TF2000 Stair Fire Test
Summary Report

Commercial in Confidence

Report reference:	TF2000 – Stair Fire Test

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Executive Summary

A full-scale fire test has been carried out within the stair shaft of the TF2000 timber frame building at Cardington. This report summarises the results and observations from the experimental programme.

Acknowledgements

Chiltern International Fire and BRE would like to thank the following organisations for their continued support and contribution to this work:

Brankbrook Ltd	Henry Godwin
British Gypsum Ltd	Mike Pritchard
Century Homes	Jim McBride
DETR	Geoff Harding
DETR	Anthony Burd
DETR Representative	Mike Payne
Devon Fire & Rescue Services	Mike Connolley
Devon Fire & Rescue Services	Doug Smith
Hickson Timber Products Ltd	David Lewis
Hickson Timber Products Ltd	Simon Atak
Home Office Fire Inspectorate	Mike Eady
NHBC	Mike Tucker
NHBC	John Haynes
The Palmer Partnership	Simon Palmer
Prestoplan	Steve Ashton
P J Steer Consulting Structural Engineer	Peter Steer
Richard Burbridge Ltd	Martin Whybrow
Richard Burbridge Ltd	Keven Jones
Scottish Executive	Paul Stollard
Stewart Milne Timber Systems	Hugh McKay
TRADA Technology	Geoff Pitts
Walker Timber Group	Charles Grant

A Single Timber Stair for a Six Storey Timber Building?

Introduction

Figure 1 shows the TF2000 building at BRE, Cardington. This building is the largest of its type in the world and is a timber frame residential building comprising of 4 flats in each of the six storeys. The height of the top storey (5th floor – level 6) above ground floor level in the building is approximately 13m. The TF2000 building is fitted with a single stair of timber construction that is located in a stair shaft the walls of which are of timber frame construction. In the photograph the stair shaft is seen as the projection from the centre of the front elevation. Figure 2 is a typical floor plan for the building showing the location of the stairs in relation to adjacent flats, storage and common areas.

Figure 1 TF2000 Building

Relationship to Current Statutory Guidance

Compliance with current statutory guidance relating to fire safety in support of the Building Regulations in England and Wales or Scotland would mean that a building like TF2000 would not be built.

The guidance of the Approved Document B of the England & Wales Building Regulations recommends that a single stair serving a building of the height of the TF2000 building should be constructed from materials of limited combustibility. Timber does not fall into this material classification (evaluated by means of the test standard BS476: Part 11) and would necessitate construction of a stair from materials such as concrete or steel.

For a building of the height of TF2000, compliance with the Scottish Technical Standards would require the enclosure of the stair and lobby to be of non-combustible construction. The stairs, landings and lobby floors would also need to be of non-combustible construction (as evaluated by means of the test standard BS476: Part 4). This is independent of whether the building is served by a single or multiple stairs. This would completely preclude the use of timber construction in the stair cores of a building like TF2000 in Scotland.

One of the main advantages of Timber Frame in the construction market is the speed at which buildings can be erected and commissioned. If a significant part of the construction involved the construction or casting of masonry elements then such benefits would be largely lost at cost to both the developer and client.

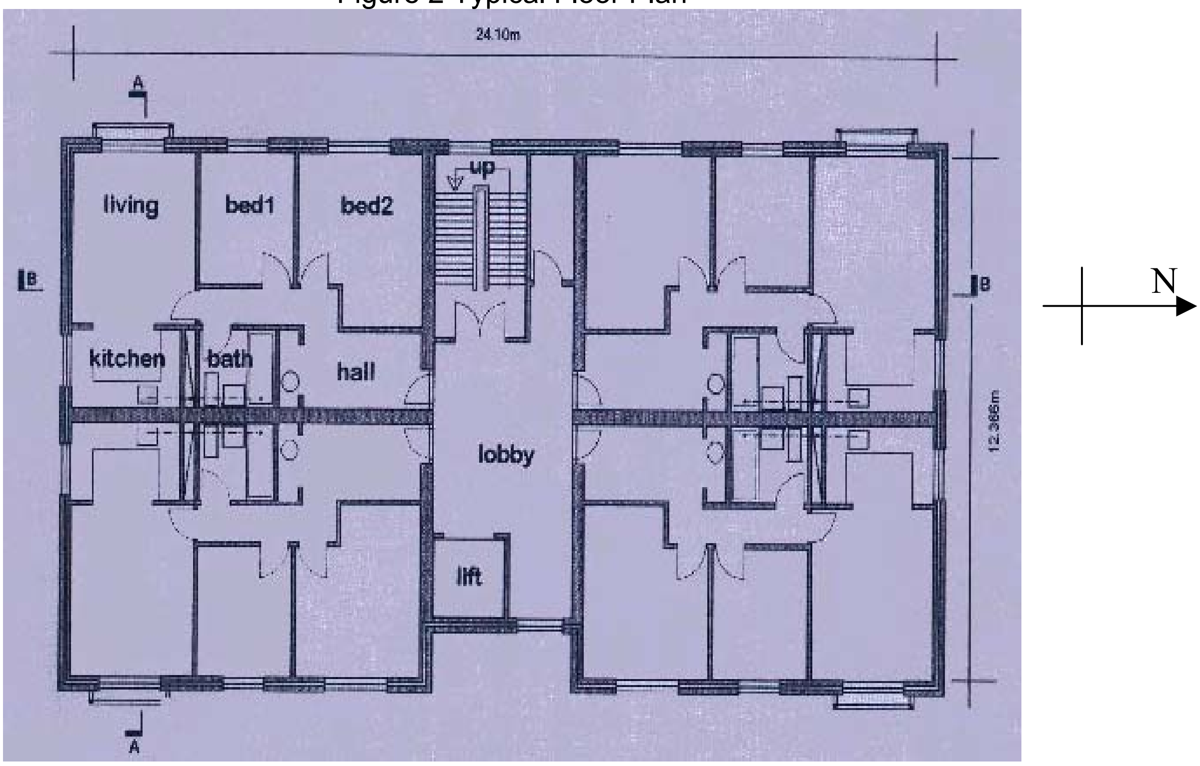
The above issues gave rise to a research proposal, supported by DETR and the timber construction industry, to carry out an experimental programme investigating the actual fire performance of timber stairs in a timber frame building.

The intention was that the results of the stair tests would provide data that would assist regulators in the United Kingdom to consider changes leading to a possible harmonisation of the technical guidance in support of their Building Regulations.

It was necessary to define at an early stage the fire performance objectives for a stair in such a residential building during a fire situation. In meeting the fire safety requirements of the Building Regulations the fundamental consideration for the stair is as follows:

The stair has to remain usable for firefighting after initial evacuation of occupants immediately at risk and for subsequent evacuation by the other occupants of the flats who are initially advised to remain in their dwellings

Figure 2 Typical Floor Plan



In the event of a fire in the TF2000 building the stair will be used by the fire brigade, upon attendance at the scene, to gain rapid access to the building to remove any people who are immediately at risk from the fire. Upon completion of this duty, the stair will provide the access for the fire brigade to fight the fire from inside the building. Once the fire has been brought under control or extinguished the stair would then be used to complete the safe evacuation of other occupants.

During all these operational phases the stair must remain usable. It must continue to support its design load for the duration of the incident and must not itself contribute significantly to a state of fire development that would render the stairwell space inaccessible to firefighters.

In terms of fire, the most onerous situation was regarded as one where the fire is actually in the stair itself. A fire that starts and grows in the stair may arise due to materials being left or stored in the stairwell that are then either accidentally or purposefully ignited.

It was recognised that a large fire load in the stairwell could result in the development of untenable conditions for means of escape from heat, smoke and toxic fumes. This could happen at an early stage independent of the type of construction of the stair enclosure and stairs themselves.

With these points in mind it was proposed that the stair in the TF2000 building should demonstrate a significant resistance to becoming involved in a fire when subjected to an appropriately severe fire source that is in intimate proximity to exposed timber components of the stair. The resulting fire (including any contribution from the stair construction) should not cause the loadbearing capacity of the stair to be reduced below a serviceable level and should not cause a breach of the compartmenting elements of structure enclosing the stair.

Stair Specification

It was recognised at an early stage that, in order to satisfy the identified functional performance requirements it would be necessary to modify the reaction to fire characteristics of the timber of the stair. Concerns that were expressed relating to durability of such protection indicated that the most appropriate course of action would be to utilise impregnated fire protective timber treatments rather than those which are surface applied.

It was considered that a scissors stair would represent the most onerous case in terms of potential fire propagation and that the results of a test on a scissors stair could be conservatively applied to single rise stairs.

In order for the results from the project to have a wide field of application the new stairs were constructed from Whitewood which, at the time of the project, represented a commonly imported timber variety used in the construction of timber stairs. Both the sapwood and heartwood of this type of timber have a low permeability and therefore are not penetrated to a significant depth by pressure impregnated timber treatments. A penetration depth of between 1 and 2mm is normal for this type of timber. The sapwood of Redwood for instance is very permeable and can be completely penetrated by impregnation treatments at significant section sizes. Thus if Whitewood could be shown to produce an adequate performance then other timber species having a higher permeability could be assumed to potentially provide at least an equal performance under the same fire conditions.

In all tests the stairs were underdrawn with a single layer of 12.5mm thick Gypsum wallboard that was fixed to the stringers of the stair (without cross noggins) at 150mm centres.

Trial Tests

The purpose of the trials was to ascertain the required level of protection to a commonly used timber stair specification in order to achieve these performance attributes.

For the trials, a purpose built compartment of similar dimensions and construction to the existing TF2000 stair shaft was built in the Cardington hangar.

In terms of the design fire, the intention was to simulate a deliberate fire event where a double mattress stored in the stair shaft at ground floor level had been doused with an accelerant and ignited. For the purposes of the experiments, the mattress was set in a steel tray and fixed to the handrail of the lower flight of stairs. This guaranteed that the mattress would not slump over and thus ensured that the mattress, once ignited, burned with maximum intensity. Approximately one litre of paraffin was poured onto porous fibre strips placed alongside the mattress in the steel tray.

The double mattresses used were identical for each test and were purchased from a high street retailer. The mattresses were labelled as complying with latest fire safety regulations in force for such products.

The stairs for the first trial were not provided with a fire retardant treatment. In the trial complete combustion of the mattress took place. The spindles and handrail of the baluster were involved in the fire causing extensive charring to these members. However, virtually no damage was inflicted on the stair treads and risers, and only very limited charring to the vertical face of the lower stringer was observed.

An attempt was then made to initiate a trench effect by placing paraffin soaked fibre strips at the junction between the treads and risers of the first five steps of the lower flight. Approximately 0.5 litres of paraffin was used. Ignition of the strips led to a short period of sustained flaming where flames were observed ‘lying down’ and surface charring of 2 to 3 mm on the first five steps was the result. The fire died out as the strips and paraffin were completely consumed and there was no further spread of flame. The structural integrity of the stairs was maintained and verified by personnel walking on the treads.

The final phase of this first trial involved removing the plasterboard to the underside of the stair and building a small crib (16 sticks of 50x50x500mm softwood) underneath the lower surface of the first flight. Again approximately 0.5 litres of paraffin was used to initiate burning. This final test led to a break through of the fire on the stairs and the string after approximately 10 minutes with the lower flight becoming fully involved in the development of the fire. The test fire was vented and extinguished using a fire hose reel to prevent the fire in the compartment from reaching an imminent flashover.

Figure 3 shows the temperature of the lower flight of stairs, the air temperature immediately above the mattress and the oxygen concentration in the compartment over the complete duration of the trial.

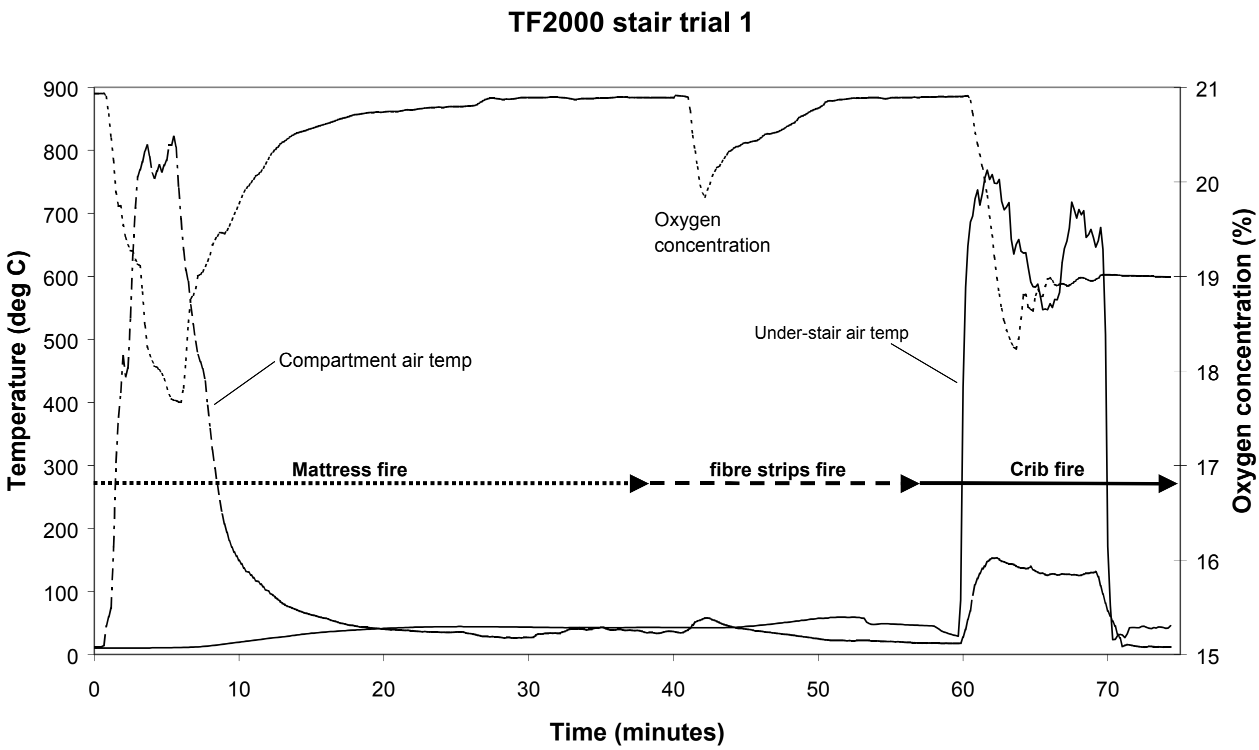


Figure 3 – data from Trial 1

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For the second trial timber stair components were treated using Dricon by Hickson Timber Products Ltd.

After treatment and kiln drying, the components were returned to Cardington and assembled on site. This second trial was performed in two stages. The first involved the mattress and fibre strips placed at the intersection of the treads and risers of the first flight. The second stage consisted of removal of the plasterboard fixed to the underside of the stairs and ignition of a single crib immediately below the first flight.

The mattress fire test did not cause any significant damage to the stair. The treatment clearly provided an enhanced performance over that observed during Trial 1. The mattress burned for approximately 13 minutes. The inclusion of the fibre strips on the treads of the lower flight led to limited charring (approximately 5mm) on the face of the risers in the immediate area around the fibre board. However, there was no evidence of flaming on the nosing, string or even on the treads and risers remote from the fibre strips. In general the spindles on the lower flight remained intact with only limited localised charring on the handrail closest to the mattress. Surface charring was observed on the lower string to a depth of 6 or 7mm with a maximum depth in a very localised area of 10mm or approximately half the thickness. In general there was no spread of flame away from the immediate vicinity of the mattress. There was limited charring (approximately 3mm) on the upper flight spindles and a similar level on the upper string.

The second phase consisted of the crib burn under the first flight, with the plasterboard to the underside of the stairs removed for both flights.

Localised flaming was observed on the second step some 12 minutes into the crib fire although this remained localised until the test was completed. The steps immediately over the crib sustained severe damage but this did not lead to fire spread away from the crib location. At no stage did the fire spread towards the half landing or the upper flight. Complete combustion of the crib was reached after approximately 30 minutes with no intervention necessary in contrast to the first trial.

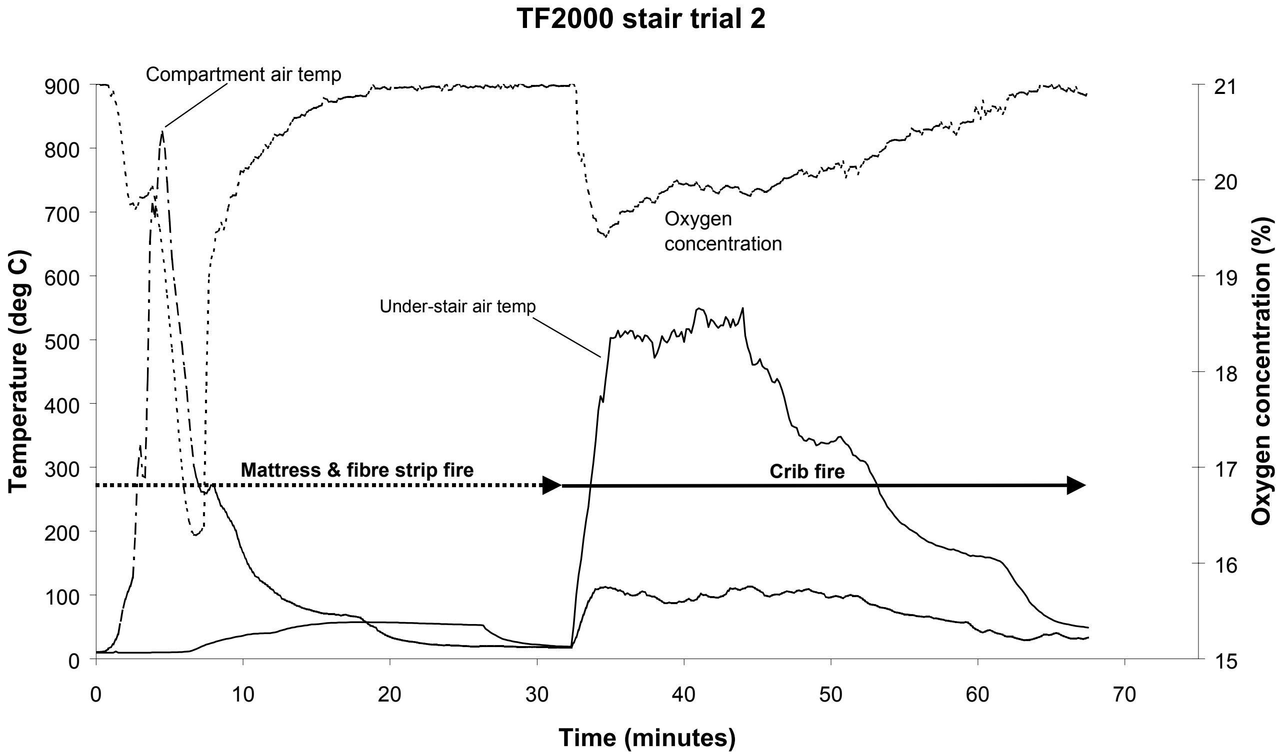

Figure 4 – data from Trial 2

Figure 5 – Trial 2 mattress & fibre strip fire

For the crib fires, the higher temperatures and lower oxygen levels recorded for Trial 1 illustrated a greater rate of heat release and were indicative of the relative degree to which the untreated stair was contributing to the fire. The rapid drop in temperature shown in Trial 1 at just before 12 minutes was as a result of fire intervention using water spray to suppress the fire. In contrast, despite an initially faster development in the crib fire in Trial 2, the peak temperatures recorded in the test compartment were nearly 50% of those recorded in Trial 1 with a corresponding higher level of oxygen showing a lower consumption of fuel.

Following the trial tests a number of recommendations were made with respect to the main stair test on the TF2000 building. These included

- Stairs would be treated using Dricon by Hickson Timber Products
- Thermosetting adhesive (i.e. not thermoplastic) would be used in the assembly of the stairs from the treated components. A Urea Formaldehyde adhesive type was selected
- Stairs would be underdrawn with a single layer of 12.5mm Gypsum Wallboard fixed using clout nails at a150mm centres to the stringers of the stair only
- The test would use a double mattress identical to that used in the stair trials 1 and 2 similarly located on the ground floor of the building and tied back to the handrail and spindles of the lower stair flight. In addition a single crib, identical to that used in the stair trials and built under the lower flight of stairs on the ground floor, would be ignited simultaneously as would single strips of paraffin soaked fibre board on the first five treads
- Following burn out of the fire load an inspection would be carried out to assess the capability of the stairs as a means of access and escape

The scenario for the main stair test on the TF2000 building represented a significantly more severe test than the original mattress fire in isolation. For this reason it was decided to replicate the main TF2000 building test scenario in a final trial.

The third trial test lasted for approximately 30 minutes with the plasterboard soffit protection to the stair cracking and falling apart some 28 minutes into the test. However, by this stage the fire load had been almost completely consumed. No break out of fire through the treads or risers was observed and the stairs remained usable following completion of the test.

The Main Test

In the fire condition, the ventilation conditions within the full six-storey stair shaft of the TF2000 building differed considerably from those present in the trial compartment

In terms of providing ventilation for the fire and to ensure fire sustainability, the top window at 5th floor (level 6) was left completely open for the test to provide exhaust for fire gases. Inlet ventilation was provided by two openings in the northern wall of the stair shaft that were sized so that, together, they were equivalent in free area to the open widow at 5th floor.

A large amount of instrumentation was installed in the stair shaft, in the lobby areas and in adjacent rooms. This included thermocouples (both type T and type K) to measure air and element temperatures, aluminium billets to determine heat flux, probes for oxygen and carbon monoxide concentrations, smoke detectors, and load cells to measure burning rate. The moisture content of the wood forming the timber crib was measured at between 12 and 13%.

Fire development was very rapid following ignition. Flames could be seen licking around the newel post and handrail approximately 1 minute from ignition. The fibre strips soaked in paraffin ignited some 3 minutes into the test and continued to burn for approximately 12 minutes. At no stage was there any spread of fire from this source. The mattress burned extremely intensely and had been largely consumed by about 4.5 minutes into the test.

Despite the areas of inlet and exhaust ventilation being similar to those used in the trial an appreciably faster flow of air was established in the test in the TF2000 stair shaft. The velocity of smoke exhausting from the 5th floor (level 6) stair shaft window was noted as being significant and was estimated at approximately 5 metres per second. This through draught very evidently dictated the path of flames at the seat of the fire.

The fire lasted for approximately 31 minutes. At this stage the fire load had reduced to a few smouldering embers. The Fire Brigade attended the test but did not have to intervene to suppress the fire. Following combustion of the fire load the integrity of the stair was confirmed by asking Fire Brigade personnel in full equipment to use the stairs to access the first and second floors.

The air temperatures at first and ground floor level are shown in figure 6. Air temperatures remained below 300°C. The peak temperature is due largely to the peak rate of heat release associated with the mattress as no combustion of the handrail or spindles took place. The location of the timber crib provided a worst case in terms of the thermal exposure to the stairs although this meant that the effect of the crib was very localised in terms of the air temperature in the shaft.

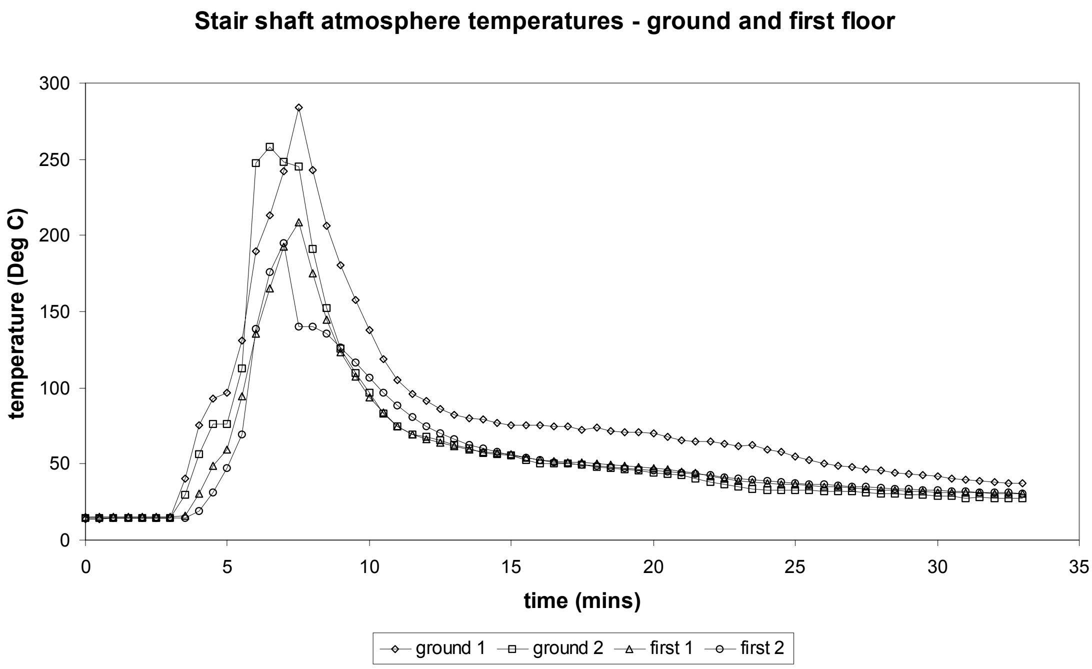

Figure 6 – stair shaft air temperatures ground and 1st floor (levels1 & 2)

Tenability Conditions During the Fire

Instrumentation was also provided to gather data relevant to tenability conditions in the TF2000 building.

Smoke detector response in the test is summarised in Table 1. As expected, fire was detected first at the head of the stair shaft where it was expected that smoke would rise and accumulate whilst exhausting from the 5th floor window. The data shows earliest detection of the fire at 4 minutes and 21 seconds by the ionisation type smoke detector at the head of the stair shaft. It is interesting to note that ionisation and optical detector types that located in the same vicinity gave very similar actuation times. The time taken for carbon monoxide levels at the head of the stair shaft to reach the actuation threshold of the domestic carbon monoxide detector was somewhat longer. An analysis of instrument data indicated that the carbon monoxide detector did not actuate until the oxygen concentration significantly diminished. This coincided with the fire burning at its maximum ferocity with the fire becoming ventilation controlled and thus producing more products of less efficient combustion including more carbon monoxide gas.

Location	Type	Actuation time after ignition (mins.secs)
1st floor (level 2) lobby centre	Ionisation	did not actuate
2nd floor (level 3) lobby centre	Ionisation	5.54
5th floor (level 6) lobby centre	Ionisation	5.51
1st floor (level 2) Bedroom 2 of SW flat	Ionisation	8.00*
1st floor (level 2) store room	Ionisation	did not actuate
5th floor (level 6) lobby centre	Optical	5.33
5th floor (level 6) head of stairs	Ionisation	4.21
5th floor (level 6) head of stairs	Carbon monoxide	7.15
5th floor (level 6) head of stairs	Optical	4.30

Table 1 – Sensor Actuation

* actuation of this detector at 8 minutes was most likely attributable to smoke from the test passing into the bedroom of the flat via its open window

Figure 7 shows a record of carbon monoxide concentration monitored close to the 5th floor lobby door on the lobby side at approximate head height. What is noticeable is that the increase in detectable carbon monoxide is concurrent with detector actuation in the lobby at which time the vent panel was removed to simulate automatic ventilation of the lobby. The peak carbon monoxide concentration measured in the lobby was approximately.

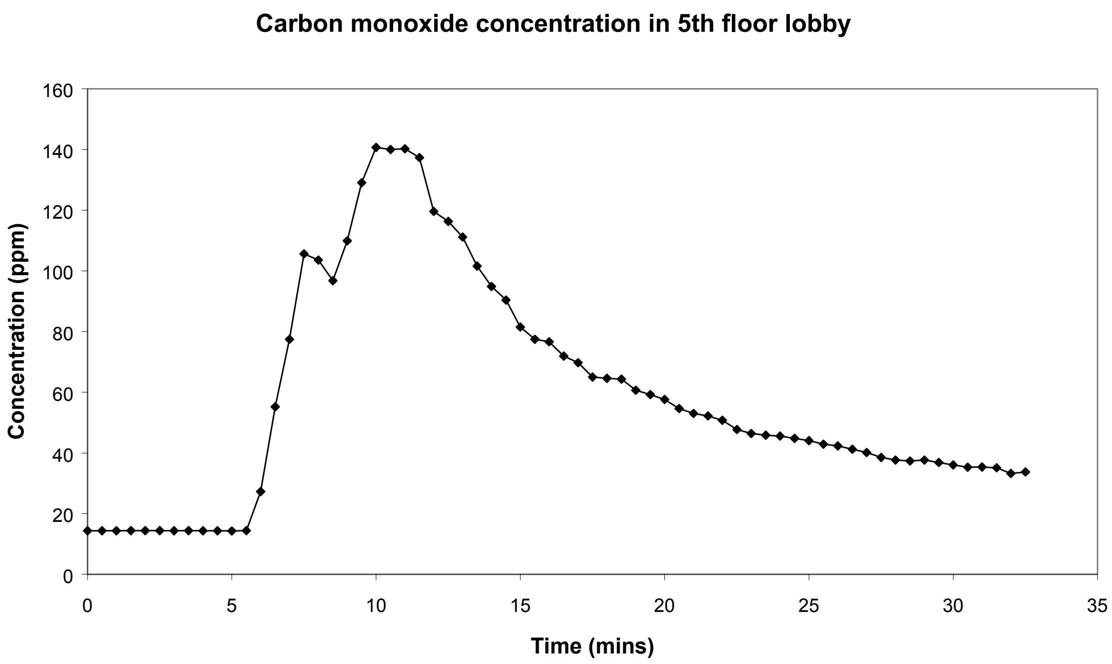

Figure 7 – carbon monoxide concentration measured in protected lobby at 5th floor

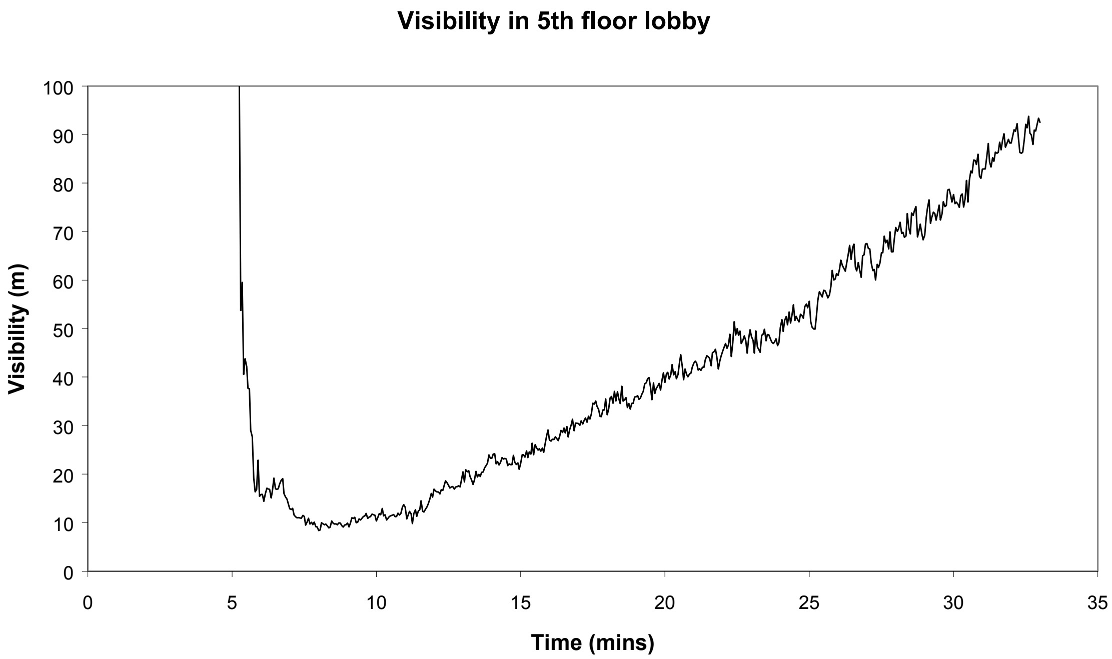

Figure 8 – visibility monitored in 5th floor lobby

The results of visibility measurements shown in figure 8 indicated that the visibility diminished to about 10m and the time of duration of the low visibility was coincident with peak carbon monoxide levels.

Figure 9 shows levels of heat flux measured in the stair shaft. At the underside of the 2nd floor half landing the peak heat flux level reached 14 KW/m^2 which is sufficient to cause the pilot ignition of timber under sustained exposure. At 5th floor level the peak heat flux was significantly lower with a peak value slightly in excess of 5 KW/m^2. This level of heat flux is tolerable for about 12 seconds without suffering severe sever pain.

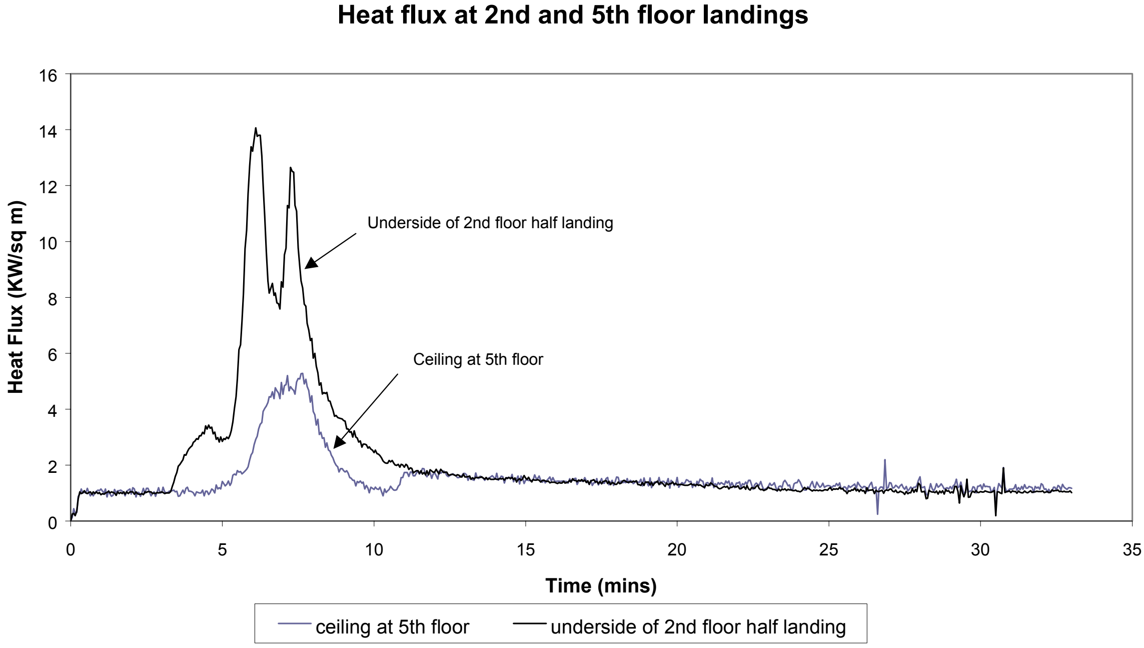

Figure 9 – heat flux levels in stair shaft

The first automatic detection of the fire occurred at 4 minutes and 21 seconds after ignition. Air temperatures monitored in the stair shaft indicate that by 6 minutes conditions would have been unpleasant enough to render the entire stair shaft untenable for persons without protective clothing and breathing apparatus. Taking into consideration human reaction time (longer if occupants asleep) and the time needed to egress from flats, through the protected lobbies and into the stair shaft, the time available between detection and untenable conditions would not be regarded as sufficient time to effect an escape from the building.

Hence the fire scenario used in the main stair test could be considered as rendering the stair shaft untenable for means of escape from the building during the fire. The timber structure of the stair and shaft contributed insignificantly to the fire event. Because of this it is appropriate to consider that similarly untenable conditions would have prevailed were the test to have been carried out in a masonry shaft with a non-combustible stair construction.

Visibility and carbon monoxide data recorded in the 5th floor lobby indicated that conditions in the protected lobbies of the building would have remained tenable for occupants throughout the fire event.

Post-fire Inspection

Following complete combustion of the fire load, the stairs were visually inspected to ensure that they were still serviceable. There was limited charring to the exposed stringers, the handrail and the spindles. To demonstrate the ability of the stairs to continue to meet the functional requirement for access and means of escape, Fire Brigade personnel were asked to inspect the upper floors using the stairs for entry. Fire fighters in full breathing apparatus were able to access all levels without any difficulty – see figure 10.

Figure 10 – Fire-fighters accessing upper storeys using stair after fire exposure

Conclusions

The test has demonstrated that the specific timber type and treatment used for the experiment together provided an appropriate level of fire performance to satisfy the functional fire safety objectives for a stair in the residential building.

As a consequence of this research project, regulatory authorities may wish to consider the use of an appropriately treated timber stair as adequate in terms of meeting the functional requirements of the UK Building Regulations, when used in a single stair medium-rise building, on a case by case basis.

Key Generic Features of the tested stair construction:

- **Scissors type stair geometry**
- **Whitewood timber type**
- **Thermosetting type glue – Cascamite**
- **No stair coverings**
- **Pressure impregnated Hickson Timber Products Ltd Dricon treatment process to give notional Class 1 reaction to fire performance**

Future Work

In order to provide a link between the data generated from this project and the standard tests that are carried out to establish and classify the Reaction to Fire performance of materials, it has been proposed that benchmark testing be carried out to national and new European standards. Designers and enforcing authorities will then be able to employ the research data to assess proposed building designs incorporating single timber stairs where the design of the stair differs from that which was evaluated in the TF2000 fire experiments.