Grenfell Tower – fire safety investigation: The fire protection measures in place on the night of the fire, and conclusions as to:

the extent to which they failed to control the spread of fire and smoke; the extent to which they contributed to the speed at which the fire spread.

Phase 1 Report – Section 19

How the protected stairs and lobbies failed for the residents and firefighters

REPORT OF

Dr Barbara Lane FREng FRSE CEng

Fire Safety Engineering

24th October 2018

Specialist Field	:	Fire Safety Engineering
Assisted by	:	Dr Susan Deeny, Dr Peter Woodburn, Dr Graeme Flint, Mr Tom Parker, Mrs Danielle Antonellis, Mr Alfie Chapman
On behalf of	:	Grenfell Tower Inquiry
On instructions of	:	Cathy Kennedy, Solicitor, Grenfell Tower Inquiry
Subject Matter		To examine the circumstances surrounding the fire at Grenfell Tower on 14th June 2017
Inspection Date(s)	:	6th October, 1st November, 7-9th November 2017

Dr Barbara Lane
Ove Arup & Partners Limited
13 Fitzroy Street
London W1T 4BQ

CONTENTS

19 How the protected stair and lobbies failed for the residents and firefighters

19.1 Purpose of Section 19

19.1.1 In Section 14 of my Expert Report, I described the deterioration of conditions within the protected stair and lobbies and how that impacted on the self-evacuation potential for the residents; on the ability of the London Fire Brigade to execute internal firefighting; and on the ability of the London Fire Brigade to execute rescues at the scale required.

19.1.2 This description is based on the evidence available to me at this time and will be updated when the bereaved, survivor and residents' oral evidence is completed.

19.1.3 I then explained the findings from my investigation in Sections 15 and 16, regarding the compliance status of the active and passive fire safety measures required for the single safety condition Stay Put and the Defend in Place internal firefighting process.

19.1.4 For all the fire safety measures I have investigated, I have explained my understanding of what was required by the Regulations and its statutory guidance at the time of construction of Grenfell Tower. I have also then explained what is required under the current Building Regulations and its statutory guidance.

19.1.5 Based on my findings in Sections 14, 15 and 16, and the associated appendices Appendix C, D, G, H, I, J, K, L and M, I will now explain my opinion on how protection measures in the stair and lobbies failed to control the spread of fire and smoke; and how this contributed to the speed at which the fire and smoke spread within the building.

19.1.6 These failures occurred during a multi floor external fire which then caused a series of internal fires.

19.1.7 Some failures were directly caused by the multi-storey fire condition, but other failures occurred in a classic "single flat fire" conditions – with that failure then contributing to the overall internal scale of the fire.

19.1.8 The external fire was sustained and promoted by the rain screen cladding system, installed on Grenfell Tower during the refurbishment in 2012 - 2016. I have described the impact of the external fire, and the corresponding internal fires in Section 12 of my Expert Report.

19.2 Summary of conditions within the protected stair and lobbies

19.2.1 Progression of conditions during the fire within the protected stair and lobbies

19.2.2 I described within Section 14 how the conditions deteriorated with the protected stair and lobbies of Grenfell Tower during the fire. In summary:

a) **00:59 – 01:18:**

i. Smoke is described as entering the Level 4 lobby through the open door of Flat 16; by 01:13 the smoke colour is described as black.

ii. The stair is described by fire fighters and residents as being clear of smoke.

b) **01:19 – 01:38:**

i. Smoke reported is reported in 13 out of 20 lobbies (L4-23) by this time. smoke is described as hazy and light on Level 22 to thick and black on Level 16 (one of 7 lobbies).

ii. The first evidence of thick black smoke flowing into the stair at Level 4 is reported. Near the top at Level 22 the stair is described as having some 'hazy' smoke only. Residents who escape from Levels 17, 19 and 20 during this period describe the smoke thickening progressively within the stair as they descended.

iii. **Note:** it is during this period that some residents were observed walking up the stair as a result of conditions lower in the stair being perceived as *"too smoky"* or being told by others to *"go back"*.

c) 01:38 – 01:58:

i. The number of lobbies reported to be affected by smoke has increased to 15 out of 20; in 10 of these the smoke is described as thick and black.

ii. There are limited resident observations due to no evacuations from above Level 11 in this period, and above Level 3 between 01:49 – 01:58. Firefighter evidence describes thick black smoke from Level 3 up to Level 21. However, this conflicts with slightly later Firefighter evidence where clearer conditions are reported above level 10 or at 15 and above.

d) 01:59 – 02:38:

i. The number of lobbies affected by smoke has increased to 19 out of 20; in 17 of these the smoke is described as thick and black. Severe temperatures are described in the lobbies at Levels 6 – 10.

ii. I have not seen any resident evidence describing conditions between 01:59 – 02:18. Firefighter evidence from this time describes the stair as being full of thick black smoke with poor visibility up to Level 21 (note there is some conflicting observations in the fire fighter evidence; with some suggestion conditions were clearer between 15 -20). Residents escaping in the overlapping period between 01:18 and 02:28 describe increasing heat in the stair: a resident escaping from Level 19 describes the stair as progressively hot and the handrail as too hot to hold. A resident who is overcome in the stairs is carried out by fire fighters.

e) 02:39 – 02:58:

i. The number of smoke affected lobbies remains at 19 out of 20; conditions are thick, black smoke with high temperatures.

ii. From Level 23 down residents describe zero visibility and residents at Level 12 and 14 describe extreme heat, with conditions described as "roasting" or "sweltering".

iii. Note: It is shortly before (Jo Smith at 2.35) and during this period (Roe at 2.47) that the stay put guidance is changed by the LFB.

f) After 02:59:

i. **The number** of smoke affected lobbies remains at 19 out of 20; conditions are thick, black smoke with high temperatures. Temperatures in 2 lobbies (L10 and 11) are described as extreme as to be inaccessible by fire fighters.

ii. The last FSG call active above Level 13 concluded at 03:33 and the last evacuation of a resident from above Level 13 occurred at 03:55. By 04:15 the LFB appear to have been unable to access floors above Level 11.

19.2.3 **Resulting damage within the protected stair and lobbies**

19.2.4 In my post-fire survey of the stair and protected lobbies I observed:

a) Heavy damage in all lobbies from Level 10 – 23; heavy damage to the north side of the lobby (Entrances to flats 4, 5 and 6); and light to medium in the south side of the lobby (Entrances to Flats 1, 2 and 3) on Levels 5, 7 – 9. There was no damage in the Level 6 lobby.

b) Symptoms of high temperatures (> 150°C) within the stair, particularly at Levels 13 -16.

19.2.5 **Effect of conditions for evacuation and rescue from Grenfell Tower**

19.2.6 By the time the formal Stay Put guidance was changed by London Fire Brigade between 02.35 and 02.47 (Section 13), a total of 177 had escaped from the building. A total of 107 then remained in the building, of which 36

would be able to evacuate. I have provided my analysis of the remaining 71 persons and their movements, in Section 20 of my report.

19.2.7 I consider the deterioration in the condition of the stair and lobbies to have impacted on the evacuation rates of the residents. This impact is summarised as follows.

a) 144 people in total left the building before 01:38. During this time the stair progresses from clear on all levels to thickening smoke at the lower levels, starting from Level 4. Smoke is also reported by this time in 13 lobbies. A total of 110 people evacuated between 01:18 and 01:38 whilst smoke started to enter the lobbies of Grenfell Tower. The rate of evacuation between 00:58 and 01:40 is 3.6 persons/min. At 01:40 there were still 150 residents inside the building. This includes the people observed to be walking upstairs in this time period. I have provided my analysis the upward movement of residents in Section 20 of my report.

b) Between 01:39 and 01:58 the number of smoke affected lobbies increased to 15. Thick smoke with low to zero visibility is described as filling the stair. It is described as becoming increasingly hot below Level 20. Additionally, lobbies on levels 5-6, 9-12 and 20 are all described as being filled with thick black smoke. Further:

   i. The rate of evacuation from all floors of the building slows substantially between 01:38 and 01:58. A total of 20 people evacuate from Levels 1 to 20 in this ~20minute window (1 person/min) compared to 3.6 persons/min up to 01:38. The flow rate is therefore 72% less than before 01:38.

   ii. The people who do manage to evacuate at this time come from Levels 1, 3, 6, 7, 10, 11 and 20 only. Therefore, they evacuate through lobbies described filled with black smoke, and for Levels 15-20, from above the portion of the stair described as hot. A total of 130 people remained inside the building at this time.

c) Between 01:59 and 02:58 the rate of evacuation slowed even further, to a total of 24 people which is 0.4 persons/min: this is now only 10% of the flow rate in the first 40 minutes of the fire event. At this time, some lobbies, in particular Level 10 are described as *'incredibly hot'*. Lobbies on Levels 6 - 10 are described as containing smoke hotter than the stair. The stair at Level 10 is also described as *'boiling hot'* with thick heavy smoke and severe heat reported between Levels 2 to 20. The people who were able to evacuate, and importantly willing to evacuate in such conditions, came from multiple floors, from Level 3 to 23.

d) The heat and smoke in the lobbies and stair effectively created a barrier to residents on any level and so impacted on their ability and/or willingness to move from their flats down the stair to a place of safety.

e) Between 03:00 and 08:07 when the last person escaped, a total of 35 people evacuated the building:

i. Between 03:00 and 03:55, 24 people evacuated from Levels 12 and above. Five people evacuated from Level 12 and 19 people from Levels 15, 16, 18, 21 and 22. This indicates that conditions on the stair could not have been such that the stair lights on Level 13 -16 were melting at that time. I consider this to be significant evidence which suggests that the 'hot spot' may have been a temporary earlier condition, at around 02:00 – 02:15.

ii. After 03:55, 11 more people escaped but from Levels 10 and 11 only. I note the lobbies on these Levels described as inaccessible by LFB prior to this time (Level 10 around 02:58 and Level 11 around 03:20).

19.3 Conditions required for safe means of escape

19.3.1 To describe conditions required for means of escape I have referred to '*The Application of fire safety engineering principles to fire safety design of buildings – part 6: human factors: life safety strategies – occupant evacuation, behaviour and condition* (PD 7974-6:2004).

19.3.2 Section 6.1 of PD 7974-6:2004 provides the following description of 'untenable conditions' for occupants:

"Untenable conditions occur when it is predicted that an occupant inside or entering an enclosure is likely to be unable to save themselves (is effectively incapacitated) due to the effects of exposure to smoke, heat or toxic effluent.

The psychological and physiological effects of exposure to toxic smoke and heat in fires combine to cause varying effects on escape capability, which can lead to physical incapacitation and permanent injury or death."

19.3.3 The loss of tenability in a space for a person to escape is considered by PD 7974-0 '*Application of fire safety engineering principles to the design of buildings Part 0 Guide to design framework and fire safety engineering procedures*' (6.7.2.2) to be caused by:

a) Loss of visibility;

b) Exposure to toxic and irritant products;

c) Exposure to heat;

d) Structural failure.

19.3.4 I did not observe any structural failure in the lobbies or single protected stair of Grenfell Tower therefore I have only described items a) to c) further here.

19.3.5 PD 7974-6:2004 provides tenability criteria, it describes the basis of criteria for tenability:

"With regard to hazard assessment and tenability criteria, the major considerations with respect to means of escape and life safety are as follows:

a) the psychological effects of seeing fire effluents on escape behaviour in the absence of direct exposure;

b) the psychological and physiological effects of exposure to heat and toxic smoke on escape behaviour and ability;

c) the point where exposure results in incapacitation;

d) the point where exposure results in death.

In a design context, the important considerations with respect to psychological and physiological considerations are to set reasonable tenability limits for occupants to remain in a place of relative safety or to use a particular escape route, and to determine the likely effects of any exposure sustained on escape capability and subsequent health."

19.3.6 The tenability criteria for each of these parameters is defined in Annex G of PD 7974-6:2004. Where these limits are exceeded in an escape route an occupant may be unable to use that escape route due to psychological effects. Their escape may also be unsuccessful due to immediate physical effects (incapacitation or death). If they do escape through the space, they may experience injury and/or subsequent health effects.

19.3.7 I have summarised the recommend limits of tenability for safe use of an escape route in PD 7974-6:2004, Annex G here:

a) Visibility criteria: Table G.1 recommends 5m visibility for small or domestic enclosures;

b) Exposure to toxic and irritant products: requires specific calculation - as a guide Table G.2 recommends less than 125 ppm of Carbon Monoxide;

c) Exposure to heat: Table G.3 advises that radiation exposure from a hot smoke layer above a person should not exceed 2.5kW/m^2 (approximately 200°C). Where a person has to pass through smoke the temperature should not exceed 60°C (convected heated).

19.3.8 In the following sections I have described the effects of visibility, toxicity and heat on humans, as described in PD 7974-6, as well referring to the Society of Fire Protection Engineering Handbook 5th edition and other referenced peer reviewed scientific journal papers.

19.3.9 **Visibility**

19.3.10 Section 61 of the SFPE Handbook (5th edition) presents research into how loss of visibility can affect human behaviour when in a building affected by fire. This research shows that people move more slowly when visibility is poor.

19.3.11 Specifically, as indicated in Figure 19.1 below, when poor visibility is caused by smoke, people will move even more slowly when compared with poor visbility not caused by smoke. For example, for the same illumination (1 Lux) walking speed of the elderly would reduce from 1.3m/s without smoke to

1m/s with smoke. This research also indicates that the slowing effect of poor visibility is more acute in older people compared to younger people.

19.3.12 A summary of the relevant conclusions of the research presented in Section 61 of the SFPE Handbook are:

a) The visibility in smoke from fire depends on its irritating nature for the person, as well as the optical density through the smoke.

b) Smoke that is more irritating (see sensory irritants in the following section) causes a greater drop in visibility because it causes irritation to the eye.

c) There are various indirect effects of smoke on visibility, i.e. dark smoke adhering to surfaces which can block light sources, dark smoke absorbing light that would otherwise be reflected and thus reducing the visibility of emergency signage; hot smoke destroying light sources and signs.

d) Travel speed of people in low light conditions is substantially reduced. This effect is more apparent when smoke is also present.

e) The travel speed of older people is reduced more than that of younger people.

19.3.13 In addition to the above, PD 7974-6:2004 Section 6.3 describes the effect of poor visibility as causing a proportion of people, approximately 30%, to turn back rather than continue through smoke-logged areas. Therefore, the presence of visible smoke impacts people's willingness to evacuate.

19.3.14 Therefore, how visibility presented within the protected lobbies and stair case and the extent to which visibility deteriorated as result of the multiple internal flat fires ignited by the external fire, is relevant to how both lobbies and stair failed to act as means of escape. It is also relevant to how the lobbies and stair failed as a means of access for LFB to the fire main, and to provide a safe place to rescue occupants.

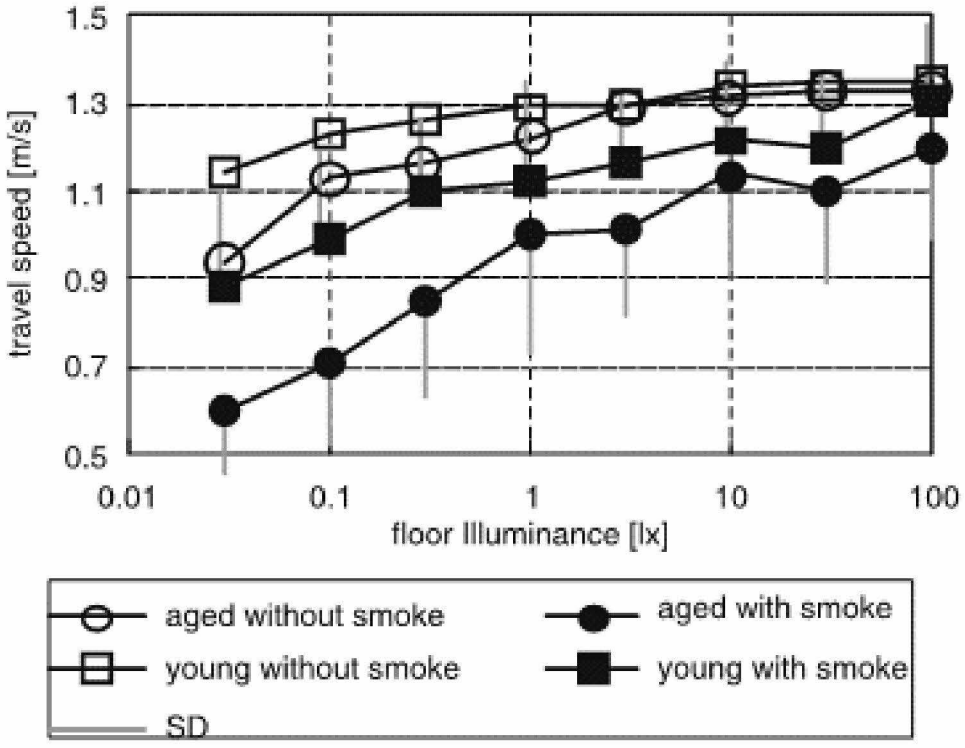


Figure 19.1 Illuminance and travel speed in smoke (Excerpt from SFPE Handbook Fig 61.20)

19.3.15 Smoke Toxicity

19.3.16 The SFPE handbook 5th Edition p. 2249 describes the effect of sensory irritants in the products of fire (smoke) on humans as follows:

"Unlike the incapacitating effects of asphyxiants, which are clear-cut and well understood, the incapacitating effects of irritants are much more difficult to determine … Irritant fire products produce incapacitation during and after exposure in two distinct ways. During exposure the most important form of incapacitation is sensory irritation, which causes painful effects to the eyes and upper respiratory tract and to some extent also the lungs. Although exposure may be painful and thus incapacitating, it is unlikely to be directly lethal during exposure unless exceptionally high concentrations of irritants are present. However, the second effect of irritants penetrating into the lungs is an acute pulmonary irritant response, consisting of edema [oedema] *and inflammation, which can cause respiratory difficulties and may lead to death 6–24 h after exposure"*

19.3.17 The SFPE handbook 5th Edition p. 2265-66 describes the effect of toxic gases produced during a fire on humans as follows:

"The effects of asphyxiant fire gases are not instantaneous as with sensory irritant, but develop when a sufficient dose has been inhaled. The main asphyxiant gases in fire effluents are CO and HCN. The effects of these gases, consisting of tissue hypoxia are additive, and combine to some extent with

direct low oxygen hypoxia. Carbon dioxide increases the rate of uptake of CO and HCN, and itself causes narcosis after a few minutes inhalation at concentrations above approximately 7 %CO2. The combined effect of exposure to these gases is to cause incapacitation (loss of consciousness) during exposure above a critical dose threshold.

After a further few minutes as inhalation continues this is followed by death from respiratory and cardiac arrest."

19.3.18 The SPFE Handbook provides further information on effect of sensory irritants and asphyxiant gases (at pp. 2231, 2232, 2301), which I have summarised below:

19.3.19 **Effect of CO (Carbon Monoxide) and HCN (Hydrogen Cyanide)** – These are both asphyxiant gases, the effect of which is to decrease the oxygen content, and increase the carbon dioxide content of blood. This can result in central nervous system depression thus causing reduced awareness, intoxication, and so reduced escape capability. In can also lead to loss of consciousness and also death in high dose cases. Hydrogen Cyanide is more potent (20-40 times) than Carbon Monoxide. The amount needed of Hydrogen Cyanide to be inhaled to cause collapse is a much smaller than the amount of Carbon Monoxide to be inhaled for collapse.

19.3.20 **Effect of NO2 (Nitrogen Dioxide) and HCL (Hydrogen Chloride)** – are both sensory irritants. These are irritants which impair escape efficiency or cause incapacitation (sensory irritation). The symptoms occur immediately upon exposure (at least at painfully irritant concentrations), consisting of a burning pain, followed by a characteristic breathing pattern consisting of a pause at the end of each inspiration, which results in reduction in breathing rate. Sensory irritants also cause pulmonary oedema and inflammation of the lungs, which can lead to infection.

19.3.21 Additionally, exposure to low oxygen can lead to seizures. A visible symptom of seizures, caused by smoke exposure sufficient to create fluid build-up in the lungs (pulmonary oedema), is foaming at the mouth. There is evidence this occurred in Grenfell Tower (Firefighter Fernandes (MET000083292)).

19.3.22 Stec and Hull (2011[1]) measure the following asphyxiate and irritant gases from polyisocyanurate, phenolic and polystyrene insulation: carbon monoxide, hydrogen cyanide, hydrogen chloride and nitrogen dioxide. Celotex RS5000, TB4000 and Kingspan TP10 are all Polyisocyanurate. Kingspan K15 is phenolic. Styrofoam is polystyrene. The Reynobond 55 PE ACP panel contained polyethylene.

19.3.23 Using these measurements, Stec and Hull calculate the material toxicity using the 'LC_{50}' metric. 'LC_{50}' is the concentration lethal to 50% of the population. The smaller the value of 'LC_{50}' for a given material the greater the toxicity of

[1] Stec and Hull, 2011, Assessment of the fire toxicity of building insulation materials, Energy and Buildings, 43 (2-3), pp. 498-506 (2011)

the gases produced by the material. The values they have calculated from their measurements for a well-ventilated flaming fire are reproduced in Table 19-1.

19.3.24 This shows that well-ventilated burning of 16.5g of PIR (for example burning externally) will produce $1m^3$ of lethal gases. Under the same conditions 43.3g of phenolic insulation will produce $1m^3$ of lethal gases and 28.4g of polystyrene will produce $1m^3$ of lethal gases.

19.3.25 Therefore, the externally burning polymeric materials, produced toxic gases, the potential effects of which I have described above.

19.3.26 How the toxic gases from the external wall fire was able to spread in the early stages to flats and then to the protected lobbies and spread from there to the protected stair is relevant to the failure of both to provide a means of escape, and a safe area to exercise rescue.

Table 19-1 reproduction of the LC_{50} calculations for PIR, phenolic, polystyrene and stonewool insulation materials by Stec and Hull (2011[2])

Material	Fire conditions	LC_{50} (g/m^3)
Polyisocyanurate (Celotex RS5000, TB4000 and Kingspan TP10)	Well-ventilated	16.5
Phenolic (e.g. Kingspan K15)	Well-ventilated	43.3
Polystyrene (e.g. Styrofoam)	Well-ventilated	28.4

19.3.27 **Heat stroke**

19.3.28 The SFPE handbook 5th Edition pg 2374 describes the human effect of a hot environment experienced during a fire:

"If a subject is exposed to a hot environment, especially if the humidity is high and the subject is active, there is a danger of incapacitation and death due to hyperthermia. The time to effect and the type of hyperthermia depend principally on the heat flux to which the subject is exposed and are greatly affected by factors such as the amount and type of clothing and degree of work performed."

19.3.29 The peak temperatures estimated to have occurred in the stair between Levels 13 and 16 exceeded 150°C (Section 14.4). High temperatures were also experienced in the lobbies as shown by my post fire damage survey and fire fighter witness statements (Section 14.6).

[2] Stec and Hull, 2011, Assessment of the fire toxicity of building insulation materials, Energy and Buildings, 43 (2-3), pp. 498-506 (2011) - See Appendix B

19.3.30 I have extracted in Figure 19.2 and Figure 19.3 data on human tolerance of heat as a function of time. The human tolerance time of temperatures below 121°C is limited by hyperthermia, that is where the core body temperature > 40°C. Above 121°C the tolerance time is limited by skin pain.

19.3.31 Therefore, for temperatures in excess of 150°C persons at rest can tolerate these temperatures on unprotected skin for no more than 4 minutes. I have over-marked this in Figure 19.2. It should be noted this is not a time to lower pain threshold. Under these conditions skin pain and potential skin and respiratory tract burns would be experienced.

19.3.32 Where a person has to walk through smoke, as opposed to walking or crouching beneath a hot smoke layer, the recommended tenability limit of the smoke one is passing through is 60°C. This is less than the minimum 150°C temperatures that appear to have occurred in the Level 13 -1 6 hot spot in the stair of Grenfell Tower.

19.3.33 The heat conditions - recorded in London Fire Brigade witness statements, and resident witness statements, along with the damage recorded by me in my post fire site inspections - would therefore have presented a significant barrier to the residents, should they have been capable of evacuating from their flats.

19.3.34 There is evidence that, despite the heat entering their flats directly from the cladding fires, the fear of the conditions in the lobby prevented residents from making an attempt to reach the stairs, when eventually told to do so.

19.3.35 Therefore, how the protected lobbies became so hot and how that heat was able to enter the stair case, is relevant to the failure of both to provide a means of escape and provide a safe working area for rescue by the fire fighters.

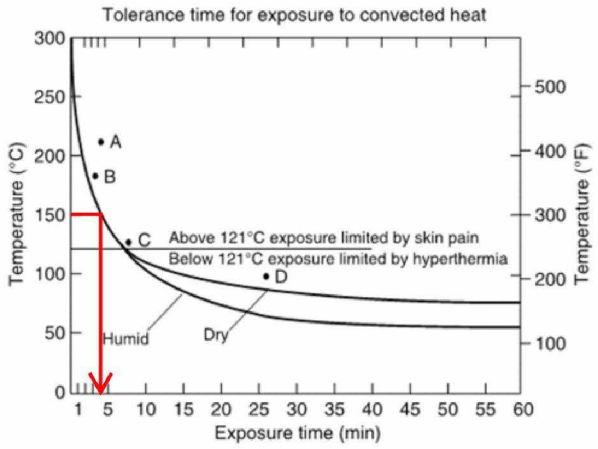


Fig. 63.28 Thermal tolerance for humans at rest, naked skin exposed, with low air movement (less than 30 m/min) (Adapted from Blockley [111]. See text and Table 63.17 for discussion of data points A to D) [110, 113, 114]

19.3.36

Figure 19.2: Thermal tolerance for humans at rest, naked skin exposed, with low air movement reproduced from SFPE Handbook 5th edition (Figure 63.28)

Table 63.17 Reported tolerance times for exposures to hot air

Temperature (°C)		Time (min)		Reference	Letter in Fig. 63.28
Dry air					
	110	25		Simms and Hinkley [110]	D
	180	3		Simms and Hinkley [110]	B
	205	4	Bare headed, protected	Veghte [113]	A
	126	7		Elneil [114]	C
Humid air	32 at 100 % RH	32	Men working	Leithead and Lind [115, 116]	

Figure 19.3: Reported tolerance times for exposures to hot air SFPE Handbook (5th edition) Table 63.17

19.3.37 Summary

19.3.38 The poor visibility present in the lobbies and stair would have reduced the speed at which people could travel therefore increasing the time required to make an escape. The duration of exposure to the products of fire (smoke and heat) would therefore increase. This is in addition to the difficulties in way-finding for escape and search and rescue presented by reductions in visibility.

19.3.39 These factors on their own, or in combination, would discourage residents from evacuating independently. This is of particular concern when considering the very large reduction in evacuation rates after 01:40, compared to the first 40 minutes in the fire (before 01:40).

19.3.40 The effect of heat - where temperatures exceeded 150°C - can be tolerated for only very short periods of time (3-5 mins), if at all, by very young or elderly persons. They would cause immediate pain to any exposed skin.

19.3.41 Based on my post-fire site inspections these temperatures appear to have occurred for a time in the stair over Levels 13 -16 and within all lobbies on Level 5 and Levels 7 -23.

19.3.42 It is possible that someone moving at speed may have been able to escape through these conditions, or be carried through by fire fighters in protective clothing. However, the immediate physical pain caused by these temperatures would, if occurring whilst people were attempting to escape have also prevented some individuals from either leaving their flats and entering the lobby or attempting to enter the stair between Level 13 – 16 or descend below Level 16 where one was already in the stair.

19.3.43 Toxicity – Fire smoke, which the lobbies and stair became filled with, contains a number of toxic asphyxiate gases in potentially lethal concentrations and sensory irritants:

(a) The asphyxiant gases could slow escape by reduced awareness or cause incapacitation or death.

(b) The sensory irritants, which cause immediate symptoms on exposure, could slow evacuation by impairing vision, causing a burning pain, reducing breathing rates and causing pulmonary oedema (a build-up of fluid in the lungs).

19.3.44 The combination of poor visibility and sensory irritants when residents opened their flat entrance doors to try and enter lobbies, would have been a significant deterrent to escape. The resident evidence to date demonstrates this was the case. When residents were told to Stay Put - the lobby conditions would have emphasised to some that this was indeed the safer option.

19.3.45 From the evidence of 999 call transcripts I have reviewed (Section 20), once the Stay Put guidance changed, poor visibility and sensory irritants appear to have been a substantial deterrent for many residents when considering their own evacuation. In conditions where a major flame front was entering the flat in which they were located, many residents appear to have been too overwhelmed with what faced them in the lobbies to make their own way out of the building.

19.3.46 The evacuation rates from the building became the slowest after 3am and evacuation ceased above Level 13 after 03:55. Evidence presented in Section 20, describes the consequences for residents sheltering within flats during this time.

19.4 Conditions required for fire fighting

19.4.1 In Section 3 and Appendix H, I have set out a summary of the standard operational procedures for the fire and rescue services in fighting fires in high rise buildings, based on the guidance in GRA 3.2 and in the 2008 Incident Command manual.

19.4.2 This is to help me understand how the stairs and lobbies are used by fire fighters, and the working conditions they require.

19.4.3 In summary, the first approach is described as follows:

(a) On arrival the Incident Commander appraises the situation and defines operational objectives.

(b) A water supply is secured and connected to the dry rising main.

(c) 2 crews use the firefighting lift to go to the firefighting lobby 2 floors below the fire.

(d) A Bridgehead is established in the lobby 2 floors below the fire in a safe air environment.

(e) A crew is tasked with approaching the fire and dons breathing apparatus in the Bridgehead.

(f) The first crew uses the firefighting stair to reach the firefighting lobby on the floor below the fire and connects a hose to the rising main outlet there.

(g) The first crew moves to the fire floor with a charged hose using the firefighting stair and is tasked with fighting the fire.

(h) A second crew dons breathing apparatus in the Bridgehead and heads to the fire floor to connect into the rising main there and is tasked with protecting the first team.

19.4.4 The Incident Command manual also provides guidance on how control of fire incidents in high rise buildings should be broken down into operational sectors. As described on Page 25 of the Incident Command manual:

"Sectorisation should be introduced when demands placed upon an IC make it imperative that responsibility and authority are delegated to ensure appropriate command and safety monitoring of all activities, and to reduce officer' spans of control. Even if it is possible for the IC to oversee all operations, the need to sectorise will arise if there is so much going on that the IC risks being distracted and unable to give sufficient attention to each task. This would indicate that the IC's span of control is in danger of becoming too great. Where spans of control begin to reach or exceed 5 lines of direct communication t a working incident, it is possible that performance will be adversely affected."

19.4.5 The fire sector for Grenfell Tower was defined by Incident Commander O'Loughlin (MET00005213) at approximately 02:15 as all floors above the Bridgehead. At this time the Bridgehead was located at Level 03 (Section 14) therefore, the fire sector in Grenfell Tower was Level 03 – 23.

19.4.6 Therefore, whether sectorisation is in place or not, the following was required in the stair and lobbies of Grenfell Tower for fire-fighting operations:

a) the firefighting stair and lifts are required to provide a safe air environment to reach the Bridgehead which is typically located in the lobby two floors below the fire floor.

b) The lobbies below the fire floor are required to provide a safe air environment to act as the Bridgehead.

19.4.7 The stair above the Bridgehead, which is only accessed by crew in breathing apparatus, is required to provide tenability for crews to work which includes finding and connecting hoses to fire mains and the carry down of any occupants rescued.

19.4.8 Firefighting crew wear breathing apparatus and protective clothing to help increase time in untenable conditions (see Section 19.3).

19.4.9 Specifically, for firefighting, how smoke and heat was able to enter the lobbies is relevant to their failure to be a safe air environment for the LFB Bridgehead.

19.4.10 During the period of active FSG calls from above Level 13i.e. 01:21 to 03:33 (LFB00004695), the Bridgehead was positioned at Level 2 up to 02:17, Level 3 until 03.08 and at ground level after that.

19.4.11 This extended the time required for fire fighters to reach the upper levels of Grenfell Tower, reducing the time available for firefighting and search and rescue when they reached those levels.

19.4.12 Above the Bridgehead, how smoke and heat was able to enter the lobbies on multiple floors as well as the stair, is relevant to the failure to provide a safe place of work for LFB to undertake firefighting and search and rescue operations on those levels:

a) The reduction in visibility caused by smoke limited the ability of fire fighters to find the fire main within the lobbies, as well as limit the ability to access flats easily. As they were so reliant on breathing apparatus, again due to the presence of smoke throughout, any additional time lost on tasks was time lost for rescue.

b) It also slowed the speed at which they were able to ascend the stair. From the fire fighter witness statements reviewed (see my Section 14) poor visibility also appears to have caused confusion and specific issues regarding orientation within the Grenfell Tower. This affected their ability to conduct time effective search and rescue operations, as well as impact their ability to communicate conditions accurately to the Bridgehead.

c) The communication between the Bridgehead and Control was critical regarding the rescue actions required, and location specific advice was very critical. Difficulties with orientation within the building also impacted on this process.

d) The extreme heat experienced within the stair and some of the lobbies, prevented the fire fighters from reaching the fire main to undertaking firefighting. It also added to the physical stress experienced by having to ascend up to 16 stories or so, above the Bridgehead in breathing apparatus.

e) Although the toxicity of smoke should not have affected fire fighters directly, due to their breathing apparatus, it limited their time available for rescue due to their high reliance on breathing apparatus.

f) It also impacted on their ability to rescue with respect to exit time from the building with rescued residents – the toxic smoke increasing the need for the fire brigade to physically support and even carry down residents due to toxic smoke impairing residents' movement in the stairs.

19.5 How the protected lobbies failed

19.5.1 Lobby Enclosure

19.5.2 The enclosure of the lobbies of Grenfell Tower, that is the walls separating it from the flats, were required to be fire resisting. Openings for flat entrances were required to be protected by doors with fire resistance and smoke leakage performance.

19.5.3 Risers (vertical shafts) penetrating the lobbies were also required to be protected shafts and so enclosed by fire resisting walls. The required protected risers in Grenfell Tower included the smoke control system ventilation shafts, the lift shafts and the refuse chute. Openings in the walls of the protected risers were required to be protected by fire resisting construction with smoke leakage performance where applicable.

19.5.4 Each are described in the following sections.

19.5.5 **Lobby Enclosure – flat walls**

19.5.6 As I have explained in section 15 of my report, the walls separating flats from the lobby were compliant with the statutory requirements. Furthermore, during my site inspections I did not find any sign of failure of the walls separating the flats from the protected lobby. Therefore, the construction of the internal walls separating flats from the lobby do not appear to have been a cause of failure to control the spread of fire and smoke.

19.5.7 **Lobby Enclosure -Lobby fire doors**

19.5.8 During my site inspection I did find that the flat entrance fire doors, which in general were of composite form, were destroyed or partially destroyed where an internal flat fire had occurred. I also observed heavy spalling to the surface of the concrete ceiling directly in front of these doors, on the flat side.

19.5.9 I have assessed the Masterdor Suredor composite door flat entrance doors, currently understood to have been installed to 106 flats on Level 04 -23 in 2011-2012 (MAS00000003) as non-compliant with the current statutory guidance (Section 15.5 and Appendix I).

19.5.10 Their non-compliance would have contributed to the failure to prevent the spread of:

a) fire and hot smoke from the internal flat fires ignited by the external fire; and

b) hot smoke from the lobbies to flats not yet affected by the external fire or smoke.

19.5.11 I have shown that the installed doors differed substantially in their assembly from the door for which the FD30 BS476-22 test report relevant at the time of installation, has been disclosed. No test report to certify cold smoke leakage performance has been disclosed.

19.5.12 As I identified in Appendix J, Grenfell Tower was not installed with a pressure differential system compliant with BS EN 12101-6. Smoke leakage performance was therefore required on all doors to flats opening directly onto every lobby.

19.5.13 The installed doors contained different locks, hinges, letter plates and self-closers. These metal fittings, which are embedded into the door, can significantly affect the performance by reducing the time to burn through the

door. Therefore, the installed doors may have prematurely burnt through around these untested fittings.

19.5.14 The installed doors contained glazing not included in the disclosed fire door test report. This untested glazing could fail prematurely allowing fire and smoke to vent directly through the door.

19.5.15 The installed doors contained different intumescent seals. These seals are intended to seal the gaps between the door leaf and its frame to prevent passage of smoke and flame. This is in addition to the lack of certification for cold smoke leakage performance. This means that it may have been possible for fire and smoke to vent through the gaps in the door set in the early stages of the fire.

19.5.16 BRE Global, on behalf of the MPS, conducted a fire resistance test of a Masterdor suredor flat entrance door from Grenfell Tower on 13/02/2018 to BS EN 1634-1:2014 (MET00019996). The sample door tested included a glazed panel. In this retrospective test the door achieved 15 minutes integrity fire resistance; half the required duration for compliance with ADB 2010.

19.5.17 This therefore confirms my assessment that the differences between the door assembly tested in the original fire test report and the doors installed in Grenfell Tower, would have resulted in a lower fire resistance performance.

19.5.18 For 14 flats (12 leaseholders and 2 tenanted) on Levels 8, 9, 11 – 14 and 17 – 23, it is believed the original fire doors were retained. The performance of these doors is unknown. All of these doors were destroyed during the fire, therefore it was not possible for me to survey their construction.

19.5.19 Concealed door closers were noted on all eight of the flat main doors surveyed by my site inspection team. These were all disconnected at the time of our survey.

19.5.20 Resident and caretaker evidence states that faulty door closers were frequently disconnected and never replaced. This is corroborated by photographs disclosed by the MPS dated 17/06/2017 (three days after the fire) which show that door closers were disconnected (on every flat on level 4, Flat 35 on Level 6 and Flats 41, 42, 43 on level 7.

19.5.21 One overhead door closer and one concealed door closer were observed in photographs disclosed by the MPS dated 17/06/2017 (three days after the fire) for Flats 23 (MET00018892) and Flat 34 (MET00018847) respectively. This is the only evidence I have to date that any door closers on levels 4-23 were connected on the night of the fire.

19.5.22 The lack of effective door closers is non-compliant with ADB 2010 (and the LGA guidance). The evidence suggests this was a post-handover maintenance issue and I will incorporate that aspect in my investigations in Phase 2.

19.5.23 Self-closing devices that were not installed, disconnected or not maintained would result in flat doors not closing automatically behind escaping

occupants. Where doors failed to close, such doors would provide no barrier to the spread of fire and smoke.

19.5.24 The operation of these fire doors was reliant on the escaping person closing the door behind them. I have found evidence of some residents closing doors behind them and other residents not closing doors behind them as they escaped from the building (Section 15).

19.5.25 Fire doors are required to perform when closed, and to perform when opened – i.e. to close automatically. Both performances are important during a fire for limiting fire and smoke spread from a flat out to the lobby, and from a lobby into other flats.

19.5.26 If a resident left early and the door did not close behind them, this would have consequences for the conditions in the lobby on that floor.

19.5.27 Any resident who did not self-evacuate, for example before 01:40, became reliant on their flat entrance fire door to protect them from ever increasing quantities of fire and smoke that could leak into their flat from the lobbies.

19.5.28 Therefore, I consider the evidence demonstrates that it is most likely that the flat entrance doors in Grenfell Tower failed to control the spread of fire and smoke to the lobby by:

a) Failure to prevent the spread of smoke and flame by leakage through gaps between the door leaf and door frame. This could occur early in the development of fire within the flat but also early in the smoke spread development from the external wall fire, prior to any flat fire.

b) Failure of the fire door to resist the spread of fire and smoke from a flashover fire within an apartment due to the presence of multiple untested components within the doors – all 106 doors. (Note retrospective testing by BRE Global, which included untested components such as the glazing, has demonstrated that these reduce the fire resistance of the door to half of that required for compliance with ADB 2010).

c) Failure of the fire door to resist the spread of fire and smoke from a flashover fire within the apartment due to the presence of glazing in the fire door which would be expected to cause failure early in the development of a fire within the flat. A total of 48 doors were specified with glazing by Manse Masterdor out of 106 doors; although the BRE have advised me that they observed 29 doors with glazing and it was unknown whether a further 29 doors had glazing or not.

d) Failure of an unknown number of doors to self-close after an occupant escape. Fire and smoke spread to the lobby would then be immediate from the flat to the lobby. In Section 20, I show how many occupants left early, and their location. Any failure of those fire doors at that time, would have had serious consequential effects on the lobbies.

19.5.29 The fire doors also failed in a second way; to resist the spread of fire and smoke from the lobby – given that fire doors are required to perform in both directions. This became increasingly important, when occupants stayed put in their flats, or travelled to a neighbour's flat and stayed there (See section 14.6).

19.5.30 Whilst it is noted that the fire performance of the flat entrance doors FD30S is not intended to provide indefinite and therefore complete protection to the lobbies (ADB 2013 B1.viii), they are intended to provide protection from flames, smoke and gases (ADB 2013 B1.ix) i.e. growing fires and flashover fires within the flats.

19.5.31 The non-compliances I have found on site, relative to the test evidence provided, together with the retrospective testing of the flat front entrance doors by BRE Global, means I must conclude that those doors could not function as they were required to do in accordance with Approved Document B 2010.

19.5.32 Further, I consider the evidence of sufficient quality to allow me to conclude that the fire doors and their lack of performance, contributed significantly to the spread of smoke, and fire, to the lobbies. This failure would have materially affected the ability and/or willingness of occupants to escape independently through this space to the stair.

a) As I have explained in Section 19.3 smoke containing sensory irritants would have caused immediate effects for anyone entering a smoke filled lobby.

b) Where substantial heat was able to enter the lobby, temperatures over 121°C would have caused immediate pain to exposed skin, whereas temperatures below this would have caused hyperthermia over a period of exposure. Substantial heat within the lobbies could also have prevented fire fighters from reaching the fire main, which was located directly outside a flat entrance door (Flat 3 on Levels 4 - 23).

c) Poor visibility due to the presence of thick black smoke, which obscured the stair door several meters from the flat entrance doors, may have also prevented occupants from attempting to escape through the lobbies to the stair. For example the Flat "1"s are only 5.5m from the stair door.

d) The failure of the flat entrance fire doors to control the spread of fire and smoke from flats to the lobbies also materially affected the operations of LFB:

    i. As I have explained in Section 19.4 this meant these lobbies could not be used as a safe air environment for the LFB Bridgehead and so forced the Bridgehead to remain at or below Level 04 until 08:30. This greatly reduced the time available using breathing apparatus, and so the time available for rescue on upper floors, and particularly above level 15.

ii. Above the Bridgehead it affected ability of LFB to conduct search and rescue operations in the poor visibility of the lobbies. It also materially affected LFB's ability to locate and operate the fire main which they could have used to cool the lobbies

iii. As the rescue needs increased, with for example the peak of FSG calls under way between 03:00 and 03:15 (MET0004695) when there were 27 active calls, the fire fighter numbers beyond the bridgehead had dropped to 13 at 03:00 (LFB00023326). This had serious consequences for any potential rescues during this time.

19.5.33 Lobby enclosure - protected shafts

19.5.34 *Refuse chute* - The fire performance doors to the refuse chute is unknown, however during my site inspection, I have found no evidence that fire and smoke either entered or spread via the refuse chute. Therefore, I have not investigated this further.

19.5.35 *Smoke ventilation shafts* - The North and South ventilation shafts for the smoke control system penetrated every lobby of Grenfell Tower. The AOVs created an opening between the lobby on the shafts on every level of Grenfell Tower.

19.5.36 I can find no evidence a fire resistance or smoke leakage performance was specified for the AOVs or the ventilation shafts by PSB or any other party.

19.5.37 I have found evidence that the AOVs installed as part of the smoke control system were to a lower standard of smoke leakage performance than required by BS EN 12101-6 (see Appendix J). The AOVs installed were tested to the standard required for a natural ventilation system, not a powered system using pressure differentials. Powered smoke extract AOVs are required to meet the smoke leakage criterion when tested exposed to higher pressures.

19.5.38 Therefore, the lower standard of AOVs could have allowed more smoke to leak from the shafts into other lobbies, than may have been the case with a compliant AOV. This could have contributed to the internal spread of smoke in Grenfell Tower. If the AOVs did allow more smoke to leak into other lobbies, this would be a critical failure as the ventilation shafts connect every lobby in Grenfell Tower.

19.5.39 To date, I have found no evidence that the design team tested the ventilation shafts, which were constructed from blockwork (builders work shafts), for leakage as required by BS EN 12101-6:2005 and the Smoke Control Association document *Guidance on Smoke Control to Common Escape Routes in Apartment Buildings (Flats and Maisonettes)* (The SCA Guide, PSB00001130).

19.5.40 *Lift shaft* - I have found no evidence fire resisting doors were specified for the lift doors by any party during the 2005 or 2012-2016 works, as required for a protected shaft.

19.5.41 Failure to vent smoke and heat from the lobbies

19.5.42 A smoke control system was provided in the lobbies of Grenfell Tower. The provision of smoke ventilation to the lobbies was required under design guidance applicable at the time of construction and also under current statutory guidance.

19.5.43 As I explain in Section 3, and Appendix J the purpose of smoke ventilation under the statutory guidance is to provide protection to the single escape stair, by removing smoke from the lobbies, in the event the fire doors do not operate.

19.5.44 I have described in Section 19.6, how the smoke ventilation system contributed by its failure to operate as intended on 14th June 2017.

19.5.45 Travel distance within the lobbies

19.5.46 Travel distances within protected horizontal escape routes are required to be limited because the enclosing structure does not provided protection indefinitely (ADB 2013 B1.viii).

19.5.47 I have shown in Section 15 travel distance through the lobby by occupants of Flat 5 or Flat 6 on Levels 4 – 23 exceeded the maximum distance recommended under the current statutory guidance – however it was compliant with the design guidance at the time of the building's construction.

19.5.48 During the time that all lobbies, except Level 4, remained free of hot smoke and gas, which was only up to approximately 01:18 (Section 14), the increased travel distance of 3m would have little effect on the ability of occupants to make their escape.

19.5.49 After this time and progressively through the night the lobbies became filled with smoke and heat. An increased travel distance of even just 3m has the effect of prolonging the duration of exposure to heat, toxic products and irritants, reducing the visibility of the stair exit door and increasing the difficulty in way-finding.

19.5.50 However, the effect of an increased travel distance within the lobby appears at this stage, not to have had a dominating impact on the failure of the lobbies in providing a safe means of escape for the fire that occurred at Grenfell Tower. The presence of smoke and heat and the poor visibility are likely to have been the primary deterrents for residents.

19.5.51 Provisions for persons requiring assistance to escape

19.5.52 Levels 3 – 23 of Grenfell Tower, which were residential only, were not required by ADB 2013 to be provided with provisions for occupants that require assistance to escape (i.e. refuges or emergency voice communication). However, the introductory text of ADB 2013 does acknowledge that in some circumstances a lift may be provided as part of a management plan for evacuating people and that a firefighting lift may be used for this purpose.

19.5.53 The 2016 Fire Risk Assessment for Grenfell Tower (LFB00000066) describes the potential use of the lobby lifts as a means of evacuation of persons requiring assistance by the fire and rescue services. As I have explained in Section 18, BS9991 which also provides guidance on this topic and explicitly states that evacuation should not be reliant on the intervention of the fire and rescue service. I explain in Appendix L and 19.5.58 below that these lifts were not available to London Fire Brigade as they failed to operate under their control during the fire incident.

19.5.54 The currently available evidence indicates a concerning lack of provisions for persons who require assistance, which requires further investigation. However, for any persons requiring assistance to escape, the deteriorating conditions within the lobbies would have prevented their use as a refuge as part of any escape plan. Refuges are used in other building types (for example offices), to wait for the lift or wait for rescue down the stairs.

19.5.55 As I have described in Sections 15 and 18, any persons requiring assistance from the fire fighters for evacuation using the lift (assuming it had been operable and was a full fire fighting lift), would have been required to wait in the lobby.

19.5.56 However, the conditions within the lobbies became untenable and therefore this method of refuge was not possible. In this respect the lobby failed to provide a means of escape for persons requiring assistance to evacuate.

19.5.57 It should also be noted that rescue using the lobby lift would only be safe where it was designed as a firefighting lift. The lifts in Grenfell Tower do not appear to have been designed as firefighting lifts but instead appear to be what is termed *fire lifts* (see below), which have a lower standard of performance. This meant there was no way to exit, unless rescue direct from a flat could occur. I have explained the serious impact the conditions on the lobbies and stairs had on rescue potential above.

19.5.58 **Fire lifts**

19.5.59 Based on the documentation assessed (Appendix L) the lifts within Grenfell Tower were not designed in accordance with the requirements for a fire-fighting lift as described in ADB 2013 (the most recent refurbishment works to the lifts were conducted in 2014-216).

19.5.60 In my preliminary Phase 1 report I concluded that the lifts did appear to have been provided with the features consistent with a *fire lift* as described in CP3 (the original design guidance available at the time of construction).

19.5.61 This is a lower standard of performance which lacks a secondary power supply, water ingress protection or FD60 performance for the lift landing doors. It does provide a fireman's switch, which automatically grounds the lift and stops it from being called to other floors by building occupants.

19.5.62 This lower standard of fire lift is not typically used by fire fighters to transport anything other than equipment due to safety concerns during a fire.

19.5.63 On the 14 June 2017, fire fighter contemporaneous notes (MET00005384) describe the failure of the ground level fireman's switch to recall the lift or alter its control to firefighting mode during the initial response to the flat 16 fire on Level 4.

19.5.64 Further evidence has now been provided through CCTV footage and oral evidence from Firefighters Secrett, Badillo and Brown (Appendix L). This confirms that Firefighter Secrett attempted to use his drop key to operate the ground floor fire control switch, but the switch failed to engage.

19.5.65 CCTV evidence from the lobby confirms the lifts continued to operate as normal lifts, that is, not under firefighter control. Specifically, residents were able to continue to call the lifts using the landing controls with the effect that residents used the lift during the fire, and firefighters using the lift were called to floors they had not selected.

19.5.66 The significant findings from the 2016 risk assessment (TMO10017691) note that the fireman's switch was at that time located at Level 2 and was required to be moved to ground. I observed a switch at ground level and one at Level 2.

19.5.67 Further evidence has now been provided on these switches from a site investigation by WSP on behalf of MPS. This investigation has provided evidence that the Level 2 fire control switch was not connected and so could not be used to control the lifts.

19.5.68 The switch at ground level was connected, but the mechanical mechanism was seized and could not be operated by WSP. It could not be used to control the lifts. The current state of the evidence therefore indicates that neither switch could provide the fire service with fire control of either lift.

19.5.69 Further investigation is required in relation to the ground level fire control switch to establish if the switch, irrespective of the condition of the mechanism, was interfaced with one or both of the lifts and what control operation for the lift it would have provided.

19.5.70 This is necessary in order to confirm whether either of the lifts met the lower fire lift standard.

19.5.71 Whilst the lack of a fire fighting lift could have delayed the initial LFB response, the oral evidence from Firefighter Batterbee (28th June Day 12 at p41) confirms that the fire service did use the lift in normal operation to facilitate equipment transport to the level 2 bridgehead. In those circumstances, it appears that this non-compliance did not cause a delay to the initial fire fighting response.

19.5.72 However, all other operations by the LFB within the 23 storeys were required to be by means of walking up and down the stair only (including carrying their equipment). This would have increased the time required by the firefighters wearing breathing apparatus to reach the upper levels and reduce

the time available to them to undertake rescue operations. This was exacerbated by the very low position of the Bridgehead.

19.5.73 Failure of the fire control switch at ground floor, meant that the lifts continued to function as normal in the early hours of the fire. Had the fire control switch been operable, LFB could have used the fire control switch to isolate the lifts and so prevent residents from using the lifts during the fire.

19.5.74 This would have removed an unnecessary risk to residents. I note that Nadia Jafari (oral evidence Day 54 8th October 2018 at p45-57) lost her father during their evacuation from Level 11 to ground as a result of using the lift.

19.5.75 **Fire main**

19.5.76 A dry fire main was provided at Grenfell Tower instead of a wet fire main. This was non-compliant with the design guidance in force at the time of original construction, and is also non-compliant with current standards.

19.5.77 The fire main was located within the lobby and not within the stair. This was compliant with the design guidance available at the time of construction only.

19.5.78 There were no difficulties associated with the dry fire main position in the lobby during the LFB response to the initial fire in Flat 16, Level 04.

19.5.79 However, following the ignition of multiple internal flat fires by the external wall construction fire (which required LFB to operate multiple hoses on multiple levels), the operation of the dry fire main failed in two ways:

a) LFB was unable to get adequate water for firefighting from the dry main on the upper levels due to the lower capacity of the dry main system compared to a wet main system. This failure is relevant to the non-compliant installation of a dry fire main instead of a wet fire main.

b) The requirement for LFB to connect multiple hoses to fight the multiple internal fires meant the demand for water outstripped the capacity of the system. However, this failure is not relevant to the non-compliant installation of a dry fire main. Wet fire mains are also only designed to supply up to 2 hoses operating simultaneously.

19.5.80 In a wet riser, the system would already have been charged with a pump connected when LFB arrived. There would have been no operations required by LFB to find external hydrants, connect to their pumping appliance and connect to the riser inlet. Therefore, the provision of a dry main would have contributed to increasing the time required by LFB to get water to the initial fire event in Flat 16.

19.5.81 Therefore, a wet fire main could have enabled a faster initial response time to the fire in Flat 16 which might have increased the chances of extinguishing the fire before it spread externally. However, it cannot be asserted it would have absolutely achieved this.

19.5.82 A wet fire main, could have enabled greater water pressure for fire-fighting on the upper floors of Grenfell Tower, which may have allowed LFB to use water to cool lobbies and stair and therefore provide more assistance to people trying to escape.

19.5.83 Whilst the dry fire main failed for the fire service in controlling fire and smoke spread in the lobbies and stair and particularly on the upper levels, a wet fire main could also have failed to provide sufficient water and pressure to control fire and smoke spread once more than 2 hoses were in operation.

19.5.84 **General Provisions for Lobbies**

19.5.85 The general provisions with regard to headroom, flooring and refuse chutes all appear to have been compliant with the requirements of ADB 2013. I did not observe any failings relevant to these items nor find any evidence of their failing in the fire fighter witness statements. Therefore, in my opinion, these provisions did not contribute to the failure of the protected lobbies for occupant escape and fire fighter operations.

19.5.86 Emergency lighting appears to have been present within the lobbies. Based on the evidence currently available to me I do not know of any failures in the emergency lighting system.

19.5.87 The intent of emergency lighting is to provide lighting for escape in the event of power failure. It is not intended to provide illumination in a smoke filled environment. Therefore, once the lobbies filled with dark smoke the illumination of the emergency lighting would have reduced substantially if not to zero. Therefore, it is likely that the emergency lighting in itself, did not contribute to the failure of the protected lobbies for occupant escape and fire fighter operations.

19.5.88 **Fire Detection & Alarm**

19.5.89 The absence of a detection and common alarm system within the protected lobby was compliant with the current statutory guidance and the design guidance available at the time of construction.

19.5.90 A detection system was present in the lobbies, which should have been interfaced with the smoke ventilation system (see Section 19.6 below).

19.5.91 Further evidence has been provided that the smoke panel in Grenfell Tower operated at 00:55 (THL00000003) and triggered autodial equipment which notified Tunstall of the activation. The specific location of the device that caused this activation is not specified in the evidence.

19.5.92 The time of activation was is within 1 minute of Mr Kebede's 999 emergency call, at 00:54 (LFB00004695), in which he states he is outside his flat and therefore is shortly after the outbreak of fire in Flat 16.

19.5.93 In my opinion, it is likely that a Level 4 lobby detector activated the smoke panel, for the following reasons:

a) At 00:55 as the fire was still contained within Flat 16 (Section 5 and 6) and there is no evidence it had spread to any other flats (Section 12); and

b) From my site investigation the only route I have found for smoke to spread from a flat kitchen to the lobby is through the flat entrance door.

19.5.94 I have not found any evidence that the fire lifts were intended to be interfaced with the lobby smoke detection system at this time. CS Stokes in the 2016 fire risk assessment (TMO10017691) states that the lift would not be interfaced with the detection system. However, this evidence conflicts with the findings of the WSP lift inspection report (MET00019973). I would recommend that a specialist lift expert, instructed by the Inquiry at Phase 2 of its work, should investigate this further.

19.5.95 **Impact of external fire-fighting on lobby protection**

19.5.96 As I have explained in Section 17 the LFB was able to undertake external firefighting, using improvised locations around the Grenfell Tower, despite the lack of access facilities.

19.5.97 Current evidence indicates that the external firefighting the LFB were able to improvise may have prevented or delayed the ignition of internal flat fires on Level 9 and below on the East and South elevations of Grenfell Tower.

19.5.98 Therefore, it is possible that external firefighting contributed to relatively better conditions in the stair and lobbies on Level 9 and below, once consistent water application was achieved on those elevations of the Tower. There is an exception on the East elevation, where external water was applied up to Leve18. However, this position had to be abandoned by 02:18 due to falling debris.

19.5.99 I also note that some of the latest residents to evacuate from Grenfell Tower came from flats with external walls on the south and east elevations with the highest water application. Specifically: three people in Level 11 Flat 82 at 04:47; and one person from Level 10 Flat 72 at 06:05.

19.5.100 It is likely therefore, that the application of fire fighting water to the external walls of these flats slowed the rate of external fire spread and therefore slowed down the spread of fire into these flats, and helped mitigate the risk to life in those locations.

19.6 How the protected stair failed

19.6.1 With regard to the protected stair in Grenfell Tower, it is useful to note its function as described in BS9991: 2015:

"Whilst a simultaneous evacuation is normally unnecessary (see A.1 regarding stay put strategy), there will be some occasions where operational conditions are such that the fire and rescue service decide to evacuate the building. In these situations, the occupants of the building will need to use the common stair, sometimes whilst firefighting is in progress. As such, the

measures in this British Standard for the protection of common stair are designed to ensure that they are available for use over an extended period."

19.6.2 Smoke and heat was able to penetrate the protected stair on Levels 3 -23 during the fire. The heat within the stair on Levels 13 – 16 appears to have been particularly severe as evidenced by the melted and deformed plastic stair lights. I have described this in Section 14 as a hot zone within the stair.

19.6.3 In this section therefore I describe how and if, each active and passive fire protection measure failed to prevent fire and smoke spread to the protected stair.

19.6.4 I also provide a description of my investigations into how Levels 13 -16 came to be particularly hot, within the stair, as compared to the other levels.

19.6.5 **Stair Enclosure**

19.6.6 As I have explained in Section 16, the walls enclosing the protected stair were compliant with the requirements of ADB 2013 and CP3 1971 to provide 120 minutes fire resistance.

19.6.7 The walls enclosing the stair were compliant with the statutory requirements. Furthermore, during my site inspections I did not find any sign of failure of the walls enclosing the stair. Therefore, the construction of the walls enclosing the stair lobby do not appear to have contributed to the failure to control the spread of fire and smoke (Section 16.6) observed within Grenfell Tower.

19.6.8 During my site inspection I observed service penetrations included a lateral gas pipe penetration on 12 floors (Levels 5, 6, 8, 9, 10, 11, 12, 13, 14, 16, 17 and 21) to the riser gas pipe within the stair. These pipe penetrations did not appear to be fire stopped (Section 16.7).

19.6.9 However, I did not observe evidence of fire spread to the stair by this penetration. Therefore, it does not appear that this non-compliance contributed to the spread of fire to the protected stair.

19.6.10 I also observed equipment associated with the smoke ventilation system which penetrated the wall separating lobby riser cupboard from the stair. This was a small diameter plastic tube for sampling air pressure in the stair and lobby. I observed the plastic material of this equipment to have melted and deformed on Level 22 of Grenfell Tower. Due to the small diameter of the equipment in question, I do not believe these penetrations provided a significant route for spread of fire and smoke between the lobby and the stair.

19.6.11 **Stair Doors**

19.6.11.1 Since the publication of my preliminary Phase 1 report I have conducted an investigation of historic timber door construction to identify: the likely date of construction of the Grenfell Tower stair doors, their fire performance (Appendix M) and whether they were compliant with the relevant guidance.

19.6.11.2 From these investigations I am satisfied that the stair door was constructed as a No. 3 Class A door from Table G of Schedule VI of the *London Building Constructional Amending Bylaws*.

19.6.11.3 This is based on the internal stile and rail with plasterboard infill panel construction of the door and the presence of a 12mm rebate in the door frame, which I find to be consistent with the specification for a No. 3 Class A door.

19.6.11.4 These further investigations, together with RBKC's statement (by letter to the inquiry dated 27th September 2018 (RBK00029044)) that no replacement or changes were made to the Level 4 to 23 stairwell doors during the 2012-2016 refurbishment, lead me to conclude that the stair doors in Grenfell Tower were probably the original stair doors from the time of construction. This conclusion is supported by the physical evidence from site which I have set out in detail in Appendix M, and I summarise below.

19.6.12 A Class A door was the standard of door required by the *London Building Constructional Amending Bylaws* and the GLC Section 20 Code of Practice 1970 both of which were applicable at the time of construction.

19.6.13 However, a No. 3 Class A door with 12mm rebate would not satisfy CP3 part 4 (1971) which was used for the means of escape design, including the lobby smoke control provision, at Grenfell Tower. CP3 part 4 (1971) relied upon the provision of a Type 2 stair door (with a 25mm rebate), a Type 3 flat entrance door (with a 12mm rebate) and a ventilated lobby, to provide protection to the single staircase.

19.6.14 My investigations have presented evidence that a No. 3 Class A door would achieve a fire resistance period as low as 12 minutes integrity; increasing to 20 minutes integrity where constructed with an intumescent strip at the edge of the door leaf. A Type 2 door to CP3 part 4 (1971) was required to achieve the higher standard of 30 minutes integrity fire resistance.

19.6.15 I do not know why the lower standard Class A. No.3 doors were deemed acceptable by the approving authorities at the time of construction in the 1970s. The performance is lower than that of the Type 2 stair fire door required to comply with CP 3 Part 4 (1971). These doors are also needed as part of the smoke control system in the lobby. On this basis, my opinion is that none of the stair doors from Level 4 upwards complied with the design guidance used for the original design of the building (CP3 1971).

19.6.16 I have not been able to determine compliance with the LGA guide, which recommends an upgraded FD30S doors for the arrangement in Grenfell Tower.

19.6.17 An upgraded FD30S door would be the original door (i.e. a notional FD30 door) fitted with intumescent strips and cold smoke seals. I have not been able to independently confirm at this time, whether intumescent strips were present in the Grenfell Tower stair doors. Please refer to Appendix M.

19.6.17.1 The level 6 stair door was fire tested to BS 476-22 by BRE as part of the MPS investigation (MET00021780). The door was found to achieve 16 minutes integrity and 3 mins insulation. This is a lower standard than the 60 minutes integrity to comply with current guidance in ADB 2013.

19.6.18 ADB 2013 also requires stair doors to achieve cold smoke leakage performance requirements. This performance is required where stairs and their lobbies have not been designed to the pressurisation requirements of BS EN 12101-6. As I explain in Appendix J this was not provided for at Grenfell Tower, therefore the smoke leakage performance applies.

19.6.19 When the fire started at Level 4, the performance specification in BS EN 12101-6 assumes that the stair fire door and the stair door on the floor below is open (due to firefighting operations) and smoke is prevented from leaking out to the stair by means of the lobby smoke control system. I address this in Section 16 and Appendix J of my Expert Report.

19.6.20 After the fire spread from Flat 16, several other stair fire doors had to be opened for firefighting purposes (See Section 14.4), contributing to smoke and heat spread out into the stair case. This is a condition not considered in the statutory design guidance.

19.6.21 I note that the PSB design intent appears to be based on one stair door only being open.

19.6.22 The first time multiple doors were observed to be open simultaneously was 01:30 by Firefighter Archer (MET00008001). The smoke control system was required to inhibit smoke spread through from the lobby to the stair when up to 2 stair doors are open. It was not required to be designed for more than 2 doors being open.

19.6.23 I have concluded that the smoke control system was not designed to this standard (19.6.30). Nonetheless, once at least 3 doors were open to the stair, the system, even if compliant, could not have provided as effective control of smoke spread to the stair.

19.6.24 As I have described in Section 14.6 severe fire damage occurred in the lobbies on Levels 10 and above, and on the North side of the lobbies only on Levels 5, 7-9. From the evidence available it does not appear that there was a substantial quantity of combustible materials within the lobbies to cause the level of fire damage observed and the fire like conditions described by the fire fighters witness statements.

19.6.25 The patterns of damage within the lobby, as evidenced by damaged or destroyed partitions, destroyed ceiling and wall linings, and spalling of the concrete structure, indicate intense fire and smoke venting from the flats into the lobbies.

19.6.26 The corridor arrangement on both sides of the lobbies would have channelled the vented fire and smoke, towards the centre of the lobby and directly

impacting the stair doors. This direct heating may have caused integrity failures in the stair door, allowing smoke spread to the stair.

19.6.27 Under these conditions, the non-compliances I have identified would have contributed to the failure to prevent the spread of smoke to the stair as the doors installed at the time of the fire had a lower standard of fire resistance than required by current guidance and the guidance in CP3 part 4 (1971) for protection of the single escape stair.

19.6.28 Additionally, I have identified that firefighting operations in response to the multi-storey fire may have contributed to the failure of the stair fire doors to prevent fire and smoke spread. In Section 14.4 I found evidence from witness statements that stair doors were held ajar either because fire fighters were holding open doors or because there were obstacles such as hoses on Level 3 at 01:12, Level 5 and 6 at 01:30, Level 4 and 5 at 01:45, Level 10 or 11 at 02:10 and Level 9 at 02:20

19.6.29 Therefore, the stair doors may have failed to prevent the spread of smoke to the protected single stair due to:

(a) Non-compliances in the construction of the door against current statutory guidance for 60 minutes integrity fire resistance and cold smoke leakage.

(b) The LGA guide permitted 30 mins integrity fire resistance. From my survey the performance may actually have been as low as 20 minutes integrity fire resistance.

(c) Further evidence is required regarding the cold smoke leakage performance potential from the stair doors, about which I have no information.

(d) Doors being held open by the presence of firefighting hoses and in one reported case a fatality. Further forensic investigation is under way to determine the exact number and location of hoses and how long they were in place.

(e) I was not able to determine whether any stair door self-closers failed to operate, however, I did not find any evidence of this in fire fighter witness statements. Evidence from the 2016 risk assessment described two stair doors as failing to self-close fully and resident evidence from prior to the fire refers to a faulty stair door closer on Level 15 (IWS00000852). I currently have no evidence these defects were dealt with.

19.6.30 **Lobby smoke control system**

19.6.31 As I explain in Appendix J the purpose of lobby smoke ventilation under the statutory guidance is:

"There should therefore be some means of ventilating the common corridors/lobbies to control smoke and so protect the common stairs. This offers additional protection to that provided by the fire doors to the stair. (The ventilation also affords some protection to the corridors/lobbies)."

19.6.32 Therefore, the purpose of the smoke ventilation system is to control the amount of smoke entering the lobby and therefore reduce the risk of smoke spread from the lobby to the protected stair.

19.6.33 I have concluded that the original smoke ventilation system was not designed on the basis of the recommended provisions of the GLC Section 20 Code of Practice 1970. However this is not to imply that the original design was not compliant with the requirements of Section 20 of the London Building Acts (Amendment) Act 1939.

19.6.34 I have concluded that the original smoke ventilation system was designed as a corridor smoke dispersal system as defined in Figure 16b of CP3 1971, but was not compliant with the recommended provisions of that Code.

19.6.35 I present my investigation into the smoke control system that was present in Grenfell Tower on the 14th June 2017 in Appendix J. The system consisted of brand new equipment (fans, dampers and associated power supplies and control equipment) that used the pre-existing smoke ventilation shafts serving from Level 4 to Level 23.

19.6.36 Smoke detectors positioned in the lobby were intended to automatically activate the smoke system, shutting down and isolating the environmental ventilation if operating, isolating all lobbies except for the fire floor by shutting AOVs on all other floors and activating the extract fans serving the North and South shafts.

19.6.37 During a fire the system was intended to operate in 2 modes:

a) When the stair door was closed, the system would draw air at low speed from the North and South vent shafts. This would maintain the lobby at a lower pressure than the stair to prevent smoke leaking into the stair via the cracks around the stair door.

b) When the stair door was open, fans would draw air at full speed through the North and South vent shafts drawing air into the lobby from the stair thereby preventing smoke from passing through the open door into the stair. The stair was provided with a permanently open vent at roof level to provide replacement air into the stair.

19.6.38 Extraction would occur from a single floor only.

19.6.39 I have concluded from my review of the design documentation in Appendix J that the smoke ventilation system installed during the 2012 -2016 refurbishment was intended to provide an *"average open door velocity"* between the lobby and the stair, and that this velocity was intended to comply with the airflow performance criterion of a Class B pressure differential system as defined in BSEN 12101-6:2005.

19.6.40 However, I can find no further evidence the system was designed to meet all the performance requirements of a Class B pressure differential system and is therefore not a compliant BS EN 12101-6:2005 system.

19.6.41 Despite my review of the extensive documentation available, I have been unable to determine how the design was intended to meet the requirements of the Statutory Guidance.

19.6.42 Firstly, with regard to functional operation of the system, I have found omissions in respect of a substantial number of performance criteria required for a Class B system from the design. I do not presently understand how the system was to achieve the stated aim of BS EN 12101-6:2005 – "*minimise the potential for serious contamination of firefighting shafts by smoke during means of escape and fire service operations*".

19.6.43 This is particularly relevant during the period after smoke first spread into the lobby of Level 4, which I believe to be at 00:55 (Section 14.6) and 01:30.

19.6.44 At, 01:30, Archer confirmed that the fire hose he was using on Level 6 came from the rising main outlet on Level 5 and therefore two stair doors were held open (MET00008001). Therefore, 3 stair doors were now being held open by fire-fighting hoses (L3, 5 and 6).

19.6.45 BS EN 12101-6:2005 requires the system to be designed for a minimum of two doors open. Therefore, up until 01.30 a compliant smoke control system was required to minimise smoke contamination of the stair. Resident Ahmed of Flat 102, first reports smoke entering the stair at Level 4 before 01:21 (MET00016072).

19.6.46 Resident Mekonnen (Transcript 9th October, p35) and fire fighter O'Beirne (Transcript 3rd July 2018, p20) provide evidence that the open stair doors at 01:30 and 01:38 were allowing black smoke to spread from lobbies to stairs.

19.6.47 Secondly, smoke control systems that use pressure differentials impose additional performance requirements on the components of the system in terms of maintaining compartmentation between the lobbies and dwellings. It is important to note that the ventilation shafts and AOVs connect every lobby in Grenfell Tower.

19.6.48 Thirdly, I have found substantial omissions in the commissioning of the system. I consider the commissioning of the smoke ventilation system in Grenfell Tower to be non-compliant with the relevant British Standards and Industry guidance, which are: BS EN 12101-6:2005, the SCA guide and BS 7346-8:2013 *Components for smoke control systems Part 8: Code of practice for planning, design, installation, commissioning and maintenance*.

19.6.49 Commissioning of active systems is required to demonstrate compliance with Regulation 7 of The Building Regulations 2010.

19.6.50 The difficulties with the commissioning mean that there is a lack of evidence about the performance that could be achieved by the installed system in the event it operated. This is relevant to how well the system could have performed during the fire in Flat 16.

19.6.50.1 There is an increasing amount of resident evidence about the system on the night. I will need to review this very carefully when their evidence is completed. This includes evidence of noise in the lobbies at level 23 and noise in the north and south shafts on other floors.

19.6.51 Regarding the operation of the system on the 14th of June 2017, I have been unable to retrieve information from the system itself as the system log for 14th June 2017 appears to have been overwritten. The only recorded evidence I have of system operation is the activation of a smoke detector in Grenfell Tower at 00:55, based on the records of the autodialler connected to the smoke control system.

19.6.52 I am therefore required to rely on post-fire inspections of the system and the witness evidence provided during the Public Inquiry by firefighters and residents regarding the system operation.

19.6.53 At this stage, I am not in a position to express any opinions on the operation of the system on the night. I will complete this work when the resident evidence is completed. I have explained all the work that is in progress on this topic at the end of Appendix J of my expert report.

19.6.54 I will then combine all of the evidence regarding the system's operation on the 14th June 2017 in order to investigate:

a) Whether the system operated to control the flow of smoke from the Level 4 lobby to the single stair prior to the multi-floor internal fire filling multiple lobbies with smoke; and

b) Whether the construction of the smoke ventilation system provided a route for smoke spread between lobbies in Grenfell Tower.

19.6.55 **Fire fighter control of the lobby smoke control system**

19.6.56 I have concluded that the smoke control system was provided with an override control for fire fighters. This was by means of a touch screen HMI control panel at ground level entrance lobby and key switches in each of the lobbies served by the system.

19.6.57 From the HMI panel in the ground floor lobby the status of the system could be checked, the system shut down and/or the floor on which the system was operating could be controlled.

19.6.58 There is evidence that fire fighters interacted with the HMI panel as follows:

a) There is CCTV evidence of fire fighters opening the HMI panel enclosure and interacting with it (INQ00000343) this was first at 01:35.

b) There has been oral evidence from fire fighters indicating that WM Dowden (Transcript 26th June, p136) attempted to use the override (yellow) key switch on the Ground floor at 02:01.

c) There is oral evidence from fire fighters (Transcript of Egan, 4th July, p2) and photographic evidence (MET00018915) indicating that the override switch was turned from "Auto" to "on".

19.6.59 Therefore, it is possible from these interactions that the floor of operation was changed by LFB.

19.6.60 It is possible to shut down the system from the touch screen but I currently don't have any evidence that allows me to conclude either way on this operation.

19.6.61 **Stair width**

19.6.62 As I have explained in Section 15 and 16, the width of the single stair in Grenfell Tower was 1,040mm. This was compliant with the requirements of design guidance applicable at the time of construction, CP3. However, the stair width was 60mm less than required by current statutory guidance in ADB 2013.

19.6.63 In Section 16.5, I found that a stair of this width and height, is deemed to provide escape capacity for [150 + (22 x 40)] = 1,030 people in accordance with Table A7 of ADB 2013. This is significantly higher than the 293 residents believed to be in the building at the start of the fire. As I have identified in Section 14 of my report, there were a maximum of 9 firefighters deployed inside the building beyond the Bridgehead between approximately 00:55 and 01:40, i.e. the point beyond which conditions in the stair deteriorated significantly. These firefighters were deployed in teams of between 2 or 3 and spent part of their time in the lobbies of specific floors. Therefore, the teams were not within the stair for the full time of their deployment.

19.6.64 Between 00:55 and 01:38, 110 people evacuated the Tower. This was the maximum flow rate at any time during the fire.

19.6.65 I am not aware of evidence from the fire brigade that those 110 people caused an obstruction on the stairs.

19.6.66 This left 184 residents remaining in the Tower.

19.6.67 In Section 13.5 of my report, my analysis of the LFB BA telemetry data (LFB00023326) shows that the maximum number of fire fighters in the building at any one time was 28 fire fighters at 02:15.

19.6.68 At 02:15 125 residents were remaining in the tower.

19.6.69 This is still significantly lower than the capacity of the stairs for simultaneous evacuation i.e. of 1030 persons.

19.6.70 AT 02:35 117 residents were remaining in the tower.

19.6.71 Therefore, although non-compliant with ADB 2013, it is my opinion that the stair had sufficient capacity for simultaneous evacuation (all out) of the building

19.6.72 In his oral evidence on 26th September AC Roe (Transcript p36) addressed the capacity of the stair to accommodate evacuating residents and fire fighters:

"It's [the stair] *not designed for both our personnel and personnel trying to leave being on it but I didn't have a choice.*
So, again, that's why it was important the fire sector knew the advice had changed, because they then needed to be aware they might need to manage that flow of people out against the stream of people we wanted to go in. My general sense, though, was very few people were going to be able to make their way out on their own, so, actually, I thought it was more likely that it was about ensuring we had a constant flow of breathing apparatus crews up inside the building as far as they could to rescue people"

19.6.73 Taking on board AC Roe's point that firefighting personnel moving up the building reduces the available capacity of the stair for residents moving down the building to escape, one could assume that 50% of the stair capacity is unavailable.

19.6.74 On this basis and using the escape capacity outlined in ADB, the it

19.6.75 stair capacity would reduce from 1030 persons to 515 persons. However, this is still a significantly higher number than the peak number of fire fighters who were in the Tower and the total number of residents in the building combined, which is 321 persons.

19.6.76 It is my opinion that it is the conditions on the stairs (which I deal with in detail in Section 14), rather than the width of the stairs, which is the key consideration regarding evacuation and rescue potential.

19.6.77 As I have presented in Section 14.4 and Appendix N, fire fighter witness statements identify that the stair was narrow when they were trying to operate in small teams, and not in single file; and when they had to undertake a physical rescue down the stairs.

19.6.78 In Figure 19.4(a) I have illustrated a human's typical dimensions (Metric Handbook) and standard dimensions for fire and rescue service breathing apparatus.

19.6.79 Based on these dimensions, I have illustrated the following in Figure 19.4(b) through Figure 19.4(f):

(a) Two persons passing on the stair – Figure 19.4(b)

It is theoretically possible for two people to stand shoulder to shoulder, however in poor visibility there may be insufficient width. The 60mm non-compliance with statutory guidance would not have significantly alleviated this failure to accommodate fire fighters passing in opposite directions.

(b) Rescue operation, "*dragging a person down the stair whilst wearing BA*" (Manual of Firemanship (1983 edition)) – Figure 19.4(c) (d)

Again, it is theoretically possible to stand two persons should to shoulder, however when dragging a person down the stair, the required width is likely to be greater than a standard shoulder width apart. The 60mm non-compliance with statutory guidance would not have significantly alleviated this failure to accommodate fire fighters passing in opposite directions whilst carrying down occupants.

(c) Rescue operation, fireman's lift. – Figure 19.4 (e)

Although not recommended in BA (Manual of Firemanship (1983 edition)), in this scenario a fire fighter physically carrying an occupant down the stair would use the majority width of the stair. Therefore, no fire fighters would be able to pass in the opposite direction.

The 60mm non-compliance with statutory guidance would not have significantly alleviated this lack of capacity for firefighting carry down procedures, and ascending fire fighters.

(d) Use of stair with the presence of hoses – Figure 19.4 (f).

London Fire Brigade were required to run hoses up through the stair to fight fires on multiple floors. This would have further restricted the usable width of stair. Multiple hoses are described as being in place in the firefighter witness statements. However, the 60mm non-compliance with statutory guidance would not have significantly alleviated this lack of capacity for firefighting hoses, escaping occupants and ascending fire fighters, in the specific conditions that occurred at Grenfell Tower.

19.6.80 Although the width of the single protected stair was non-compliant with the current statutory guidance, increasing the width by 60mm to meet the current guidance would not have mitigated the significant demands placed on the single protected stair whilst visibility reduced to zero by thick black smoke and heat increased. These demands were:

a) the only route of escape for all occupants;

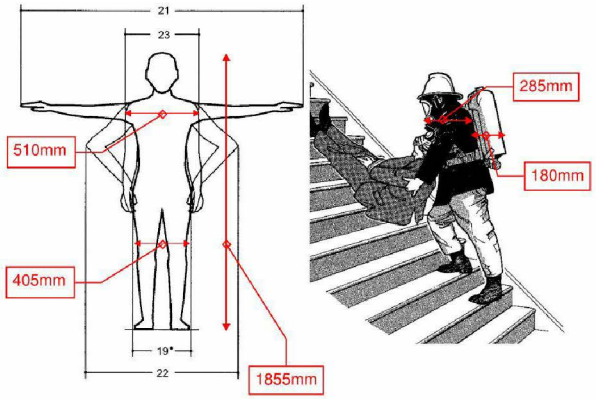
b) the only access route for fire fighters ascending for rescue or conduct firefighting;

c) the only route to run water up the building in hoses when the fire main had failed;

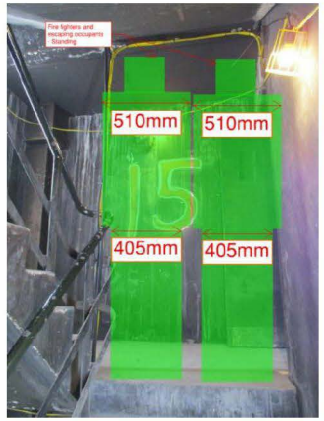
d) the only route to carry down rescued residents; and

e) the only route to carry up and down equipment from the Bridgehead.

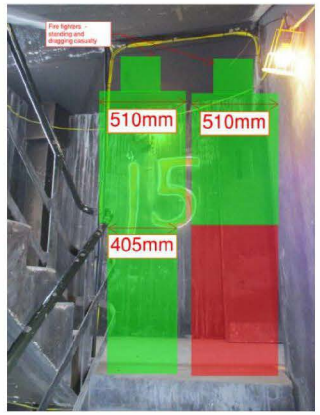
19.6.81 Despite the Grenfell Tower stair being perceived to be narrow I have so far seen no evidence that the stairs actually became blocked at any stage or that its width in and of itself significantly impacted on escape by the residents or access by fire fighters.



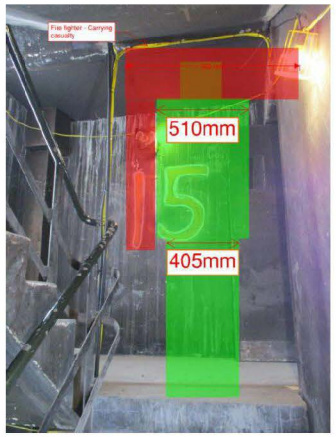
(a) Typical dimensions for a person using Metric Handbook and standard BA dimensions



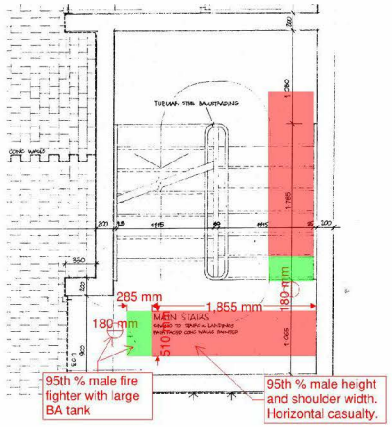
(b) Illustration of the capacity of 2 people side by side in the stair of Grenfell Tower on the stair



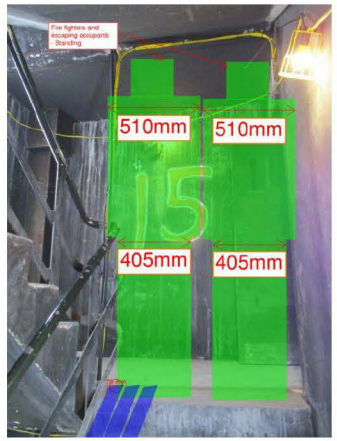
(c)Width required for fire fighter to pass a casualty evacuation



(d) Width required for casualty evacuation using fireman's lift



(e)Space used by fire fighter dragging a casualty



(f) Impact of hoses on usable stair width of Grenfell Tower

Figure 19.4 Illustration of available width in the single protected stair of Grenfell Tower

19.6.82 Services within the stairway

19.6.83 During my site inspection, I observed heating system pipes and gas pipes within the single protected stair of Grenfell Tower. The presence of heating pipes in the stair is non-compliant with the requirements of ADB 2013 (Section 16.7)

19.6.84 Gas pipes are only permitted in the protected stairway where the gas services comply with the relevant legislation. The gas services do not appear to have been installed at the time of the fire in accordance with the relevant legislation (Section 16.7, Appendix K). The construction works related to these services was ongoing at the time of the fire. A gas expert has been appointed by the Public Inquiry and is currently investigating the compliance of this system.

19.6.85 As I have explained above, although I have identified non-compliances related to these gas services from the perspective of the Building Regulations, I have found no evidence in my site inspection that they contributed to the spread of fire and smoke within the stair itself.

19.6.86 However, I have found evidence that the gas fires within the flats continued into the day within Grenfell Tower and affected firefighting operations (Section 14.6). Gas supply to the building was not isolated until approximately 23:30 on 14th June 2017 (Appendix K.8).

19.6.87 The specific failures with respect to isolation of the gas supply were:

a) It was not possible to isolate any of the three gas supplies to Grenfell Tower using control valves. Unsuccessful attempts were made to access these in the basement. The investigation into where the isolation valves were located and if they were operable is ongoing by Mr Rodney Hancox, the appointed Gas Expert.

b) LFB were then unable to extinguish the gas fires within the flats, due to the risk of gas explosion (MET00005756). The presence of gas fires which could not be extinguished meant that the Bridgehead could not be moved above these floors.

19.6.88 From the LFB command log of AC Ellis (MET00005756) this appears to have been relevant around much later in the day around 13:25. Therefore, it currently does not appear that the gas fires within the Grenfell Tower contributed to the spread of fire throughout the building. However, they do appear to have sustained the duration of fire within the building.

19.6.89 General Provisions for the single stair case

19.6.90 The general provisions with regard to the construction of the flights and landings and headroom, all appear to have been compliant with the requirements of ADB 2013. The handrail provision on a single side only is non-compliant with current statutory guidance. I have not been able to determine the compliance of the stairway construction with respect to slipperiness when wet. I did not observe any failings relevant to these items nor find any evidence of their failing in the fire fighter witness statements.

Therefore, these provisions did not contribute to the failure of the protected stair for occupant escape and fire fighter operations.

19.6.91 Emergency lighting appears to have been present within the stair. Based on the evidence currently available to me I do not know of any failures in the emergency lighting system in the stair (see Section 19.5.87 above).

19.6.92 **The hot zone between Levels 13 – 16**

19.6.93 During my site inspection I found the plastic stair lights on Level 13, 13.5, 14, and 14.5 stair landings have been fully destroyed whereas the plastic stair lights on Levels 15, 15.5, and 16 stair landings are deformed/partially melted. I have carried out extensive analysis to try and conclude how this happened. In summary I can conclude the following:

a) The levels 13, 14, and 16 lobbies are severely damaged and the stair doors on these levels are gone (Note in MPS photographs after the fire, the Level 16 door is visible where it is badly damaged and located on the floor of the lobby).

b) The stair door which separates the lobbies from the stair was missing or fire damaged on Levels 10 – 23, with the exception of Levels 11, 12, 15 and 17. Therefore, the pattern of missing stair doors after the fire does not correlate with the damage within the stair on Levels 13 -16.

c) The Level 15 stair door is intact and the lobby damage is less severe than Levels 13, 14, and 16 (in particular, the riser partitions and ceiling are in better condition on level 16)

d) No flat entrance doors are remaining on Levels 13 and above. I have reviewed the distribution of leaseholder flat doors and found no patterns/trends. I have reviewed the distribution of glazed flat doors (information available by level only) and found no patterns/trends.

e) Firefighters working at Level 10 or 11 (Desforges MET00008013) describe extreme heat within the lobby whilst conducting a search and rescue operation. The witness statement describes the stair door being held open during this operation. This occurred around 02:10.

f) The witness evidence of Rosemary Oyewale (IWS00000852) indicates there was much fire-fighter activity around Level 14 from around 02:00 onwards. This activity will have required opening and closing of stair doors.

g) I have no evidence of the operation of smoke control system which could connect it with the plastic light damage at this time. However, I am investigating the performance of the smoke control system with regard to maintaining compartmentation between the lobbies of Grenfell Tower.

19.6.94 I have not been able to establish a correlation between the rate of evacuation from levels 13 – 16 and the fire damage observed in the stair; the rate of

evacuation from these levels is similar to the overall building evacuation time curve.

19.6.95 No residents evacuated from above Level 11 between 01:42 and 02:24.

19.6.96 Evacuation continued after that, from above Level 13 up until 03:55. However, the last FSG call from above Level 13 was at 03:33, therefore it is likely evacuation from above Level 13 ceased at 03:55 because, by that time, residents within those flats were overcome by internal fires (Please refer to Section 20).

19.6.97 The strongest evidence of the cause of the plastic light damage is smoke and heat entering the stair from open doors to the lobby during the fire event. I have found evidence of substantial fire-fighter activity between 02:00 and 02:30 on Levels 10 – 14 (Desforges, MET00008013 and Oyewale, IWS00000852)

19.6.98 From the physical damage observed during post site inspections it could have occurred due to the stair doors being held open on each level, although it appears it may have been as a result of one or both of the Level 13 and 24 doors being held open.

19.7 Summary

19.7.1 **Protected Lobbies**

19.7.2 Fire and smoke spread to and throughout every Lobby above Level 10 in Grenfell Tower. On Levels 04 -10 fire and smoke also spread, however post fire damage indicates the spread was more severe on the North side of the lobby and less severe on the South side of the lobby.

19.7.3 The heat, toxicity and reduced visibility caused by this fire and smoke spread slowed the rate of evacuation of people through the lobbies. People were unable to enter the lobbies, or more substantially were unwilling to enter the lobby outside their flat entrance door, due to the immediate physical and psychological effects of entering the smoke and heat filled lobbies.

19.7.4 The heat and smoke within the lobbies prevented their use as a Bridgehead by the LFB, and so they were never able to move the Bridgehead higher up in the building.

19.7.5 The low Bridgehead location and large fire sector reduced the time available to conduct rescue operations at higher levels whilst wearing breathing apparatus.

19.7.6 Above the Bridgehead the heat and smoke within the lobbies either prevented or reduced access to the fire main and prevented or reduced the ability to find and locate occupants.

19.7.7 The current evidence regarding the passive and active fire systems indicates:

19.7.8 *Lobby enclosure* – The flat entrance doors appear to be the primary route of fire and smoke spread from internal flat fires to the protected lobbies. I also now have evidence from resident witness statements (please refer to Section 14) that they were a route of smoke spread from smoke filled lobbies to flats not yet affected by fire. I found no evidence of other breaches in the construction separating the flats from the lobbies. The non-compliances I have identified with the composite fire doors installed in 2011-2012 could have contributed substantially to the failure of the fire doors to control the spread of fire and smoke. Specifically, the lack of cold smoke leakage performance would have contributed to the failure of the flat entrance doors in preventing smoke spread from smoke filled lobbies to flats via gaps between the door leaf and frame and letterboxes.

19.7.9 The self-close function of the doors is now known to have been disconnected for a number of flat doors. For these doors, the performance would have been solely reliant on whether residents closed doors after their escape. I have seen evidence of both residents closing and not closing flat doors as they made their escape. The open and close action as people evacuated could also have contributed.

19.7.10 *Lobby enclosure – protected shafts*: There is resident witness evidence (Neda, transcript 18th October, p41) that smoke leaked from the smoke shafts into the lobby on Level 23 via the dampers that served as AOVs in the lobby walls.

19.7.11 My investigation into the smoke control system (Appendix J) has identified that the AOVs used in Grenfell Tower did not have the required certification, based on high temperature fire tests, for the role that they were performing. One of the key performance criteria of AOVs is the rate at which they leak during the test.

19.7.12 The AOVs were critical in separating the vertical shaft from the lobbies, appear to have been to a lower standard than required. Specifically, this lower standard may have allowed more smoke to leak from the shafts into lobbies on other floors compared to if compliant AOVs had been used.

19.7.13 If the dampers had been correctly tested and certified, the leakage of smoke into the lobbies could have been less than that observed on the 14th June 2017.

19.7.14 The smoke ventilation shaft itself, which were installed as part of the original building construction were re-used as part of the new smoke control system. There is no evidence that the design team undertook any leakage testing on the shafts, or that they applied a render or sheet metal lining to the inside of the shafts to control leakage, as required by the relevant British Standard and Industry guidance. This may have contributed to poor operation of the system

and may have permitted smoke to spread from the shafts into the surrounding flats.

19.7.15 I have no evidence that fire resisting doors were provided to the lift doors as required either.

19.7.16 The post-fire inspection evidence is that the refuse chute did not provide a route for internal fire and smoke spread/

19.7.17 *Travel distance within the lobby* – The extended, 3m, travel distance within the lobby from the flat entrance door to the stair door through the protected lobbies would not have contributed to the failure to control fire spread. It may have affected the visibility of the stair exit door and taken occupants longer to reach the exit. However, given the conditions described within the lobbies, a 3m reduction in travel distance would not have mitigated the loss in tenability (visibility, heat and toxicity) experienced in the lobbies.

19.7.18 *Fire main* – Had a wet riser been provided as required, the initial firefighting response to Flat 16 may have been faster, however, this would not necessarily have prevented fire spread to the external wall. A wet riser would have provided greater water pressure and flow at high levels than the installed dry fire main where no more than 2 hoses were in operation. The demand for fire water on multiple levels which appears to have caused a failure in the dry riser system, would also have caused a failure in the wet riser system. The failure of the internal fire main reduced the ability of LFB to cool the lobbies and so limit the spread of fire and smoke to the lobbies and to the stair.

19.7.19 *Bridgehead* - There were specific times throughout the fire when the Bridgehead had to be moved, such as when the Bridgehead was moved at 03:08 to ground level. At that time all firefighters and therefore fire fighting actions were temporarily withdrawn from the building.

19.7.20 *Fire lift* – The lower standard of fire lift that appears to have been provided, failed to operate for the LFB. Further evidence is required to assess the compliance and function of the fire control switch for the lift observed at ground floor. I consider the lift operation to have indirectly contributed in that it affected the operations of the LFB, who rely on firefighting lifts to transport equipment. It directly contributed to the failure by the LFB to take control of the lift, meaning that residents were not prevented from using it during the fire.

19.7.21 *Fire detection and alarm* – A fire detection system was provided to activate the smoke control system. From evidence of the autodialler system interfaced with the lobby smoke detection system, it appears a smoke detector did active in a lobby of Grenfell Tower. It is likely this detector activated within the Level 04 lobby.

19.7.22 *General provisions* – I did not observe any failings with regard to headroom, flooring and refuse chutes in the lobby which contributed to or failed to control the spread of fire and smoke.

19.7.23 *External firefighting* – The failing of the internal firefighting systems caused the LFB to improvise and use external firefighting measures. There appears to be a correlation between the application of external fire fighting water which may have prevented or delayed the ignition of internal flat fires on level 9 and below on the East and South elevations of Grenfell Tower. This may have contributed the relatively better conditions in the stairs and lobbies on Level 9 and below,

19.7.24 I have also noted a correlation with the late evacuation of residents from two flats on the 10th and 11th floor (Flat 72 and 82); it is possible the improvised application of external fire fighting water by LFB delayed the spread of the external fire to these flats and so enabled residents within to survive for longer.

19.7.25 **Protected Stair**

19.7.26 Smoke spread to the stair on Levels 3 – 23 of Grenfell Tower. The post-fire damage to the stair indicates particularly hot smoke entered the stair between Levels 13 -16. This smoke was hot enough to melt the plastic lights located within the stairs at these levels.

19.7.27 *Stair enclosure – failure to prevent smoke spread*: The stair doors appear to be the primary route of spread of smoke and heat to the stair. No other significant failures in the construction separating the stair from the lobby or flats has been observed. At this stage the stair doors being opened, or held open, by either fire-fighting equipment or other objects appears to be the primary failure. I have considered this a failure only after more than 2 doors were held open at any one time. This is because a compliant smoke ventilation system was required to provide protection where up to 2 stair doors were open. The current evidence shows between 01:30 and 01:45 up to 4 stair doors were open. I am not able to provide a precise time based on the evidence available.

19.7.28 Whilst the fire was still a single flat fire, the smoke ventilation system should have provided protection against smoke ingress from the level 4 lobby to the stair with the L4 door open. Please refer to *Smoke ventilation* below.

19.7.29 For closed doors, the possible absence of cold smoke seals to the stair doors would have allowed hot smoke to leak into the stair on from lobbies multiple levels. As the internal flat fires spread and the lobbies become increasingly hot, the lower than required integrity fire resistance of the stair doors would have contributed to the spread of further heat and smoke into the stairs.

19.7.30 *Stair enclosure – failure to prevent the spread of hot smoke (L13 -16)*: Having reviewed all the passive and active systems required to provide protection to the stair, the strongest evidence of the cause of the plastic light damage between Levels 13 and 16 is a stair door being held open and allowing hotter smoke from a lobby to vent into the stair.

19.7.31 Current evidence supports these conditions being temporary around 02:10 when a stair door at Level 10 or 11 was held open by a firefighter team.

19.7.32 *Stair width* – The width of stair was non-compliant with the current statutory guidance. Despite this, I have presented evidence that the capacity of the stair was at all times sufficient for the simultaneous evacuation of residents from all levels; even when considering a 50% reduction in stair capacity to allow for ascending fire fighters. I have found no evidence that the stair at Grenfell Tower was blocked at any point or that its width alone significantly obstructed occupant escape or firefighter access. Therefore, the conditions which developed within the stair with respect to visibility, toxicity and heat were the key considerations regarding evacuation rather than the width of the stairs.

19.7.33 Fire fighter evidence regarding space in the stair to work in teams or conduct physical rescues described the stair as narrow and/or congested. A compliant fire fighting stair width (an extra 60mm width) would likely not have mitigated these effects.

19.7.34 *Smoke ventilation* – I have conducted extensive reviews of the design documentation and control software for the smoke ventilation system. From this I have been unable to determine how the design was intended to meet the requirements of the statutory guidance. This lack of design evidence is exacerbated by only partial commissioning of the system. I therefore have concerns regarding what performance could be achieved by the installed system and will continue my investigations in Phase 2.

19.7.35 Regarding the operation of the system on the 14th June 2017; no system records remain. I am therefore required to rely on post fire inspection and witness evidence only. I will provide my opinion on this issue once the resident oral evidence is complete. Specifically, my further investigation will focus on:

a) Whether the system operated to control the flow of smoke from the Level 4 lobby to the single stair prior to the multi-floor internal fire filling multiple lobbies with smoke; and

b) Whether the construction or operation of the smoke ventilation system provided a route for smoke spread between lobbies in Grenfell Tower.

19.7.36 *General provisions* – I have not observed at this time any failings associated with headroom, construction of flights and landings which contributed directly or indirectly to the contribution to or failure to control the spread of fire and smoke in Grenfell Tower.