Office of the
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Physiological Assessment of Firefighting, Search and Rescue in the Built Environment

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Fire Research Technical Report 2/2005

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Optimal Performance Limited
On behalf of the
Office of the Deputy Prime Minister: London

The findings and recommendations in this report are those of the consultant authors and do not necessarily represent the views or proposed policies of the Office of the Deputy Prime Minister.

Following the reorganisation of the government in May 2002, the responsibilities of the former Department of the Environment, Transport and the Regions (DETR) and latterly Department for Transport, Local Government and the Regions (DTLR) in this area were transferred to the Office of the Deputy Prime Minister.

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Executive Summary

All firefighting and other rescue activities are dependent to a greater or lesser extent upon the physiological capabilities of firefighters. Thus the physiological limitations of firefighters must be considered when planning for conventional and terrorist incidents within the built and natural environment.

Currently, there is limited information available to fire and rescue service incident commanders on whether activities assigned to firefighters may exceed their ability to undertake the task safely within their physiological limitations, taking account of appropriate personal and respiratory protective equipment (PPE and RPE). This information is required for all operational incidents, from those attended on a routine basis, through to extreme events. While acknowledging that the expectations and performance demands placed upon firefighters will differ with the activity, there is presently little human factors guidance to support both planned and dynamic risk assessment of work activities.

Optimal Performance Ltd. (OPL) was commissioned by the Fire Statistics and Research Division (FSRD) in the Office of the Deputy Prime Minister (ODPM) to investigate the physiological demands of firefighting in the built environment. This project was undertaken on behalf of The Building Disaster Assessment Group (BDAG) and managed by seconded officers from London, Greater Manchester and Merseyside Fire and Rescue Services (F&RSs) within FSRD.

BDAG was established to consider the issues for fire authorities and their Services in the UK that have been highlighted by the World Trade Centre incident of 11th September 2001. The terms of reference of BDAG are:

> "*To consider the potential implications, for the UK fire service, of terrorist activities within the built environment, taking into account fire authorities' responsibilities for ensuring the provision of appropriate fire precautions for buildings in use and safe operating procedures that reflect building design.*"

Within these terms of reference an overall *"Review of the Interaction between Operational Fire Fighting Procedures and Building Design"* is being conducted. In particular, issues related to the interaction between building design and firefighting procedures in very large, high rise and complex buildings will be considered.

This document reports the findings from a series of physiological studies investigating the demands of conventional firefighting and search and rescue operations in the built environment. Three phases of work were carried out.

Phase 1
Phase 1 investigated the physiological demands of simulated firefighting and search and rescue operations in ambient conditions.

Phase 2
Phase 2 investigated the physiological demands of firefighting and search and rescue operations under live fire conditions.

Phase 3
Phase 3 investigated the physiological demands associated with the vertical component of firefighting and rescue operations in tall buildings.

For phases 1 and 2 a generic scenario was used simulating the rescue of a 75 kg unconscious casualty (manikin), representing a 32nd percentile male, positioned 45 metres horizontal distance into a 'fire' compartment. This scenario was chosen to represent a 'normal' condition for the horizontal component of firefighting and search and rescue operations anticipated under current building design guidance. Vertical distances between –5 metres (basement) and +18 metres (4th floor) were selected as representative of the reasonable worst case likely to be encountered where firefighters would have to climb internal stairs to gain access to a fire compartment. To replicate the response using a firefighting shaft a specific condition was defined where access to the fire compartment was undertaken via a firefighting lift with the use of a rising main.

The objectives of the studies were to:

1. assess the outcome (i.e. success or failure to achieve the operational objective);

2. quantify the physical strain on the firefighters;

3. identify limitations to performance and identify possible ways of overcoming them.

It is intended that the outcome of this work will support and inform:

- the health and safety of firefighters, by reducing risks from work activities within the built environment;

- the development of firefighting operational practices and procedures and associated training;

- the conduct of generic and dynamic risk assessments;

- the revision of the guidance documents supporting the Building Regulations and other fire safety design guidance to ensure they are consistent with modern working practices.

The work was carried out at the Fire Service College (FSC), in Moreton-in-Marsh, Gloucestershire, and Portland House[1], London, in three phases over a period of 7 months and involved a total of 28 male and female firefighter volunteers from London and the West Midlands Services, plus support and safety staff from Greater Manchester, Merseyside, Norfolk, Oxfordshire and the Fire Service College. In all 77 serials were undertaken. In each serial the make up of firefighting, rescue and support teams was varied.

1 ODPM Offices, Central London.

PHASE 1

Phase 1 involved ambient environmental conditions only (i.e. no fire), with total visual obscuration, along 3 different routes into a building. Measurements were made on 2 lead firefighters (FF) whose primary role was to firefight and to search for and rescue a casualty. Four experimental conditions were explored to investigate the impact of Standard Duration Breathing Apparatus (SDBA) versus Extended Duration Breathing Apparatus (EDBA), and 45mm versus 70mm diameter hose. The firefighters carried approximately 24 kg of external load while wearing SDBA and approximately 33 kg of external load while wearing EDBA, equating to approximately 28% and 39% of their group mean body mass, respectively.

The firefighters performed manual dexterity and cognitive tests, were weighed nude, and provided subjective ratings of perceived exertion and thermal sensation pre- and post-performing the serials. During the serials, heart rate, core temperature, skin temperature, and air use were monitored. Ambient temperature and humidity were monitored via a body-borne probe carried by the firefighters.

The Phase 1 ambient scenario was not successfully achieved by any firefighter team on their first exposures to the various routes and in only 12% of all occasions was the outcome successful. Success was contingent on adequate support being given by firefighters in ancillary roles. Even then, progress was slow in all conditions, especially with 70mm hose. The firefighters rated the experience as 'very hard' and reported being 'hot' on termination. The physiological data supported these ratings. When wearing SDBA the majority of teams withdrew early due to insufficient air. Ventilation averaged 58 $l.min^{-1}$; some 45% higher than assumed in the Breathing Apparatus (BA) Entry Tables. When wearing EDBA the majority of teams withdrew early due to raised core temperatures and/or suspected exertional heat stress. Rate of heat gain was not different between experimental conditions averaging approximately 0.05°$C.min^{-1}$. This rate of rise allows, on average, 32 minutes of operational time before a suggested upper safe working limit of 39°C is reached. Ventilation averaged 69 $l.min^{-1}$ under EDBA, some 72% higher than the BA Entry Tables.

PHASE 2

Phase 2 extended the investigation to include live fires on various floors between the basement and the fourth. One firefighter team (FF) and one search and rescue team (SR) were monitored per serial. Building on the experience from Phase 1, EDBA was exclusively worn to overcome the air limitations imposed by SDBA, and 51mm hose was selected as representing the best compromise between the manoeuvrability of the 45mm and the water delivery of the 70mm hoses. This hose size had also been identified in other BDAG work as offering hydraulic advantages over existing 45mm hose used for firefighting in tall buildings. In addition to the physiological monitoring undertaken in Phase 1, the fire compartment conditions were monitored by fixed thermocouples and radiometers. Smoke density meters measured visibility and water use was also monitored via calibrated flow meters. All serials were filmed from both fixed and roving cameras and key time points were noted. A common time line of the monitoring of the firefighting environment, physiological activity and firefighting intervention was established.

The total external load carried by the firefighters in the form of PPE and RPE was 33 kg, equating to approximately 41% of the group mean body mass. Forty serials were conducted on 6 floor conditions. In each serial the make up of firefighting, rescue and support teams was varied.

While the serials varied in terms of the number of floors, stairs climbed, fire cribs, layout, environmental conditions, smoke, heat flux etc., the main physiological responses of the firefighters between teams and floors were similar. While the FF role was slightly more demanding than the SR role, few differences were noted between floors. This suggests that the results presented in this report have broad applicability to operational response (against 45m horizontal penetration and rescuing a 75 kg casualty) and are not merely relevant to a limited range of firefighting responses.

Mean ambient temperatures throughout the live fire scenarios, by floor, as measured by the body-borne probes, were between 27ºC and 53ºC, while mean peak temperatures ranged from 65ºC to 103ºC. The live fire scenario duration averaged approximately 31 minutes for FF and approximately 33 minutes for SR. Time under air averaged approximately 24 and 27 minutes, respectively. In only 9 (22.5%) of the serials was the scenario concluded with the firefighting and search and rescue teams both achieving the casualty evacuation and returning to the entry control point safely and under control. Self-reported ratings of exertion and thermal sensation at the end of the serials again averaged 'very hard' and 'hot', with the physiological data supporting these ratings.

Heat-related problems were by far the most prevalent. Fifteen serials (37.5%) were stopped due to the firefighters' core temperature exceeding 39.5ºC (the study termination criterion; and 0.5ºC above the limit recommended by Graveling and co-workers for hot fire training). A further 16 (40%) were stopped for safety reasons, either by the Safety Officers or by the firefighters themselves, most of which were heat-related. Rates of rise of core temperature averaged 0.054ºC.min^{-1} and 0.045ºC.min^{-1} for FF and SR teams, respectively, which is a statistically significant difference. Although both teams started the scenario at the same core temperature (approximately 37.5ºC), the FF team ended hotter averaging 39.1ºC compared to 38.9ºC for SR. The greater proximity of the FF team to the fire may have accounted for the higher rise and rate of rise in core temperature. No differences were found in core temperature response between floors, even though temperature data from both the instrumented compartment and the body-borne external sensors showed differences, with the basement being the hottest and the fourth floor being the coolest.

No serials were stopped prematurely for air management reasons as the EDBA supplied ample air. The ventilation did not differ between teams averaging an estimated 56 l.min^{-1}, some 40% above the BA Entry Tables.

PHASE 3

Phase 3 examined the physiological load associated with climbing stairs up 28 floors to explore further the vertical component of firefighting and rescue operations. This assessment did not cover the physiological component of returning to fire service access level. Climbing stairs may be required where either no firefighting lifts have been provided or in the case of their failure. Two separate assessments were conducted in PPE both with and without carrying EDBA and hose. When carrying EDBA and hose it took approximately 30 seconds and core temperature rose by approximately 0.02ºC, per floor. When climbing unloaded it took approximately 15 seconds and core temperature rose by approximately 0.01ºC, per floor.

Climbing stairs in PPE while carrying EDBA and hose is very physically demanding. Operational planning assumptions, including levels of resources, should take account of the physiological demands of reaching the upper floors of tall buildings with RPE and PPE including any equipment carried.

PREDICTIVE MODEL

Using the findings from all three phases a predictive model is presented to estimate the combination of maximum vertical and horizontal distances that firefighters with EDBA could achieve, while remaining within a core temperature limit of 39ºC. This model could be refined and further validated in future studies.

CONCLUSIONS

Assuming 95% confidence in the outcomes, the model suggests that 34m is the maximum distance firefighters should penetrate into a fire compartment to rescue a casualty, where no stair climbing is required to access the point of entry. Having to climb stairs beforehand reduces the maximum penetration distances proportionally. Climbing 10 floors, for example, reduces the penetration distances to around 25m. Climbing 20 and 30 floors allows penetrations of approximately 20m and 12m, respectively.

Heat strain among the firefighters was the greatest single source of performance limitation in the scenarios investigated, causing the premature termination of approximately 65% of serials.

RECOMMENDATIONS

1. Building design guidance on fire service access and facilities should be revisited in light of these findings with the aim of developing revised guidance which acknowledges the physiological limitations of search and rescue operations within the built environment.

2. A scoping study should be undertaken to identify the implications of this work on relevant areas of fire and rescue service activities, together with appropriate changes which need to be made to improve firefighter safety within the built environment.

3. The BA Entry Tables should be revised.

4. Further research should be conducted on techniques and strategies to alleviate heat strain during firefighting operations.

5. Further research should be conducted on defining the physical fitness and physical capabilities of firefighters.

6. Further research should be conducted on methods of identifying heat intolerance in firefighters and its implications for firefighting operations.

CONTENTS

CHAPTER 1
Introduction

This report is one of two major reports describing the findings of a series of studies conducted to measure the physiological demands associated with specified Conventional, Chemical, Biological, Radiological and Nuclear (CCBRN) tasks performed by the UK Fire and Rescue Service (referred to henceforth as 'the Service'). The work was commissioned to Optimal Performance Ltd. (OPL) by the Fire Statistics and Research Division (FSRD) in the Office of the Deputy Prime Minister (ODPM). The project sponsors comprised The Building Disaster Assessment Group (BDAG) and the Civil Resilience Directorate (CRD). This report focuses on conventional firefighting in the built environment.

BDAG was established to consider the issues for fire authorities and their Services in the UK that have been highlighted by the World Trade Centre incident of 11th September 2001. The terms of reference of BDAG are:

> "*To consider the potential implications, for the UK fire service, of terrorist activities within the built environment, taking into account fire authorities' responsibilities for ensuring the provision of appropriate fire precautions for buildings in use and safe operating procedures that reflect building design.*"

Within these terms of reference an overall *"Review of the Interaction between Operational Fire Fighting Procedures and Building Design"* is being conducted. In particular, issues related to the interaction between building design and firefighting procedures in very large, high rise and complex buildings will be considered.

Safety and efficiency are the two major operational concerns of the Service and both require judgements to be made about the workload that firefighters can undertake in different circumstances within the built and natural environment. The variables that have to be taken into consideration include:

- tasks (carrying, dragging, lifting, on the level or up or down stairs);
- ambient conditions (primarily heat);
- physical load (equipment, including Respiratory Protective Equipment (RPE) and Personal Protective Equipment (PPE));
- type of PPE and RPE worn;
- stature, body composition, strength and aerobic fitness of firefighters;
- gender and age of firefighters;
- terrain (underfoot conditions, lighting, etc).

At an incident, when committing personnel to action, the Incident Commander has to decide how many personnel are required to carry out the necessary tasks and how long they can continue to work safely and efficiently. Currently these judgements are largely based on experience and on the normal capacity of the breathing apparatus (BA) when used. There is, however, a need to quantify the impact of the factors listed above on work capacity to:

- support and assist those in command;
- anticipate how new equipment, responsibilities and techniques will impact on work capacity;
- assist in revising the Building Regulations and other building design guidance so they are consistent with modern working practices.

The workloads that firefighters are likely to endure for what may be considered the normal range of operational incidents attended on a routine basis, through to those rare incidents which may be classed as extreme events, have yet to be fully quantified. Similarly, there is a lack of knowledge as to whether firefighters can perform the tasks that might be expected of them or for how long the tasks can be sustained. These issues are compounded by a lack of accurate and detailed knowledge about the fitness and work capacity of firefighters, and also by the gaps in knowledge relating to the thermal and metabolic strain associated with the various configurations of PPE and RPE deployed.

For the purpose of this project, a number of planning scenarios that firefighters are expected to perform under operational conditions were defined. This report addresses firefighting in the built environment. A separate report discusses the outcomes from a number of CBRN scenarios.

The desired outcome of each trial was the rescue of a 75 kg[2] unconscious casualty (manikin) positioned 45 metres (m) horizontal distance into a 'fire' compartment. This scenario was chosen to represent a 'normal' condition for firefighting and search and rescue in a large, complex or high rise building. This phase of the project included firefighting and search and rescue from various floors in a building with and without the use of firefighting facilities. Vertical distances between –5m (basement) and +18m (4th floor) and a horizontal distance of 45m were selected as representative of the reasonable worst case likely to be encountered where firefighters would have to climb internal stairs to gain access to a fire compartment. To represent fire compartments up to this height, scenario conditions were undertaken in the first, second, third and fourth floor of a building. A basement condition was also used to assess the physiological demands of descending through a heat barrier to deal with a compartment fire. In tall buildings with upper storeys more than 18m above Fire Service access level firefighting lifts, stairs and lobbies, are provided. This is known collectively as a firefighting shaft. To replicate Service response using a firefighting shaft, a specific condition was defined where access

2 The mean mass of males aged 16 upwards from the Department of Health's Health Survey of England in 2000 was 81.6 kg, with a standard deviation 14.4 kg. By calculation the 90th percentile male would be 100.0 kg (81.6 + (1.28*14.4, where 1.28 SD above the mean represents the 90th percentile). The 95th percentile adult male is 105.0 kg. The 75.0 kg casualty used in this study represents only the 32nd percentile male.

to the fire compartment was undertaken via a firefighting lift. In these instances firefighting hoses were connected to a rising main which was charged from an appliance adjacent to the building.

For all scenarios a distance of 45m of horizontal penetration was chosen to represent a typical distance to be travelled for firefighters to reach parts of a fire compartment. It should be noted this is less than the 60m that firefighters may travel in a tall building to reach parts of the floor area[3].

To our knowledge no performance or physiological data exist to underpin the current specifications described in the Building Regulations 1991. Nor is it known, prior to the present research, whether UK firefighters are physically capable of completing such search and rescue tasks, with or without fire, during real emergencies. This investigation set out to assess the outcome (i.e. success or failure to rescue a casualty and safely withdraw from the compartment) of the scenario and to identify the primary physiological reasons for limitations to performance under controlled conditions.

It is intended that the outcome of this work will support and inform:

- Health and safety of firefighters by reducing risks from work activity within the built and natural environment.
- Firefighting operational practices and procedures and associated training.
- Generic and dynamic risk assessment information.
- Information exchanges during building design, approval and 'in use' stages.
- Future fire safety design guidance (for example: Building Regulations Approved Document B, European and British Standard Series).

3 Department of the Environment Transport and Regions The Building Regulations 1991. Approved Document B. Fire Safety HMSO London 2000 Page 106.

CHAPTER 2
Approach

2.1 PARTICIPANTS

With the assistance of London Fire Brigade and the West Midlands Fire and Rescue Service, a group of 28 firefighters were secured as volunteers for participation in the series of high rise studies. All participants were briefed and informed written consent was provided. The Occupational Physician from their respective brigades medically screened participants. All but one participant then attended the Middlesex Hospital to undergo a series of baseline tests[4] and measures to provide an individual physiological profile of each participant. The tests and measures included height and mass, body composition, lung function, and both a sub-maximal and maximal exercise test on a treadmill to determine lactate threshold, and maximal aerobic power (VO_{2max}), heart rate and ventilation. Sixteen of the 28 were selected as the primary participant pool for the ambient trials (Phase 1) and 24 were selected for the later live fire trials (Phase 2). The demographic and physiological profile of these two groups of participants is shown at Appendix A in Tables A1 and A2. A risk assessment was performed and risk management strategies were adopted. Ethics approval for the procedures was secured from the University of Birmingham.

2.2 EXPERIMENTAL CONDITIONS AND PROCEDURES

During the week commencing 22 September 2003, participants attended the Fire Service College at Moreton-in-Marsh to undergo the Phase 1 ambient scenario four times, under each of the experimental conditions defined by the client. All conditions were performed in the BA Complex building by eight teams of two firefighters. The teams were formed in a randomised fashion and varied from day to day, and the order in which the conditions were performed was also randomised to minimise learning effects and bias. The four conditions, referred to as C1-C4, are depicted in Table 2.1, where SDBA and EDBA refer to Standard and Extended Duration Breathing Apparatus, and 45 and 70mm refer to the diameter of hose used inside the building and dragged up to 45m where the casualty was located. Where the larger diameter 70mm hose was used, the pair of firefighters being assessed was assisted by a further pair of firefighters to advance the hose line into the 'fire' compartment. Eight serials were performed per experimental condition.

Table 2.1 **Phase 1: ambient experimental conditions**

	45mm	Number of Tests	70mm	Number of Tests
SDBA	C1	8	C3	8
EDBA	C2	8	C4	8

4 A test is defined as a specific trial of one component under investigation (e.g. body fatness, aerobic fitness, core temperature).

Standard Operating Procedures (SOP) were followed at all times. Under all conditions 70mm hose was used between the appliance and the door to the building on the fire floor. Assistance was provided with all of the support tasks (e.g. charging the hose, pulling the hose up the stairs to the door, feeding the hose in through the door), enabling the two firefighters who were being monitored to focus on their designated lead role. Safety Officers were in attendance at all times. The trials were performed self-paced. With the exception of a few early trials on the first day, all conditions were performed with total visual obscuration to simulate worst case conditions. Participants were instructed to 'stay low' at all times when in the building, again to mimic worst case scenario under conditions of live fire.

Three different search routes were followed, referred to as the red, blue and yellow routes. The original intention had been to randomise the trials between only two routes (red and blue), which shared a common access corridor. However, it became clear after the initial exposure to either of the routes that the firefighters retained a mental picture of the route, and on subsequent trials they proceeded faster, and on occasion completed the objectives because of their prior knowledge. For this 'route-learning' reason, a yellow route was introduced on the fourth day (corresponding to the fourth trial for the majority of teams), to re-introduce a novel course to which participants had had no exposure.

On four specified periods between 15 December 2003 and 5 March 2004, the firefighters again attended the Fire Service College at Moreton-in-Marsh to undergo Phase 2 of the trials. The operational details had evolved from Phase 1, and live fires were included. Three live fire serials[5] were performed each test day, involving fire crews on three appliances. Participants were randomly allocated in pairs to a Firefighting Team (FF), a Search & Rescue Team (SR), and to the various support roles. Both FF and SR wore EDBA[6], while personnel in support roles, when required to wear BA, wore SDBA. 70mm hose was used to supply water from the hydrant to the appliance, and, when it was used from the appliance to the dry riser. In all instances the firefighting attack was undertaken using 51mm hose either direct from the fire appliance or from a dry rising main[7].

Overall, 40 live fire serials were conducted over 6 different conditions. The number of serials by floor is shown in Table 2.2. Throughout this report results are reported separately for the FF and the SR teams, unless specified otherwise.

Table 2.2 **Phase 2: live fire experimental conditions**

Floor	Number of Tests
Basement (B)	9
1	9
2	8
2 Fire Shaft (FS)	9
3	2
4	3
Total	**40**

5 A serial is defined as one repetition of the scenario, irrespective of the experimental condition.

6 Phase 1 had determined that in order to explore the physiological limits, EDBA was required. SDBA did not provide sufficient air to complete the task.

7 51mm hose was selected to provide pull-through to other work that was being conducted on high-rise buildings. 51mm appears to provide the best compromise between volume and power of water delivery, with manoeuvrability of charged hose deep into a fire compartment.

2.3 FIRE AND FIREFIGHTING ENVIRONMENT INSTRUMENTATION

Each scenario used a different floor in the Commercial or Industrial 'A' building at the Fire Service College (FSC). A number of wooden cribs were used that had been specifically designed by the Building Research Establishment (BRE) as the target fires. In addition straw bails were ignited to create smoke. The cribs were positioned in various arrangements, either double or single cribs, depending on the size and layout of the fire compartments for each scenario.

2.3.1 Crib Design and Distribution

The cribs used in the trials were designed to replicate the 'standard' cribs used by the FSC which were found to be inconsistent in terms of burn rate and rate of heat output, requirements which would be essential for standardisation and repeatability of the trials. A 'standard' FSC crib was evaluated under the 9m cone calorimeter at BRE in order to determine its characteristics and overall energy output and these figures were used to design a consistent and reproducible crib.

The cribs consisted of 96 pieces of 75mm x 75mm kiln dried timber. Two lengths (680mm and 800mm) of the individual pieces were necessary to fit the cribs into the cages provided by the FSC.

A crib consisted of 8 layers of 680mm lengths and 8 layers of 800mm lengths. Each layer contained 6 pieces of wood of the appropriate length with each layer stacked at right angles to each other to form a crib. The cribs were ignited from the bottom layer by using at least six 25mm x 6mm x 500mm lengths of low density fibre board. The fibre board strips were soaked in diesel before being inserted in to the bottom layer of the crib and ignited with a blowtorch.

Under fully ventilated conditions the cribs reached a steady heat output of 0.8 mega Watts (MW) after 15 minutes and continued to burn at this output for approximately 40 minutes before the output declined. These measurements were taken under the 9m cone calorimeter at BRE.

For each trial scenario FSC cribs, as specified for training scenarios on that floor, were replaced with BRE designed cribs. The total heat release for each scenario was between approximately 3 and 5 MW. The upper figure equates to a fully developed living room fire or the early stages of a fire in a commercial property. Five MW is also a commonly assumed fire size used in building design.

2.3.2 Instrumentation to Measure the Firefighting Environment

Each scenario was instrumented with the following equipment:

- 2 Thermocouple trees to measure fire gas temperatures..
- 1 Radiometer to measure radiant heat flux.
- 2 Smoke density meters.

Thermocouples

Two thermocouple trees were used in each scenario. They were positioned such that one was fairly close to one of the crib positions and the other was on the perimeter of the fire compartment. Table 2.3 gives the heights of the thermocouples that were used.

Table 2.3 **Position of thermocouples by floor**					
	Commercial Building				**Industrial A**
Height (m)	**Basement (B)**	**1st floor (1)**	**2nd floor (2 & FS)**	**3rd floor (3)**	**4th floor (4)**
4.50		X			
4.00		X			
3.50	X				
3.00	X	X	X		X
2.50			X	X	X
2.00	X	X	X	X	X
1.50	X		X	X	X
1.00	X	X	X	X	X
0.50	X	X	X	X	X

Radiometer

A water cooled radiometer was used to measure heat flux. It was positioned such that it focused on one of the crib arrangements and was next to one of the thermocouple trees. Details of the radiometers and cribs are given in Table 2.4.

Table 2.4 **Number of cribs and distance of radiometers from cribs by floor**					
	Commercial Building				**Industrial A**
	Basement	**1st Floor**	**2nd floor**	**3rd floor**	**4th floor**
Total number of cribs for scenario	6	4	5	3	3
Distance from crib	4.3m	2.7m	4.0m	4.0m	4.0m
Height	1.3m	1.3m	1.3m	1.3m	1.3m

Smoke Density Measurement

The smoke density was measured using optical instruments, and the output processed to give readings in Optical Density (OD). OD is a logarithmic scale, with zero corresponding to clear air. One OD corresponds with 10% transmittance, and two OD with 1%. The optical path length used in the measurements was 0.5m. The height in the compartments that the meters were mounted is shown in Table 2.5.

Table 2.5 **Heights of optical meters**	
Conditions	**Height (m)**
B (C1)	0.2
1 (C2)	1 & 1.5
2 (C3)	0.2 & 0.8
FS (C5)	0.2 & 0.8
3 (C4)	0.8
4 Industrial	1.5

2.4 ENVIRONMENTAL CONDITIONS

2.4.1 Ambient conditions during ambient serials

An external temperature probe that one of the pair of firefighters carried, attached to, but not in contact with the BA set, recorded ambient temperature and humidity during the ambient serials. Summary data for both the initial approximately 6 minutes spent outside of the building (Out), and the remaining time spent inside (In) the building (averaging approximately 19 and approximately 28 minutes, respectively for the SDBA and EDBA conditions) are displayed in Figures 2.1 and 2.2 and Table B1 in Appendix B. The overall mean temperature outside was 17°C and inside was 27°C. Mean humidity was 53% outside and 50% inside.

Figure 2.1 **Mean ambient temperature**

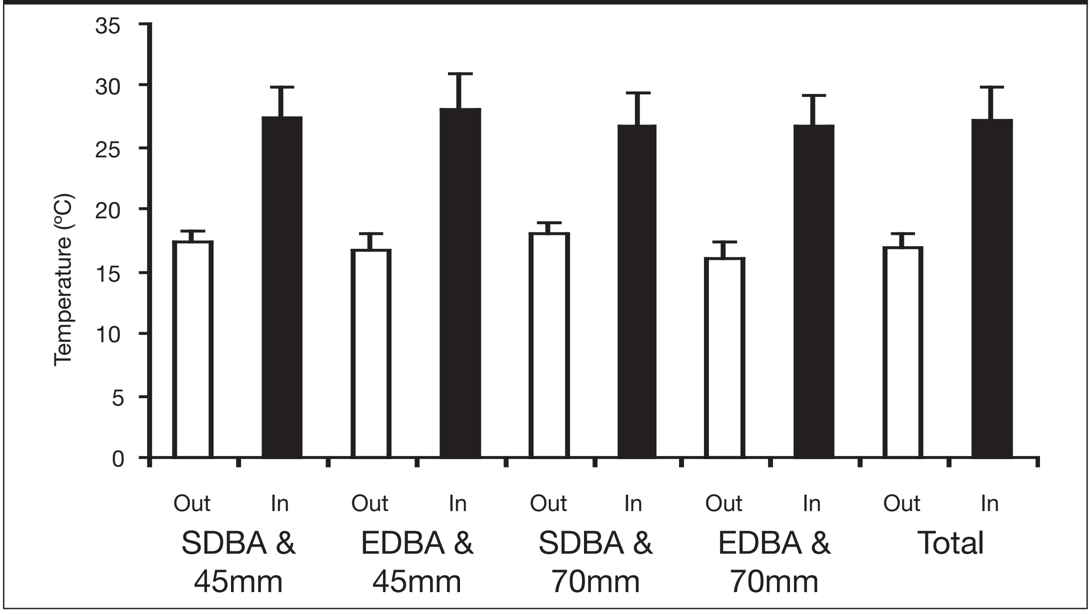
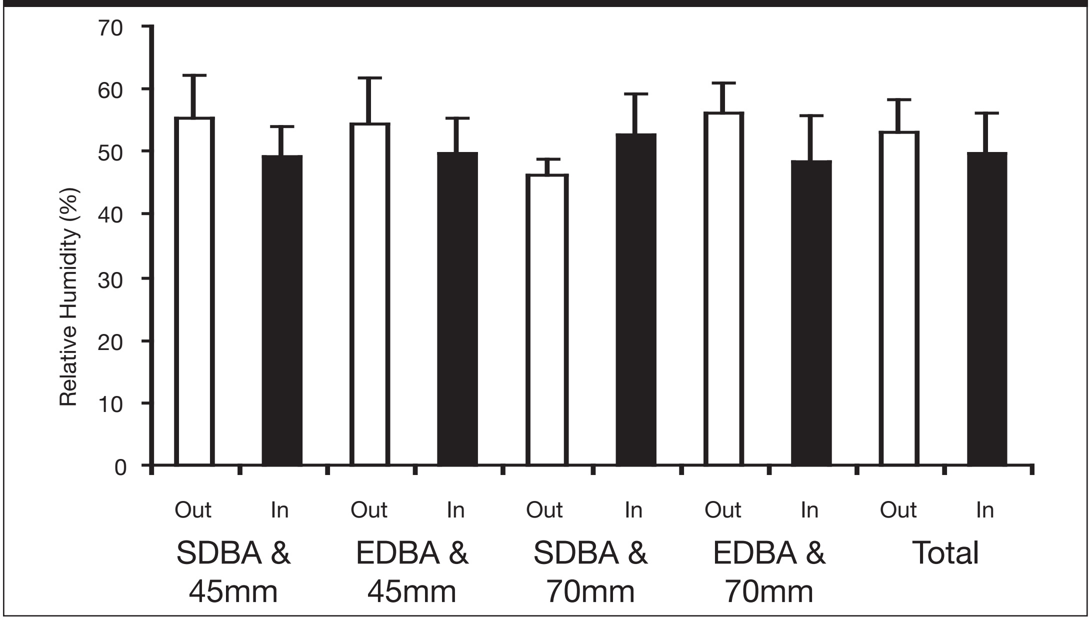


Figure 2.2 **Mean relative humidity**

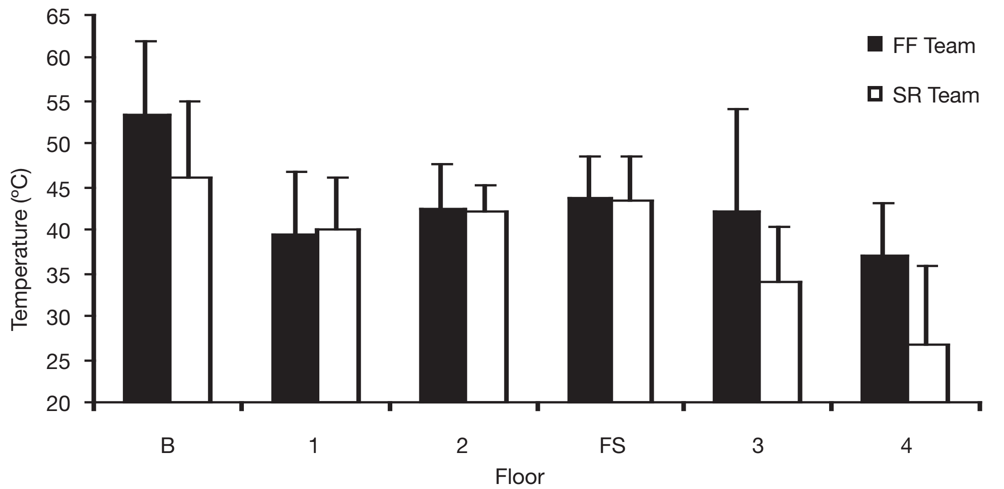


2.4.2 Live fire environmental conditions

One member of the FF and SR teams carried an external temperature probe that recorded ambient dry bulb[8] temperature during the live fire serials. The mean ambient dry bulb temperatures experienced by the firefighters from the start of the serial to when they came 'off air'[9] are shown in Figure 2.3 and Table C1 in Appendix C and the peak temperatures recorded are shown in Figure 2.4 and Table C2 in Appendix C.

The FF team were exposed to an average of approximately 44°C which was somewhat higher than the approximately 41°C experienced by the SR team (p=0.08). There were significant differences in the temperatures experienced between floors, with the temperatures in the basement higher than all other floors. The hotter temperatures recorded during the basement serials were as anticipated given that the firefighters had to descend the stairs through the heat barrier. The 2nd floor with and without fire shaft was also hotter than the 4th floor, which was the coldest. The cooler temperatures recorded for the 4th floor were probably a function of both the cooler time of year when these serials were performed (December), the nature of the fires themselves, and the ventilation within the 'Industrial 'A' Building' at the Fire Service College, where only this floor was assessed.

Figure 2.3 **Mean ambient temperature by floor and team**



8 No measure of radiative heat was made by the body-borne probes, which would have been significant in these live fire situations. Measures of radiative heat were, however, made by fixed sensors within the compartment (see Figure 2.7).

9 'Off air' refers to the moment at which the firefighter stops breathing air from the breathing apparatus. 'On air' refers to the moment at which the firefighter starts breathing from the breathing apparatus. 'Under air' refers to the period in between going 'on air' and 'off air'.

Figure 2.4 **Peak ambient temperature by team and floor**

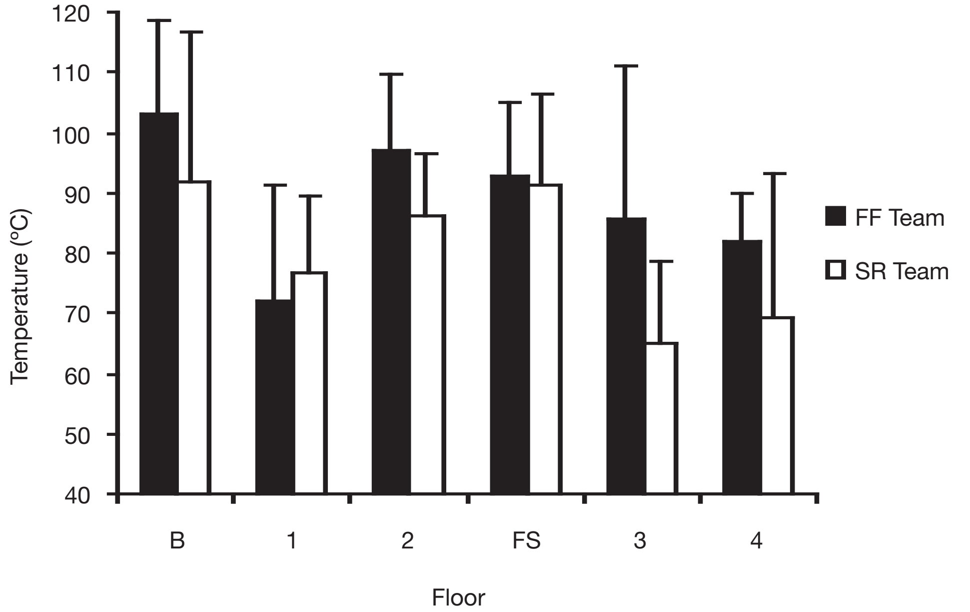
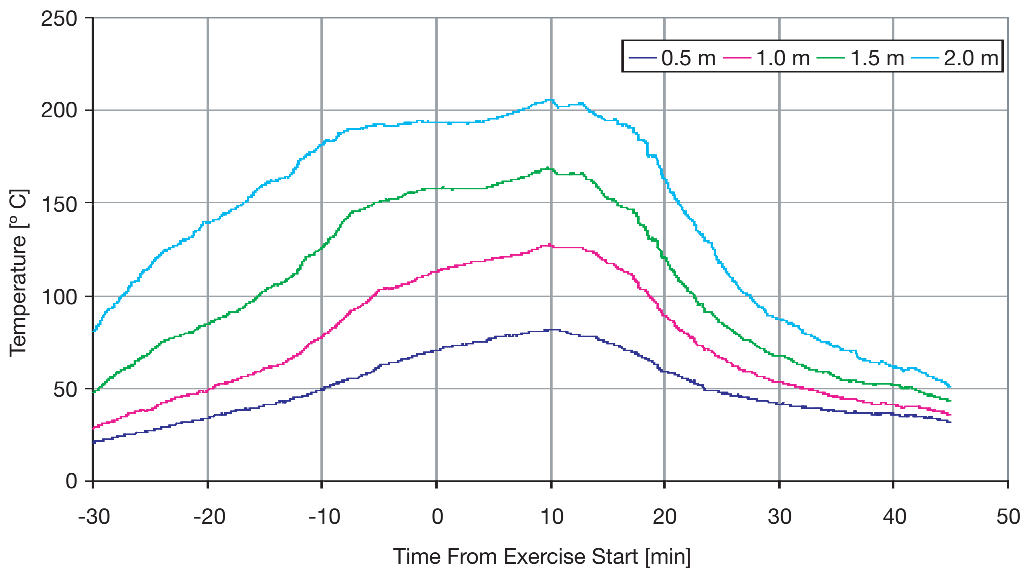


Figure 2.5 shows the mean temperatures recorded by the thermocouples mounted at different heights (0.5, 1.0, 1.5 and 2.0 metres from the floor) in the compartment. Progressively increased temperatures were recorded with increasing height within the compartment. For example, peak temperatures of approximately 130°C were recorded at 1m, whereas approximately 200°C were reached at 2m. The figure also shows the temperature rising up to approximately 10 minutes after the start of the scenario (zero time) and declining thereafter as the firefighters attacked the fires.

Figure 2.5 **Mean temperatures in the fire compartments for all fires**



Figures 2.6 and 2.7 show the mean optical density and heat flux in the compartments, at a height of 1m from the floor, respectively. Mean optical density peaks at approximately 10 minutes and declines in a fairly linear fashion thereafter. Heat flux reached a plateau at around zero time, maintained a plateau for around 15 minutes (as the fires were designed to do) and decayed fairly rapidly thereafter due to firefighting intervention.

Figure 2.6 **Mean optical density in the fire compartment for all fires**

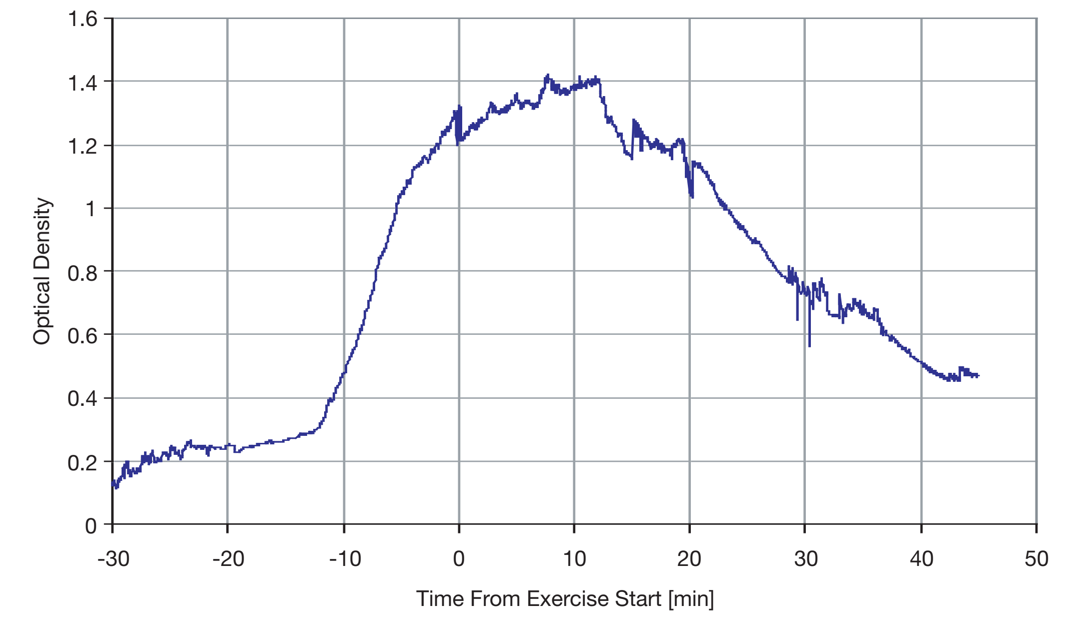
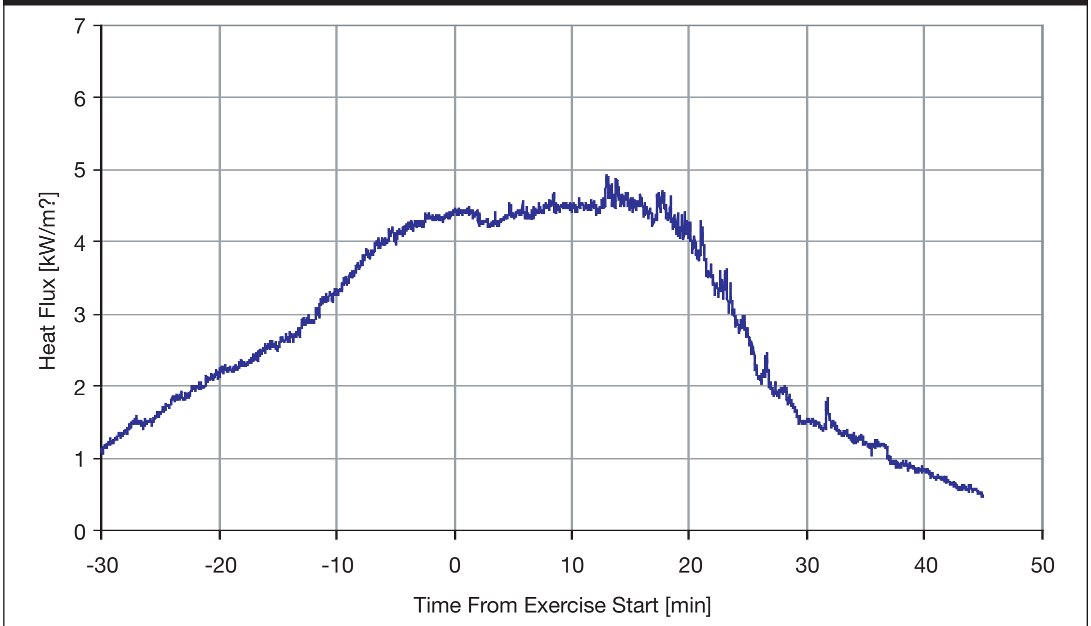


Figure 2.7 **Mean heat flux in the fire compartment for all fires**



2.5 PHYSIOLOGICAL AND COGNITIVE MEASUREMENTS

The firefighters arrived in their teams at least one hour before performing each serial for pre-testing and instrumentation. They had been asked to abstain from eating for 3 hours prior to their test and to ensure that they were in a state of good hydration. Following ingestion of a temperature pill, a manual dexterity test and three cognitive performance tests were performed (pre- and post-instrumentation) on a sample of firefighters. The manual dexterity test comprised assembly and disassembly of a PortoPower unit. The cognitive performance tests used touch-screen technology and comprised three computerised tests involving Rapid Visual Information Processing (RVIP), Spatial Memory Span (SMS) and Reaction Time (RT) supplied by CANTABexpedio (Cambridge Cognition Ltd, Cambridge, UK).

The RVIP is a test of visual sustained attention, in which a box appears in the centre of the monitor, inside which digits from 2 to 9 appear in a pseudo-random order at the rate of 100 digits per minute. The test lasts for 4 minutes, during which time participants try to identify 3 consecutive sequences of digits (e.g. 2-4-6, 3-5-7, and 4-6-8) and register their response by depressing the keyboard space bar. The maximum achievable score for this test is 1.

The SMS is a test of spatial memory span. A random pattern of white squares is shown on the screen. Some of the squares change in colour, one by one, in a variable sequence. At the end of the presentation of each sequence, a tone indicates that the participant should touch each of the boxes coloured by the computer, in the same order as they were originally presented. The number of boxes in the sequence is increased from a start level of 2 to a final level of 9. Three attempts are allowed at each level. The last sequence (level) correctly identified provides the score.

The RT is a two-part test of simple and 5-choice reaction time. In the simple reaction time task, the participant has to hold the space bar down, then release it and touch the screen as soon as possible after a yellow dot appears in the centre of the circle. In the 5-choice reaction task, the yellow dot appears in any one of 5 locations. The test is scored in milliseconds, where the smaller the number, the faster the reaction time.

Following nude weighing, firefighters were instrumented for skin temperature (4 sites: neck, shoulder, hand and shin) using skin thermistors (Grant, UK) and heart rate (Polar Team System, Polar, Finland), the data loggers (Squirrel Loggers, Grant, UK; and HQI Cortemp, USA) were connected and secured to the firefighters and recording was started. Data were logged every 5 seconds (heart rate) and 20 seconds (core and skin temperature) throughout each scenario. Finally the firefighters dressed in their standard firefighting PPE, then donned EDBA sets, were re-weighed and then walked approximately 50m and boarded the appliances.

Immediately prior to the start of the serial, baseline measures of EDBA pressure and core temperature[10] were recorded, as well as subjective ratings of perceived exertion[11] and thermal sensation[12]. Thereafter, at 5-minute intervals, readings of core temperature were taken either by hand (ambient) or via telemetry (live fire), both as a backup to the 20-second logged data and for safety reasons. If a core temperature of 39.0ºC was reached, core temperature readings were taken every 2.5 minutes. Ambient temperature was recorded using a temperature probe attached to but not in contact

10 Internal body temperature is kept nearly constant in humans, with fluctuations during normal life rarely exceeding 1 degree centigrade (ºC). Only during prolonged strenuous exercise, with illness, or in extreme environmental conditions do body temperatures deviate outside the normal range (37 ± 1ºC). Body temperature reflects a careful balance between heat production and heat loss. If heat production exceeds heat loss, internal body temperature rises. If core temperature rises more than about two degrees, degradations in performance become apparent. Heat exhaustion, which is typically accompanied by symptoms such as extreme fatigue, breathlessness, dizziness, vomiting, and fainting is caused by the cardiovascular system's inability to adequately meet the body's needs. If core temperature rises to values exceeding 40ºC, heat stroke can occur, which is a life threatening heat disorder requiring immediate medical attention.

To mitigate the risks of heat exhaustion and heat stroke, the World Health Organisation proposes an upper core temperature limit of 38.5ºC for industrial populations. The ODPM Guidance on the Management of the Risk of Heat Stress during Training (Fire Research Report Number 1/2001) proposes 39ºC as a safe upper limit for live fire training in firefighters. In this series of research studies conducted by OPL, an upper working limit of 39.5ºC was imposed, coupled with individual monitoring of core temperature.

11 Borg GAV (1982). Psychophysical bases of perceived exertion. Med Sci Sports Exerc, 14 (5), 377.

12 Gagge, Stolwijk and Hardy (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environ Res, 1 (1), 1-20.

with the upper back of the firefighters, on top of the EDBA sets, sampling every 20 seconds. Air use was recorded both as pre- and post-pressure gauge readings, and also by the Draeger BodyGuard computerised system. The BodyGuard system records the pressure drop in the EDBA every 20 seconds and the data are uploaded at the end of the serials.

The serials began on the instruction of the Incident Commander, once the fires had established themselves, and the film crew, physiologists and firefighters were ready. The first two appliances arrived at the scene within 1 minute of commencement of the serial, with a third appliance arriving 0.5-1 minute later. The FF and SR teams were briefed by the Incident Commander before proceeding to the entry control point where they went under air and subsequently entered the fire compartment. Support teams fed hose as far as the compartment entrance. The teams were instructed to perform a right or left-hand search, following the walls in the nominated direction. The primary role of the lead FF team was to suppress the fires, while that of the SR team was to search the compartment for casualties and remove them from the fire compartment, handing them to support firefighters at the compartment entrance.

At the termination of the test, final readings were taken of EDBA pressure and core temperature, and firefighters provided subjective ratings of perceived exertion and thermal sensation. A finger-prick lactate sample was taken as soon as possible (approximately 1-3 minutes) after completion of the serial. The purpose of taking a lactate sample was to identify if the participants had elevated lactate levels, which was indicative of whether they were working at a sustainable pace. Elevated values, where they exceed the lactate threshold, are indicative of an unsustainable workload. After resting, cooling and rehydrating, firefighters were escorted back to the instrumentation area on foot where they were de-instrumented, re-weighed nude, and performed the manual dexterity or cognitive performance tests.

All events were filmed and time-coded by ViewPoint[13] using both fixed and roving cameras positioned inside and outside the building. The film crew kept note of the time taken to reach certain pre-determined points during the serial. Subsequently, further timeline and event information was extracted from the digital video recordings. All measurements of firefighters' activity, water usage and changes in environmental conditions as a result of firefighting activities were recorded on a common time line for subsequent analysis.

2.6 TERMINATION AND SAFETY CRITERIA

The overall exercise was under the control of an officer with extensive experience of fire ground exercises at the FSC, retained to the project for this purpose. Full paramedic cover was available throughout the trial to deal with any medical emergency which may have occurred. Each pair of firefighters undertaking the trials was monitored by one safety officer who was familiarised with the escape points from every floor of the firehouse.

The test termination criteria were four-fold:

1. The air pressure in the BA sets, as judged by the firefighters, became low and the firefighters withdrew.

13 VPTV, Chipping Norton, Oxfordshire.

2. Core temperature of 39.5°C was reached, the firefighter team was withdrawn and the individual actively cooled.

3. Safety Officers judged the firefighter to be unsafe at any time, or the firefighter requested to stop for any reason, the firefighter was withdrawn, and where appropriate, actively cooled.

4. The firefighter team succeeded in completing the task (i.e. rescuing the casualty using standard operating procedures and returning safely to the entry control point).

Members of the safety staff were also dynamically monitored for core temperature and withdrawn from the compartment if their core temperature reached 39.5°C, though these data were not recorded.

2.7 STATISTICAL ANALYSIS

The results in this report are expressed as mean ± one standard deviation (SD). Comparative analyses were performed using standard parametric statistics (ANOVA) run on Statistical Package for the Social Sciences (SPSS) version 11 for Windows. *Post-hoc* pair wise comparisons were made using Tukey's honestly significant differences test. Statistical significance was set *a-priori* at $p<0.05$; where $p<0.05$ indicates the probability that the difference documented occurred by chance is 0.05, or 5%. P values of 0.01 and 0.001 indicate significance at the 1% and 0.1%, respectively, indicating progressively increasing degrees of confidence in the differences reported. The terms 'approaching statistical significance' or 'tended' are used to denote a probability of less than 0.1 or 10%.

Heart rate data were expressed as a percentage of Heart Rate Reserve (%HRR) as this index of cardiovascular strain is recommended by the American College of Sports Medicine, and it takes into account individually measured sleeping and maximal heart rates measured during the fitness tests. The resultant %HRR data were applied to Howley's (2001) classification system, quantifying the time in minutes and the percentage of time spent in 5 zones of intensity, corresponding to 'very light' (<20%), 'light' (20-39%), 'moderate' (40-59%), 'hard' (60-84%) and 'very hard' (>85%). In this report the percentage of time spent in the upper 2 zones combined (i.e. hard or very hard, equivalent to > 60% HRR) only are presented.

2.8 PARTICIPANTS' FITNESS

From the Phase 1 cohort, 15 of the 16 that participated were male. All attended baseline fitness tests. An individual breakdown of participant's physiological characteristics is provided at Appendix A, Table A1.

In summary, age averaged 31 years and ranged from 21 to 38 years. Mean height was 179cm and mean mass was 84 kg. Mass ranged from 64 to 94 kg providing a good range of body sizes. Percentage body fat averaged 17%, which is similar to results reported in previous firefighter studies of 18% (Brewer *et al.*, 1999) and 17% (Love *et al.*, 1996), but is lower than is suspected among the wider firefighter population. From the fitness assessment, mean maximal ventilation was 141 litres per minute and maximal aerobic power (VO_{2max}) was 48 $ml.kg.^{-1}min^{-1}$ and 4.0 $l.min^{-1}$

with values ranging from 42 to 55 $ml.kg.^{-1}min^{-1}$ and from 3.0 to 5.1 $l.min^{-1}$. Lactate threshold equated to a mean blood lactate concentration of approximately 5 $mmol.l^{-1}$ and a heart rate of approximately 170 $beats.min^{-1}$.

From the Phase 2 cohort, all bar one of the firefighters (missing due to injury as discussed earlier) attended the fitness tests. An individual breakdown of participant's fitness is provided at Appendix A, Table A2.

In summary, age averaged 30 years and again ranged from 21 to 38 years. Mean height was 177cm and mean mass was 81 kg. Mass ranged from 59 to 94 kg. Percentage body fat averaged 18%. Mean maximal ventilation was 137 litres per minute and maximal aerobic power (VO_{2max}) was 48 $ml.kg.^{-1}min^{-1}$ and 3.9 $l.min^{-1}$ with values ranging from 36 to 65 $ml.kg.^{-1}min^{-1}$ and from 2.6 to 5.1 $l.min^{-1}$.

It appears that a majority of participants in both cohorts fell in the top half of the fitness distribution of serving firefighters, based on our best estimate that the mean VO_{2max} of serving firefighters is around 43 $ml.kg.^{-1}min^{-1}$ (Rayson *et al.*, 2003). Four of the 23 fitness-assessed participants from the phase 2 cohort were below this value. Two were male and 2 were female. Mean aerobic fitness data on the UK general population[14] have been reported as being approximately 50 $ml.kg.^{-1}min^{-1}$ for men aged 25-34 and approximately 46 $ml.kg.^{-1}min^{-1}$ for men aged 35-44, though these figures are thought to be unrepresentatively high. Comparative values for women are 38 and 35 $ml.kg.^{-1}min^{-1}$, respectively. The mean values of around 48 $ml.kg.^{-1}min^{-1}$ in these cohorts is above the required level of 45 $ml.kg.^{-1}min^{-1}$ until recently recommended by the Office of the Deputy Prime Minister for entry to the Service.

Fourteen participants also underwent the battery of job simulations developed as part of the Point of Entry Selection (PES) Project for assessing suitability of candidates to join the Service. These data are reported at Appendix E. They show a high pass rate among the male firefighters, but a low pass rate among the female firefighters. One firefighter failed the ladder extension, ladder lift, ladder climb and domestic simulation, and four failed the rural simulation. Those who failed would appear to have insufficient aerobic power and/or body size.

14 The Allied Dunbar National Fitness Survey, 1992, p88.

CHAPTER 3
Phase 1 results: Ambient conditions

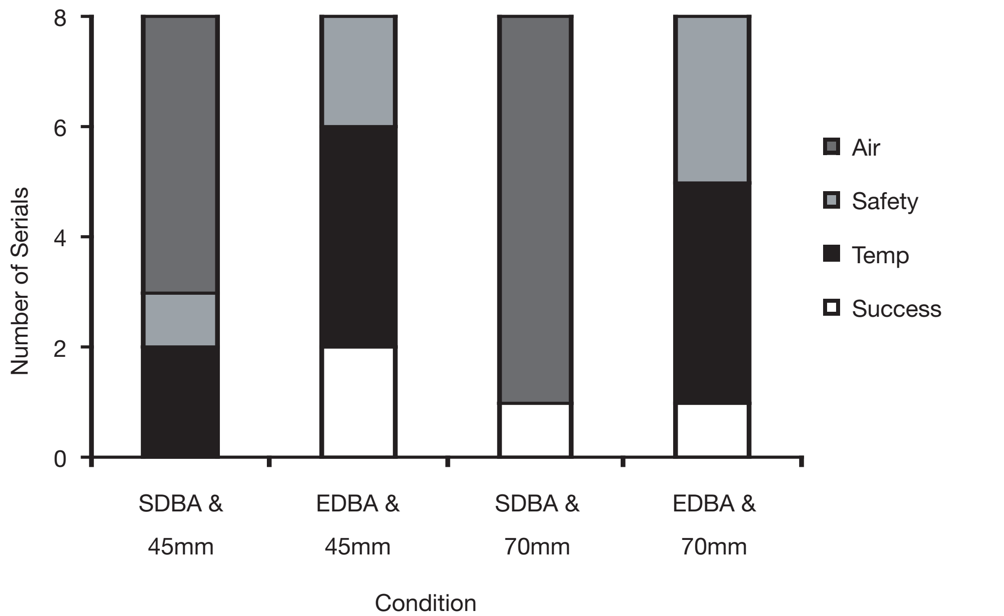
3.1 SUMMARY OF OUTCOMES BY CONDITION

The outcomes of the four experimental conditions each performed by eight teams are shown in Figure 3.1 and provided numerically in Table B2 in Appendix B. Over all the ambient condition serials:

- 4 (12%) were successful in completing the scenario, rescuing the casualty;
- 10 (31%) were terminated because the threshold core temperature was reached;
- 6 (19%) were stopped for safety reasons (usually associated with apparent uncertainty or confusion on the part of the firefighter, possibly fatigue or heat induced); and
- 12 (38%) were terminated prematurely due to a shortage of air (all in the SDBA conditions).

There were no successful outcomes on the two days when the routes were novel to all participants (day 1 and day 4), suggesting that participants achieved success on the scenario only once they had 'learned' the route.

Figure 3.1 **Scenario outcomes by Condition**



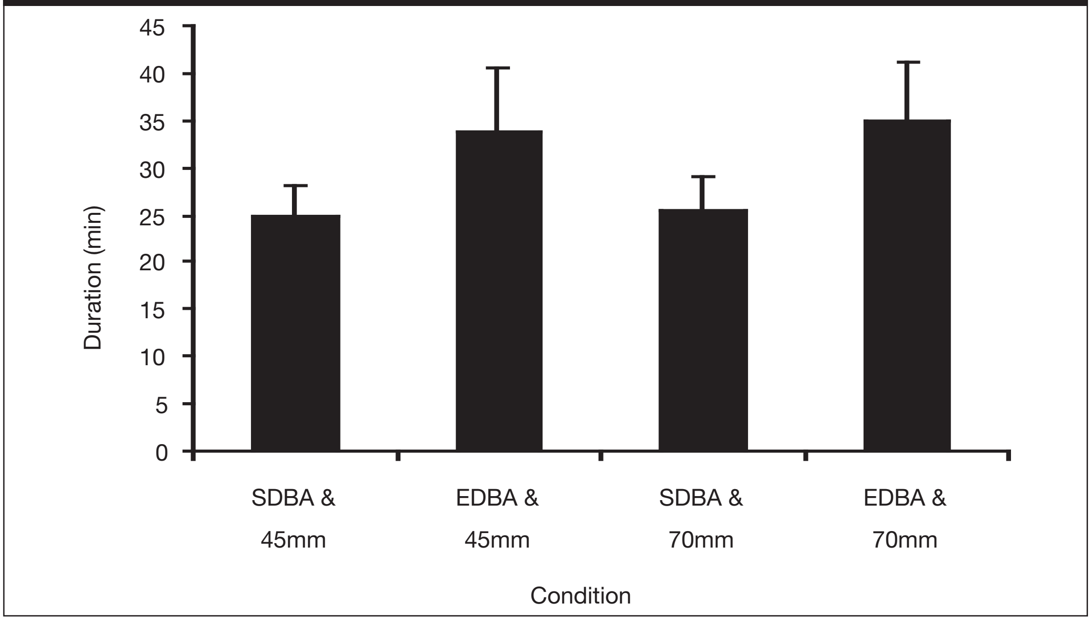
The primary reason for early termination of both conditions using SDBA (C1 & C3) was shortage of air, with 12 of 16 teams terminated for this reason. Two of 16 teams were terminated for reaching threshold core temperatures, 1 was stopped for safety reasons, and 1 was successful in achieving the task in full (i.e. rescuing the casualty). In short, under conditions of SDBA, shortage of air was the primary limitation to performance.

Under the conditions using EDBA (C2 & C4) achieving threshold temperatures was the primary cause of termination, occurring in 8 of 16 teams. A further 5 teams were stopped for safety reasons, most of which appeared to be associated with confusion or disorientation, which may have been associated with fatigue and/or heat stress. In brief, under conditions of EDBA, achieving threshold core temperatures and fatigue/heat related problems were the primary limitations to performance.

3.2 WORK DURATION AND EXTERNAL LOAD

The total work duration, calculated as the time from the start of the serial (at the entrance to the building at the base of the stairs) to coming off air is summarised in Figure 3.2. Work duration averaged approximately 25 minutes for the SDBA conditions and approximately 34 minutes for the EDBA conditions, which was statistically significantly longer under EDBA ($p<0.001$). Size of hose had no influence on the work duration.

Figure 3.2 **Work duration by team**



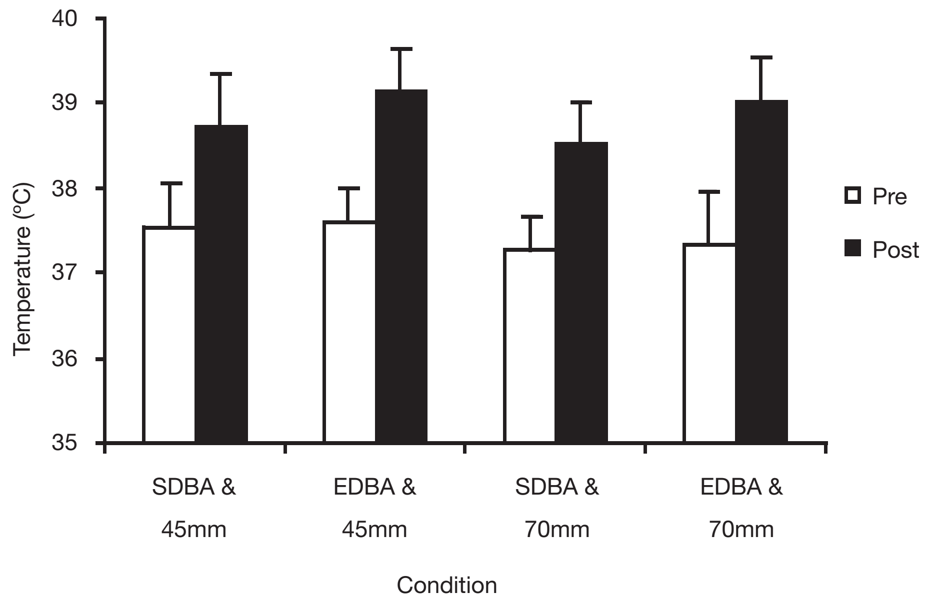
Time under air averaged 21.6 (± 2.9), 22.1 (± 3.3), 32.2 (± 4.1) and 31.4 (± 6.1) minutes for the SDBA 45mm, SDBA 70mm, EDBA 45mm and EDBA 70mm conditions, respectively. Time under air in the two EDBA conditions was, unsurprisingly, statistically significantly longer than in the two SDBA conditions ($p<0.001$).

Firefighters carried 23.6 (+ 0.7) kg of external load while wearing SDBA and 32.6 (+ 0.7) kg of external load while wearing EDBA which equated to 28 (+ 4)% and 39 (+ 5)% of their group mean body mass. Some firefighters carried relatively less load than others. For example, in the EDBA condition external loads represented only 35% of body mass for the heaviest firefighter, compared to 51% for the lightest.

3.3 CORE TEMPERATURE RESPONSE

The mean core temperature response to each of the four conditions is shown in Figure 3.3 and Table B3 in Appendix B. The columns in Table B3 show the number of firefighters in each condition, the mean duration of the test in minutes, the core temperatures at the beginning and end of the test, the rise in core temperature over the duration of the test, and the rate of rise of temperature, all in degrees centigrade.

Figure 3.3 **Mean core temperature response by condition**



As expected, final core temperature reached statistically significantly higher values in the EDBA conditions (C2 and C4) at 39.1 (+0.5)°C compared to SDBA conditions (C1 and C3) at 38.6 (+0.5)°C, as the EDBA teams had longer work durations (approximately 34 vs 25 min; $p<0.001$). Correspondingly, the rise in temperature was also greater under the EDBA conditions ($p<0.01$). However, the mean rate of rise (0.047°C.min^{-1}) did not differ ($p=0.95$) between conditions, suggesting the difference in core temperature between conditions was the result of the longer duration of the EDBA trials. Heat gain, surprisingly, was therefore independent of both BA worn and size of hose carried throughout the condition. However, it is not known if the firefighters were operating at the same work rate across conditions.

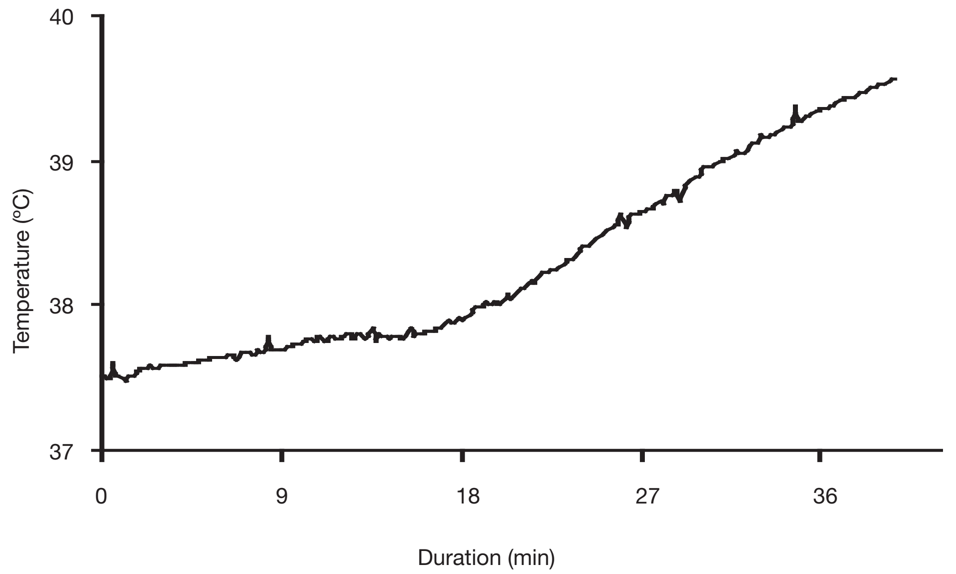
The number of firefighters reaching the threshold value of 39.5°C in each condition was 2, 4, 0 and 4, respectively for conditions 1-4. As expected, the additional air volume provided by the EDBA removed ‘shortage of air’ as a termination criterion under these conditions, with 8 firefighters achieving the threshold core temperature value of 39.5°C.

Attainment of high core temperatures, as reported in this scenario, is not uncommon in operational firefighting. Graveling *et al.* (2001)[15] reported that of all search and rescue training exercises in which core temperature data were collected, approximately 18% resulted in core temperatures greater than 39.0ºC. In the same report it was stated that body temperatures in excess of 39ºC were regarded as 'typical' by staff at several UK fire training centres. That is not to say that these core temperatures are regarded as 'safe'. The World Health Organisation limit for 'heavy work' is 38°C and the US ACGIH guidelines are based on the same (38°C) limit. Graveling *et al.* recommend an upper limit of 39°C, albeit measured in the ear.

An individual plot of core temperature response is shown in Figure 3.4 as an example. This particular firefighter spent approximately 40 minutes working in this condition (C2). The core temperature response shows a markedly sharp increase after approximately 16 minutes, which reflects the time the firefighter started to 'pull-in' charged hose for further advancement into the building. The test was terminated when the firefighter reached 39.5ºC at approximately 40 minutes. At this point both firefighters were led out of the building and body cooling procedures commenced. The rate of temperature rise is fairly linear between 16 and 40 minutes, up to the point of termination at 39.5ºC, with the participant showing no signs of reaching any thermal equilibrium, demonstrating the dangers inherent during these operations.

There is nothing atypical about this core temperature response, nor does it show heat intolerance in this particular individual. It is, however, somewhat surprising given the nature of the firefighters role and the exposure to high environmental temperatures during training and operations that heat tolerance of individual firefighters is never formally assessed at any stage of a firefighter's career.

Figure 3.4 **An example core temperature response to C2**

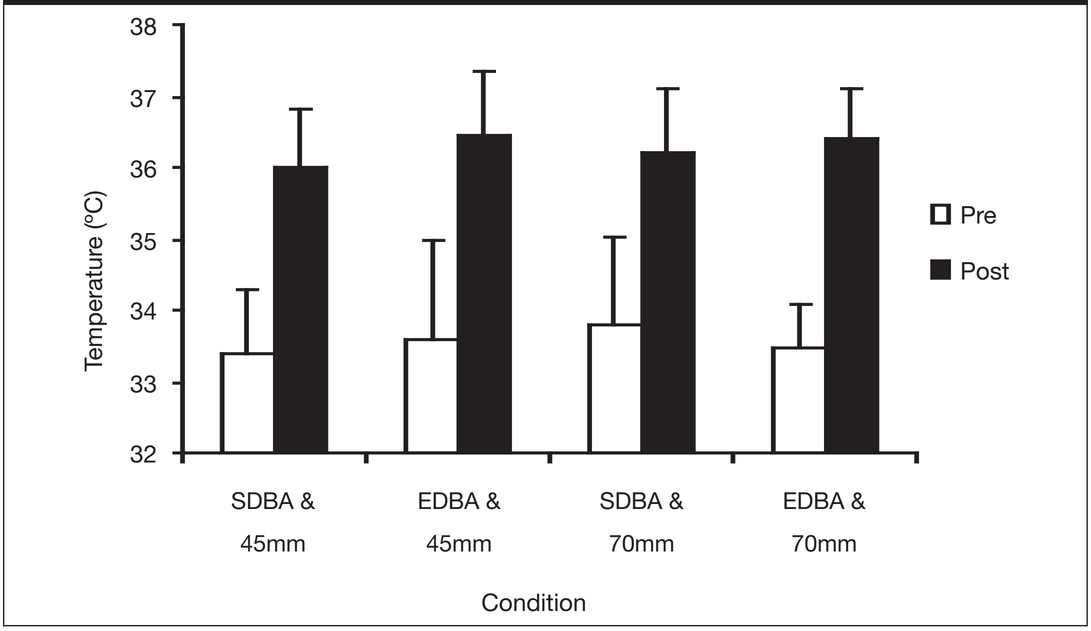


15 Graveling et al (2001). Firefighter Training: Physiological and Environmental Factors. Fire Research Report Number 1/2001. Institute of Occupational Medicine.

3.4 SKIN TEMPERATURE RESPONSE

A summary of the mean skin temperature response is shown in Figure 3.5 and the data are shown in Table B4. Overall, the mean rise was 2.8 (+0.9)ºC and the rate of rise was 0.098 (+0.039)ºC per minute. There were no differences between any of the conditions in the pre-, post-, or rise in skin temperature, despite the longer durations of the EDBA (C2 & C4) conditions. However, there was a greater rate of rise in skin temperature by BA set ($p<0.01$), where the SDBA wearers averaged 0.11 (+0.04)ºC.min^{-1} and EDBA wearers averaged less at 0.09 (+0.03)ºC.min^{-1}. It is unclear why this should be so, though one possible explanation is a greater cooling effect of the EDBA permeating through the PPE to the skin on the back and neck.

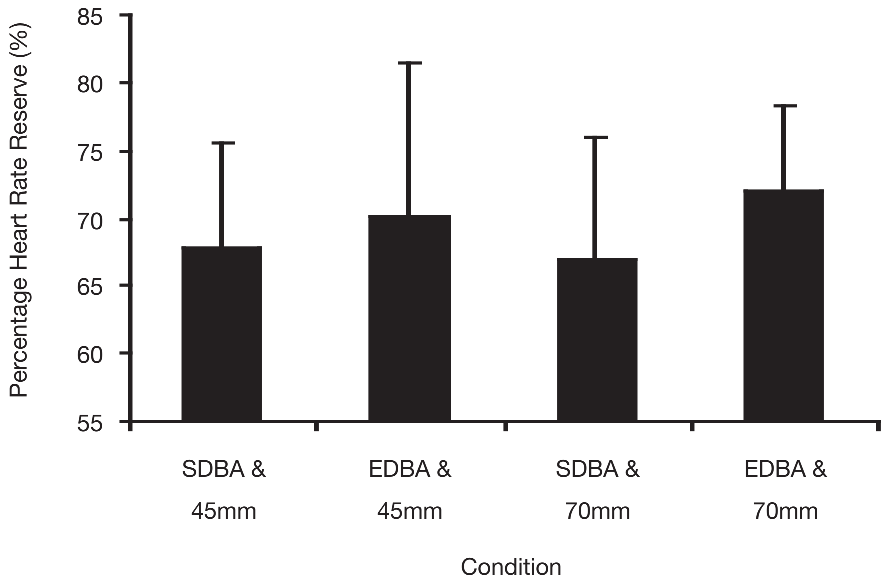
Figure 3.5 **Mean skin temperature response by condition**



3.5 HEART RATE RESPONSE

Figure 3.6 and Table B5 in Appendix B summarise the mean and standard deviation %HRR for each of the four conditions. All mean values in this table correspond to Howley's 'hard' classification of intensity (60-84%HRR), though some (8) individuals completed some conditions with a mean %HRR corresponding to 'moderate'. There was a statistically significant difference in the heart rate responses between the EDBA and SDBA conditions where the former averaged 72 (+7) %HRR and the latter less at 67 (+8) %HRR ($p<0.01$). Similarly, a statistically significant difference was found between the BA conditions in the proportion of time spent in the 'hard' and 'very hard' categories, shown in Table B6. The EDBA conditions spent more time than the SDBA in these 'hard' zones (77% (+11) vs. 69% (+16) ($p<0.05$)).

Figure 3.6 **Percentage Heart Rate Reserve by Condition**



3.6 BODY MASS CHANGES

Body mass changes during the trials, which primarily reflect fluid loss, are shown in Tables 3.7 and B7. On average, during the SDBA trials, participants lost approximately 0.75 litres in approximately 25 minutes, and during the EDBA trials they lost 1.02 litres in approximately 34 minutes. While these estimated sweat losses between SDBA (C1 & C3) and EDBA (C2 & C4) conditions were statistically significantly different ($p<0.002$), the *rate* of sweat loss, shown in the final column to average 0.03 litres per minute, was not different. These sweat rates equate to 1.8 litres per hour on average.

Table 3.7 **Mean sweat loss and sweat rate by condition (mean ± SD)**

Condition	Duration (min)	Sweat Loss (l)	Sweat Rate ($l.min^{-1}$)
C1	25.0 ± 3.1	0.78 ± 0.31	0.03 ± 0.01
C2	33.7 ± 6.8	1.04 ± 0.52	0.03 ± 0.01
C3	25.6 ± 3.5	0.73 ± 0.27	0.03 ± 0.01
C4	34.9 ± 6.2	1.00 ± 0.39	0.03 ± 0.01

3.7 LACTATE CONCENTRATION

Tables B8 and B9 in Appendix B summarise lactate concentrations at the end of each serial, by condition. The numbers in B8 represent the percentage of peak lactate (measured during the maximal exercise test prior to the trials), while those in B9 show the mean lactate concentrations at the end of the scenario, and whether they lie above or below the lactate threshold (5 $mmol.l^{-1}$).

Thirty eight of the 57 participants measured (67% – see Table B9) had peak lactate values above their anaerobic threshold, indicating that the majority were working at an unsustainable pace. Peak values averaged 9 (+3) $mmol.l^{-1}$ with EDBA and 45mm hose, which was somewhat higher than the remaining 3 conditions. However, caution should be exercised when interpreting these data as the concentrations reflect primarily the most recent activity that the firefighters had engaged in. Given that the EDBA conditions were more successful at rescuing the casualty than the SDBA, their final lactate values were more likely to reflect the final effort of extracting the casualty to the exit of the compartment.

3.8 RATINGS OF PERCEIVED EXERTION AND THERMAL SENSATION

The participant's Ratings of Perceived Exertion pre- and post-trials for each condition are shown in Figure 3.8. The overall mean pre-trial rating was 9, equating to 'light', and mean post-trial rating was 17 equating to 'very hard'. The only significant differences were between the EDBA and SDBA conditions in post-trial ratings, where in both cases the EDBA teams gave higher ratings than did the SDBA teams (17.6 (+1.4) vs. 15.9 (+2.0); p<0.001). This tallies with the heart rate data, and may have been a function of the additional load carried, and the greater duration of the EDBA trials.

Figure 3.8 **Ratings of Perceived Exertion by Condition**

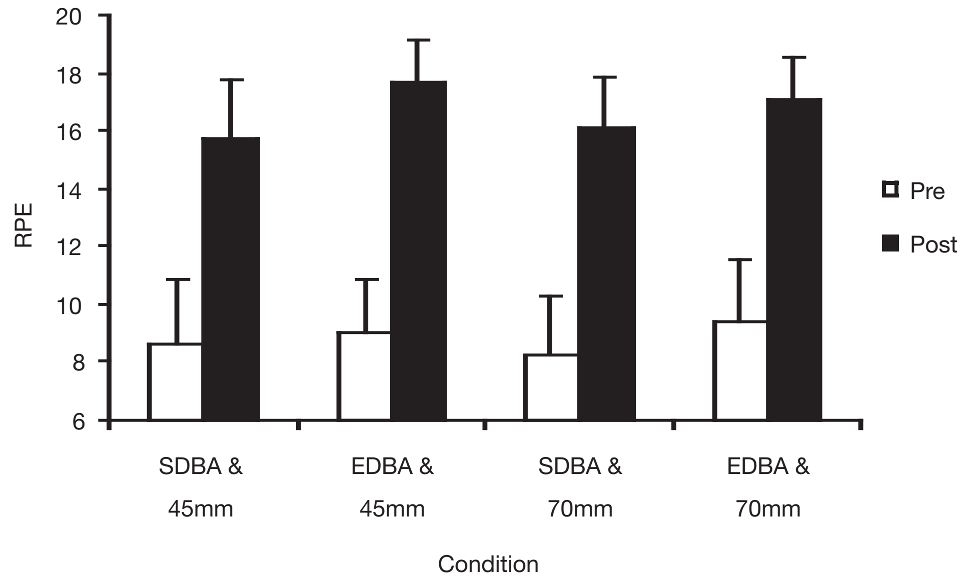
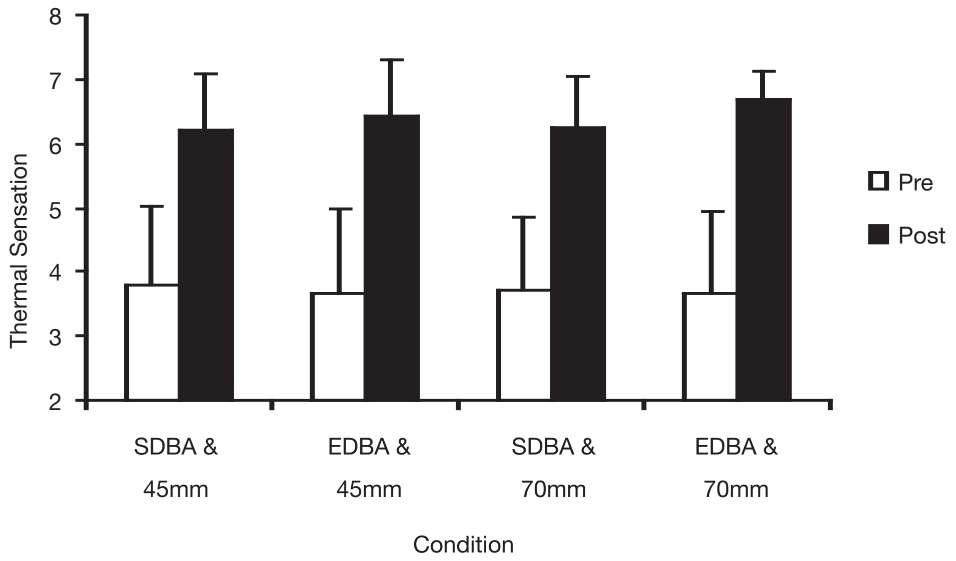


Figure 3.9 shows the mean ratings of Thermal Sensation pre- and post-trial for each Condition. Overall, pre-trial ratings averaged 3.8 equating to 'neutral' and responses did not differ between conditions. Post-trial ratings averaged 6.4, where 6 equates to 'warm' and 7 equates to 'hot'. As for the Ratings of Perceived Exertion, the EDBA teams gave higher post-serial ratings than the SDBA teams (6.8 (+0.5) vs. 6.2 (+0.8); p<0.01).

Figure 3.9 **Ratinigs of Thermal Sensation by Condition**



3.9 AIR USE

Estimated air use, derived from pressure gauge readings at the beginning and end of each trial, indicated mean air use in SDBA to be 58 $l.min^{-1}$ and in EDBA to be 69 $l.min^{-1}$. This assumes conversion factors of 'bar used' x 8.37 (9 litres x 1 cylinder x 0.93 correction factor[16]) for SDBA, and bar used x 12.65 (6.8 litres x 2 cylinders x 0.93 correction factor) for EDBA.

The EDBA Conditions (C2 & C4) resulted in 19% higher ventilation than the SDBA Conditions (C1 & C3). Whether this premium is due to the greater mass associated with the EDBA, the extended duration and harder work towards the end of the EDBA serials, or the faster pace of work with EDBA in the knowledge that conservation of air was not an issue, is not known. Further, it is unlikely that this ambiguity can be resolved in this trial as the work rate was not controlled, but rather performed self-paced[17].

The BA Entry Tables assume a mean ventilation of 40 $l.min^{-1}$. The SDBA Conditions therefore used 145% and the EDBA Conditions used 172% of the ventilation assumed in the BA Entry Tables.

16 Telecons Kerry Donovan (OPL) with Dave Mannings & Malcolm Stanton (LFB) & Mark Rayson (OPL) with Tom Ore (Draeger).

17 Attempts to resolve this query by comparing 'split times' on the different routes were unsuccessful due to the wide variations in progress made both between teams within a Condition and between Conditions.

3.10 SUMMARY OF MAIN FINDINGS AND CONCLUSIONS

1. The High Rise Scenario performed under ambient conditions, was not successfully completed by any team under any condition on their first exposure to the various routes.

2. With SDBA, the majority of teams had to withdraw early due to shortage of air. Air use averaged 58 litres per minute, which equates to 145% of the use assumed in the BA Entry Tables.

3. With EDBA, the majority of teams had to withdraw early due to raised core temperatures and/or suspected exertional heat stress. Air use averaged 69 litres per minute, which equates to 172% of the use assumed in the BA Entry Tables. Air use with EDBA was 19% greater than with SDBA, which probably reflects the greater external load imposed by EDBA.

4. Performance with both 45mm and 70mm hose was viable, provided adequate support was given by additional firefighters, though progress was slow in both conditions, especially with EDBA, with either air shortage (with SDBA) or core temperature (with EDBA) limiting performance under both hose conditions.

5. While the EDBA conditions resulted in higher final core temperatures than the SDBA conditions, this was a consequence of the longer work duration rather than more rapid heat gain associated with EDBA use. Rate of heat gain averaged $0.047^{\circ}C.min^{-1}$ in all conditions. This rate of rise allowed on average 32 minutes of operational time from the start of the scenario before Graveling's proposed upper limit for trainers of 39ºC was reached[18].

6. There was no difference between conditions in the mean skin temperature response. The mean rise was 2.8ºC and the mean rate of rise was $0.1^{\circ}C.min^{-1}$.

7. Fluid loss through sweating averaged 0.75 litres in approximately 25 minutes with SDBA, and 1.02 litres in approximately 34 minutes with EDBA. The *rate* of sweat loss, averaging 1.8 litres per hour, did not differ between conditions.

8. The heart rate data, providing an index of cardiovascular strain, indicated that firefighters were working 'hard', averaging 69% of their Heart Rate Reserve across all conditions. A minority worked 'moderately'. 73% of the total duration of the trials was spent working 'hard' or 'very hard'. Greater cardiovascular strain was experienced using EDBA than SDBA.

9. Final lactate levels post-trial averaged $6.5\ mmol.l^{-1}$, with 67% of participants recording final values above their anaerobic threshold, indicating that the majority were working at an intense and unsustainable pace.

10. Post-trial ratings by the firefighters of Perceived Exertion averaged 'very hard' and of Thermal Sensation averaged 'hot'. The EDBA Conditions tended to elicit higher responses than the SDBA, as might be expected due to their greater load and longer duration.

18 Graveling et al (2001). Firefighter Training: Physiological and Environmental Factors. Fire Research Report Number 1/2001. Institute of Occupational Medicine.

CHAPTER 4
Phase 2 results: Live fire scenario

4.1 SUMMARY OF OUTCOMES

Of the 40 serials on all floors, 9 (22.5%) were classified as *completely* successful, where 'completely successful' was defined in this study as the casualty being evacuated as far as the entry control point and both the FF and SR teams withdrawing to the entry control point using SOPs. In 7 (17.5%) of the serials the casualty was not recovered from the compartment before one of the other termination criteria was reached. None (0%) of the combined teams (both FF and SR teams) were stopped prematurely for air management reasons. EDBA therefore provided sufficient air on all occasions, fully overcoming the primary limitation seen in Phase 1 with SDBA. However, as in Phase 1, the most frequent termination criterion under EDBA was associated with elevated core temperatures. Fifteen (37.5%) were stopped as their core temperature exceeded the termination criterion of 39.5ºC, and a further 16 (40%) were stopped for safety reasons either by the safety officers or by the firefighters themselves.

In 24 of the 40 serials, the casualty was successfully rescued, but the serial was subsequently stopped prematurely as one of the termination criteria was reached during the remaining firefighting and search and rescue operations. These were classified as a 'partial success', as although the desired outcome of casualty rescue was achieved, the firefighters failed to complete the scenario safely using SOPs. A tabulated version of the results is shown at Appendix C, Table C3, with a summary of outcomes shown in the bottom row.

4.2 SUMMARY OF OUTCOMES BY FLOOR

The outcome of both FF and SR teams combined is summarised by floor in Figure 4.1 and Appendix C, Table C3. Subsequently the outcome of each of the teams by role was considered (see Appendix C, Tables C4 for FF, C5 for SR). The outcomes were classified according to the following criteria:

- If the 75 kg casualty was successfully evacuated from the building, the fires suppressed and both teams withdrew to the entry control point according to SOPs, the serial was classified as a combined team 'success'.
- If one team was successful, but the other had been withdrawn for one of the test termination reasons (except success), the combined team outcome was classified as that particular termination reason ('air', 'temperature', 'safety').
- If both teams were withdrawn before successful completion, the reason for the first team to be withdrawn was classed as the combined team outcome.

The final column in the table headed Partial Success refers to the outcome where the 75 kg casualty had been evacuated but one of the teams was subsequently stopped prematurely for meeting one of the termination criteria.

Notable for its lack of successful serials is the 2nd floor fire shaft condition (FS), which had fewer successes than any other floor including the higher 3rd and 4th floors.

Figure 4.1 **Summary of outcomes by floor**[19]

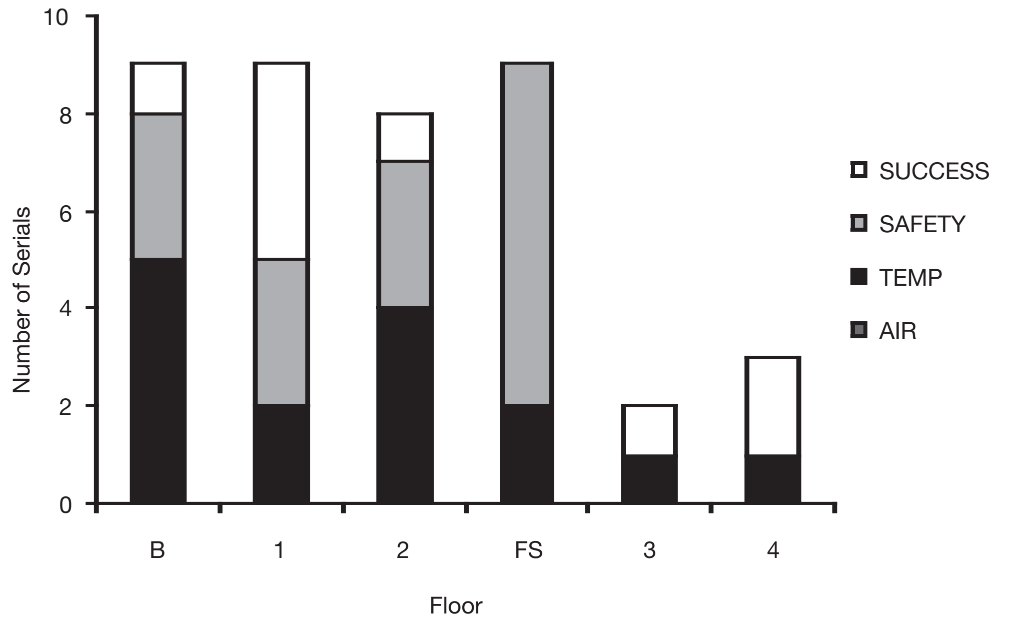
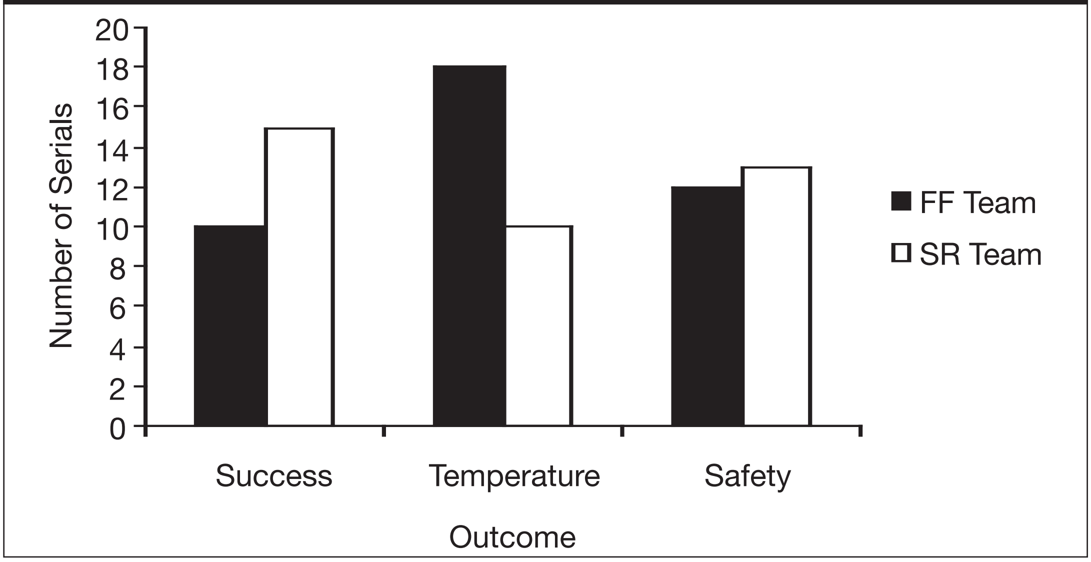


Figure 4.2 and Appendix C, Tables C4 and C5, provide a similar breakdown for the FF teams and the SR teams, respectively, independent of each other. Among the FF teams, 10 (25%) were classified as successful, fulfilling their objectives and withdrawing under SOPs. The remainder were withdrawn for exceeding the core temperature criterion in 18 cases (45%) or were withdrawn for safety reasons in 12 cases (30%). None were limited by their air supply. Among the SR teams, 15 (37.5%) were successful in meeting their objectives. 10 (25%) were stopped for exceeding the core temperature criterion and 13 (32.5%) were stopped for safety reasons. A further 2 (5%) were stopped for technical reasons[20].

19 Where floors are coded as: B = basement; 1 = 1st floor; 2 = 2nd floor; FS = 2nd floor via the fire shaft; 3 = 3rd floor; 4 = 4th floor.

20 These tests were terminated prematurely by OPL due to technical difficulties, such as the loss of core temperature readings. Subsequent analysis revealed that these 2 firefighters' core temperature was below the termination value of 39.5ºC and, therefore, their test could have continued safely.

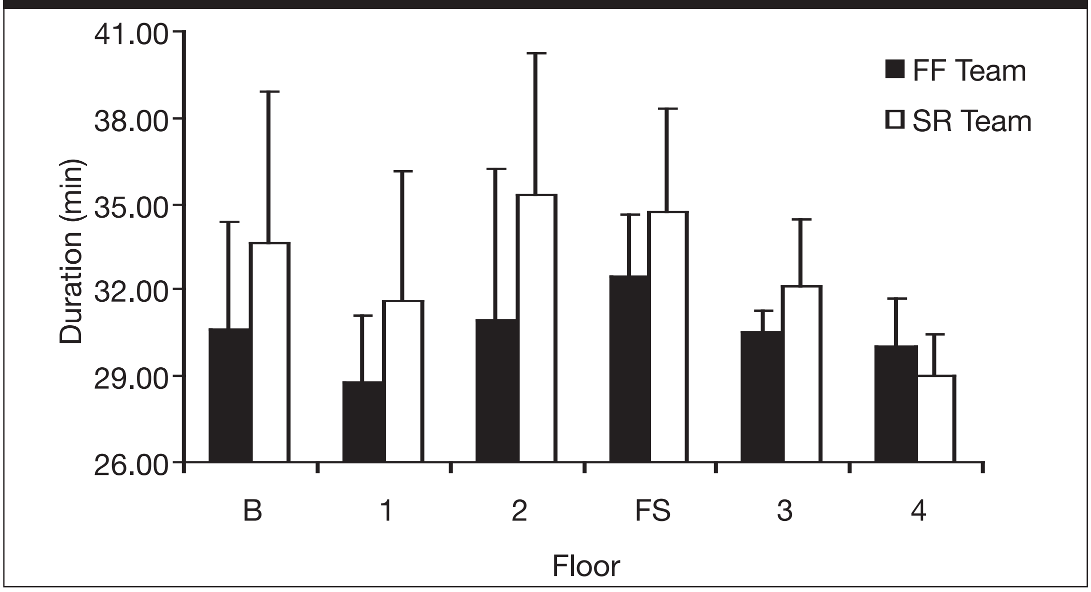
Figure 4.2 **Serial outcome by team**



4.3 WORK DURATION AND EXTERNAL LOAD

The total work duration, calculated as the time from the start of the serial[21] to coming off air is summarised in Figure 4.3 and Table C6 in Appendix C, where ‘n’ refers to the number of firefighters on each floor, FF refers to the firefighting team and SR refers to the search and rescue team. Work duration averaged approximately 31 minutes for FF and statistically significantly longer at approximately 33 minutes for SR ($p<0.001$). The SR team sometimes remained in the compartment, or recommitted into the compartment, after the FF team had withdrawn. Work duration also differed by floor with both the 2nd floor and 2nd floor with fire shaft (FS) taking longer than the 1st floor, and FS taking longer than the 4th floor.

Figure 4.3 **Work duration by team**



21 Defined as the time the appliance left the BA School.

Time under air averaged approximately 24 and approximately 27 minutes for FF and SR, respectively, which is a statistically significant difference ($p<0.001$). Time under air did not differ between floors, suggesting that the work durations differed due to differing times taken to establish and reach the control entry point, rather than in the fire compartment (see Section 5).

Firefighters carried 33.1 (+ 0.6) kg of external load[22] which equated to 40.7 (+5.6)% of their body mass. Not surprisingly given the firefighters were dressed in a common PPE configuration, the external loads did not differ between team or between floors.

4.4 CORE TEMPERATURE

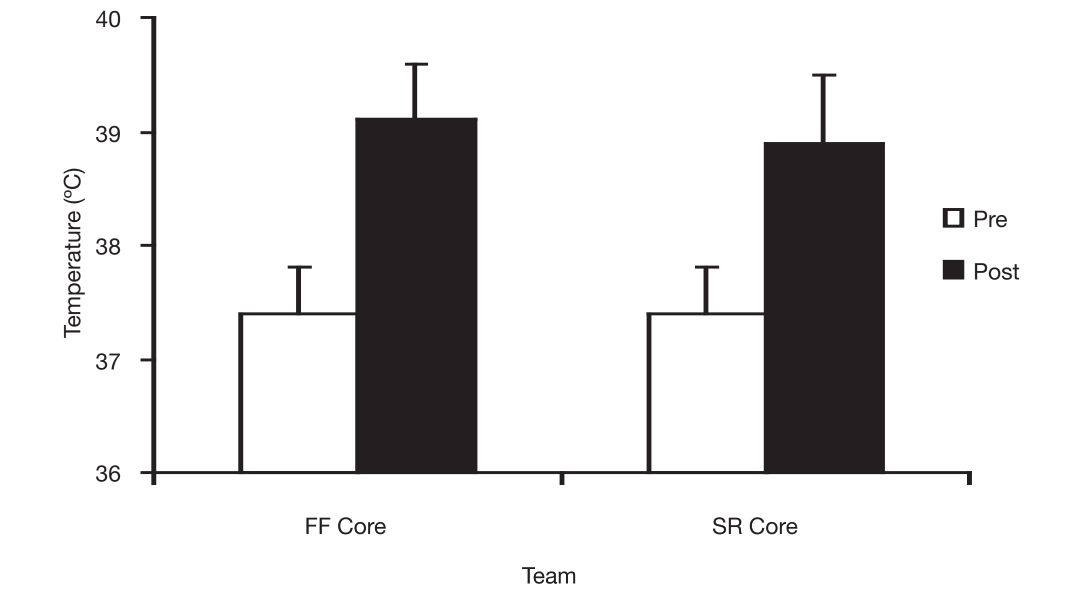
The mean core temperature responses to each floor by the FF and SR teams are shown in Figure 4.4 and Tables C7 and C8 in Appendix C, respectively. The columns in the tables show the floor (Fl), the number of firefighters (n), the mean duration of the test in minutes, the core temperatures at the beginning and end of the test, the rise in core temperature over the duration of the test, and the rate of rise of temperature, all in degrees centigrade.

At the start of the serials both FF and SR teams averaged 37.4ºC, and by the end they averaged 39.1ºC and 38.9ºC, respectively. The final temperature experienced by the FF team was statistically significantly higher than that by the SR ($p<0.01$). While there are no differences between floors in start temperature, there was a statistically significantly higher end temperature in the basement, compared to the 4th floor ($p<0.05$). This finding is in keeping with the data reported on ambient temperature as measured by the body borne probe in Section 2.4.2, which showed the basement to be hottest and the 4th floor to be the coolest. However, there were no differences in the rise in core temperature both between teams and between floors, with rises averaging 1.6ºC over approximately 32 minutes. Individual firefighters who were stopped prematurely for exceeding a core temperature of 39.5ºC took approximately 26 ± 4 minutes after going under air.

The rate of rise in core temperature, though, was statistically significantly higher in FF ($0.054ºC.min^{-1}$) than SR ($0.045ºC.min^{-1}$) ($p<0.01$), presumably due to the greater proximity of the FF team to the fire. However, the rate of rise in core temperature did not differ between floors, despite variations in the ambient temperatures. It appears that the firefighters may have achieved a maximum rate of rise of core temperature, irrespective of their ambient conditions. This may indicate that workload is a predominant factor.

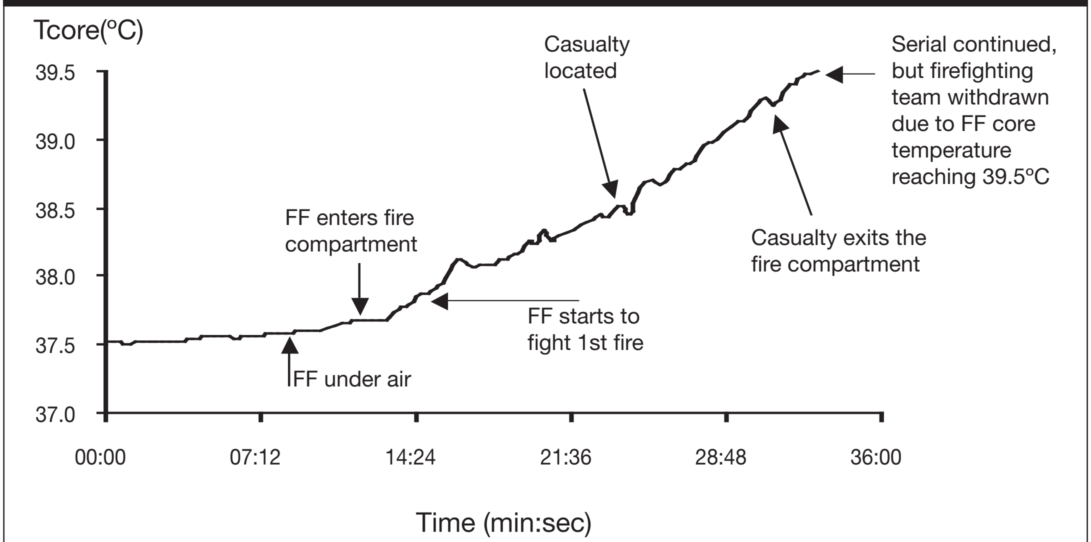
22 This load included approximately 1.5 kg of physiology monitoring equipment.

Figure 4.4 **Core temperature response by team**



An individual plot of core temperature response is shown in Figure 4.5 as an example. This particular firefighter spent approximately 34 minutes working in this serial. The core temperature response shows a markedly sharp increase at approximately 13 minutes when the firefighter starts to fight the fire, and a further upturn is apparent at approximately 23 minutes when the casualty is located. The serial continued beyond 34 minutes, but the firefighter team were withdrawn at this point as core temperature had reached 39.5°C. There is little indication that the firefighter in this example was reaching thermal equilibrium when the serial was terminated.

Figure 4.5 **An example core temperature response to floor 2, firefighting team**



4.5 SKIN TEMPERATURE RESPONSE

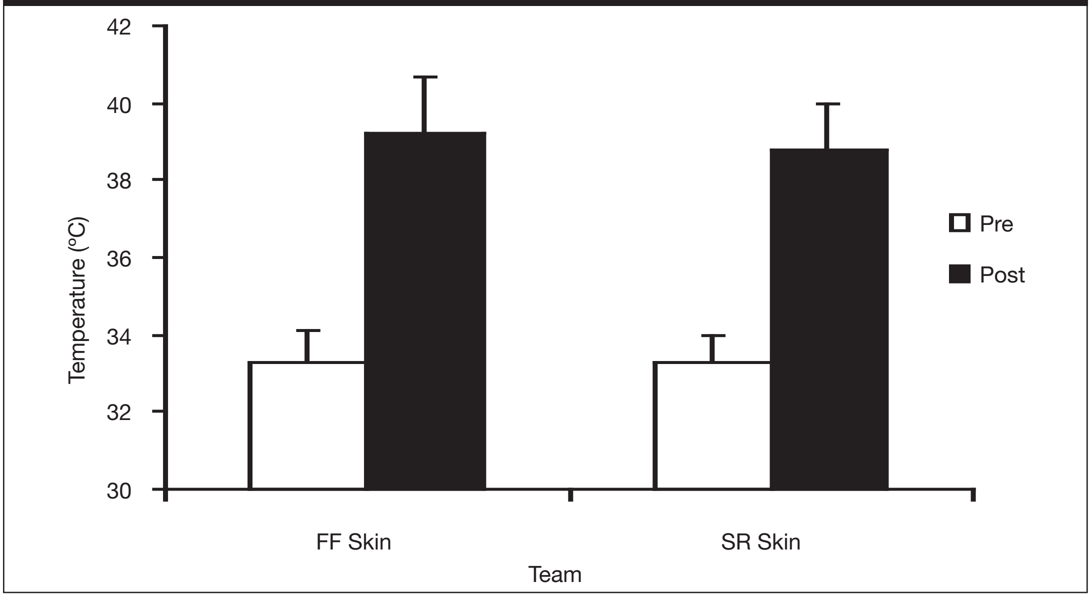
A summary of the mean skin temperature response is shown in Figure 4.6 and Tables C9 and C10 in Appendix C for the FF and SR teams, respectively. Initially, skin temperatures averaged 33.3°C with no difference between teams or between floors. Final skin temperatures tended to differ (p=0.06) between the FF and SR teams, averaging 39.2°C and 38.8°C, respectively.

A comparison of final skin temperatures between floors showed that: the basement (39.8°C) resulted in statistically significantly higher skin temperatures than did the 3rd (37.3°C) and 4th (38.7°C) floors; the 1st (39.1°C) was statistically significantly higher than the 3rd (37.3°C) floor; and the 2nd floor with fire shaft (39.8°C) was statistically significantly higher than the 3rd (37.3°C) and 4th (38.7°C) floors.

Increases in skin temperature averaged 5.9°C and 5.5°C for FF and SR teams respectively; this difference approaching statistical significance (p=0.06). Statistically significant differences in increases were found between floors, with the basement and 2nd floor with fire shaft skin temperatures greater than the 3rd floor.

For rates of rise in skin temperature, the FF team showed statistically significantly faster gains (0.196°C.min^{-1}) than the SR team (0.172°C.min^{-1}) (p<0.01). The only significant difference in rate of rise between floors was between the basement and the 3rd floor, with the basement resulting in greater rises.

Figure 4.6 **Mean skin temperature response by team**



4.6 HEART RATE RESPONSE

Figure 4.7 and Table C11 in Appendix C summarise the mean and standard deviation %HRR for each floor for the FF and SR teams. There was a tendency for the FF team to work at a marginally higher level of cardiovascular strain than the SR team (69 vs. 66 %HRR; p=0.07), though the level of strain between floors did not differ. Finding no difference in the cardiovascular strain between floors suggests either that the additional work associated with accessing floors between the basement and the 4th was insignificant compared to the work involved in the scenario as a whole[23], or that firefighters self-paced to control their level of cardiovascular strain.

All mean %HRR values in Table C11 correspond to Howley's 'hard' classification of intensity (60-85%HRR), though some individual firefighters in both FF and SR teams operated at a lower 'moderate' level of cardiovascular strain.

Figure 4.7 **Percentage heart rate reserve by team**

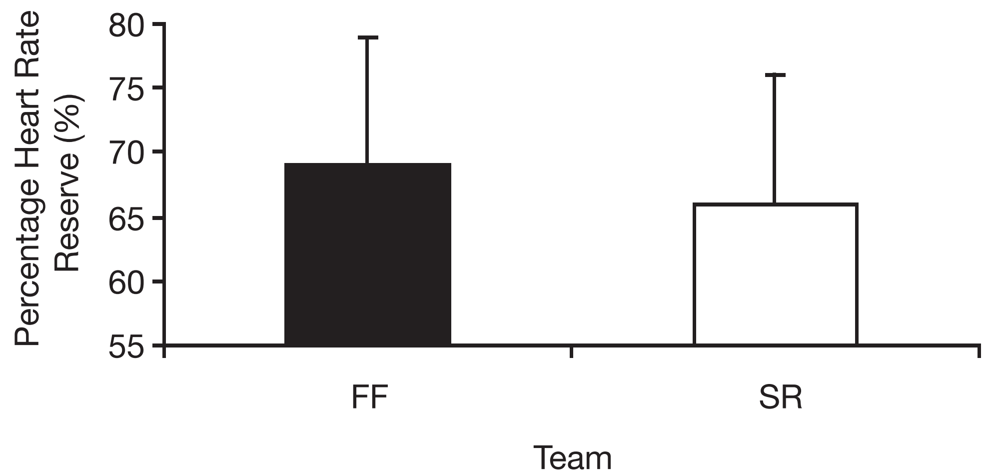


Table C12 shows the proportion of time (from the start of the serial to coming off air), that the FF and SR teams spent at Howley's work intensities corresponding to 'hard' or 'very hard'. For 66% of the time the FF teams worked at this 'hard' intensity, statistically significantly more than the 61% of time the SR team spent ($p<0.05$). There was no difference in the proportion of time spent working at this intensity between floors suggesting again that the additional work in climbing a few extra floors was swamped by the demand of the scenario as a whole, or the firefighters self-paced.

4.7 BODY MASS CHANGES

Body mass changes during the serials, which primarily reflect fluid loss from sweating, are shown in Table C13 in Appendix C. On average, firefighters are estimated to have lost approximately 0.9 litres and sweated at a rate of around 0.03 litres per minute or 1.7 litres per hour. There were no differences in sweat loss or sweat rate between teams. Small differences were found in sweat loss between floors, but not in sweat rate, suggesting that any differences in sweat loss were solely a function of the variations in work duration between floors.

Performance is reported to degrade after around 2% of body mass has been lost. At the estimated sweat rate of 1.7 litres per hour, and with no opportunities with current PPE/RPE to take on fluid while under air, performance due to dehydration would degrade after around 1 hour assuming euhydration at commencement of activity. Achieving other termination criteria (e.g. core temperature) currently limits performance

23 That said, the physiological load associated with climbing a greater number of floors is substantial as reported in Section 6.

on this scenario to well under 1 hour, thereby limiting sweat loss to below the point where performance is marred. However, should the firefighters need to be recommitted to another task soon after completion of this type of scenario, they would not have had the opportunity to rehydrate effectively and subsequent performance would therefore be degraded. Similarly, their performance would be degraded if they are not fully hydrated at the commencement of the scenario.

4.8 LACTATE CONCENTRATIONS

Lactate levels at the end of the serials averaged 4.4 $mmol.l^{-1}$, which is close to the mean lactate threshold of approximately 5 $mmol.l^{-1}$. An estimated 38% of the firefighters had values in excess of their lactate threshold. No statistically significantly differences were found in final lactate concentrations between teams or between floors. The more detailed data for FF and SR teams are shown in Tables C14 and C15 in Appendix C, respectively. The columns show lactate concentrations, and the number of firefighters who had concentrations of less and more than 5 $mmol.l^{-1}$ (i.e. below or above the lactate threshold).

4.9 RATINGS OF PERCEIVED EXERTION AND THERMAL SENSATION

The participant's Ratings of Perceived Exertion pre- and post-serial for each floor are shown in Figure 4.8 for the FF and SR teams combined. The overall mean pre-trial rating was 9, equating to 'light', and mean post-trial rating was 17 equating to 'very hard'. While the post values were consistently and statistically significantly higher than pre-values, values did not differ between FF and SR teams – hence they are combined in the figure. The only statistically significantly difference in ratings between floors was found between the basement and the 2nd floor, with the basement being rated as more demanding, possibly due to the higher ambient temperature reported in Section 2.4.2, though not in the resultant core temperatures reported in Section 4.4. Skin temperature is probably a better mediator of perceived exertion than core temperature. Correspondingly, mean skin temperature increases were significantly greater during basement serials compared to 2nd floor serials.

Figure 4.8 **Rating of perceived exertion by floor**

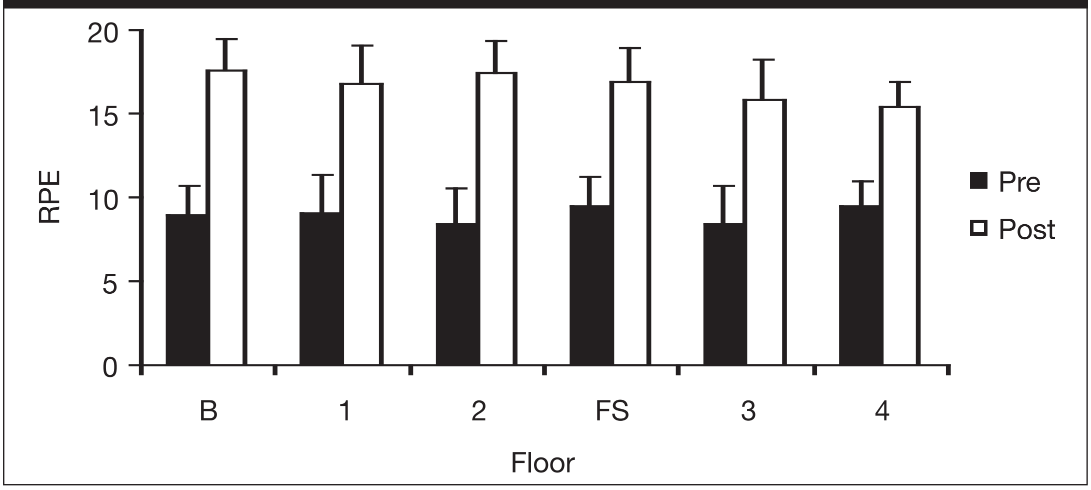
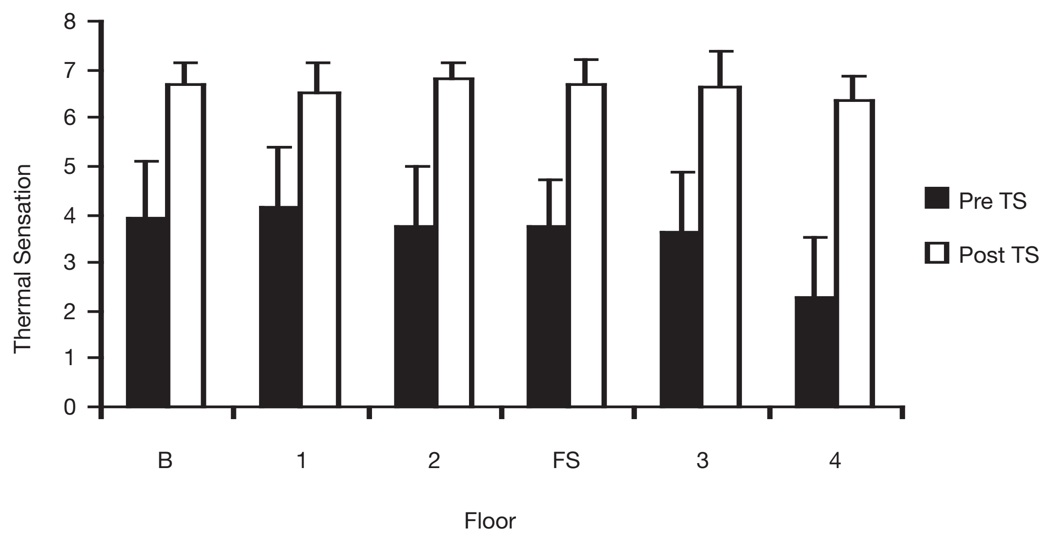


Figure 4.9 shows the mean ratings of Thermal Sensation pre- and post-serial for the FF and SR teams combined. Overall, pre-trial ratings averaged 3.8 equating to 'neutral' and responses did not differ statistically between conditions. Post-trial ratings averaged 6.6, where 6 equates to 'warm' and 7 equates to 'hot' (7 being the highest rating on the scale). Of those firefighters that achieved a final core temperature of 39.5°C and for whom the serial was terminated, the mean rating was 6.8 – very close to the maximum rating. While post-ratings were consistently and statistically significantly higher than pre-ratings, there were no statistically significant differences between teams or floors. Possibly the 7-point scale used in this study was not sufficiently sensitive at the top end to discriminate between degrees of hotness. The apparently lower pre-rating for the 4th floor may have been a function of the cooler outside temperatures encountered in December, when the 4th floor serials were conducted.

Figure 4.9 **Rating of thermal sensation by floor**



4.10 AIR USE

Time under air averaged approximately 24 minutes for the FF team and approximately 27 minutes for the SR team, which was statistically significantly different ($p<0.001$). Air use and rate of air use were derived from the BodyGuard computer records, which gave use in terms of change in cylinder pressure. The mean air use of approximately 109 bar for the FF Team was somewhat lower than that of approximately 116 bar for the SR team ($p=0.06$), though the rate of use did not differ statistically between team averaging approximately 4.5 bar per minute. The somewhat higher volume of air used by the SR teams could therefore be attributed to the longer duration under air by the SR, compared to the FF teams. There was no difference in air use or rate of air use between floors, again suggesting that firefighters were self-pacing, and that the responses are fairly generic. Air use would appear to be independent of the details of these scenarios (e.g. the floor, the temperature). A detailed breakdown of the air use data are shown in Tables C16 and C17 in Appendix C.

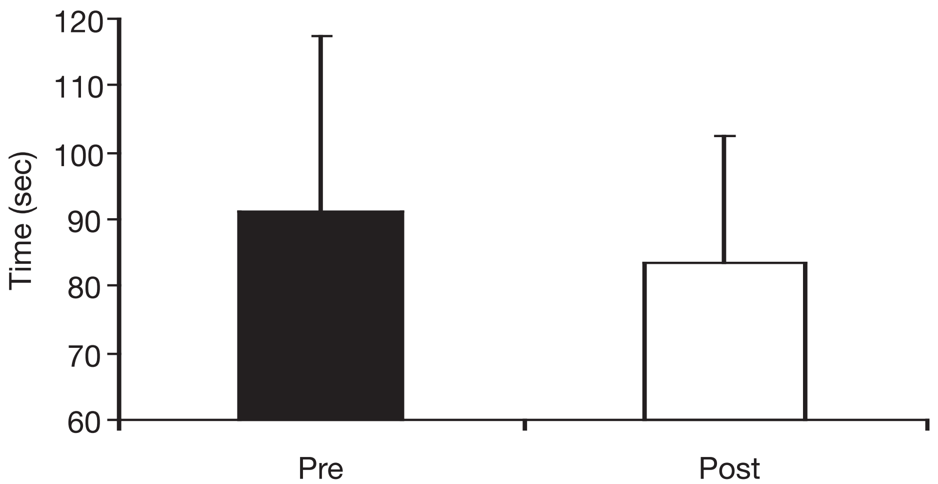
The air use values equate to estimated mean ventilation rates of 57 and 55 $l.min^{-1}$ for the FF and SR teams, respectively. This assumes conversion factors of 'bar used' x 12.65 (6.8 litres x 2 cylinders x 0.93 correction factor) for EDBA. Ventilation rates are therefore around 40% higher than the 40 $l.min^{-1}$ assumed in the BA Entry Tables.

4.11 MANUAL DEXTERITY

The time to assemble and disassemble the PortoPower unit pre-serial and post-serial and the change in time (delta), all in seconds, are summarised in Figure 4.10 and detailed in Table C18 in Appendix C by team and by floor. Caution should be exercised when interpreting these data, due to the time lapse between the end of the scenario and the measurement post serial, during which time substantive recovery appeared to take place. The focus on the physiological measurements and safety safeguards delayed the post-serial measurements of both the manual dexterity and cognitive performance by around 30 minutes. While no hard evidence of the psychological status of the firefighters was collected *immediately* post-serial, observation suggested that many firefighters were fit for little activity other than recovery.

The measured data, however, showed that while there were no differences between teams or floors, the firefighters did statistically significantly improve their performance post-serial compared to pre-serial, reducing their average times by 8 seconds, from 91 to 83 seconds. It appears that manual dexterity performance is enhanced some 30 minutes post serial, possibly as a consequence of raised core temperature and therefore raised muscle temperature. Alternatively, this could be attributable to practise on the day, or greater motivation at the time of retest.

Figure 4.10 **Manual dexterity scores for team and floor combined**



4.12 COGNITIVE FUNCTION

Due to the relatively small sample size, data from both the FF and SR teams were combined. Table 4.1 summarises the mean pre-, -post- and delta results from the 3 Cognitive Performance tests. More detailed tables are shown in Tables C19 to C21 in Appendix C. Only the RVIP results showed any statistically significant difference between pre- and post-serial ($p<0.05$), improving post-serial by less than 0.1 – a tiny and practically insignificant improvement. SMS and RTI scores showed no changes in performance..

These findings tentatively suggest that cognitive performance, as assessed by the tests used and re-measured some 30 minutes after completion of the serials, is unaffected by the performance of these scenarios. These findings contradict our expectations and anecdotal observations that cognitive performance is substantially impaired immediately post serial. They also run counter to the withdrawal of some teams by safety staff who judged that the firefighter's mental performance had become impaired. The most likely explanation is that any effect on performance is transitory and is lost by the time cognitive performance was reassessed.

Table 4.1 **Overall cognitive function summary by test (mean ± SD)**

Test	n	Pre	Post	Delta
RVIP	52	0.955 ± 0.05	0.963 ± 0.04	0.008 ± 0.03
SMS	54	7.9 ± 1.2	8.0 ± 1.2	0.1 ± 1.0
RTI	54	360.9 ± 56.6	363.0 ± 52.6	2.1 ± 30.1

CHAPTER 5
Physiological response by stage of scenario

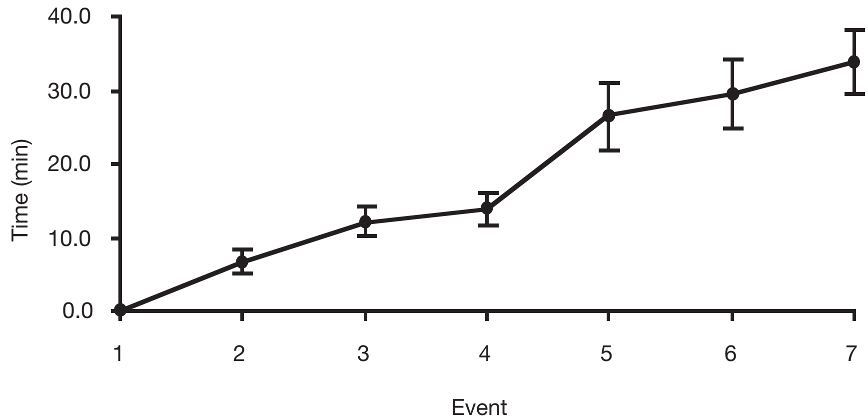
5.1 DURATION OF STAGES

Seven key events during the scenario were identified, and data for selected variables are displayed in Section 5, by these events. The events are defined in the footnote[24]. The time when the 7 key events occurred during performance of the scenarios, relative to time zero when the serials commenced (event 1), is summarised at Figure 5.1 and provided in detail by floor in Table D1 in Appendix D. The data points on the graph and the numbers in Table D1 represent the average (+ 1sd) time either for the teams of 4 firefighters where all 4 completed an event (e.g. going under and coming off air), or alternatively for the action of a FF or SR team of 2 firefighters in the case of attacking fire 1, locating the casualty, and exiting the compartment with the casualty.

Amalgamating the data from different floors provides a generic timeline. Going under air occurred at approximately 7 minutes, entering the fire compartment at approximately 12 minutes (around the time that fire compartment temperature, optical density and heat flux peak: refer to Section 2.4.2), attacking the first fire at approximately 14 minutes, locating the heavy casualty at approximately 26 minutes, exiting the compartment with the casualty at approximately 29 minutes and coming off air at approximately 32 minutes. The teams therefore took approximately 5 minutes from going under air to entering the compartment. Once in the compartment they took approximately 2 minutes to start attacking the first fire. Where the casualty was successfully located, it was found approximately 14 minutes after entering the compartment and evacuated from the building approximately 17 minutes after entering the compartment. Total time in the compartment was approximately 17 minutes, unless the team recommitted to search for further casualties.

24 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

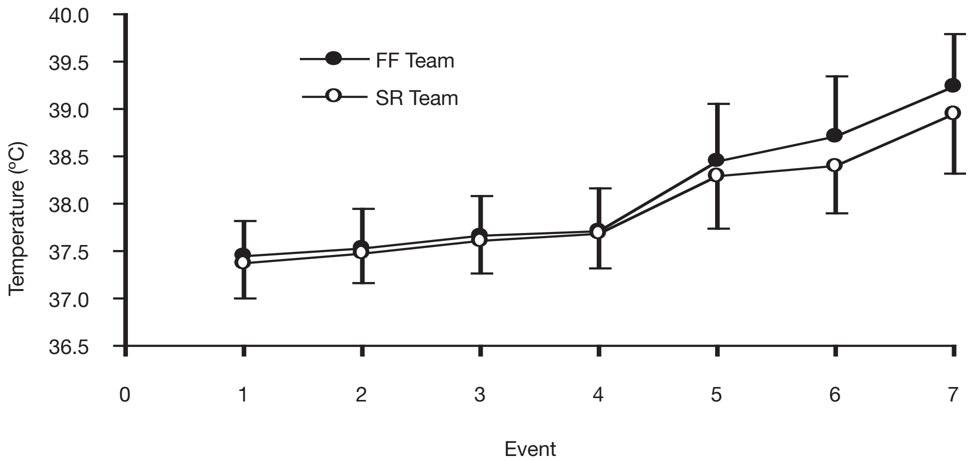
Figure 5.1 **Time at which key events occured[25]**



5.2 CORE TEMPERATURE RESPONSE BY EVENT

Figure 5.2 shows the core temperature by team at each of the seven events. While the core temperatures are the same for the two teams at the start of the scenario, the lines diverge after the firefighting commences (event 4), with the FF team showing higher temperatures in the latter stages of the serial. The means and standard deviations together with the number of observations at each event are shown in Table D2 in Appendix D.

Figure 5.2 **Core temperature response by event[26] and team**

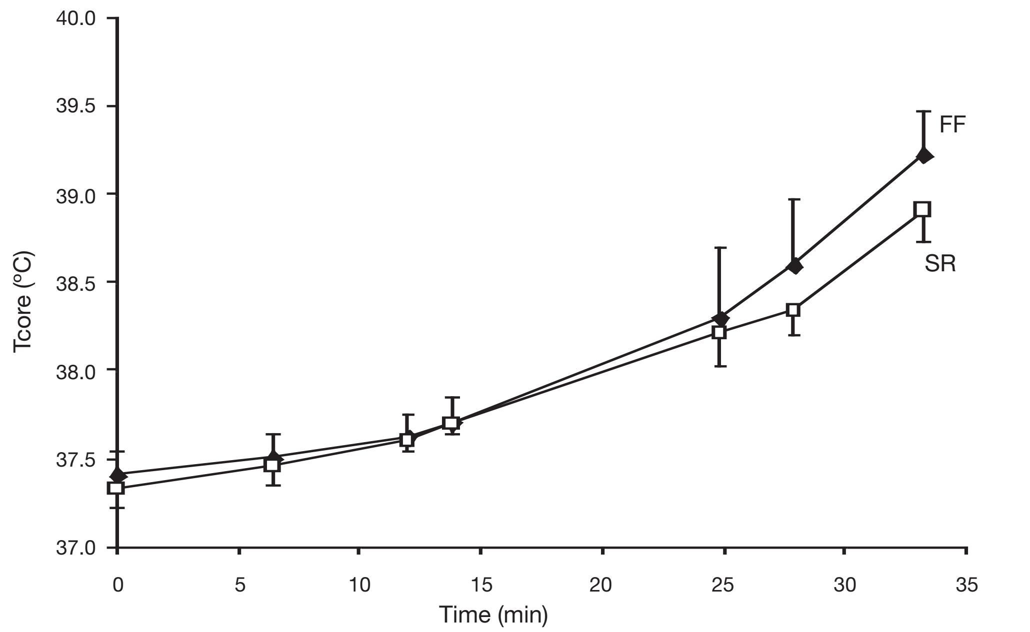


The rate of rise of core temperature by event is shown in Table D3 in Appendix D. These data are shown graphically in Figure 5.3 with time on the x-axis rather than event. It is these data that have been used to model the time and distance firefighters are estimated to take before they reach a proposed upper operational threshold of 39°C, described in Section 6.

25 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

26 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

Figure 5.3 **Rate of rise in core temperature by time and event**[27]



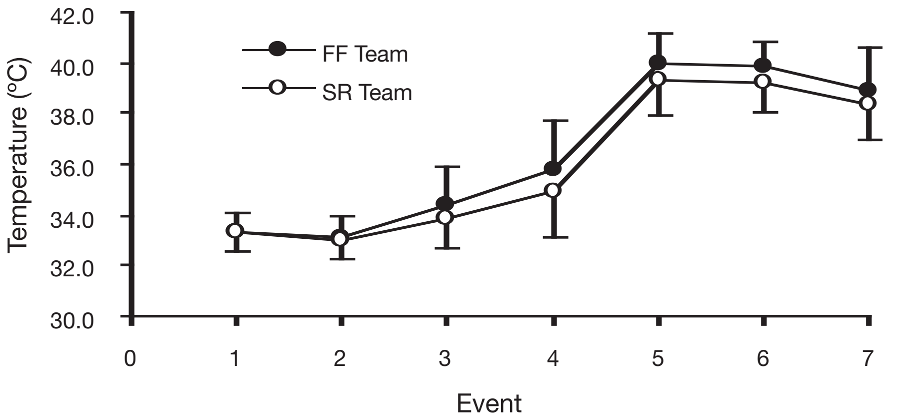
5.3 SKIN TEMPERATURE RESPONSE BY EVENT

Figure 5.4 shows the skin temperature by team at each of the seven events. While the skin temperatures are the same at the start of the scenario, the lines diverge after the teams go under air (event 2), with the FF team showing higher temperatures thereafter. The lines remain parallel after event 4. This divergence is likely to be the result of the FF team leading into the compartment ahead of the SR team and being exposed to greater ambient temperatures earlier, and the skin reacting accordingly. The increase in skin temperature is seen almost immediately, in contrast to the core temperature which has a more latent response. Similarly, whereas the skin temperatures start to decline from event 5, probably reflecting the reduction in radiant heat in the compartment (refer to Figure 2.7), the core temperature continues to rise.

The means and standard deviations, together with the number of observations at each event, are shown in Table D4 in Appendix D. Rate of rise of skin temperature is shown in Table D5.

27 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

Figure 5.4 **Mean skin temperature response by event[28] and team**

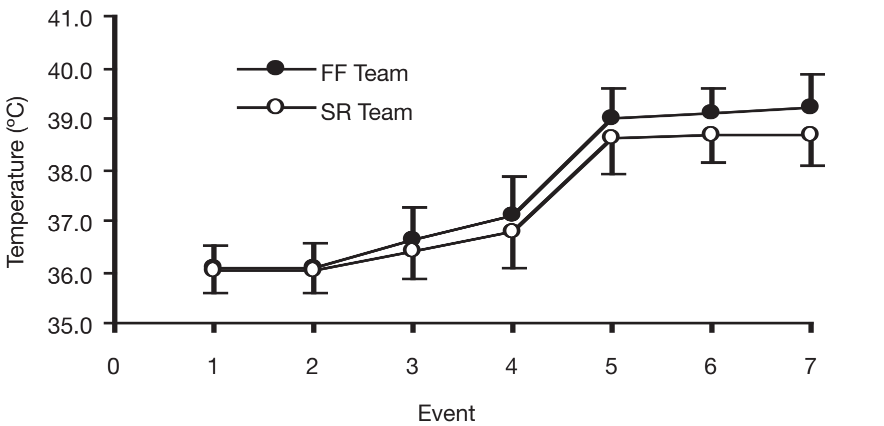


5.4 TOTAL BODY TEMPERATURE BY EVENT

Total body temperature is calculated as a function of both core and skin temperatures and is thought to reflect the body's thermal sensation better than either core or skin temperatures alone. Figure 5.5 shows the temperature by team at each of the seven events. As anticipated from the previous two figures, the temperatures are the same at the start of the scenario, the lines showing increasing divergence after the teams go under air (event 2). It is interesting to note the plateau in total body temperature after event 5, despite continuing increases in core temperature up to and beyond recommended working limits. The continued rise in core temperature is compensated for by the drop-off in mean skin temperature, suggesting that the weighting of skin temperature to core temperature in this total body temperature index may be inappropriately high for this type of environment and PPE.

The means and standard deviations together with the number of observations at each event are shown in Table D6 in Appendix D. Rate of rise in total body temperature is shown in Table D7.

Figure 5.5 **Mean total body temperature response by event[29] and team**



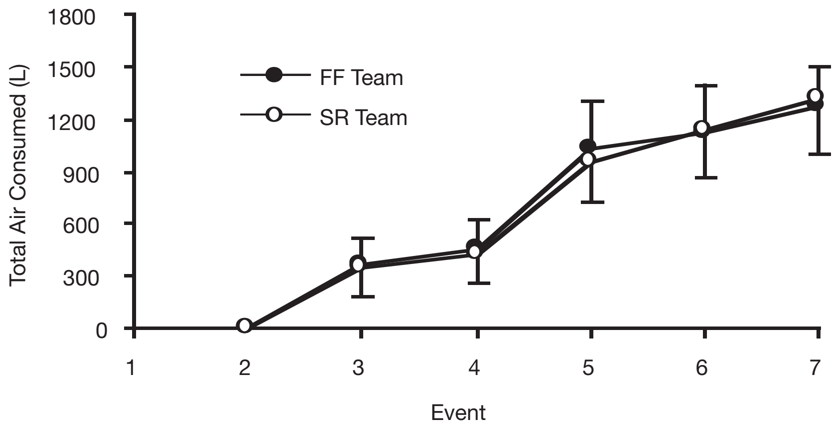
28 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

29 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

5.5 AIR USED BY EVENT

Figure 5.6 shows the air used from the Draeger computerised records by team at each of the seven events. The lines are similar at all events. The means and standard deviations together with the number of observations at each event are shown in Table D8 in Appendix D. Rate of air use is shown in Table D9.

Figure 5.6 Mean air use by event[30] and team



5.6 SUMMARY OF MAIN FINDINGS AND CONCLUSIONS

1. In only 9 of the 40 (22.5%) live fire serials using EDBA and 51mm hose was the scenario concluded according to SOPs with the teams both achieving the casualty evacuation and returning to the entry control point safely and under control.

2. 15 of the 40 serials (37.5%) were stopped as the firefighters' core temperature had exceeded 39.5°C, 0.5°C above Graveling's recommended limit for live fire training, and a further 16 (40%) were stopped for safety reasons either by the Safety Officers or by the firefighters themselves.

3. In 33 of the 40 (82%) serials the firefighting teams penetrated the full 45m and evacuated the casualty from the fire compartment. However, in 24 of the 33 serials teams either exceeded safe core temperatures or were withdrawn for safety reasons.

4. No serials were stopped prematurely for air management reasons, the EDBA supplying ample air during all serials.

5. Scenario duration averaged approximately 31 minutes for FF and approximately 33 minutes for SR. Time under air averaged approximately 24 and approximately 27 minutes, respectively.

6. The total external load carried by the firefighters in the form of PPE and RPE was 33 kg, equating to 41% of the group mean body mass.

30 Events coded as: 1 = start; 2 = go under air; 3 = enter compartment; 4 = attack fire 1; 5 = locate casualty; 6 = exit compartment with casualty; 7 = go off air.

7. Rate of rise of core temperature averaged 0.054ºC.min^{-1} and 0.045ºC.min^{-1} for FF and SR teams, respectively. Although both teams started at the same temperature, the FF team ended with higher core temperatures, averaging 39.1ºC compared to 38.9ºC for SR. Firefighters indicated that they felt 'hot' on the thermal sensation scale at the end of the serial.

8. Increases in skin temperature averaged 5.9ºC and 5.5ºC for FF and SR teams respectively, with final skin temperatures averaging 39.2ºC and 38.8ºC, respectively.

9. The heart rate data suggested the firefighters were working at a 'hard' work intensity, with the FF team averaging 66% and the SR team 61%HRR. Self-reported ratings of exertion at the end of the serials averaged 'very hard'.

10. The rate of air use did not differ between team averaging approximately 4.5 bar per minute, equating to approximately 56 l.min^{-1}. Ventilation rates were therefore around 40% higher than the 40 l.min^{-1} assumed in the BA Entry Tables.

11. Manual dexterity improved by 9% post-serial, compared to pre-serial. Cognitive function was mainly unchanged when re-assessed approximately 30 minutes after the end of the serial. Cognitive function appears to recover over this time interval.

CHAPTER 6
Phase 3: High-rise stair climbing and hose running

6.1 INTRODUCTION AND APPROACH

Firefighters may need to climb stairs to deal with a fire on the upper floors of a tall building where either dedicated firefighting lifts have not been provided or where they have failed. The aim of this mini study was to report on the physiological response of firefighters during and after a stair climb to the site of a notional fire on the upper floors of a tall building. Both the lead firefighting team and the support hose-running team were monitored. The firefighting teams attended on two occasions to be monitored firstly while wearing EDBA and carrying hose, and then subsequently with no external loads above their standard PPE. The concept for this second condition was that a support group would carry the EDBA and hoses, allowing the firefighting team to climb the stairs without the added demand of carrying approximately 33 kg or more of equipment.

The purpose of this assessment was twofold:

- Firstly, to assess the physiological demands of firefighters gaining access to the upper floors of a tall building, where facilities such as firefighting lifts and rising mains have failed.

- Secondly, to inform the provision of firefighting lifts to assist firefighters gaining access to the upper floors of a tall building as part of normal arrangements.

The trial involved 13 firefighters from the London Fire Brigade (12) and West Midlands Fire Brigade (1). Participant statistics are shown in Table 6.1.

Table 6.1 **Participant details (means ± SD)**

Gender	Number (n)	Age (years)	Mass (kg)	Height (m)
male	10	33.2 ± 4.2	83.2 ± 10.6	1.79 ± 0.06
female	3	26 ± 2	70.3 ± 9.78	1.72 ± 0.03

The trial involved the firefighters climbing 28 floors of a high-rise building and was performed three times on each occasion. The 28th floor level was chosen to allow interpolation of data to floor levels beneath this height. The firefighters were randomly assigned to groups. Group one consisted of four firefighters (lead group) and the remaining nine were allocated to group two (hose group).

The aim of the lead group was to climb the 28 flights of stairs wearing standard personal protective equipment (PPE) while carrying extended duration breathing apparatus (EDBA) with the purpose of entering the fire compartment to firefight and conduct a search and rescue. The average total load of the PPE and RPE in this cohort of 13 firefighters was 32.2 ± 0.5kg equating to an average of 39 ± 6% total body mass. In addition, each member of the lead team carried a length of 51mm hose with one of the pair also carrying a firefighting branch. The additional loads carried by the lead pair were 11.5 and 13.5 kg, respectively.

The hose group was responsible for rolling out and connecting sufficient hose as was necessary to reach the site of the fire on the 28th floor. This required group two to carry the 70mm hoses, each weighing ~15 kg up the stairs, rolling them out and connecting them as necessary to provide a water supply to the top floor. This scenario was repeated three times, with the lead group changing each time.

The majority of the physiological monitoring and tests were carried out on the lead group. Nude mass was measured at the start and end of each serial as well as total mass, which included all the equipment and breathing apparatus. Rate of Perceived Exertion and Thermal Sensation were also noted at the start and end of the test. Blood samples for lactate analysis were taken from two randomly selected firefighters at the end of the test. Throughout the test the lead group was also monitored for core temperature, skin temperature and heart rate. Heart rate and core temperature only were collected on the hose group.

The lead group started at time zero. The hose group started 5 minutes (300 seconds) later. Overall time from the start to reaching floor 28 was recorded for each group for each of the three serials. The duration of any rest periods taken was noted as was the time at which they occurred. The time and the floor number were also noted for the hose group as each of the 8 hoses were connected.

6.2 RESULTS WITH EDBA AND HOSE

The mean time taken for the lead group to reach the 28th floor was 14.6 ± 1.3 minutes and for the hose group was 10.5 ± 0.5 minutes. Allowing for the 5 minutes' delay in the start time of the hose group, the two groups reached the 28th floor at a similar time. The time taken per floor for the lead and hose groups, respectively is shown in Figures 6.1 and 6.2.

As can be seen in Figures 6.1 and 6.2, lines of best fit have been imposed on the measured data. The closeness of fit (shown statistically by the R^2 values which approach a value of 1 equating to a perfect fit) indicates that progression was fairly steady throughout the climb, though the lead team tended to slow beyond the 18th floor. Time taken can be predicted using the equations in the figures. For example the time required for the lead team to reach the 10th floor is calculated as: 0.489 x 10 floors = 4.89 minutes or 4 minutes 53 seconds. The time required for the hose team to reach the 10th floor would be 24.026 x 10 floors + 282.2 – 300[31], which equals 222 seconds, or 3 minutes 42 seconds (Figure 6.2).

31 The 300 seconds correction time refers to the 5 minute delay in the start time of the hose group.

The lead groups stopped between four and eight times to rest, with each rest period averaging 62 ± 17 seconds. The hose groups did not make any voluntary stops. However, during the last four minutes of serial three, three stops of approximately 30 seconds were forced on the hose group as they had caught up the lead group and were prevented from overtaking them by the Safety Staff.

Figure 6.1 **Mean time taken for the lead group to reach each floor**

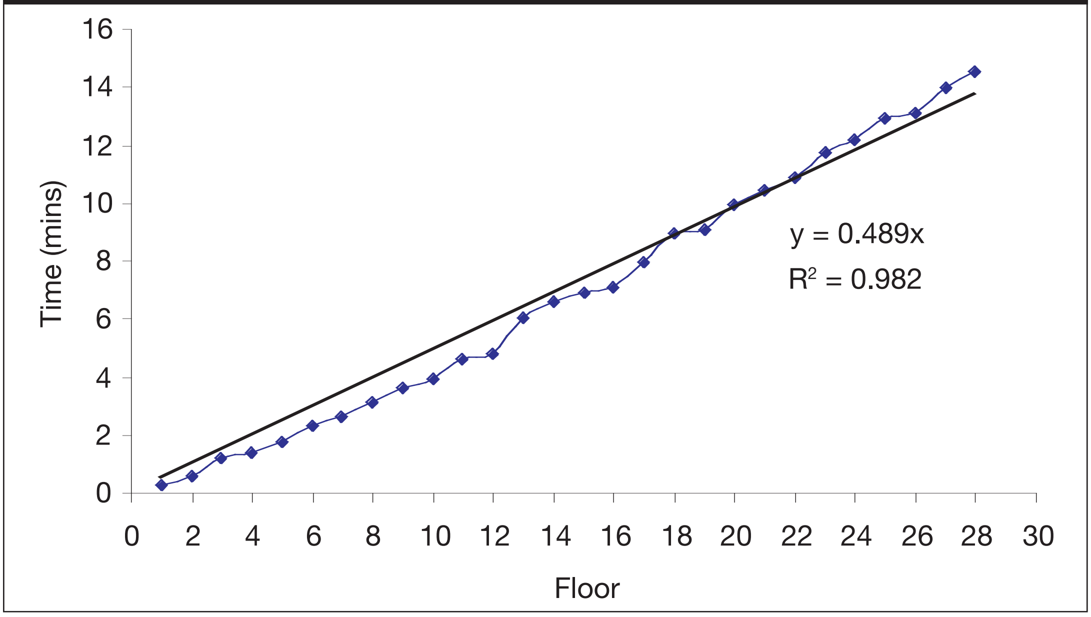
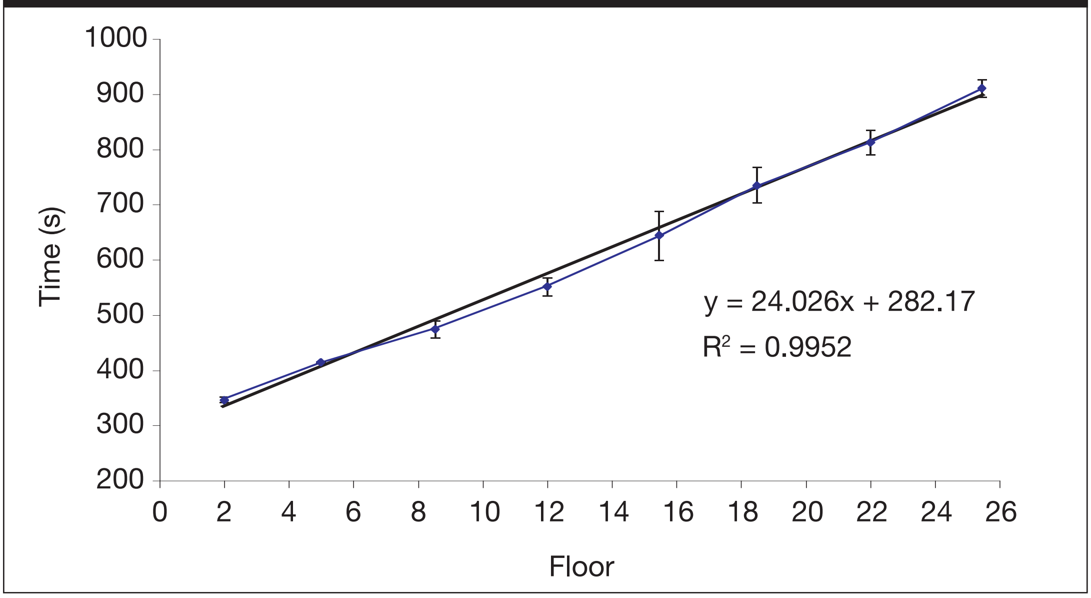


Figure 6.2 shows the floor and time taken to roll out each of the eight hoses. Floor 28 was reached before the final (ninth) hose was completely rolled out so there are no points on the graph after the 26th floor. This can be extrapolated in order to calculate how many hoses would be needed for more floors and how long it would take for these to be connected and in place. Additional time would however, be required to charge this hose line and undertake the necessary entry control procedures before undertaking firefighting activities. This assessment does not cover those aspects of the firefighting intervention.

Figure 6.2 **Mean time for hose team to connect 8 hoses, by floor**



The heart rate data are displayed in Table 6.2 as mean % of heart rate reserve (%HRR) and the percentage of exercise time spent over 60%HRR. The lead team worked at approximately 81%HRR while the hose team averaged approximately 69%. Both correspond to a 'hard' work intensity according to Howley's criteria. The lead team spent almost 90% of exercise time over 60%HRR (the lower border of the 'hard' zone) with two subjects working at this intensity for the entire exercise duration. These high heart rates were found despite the lead teams taking up to 8 rest periods of approximately 1 minute each. The hose group completed their task by spending just under 70% of exercise time over 60%HRR. This is due to the nature of their task, which involved shorter periods of intense exercise whilst rolling out the hose followed by a rest.

Table 6.2 **Mean heart rate (± sd) expressed as %HRR and proportion of time spent over 60%HRR.**

Condition	Number (n)	% Mean HRR	%Time > 60% HRR
Lead	12	81 ± 12	89 ± 14
Hose	10[32]	69 ± 8	69 ± 16

Table 6.3 shows the 'start', 'stop', difference and rate of rise in both core and skin temperatures in the two teams. Core temperatures on reaching the 28th floor averaged 38.1ºC and 37.5ºC in the lead and hose teams, respectively, rising by 0.6ºC and 0.4ºC during the climb, respectively. The lead teams' temperature increased at a higher rate than the hose teams', by 0.007ºC per minute on average. The highest final core temperature was 38.4ºC. Skin temperatures in the lead teams rose by on average 1.9ºC.

It would take an estimated 37 and 44 minutes for the lead and hose teams respectively to reach a core temperature of 39ºC, the proposed upper safe operational limit (Graveling *et al.*, 2001[33]), while conducting these stair climbing tasks at the same pace. This estimate is based on the measured rates of rise for both teams, and assumes a start temperature of 37.5ºC. If the teams were able to sustain the rates of work demonstrated over the first 28 floors, we estimate the firefighters would be able to climb 76 and 109 floors, respectively before achieving a core temperature of 39ºC. However, the remaining physiological data suggest the firefighters were near the point of fatigue after 28 floors, suggesting this extrapolation is purely hypothetical.

Table 6.3 **Mean (± sd) core and skin temperature responses for lead and hose teams with EDBA**

Temp	Teams	Start (ºC)	Stop (ºC)	Difference (ºC)	Rate of rise (ºC.min^{-1})
core	Lead	37.5 ± 0.2	38.1 ± 0.21	0.6 ± 0.2	0.041 ± 0.016
	Hose	37.1 ± 0.2	37.5 ± 0.23	0.4 ± 0.2	0.034 ± 0.017
skin	Lead	33.6 ± 1.0	35.5 ± 0.72	1.9 ± 0.6	0.131 ± 0.049

32 Heart rate was recorded on the second and third serials only.

33 Graveling et al (2001). Firefighter Training: Physiological and Environmental Factors. Fire Research Report Number 1/2001. Institute of Occupational Medicine.

Raised core temperature is a definite limitation to firefighting performance as has been demonstrated in the previous sections of this report and in OPL's other preliminary reports describing the physiological responses of firefighters to CCBRN operations. It took the firefighters on average 24 minutes from going under air to reaching a core temperature of 39.5ºC during the live fire scenario. Thus, it follows that if the start core temperature is already 0.6ºC elevated before entry to the compartment, in a functional range of core temperature of only around 1.5ºC (37.5 to 39ºC) then the firefighter will reach a critical temperature sooner. The time available for them to stay under air will therefore be reduced by the order of 10 minutes.

The mean lactate concentration at the end of each serial was 6.7 ± 2.9 $mmol.l^{-1}$, with the highest value reaching 10.4 $mmol.l^{-1}$. Lactate concentration is perhaps the best indicator of work intensity, lactate being a waste product produced during exercise over about 55% of VO_{2max} in a healthy untrained individual. The most rapidly accumulated and highest lactate levels are reached during all-out exercise and 12 $mmol.l^{-1}$ would be regarded as a high level of lactate at the end of an intense period of exercise for an untrained individual. The average value of 6.7 $mmol.l^{-1}$ is reasonably high and suggests that the lead team were working hard and beyond steady-state work intensity. Lactate accumulation would have continued if work had been maintained at this level and would soon have become a limiting factor. The highest level reached was 10.4 $mmol.l^{-1}$ and it is almost certain that this subject was at or near their limit.

Subjective ratings of Perceived Exertion and Thermal Sensation for the lead team are shown in Table 6.4. The average rating at the start of the exercise was 9 equating to 'light' and at the end was 17 equating to 'very hard'. Two subjects reported a final rating of 20, which equates to maximal exertion. Thermal sensation ratings increased from 3.5 before the test to 6.4 after, which shows that the firefighters were aware of the rise in core and skin temperatures.

Table 6.4 **Ratings of Perceived Exertion and Thermal Sensation**

	Pre	Post
Rating of Perceived Exertion	9.5 ± 1.7	17.1 ± 2.6
Thermal Sensation	3.5 ± 1.4	6.4 ± 0.6

6.3 RESULTS WITHOUT EDBA AND HOSE

Ten of the same subjects took part in the second experimental trial in this study, and in teams of 6 and 4 they undertook one ascent of the stairs to floor 28 whilst wearing full PPE. Figure 6.3 shows the time taken to ascend the 28 floors both with and without EDBA. It took nearly twice as long to climb the stairs with EDBA as without.

Figure 6.3 **Mean time taken for the lead group to reach each floor with and without EDBA**

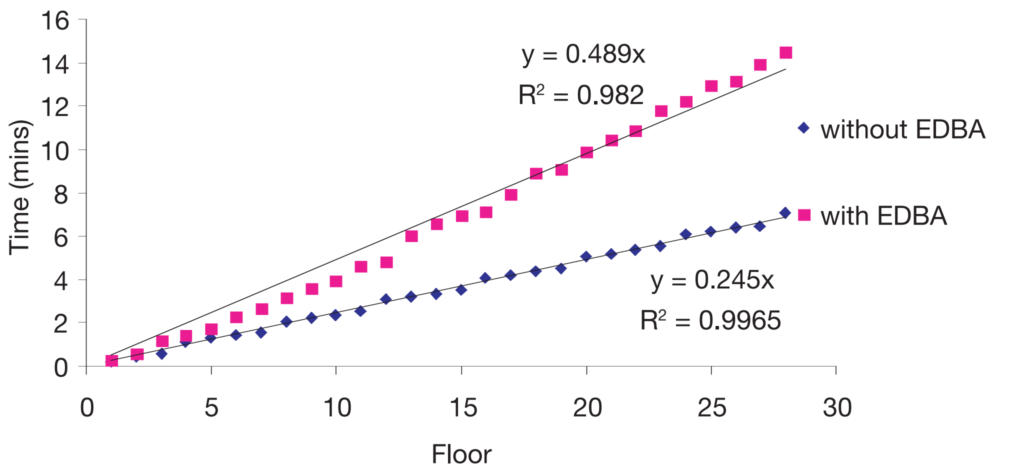


Table 6.5 shows the mean (+ sd) core temperature and skin temperature for the lead group. Rate of rise for core temperature was 0.042 ± 0.025°C.min^{-1} which was not statistically significantly different from the previous occasion when the firefighters were carrying EDBA. However, it took only half the time without EDBA so final core temperature was 0.5°C lower than with EDBA. Mean skin temperature increased at a rate of 0.068 ± 0.064°C.min^{-1} compared with 0.131 ± 0.049°C.min^{-1} with EDBA. Final skin temperature was 0.8°C lower without EDBA.

Table 6.5 **Mean (± sd) core and skin temperature responses for lead and hose teams without EDBA**

Temp	Start (°C)	Stop (°C)	Difference (°C)	Rate of rise (°C.min^{-1})
core	37.32 ± 0.33	37.61 ± 0.42	0.30 ± 0.18	0.042 ± 0.025
skin	34.18 ± 0.38	34.66 ± 0.41	0.48 ± 0.45	0.068 ± 0.064

Estimated sweat rate without EDBA was 0.05 ± 0.03 l.min^{-1}, very similar to the 0.04 ± 0.01 l.min^{-1} when carrying EDBA. Lactate concentration was 4.5 ± 2.0 mmol.l^{-1} suggesting that the firefighters were working at a steady state, unlike with EDBA. Without EDBA the firefighters worked at 71 ± 9 %HRR compared with 81 ± 12 with EDBA. This 10% difference suggests a lower level of cardiovascular strain without EDBA.

Table 6.6 shows the Ratings of Perceived Exertion (RPEx) and Thermal Sensation (TS) before and after the stair climb for the lead group. PREx was approximately 5 points lower following the stair climb without EDBA and TS was approximately 1 point lower.

Table 6.6 **Ratings of Perceived Exertion and Thermal Sensation**

	Pre	Post
Rating of Perceived Exertion	7.2 ± 1.5	12.0 ± 1.6
Thermal Sensation	2.8 ± 1.0	5.3 ± 0.8

6.4 CONCLUDING REMARKS

Firefighters may need to climb stairs to deal with a fire on the upper floors of a tall building where either dedicated firefighting lifts have not been provided or where they have failed. Climbing stairs in PPE while carrying EDBA and hose is very physically demanding. Operational planning assumptions, including levels of resources, should take account of the physiological demands of reaching the upper floors of tall buildings with RPE and PPE including any equipment carried. As an example, while it takes only around 15 minutes for the lead team and 10 minutes for the supporting hose team to reach the 28th floor, the cardiovascular and thermal demands are substantial, especially on the lead team. As well as feeling hot and fatigued by the time they reached the 28th floor, the physiological data indicated that the lead team would not be fit to commit to the fire compartment. Lactate concentrations were significantly elevated and core temperature had already risen 40% of its tolerable range. The hose team showed a less marked physiological response, though the physiological demands were still high.

Climbing stairs in PPE while *not* carrying any additional items of equipment is significantly less physically demanding. The time taken to reach the 28th floor (approximately 7 minutes) was half that with EDBA. While the rate of rise in core temperature was the same, change in core temperature, perceived ratings, lactate concentration and HRR were significantly lower, all suggesting lower physiological strain.

CHAPTER 7
Predicting safe penetration distances

Given the relatively minor differences observed between teams and floors, and therefore the apparent generic nature of the physiological responses to this scenario, the data from all of the firefighters from the live fire serials were pooled to add power to the modelling process. The aim was to predict the maximum combination of vertical floors that could be climbed and horizontal distance that could be penetrated, while evacuating the casualty from the fire compartment, and remaining below an upper core temperature limit of 39.0ºC[34]. A 3-component model based on the rate of rise of core temperature was deemed the most appropriate. The model incorporated rates of rise in core temperature from, firstly, climbing the stairs with and without EDBA (taken from the Portland House trials; refer to Section 6); secondly, from going under air to finding the casualty (taken from those firefighters who found the casualty in the live fire trials); and thirdly, from finding the casualty to exiting the compartment with the casualty (taken from those firefighters who successfully exited the compartment with the casualty in the live fire trials).

Modelling (predicting responses from a number of input variables) requires a number of assumptions to be made. Those assumptions used in this model are outlined below:

- A starting core temperature of 37.5∞C and an upper limit of 39.0ºC.
- A level of certainty of 95% (i.e. on 5% of occasions firefighters are likely to exceed these predictions); this 'risk' level can be varied using the underlying equations.
- A mean (sd) rate of core temperature rise during stair climbing with EDBA of 0.0410 (+0.0160)ºC.min^{-1}.
- A mean (sd) rate of core temperature rise from going under air to finding the casualty of 0.0465 (+0.0212)ºC.min^{-1}.
- A mean (sd) rate of core temperature rise from finding the casualty to exiting the compartment with the casualty of 0.0857 (+0.0494)ºC.min^{-1}.
- A mean speed of progress from going under air to finding the casualty of 2.38 m.min^{-1}.
- A mean speed of progress from finding the casualty to exiting the compartment with the casualty of 16.38 m.min^{-1}.
- No pause occurs between reaching the top of stairs and going under air.

- The scenario ends as soon as the casualty is brought out of the compartment.

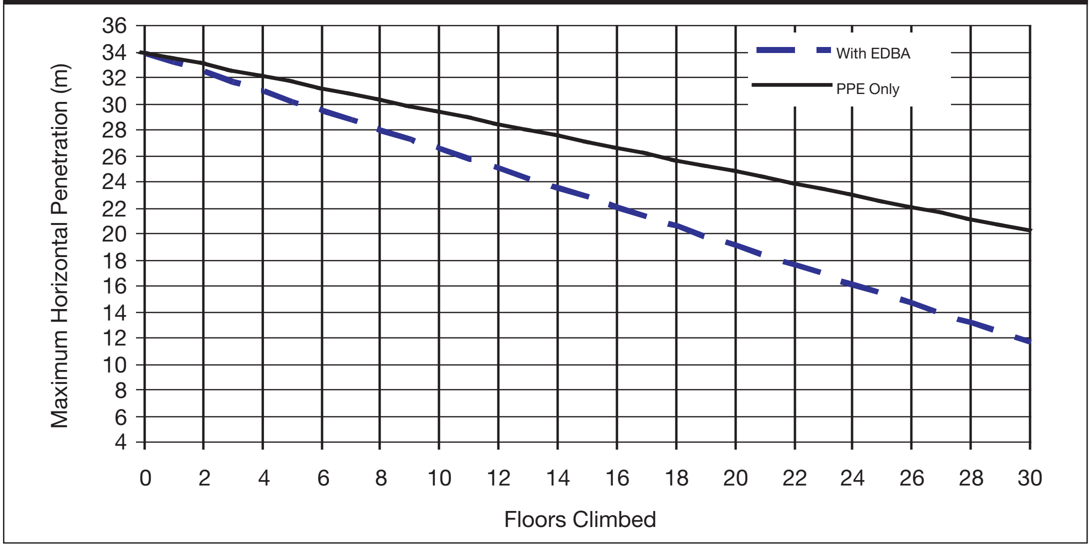
- The relationship between climbing floors and time taken while carrying EDBA is: floors * 0.489 = time (min); and without EDBA is: floors * 0.245 = time (min).

The model is as follows, where T_{core} refers to core temperature and RoR refers to rate of rise:

Max horizontal penetration (m) =
[(T_{core} upper limit – T_{core} start) – ((mean T_{core} RoR while stair climbing + (1.64 * sd)) * (time per floor * floors)]
/ [((mean T_{core} RoR from on air to find casualty) + (1.64 * sd)) * (1/speed to casualty)]
+ [((mean T_{core} RoR from find casualty to exit compartment) + (1.64 * sd))
* (1/speed out of compartment)]

Figure 7.1 shows the output from the models, relating the number of floors climbed on the x-axis with the maximum horizontal penetration into a fire compartment on the y-axis. The dotted line represents the stair climb while carrying EDBA and the solid line represents the relationship without any other items carried except the PPE worn. For example, if there was a fire on the 2nd floor, the models estimate that in 95% of cases, the firefighters could penetrate up to approximately 32m into the fire compartment, rescue the casualty, and exit the building before exceeding a core temperature of 39ºC. If the fire was on the 30th floor, the horizontal distances would be reduced to approximately 20m and 12m, if the stairs were climbed without and with EDBA, respectively. A horizontal distance of 34m into the fire compartment seems to be the maximum distance, even on the ground floor, given the assumptions listed on the previous page.

Figure 7.1 Predicting maximum vertical and horizontal penetration into a high rise building under conditions of live fire



34 Graveling et al (2001). Firefighter Training: Physiological and Environmental Factors. Fire Research Report Number 1/2001. Institute of Occupational Medicine.

7.1 SUMMARY OF MAIN FINDINGS AND CONCLUSIONS

1. The physiological load associated with climbing stairs up 28 floors in PPE both with and without EDBA and hose was investigated. When carrying EDBA and hose it took approximately 30 seconds and core temperature rose by approximately 0.02ºC, per floor. When climbing unloaded it took approximately 15 seconds and core temperature rose by approximately 0.01ºC, per floor.

2. Climbing 28 floors with EDBA and hose resulted in fatigue, heat strain and physical exhaustion to the extent that committing firefighters into a fire compartment would be unwise.

3. Climbing unloaded was less arduous and subsequent commitment to the fire compartment would appear to be tolerable by the majority of firefighters investigated.

4. A predictive model to estimate the combination of maximum vertical and horizontal distances that firefighters could achieve, while remaining within a core temperature limit of 39ºC is presented. Assuming 95% confidence in the outcomes, the model suggests that 34m is the maximum distance firefighters should penetrate into a fire compartment to rescue a casualty, where no stair climbing is required to access the point of entry. Having to climb stairs beforehand or undertake other activities reduces the maximum penetration distances proportionally.

CHAPTER 8
Reducing heat strain during active duty

A major finding of the high-rise scenarios and of the PAFF study in general, is that a rising core temperature was a main factor limiting firefighter performance. This finding transpires not only from the number of firefighters attaining the 'pull-out' core temperature of 39.5°C, but also through the considerable number of safety withdrawals, both voluntary and at the safety staff's discretion. This also included on occasions the withdrawal of safety staff who exceeded safe core body temperatures. Although firm evidence does not exist, it was likely that the majority of the safety withdrawals were a function of a rising body temperature and concomitant exertional heat stress. Many of the firefighters actively withdrawn from the fire compartment complained of feeling 'too hot' and demonstrated classic signs of excessive heat stress e.g. dizziness, light-headedness and disorientation. Assuming that all serials terminated for safety reasons were in some way related to an increased body temperature, approximately 65% of all serials from both high rise scenarios (simulated live fire and live fire) were terminated before successful completion due to a rising body temperature. Limitations due to rising core body temperature were also noted in the studies of CCBRN scenarios referred to in the introduction. In view of this it is our recommendation that interventions to prevent or attenuate rises in firefighter body temperature during active duty are considered.

A logical approach to maintaining safe working practice in the heat would be to lower the initial core temperature of the working participant and therefore widen the gap before limiting temperatures are reached (Marino, 2002[35]). This has been investigated to some success by many researchers, employing, among other things, pre-cooling techniques and periods of heat acclimation to lower workers resting core temperature. However, the nature of the UK Fire and Rescue Service and the typical work encountered, makes pre-cooling strategies impractical. On the contrary, strategies to attenuate the rising core temperature during active duty may prove to be more suitable. The wearing of clothing or apparatus to cool various parts of the body has received considerable investigation, both during athletic and occupational participation. Although a detailed discussion of this area is not appropriate within this report, a brief summary of two potential cooling techniques is provided below.

35 Marino F. Methods, advantages, and limitations of body cooling for exercise performance. *Br J Sports Med* 36: 89-94, 2002.

The first technique concerns the wearing of 'cooling garments' that reduce the temperature of the torso. Numerous studies have investigated these garments during exercise in the heat, and reductions in heat strain have been reported with torso cooling in a variety of occupations, including aircrew (Frim, 1989[36];Vallerand *et al.,* 1991[37]), firefighters (Bennett *et al.,* 1995[38]; Carter *et al.,* 1999[39]), and personnel wearing NBC or equivalent clothing ensembles (House *et al.,* 2003[40]; McLellan *et al.,* 1999[41]). Although the extent of the alleviation of heat strain depends upon the level of heat stress, core temperature reductions of 1-1.7°C during 90-120 minutes of physical work have been reported. Furthermore, over shorter duration's of work (<60 minutes) reductions in core temperature of 0.4-0.7°C are common.

The second technique also concerns cooling of the torso, but specifically involves harnessing the cooling potential of the compressed gas cylinders that the firefighters use for breathing purposes. The compressed air in the cylinders carried by firefighters is a major potential source of cooling. The energy required to pressurise even the smaller cylinders is several mega joules (MJ), many times more than the total energy expenditure of a firefighter even in the most demanding situations. When the gas is allowed to expand an equivalent amount of energy is absorbed from the surroundings, hence the well-known frosting around the outlet valves and our observation that gas entering the mask is at about 8°C whilst the ambient temperature may be ten times this value. The cylinder and expansion valve act as half a refrigeration unit and if only a fraction of this energy could be harnessed it would provide a very effective cooling system. One of the attractive features of such as system is that it would be self-regulating in as much as the rate of ventilation and therefore gas expansion and subsequent cooling (in a demand respirator), would be proportional to the firefighter's work load and thus heat production. At present the major part of this cooling effect is dissipated to the environment with little or no benefit to the firefighter. Research is therefore needed to find ways to develop the potential of such a cooling system.

In conclusion, it should be recognised that numerous techniques and strategies to reduce heat strain during active duty are potentially available to the UK Fire and Rescue Service. A detailed account of these options is not within the scope of this report. However, the reader should be aware of OPL's recent literature review concerning methods to limit hyperthermia during occupational heat stress (Carter *et al.,* pending publication[42]).

36 Frim J. Head cooling is desirable but not essential for preventing heat strain in pilots. *Aviat Space Environ Med* 60: 1056-1062, 1989.

37 Vallerand AL, Michas RD, Frim J and Ackles KN. Heat balance of subjects wearing protective clothing with a liquid- or air-cooled vest. *Aviat Space Environ Med* 62: 383-391, 1991.

38 Bennett BL, Hagan RD, Huey KA, Minson C and Cain D. Comparison of two cool vests on heat-strain reduction while wearing a firefighting ensemble. *Eur J Appl Physiol* 70: 322-328, 1995.

39 Carter JB, Banister EW and Morrison JB. Effectiveness of rest pauses and cooling in alleviation of heat stress during simulated fire-fighting activity. *Ergonomics* 42: 299-313, 1999.

40 House JR, Lunt H, Magness A and Lyons J. Testing the effectiveness of techniques for reducing heat strain in royal navy nuclear, biological and chemical cleansing stations' teams. *J R Nav Med Serv* 89: 27-34, 2003.

41 McLellan TM, Frim J and Bell DG. Efficacy of air and liquid cooling during light and heavy exercise while wearing NBC clothing. *Aviat Spce Environ Med* 70: 802-811, 1999.

42 Carter JM, Rayson M and Jones DA. Limiting Occupational Hyperthermia During Active Duty: A Literature Review. *Pending publication*.

APPENDIX A

Fitness data

Table A1 **Phase 1: ambient cohort physiological characteristics**											
FF No.	FF Sex	Age (y)	Height (cm)	Mass (kg)	Body Fat (%)	HR max (beats $.min^{-1}$)	FVC (l)	FEV1 (l)	Peak V_E ($l.min^{-1}$)	VO_{2max} ($ml. kg^{-1} .min^{-1}$)	VO_{2max} ($l.min^{-1}$)
1	m	21	177	63.7	7.8	201	5.05	4.32	117.1	47.7	3.038
4	m	30	168	78.7	20.6	182	4.78	3.8	135.7	53.6	4.218
5	m	38	181	83.7	18.3	182	5.78	4.18	120.0	42.8	3.582
6	m	33	177	87.0	15.2	178	5.06	4.23	128.9	46.6	4.054
7	m	33	185	92.0	18.9	196	6.34	5.23	164.6	49.4	4.545
8	m	36	181	90.6	17.3	200	6.08	5.09	160.0	52.4	4.747
10	m	35	184	88.2	18.9	195	6.09	4.91	162.5	44.1	3.890
11	m	37	175	89.1	20.8	195	4.66	3.48	133.7	43.8	3.903
12	m	32	179	90.9	18.3	183	5.96	4.74	161.8	48.0	4.363
13	m	27	182	87.7	20.0	194	5.92	4.5	133.2	44.6	3.911
14	m	31	181	87.6	16.7	189	6.8	5.52	137.8	48.4	4.240
15	m	33	174	70.9	10.4	197	5.75	4.81	141.6	53.2	3.772
17	m	26	187	90.3	11.0	185	6.01	5.58	136.4	48.0	4.334
18	m	26	180	93.6	19.3	191	6.36	5.17	173.7	55.0	5.148
19	m	36	178	79.2	16.3	196	5.83	4.29	126.3	42.1	3.334
20	f	26	172	66.7	25	187	3.80	3.18	115.9	47.8	3.188
Mean		31.3	179	83.7	17.2	191	5.64	4.56	140.6	48.0	4.017
SD		4.9	5.0	9.3	4.4	7	0.77	0.70	18.4	4.0	0.566

Table A2 **Phase 2: live fire cohort physiological characteristics**

FF No.	FF Sex	Age (y)	Height (cm)	Mass (kg)	Body Fat (%)	HR max (beats $.min^{-1}$)	FVC (l)	FEV1 (l)	Peak V_E ($l.min^{-1}$)	VO_{2max} ($ml. kg^{-1} .min^{-1}$)	VO_{2max} ($l.min^{-1}$)
1	m	21	177	63.7	7.8	201	5.05	4.32	117.1	47.7	3.038
2	m	32	175	79.0	13.2	185	5.13	4.69	154.1	60.7	4.795
3	m	38	179	74.5	13.8	196	5.32	4.54	163.8	65.3	4.865
4	m	30	168	78.7	20.6	182	4.78	3.8	135.7	53.6	4.218
5	m	38	181	83.7	18.3	182	5.78	4.18	120.0	42.8	3.582
6	m	33	177	87.0	15.2	178	5.06	4.23	128.9	46.6	4.054
7	m	33	185	92.0	18.9	196	6.34	5.23	164.6	49.4	4.545
8	m	36	181	90.6	17.3	200	6.08	5.09	160.0	52.4	4.747
9	f	24	169	59.3	16.9	189	4.40	3.48	98.1	44.6	2.643
10	m	35	184	88.2	18.9	195	6.09	4.91	162.5	44.1	3.890
11	m	37	175	89.1	20.8	195	4.66	3.48	133.7	43.8	3.903
15	m	33	174	70.9	10.4	197	5.75	4.81	141.6	53.2	3.772
16	m	33	170	79.5	17.5	193	4.75	3.85	137.4	51.2	4.070
17	m	26	187	90.3	11.0	185	6.01	5.58	136.4	48.0	4.334
18	m	26	180	93.6	19.3	191	6.36	5.17	173.7	55.0	5.148
19	m	36	178	79.2	16.3	196	5.83	4.29	126.3	42.1	3.334
21	f	26	173	76.7	27.0	204	4.85	3.95	134.3	46.7	3.581
22	m	26	168	79.2	15.2	208	4.84	4.25	155.3	50.5	3.999
23	f	27	177	79.5	27.4	170	4.18	3.39	97.2	35.8	2.849
24	f										
25	m	29	175	84.2	19.5	207	5.55	4.08	103.5	47.8	4.026
26	m	29	184	87.7	16.5	210	6.38	4.93	141.2	47.8	4.195
27	f	24	168	67.0	27.3	186	3.96	3.30	109.9	42.4	2.844
28	f	29	174.5	75.8	25.1	198	4.26	3.48	127.6	47.6	3.611
Mean		30.4	176.9	81.4	18.0	192.7	5.39	4.38	136.8	48.5	3.944
SD		5.1	5.9	9.5	4.8	10.2	0.74	0.66	22.9	6.6	0.701

Where FF indicates firefighter, m indicates males, f indicates female, HR indicates heart rate, beats.min-1 indicates beats per minute, FVC indicates forced vital capacity, FEV1 indicates forced expiratory volume after 1 second, V_E indicates ventilation and ml.kg-1.min-1 indicates millilitres of oxygen consumed per kilogramme body mass per minute.

Firefighter 24 became injured during the study (due to an unrelated reason) and was not able to be fitness tested.

APPENDIX B

Phase 1: Ambient scenario results

Table B1 Temperature and humidity by condition

	C1		C2		C3		C4		C1-C4	
Temp (°C)	Out	In	Out	In	Out	In	Out	In	Out	In
Mean	17.3	27.5	16.7	28.2	18.0	26.8	16.1	26.7	17.0	27.3
SD	1.0	2.4	1.4	2.8	1.0	2.6	1.2	2.6	1.1	2.6
Humidity (%)										
Mean	55.2	49.1	54.5	49.6	46.2	52.6	56.3	48.4	53.0	49.9
SD	7.1	5.1	7.1	5.7	2.8	6.7	4.7	7.2	5.4	6.2

Table B2 Outcomes by condition

	Success	Temp	Safety	Air	Totals
C1: SDBA & 45mm	0	2	1	5	8
C2: EDBA & 45mm	2	4	2	0	8
C3: SDBA & 70mm	1	0	0	7	8
C4: EDBA & 70mm	1	4	3	0	8
Totals	**4**	**10**	**6**	**12**	32

Table B3 Core temperature response by Condition

C	n	Mean Duration (min)	Core Temperature			
			"Start" (°C)	"Stop" (°C)	Rise (°C)	Rate of Rise (°C.min^{-1})
C1	16	25.0 ± 3.1	37.5 ± 0.5	38.7 ± 0.6	1.2 ± 0.4	0.047 ± 0.014
C2	16	33.7 ± 6.8	37.6 ± 0.4	39.1 ± 0.5	1.5 ± 0.4	0.045 ± 0.009
C3	16	25.6 ± 3.5	37.3 ± 0.4	38.5 ± 0.5	1.2 ± 0.5	0.049 ± 0.018
C4	16	34.9 ± 6.2	37.3 ± 0.6	39.0 ± 0.5	1.7 ± 0.7	0.048 ± 0.014
T	**64**	**29.8 ± 6.8**	**37.4 ± 0.5**	**38.9 ± 0.6**	**1.4 ± 0.5**	**0.047 ± 0.014**

Table B4 Skin temperature response by condition

C	n	Mean Duration (min)	Skin Temperature			
			"Start" (°C)	"Stop" (°C)	Rise (°C)	Rate of Rise (°C.min^{-1})
C1	15[43]	24.6 ± 2.8	33.4 ± 0.9	36.0 ± 0.8	2.6 ± 0.8	0.115 ± 0.034
C2	16	33.7 ± 6.8	33.6 ± 1.4	36.5 ± 0.9	2.9 ± 1.1	0.090 ± 0.041
C3	16	25.6 ± 3.5	33.8 ± 1.2	36.2 ± 0.9	2.4 ± 1.2	0.104 ± 0.046
C4	16	34.9 ± 6.2	33.5 ± 0.6	36.4 ± 0.7	2.9 ± 0.7	0.086 ± 0.026
T	**63**	**29.8 ± 6.8**	**33.6 ± 1.1**	**36.4 ± 0.8**	**2.8 ± 0.9**	**0.098 ± 0.039**

43 One data set of skin temperature was lost under Condition 1.

Table B5 **Percentage Heart Rate Reserve by condition**				
ID No.	**C1**	**C2**	**C3**	**C4**
Mean	68	70	67	72
SD	8	11	9	6
n	16	16	16	16

Table B6 **Proportion (%) of time spent working 'hard' or 'very hard' by condition**				
ID No.	**C1**	**C2**	**C3**	**C4**
Mean	72	76	68	78
SD	13	13	18	10
n	16	16	16	16

Table B7 **Mean sweat loss and sweat rate by condition (mean ± SD)**				
C	**n**	**Duration** (min)	**Sweat Loss** (l)	**Sweat Rate** ($l.min^{-1}$)
C1	16	25.0 ± 3.1	0.78 ± 0.31	0.03 ± 0.01
C2	16	33.7 ± 6.8	1.04 ± 0.52	0.03 ± 0.01
C3	16	25.6 ± 3.5	0.73 ± 0.27	0.03 ± 0.01
C4	16	34.9 ± 6.2	1.00 ± 0.39	0.03 ± 0.01

Table B8 **% Peak lactate concentrations by Condition**				
% Peak	**C1**	**C2**	**C3**	**C4**
Mean	48	61	50	44
SD	17	20	21	18

Table B9 **Lactate concentrations and number of firefighters above and below the lactate threshold**				
C	**n**	**Lactate**	**n < 5mmol.l^{-1}**	**n > 5mmol.l^{-1}**
C1	14	6.0 ± 2.2	5	9
C2	12	8.2 ± 3.4	3	9
C3	16	6.3 ± 2.4	7	9
C4	15	5.5 ± 1.4	4	11
Total	**57**	**6.4 ± 2.5**	**19**	**38**

APPENDIX C

Phase 2: Live fire scenario results by floor and team

Table C1 **Ambient temperature experienced by the firefighters by team and floor (mean ± SD)**		
Floor	**FF Team (ºC)**	**SR Team (ºC)**
B	53.3 ± 8.6	46.1 ± 9.0
1	39.5 ± 7.2	40.0 ± 6.2
2	42.5 ± 5.2	42.1 ± 3.3
2FS	43.8 ± 4.8	43.5 ± 5.0
3	42.1 ± 11.8	33.9 ± 6.4
4	37.2 ± 6.0	26.7 ± 9.2
Total	**44.1 ± 8.6**	**41.7 ± 7.7**

Table C2 **Peak ambient temperature by team and floor (mean ± SD)**				
Floor	**FF Team (ºC)**	**FF n**	**SR Team (ºC)**	**SR n**
B	103.1 ± 15.3	16	91.9 ± 24.7	17
1	72.1 ± 19.4	15	76.9 ± 12.3	17
2	97.1 ± 12.6	15	86.1 ± 10.3	15
2FS	92.6 ± 12.5	15	91.3 ± 15.0	18
3	85.5 ± 25.8	4	64.9 ± 13.8	3
4	81.9 ± 8.1	6	69.4 ± 23.8	4

Table C3 **Overall outcomes by floor**						
Floor	**Success**	**Air**	**Temp**	**Safety**	**Totals**	***Partial Success***
B	1	0	5	3	**9**	***6***
1	4	0	2	3	**9**	***3***
2	1	0	4	3	**8**	***6***
FS	0	0	2	7	**9**	***7***
3	1	0	1	0	**2**	***1***
4	2	0	1	0	**3**	***1***
Totals	**9**	**0**	**15**	**16**	**40**	***24***

Table C4 **Firefighting team outcomes by floor**						
Floor	**Success**	**Air**	**Temp**	**Safety**	**Technical**	**Totals**
B	1	0	5	3	0	**9**
1	4	0	3	2	0	**9**
2	1	0	4	3	0	**8**
FS	1	0	4	4	0	**9**
3	1	0	1	0	0	**2**
4	2	0	1	0	0	**3**
Totals	**10**	**0**	**18**	**12**	**0**	**40**

Table C5 Search and rescue team outcomes by floor						
Floor	**Success**	**Air**	**Temp**	**Safety**	**Technical**	**Totals**
B	2	0	2	4	1	**9**
1	4	0	3	2	0	**9**
2	3	0	3	2	0	**8**
FS	1	0	2	5	1	**9**
3	2	0	0	0	0	**2**
4	3	0	0	0	0	**3**
Totals	**15**	**0**	**10**	**13**	**2**	**40**

Table C6 Work duration by team and floor (mean ± SD)				
Floor	**FF Work duration (min)**	**FF n**	**SR Work duration (min)**	**SR n**
B	30.6 ± 3.8	18	33.6 ± 5.4	18
1	28.8 ± 2.3	18	31.6 ± 4.6	18
2	31.0 ± 5.2	16	35.3 ± 5.0	16
2FS	32.5 ± 2.1	18	34.7 ± 3.6	18
3	30.5 ± 0.8	4	32.1 ± 2.4	4
4	30.0 ± 1.6	6	29.0 ± 1.4	6
Totals	**30.6 ± 3.5**	**80**	**33.3 ± 4.7**	**80**

Table C7 Core temperature for firefighting teams by floor (mean ± SD)						
Fl	**n**	**Mean Duration** (min)	**Core Temperature**			
			"Start" (ºC)	"Stop" (ºC)	Rise (ºC)	Rate of Rise (ºC.min^{-1})
B	18	30.6	37.5 ± 0.3	39.3 ± 0.5	1.8 ± 0.5	0.060 ± 0.017
1	18	29.1	37.5 ± 0.4	39.1 ± 0.4	1.6 ± 0.4	0.055 ± 0.014
2	16	31.0	37.5 ± 0.4	39.1 ± 0.7	1.6 ± 0.7	0.054 ± 0.024
2FS	17[44]	32.7	37.4 ± 0.4	39.0 ± 0.5	1.6 ± 0.4	0.048 ± 0.013
3	4	30.4	37.3 ± 0.3	39.0 ± 0.5	1.7 ± 0.3	0.056 ± 0.007
4	6	30.0	37.2 ± 0.2	38.8 ± 0.4	1.6 ± 0.4	0.053 ± 0.013
T	**79**	**30.7**	**37.4 ± 0.4**	**39.1 ± 0.5**	**1.7 ± 0.5**	**0.054 ± 0.017**

Table C8 Core temperature for search and rescue teams by floor (mean ± SD)						
Fl	**n**	**Mean Duration** (min)	**Core Temperature**			
			"Start" (ºC)	"Stop" (ºC)	Rise (ºC)	Rate of Rise (ºC.min^{-1})
B	18	33.4	37.4 ± 0.4	38.9 ± 0.6	1.4 ± 0.6	0.044 ± 0.017
1	18	31.6	37.5 ± 0.4	39.0 ± 0.6	1.5 ± 0.7	0.045 ± 0.019
2	16	35.3	37.3 ± 0.4	39.1 ± 0.7	1.8 ± 0.8	0.050 ± 0.022
2FS	18	34.7	37.3 ± 0.2	38.7 ± 0.5	1.4 ± 0.5	0.040 ± 0.015
3	4	32.0	37.2 ± 0.1	39.0 ± 0.5	1.7 ± 0.4	0.055 ± 0.011
4	6	28.6	37.2 ± 0.2	38.4 ± 0.6	1.2 ± 0.6	0.041 ± 0.018
T	**80**	**33.3**	**37.4 ± 0.4**	**38.9 ± 0.6**	**1.5 ± 0.6**	**0.045 ± 0.018**

44 One core temperature data set was excluded due to the loss of radio transmission.

Table C9 Skin temperature for firefighting team by floor (mean ± SD)

Fl	n	Work Duration (min)	Mean Skin Temperature "Start" (ºC)	"Stop" (ºC)	Rise (ºC)	Rate of Rise ($ºC.min^{-1}$)
B	16	30.7	33.2 ± 0.9	39.8 ± 1.6	6.6 ± 1.6	0.218 ± 0.053
1	15	29.0	33.4 ± 0.6	39.1 ± 0.7	5.7 ± 0.8	0.197 ± 0.030
2	15	30.6	33.4 ± 0.9	38.9 ± 1.5	5.5 ± 2.1	0.182 ± 0.063
2FS	16	32.4	33.4 ± 0.7	39.8 ± 1.4	6.3 ± 1.7	0.199 ± 0.063
3	5	29.9	33.1 ± 0.4	37.3 ± 1.2	4.2 ± 1.1	0.141 ± 0.041
4	6	29.2	33.0 ± 0.3	38.7 ± 1.4	5.7 ± 1.3	0.195 ± 0.042
T	**73**	**30.5**	**33.3 ± 0.8**	**39.2 ± 1.5**	**5.9 ± 1.6**	**0.196 ± 0.054**

Table C10 Skin temperature for search and rescue team by floor (mean ± SD)

Fl	n	Work Duration (min)	Mean Skin Temperature "Start" (ºC)	"Stop" (ºC)	Rise (ºC)	Rate of Rise ($ºC.min^{-1}$)
B	17	33.1 ± 5.4	33.4 ± 0.9	39.4 ± 1.1	6.0 ± 1.5	0.185 ± 0.059
1	17	31.0 ± 4.0	33.4 ± 0.6	38.7 ± 0.9	5.4 ± 1.0	0.174 ± 0.038
2	16	32.4 ± 4.8	33.2 ± 0.8	38.7 ± 1.0	5.4 ± 1.3	0.171 ± 0.046
2FS	17	34.2 ± 3.3	33.6 ± 0.5	39.2 ± 1.1	5.6 ± 0.9	0.166 ± 0.034
3	3	32.1 ± 3.3	33.2 ± 0.5	37.5 ± 0.3	4.4 ± 0.9	0.136 ± 0.021
4	4	28.6 ± 2.2	32.5 ± 0.7	37.4 ± 2.0	4.9 ± 1.4	0.175 ± 0.060
T	**74**	**32.4 ± 4.5**	**33.3 ± 0.7**	**38.8 ± 1.2**	**5.5 ± 1.2**	**0.172 ± 0.046**

Table C11 Percentage Heart Rate Reserve by team and floor (mean ± SD)

Floor	FF Team HRR	FF n	SR Team HRR	SR n
B	69 ± 8	18	67 ± 11	18
1	67± 13	17	67 ± 10	18
2	70 ± 14	16	64 ± 11	15
2FS	70 ± 7	17	64 ± 11	16
3	68 ± 10	4	68 ± 4	4
4	64 ± 11	6	62 ± 13	6
Total	**69 ± 10**	**78**	**66 ± 10**	**77**

Table C12 Proportion (%) of time spent working 'hard' or 'very hard' by team and floor

Floor	FF Team >60% HRR	FF n	SR Team >60% HRR	SR n
B	66 ± 11	18	62 ± 17	18
1	64 ± 20	17	64 ± 18	18
2	66 ± 18	16	60 ± 17	15
2FS	69 ± 10	17	56 ± 17	16
3	69 ± 20	4	67 ± 8	4
4	60 ± 16	6	60 ± 23	6
Total	**67 ± 15**	**78**	**61 ± 17**	**77**

Table C13 Estimated sweat loss and sweat rate by team and floor (mean ± SD)						
	FF	**FF Sweat Loss**	**FF Sweat Rate**	**SR**	**SR Sweat Loss**	**SR Sweat Rate**
Floor	**n**	(l)	(l.min^{-1})	**n**	(l)	(l.min^{-1})
B	18	0.86 ± 0.30	0.03 ± 0.01	18	0.90 ± 0.28	0.03 ± 0.01
1	18	0.76 ± 0.33	0.03 ± 0.01	16	0.82 ± 0.27	0.03 ± 0.01
2	14	0.82 ± 0.40	0.03 ± 0.01	16	0.85 ± 0.28	0.02 ± 0.01
2FS	18	1.05 ± 0.37	0.03 ± 0.01	18	1.04 ± 0.30	0.03 ± 0.01
3	4	0.62 ± 0.31	0.02 ± 0.01	4	0.99 ± 0.33	0.03 ± 0.01
4	6	0.82 ± 0.44	0.03 ± 0.01	6	0.73 ± 0.33	0.02 ± 0.01
Total	**78**	**0.86 ± 0.37**	**0.03 ± 0.01**	**78**	**0.90 ± 0.30**	**0.03 ± 0.01**

Table C14 Peak lactate concentrations and number of firefighters working below and above the mean lactate threshold for firefighting team by floor (mean ± SD)				
Floor	**N**	**Lactate**	**n < 5mmol.l^{-1}**	**n > 5mmol.l^{-1}**
B	18	4.3 ± 1.4	13	5
1	17	4.9 ± 1.9	10	7
2	16	4.1 ± 1.9	9	7
2FS	18	4.4 ± 2.2	12	6
3	4	3.5 ± 1.6	3	1
4	4	2.8 ± 1.2	3	1
Total	**77**	**4.3 ± 1.9**	**50**	**27**

Table C15 Peak lactate concentrations and number of firefighters working below and above the mean lactate threshold for search and rescue team by floor (mean ± SD)				
Floor	**N**	**Lactate**	**n < 5mmol.l^{-1}**	**n > 5mmol.l^{-1}**
B	17	4.9 ± 1.8	10	7
1	18	3.9 ± 1.9	13	5
2	16	4.8 ± 1.9	9	7
2FS	18	4.8 ± 2.2	8	10
3	4	4.0 ± 1.6	3	1
4	6	4.5 ± 1.2	4	2
Total	**79**	**4.5 ± 1.9**	**47**	**32**

Table C16 Air use for Firefighting team by floor (mean ± SD)					
Fl	**n**	**Duration under Air (min)**	**Air Use (bar)**	**Rate of Air Use (bar.min^{-1})**	**Ventilation Rate (l.min^{-1})**
B	18	24.6 ± 3.5	107 ± 19	4.4 ± 0.6	55.3 ± 7.6
1	18	23.5 ± 2.1	109 ± 17	4.7 ± 0.7	58.9 ± 8.2
2	16	23.2 ± 5.0	107 ± 27	4.6 ± 0.7	58.7 ± 9.3
2FS	18	24.6 ± 2.3	111 ± 16	4.5 ± 0.5	57.0 ± 6.8
3	4	23.3 ± 0.6	92 ± 18	4.0 ± 0.7	50.0 ± 8.6
4	6	26.2 ± 0.3	127 ± 21	4.9 ± 0.8	61.4 ± 10.0
Total	**80**	**24.1 ± 3.2**	**109 ± 20**	**4.5 ± 0.7**	**57.4 ± 8.3**

Table C17 Air use for the Search & Rescue team by floor (mean ± SD)

Fl	n	Duration under Air (min)	Air Use (bar)	Rate of Air Use (bar.min^{-1})	Ventilation Rate (l.min^{-1})
B	18	27.6 ± 4.9	116 ± 26	4.2 ± 0.5	53.2 ± 6.2
1	18	25.9 ± 4.3	106 ± 31	4.1 ± 0.8	51.4 ± 10.6
2	16	27.5 ± 5.3	123 ± 22	4.6 ± 0.8	57.6 ± 10.0
2FS	18	26.4 ± 3.3	114 ± 17	4.3 ± 0.4	54.3 ± 4.6
3	4	24.9 ± 1.1	126 ± 11	5.0 ± 0.5	63.9 ± 6.7
4	6	25.1 ± 1.1	124 ± 15	5.0 ± 0.5	62.7 ± 6.9
Total	**80**	**26.6 ± 4.2**	**116 ± 24**	**4.4 ± 0.7**	**55.2 ± 8.6**

Table C18 Manual dexterity time for firefighting team by floor (mean ± SD)

	Firefighter Teams				Search & Rescue Teams			
Floor	n	Pre (s)	Post (s)	Delta (s)	n	Pre (s)	Post (s)	Delta (s)
B	12	85 ± 21	80 ± 18	-5 ± 12	12	87 ± 18	81 ± 18	-6 ± 11
1	12	98 ± 38	93 ± 27	-6 ± 28	12	108 ± 34	84 ± 20	-24 ± 16
2	10	100 ± 31	92 ± 28	-8 ± 18	10	85 ± 21	77 ± 16	-8 ± 13
2FS	13	86 ± 22	81 ± 15	-5 ± 13	13	84 ± 21	80 ± 14	-4 ± 12
3	2	99 ± 4	84 ± 1	-14 ± 4	2	90 ± 1	74 ± 1	-16 ± 1
4	2	82 ± 14	76 ± 9	-6 ± 5	2	74 ± 2	91 ± 3	16 ± 1
Total	**51**	**92 ± 28**	**86 ± 22**	**-6 ± 18**	**51**	**90 ± 25**	**81 ± 16**	**-10 ± 15**

Table C19 Rapid Visual Information Processing (RVIP) test scores by floor

Floor	N	Pre	Post	Delta
B	10	0.95 ± 0.06	0.96 ± 0.05	0.01 ± 0.02
1	12	0.95 ± 0.04	0.96 ± 0.04	0.00 ± 0.02
2	10	0.96 ± 0.03	0.96 ± 0.03	0.00 ± 0.02
2FS	10	0.97 ± 0.05	0.97 ± 0.05	0.00 ± 0.02
3	4	0.90 ± 0.09	0.94 ± 0.04	0.04 ± 0.06
4	6	0.98 ± 0.02	0.98 ± 0.03	0.00 ± 0.02
Total	**52**	**0.96 ± 0.05**	**0.96 ± 0.04**	**0.01 ± 0.03**

Table C20 Spatial Memory Span (SMS) test scores by floor

Floor	N	Pre	Post	Delta
B	10	7.8 ± 1.6	8.1 ± 1.2	0.3 ± 0.5
1	12	7.8 ± 1.1	7.9 ± 1.2	0.1 ± 1.1
2	12	7.9 ± 1.3	7.7 ± 1.7	-0.3 ± 1.4
2FS	10	7.8 ± 1.1	8.2 ± 1.9	0.4 ± 1.0
3	4	7.0 ± 0.8	7.8 ± 0.5	0.8 ± 1.0
4	6	8.5 ± 0.5	8.5 ± 0.8	0.0 ± 0.9
Total	**54**	**7.9 ± 1.2**	**8.0 ± 1.2**	**0.1 ± 1.0**

Table C21 Reaction Time (RTI) test scores by floor

Floor	N	Pre (s)	Post (s)	Delta (s)
B	10	368.2 ± 56.1	360.8 ± 52.1	-7.4 ± 29.3
1	12	354.7 ± 42.8	356.0 ± 45.3	1.3 ± 21.6
2	12	351.0 ± 68.6	360.3 ± 80.2	9.3 ± 23.2
2FS	10	372.4 ± 63.3	356.9 ± 40.1	-15.5 ± 29.6
3	4	365.3 ± 57.5	392.8 ± 40.9	27.5 ± 38.5
4	6	358.7 ± 62.8	376.3 ± 27.1	17.7 ± 40.5
Total	**54**	**360.9 ± 56.6**	**363.0 ± 52.6**	**2.1 ± 30.1**

APPENDIX D

Phase 2: Tabulated results by key events

The bottom one or two rows in each table indicate the number (n) of valid datasets for each event. Near-complete datasets were collected on all 40 serials (on 80 FF team firefighters and 80 SR team firefighters). A small number of datasets were lost for technical reasons diminishing the number reported. In addition, the number of datasets reported is reduced with subsequent activities, due either to the event not occurring at all (e.g. not all casualties were located; and fewer were rescued), or occurring but not being discernible from the video footage. Where data are reported by FF and SR team separately, there is a further reduction in data due to asynchronous activities taking place. For example, by the time the casualty is brought out of the compartment (event 6), the FF team may already have terminated the serial and gone off air. Thus the data presented in this appendix refer only to those teams of four firefighters that were still operating using SOPs when an event was completed.

Table D1 **Split times for the live fire scenario by floor (mean ± SD)**

Floor	n	Start (1)	Go Under Air (2)	Enter Compartment (3)	Attack Fire 1 (4)	Locate Casualty (5)	Exit Compartment with Casualty (6)	Go Off Air[45] (7)
B	9	0.0 + 0.0	6.0 ± 0.9	10.8 ± 1.1	12.8 ± 1.2	25.2 ± 4.2	29.6 ± 5.0	34.2 ± 5.2
1	9	0.0 + 0.0	5.7 ± 1.6	11.2 ± 2.0	12.5 ± 2.2	26.3 ± 3.2	28.9 ± 4.0	32.4 ± 4.1
2	8	0.0 + 0.0	7.8 ± 0.7	13.4 ± 2.4	14.7 ± 1.9	26.3 ± 4.8	29.4 ± 5.6	35.3 ± 5.2
2FS	9	0.0 + 0.0	8.1 ± 0.9	13.6 ± 1.8	15.4 ± 1.8	29.9 ± 5.0	32.1 ± 4.2	35.4 ± 3.0
3	2	0.0 + 0.0	7.2 ± 1.6	10.4 ± 1.9	13.2 ± 0	18.3 ± 0	20.6 ± 0	32.1 ± 3.0
4	3	0.0 + 0.0	3.9 ± 1.5	12.6 ± 1.4	13.9 ± 0.8	23.0 ± 1.8	26.6 ± 2.9	30.1 ± 1.8
Total	**40**	**0.0 + 0.0**	**6.7 ± 1.7**	**12.2 ± 2.1**	**13.8 ± 2.0**	**26.4 ± 4.6**	**29.4 ± 4.8**	**33.9 ± 4.4**
n	40	40	40	40	39	37	32	40

Table D2 **Core temperature by event and team (mean ± SD)**

Team	Start (1)	Go Under Air (2)	Enter Compartment (3)	Attack Fire 1 (4)	Locate Casualty (5)	Exit Compartment with Casualty (6)	Go Off Air (7)
FF	37.5 ± 0.4	37.5 ± 0.4	37.7 ± 0.4	37.7 ± 0.4	38.4 ± 0.6	38.7 ± 0.6	39.2 ± 0.6
SR	37.4 ± 0.4	37.5 ± 0.3	37.6 ± 0.3	37.7 ± 0.4	38.3 ± 0.5	38.4 ± 0.5	38.9 ± 0.6
FF n	76	76	76	74	61	47	23
SR n	79	79	79	77	67	54	48

45 There is a mismatch between off air times in table C4 and D1 because off air times for D1 were calculated from the team (either SR or FF) that worked for the longest duration during each serial. Although in most cases the SR team worked for longest, on some occasions the FF team did. Combining the longest times for each serial produces a value that is slightly larger than both the FF and SR total work durations cited in C4.

Table D3 **Mean rate of rise of core temperature by event and team (mean ± SD)**							
Team	**Start** (1)	**Go Under Air** (2)	**Enter Compartment** (3)	**Attack Fire 1** (4)	**Locate Casualty** (5)	**Exit Compartment with Casualty** (6)	**Go Off Air** (7)
FF	0.000 ± 0.000	0.012 ± 0.021	0.022 ± 0.023	0.026 ± 0.051	0.069 ± 0.036	0.104 ± 0.061	0.083 ± 0.063
SR	0.000 ± 0.000	0.016 ± 0.021	0.024 ± 0.017	0.033 ± 0.079	0.051 ± 0.028	0.070 ± 0.029	0.083 ± 0.036
FF n	76	76	76	74	59	47	20
SR n	79	79	79	77	65	54	37

Table D4 **Mean skin temperature by event and team (mean ± SD)**							
Team	**Start** (1)	**Go Under Air** (2)	**Enter Compartment** (3)	**Attack Fire 1** (4)	**Locate Casualty** (5)	**Exit Compartment with Casualty** (6)	**Go Off Air** (7)
FF	33.3 ± 0.8	33.2 ± 0.8	34.4 ± 1.5	35.7 ± 2.0	39.9 ± 1.2	39.9 ± 1.0	38.9 ± 1.7
SR	33.3 ± 0.8	33.0 ± 0.8	33.9 ± 1.2	35.0 ± 1.8	39.3 ± 1.4	39.2 ± 1.1	38.4 ± 1.4
FF n	71	71	71	69	57	43	26
SR n	70	70	70	69	63	50	48

Table D5 **Mean rate of rise of mean skin temperature by event and team (mean ± SD)**							
Team	**Start** (1)	**Go Under Air** (2)	**Enter Compartment** (3)	**Attack Fire 1** (4)	**Locate Casualty** (5)	**Exit Compartment with Casualty** (6)	**Go Off Air** (7)
FF	0.000 ± 0.000	-0.027 ± 0.058	0.259 ± 0.290	0.825 ± 0.535	0.392 ± 0.226	-0.009 ± 0.253	-0.393 ± 0.641
SR	0.000 ± 0.000	-0.037 ± 0.060	0.165 ± 0.173	0.622 ± 0.479	0.362 ± 0.161	0.012 ± 0.271	-0.331 ± 0.428
FF n	72	71	71	69	55	43	22
SR n	70	70	70	69	62	50	35

Table D6 **Mean total body temperature by event and team (mean ± SD)**							
Team	**Start** (1)	**Go Under Air** (2)	**Enter Compartment** (3)	**Attack Fire 1** (4)	**Locate Casualty** (5)	**Exit Compartment with Casualty** (6)	**Go Off Air** (7)
FF	36.1 ± 0.4	36.1 ± 0.5	36.6 ± 0.7	37.1 ± 0.8	39.0 ± 0.6	39.1 ± 0.5	39.2 ± 0.6
SR	36.0 ± 0.4	36.0 ± 0.4	36.4 ± 0.5	36.8 ± 0.7	38.6 ± 0.7	38.7 ± 0.5	38.7 ± 0.6
FF n	68	68	68	66	53	40	17
SR n	70	70	70	69	58	45	38

Table D7 **Mean rate of rise of total body temperature by event and team (mean ± SD)**

Team	Start (1)	Go Under Air (2)	Enter Compartment (3)	Attack Fire 1 (4)	Locate Casualty (5)	Exit Compartment with Casualty (6)	Go Off Air (7)
FF	0.000 ± 0.000	-0.002 ± 0.026	0.103 ± 0.098	0.293 ± 0.185	0.180 ± 0.074	0.062 ± 0.064	-0.101 ± 0.253
SR	0.000 ± 0.000	-0.002 ± 0.024	0.070 ± 0.060	0.223 ± 0.160	0.157 ± 0.052	0.058 ± 0.086	-0.050 ± 0.154
FF n	68	68	68	66	51	40	14
SR n	70	70	70	69	57	45	28

Table D8 **Mean air use by event and team (mean ± SD)**

Team	Start (1)	Go Under Air (2)	Enter Compartment (3)	Attack Fire 1 (4)	Locate Casualty (5)	Exit Compartment with Casualty (6)	Go Off Air (7)
FF	0 ± 0	0 ± 0	366 ± 152	460 ± 153	1022 ± 271	1112 ± 282	1271 ± 228
SR	0 ± 0	0 ± 0	343 ± 164	417 ± 163	960 ± 240	1133 ± 276	1318 ± 327
FF n	68	68	66	65	52	35	20
SR n	69	69	68	66	56	44	26

Where air use is litres of air breathed.

Table D9 **Mean rate of air use by event and team (mean ± SD)**

Team	Start (1)	Go Under Air (2)	Enter Compartment (3)	Attack Fire 1 (4)	Locate Casualty (5)	Exit Compartment with Casualty (6)	Go Off Air (7)
FF	0.0 ± 0.0	0.0 ± 0.0	69.4 ± 15.3	59.8 ± 25.3	45.7 ± 9.3	54.0 ± 12.4	57.3 ± 21.3
SR	0.0 ± 0.0	0.0 ± 0.0	65.6 ± 19.4	47.6 ± 26.1	44.0 ± 9.8	65.8 ± 19.4	52.4 ± 28.3
FF n	66	66	66	65	51	35	15
SR n	68	68	68	66	54	44	18

Where rate of air use is litres consumed per minute.

APPENDIX E

Performance on PES job simulations

INTRODUCTION AND APPROACH

Another ODPM project is underway under separate contract to Optimal Performance Ltd. (OPL) to develop, validate and implement nationally new Point of Entry Selection (PES) tests for recruitment to the UK Fire and Rescue Service. As part of the process to develop and validate physical selection tests, OPL has designed seven job simulations to reflect the diverse physical demands imposed on trained firefighters. Incumbent firefighters and expert panels have input into the process that has culminated in minimum standards of performance being proposed for trained firefighters on each of the simulations. The proposed standards are common for all trained firefighters regardless of age, gender or years of service. As a pull-through to the main thrust of this project to describe the physiological requirements of firefighters performing CCBRN operations, BDAG instructed that all participants undertook the job simulations to describe their 'fire fitness' and to see if they could meet the standards set by the expert panel. The tests are listed in Table E1 along with the proposed standards expected for all serving firefighters.

Table E1 **PES job simulations and proposed standards of performance**

Job Simulation	Proposed Standard
Ladder Lift	30 kg
PortoPower assembly & disassembly	240 s (4 min)
Ladder Climb	30 s
Domestic Search & Rescue	240 s (4 min)
Rural Fire (water relay) Simulation	750 s (12 min 30 s)
Ladder Extension	25 s
Enclosed Space	420 s (7 min)

Thirteen subjects performed six of the seven tasks. PortoPower was not carried out on this occasion as the subjects had completed this many times before and the data had been collected. Subject statistics are displayed in Table E2.

Table E2 **Participant statistics (means and standard deviations)**

Gender	Number (n)	Age (years)	Mass (kg)	Height (m)	VO_{2max} ($l.min^{-1}$)
male	10	33.2 ± 4.16	83.2 ± 10.6	1.79 ± 0.06	4.27 ± 0.38
female	4	26.5 ± 2.1	72.8 ± 9.2	1.73 ± 0.03	3.17 ± 0.50

RESULTS

Tables E3, E4 and E5 show the combined, female and male results, respectively[46]. In the combined dataset, pass rates ranged from 69-100%. Only in the rural simulation was there a significant failure rate with four firefighters (31%) failing. Among the males the failure rate was low with only one firefighter failing two of the tasks (the rural and domestic simulations). The failure rate for the female firefighters was considerably higher with one failing the ladder lift, extension and climb and three out of four failing the rural simulation.

Table E3 **Combined results of all 14 participants for the six output tests**

	Ladder lift (kg)	Ladder Extn (s)	Ladder climb (s)	Rural sim (min)	Domestic sim (min)	Enclosed space (min)
N	14	14	14	13	14	13
Mean	42.4	17.6	27.4	10.44	3.01	2.54
Sd	7.2	9.5	2.5	2.21	0.39	0.43
Min	27	9.8	24	7.28	2.16	2.04
Max	47	47.6	33	14.12	4.04	4.28
n failed	1	1	1	4	1	0
% failed	7%	7%	7%	31%	7%	0%

Table E4 **Female results for the six output tests**

	Ladder lift (kg)	Ladder Extn (s)	Ladder climb (s)	Rural sim (min)	Domestic sim (min)	Enclosed space (min)
N	4	4	4	4	4	4
Mean	34.0	27.4	29.8	12.56	3.13	3.12
Sd	6.8	13.7	2.5	1.38	0.28	1.04
Min	27	17.7	27	10.44	2.44	2.18
Max	43	47.6	33	14.12	3.51	4.28
n failed	1	1	1	3	0	0
% failed	25%	25%	25%	75%	0%	0%

Table E5 **Male results for the six output tests**

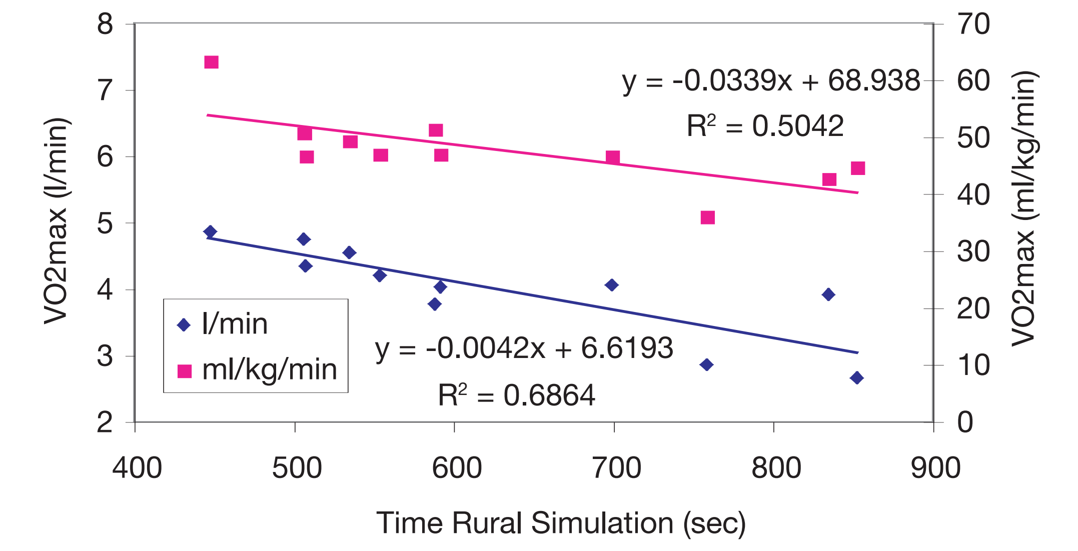
	Ladder lift (kg)	Ladder Extn (s)	Ladder climb (s)	Rural sim (min)	Domestic sim (min)	Enclosed space (min)
N	10	10	10	9	10	9
Mean	45.8	13.6	26.4	9.45	2.56	2.46
Sd	3.8	2.6	1.8	1.57	0.43	0.32
Min	35	9.8	24	7.28	2.16	2.04
Max	47	16.4	29	13.55	4.04	3.42
n failed	0	0	0	1	1	0
% failed	0%	0%	0%	11%	10%	0%

46 Only nine men took part in the rural simulation and enclosed space due to a possible injury sustained by one firefighter during the ladder lift.

Figure E1 shows the relationship between time to complete the rural simulation (x-axis) with VO_{2max} in $l.min^{-1}$ (y1-axis) and with VO_{2max} in $ml.kg^{-1}.min^{-1}$ (y2-axis). There is a positive correlation of 0.83 (R^2=0.69) between the rural test time and VO_{2max} in $l.min^{-1}$. This is substantially higher than the correlation of 0.71 (R^2=0.50) between the rural test time and VO_{2max} expressed in $ml.kg^{-1}.min^{-1}$. The stronger relationship between the rural simulation time and VO_{2max} in $l.min^{-1}$ is due to the nature of the task, which involved the firefighters carrying a number of items of equipment including two hoses weighing 11.5 kg and a light portable pump simulator weighing 33 kg over a 200 metre course. The larger firefighters tend to have the larger VO_{2max} in absolute units ($l.min^{-1}$) and are better at load carrying tasks due to their size. Conversely, a high VO_{2max} in $ml.kg^{-1}.min^{-1}$ (i.e. corrected for body mass) is a weaker predictor of how firefighters will perform in the rural test. A small, aerobically fit subject could have a high VO_{2max} when expressed in $ml.kg^{-1}.min^{-1}$ and thus perform well in a Multi Stage Fitness Test (MSFT), but due to their size will not perform well on a load carrying task. This supports the selection of job simulations as PES tests over simple fitness tests such as the MSFT.

Figure E1 can also be used to predict the VO_{2max} that is required to pass the rural simulation. A VO_{2max} of 3.47 $l.min^{-1}$ appears to be the minimum level of aerobic fitness required to pass the rural simulation. From this information we can calculate the VO_{2max} required in $ml.kg^{-1}.min^{-1}$, by dividing by body mass. Thus, a firefighter weighing 100 kg would need 34.7 $ml.kg^{-1}.min^{-1}$ to pass whereas a firefighter weighing 55 kg would need 63.1 $ml.kg^{-1}.min^{-1}$ to pass[47].

Figure E1 Relationship between maximal aerobic power and rural simulation performance



47 This assumes they have a similar body composition (i.e. lean mass to fat mass ratio).

CONCLUDING COMMENTS

In conclusion, the results from the PES job simulations show a high pass rate among the male firefighters, but a low pass rate among the female firefighters. One firefighter out of 14 failed the ladder lift, extension, climb and domestic simulation. The rural simulation was the only test with a poor pass rate with four of 13 subjects failing. Those who failed would appear to have insufficient aerobic power and/or body size.

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