires confined to the item first ignited.

The probability distribution then follows a power law with the probability that $p(A_{fire})$ (the area of the fire is a given size) is approximately proportional to $A_{fire}^{-0.2}$ (the area of the fire to the power of -0.2), while the fire is spreading within the room of origin, until the fire area is the same as the floor area. There is then a spike in the distribution, followed by a steeper power law with $p(A_{fire})$ approximately proportional to A_{fire}^{-1} while the fire is spreading beyond the room of origin.

It is interesting to note that the indices of the power laws defining the probability distributions seem to be independent of the size of the room of fire origin.

2.3.2 Fire spread beyond room of origin

In common with the trends noted in relation to Figures 1 and 2, the proportion of fires that spread beyond the room of fire origin shows an increasing trend as room area increases, for rooms below 500 m^2 in area. However, for larger rooms, the proportion of fires that spread then decreases as the room area increases, as shown in Figure 4. This may be as a result of Fire and Rescue Service activities, rather than any tendency for larger fires to self-extinguish. When modelling compartment fires, it is widely assumed that for fire areas below 500 m^2, a single zone approach is valid with reasonably uniform temperatures within the fire compartment. However, above this value, the assumption of a single zone representing fire behaviour within the compartment may no longer be appropriate.

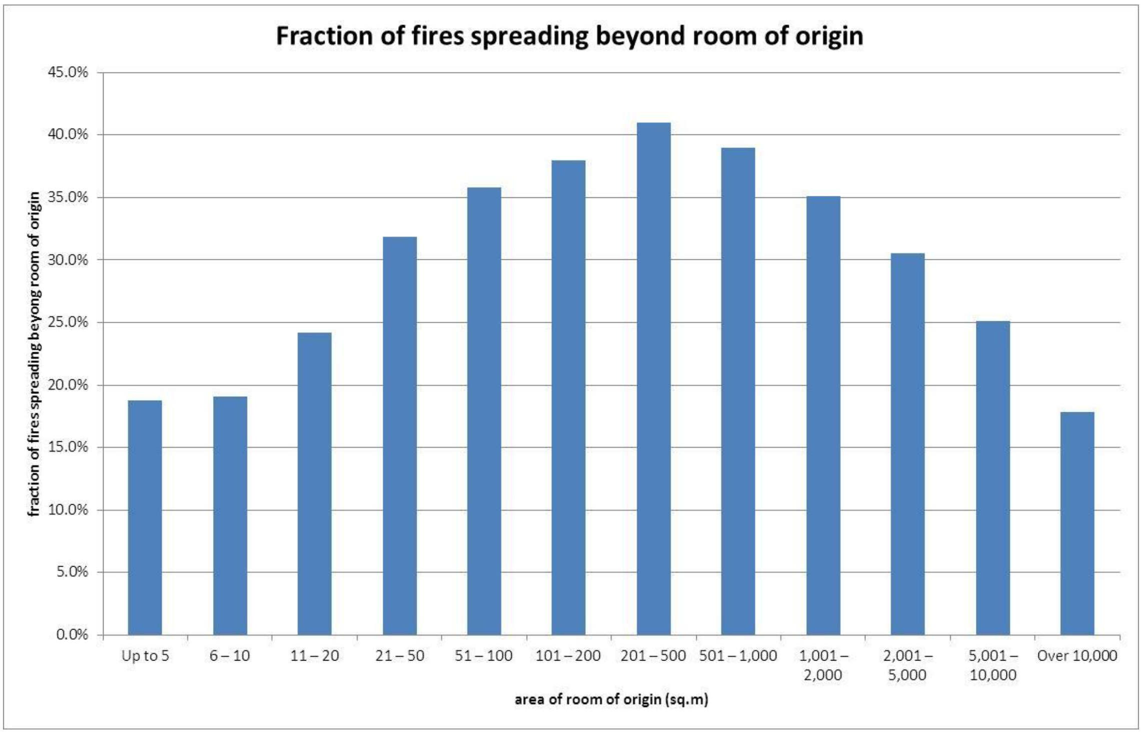

Figure 4 – Fraction of fires spreading beyond the room of fire origin as a function of the area of the room of fire origin (m^2) based on 169,000 fires (those starting in roof spaces have been excluded)

2.3.3 Life safety and compartment size

Fire fatalities and injuries have been converted to a single metric of "equivalent fatalities", according to the following scheme[7]:

- Each actual fatality = 1 equivalent fatality
- Each severe injury = 0.1 equivalent fatality

[7] The concept of "Equivalent Fatalities" has previously been used by the International Maritime Organisation (IMO, MSC/Circ 1023). The concept has been refined to include all injury classes, and rescues, recorded in the fire statistics.

- Each slight injury = 0.01 equivalent fatality
- Each injury treated by first aid = 0.003 equivalent fatality
- Each recommended precautionary check = 0.001 equivalent fatality
- Each person rescued (uninjured) = 0.001 equivalent fatality
- Each unspecified injury = 0.0003 equivalent fatality.

The justification for this is that the value assigned (on the basis of "Willingness To Pay") to the prevention of a severe injury is approximately 10% of the value for the prevention of a fatality, and the value of preventing a slight injury is approximately 1% of that for a fatality.

Figure 5 shows the life risk (expressed as "equivalent fatalities" per thousand fires) plotted against the area of the room of fire origin. There is no obvious correlation of risk against room size.

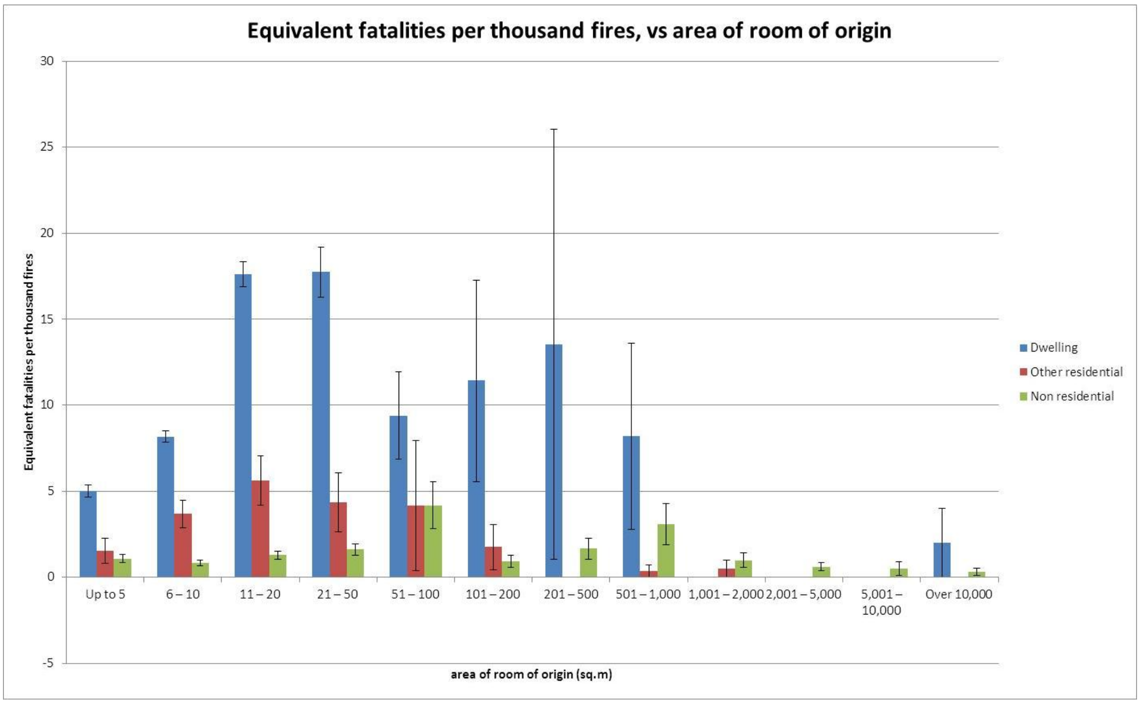

Figure 5 – Equivalent fatalities per thousand fires versus area of room of fire origin (m^2) based on 170,000 dwelling fires, 14,000 other residential and 80,000 non-residential fires

The result for dwellings with the area of the room of fire origin in excess of 10,000 m^2 in Figure 5 seems to be spurious. The statistics have five such records during the period of interest. The two equivalent fatalities per 1,000 fires result was calculated based on one slight injury in five fires.

Figure 6 shows the life risk for non-residential buildings, depending on whether fires spread beyond the room of origin or not, as well as the room area. For smaller rooms, fires contained within the room of origin have lower life safety risks than fires that spread further. However, for rooms greater than 1,000 m^2 in size, this trend disappears and the results are essentially random. This is probably because in the time it would take for a fire grow to this size, most people who are able to escape from the building would have done so.

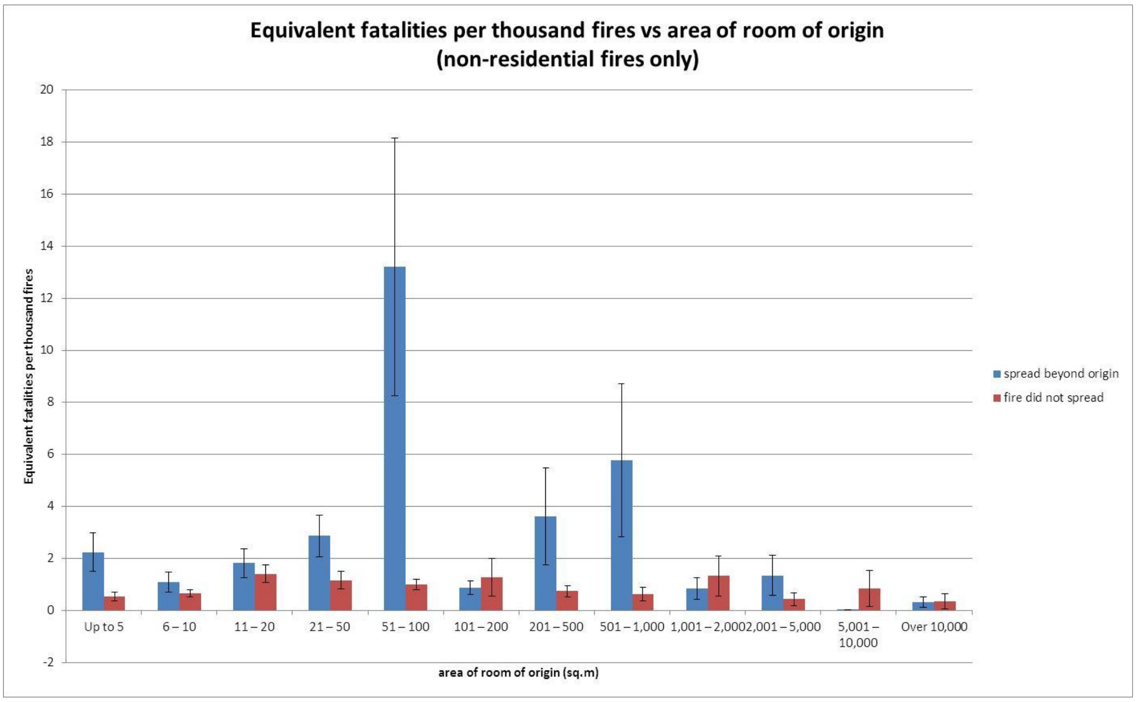

Figure 6 – Equivalent fatalities per thousand fires versus the area of the room of fire origin (m^2) for non-residential buildings based on 80,000 fires (subset 20,000 spreading fires)

Sprinklers have a beneficial impact on life safety for all room sizes, although the benefits are particularly marked for rooms in the size range 20 m^2 to 200 m^2, see Figure 7. This may be because, in small rooms, people would be in close proximity to the fire so may suffer harm before sprinklers have time to operate and control or suppress the fire. Conversely, in large rooms, people may be much further from the fire in its early stages, so have plenty of time to escape.

Note. Figure 7 is for non-residential buildings only, (there are so few fires in other building types where there are sprinklers present that a meaningful analysis is not feasible). It is also noteworthy that the analysis has only considered whether sprinklers were present; this therefore includes non-operational systems (e.g. turned off) or otherwise ineffectual ones. The proportion of non-operational systems or ineffectual ones in the analysis is not known and so it is possible that if all systems were operational and maintained according to the standards, greater benefits could be achieved.

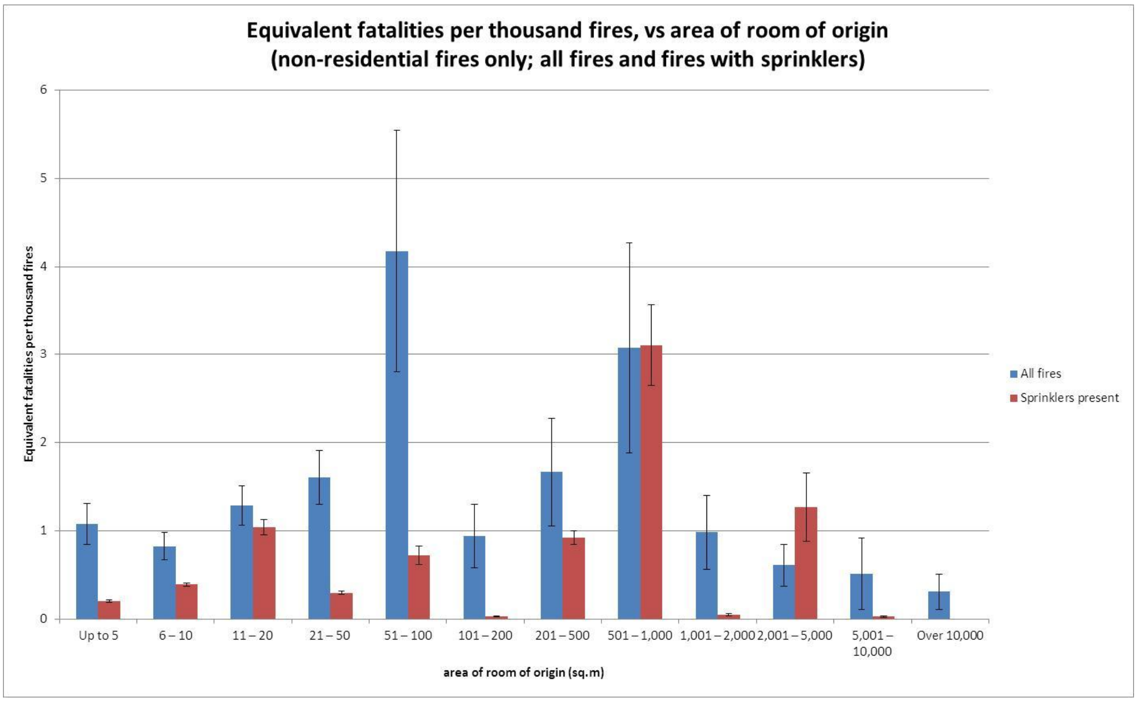

Figure 7 – Equivalent fatalities per thousand fires versus area of room of fire origin for non-residential buildings based on 80,000 fires (subset 1,800 sprinklered)

2.3.4 Conclusions of fire statistics review

The DCLG fire statistics show a clear trend for the average area damaged by fire to increase as the area of the room of origin increases up to a certain size. However, where life safety is concerned, there is no trend for the risk to increase as the area of the room of fire origin increases. This suggests that the measures currently recommended by AD B, to mitigate against (perceived) increase in risk for larger compartments, are having the intended impact i.e. the residual risk is no higher for large compartments than for smaller ones.

Generally, sprinklers are shown to reduce the life safety risks in non-residential buildings. (For dwellings and other residential buildings, the statistics are too sparse to draw meaningful conclusions). However, as the life safety risks are low to begin with, the primary benefits of sprinklers remain the economic ones (property protection of buildings and contents, reduced business interruption, etc.).

Based on the analysis of DCLG data from the UK between 2009 and 2013, there is no obvious statistical evidence for an increase in risk to life safety as compartment sizes increase.

2.4 Review of alternative approaches used to derive maximum compartment sizes

2.4.1 International approaches

A review has been undertaken of alternative approaches used to derive maximum compartment sizes to provide an international perspective in relation to regulatory requirements.

The provisions within the regulatory guidance in relation to maximum compartment sizes for single-storey industrial and storage buildings for England [1] and Wales [9] are the least onerous of all the countries investigated.

Alternative provisions for maximum compartment sizes are adopted in Scotland. For single-storey industrial buildings, the Scottish guidance to the Scottish Building Regulations [10] has two categories of factory (industrial) building and two categories for storage buildings. In these cases, the compartment size is restricted between 1000 m² (Class 1 storage buildings) and 93,000 m² (Class 2 factories). The different classifications are related to the nature of the fire load for a given occupancy and may be compared to the 'normal' and 'abnormal' definitions from the Fire Grading Report. The only type of single-storey building for which there is no restriction is an open sided car park. As with the Post-War Building Studies recommendations and the guidance in AD B, the provision of a suitable suppression system enables a doubling of the maximum compartment floor area although the technical basis for this guidance remains unclear.

Based on information provided [11], a review has been undertaken to look at international requirements in relation to maximum compartment sizes with a particular focus on single-storey industrial and storage buildings. The results from the study are summarised in Table 2 [1, 5, 9, 10, 12-20].

The results indicate a wide spread in relation to regulatory requirements concerning maximum compartment sizes, depending on the presence or otherwise of a suitable suppression system and the nature of the anticipated fire load within the building. What is clear from the above is that the guidance in England is the least onerous of all the countries considered within the review.

Restrictions on compartment size vary according to occupancy type. This represents a simplistic form of risk assessment in that danger of fire ignition and development is assumed to be related to occupancy. However, this is a very crude form of classification as the occupancy categories, industrial and storage, encompass a wide range of different activities with different levels of risk. This is taken into account to some extent in those guidance documents (such as the Scottish Non-Domestic Technical Guidance Document) that relate maximum compartment floor area to the type of industrial premises or the type of storage facility. In general, the impact of sprinklers is either not taken into account (as with the requirements related to maximum compartment floor areas for Hong Kong) or used to effectively double the allowable compartment size as in the Scottish Non-Domestic Technical Guidance Document.

In general, the requirements are related to the type of occupancy. The USA situation is different for two reasons. Firstly, design may be undertaken to any one of a number of National or State codes and secondly, requirements are related not only to the type of occupancy but also to the nature of the construction type. In this way, the USA requirements are closer to the original recommendations of the Fire Grading of Buildings Post-War Building Studies which limit floor areas (and cubic capacities) to the nature of the fire load (dependent on occupancy) and the form of construction as defined by the anticipated fire resistance. For this reason, USA requirements are excluded from the comparative study. The International Building Code (IBC) requires sprinklers in all occupancies defined as high hazard.

Information was also provided for France and Germany. However, the regulatory systems in these cases did not lend themselves to the simple comparative approach adopted in Table 2. For the French situation, every type of industry has its own specific regulations. ICPE (Installation classée pour la protection de l'environment) [21] outlines the regulations for all the industrial categories. Additionally, the local approving authorities can impose their own requirements. There are no specific limits on compartment size in Germany, although there is a requirement to provide a compartment wall every 40 m in large storage/industrial buildings.

Table 2 – International requirements for maximum compartment sizes for single-storey industrial and storage buildings (excluding car parks)

Country	Code/ Guidance/ Regulation	Single-storey industrial				Single-storey storage			
		Unsprinklered		Sprinklered		Unsprinklered		Sprinklered	
		High risk	Low risk	High risk	Low risk	High risk	Low risk	High risk	Low risk
England	AD B [1]	No limit	No limit	No limit	No limit	20000	20000	No limit	No limit
England	AD B (property protection) [5]	7000	7000	14000	14000	2000	8000	2000**	8000**
Wales	AD B (Wales) [9]	No limit	No limit	No limit	No limit	20000	20000	No limit	No limit
Scotland	NDTGD [10]	33000	93000	66000	186000	1000	14000	2000	28000
Republic of Ireland*	TGDB [12]	33000	93000	66000	186000	14000	No limit	28000	No limit
Australia *	BCA [13]	2000	2000	2000	2000	2000	2000	2000	2000
Hong Kong*	HKCPFSB [14]	10500	10500	10500	10500	10500	10500	10500	10500
South Africa	SANS 10400 [15]	5000	5000	No limit	No limit	No limit	No limit	No limit	No limit
Greece	[16]	5000	2000	12500	4000	3000	3000	3000	3000
China	GB 50016-2006 [17]	2500	2500	5000	5000	2500	2500	5000	5000
Holland	DBR [18]	2500	2500	No limit	No limit	1000	1000	No limit	No limit
India	NBCI [19]	1125	1125	No limit	No limit	1125	1125	No limit	No limit
Denmark	[20]	2000	5000	10000	10000	2000	5000	10000	10000

* Restrictions on volume also apply
** Recommended floor areas may be increased if a suitable automatic extinguishing system is provided.

AD B = Approved Document B
NDTGD = Non-Domestic Technical Guidance Document
TGDB = Technical Guidance Document B
BCA = Building Code of Australia
HKCPFSB = Hong Kong Code of Practice for Fire Safety in Buildings
SANS = South African National Standards
GB = Guobiao Standards
DBR = Dutch Building Regulations
NBCI = National Building Code of India

Table 2 reflects largely prescriptive requirements in relation to maximum compartment sizes.

Additional information [22] was provided by a Satellite Steering Group member on incentives for sprinklers in new buildings in relation to maximum compartment sizes. Where there are additional relaxations to the requirements to take account of the use of sprinklers, they do not necessarily lend themselves to the simple comparative approach set out in Table 2.

For example, in France the maximum compartment size for storage buildings (with sprinklers) is 6,000 m². However, compartments larger than this size can be constructed provided they are supported by a risk assessment and are approved by the 'Prefect' for the region.

Automatic sprinkler systems may be an integral part of a fire engineered approach to define compartment sizes (and fire resistance periods) throughout Europe using a risk based approach to define fire load density such as that in EN 1991-1-2.

2.4.2 Environmental impact and cost benefit of fire sprinklers in warehouses

The Business Sprinkler Alliance (BSA) originally commissioned a study [8] in 2010 in response to increasing annual costs of fire with the objective to determine whether it is cost effective to install and maintain fire sprinklers in warehouses in England and Wales.

Care was taken to ensure the best possible quality of data with cost and statistical information collected from a wide variety of sources across both the government and business communities, although uncertainty in the data was still present.

The first part of the project was a "cradle to site" assessment of an 'average' warehouse fire, considering both the environmental impacts and the monetary costs.

The primary focus of the study looked at a whole-life cost benefit analysis for the installation in sprinklers, for three ranges of warehouse sizes.

Specifically, this included consideration of the area of fire damage, the area of smoke damage, the expected number of casualties, carbon emissions; water used in fire-fighting, possible job losses and the chance the building would be demolished and rebuilt. The costs of sprinkler installation, maintenance, and any possible insurance premiums associated with their installation were also considered.

One of the key assumptions underpinning the study was that, where sprinklers reduce the area of fire damage, any other consequences of fire would also be reduced accordingly.

The findings showed that there is an overall net environmental benefit to installing sprinklers across the lifetime of an average warehouse. These benefits include a reduction in fire size and a corresponding reduction in carbon emissions from fire, water used in fire-fighting. There were further emissions savings from avoiding the need to replace contents and rebuild the warehouse.

For the whole life cost benefit analysis of fire sprinkler installation, the findings showed that, on average:

- it would not be cost-effective to install sprinklers in warehouses with an area below 2,000 m^2, but,
- it would be cost-effective to install sprinklers in warehouses above 2,000 m^2 in size.

It was also shown that when sprinklers are installed in warehouse above 10,000 m^2 in area, these larger warehouses benefit from whole-life costs that are 2 to 5 times smaller than equivalent warehouses without sprinklers.

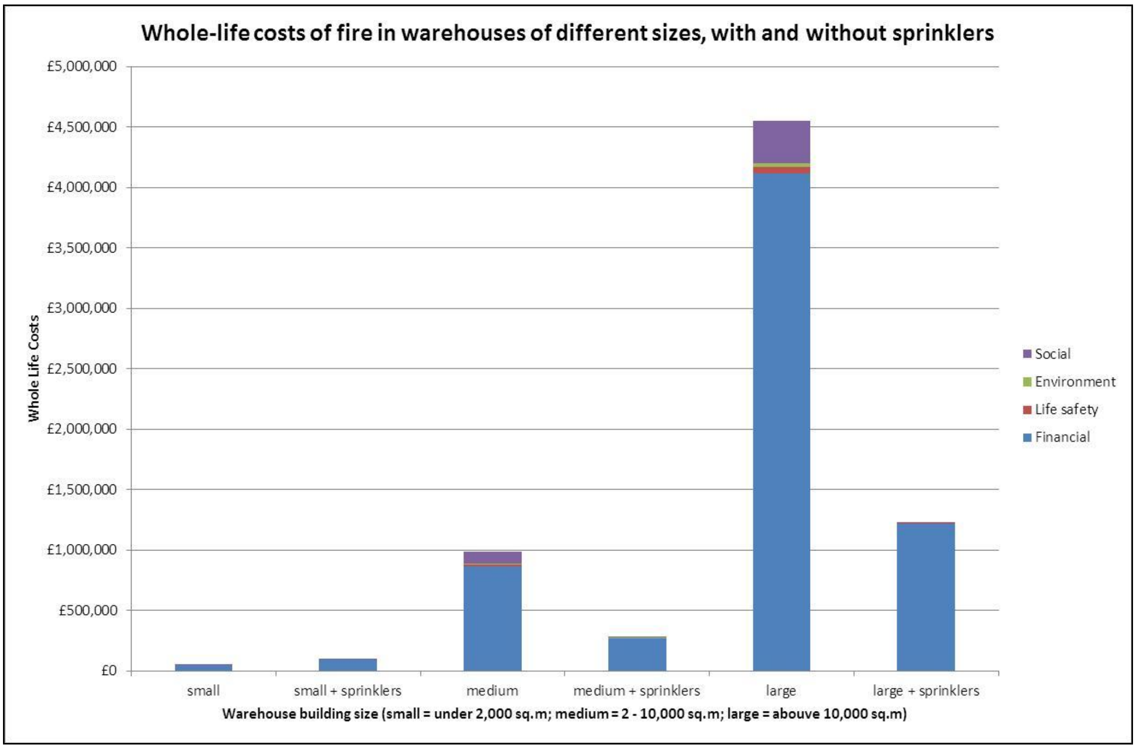

Figure 8 – Whole life costs of fire in warehouses

The components of the whole-life costs of fire are illustrated in Figure 8 and include the following:

- Financial – cost of property damage, cost of insurance (lower if sprinklers present), cost of installing and maintaining sprinklers (if present)
- Life safety – "Willingness-to-Pay" values assigned to deaths and injuries expected to occur
- Environment – the cost of carbon dioxide (CO_2) released during the fire, the cost of CO_2 embodied in replacement of lost contents, the cost of CO_2 embodied in replacement of the building should demolition be necessary, the cost of water used in fire-fighting (including sprinkler actuation where applicable), the cost of CO_2 embodied in the sprinkler system, and the cost of CO_2 released during testing of the sprinklers
- Social – the cost of unemployment following a fire.

The whole-life costs in warehouses are dominated by the "financial" component, with the life safety, "social" and "environmental" components accounting for a small fraction of the total. More details and a breakdown of these components are contained in the published BSA study report [8].

2.4.3 Number of warehouse occupants

There is some evidence of a trend for more people to be present in warehouses of a given area, arising from changing modes of warehouse operations (e.g. to satisfy internet retail businesses). However, research into the costs and benefits of sprinklers in warehouses [8] suggested that, for the entire warehouse sector, there was approximately one employee per 600m^2 of warehouse floor area. In contrast, AD B quotes a floor space factor of 30m^2 per occupant to be used when making provision for means of escape (e.g. numbers of widths of exits). It therefore seems unlikely that, within these limits, there would be an increase in risk due to inadequate provision for means of escape.

There could be an increase in risk with a rise in occupant density, simply due to the chance that “someone will be in the wrong place at the wrong time” increasing in proportion to the number of people present. The number of fires arising from human error might also be expected to rise in proportion to the number of people, all other factors being equal. On the other hand, an increased building population could lead to more fires being discovered at an early stage allowing for more effective intervention before they become a threat. Management standards may also be higher, driven by the need to optimise efficiency of business operations.

2.4.4 Cost benefit analysis for this work stream

There is no robust evidence to suggest that a change to AD B guidance (focussed on life safety) on compartment sizes is required and so it has not been necessary to perform a cost benefit analysis.

2.5 Findings

Members of the industry Steering Group felt that there was a need to include a limitation on compartment size for single-storey buildings in Approved Document B. However, such a limitation would not mean that large compartments could not be constructed, simply that they would not be covered by the simplified guidance within Approved Document B. A designer wishing to go outside the limits would need to carry out a fire engineering design in accordance with British Standards BS 9999 or BS 7974, as appropriate (Task 2.1).

Steering Group members also felt that where compartment sizes greater than the current limitations in Table 12 of AD B are constructed, it is important to realise that the access and facilities for the Fire and Rescue Service may be inadequate. It is recommended that where large compartments are constructed using alternative fire engineering approaches, the Fire and Rescue Service are consulted at as early a stage as possible (Task 2.1).

The guidance to the Building Regulations for England and related guidance for other parts of the UK sets out limits on the maximum dimensions of fire compartments based on the type of occupancy and the height of the building. In common with the periods of fire resistance discussed in relation to Work stream 1, many of the current provisions are based on the recommendations set out in the Post-War Building Studies No. 20 Fire Grading of Buildings. Tables 7a to 7c in that document specify restrictions in relation to both maximum floor areas and maximum cubic capacities dependent on the nature of the construction and the nature of the fire hazard (Task 2.2).

One of the most significant aspects of the current guidance is that there is no limitation on compartment floor area for single-storey industrial buildings. The original recommendations of the Post-War Building Studies proposed a similar solution for single-storey buildings of Construction Type 1, 2 or 3 (protected or partially protected) for low fire load occupancies but did not impose restrictions on cubic capacity in relation to other types of construction or higher fire load hazards (Task 2.2).

Very large industrial buildings have developed in cases where single-storey industrial buildings are not subject to issues around boundary conditions. In such cases, the structural elements only supporting a roof (not used as a means of escape) do not require any specific level of fire resistance and are not subject to any restrictions in terms of compartmentation (Task 2.2).

Although the regulatory guidance does not specify any limitation in maximum compartment size for such buildings, insurance industry requirements do. For single-storey buildings belonging to the industrial group where no limit on compartment floor area is specified in AD B, the property protection requirements limit the maximum compartment floor area to 7,000 m^2 where there is no automatic sprinkler system installed and 14,000 m^2 where an automatic sprinkler system is installed (Task 2.2).

A review of the DCLG fire statistics relating to the area of the fire compartment shows that, for rooms smaller than 500 m^2 floor area, an increase in floor area increases the probability that a fire will spread beyond the room of origin. As the room size increases above this figure, the relationship is reversed and there is an increasing tendency for the fire to remain within the room of fire origin. This is most likely to be a function of Fire and Rescue Service intervention but may be related to the dynamics of fires within very large compartments. It is widely assumed that for fire areas below 500 m^2, a single zone approach is valid with reasonably uniform temperatures within the fire compartment. However, above this value, the assumption of a single zone representing fire behaviour within the compartment may no longer be appropriate (Task 2.3).

There is no statistical evidence for an increase in risk to life safety as compartment sizes increase (Task 2.3).

An international review of requirements related to maximum compartment sizes in single-storey industrial and storage buildings has indicated that the provisions within the guidance to the England and Wales Building Regulations are the least onerous of all the countries investigated (Task 2.4).

The whole-life costs in warehouses are dominated by the “financial” component, with the life safety, “social” and “environmental” components accounting for a small fraction of the total (Task 2.4).

3 Overall conclusions

The aim of this work stream was to produce robust evidence and data to explore the potential to develop a systematic method for determining maximum compartment sizes based principally on life risk, but taking into account other factors such as environmental impact.

The review of statistical data has shown no clear correlation between compartment size and life safety for compartments with floor areas larger than 500 m^2 for large single-storey industrial and storage buildings.

The review of international requirements found no systematic method for determining maximum compartment sizes based principally on life risk.

4 Acknowledgements

The authors, Tom Lennon and Jeremy Fraser-Mitchell, would particularly like to acknowledge the valuable contribution provided by the following:

- Satellite Steering Group A and the overall Project Steering Group.
- BRE Project team members: Neal Butterworth, Arup Fire for the provision of international requirements related to maximum compartment sizes in single-storey industrial and storage buildings and Luke Bisby, University of Edinburgh for review comments.
- BRE colleagues: Corinne Williams and James Lavender.

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Appendix A – Summary of the Research

Building Regulations and Standards Division, Department for Communities and Local Government (DCLG) commissioned BRE to carry out a project titled “Compartment sizes, resistance to fire and fire safety”. The main aim of this project was to produce robust evidence and data based on research, experimental fire testing, computer modelling and laboratory testing, where necessary, on a number of linked work streams in relation to fire safety and associated provisions in Schedule 1 of Part B of the Building Regulations 2010.

This Final work stream report describes the findings of the research for Work stream 2 – Maximum fire compartment sizes. The aim of this work stream was to produce robust evidence and data to explore the potential to develop a systematic method for determining maximum compartment sizes based principally on life risk but taking into account other factors such as environmental impact.

The work conducted under this work stream has considered the background to the current guidance in relation to maximum compartment sizes. A review of existing fire databases has been undertaken primarily to consider the relationship between compartment size and life safety. A review has been undertaken of alternative approaches used to derive maximum compartment sizes to provide an international perspective in relation to regulatory requirements. This work stream has also involved the participation of an industry Steering Group.

Note. The statistical analysis presented in this report has been performed by BRE using raw statistical data supplied by DCLG.

The overall conclusions of this work stream are:

The review of statistical data has shown no clear correlation between compartment size and life safety for compartments with floor areas larger than 500 m^2 for large single-storey industrial and storage buildings.

The review of international requirements found no systematic method for determining maximum compartment sizes based principally on life risk.