English Heritage

Fire Testing to Show the Effect of Room Size on Fire Growth

Introduction

English Heritage undertook a series of fire tests in 2013 to assess the effect of room size on fire growth [1*] and to confirm the findings of earlier computer modelling. The reason for the fire modelling and subsequent fire testing was to find a way to avoid the alteration of historic doors, particularly in large rooms, to protect against the unrealistic conditions found in the furnaces used for standard fire testing. The results of the tests have given us a fire risk assessment tool so that historic doors can be individually assessed for their effectiveness in resisting the passage of fire and smoke. Thanks go to the National Trust and the Institution of Fire Engineers Special Interest Group for Heritage Buildings who were instrumental in the work leading up to the fire tests and subsequent reviews.

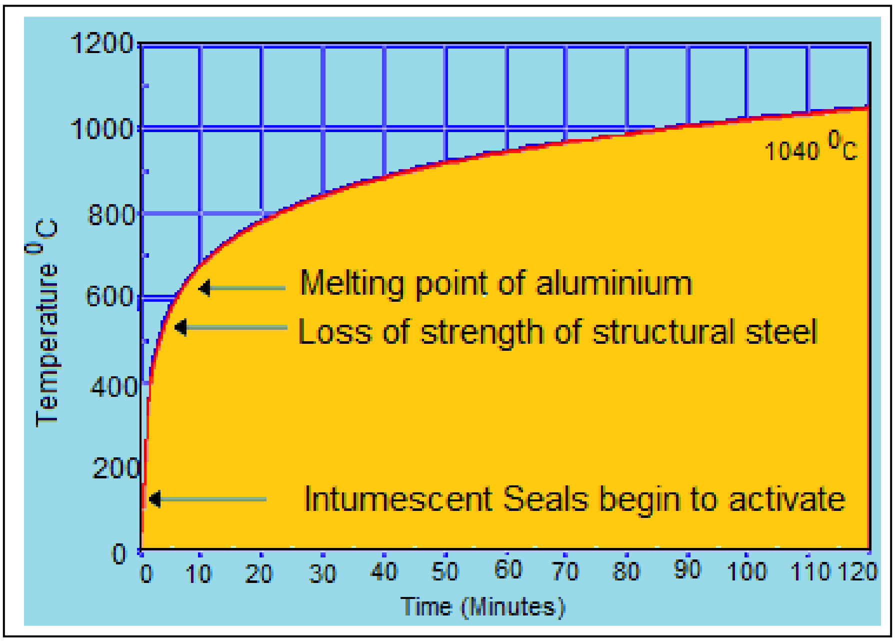
Background

Fire testing of doors

A series of fire tests on historic timber panelled doors in the 1990s showed how they could be upgraded to give 30 minutes fire resistance, to comply with the prescriptive 1971 Fire Precautions Act. This led to the writing of the English Heritage publication “Timber Panelled Doors and Fire” [2*] The upgraded doors in this publication were tested in a furnace in accordance with BS 476- 20 and 22 (BSI, 1987), standards that enable fire door manufacturers to compare their wares fairly.

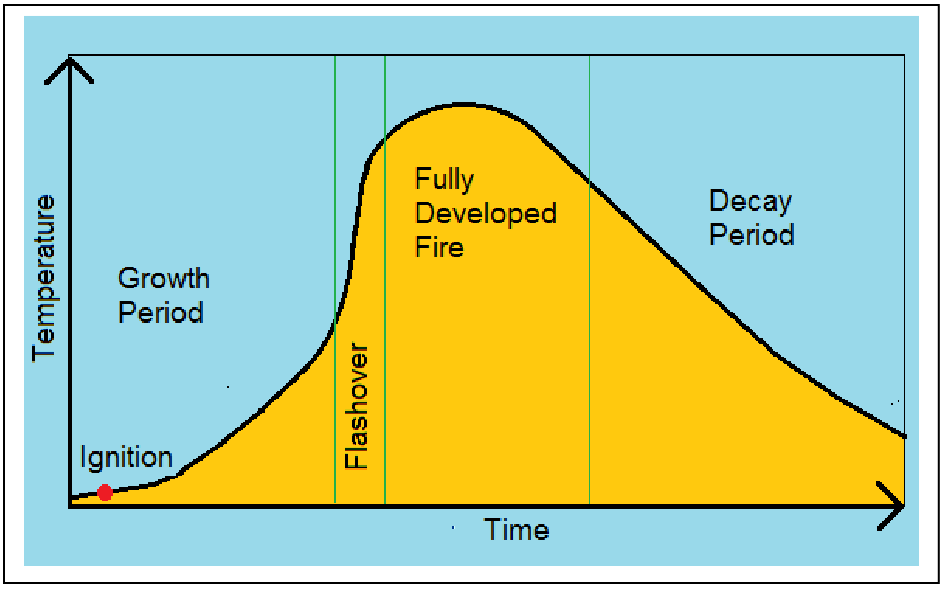
This standard has its origins in the American Society for Testing and Materials. The very first time temperature curve was based on wood burning furnaces, but was altered later to give a faster temperature rise in the first ten minutes (thought to be due to the invention of gas burner furnaces). This slightly doctored fire curve became the standard time temperature curve in ASTM E119 in 1918, and the fire testing time–temperature regime has not significantly changed since (ASTM, 1995). It is evident that the standard time temperature curve was not established on knowledge of the intensity of building fires.

British Standard Time Temperature Curve



The British Standard Time Temperature Curve differs from a real fire in that the temperature rises more rapidly from the start of a fire and does not fall when the fuel is consumed or when the fire is starved of oxygen. The diagram below shows a more realistic curve.

Typical Time Temperature Curve in Real Fire



The growth period may be different than shown as it is dependent on the materials first ignited, their proximity to other combustibles, the type of wall finish and size of room.

Change to a Risk Based Approach to Fire Safety

In 2006 the risk assessment based Fire Safety Order replaced all previous fire related legislation. The opportunity arose to challenge a Fire and Rescue Service that had served an Enforcement Notice on a Grade 1 listed hotel requiring that the bedroom doors must be upgraded. An appeal was made to the Secretary of State for Fire *3 on the grounds that;

- The hotel had a Fire Certificate under the Fire Precautions act 1971, issued by the fire authority certifying that it was safe.
- The corridors had fire doors across them every 4 bedrooms, thus limiting the travel distance to a place of safety and most importantly
- The bedrooms were double the size of bedrooms in other hotels, so any fire occurring there would be slow growing and the doors would not be subjected to heat initially, so would not burn through allowing the residents of the other three bedrooms to escape.

The appeal was rejected, and the doors had to be upgraded, which led to a meeting with the Department of Communities and Local government and the Chief Fire Officers Association's Enforcement lead. An agreement was reached that if the science behind the theory that room size could slow the growth of fire then it would be acceptable to the Chief Fire Officers Association (CFOA). It has long been recognised that the dimensions of the room and the fire loading have an effect on the rate of fire growth, but there had not been any fire tests to show it.

Fire Modelling Prior to Fire Testing

Because of the rejection of the appeal and the position of CFOA, the National Trust commissioned a fire engineering report from Trenton Fire Engineers * 4 to model the time temperature curve in a real fire. The Trenton report showed that there would be a delay before flashover conditions in large rooms. This delay could therefore be added to the time it would take for the door to burn through to give a total time that it would provide fire protection. The time taken for the door to burn through can be measured using the charring rate of the wood and the thickness of the door at its thinnest part (normally the fielded part of the panels). The Trenton report suggested that large rooms over $32M^2$ may see a slower growth rate than smaller rooms. *See Appendix 1 Trenton Report*

These limitations were discussed with Leeds University School of Fire Engineering and Simon Vickers an MSc student undertook his dissertation [*5] by looking at the dimensions of 25 rooms and their fire loads in 5 English Heritage London properties. He then modelled the expected fire growth in a selection of these rooms*. See appendix 2 Simon Vickers Dissertation.*

The following year another MSc student, Andy Foolkes looked at Simon Vickers work and was writing his dissertation based on the EH fire testing to confirm his fire modelling. The Institution of Fire Engineers Special Interest Group for Heritage Buildings and Leeds University helped to design the fire test regime.

Fire Testing to Show the Effect of Room Size on Fire Growth

Choice of Testing Facilities

Three fire testing houses were approached to undertake the fire testing; International Fire Consultants, the Fire Protection Association and the Building Research Establishment (BRE). The Fire Protection Association decided not to tender because they felt that the results of the tests would not be in the best interests of their members. International fire Consultants could only get a large enough test house in Turkey, so the BRE were chosen to conduct the tests.

Testing Criteria

Size of Room

Three different sized rooms with classical double cube proportions were chosen. The the sizes to be tested were

3M x 6M x 3M high,

4M x 8M x 4M high and

5M x 10M x 5M high

Ventilation

Six tests were conducted, each room size being tested twice, once fully ventilated with two doors on one side of the being held in the open position, the other test with the doors closed. The reason doors were chosen for ventilation purposes rather than windows was that glazing may not fail if the temperature rises slowly and this could lead to different testing regimes between room sizes. Glass fails when heated rapidly by hot smoke and gases and the internal face expands faster than the cooler outside face creating fractures. When the hot smoke and gases leave the broken window they prevent fresh air being drawn in to supply oxygen to the fire, so it is not fully ventilated. The open doors allow hot smoke and gases to leave at the top and fresh air to enter lower down.

Fire Load

The fire loading was provided by wooden cribs, each designed to give a 1MW fire, which is about the size of fire produced by a large upholstered armchair. This size of fire has been shown to produce flashover in a room size of 3M x 3m x 3M high.

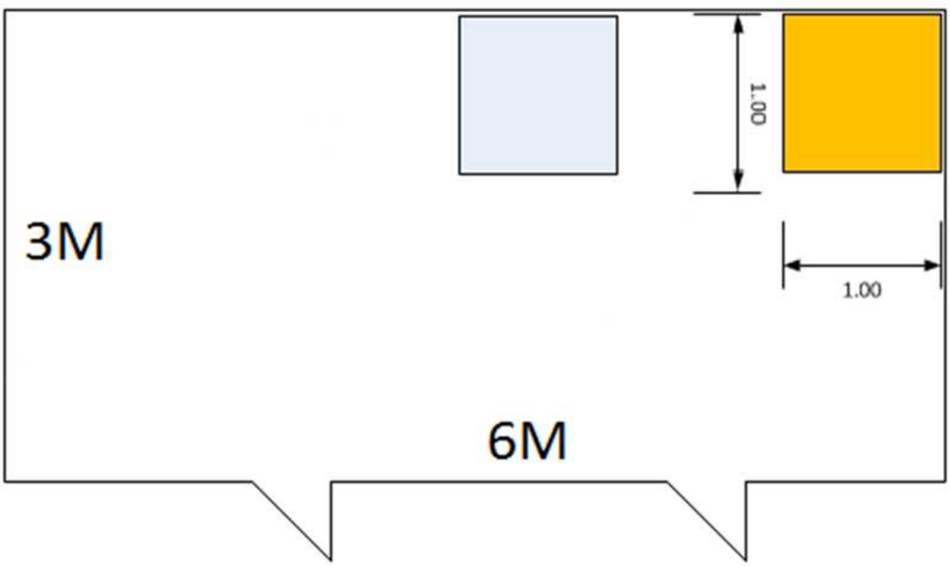
Flashover or “Full Room Involvement” is when all the combustibles in a room have ignited. It usually occurs due to convection currents creating a heat layer at ceiling level which radiates heat down onto all the combustibles in the room. These combustibles give off flammable vapours that mix with the hot smoke and gases at ceiling level and when there are enough gases in the smoke, it ignites and the sudden increase in temperature causes all the combustibles in the room, including floor coverings to ignite. Flashover is caused by a very specific set of conditions; size of room, sufficient ventilation and sufficient fire load.

The number of cribs provided was proportional to the size of room and equates to the average of the fire load surveys undertaken by Simon Vickers. The crib of origin in every test was positioned in the corner of the room, with a single crib in the 3M double cube, two cribs side by side in the 4M double cube and three cribs side by side in the 5M double cube, with additional target cubes at 1M distance. After the first test the target cribs were draped with cotton sheets to encourage fire spread.

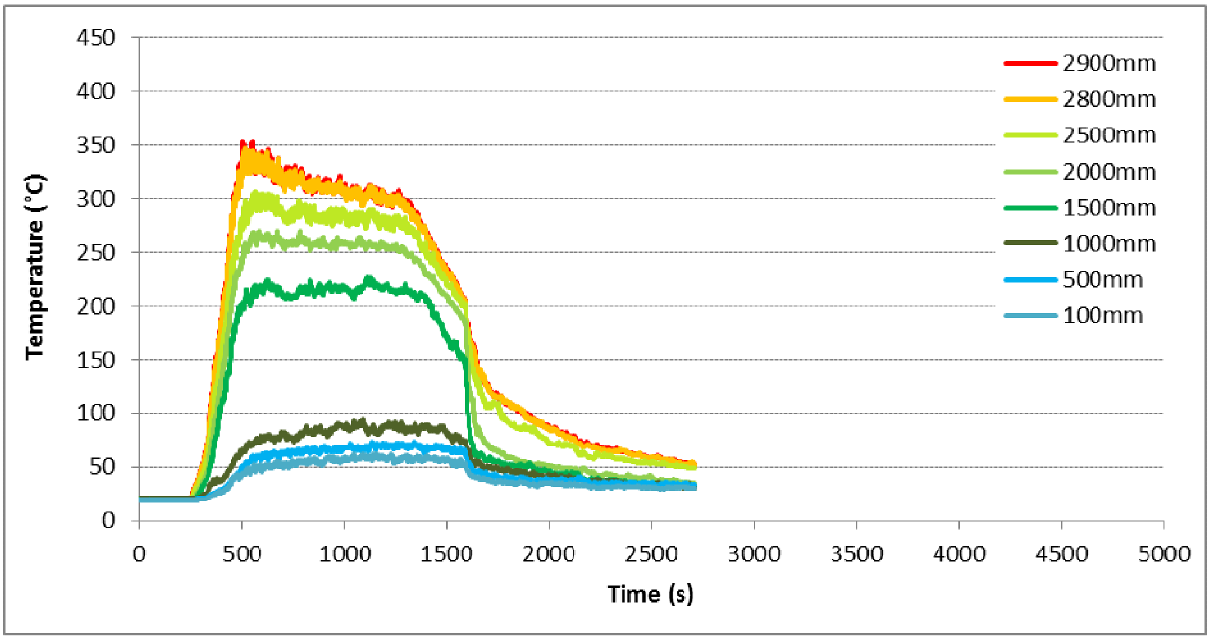
Test 1: 3M x 6M x 3M high, Fully Ventilated

The first test had two cribs; the crib to be ignited was placed in the corner of the room so that it did not lose heat from air being entrained in the rising hot smoke. Ignition was achieved by soaking felt strips in white spirit and inserting them at low level in the crib and then igniting them with a blowtorch. The second crib (target crib) was placed 1 metre away against the wall. This gave a fire loading of 2MW or $0.1MW/M^2$ (2MW Divided by $18M^2$). Both doors were in the open position to give full ventilation.

Position of Cribs in tests 1 and 2



The Time Temperature Curve for 3M Ventilated Test



The different colours show the temperatures at different heights from the floor, so there is clearly a temperature gradient. The difference between the peak temperature of 352^0C at ceiling height and the temperature of 242^0C at the top of the 2M high door being about 110^0C. The temperature climbed very quickly because the cribs have plenty of air around the individual timbers and they are stacked to allow flames from the wicks to ignite all the timbers simultaneously.

Start of test when the wicks ignite all of the timbers

The greatest heat release occurred at 516 seconds when the optimum amount of fuel was burning. The temperature began to fall slightly as the fuel was consumed and more sharply as the fuel became totally consumed. This fire was fuel load controlled and did not spread to the target crib because there was not enough heat radiated down from the hot smoke layer and there was not enough heat radiated from the ignited crib to ignite it. The test was terminated at 2700 seconds (45 minutes) because all the fuel had been consumed.

Target Crib after fire test

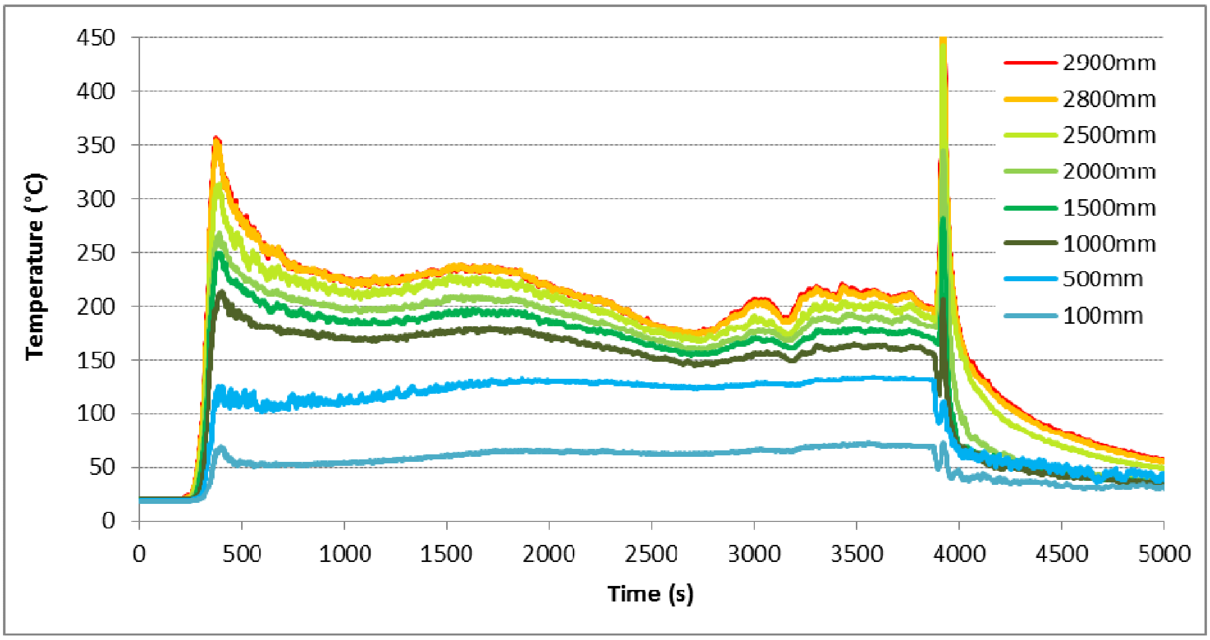
The target crib was not touched by the fire, so even if there were another 4 cribs spaced 1M apart giving a fire loading of 0.33MW/M^2 they would not have ignited.

Test 2: 3M x 6M x 3M high Unventilated

This test was identical to the first one except that both doors were closed so that there was no ventilation, except that through the gaps under the doors. The rise in temperature was slightly faster than in test 1 peaking at 354^{0}C at ceiling height in 384 seconds, but then quickly falling below 250^{0}C as the oxygen was consumed. The temperature remained under 250^{0}C until the doors were opened at 3922 seconds (65 minutes) allowing oxygen to reach the subdued fire which ignited the surface of the plasterboard and unburnt gases in the smoke momentarily peaking at 598^{0}C.

The difference between the peak ceiling height temperature of 354^{0}C and 265^{0}C at the top of the door at 2M was 89^{0}C.

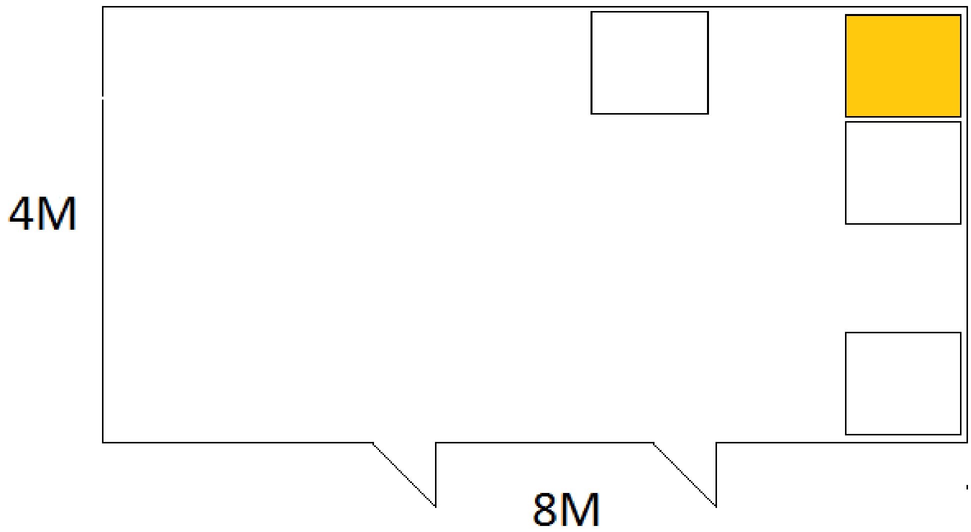
The Time Temperature Curve for 3M Unventilated Test

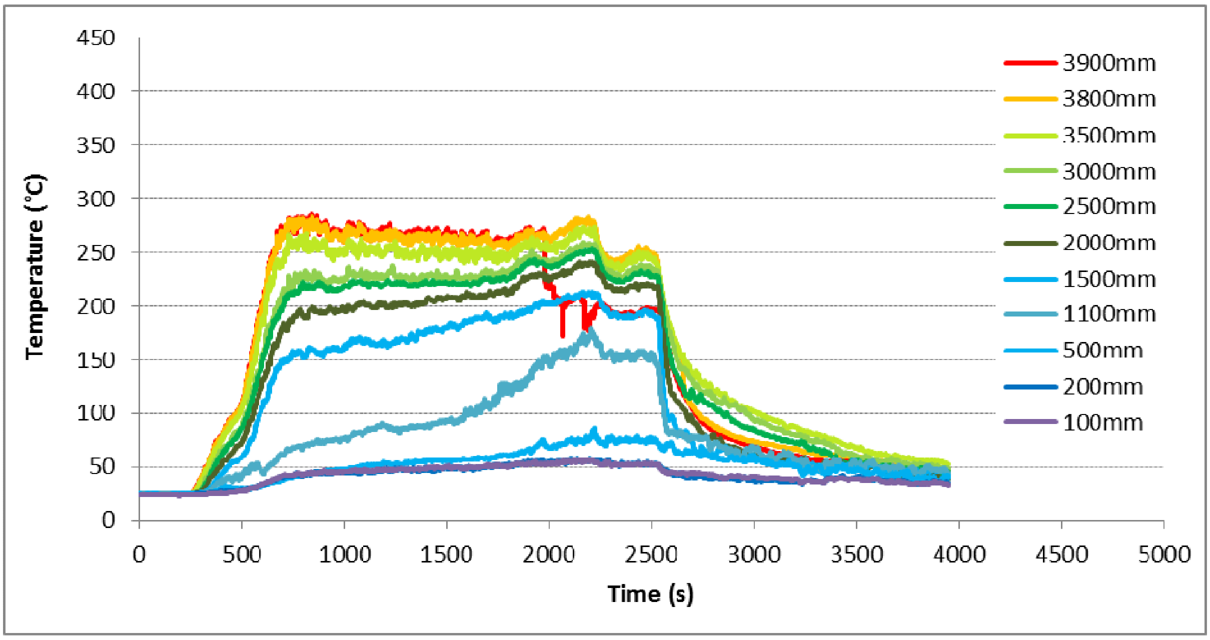


Test 3 : 4M x 8M x 4M high Ventilated

There were four cribs in this test with one crib immediately adjacent to the corner crib that was being ignited. Because the target crib did not ignite in the previous two tests it was decided to put cotton sheets over the target cribs to encourage fire spread. The total fire loading was 4MW or 0.125MW/M^2

Layout of Tests 3&4





The temperature peaked at about 280^{0}C in a slightly slower time than in the 3M tests and the top of the door had a peak temperature of 222^{0}C, a difference of 58^{0}C. The target crib was placed so that it was almost touching the ignited crib.

Target Cribs with sheets to encourage fire spread

The crib immediately next to the ignited corner crib did not become fully involved in fire, although the cotton sheet was burnt. The other two target cribs were untouched.

It would therefore be possible to have a further 8 cribs spaced 1M apart without fire spreading to them giving a fire load of 0.3 MW/M^2

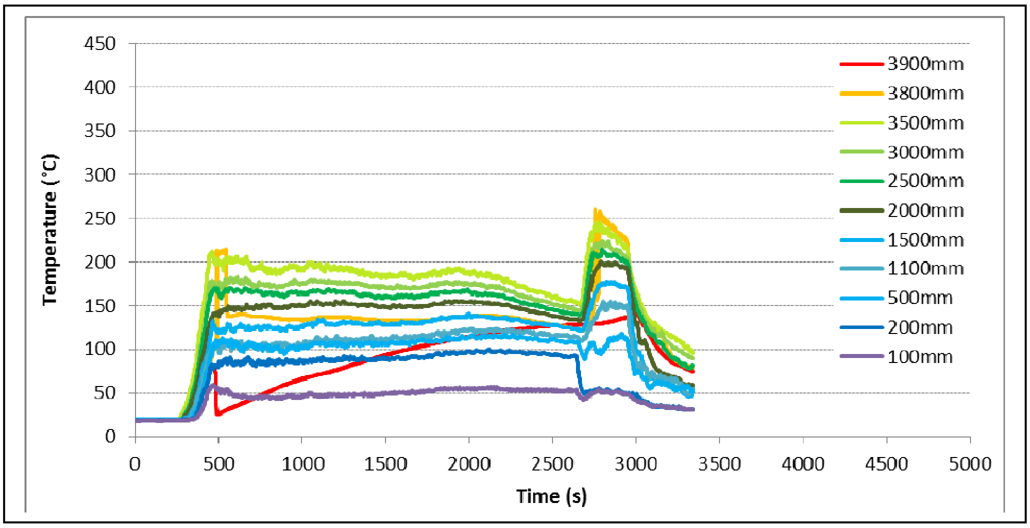
Cribs after 4M Ventilated Test

This test was terminated at 4000 seconds (67 minutes) and was fuel load controlled.

Test 4: 4M x 8M x 4M high Unventilated

Test 4 layout was the same as test 3 with cotton sheets on the target cribs and both doors closed.

Time Temperature Curve 4M Unventilated



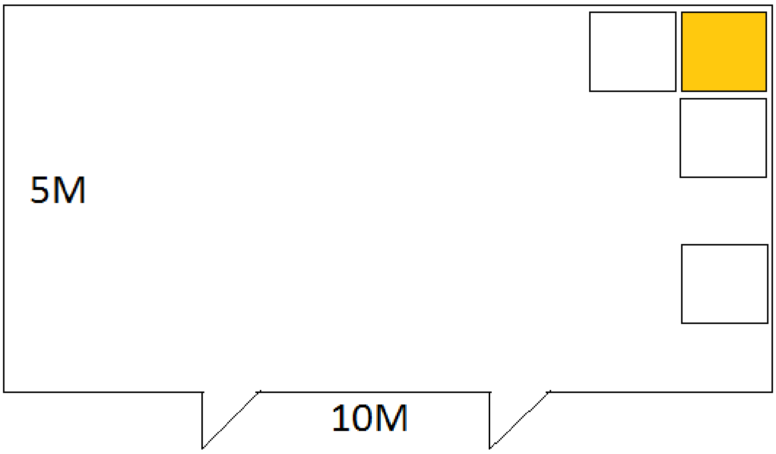
The unventilated 4M test showed a similar growth to the 4M ventilated test, except that it peaked at a lower temperature of 206.4^{0}C and quickly became ventilation controlled at 500 seconds The top of the door reached a temperature of 155^{0}C after about 30 minutes, which is a difference of 51^0C. When the door was opened at 2700 seconds there was a spike in temperature up to 254^0C as the fire became ventilated.

The target cribs did not become involved in fire except for some of the cotton sheet on the crib immediately next to the ignited crib.

Test 5: 5M Ventilated

The 5M tests had three cribs placed side by side in the corner with the cotton sheets placed on them to encourage fire spread. There was just one other target crib as the previous test showed that they would not get involved in fire. This gave a total fire load of 4MW or 0.08MW/M^2. If further 14 cribs 1M apart were added there would be a fire load of 18MW or 0.36MW/M^2

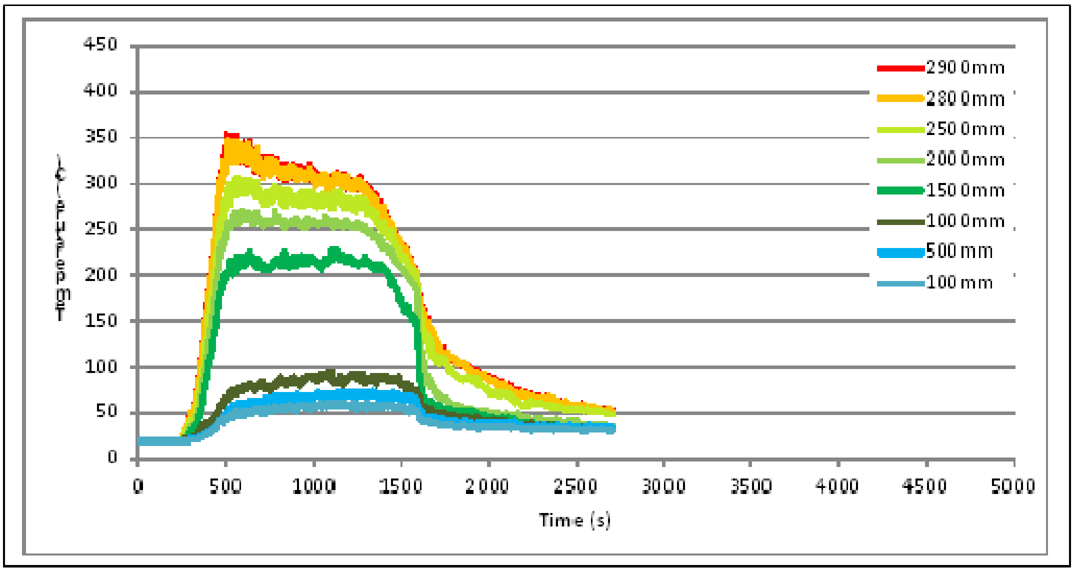
Layout of tests 5 and 6



The method of lighting the crib was different in this test as the white spirit on the felt wicks had evaporated, so more wicks were added and white spirit was poured over the timbers. This led to a quicker fire growth that involved the two adjacent cribs giving a potential 3MW fire.

Fire after 500 seconds

Time Temperature Curve for 5M Ventilated test



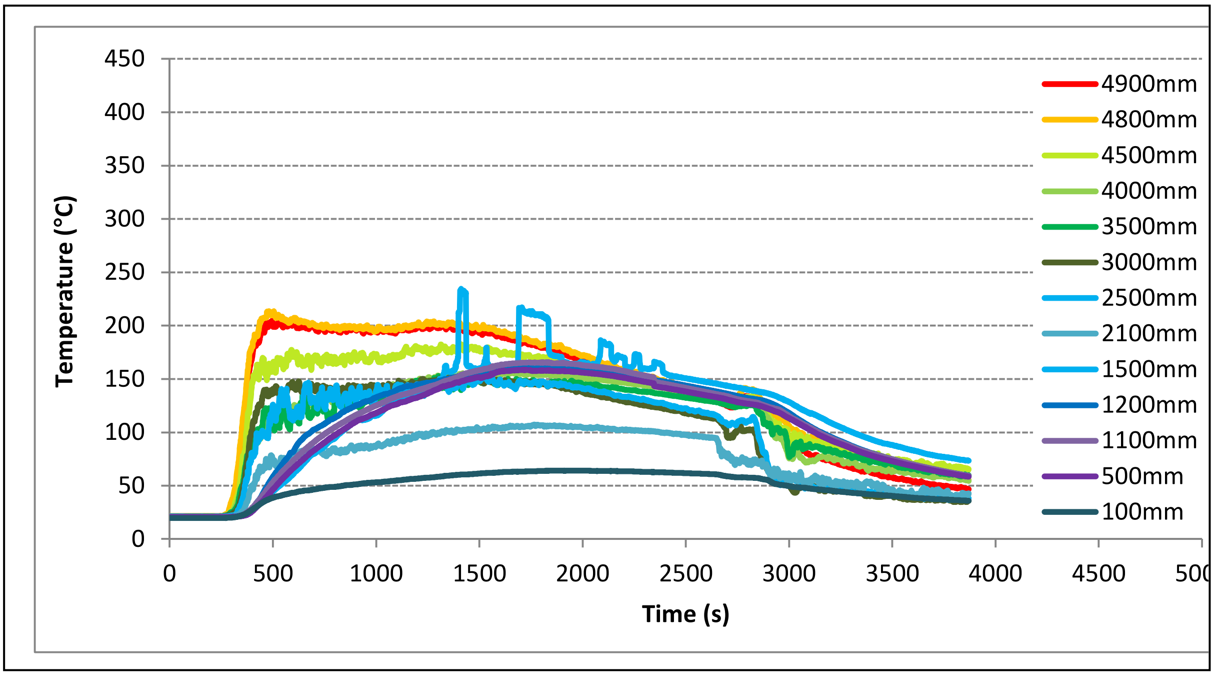
The maximum temperature of 353.4^{0}C was reached after 510 seconds (8.5 minutes) and the temperature at the top of the door was 258^{0}C, a difference of 95.4^0. The adjacent cribs were half burnt, but the fire still became fuel load controlled and had burnt out at about 2500 seconds (42 minutes)

Ignited crib burnt out, adjacent cribs half consumed

Test 6: 5M x 10M x 5M high Unventilated

The layout for this test was the same as test 5 with the doors closed. The corner crib was ignited in the normal way, so the temperature rise was not as rapid as test 5.

Time Temperature Curve for 5M Unventilated Test



The temperature peaked at about 204^{0}C remained fairly steady for about 25 minutes and then gradually declined for a further 30 minutes until 3870 seconds (64.5 minutes) when the test was terminated.

This fire was originally ventilation controlled and then became fuel load controlled because the fire did not spread beyond the ignited crib and there was enough oxygen in this larger space to allow complete combustion, although much slower than the previous ventilated test. The difference in the peak temperature between ceiling level and the top of the door was about 49^{0}C. This is the smallest difference seen, but can be explained by the fact that this was the lowest overall temperatures of all the tests.

The unusual shape of the blue line on the graph may have been cause by a hot particle settling on the temperature probe.

Cribs at the end of the 5M unventilated test

This photograph shows the ignited crib completely consumed by fire and yet the adjacent cribs were only slightly damaged. This was probably because there was limited oxygen available so the convection currents created by the fire caused incoming fresh air to blow the heat and flames away from the target cribs towards the corner of the room.

Conclusions

Initial Observations

The larger the room, the lower the overall temperature of the hot smoke and gases produced by the fire.

Fully ventilated rooms have a higher temperature and the duration of the fire is shorter than in unventilated rooms because they become fuel load controlled.

Unventilated rooms have a lower overall temperature, but the fire lasts much longer and may produce a temperature spike in smaller rooms when ventilation is introduced by opening doors. The fire services are well aware of this phenomenon and spray the hot smoke layer before entering a fire compartment.

At the end of the six fire tests the doors to the room were coated in soot, but there was no heat damage to them or the gaps around the edges.

The measurement of the temperature drop between the ceiling and the tops of the doors is interesting, but the overall drop between the ceiling and floor level is very useful as it can be used to determine the probable temperatures in rooms larger than those tested.

Comparison with Fire Modelling

The English Heritage tests showed that the spread of fire in larger rooms was slower than in smaller rooms, so a large fire would need to involve a large single item as it would be unlikely to spread to other items in the initial stages. The fire modelling carried out by Simon Vickers used larger heat sources than were available in the rooms surveyed. The model below is however very similar to the 5M ventilated test and is a very different curve from the BS476 curve.

Fire Modelling for 5MW fire in Waterloo Gallery

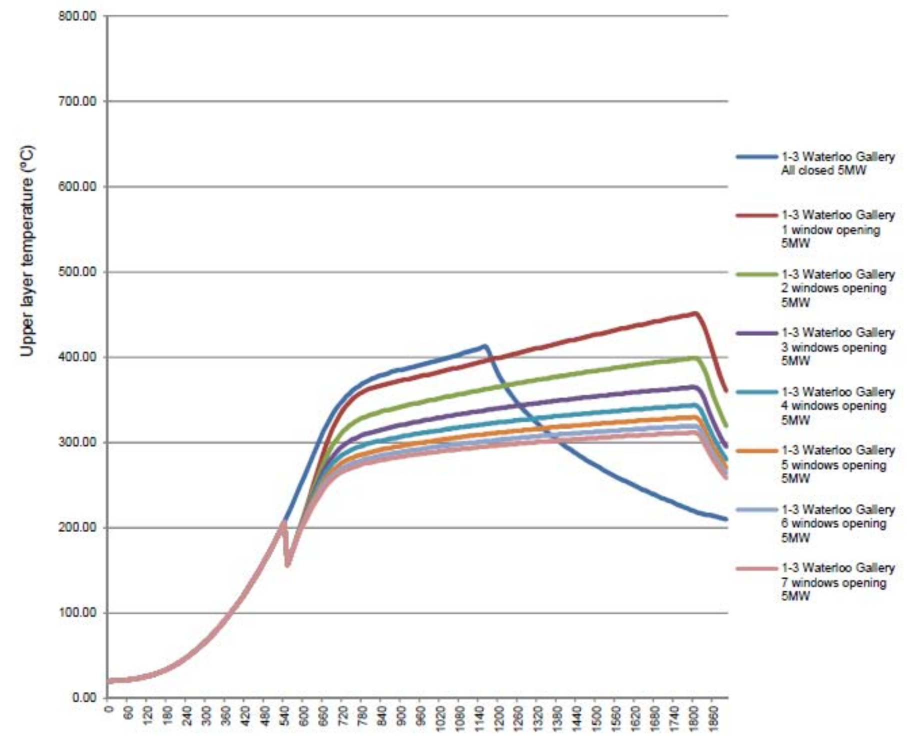


Figure 4-8 – Upper layer temperature for Waterloo Galley model at 5MW

The lines on the graph are for different ventilation scenarios, so should be compared just with the upper level temperatures in the BRE test, bearing in mind that this is a 5MW fire in a larger room of $275M^2$ with a ceiling height of 7.8 metres giving a cubic capacity of $2145M^3$.

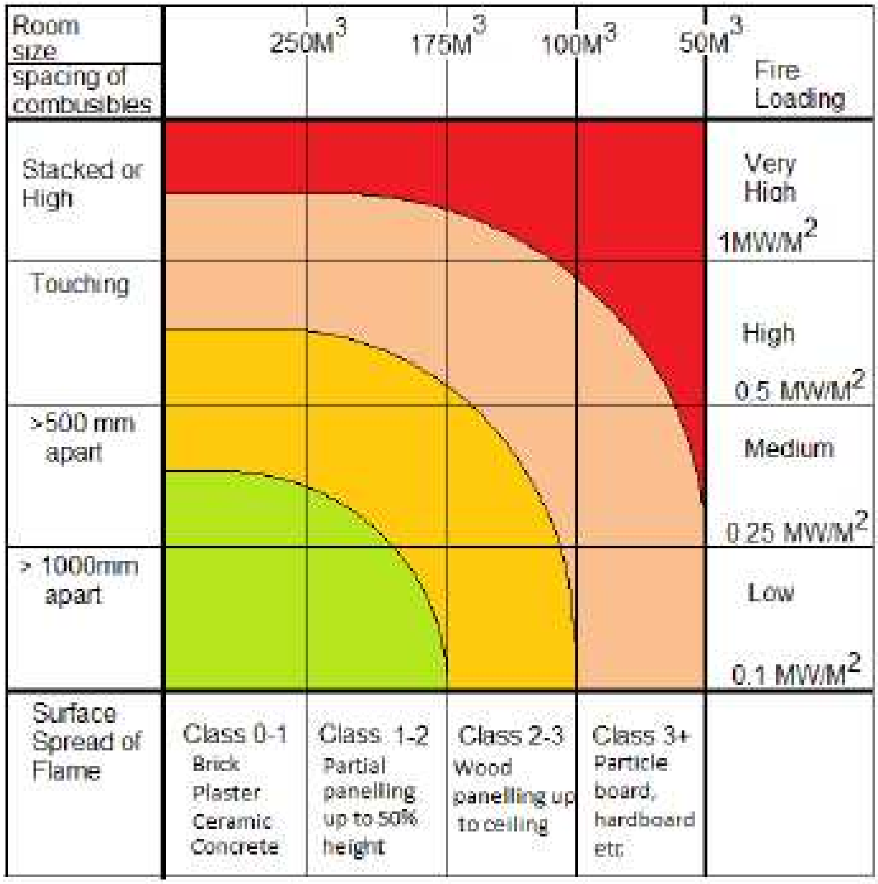
The level of the doors are at least 5 metres below the ceiling, so a temperature drop of around 249^0C might be expected giving the temperature at the top of the door in the worst case level at around 200^0C, which would not be high enough to ignite it.

This temperature drop has been extrapolated from the difference between the highest temperature in the 5M room and that 100mm above the floor.

Using the Data

The test data can be used to determine the degree of upgrading to a door to provide a period of fire resistance that is necessary for life safety (30 minutes) or longer for compartmentation purposes. To help assess the need for upgrading fire doors the matrix below has been developed. The four most critical factors affecting fire growth are used on the axis of the graph; Fuel Load, Surface Spread of Flame Rating, Room Size and how close together the packets of fuel are to each other. Vertical and Horizontal lines are draw on the graph and their intersection will determine the degree of upgrading the door will need.

Matrix for deciding how much upgrading a door will require



	PLUS		
Door to have Self-closing Device or room Steward	Door to have self-closing device and cold smoke seals	Door to have self-closing device, intumecsent strips, cold smoke seals and 30 minutes burn through	30 minute door may not give sufficient protection. Consider reducing fire load or fit suppression

The room sizes, fire loading and spacing of combustibles are those tested and the surface spread of flame has been added because this has a known effect on fire growth and contributes to the “fixed fire load” as opposed to the “moveable fire load” measured for the matrix. The fire load figures have been described as conservative, but further testing or modelling would be necessary to change them.

A booklet published by the BRE entitled “Design Fires for use in Fire Safety Engineering” gives a useful guide on the fire loading of different types of furnishings.

If the degree of upgrading to a door suggested by the matrix is not acceptable for conservation reasons, the factors such as the fire loading that led to the intersection falling where it did could be altered. If the intersection falls in the red zone, it is suggested that the factors causing it to be there should be changed (such as decreasing the fire load, improving the surface spread of flame rating or fitting a suppression system).

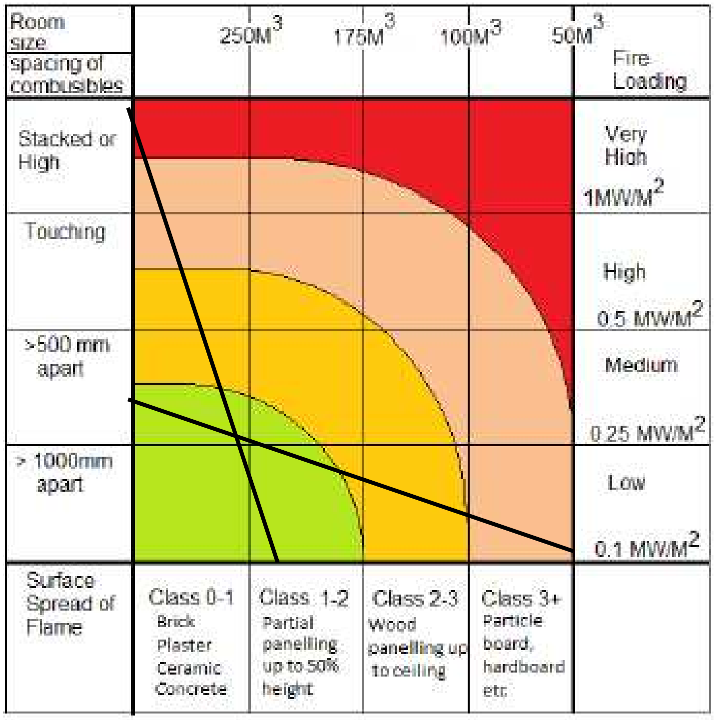
The fire door matrix can be used to record the decision about why the door has or has not received fire upgrading treatment. The example below shows how the doors to the Banqueting room in the Guildhall in Bath could be assessed.

Assessing the fire loading of the Banqueting Room

The dimensions of the room are $351M^{2,}$ which is more than the largest room tested, so the largest room size on the matrix is used (at the other end of the scale using a smaller room than shown on the matrix is not acceptable). The walls are plaster with an emulsion finish, so are Class 0 surface spread of flame rated, but there are some large oil paintings, so between class 1 and Class 2 is used. There are 200 chairs in the room giving a total fire loading of 40MW which is $0.1MW/Meter^2$. Each set of five chairs are about 750mm from the row in front so the spacing is as shown on the matrix below.

This assessment shows that the doors need self-closing devices or stewarding, but no other upgrade. The door the assessment applies to is recorded and if changes to the room or the fire loading are made, the matrix will need consulting to see if the doors are still satisfactory and a new record prepared.

Door Assessment for the Banqueting Room



	PLUS		
Door to have Self-closing Device or room Steward	Door to have self-closing device and cold smoke seals	Door to have self-closing device, intumescent strips, cold smoke seals and 30 minutes burn through	30 minute door may not give sufficient protection. Consider reducing fire load or fit suppression

Record of Decision

Door GF 20

A second appeal to the Secretary of State about the provision of smoke seals and intumescent strips to bedroom doors in an hotel was made in 2012 and it was concluded that they were not needed in that particular case. Although the appeal process is site specific it did show that fire doors could be allowed without smoke seals and intumescent strips and it is not an automatic stipulation.*7

The door to an archive room, which is a smaller room with high fire loading, has also been assessed and the matrix showed that the door would need to provide at least 30 minutes fire resistance. The intersection was at the limit of the zone, so it would be advisable to take additional precautions, such as removing combustible items from the tops of the lockers and limiting ignition sources.

Basement Archive Room

Next Steps

It is proposed that the new version of “Timber Panelled Doors and Fire” will start with an assessment of the probable fire growth in the room being protected so that the degree of upgrading can be determined. The rest of the document will show how the upgrading can be achieved.

Future tests may be undertaken to compare the growth of a fire in furniture as opposed to the cribs.

References;

BRE Report No 131120 Dec 2013

Timber Panelled Doors and Fire: Product Code XH20054 May 1997. Now out of print, but available on the EH Fire Research Database (FReD).

Advice regarding Determination of Appeal about Bedroom Doors under Article 36 by Sir Ken Knight Chief Fire & Rescue Adviser November 2008.

Trenton Report: Upgrading the Fire Resistance of Existing Historically Significant Doorsets. A Risk Assessed Approach

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Design Fires for use in Fire Safety Engineering; Christopher Mayfield and Danny Hopkins BRE Trust

Determination by the Secretary of State May 2012; Determination on the suitability and sufficiency of a fire risk assessment in a hotel in respect of the adequacy of the existing bedroom fire doors. ISBN: 987-1-4098-3457-1