FIRE ENGINEERING REPORT

Upgrading the Fire Resistance of Existing Historically Significant Doorsets

A Risk Assessed Approach
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<td>Issue One</td>
<td></td>
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<tr>
<td>12 January 2011</td>
<td>Issue Two</td>
<td>Inclusion of CFD simulation 2</td>
</tr>
<tr>
<td>31 January 2011</td>
<td>Issue Three</td>
<td>Client amendments</td>
</tr>
<tr>
<td>14 March 2011</td>
<td>Issue Four</td>
<td>Client amendments</td>
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EXECUTIVE SUMMARY

The purpose of this report is to provide evidence to support the ‘risk assessed’ approach for the assessment of the need to upgrade the fire resistance of existing historic doorsets to reduce the impact on fabric structure, whilst ensuring safe evacuation and reasonable levels of fire separation within the built heritage.

Trenton Fire have been commissioned by Nick Jordan, (Head of Fire Precautions and Emergency Procedures for the National Trust, to consider the processes involved in determining whether existing doorsets require upgrading, to enhance their inherent fire resisting properties, so as to meet the minimum requirements of designated fire compartment lines. The investigation is based around the demonstration of conditions within a specific compartment when subjected to a “real” fire, and applying those conditions to fire door performance as opposed to demonstration of performance against a prescriptive fire test curve.

The investigations show that:

- There is a link between the time to room flashover, the point of time zero for a standard fire test, and the room geometry/fire load/ventilation.

- By taking these aspects into account, depending on the room size, a delay to flashover is seen which ultimately reduces the time that a door needs to be exposed to standard fire test conditions.

- With a delayed flashover and shorter direct exposure to the standard fire test, a reduced amount of upgrading to the doorset is necessary, whilst maintaining the full compartmentation expectations of the room.
1. INTRODUCTION

1.1 The built environment is a topic that can evoke many reactions as it has the ability to encompass the memory of the past together with visions of the future, as well as providing us with spatial enjoyment of the present. Whether a building stands ruined or remains sound, is iconic or revolutionary from its build, the diversity of our building portfolio will identify with or touch the emotions of us all.

1.2 Neglecting or failing to protect our buildings is therefore something that we as a nation cannot afford to do. Maintaining to the best of our ability those “special” buildings is essential if one is to retain an identity with the past. There are of course, many threats to a built structure, some of which are man-made and others more natural but the following paragraphs will focus purely on the spread of fire from within a property, narrowing to the specific performance of timber based doorsets and their role in preventing further fire damage.

1.3 The aim of this discussion document is to demonstrate that the fire performance of a timber based doorset should be linked to the conditions of a given room/building on fire, rather than to the prescriptive standard fire test. Ultimately this will provide evidence for a reduced level of necessary upgrade to existing doorsets, whilst maintaining comparable levels of fire resistance to that needed under current building regulatory guidance.

2. BUILDING AND FIRE DESIGN

2.1 As an architect receives an instruction from a client to produce a building design (either new build or refurbishing an existing structure), there are many details that must be considered in order for the building design to satisfy the Building Regulations of England and Wales, and the associated codes of practice. Such details would be to ensure that the building is:

- energy efficient,
- uses suitable and complementary build materials for the surroundings,
- is sustainable and can be maintained,
- has suitable access requirements for all perceived users,
- etc.

2.2 The above is not an exhaustive list as one would also need to consider the health and safety of the building occupants from all matters of concerns, not least fire.

2.3 A series of documents have been approved by the Secretary of State which recommend ways in which the fundamental objectives of the Building Regulations may be achieved. The primary fire safety guidance is Approved Document B. Recent months have seen the issue of a second design document that may also be used to satisfy the objectives of the Building Regulations, that being BS 9999-2008 “Code of
practice for fire safety in the design, management and use of buildings”. Both of these
documents are generic in the sense that they apply to “common” building types and
sizes, although BS9999 is more risk specific than ADB. Certain building uses such as
schools, hospitals, prisons etc are covered under other specific guidance’s due to
their particular risks.

2.4 By dividing ADB into sections, which are similarly reflected in BS9999, it discusses the
design constraints for the following:

1. Means of warning and escape
2. Internal fire spread (linings)
3. Internal fire spread (structure)
4. External fire spread
5. Access and facilities for the fire service

2.5 The design limitations outlined within the pages of these referenced documents
encompass the likes of maximum compartment sizes, maximum travel distances and
the minimum periods of fire resistance needed to ensure that the occupants are
suitably protected from the effects of a fire.

3. TIME TEMPERATURE TEST CURVE

3.1 The measurement of how a construction is determined as being fire resisting has long
been established and is based on performance when exposed to the time temperature
curve of ISO 834. The precise test conditions have been written in the current fire

3.2 The curve is considered to be a “standard” curve that is representative of all “normal”
fire conditions. It does not take into account accelerated fire growth caused through
the presence of significant quantities of oils or gases, nor does it account for explosive
mixes. Its growth rate is considered against a freely growing fire produced by standard
cellulosic-based materials that is fed by a suitable amount of oxygen to complete
efficient combustion. It does not consider any smouldering or incipient growth phases
and assumes an exponential fire growth.

3.3 As a “standard” curve associated is used to prove the performance of a passive fire
resisting product for use in all buildings, the test does not account for the effects that a
buildings geometry can have on a fires development. Given this, the test curve rapidly
accelerates to the point of room flashover, which is the point at which all combustible
materials within the space have ignited. For the purposes of calculation against
standard cellulosic material fire loads, this is taken to be when the smoke temperature
within the room reaches between 550 and 600 degrees Celsius. Given this, the
performance of any passive fire resisting product is therefore demonstrated from room
flashover, ignoring the incipient stages of fire growth.
3.4 The standard development of a fire within any space includes growth stages before flashover, which may be long or short, depending on fire loads, compartment geometry and ventilation. Figures 1 and 2 show the standard test curve and a typical fire growth curve.

**Figure 1: Standard Fire Test Growth Curve**

**Figure 2: Fire Growth Period**
3.5 Figure 2 indicates the time of flashover during the development of a compartment fire. To the left of the flashover line is the period of fire ignition and the time known as the incipient stage of fire growth which can be long or short depending on the exact conditions of the room. To the right of the line is the period represented by the ISO curve (albeit not considering decay).

3.6 When occupied, during the incipient stage, the products of combustion (heat and smoke) are likely to have been noticed\(^1\) and the fire alert activated. Consequently, “action” will be occurring in terms of occupant evacuation and either first aid fire fighting (if under a managed procedure with trained marshals) or the alerting of the fire service. The point being made here is that an instant flashover fire is not possible as buildings would be inherently unsafe and that the evacuation time occurs within the incipient growth phase which is essentially within the predefined time period of fire resistance for a passive fire protection product.

3.7 The period that a fire stays within this growth phase is wholly dependant on a number of factors:

i. The nature of the fire load and its ease of combustion.
ii. The density of the fire load and the ease at which it fire may spread.
iii. The amount of ventilation available to provide oxygen to the fire.
iv. The height of the ceilings and overall size of the rooms.

3.8 All of the above could significantly delay the on-set of flashover and the involvement of the entire room in the fire event.

4. EXISTING BUILDINGS

4.1 Within an existing building, the compartmentation lines may be drawn on plan and be suitably located to take account of risk within the property. However, the passive fire resisting elements within those compartment lines are unlikely to have been suitably constructed to resist the modern fire resistance time-temperature curve. Whilst it is feasible to assess many constructions and recommend upgrading methods such that the resultant product\(^2\) achieves the desired fire resistance under the current test standard regime, the upgrades can be costly, time consuming and potentially damaging in terms of effecting the products main fabric. Similarly, where doorsets are concerned and the upgrades are not feasible, replicas would need to be constructed with the originals put into storage; which itself carries a significant damage risk that would not be considered desirable or appropriate.

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\(^1\) This will certainly be the case where AFD has been appropriately installed.
\(^2\) Doors, floors, walls, ceilings.
4.2 Based on the discussion in section 3, is it not therefore appropriate to assess the potential for a room to reach flashover and then to assess the passive products performance for the time difference between the calculated flashover and the end of the desired integrity duration? For example, if one requires a 30 minute compartmentation line and the room will not support a flashover condition for 20 minutes, the door should be assessed for only 10 minutes against BS 476: Part 22: 1987. Heat build up before this period will dehydrate a timber door and cause a degree of leaf movement, but there will be no undermining of materials or fierce burning of the timber.

4.3 This analysis would not remove the need for a degree of fire resistance, and would almost always require the need to reduce door edge gaps, make good significant damage, infill holes etc but would significantly reduce the extent of upgrades. The result of this is that:

i. Panels may not need to be upgraded by the use of applied intumescent sheets and veneers, or by removing them from the leaf to insert central boards and other materials. Both processes of which will affect the size of the existing mouldings as the panel thickness increases.

ii. Glass that is slowly heated has the potential not to crack, as the internal thermal gradient within the glass is not as steep as if subjected to instant intense heat of a fire test.

iii. Perimeter intumescent seals are unlikely to be needed as they do not react within a fire test for approximately 8 minutes, as the heat from a fire needs to travel through the door edge gap, heat and melt the plastic coating containing the seals and then drive off the water content of the seals. Therefore, a 10 minute performing doorset to BS 476: Part 22 is unlikely to need perimeter seals.

4.4 The above is not an exhausted list but all of the above does demonstrate how the advantages of using a “real” fire development linked to the conditions of the associated building can be used to limit the need for upgrading delicate historic items such as doors. It is not removing the need for having a doorset to be expertly surveyed or for that design to be left unattended, but to limit the need for significant alteration as recommended by an experienced fire engineer.

5. EVIDENCE OF PERFORMANCE

5.1 To demonstrate delays to the onset of flashover, the following paragraphs summarise a test that was conducted in 1967 together with additional CFD information.

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3 The ability to calculate this will be discussed later in this report.
5.2 No. 12 Chatham Row, Bath

Test Summary

5.2.1 Bath City Council carried out this test in 1967\(^4\) and it involved the burning of a single front room in an existing end terrace Georgian\(^5\) property. The primary objective was to demonstrate the inherent fire resisting properties of a traditional lath and plaster ceiling with timber joists and floor boarding. Secondary objectives consist of proving that a domestic fire is not as severe as those conditions experienced under the time/temperature curve of BS 476.

5.2.2 The building itself had a footprint of 27’ x 18’ (8.5m x 5.5m), the test room measuring 12.5’ x 13’ (3.8m x 4m) with a 9’ (2.75m) high ceiling. Wall panelling was present on all walls, which was 3’ (1m) high. No furniture was present as it was determined at the time that it was more appropriate to use a fire load manufactured from timber cribs that provided an overall fire load density of 6lbs/ft\(^2\) (29kg/m\(^2\)). Four timber cribs were used and separated with an ignition pyre in the middle; this was to enable convective and radiant heat transfer to the adjacent fire loads.

5.2.3 Ventilation was provided by virtue of the windows breaking at 25 minutes into the test. The sizes of the windows have not been specified but it is envisaged that the sash type windows mentioned in the report would have been nominally 0.75m\(^2\).

Various thermocouples were located around the fire cell to monitor the temperatures at given periods of time. Whilst no graph is indicated within the report that pictorially shows the temperature curve of the fire cell, observations were made and recorded. This information tells us that the initially growing fire began to reduce in size at about 20 minutes, which would indicate that the available ventilation was insufficient to complete combustion. At this time the ventilation increased as the windows broke and consequently revived the fire.

A sudden increase in temperature was noted at 30 minutes, which would indicate a flashover condition. A peak temperature (1000\(^\circ\)C) was observed at 42 minutes when additional air was supplied by the breaking of a window.

Test Fire Load Verification

5.2.6 The fire loading of this test has been verified as being appropriate by the calculations shown in appendix A, and would have resulted in a maximum 3MW fire. To place this into context, a typical large armchair is considered to result in a maximum 1MW fire.

\(^4\) The age of this test is largely irrelevant as it shows a typical fire scene carried out against a non-specific test standard. Therefore, if deemed by this report as showing suitable data, the evidence is considered to be valid.  
\(^5\) Constructed in 1760.
5.2.7 Whilst the recordings of this test are a little vague, we are nevertheless able to see that flashover did not occur for a long period of time, within a small room that ultimately had enough ventilation to support combustion. It can also be seen that at a point in time the fire became ventilation controlled as there was not enough oxygen to continue the fire growth, until a window broke and supplied fresh air and oxygen to the fire. Taking a worst-case look at this test situation, had ventilation been freely available for the entire burn period, the onset of flashover would have been far sooner than the 30 minutes observed (see BRE test evidence below).

5.3 BRE Front Room Fire & Other Tests
5.3.1 The Building Research Establishment have conducted fire tests whereby a typical front room was arranged and set alight. The fire loads comprised of an armchair, tables, television, video player and other associated items. From ignition (a tea-light candle against the television set) to full involvement of the room, the time elapsed was 18 minutes. Significant ventilation was available to the fire in this test by virtue of one wall not being constructed for observation purposes.

5.3.2 This data was generated to update an existing test on a comparable situation. The variation was that the furniture used in test 2 comprised of the fire retardant type as opposed to the non-fire rated furniture, which is now no longer available in the UK. Flashover within the first test occurred at 3 minutes.

5.3.3 Over the years, differing authorities have commissioned many room fire tests with varying conditions. A brief literature review only found suitable and relevant additional supplementary data from NIST\(^6\) whereby a fire within a visually “small” room (similar to the BRE tests) was carried out using non-fire rated furniture\(^7\). In this case, flashover occurred at nominally 6 minutes.

5.3.4 This data supports the original BRE test using non-rated furniture whereby the onset of flashover in a small room occurred comparatively quickly.

5.4 CFD Demonstration
Simulation 1
5.4.1 As an indicative demonstration of a large room fire, Trenton have completed a short exercise using Computational Fluid Dynamics (CFD) using FDS which is partly validated on real fire tests run by NIST. The room modelled was simple in that it was a rectangle that measured 20m x 10m x 3.5m. Appropriate ventilation was modelled (5m\(^2\) free area) to ensure that flashover conditions were optimised, giving the fire suitable oxygen to grow.

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\(^6\) NIST – National Institute of Science and Technology. A non-regulatory federal agency in the USA.
\(^7\) This information has been gained via an Internet search taking summarised descriptions only.
5.4.2 The walls of the room were modelled as having been timber clad with all other surfaces being plastered.

5.4.3 The fire followed a medium fire growth curve to a maximum of 5MW as this was considered to be an appropriately sized fire, as it would represent ignition of two or three settees. The single seat of fire was positioned within the room, offset against the buildings length so as to represent furniture close to walls as opposed to directly in the middle of the open space. See figure 1 below:

*Figure 1: CFD model and fire location*

5.4.4 Nodes were positioned within the fire cell so as to monitor the temperature increases throughout the space. The graph below indicates the temperatures recorded to the closest wall (4m away) and the walls furthest away from the fire (16m away).

*Figure 2: Simulation 1 CFD room temperatures*
5.4.5 As can be seen from the graph above, the maximum temperatures observed were below flashover on the walls far away in the room where the maximum temperatures were shown to be approximately 475 degrees Celsius after 2000 seconds (33 minutes). Localised flashover temperatures do occur closer to the fire before this time, which would of course increase the fire size and so promote flashover to the locations far away sooner than observed. However, suitable temperatures close to the fire were not reached until 1275s (21 minutes). As mentioned before, with limited ventilation, it can be argued that the correct flashover conditions will not be reached as the growing fire reduces the oxygen content of the room, which could lead to fire decay (and back-draft conditions).

5.4.6 The above data is of course indicative only, but it does demonstrate the potential for a significant delay in the time to flashover.

**Simulation 2**

5.4.7 A second CFD program was run to assess the conditions within a room of different geometry to that used previously, from exposure to a similar fire as used in simulation 1.

5.4.8 The room measured 10m x 5m x 5m and was provided with suitable levels of open windows to ensure that the fire was not ventilation controlled. The time temperature graph produced is shown below in figure 3:

*Figure 3: Simulation 2 CFD room temperatures*
5.4.9 The graph indicates that by 10 minutes, the room temperatures were approximately 400 degrees Celsius rising to between 500 and 530 degrees at 30 minutes. This indicates that the room is hotter than the larger space previously modelled which would be expected given that the volume of air within the enclosure is only 35% of that within the first test simulation. Notwithstanding this, it is also clear that the temperatures observed are far lower than at a comparable time within a typical test, which are nominally 650 and 840 degrees Celsius at 10 and 30 minutes respectively.

6. THE WAY FORWARD

6.1 There is a clear link between room size, ventilation and fire load which will determine the onset of flashover. However, the above information directly demonstrates that in a “small” room, comparable in size to that of a living room of a “standard” dwelling house, flashover is likely within the first 5 minutes of ignition if using traditionally constructed furniture. However, if that same room has been furnished with “modern” furniture then flashover will be significantly delayed, perhaps up to 15 – 18 minutes after the initial ignition. These times have been determined whereby the ventilation needed for full fire development is available.

6.2 The “real” fire test of Chatham Row used a solid timber based fire load which did not have the high fire growth rate of foam filled furniture however, its advantage was that it would be considered more “realistic” than even the BRE room tests, as ventilation was more akin to the everyday condition.

6.3 For the purposes of this report it is therefore clear that within “small” rooms, flashover will occur and this is likely within the first five minutes after ignition unless it can be shown that the furniture is “modern” and fire retardant. What constitutes a small room is open to debate and would need to be investigated further; however, a suggestion would be all rooms that are smaller than 32m² in floor area (this is twice that of the Chatham Row building).

6.4 Where modern furniture is fitted, then the evidence would support the premise that flashover, even with good ventilation would not occur for up to 15 minutes. In this case any size room above 8m x 4m x 2.75m (twice the dimensions of Chatham Row) could potentially have their associated doors performance reduced by 15 minutes, depending on a fire load analysis.

6.5 Where rooms are considered large, and furnished with traditionally constructed furniture a fire will develop quickly but will have the benefit of well-separated furniture, which will delay radiant heat spread. With suitable ventilation, the CFD model supports the premise that flashover will not occur for 20 minutes and so any associated doorset may potentially have its integrity performance reduced by a commensurate amount. Again this would be linked to a fire load analysis.

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8 Use of natural fibres and horse hair fillings.
6.6 The benefits of a large room enclosure (height) is considered within BS 9999 whereby additional travel distances/times are allowed for through high ceilings. The thrust behind this argument is that a higher ceiling will act as a larger smoke reservoir thereby keeping the escape routes tenable for longer. One of the tenable condition criteria detailed in BS 7974-6 is as having a smoke temperature of less than 200 degrees Celsius. It therefore follows that if there is a delay in reaching 200 degrees Celsius by virtue of a high ceiling, there would also be a delay in reaching 600 degrees Celsius (flashover temperature), thereby suggesting that the larger the room, the slower the onset of flashover, if all things remain equal. This subsequently supports the discussion of the previous paragraphs.

6.7 In addition to the above, where “modern” fire-rated furniture is used in a large room, one can suggest that flashover will not occur within a 30 minute period given the evidence produced. However, for the purposes of safety and given the level of research undertaken at this time, it is suggested that doors should only have their performance reduced by a maximum of 20 minutes in these cases.

6.8 Further research could be commissioned that may produce a matrix detailing the effects of ventilation, fire loads and room geometry; from where an estimation of flashover delay can be estimated.

Non-Rated Fire Doors

6.9 Specific physical test data on the development of a fire within an enclosed space is limited and time for a significant literature review is not within the scope of this project. However, post fire observations from ex-fire service personnel indicate that a suitably fitted closed doorset will, in many cases prevent significant fire spread up to the point of fire service intervention, which can be up to 20 minutes from the initial fire alert. If it is assumed that doors in these cases are about to fail on fire service arrival, the indication here is that if a non-rated doorset prevents fire spread when closed, the conditions within the fire enclosure are unlikely to have reached flashover or have met the same temperature and pressure conditions of a fire test for at least 10 minutes. This is a reasonable assumption, as it is known that a door not specifically designed as a fire resisting construction will achieve nominally 10 minutes integrity under test conditions.

6.10 With this information, where only 10 minutes integrity performance (beyond the delay to flashover) is needed, it can be suggested that the doorsets require only to be fitting well within the timber frames with all damaged areas having been appropriately made good.

6.11 The performance of details such as panels can be taken from the door fire test data produced by the historic agencies of England and Scotland to determine if they require upgrading in any way. Typically, if they are visually secure and are a minimum of 10mm thick, experience dictates that 10 minutes integrity performance would be
considered appropriate. Raised and fielded panels are more robust than flat panels if the centre section is raised to meet the thickness of the stiles and rails and the fielded section is less than 75mm down to a minimum of 10mm. This is because the hottest part of a panel is the centre, as the shadowing from the stiles and rails generally protects the edges. Panel performance will therefore be largely dictated by thickness and the condition of the beading/fixity within the leaf framing, all of which would be determined by a door survey.

6.12 Apertures glazed with non-rated glass will typically retain integrity if heated slowly, due to not having an excessive thermal gradient through their thickness. With a room fire, if determined as not being suitable to support flashover conditions, the air temperature will be rising at a rate slow enough to ensure that steep thermal gradients are unlikely. Given this, non-rated glass is likely to remain appropriate for the time assessed to flashover plus 5 minutes which is the general breakage time for non rated glass during fire test. The robustness of these existing details will need to be assessed during the required door survey.

6.13 Lugged doorsets lack test history and so the performance of these types of designs can only be linked to that of the delay to flashover observed. Upgrading methods are limited even for 20 minutes performance. Careful consideration should be made when assessing the inherent and upgraded performance of these door types.

7. RECOMMENDATIONS

7.1 Although it is advised that further research is given to this topic with more modelling of differing situations (ventilation, room size, fire loads etc) so as to provide comfort in results, the details in the following paragraphs would be considered as the proposed suppositions that may be proven.

- Small rooms (less than 50m$^2$ in floor area) will experience flashover quickly (if given suitable ventilation) and so no reduction in integrity performance of the associated fire doors should be made. If the furniture associated with rooms of this size can be determined as being “modern” and fire rated (soft furnishings) then flashover is likely to be delayed for 15 minutes and consequently the associated doors may have their performance reduced by 15 minutes – depending on other room fire loads.

- Medium rooms (50m$^2$ to 160m$^2$) would show a delay in the onset of flashover regardless of the furnishing type used and the evidence obtained would suggest that a delay of 10 minutes would be reasonable.

- Large rooms (above 160m$^2$) are likely to experience a further delay in flashover regardless of the furniture type, and so a greater reduction in the associated doorsets performance may potentially be given, up to 20 minutes.
7.2 The limitations of the above bullet points would be that the ceiling heights are no lower than 2.75m and that the fire load is considered “reasonable” for the room. Although “reasonable” is a fairly loose term, the application of a given weight per square meter would be equally difficult to police. Consequently, the term “reasonable” would have to be judged by an experienced fire engineer who should be engaged in any such determination in reduced fire performance.

7.3 Room fire detection should be provided to ensure that any alert is given at the earliest possible time and in all cases, it would be expected that not only the doorset is justified for the correct exposure to a BS 476 curve but also that the door leaf and frame condition are such that there is a good fit with adequate self-closing.

7.4 A professional fire engineer should be used to determine what is considered “reasonable” fire loads within a space, and then apply the findings of this report to reconsider actual fire growth against the room dimensions and ventilation. A determination can then be made as to any delay in fire performance of the relevant doorsets. Suitable door upgrades can then be obtained from relevant professionals based on the expected flashover conditions.

7.5 It would be envisaged that further research is likely to not only confirm the above, but may also be used to prepare a matrix that would relate the onset of flashover to ventilation, room size and fire loads. From this point, a reduction in performance of a standard fire door may be given.

8. AUTHORISATION

Quality Statement

All reasonable skill and care have been taken in the preparation of this report.

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9 To be determined by an expert in fire testing comparable constructions.
APPENDIX A

Maximum Heat Release for 12 Chatham Row

Pine has an average density of nominally 510kg/m$^3$ (taken from TRADA red book 6) and so at 29kg/m$^2$ of timber fire load, this equates to a timber section of 1m x 1m x 0.0625m. With a burn rate of 20mm per 30 minutes (taken from Eurocode 5), a timber of this size will burn through in 9.375 minutes (562 seconds).

Using the following equation we may determine the mass-burning rate:

$$ m_f = 0.02 \sqrt{A_r \left(\frac{w_c}{d_c}\right)A_w h^2} $$

where

- $m_f$ = rate of burning by mass (kg/s)
- $A_r$ = $A_t - A_w$ where $A_t$ is the total surface area of the enclosure (m$^2$) – 72m$^2$
- $w_c$ = the width of the wall containing the opening (m) – 4m
- $d_c$ = the distance front-to-back of the enclosure (m) – 3.8m
- $A_w$ = the area of the ventilation (m$^2$) – 0.75m$^2$ (assumed to be as tested)
- $h$ = the height of the ventilation openings – 1m (assumed to be as tested)

$$ m_f = 0.02 \sqrt{72 \left(\frac{4}{3.8}\right)0.75 \times 1^2} $$

$m_f = 0.151$kg/s

The above value can then be used to calculate the maximum heat release from timber burning at the rate calculated over the floor area of the room specified. The following equation is used:

$$ Q = m_{fuel}H_c $$

where

- $Q$ = rate of heat release (kW)
- $m_{fuel}$ = mass burning rate (kg/s) – 0.151kg/s
- $H_c$ = effective calorific value of fuel (Kj/kg) – 20,000KJ/kg (from BS7974-1)

$$ Q = 0.151 \times 20000 $$

- $Q = 3020$kW = 3MW