Timber escape stairs: Using timber stairs as means of escape

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Summary
In the majority of countries, the use of combustible materials in evacuation routes is severely restricted. Guidance generally suggests that a single stair serving living units above 3 storeys should be constructed from materials of limited combustibility. This precludes timber, which does not meet the required fire classification, for multi-storey residential construction. Therefore use of timber stairs as single means of escape in multi-storey and occupancy construction is in most countries prohibited. As drivers in the UK construction industry encourage the use of timber, not only for its sustainability credentials but also because of speed of erection and meeting challenges and drive towards offsite construction, the UK has reviewed this existing guidance.

In the Timber Frame 2000 (TF2000) programme the performance requirements and safety goals for escape stairs have been revisited and timber stairs have been subjected to realistic fire conditions to ascertain their performance level and subsequently inform regulations. Following from the successful completion of the programme, building regulations were adapted in the UK and timber stairs in escape routes of multi-storey and occupancy construction have been used on a case by case basis.

As the acceptability of timber stairs were restricted to the configurations trialled in the TF200 programme, new work is underway to develop a performance based requirement and accompanying test and assessment method to demonstrate compliance with the functional requirement of the Building Regulations. A general test and assessment method has been developed to ascertain the performance of escape stairs and allowing suitable timber-based products to increase market share.

1. Introduction
The timber frame market is vibrant and growing. With shares of up to 57% [1] in parts of the UK, the timber industry plays a significant role in the new built, mainly residential sector and has become a strong competitor to the more traditional forms of construction, such as brick and block. Timber frame is enjoying an increased popularity because of the efficiency of off-site fabrication and the potential to reduce CO₂ impact with timber-based solutions. This has led to rising interest in the use of timber as a key element in construction and the applications now range from the main structural frame to the external façade finishes, in the more traditional two storey domestic market but also more widely in multi-storey applications including refurbishment, for both domestic and non-domestic applications. The growth of timber frame in these market segments has been supported by strategic research and development, to extend the uses of timber to 6-storey construction. The information gathered in industry led initiatives has been vital to optimising and enabling timber design features.

Despite these advances and sizeable achievements certain applications of timber based solutions are still severely restricted. The use of timber products in escape routes is one such application [2], [3]. The regulatory restriction relate to the combustibility of timber surfaces. This affects the competitiveness of timber construction with its main advantage of speed of erection. With a significant part of the construction involved in the erection or casting of other materials into the structure the benefits would be largely lost, at cost to the developer and client.

In the Timber Frame (TF) 2000 research and development programme the performance requirements for escape stairs have been revisited [4]. Following on from the successful completion of the programme, building regulations were adapted in the UK and timber stairs in
escape routes of multi-storey and occupancy construction have been used increasingly on a case by case basis. However as the acceptability of timber stairs were restricted to the configurations trialled in the TF200 programme a new initiative has been started to develop a performance based requirement and accompanying test and assessment method to demonstrate compliance of other forms of construction, including but not restricted to timber solutions.

1.1 Safety goals for escape stairs

The common objective in providing life safety in buildings is to ensure safe escape of occupants, people in adjacent buildings and the safety of fire fighters who enter the building for rescue and fire control. Once occupants are alerted to a fire incident suitable escape routes must be available and these paths must remain unaffected by fire or smoke so that occupants can egress via those paths to a place of safety. The place of safety may be in another part or the building, an often pursued solution in multi-storey, multi-occupancy buildings, or to the outside.

Safe design routes ensure best flow of occupants out of the affected area, are generally modelled on a “hydraulic model” based on research in crowd movement [5]. The density of the population, the ability of the group and human reaction to a dangerous situation undergoing distinct stages are basic parameters underpinning escape route design. Stair layout and design play a pivotal part in enabling safe egress and also include perceptual aspects such as “visibility” [6]. Design of stairs depends on the number of people affected and the function/ use of the building [7]. Multi-storey structures often have multiple escape routes. These are used for fire fighting and search and rescue operations. Here stairs play a centre role as the fire fighting strategy is generally to “defend in place”. Structural fire containment is used to provide a place of safety within the building, so that the evacuation takes place from the compartment where the fire started to adjoining parts of the building [8]. Stairs are the communicating vertical link between different parts of the building, allowing fire fighters to access and move occupants to refuge areas, where they would await rescue in safety.

1.2 Regulatory guidance

Regulations, performance-based or prescriptive, throughout the world demand from the design of a building that means of escape

- lead occupants to a place of safety,
- that these routes can be effectively and safely used at all times,
- once occupants are inside a protected stairway, they are safe from immediate danger,
- exclude flames/ smoke/gas as far as reasonably possible, incorporating measures such as fire resisting enclosure of stairwells, fire resisting, self closing doors and adequate smoke controls (e.g. smoke vents).

Comparing regulatory requirements for stairs in escape routes in England/ Wales and Scotland allows to compile a good range of typical performance parameters required. Both also reflect the safety philosophies adopted in most countries. In the England and Wales guidance a single stair serving a building of up to 18m should be constructed from materials of limited combustibility1. Scottish regulations would require the enclosure of the stair, landing and lobby to be of non-combustible construction2. In Scotland this requirement is independent of whether the building is served by single or multiple stairs. In both instances timber cannot meet the required material classification and hence would be excluded from use in this application.

1.3 Existing test methods for stairs

Two current test methods are of direct relevance to the evaluation of escape stairs, regardless of material. One is a European standard dealing with fire resistance while the other is an International standard dealing with reaction to fire issues. The merits and drawbacks of these two documents are discussed below.

1 established by means of test standard BS 476-11 or EN 13501-1
2 established by means of test standard BS476-4 or EN 13501-1
1.3.1 Fire resistance tests for loadbearing elements - stairs

BS EN 1365-6 [9] is concerned with the ability of the test specimen to maintain the applied load for the duration of the test. Various configurations for stair systems can be tested. In each case the specimen is exposed to a standard fire curve in accordance with EN1363-1 [10]. Such a severe thermal exposure is likely to exclude timber stairs from use. The temperature levels obtained with the standard fire curve are intended to represent post-flashover fire conditions within a compartment, generally within a building. A fire originating within a stair enclosure is very likely to lead to considerably lower temperature levels.

The EN test procedure is meant to establish load bearing capacity of the structure at elevated temperature conditions and only dead load is applied during the fire test. For a typical stair the dead load would be a small proportion of the design load for most components. What is more significant in practice is the residual strength of the stair following a fire, an assessment not included in the test procedure. The test regime and aims are not deemed to be a realistic assessment of the requirements of an escape stair in practice.

1.3.2 Reaction to fire tests - fire growth - full-scale test for stairs and stair coverings

The ISO/TS 22269 [11] technical specification describes a full-scale reference scenario for assessing the burning behaviour of stairs and/or stair coverings, when exposed to a defined ignition source. The test is meant to represent an arson event and the ignition source can be either a timber crib or a gas burner. The test is carried out in well ventilated conditions, unlikely to be present within a stair enclosure. The test considers reaction to fire properties and spread of flame over the surface of the stair and stair covering. The assembly is supported by a unified framework of steel angles, independent of the stair design, material and layout. This precludes the possibility to assess the loadbearing performance of the stair during and after the test has been completed.

Both test regimes described above provide an assessment of fire resistance in the first case and reaction to fire properties in the latter. A dedicated stair test methodology is required to determine both, fire resistance/ loadbearing and reaction to fire when subjected to a realistic fire scenario.

1.4 Stair types

The most commonly used stair configurations are the straight flight and the dog-leg stairs. In a dog-leg stair two shorter flights of stairs, often of unequal length, are positioned at 180 degrees to each other and joined by a half-landing to enable the 180 degree turn. The flights of both straight and dog-leg stairs are usually structurally supported by the landings, which in turn transfer the loads into the adjoining flanking shaft walls. Dog-leg stairs are often used in higher density applications, as they allow shorter elevations.

![Fig. 1 Typical dog-leg configuration with required minimum dimensions (Approved document K, Building Regulations England, Wales and Northern Ireland)](image)
2. TF2000

The performance objective for the stair was developed from the use conditions in a fire emergency situation. In the event of a fire the stair would be used by the fire brigade, upon attendance at the scene to gain access to the building and to remove people immediately at risk. Then the stair would provide access for the brigade to fight the fire from inside the building, and once the fire has been brought under control or extinguished the stairs would then be used to complete the safe evacuation of other occupants. During all these operational phases the stair was to remain useable, hence support its design load for the duration of the incident and must not contribute itself significantly to the fire development, rendering it inaccessible to fire fighters.

The performance goal for the stair was summarised to remaining useable for fire fighting after initial evacuation of occupants immediately at risk and for subsequent evacuation by the other occupants of adjoining flats, initially advised to remain in their dwellings.

2.2 Test set-up

The most onerous fire situation for the escape stair was regarded as one where the fire was in the stair shaft itself. The typical scenario being materials left or stored in the staircase, which are accidentally or purposely ignited. The potentially large fire load could result in producing untenable conditions upon ignition and generating heat smoke and toxic fumes. This will compromise the means of escape. It has to be noted that this fire scenario and its implications would be largely independent of the material/ construction method of the stair itself.
This scenario is best represented in a test configuration using an appropriately severe fire source in close proximity to the timber stair. In the TF2000 test the stair was a dog leg shape made of European whitewood, assembled using thermosetting urea formaldehyde type adhesive (Cascamite). The stairs were pressure impregnated (Hickson Dricon). The stairs were not covered but underdrawn with 12.5mm plasterboard, which was fixed by nails. As part of the calibration both treated and untreated stairs were trialled.

Figure 3 shows the fire loading scenario. The main fire source consists of a mattress fixed to the handrail doused with accelerant and ignited. Furthermore a single crib (8kg of softwood) is placed under the lower flight of stairs and single paraffin soaked strips are placed on first five treads of stairs. Ventilation conditions were designed to ensure a realistic burning rate.

The performance of the stair configuration was to show that the damage resulting from the fire source, including any contribution from the stair, would not reduce the loadbearing ability of the stair below a serviceable level. In addition the fire progression in the stair was not to breach the compartmentation of the enclosing structure.

2.3 Results

The stair shaft was instrumented with thermocouples (type T and K) measuring air and element temperatures. Heat flux, oxygen and carbon monoxide concentrations, smoke detectors and rate of burning were also determined as part of the test.

The fire developed rapidly after the ignition of the sources. Flames attacked the newel post and handrail of the stairs after about 1 minute into the test and the mattress was consumed within 4-5 minutes. The fire did not spread beyond the direct heat sources. The fire lasted about 30 minutes.

Air temperature at ground and first floor level remained below 300°C. Despite direct exposure to the burning mattress the handrail and spindles of the stair did not contribute significantly to the temperature and heat release levels measured. The levels of heat flux measured in the stair shaft, at the underside of the 2nd floor half landing reached 14kW/m², notionally enough to cause pilot ignition of timber. The timber stair structure and shaft did not significantly contribute to the fire

Fig. 3 During and after the test: Mattress fixed to balustrade and paraffin soaked strips on first five treads (left). Crib at underside of stair lined with plasterboard and fixed with nails (right)

Fig. 4 Fully equipped fire fighters accessing upper floors via tested timber escape stair
ferocity and development. Visibility and carbon monoxide measurement indicate that 5th floor lobby conditions would have remained tenable for occupants throughout the fire event. Post fire inspection revealed no significant damage to the stair structure, with only limited charring to the exposed stringers, handrail and spindles. Following burnt out of the fire load fully equipped fire fighters used the stair to inspect the upper floors (see figure 4).

3. **Generic compliance testing**

Based on the work in the TF2000 programme a generic assessment scheme is now being developed to provide an assessment scheme for determining the contribution to fire development (reaction to fire properties) of the stair as well as determining its residual load carrying capacity. The construction of the test compartment and the connection between the stairs and the structural frame (via the landing) were considered pivotal to performance, as the geometry of the stairs and also impacted on the overall size of the test compartment. During the previous research undertaken as part of the TF2000 project it was established that a “dog leg” stair consisting of a half storey flight, a landing at mid-storey height and a landing at the lobby level was the most onerous case in terms of fire spread. However, in terms of load carrying capacity a straight flight staircase will represent a more severe case, as spans will be greater.

The connection between the stair and the structural frame is unlikely to be unduly compromised unless there is significant fire spread involving the stair itself. If this is the case the post-test loading assessment is unlikely to be undertaken as the specimen will have failed under the requirement to limit the heat release rate. The more likely scenario is that following a fire in which the heat output has been restricted to acceptable levels there may still be a risk of localised failure of one or more of the treads in close contact to the source of the fire. The compartment used for the experimental phase of the work is capable of accommodating both a “dog leg” with a half landing at mid-height and a straight flight stair to assess the impact of stair geometry on performance.

Consultation with industry representatives and members of the UK Fire and Rescue Services determined that the overall stability of the stairs should be assessed as part of the test procedure citing cases where flights of staircases, exhibiting only superficial fire damage, had been found among post-fire debris due to failure of the connections. It is considered of paramount importance that the stairs are connected to the shaft walls in a manner consistent with the end use application. All stairs tested in the current programme are connected to the landings in a manner consistent with current practice. As with most fire test methods, assessment of the results from the test will be limited to the form of construction tested. Less onerous cases could be separately assessed while any significant change in the form of construction would need to be retested.

3.1 **Test rig and fire scenario**

The test rig is designed to enclose a volume of 4m (height) x 3m (width) and 6m in length (figure 5). The intention is to simulate a deliberate fire event where a mattress stored in the stair shaft has been doused with an accelerant and ignited. In addition to the mattress a crib consisting of 16 sticks of 50x50x500mm softwood will be placed underneath the lower surface of the first flight with approximately 0.5 litres of paraffin used to accelerate ignition. This will simulate the build up of debris underneath the stairs. To initiate a trench effect on the upper surface of the stair paraffin (approximately 0.5 litres) soaked strips are placed at the junction of the treads and risers of the first five steps of the lower flight. All the specimens in the experimental/calibration phase of the project incorporate a single layer of 12.5mm Gypsum Wallboard fixed using nails at 150mm centres to the stringers of the stairs. Input ventilation is provided by three 500mm x 500mm openings at low level in the front elevation of the compartment. Exhaust gases are removed via three adjustable openings 500mm x 500mm in the ceiling. The initial condition would correspond to a lobby door left open and an opening at the stairhead corresponding to an open window or door or an automatic ventilation opening. The compartment is lined internally with fire resistant plasterboard. This will simulate normal conditions where the stair shaft will be constructed from fire resistant materials to provide the required separation between dwellings and means of escape. In order to achieve the required conditions within the test compartment the thermal absorptivity ($b = \sqrt{\rho c \lambda}$) of the lining materials used is less than 1200 J/m²s⁻¹K.
3.2 Performance influencing parameters

The potential variation in products, components and installation procedures need to be assessed. With regard to the fire performance of escape stairs the following parameters are particularly significant:

- Stair geometry (potential stair geometries range from straight flights to spiral staircases and incorporating a variety of returns generally at right angles to the original flight)
- Structural concept of stair and fixings to shaft walls/landings
- Timber type and species
- Type of fire retardant treatment (impregnated, pressure-induced treatments, surface coatings and intumescent coatings)
- Type of adhesive (thermosetting or thermoplastic adhesives are both used in the industry)
- Provision of passive fire protection. The underside of a timber stair may be particularly vulnerable due to the presence of stored materials or rubbish. One option is to line the underside with plasterboard.

3.3 Performance criteria

The fire test is to provide a demonstration of the ability of the stair to resist the spread of flame as well as to remain structurally performing. The test performance is therefore assessed based on visual observation, quantifiable increase in temperature and a load test. A recorded atmosphere temperature in excess of 600°C for a duration of 15 minutes suggests that the stair is contributing significantly to the fire. Where this is confirmed by flaming of the treads and risers away from the initial fuel source the test will be terminated. In the absence of the termination criteria being reached the test will continue until all the fire load has been completely consumed. Following any fire incident within the stair enclosure the stair needs to be capable of performing its function as a means of escape. Therefore a static load test is conducted after the fire test to assess the stability of the stair. After a minimum period of 30 minutes from the end of the fire test each of the central three treads of the lower flight of the stair (most severely exposed part of the stair) are loaded in equal increments up to a maximum value. The degree of the initial loading is related to the design load of the stair and should not be less than the load induced by two fire men, carrying an incapacitated person in full fire fighting gear. The load is maintained for a period of 30 minutes and
the deflection of the string at the centre point measured continually during this period. If the integrity of the stair is maintained for the period of the test then the load will be removed and the condition of the stair including any residual displacement noted. Further load testing can be undertaken to determine ultimate post-fire loadbearing capacity of the construction.

4. Conclusions, recommendations way forward

Currently available test regimes for escape stairs have shown to be of limited applicability for UK use and not able to support the wider application of timber based materials in off-site construction solutions. The methodology developed from the TF2000 programme in consultation with UK industry representatives, members of the Fire, and Rescue Services and regulators has been used to develop a test and assessment method for evaluating the fire performance of escape stairs. Initial test results using the procedure outlined shows promising performance levels for a wide variety of timber stair configurations. The method is currently being evaluated through a research and developmental test programme. Results will be available in due course.

5. Acknowledgments

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6. References

[6] Pauls, J. Section 1/ Chapter 15 Movement of people, The SFPE handbook of fire protection engineering, National fire Protection Association (NFPA), Quincy, MA, 1988