PRE-MOVEMENT TIMES IN UCL HERITAGE BUILDINGS

A Dissertation submitted in part fulfilment of
BSc (Honours) Fire Risk Engineering

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Abstract:

This dissertation focuses on the pre-movement phase of evacuations in Heritage buildings used for office and educational purposes. A literature review was carried out of material relevant to the topic. Research in support of the dissertation involved carrying out monitored, unannounced egress drills as evaluation exercises at a number of premises. Analysis of fire safety management at the premises was carried out, and further training was provided to occupants of one of the sample buildings, in which a CFD simulation was shown to occupants. Following the further training, another monitored, unannounced egress drill was carried out to determine whether the training was effective in reducing pre-movement times.

Whilst there were difficulties in establishing direct correlation, a number of points were raised in support of using CFD simulations as training tools. In particular, occupants did engage with the training, and this was expressed in the form of positive feedback. Consequently, there are a number of points relevant in terms of using egress drills as an evaluation exercise, as well as using CFD simulations to enhance fire safety training provided to staff in single staircase Heritage (and other) buildings. The benefits identified from this approach to training are not limited, simply to evacuation behaviour, but also apply to understanding fire safety measures in buildings by building occupants, such that they are less likely to compromise these measures and may even be proactive in identifying deficiencies.

Contents

List of Tables

List of Figures

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Chapter 1 Introduction to the Dissertation

1.1 Background

University College London (UCL) operates numerous Heritage buildings located in and around the Bloomsbury area of London. A number of these Heritage dwelling-houses are now used for office and assembly purposes. English Heritage have previously reported that, on average, two historic buildings burn down each week **(Arnold, 2007)**.

Whilst such buildings are relatively small in size and occupancy, reliance on an un-lobbied single staircase for means of escape purposes, and on original building fabric, such as lath and plaster ceilings, for adequate fire-resistance to protect the means of escape and limit fire spread, does not meet current statutory guidance **(HM Government, 2006 incorporating 2007, 2010 and 2013 amendments)**. Risk of collapse in case of fire is also recognized **(Gustin, 2006)**.

The buildings take a similar form to those examined by Norris et al. **(Norris, et al., 1996)**. Upgrade of existing fabric can be problematic, and the objectives of Conservation Officers and fire safety requirements can frequently differ. As such, modern guidance "*introduced a fire engineering approach and makes particular reference to its application in buildings of special architectural or historic interest where compliance with the approved document might prove unduly restrictive*" **(Norris, et al., 1996)**.

The use of fire safety engineering in heritage buildings is recognized by the relevant enforcing authority, which specifically references BS 7974 as a potentially suitable approach to meeting the requirements of legislation **(London Fire Brigade, 2015)**.

In terms of life safety, UCL has provided automatic fire detection and alarm systems in accordance with the recommendations of BS 5839-1 for Category L2 systems **(British Standards Institution, 2017)**. Whilst this provides some additional protection to occupants by offering early warning in case of fire, which is a recognized enhanced approach **(British Standards Institution, 2017)**, the safety of occupants in case of fire remains dependent, to a large extent, on an adequate response to the alarm **(British Standards Institution, 2004)**.

This standard of detection, instigating a simultaneous alarm signal throughout the premises, can be considered to offer an A1 standard of alarm **(British Standards Institution, 2004)**. There is arguably already a good system for detecting and providing warning. The other component of the evacuation, which cannot be improved practicably due to existing paths and movement capabilities of occupants, is the travel time.

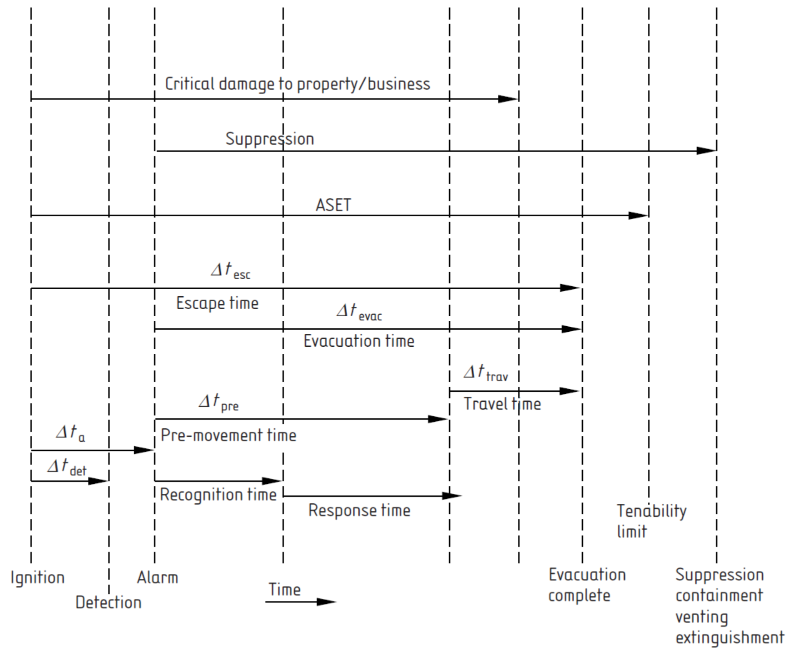

Figure 1. 1 Example of time line comparison between fire development and evacuation, adapted from BS 7974 Figure 4 **(British Standards Institution, 2001)**.

It is noted that determining the pre-movement time (incorporating both 'recognition' and 'response' times as shown in **Figure 1. 1**) can be difficult due to "*a lack of viable data and the fact that the range of possible behaviours are considerable*" **(Lawrence Webster Forrest, 2018)**.

However, this part of the evacuation timeline is arguably the determinant of life safety in case of fire within these historic premises. It is also the component of the evacuation that may be expected to improve through fire safety management functions, including training and appointment of floor wardens **(British Standards Institution, 2004)**.

1.2 Aim

The aim of this dissertation is:

- to determine pre-movement times in UCL Heritage, single staircase buildings
- to try to determine some features of occupant understanding that correlate to the pre-movement times recorded
- to determine whether improvements can be made to pre-movement times by showing occupants data obtained from a computational fluid dynamics (CFD) model in the form of face-to-face training.

1.3 Objectives

To meet the above aim, the following objectives will be addressed:

1. To carry out a literature review of the subject area.
2. To determine measurable pre-movement times by carrying out monitored evacuations.
3. To examine data relating to fire safety training, fire marshals and unwanted fire signals in the relevant Heritage buildings.
4. To determine occupant understanding of available safe egress time through use of questionnaires.
5. To prepare a CFD model of a typical UCL Heritage educational building.
6. To provide CFD model results to occupants as face-to-face training.
7. To evaluate any improvements in pre-movement times by carrying out further monitored evacuations.

1.4 Methodology

To meet the objectives, an extensive reading list of relevant literature has been developed. This includes literature relating to Heritage buildings, research papers relating to similar and relevant research carried out by others, relevant Standards and guidance relating to pre-movement times and performance-based models, as well as documented research relating to human behaviour in fire and during fire alarms. Also of relevance is literature relating to the effect of unwanted fire alarms or experience of fires in relation to pre-movement times. Full details of the literature review conducted are contained within Chapter 2 of this dissertation.

The literature review provides a context against which the research of this dissertation can be analyzed. It is also relevant to note the implementation of the General Data Protection Regulations (GDPR), which has had implications on the methodology employed for this dissertation. Specifically, research similar to aspects of the objectives of this dissertation involved use of video recording equipment **(Society of Fire Protection Engineers, 2016)**. The challenges involved in GDPR compliance using such a methodology necessitated use of an alternative approach.

The methodology adopted to date for collation of evacuation data on pre-movement times encompassed unannounced fire drills at eight Georgian townhouse buildings, being used for educational purposes. To enable accurate recording of data, a team was assembled, and provided with clear instructions as to how data was to be recorded.

Pre-movement times were recorded for each floor within each building, and an overall evacuation time was also recorded for the building. This involved recording of the pre-movement time of the first occupant and the pre-movement time of the last occupant on each floor. It is noted that there may be similarities in recording of this data between the pre-movement time and the "*presentation time*" **(British Standards Institution, 2004)**. Further discussion on these concepts is detailed in further chapters of this dissertation.

Other aspects of execution of the emergency plan were recorded, including whether floor wardens were present (and which floors were checked), whether there were issues with fire alarm sound pressure levels or fire exit routes, and whether there were any other factors deemed worthy of note by the observers involved in the egress drills.

All occupants willingly returned questionnaire following the drill (usually, a 30% response rate would be expected, so the 100% response provided a more comprehensive understanding than might otherwise be expected). The purpose of the questionnaire was to determine features of occupant understanding in relation to fire and available safe egress time within their building, as well as other factors, such as how long they had worked at the building and how relevant they had found fire safety training to be.

Other data held by UCL in relation to fire warden provision and fire detection and alarm systems at buildings examined within the study were also considered relevant and subsequently subject to review within the project methodology.

On completion of this phase of the programme, further work was undertaken in respect of preparing a computational fluid dynamics model of a fire within one of the buildings, 34 Tavistock Square. The results of this model were shown to a number of building occupants in a form of face-to-face training, and further questionnaires were distributed to assess the perceived effectiveness of this training.

The final exercise involved the carrying out of a further, unannounced egress drill, with recorded observations and pre-movement times, as well as a further short questionnaire. This was to assist in measuring any impact of the training.

1.5 Results and Analysis

Chapters 4 and 5 of this dissertation contain the respective Phase 1 and Phase 2 results of research conducted, and analysis of this data. There is a large amount of quantitative data involved with the recorded pre-movement times and certain aspects of the questionnaire data, as well as qualitative data. In terms of the questionnaire responses, a degree of correlative analysis has been conducted, exploring whether there are relevant correlations between aspects of occupant understanding and experience of fire, fire safety training, perception of unwanted fire alarms and drills, and how these relate to perception of risk.

Some consideration is given to the fire simulation results, although the primary purpose of the simulation was to form part of an illustrative training package to occupants, and, as such, analysis of the results of the model primarily relates to its effectiveness as a training tool.

1.6 Conclusions and Recommendations

The final chapter of this dissertation concludes the work and makes relevant recommendations. There are relevant conclusions and recommendations that relate to UCL as an organization operating these premises. However, noting that there are many similar Heritage buildings that have been adapted to comprise office and assembly accommodation where previously they served a domestic function, some conclusions and recommendations will be relevant to industry in general.

Chapter 2 Literature Review

Relevant literature has been collated for review, primarily involving academic and peer-reviewed work from trustworthy sources.

2.1 Human Behaviour

Of relevance to this research dissertation is work carried out by Sime et al. **(Sime, et al., 1992)** and Canter **(Canter, 1985)**.

Sime et al. **(Sime, et al., 1992)** carried out monitored evacuations of lecture theatres in higher education institutions, following the evacuations with questionnaires distributed to occupants. The difference between that research and the research to which this dissertation relates was the choice that occupants had over exits. The Heritage buildings to which this dissertation refers have single escape conditions.

Sime et al. **(Sime, et al., 1992)** also recognized the importance of authoritative instructions in the course of their research, although that this was recognized as only one part of the success of the evacuation. In terms of the UCL study, relevant policies and procedures (formulated in response to legislative requirements **(HM Government, 2006)**) require provision of fire marshals.

The Society of Fire Protection Engineers (SFPE) expand on the findings of Sime et al. and note that "*Sufficient, well-trained, and authoritative staff will shorten the ambiguous, information gathering phase of pre-evacuation time*" **(Society of Fire Protection**

Engineers, 2019, p. 17). The SFPE describe the Protective Action Decision-Making Process, which has key components in determining how people respond to emergency situations. Part of this relates clearly to 'risk perception' (which is discussed in further detail within this chapter), and this, in turn, has some basis in "*their previous knowledge and experience in fire events…, the types of actions in which they were engaged at the time…, and relationships with others in the building*" **(Society of Fire Protection Engineers, 2019, p. 22)**.

These are all key points to the UCL environment. Specifically, the 'well-trained' aspect, again, is a requirement of legislation **(HM Government, 2006)**. 'Authoritative' implies a relationship with others in the building, namely that occupants trust the information and instructions that they are receiving from fire marshals in respect of the actions that they are to take. Based on office environments operating a hierarchical structure, the role of the fire marshal may actually be effectively overruled in an alarm situation. This could occur in instances where a person in a position of greater authority within that structure, who is engaged in an activity of perceived importance to the work being undertaken, does not accept the need to take protective action **(Society of Fire Protection Engineers, 2019, p. 39)**.

This is perhaps extremely difficult to quantify, as there are other factors, such as previous experience of fires, the nature of the 'cue' and actions of other occupants, which will affect human behaviour in such situations. That said, occupant experience can, at least to some extent, include experience that they have attained in the course of effective training.

The Protective Action Decision-Making Process described by the SFPE builds on previous work completed by Withey et al. as is noted by Gwynne et al. **(Gwynne, et al., 2019)**.

2.2 Pre-Movement Time

In many of the sources, there is a recognition that a variety of individual factors contribute to the intial delay in initiating movement to a place of safety, referred to as the pre-movement (or pre-evacuation, or PTAT) phase. Actions undertaken within the pre-movement phase frequently include "*investigate, seek information, prepare to evacuate, alert others or report incident, assist others, seek refuge, and wait*" **(Society of Fire Protection Engineers, 2016, p. 2040)**.

Sime et al. **(Sime, et al., 1992)** found that pre-movement time accounted for two-thirds of the time between alarm and escape where a poor alarm system indicated the need to move. All alarm systems in the UCL Heritage buildings involved in this study operate conventional bell or two-tone sounder alarm systems, which, it is noted, are sufficient "*in buildings where occupants are adequately trained to respond effectively to a fire alarm and where trained fire wardens are available to marshal the evacuation*" **(British Standards Institution, 2013, p. 5)**.

Whilst it could be argued that fire safety management levels would be increased through provision of a voice alarm system, leading to reduced pre-movement times **(British Standards Institution, 2004, p. 26)**, it could be seen that any associated impact in terms of increased pre-movement times may be mitigated through staff training and warden provision. This is directly relevant in the case of the UCL study.

Fahy and Proulx **(Fahy & Proulx, 1997)** carried out a study on the 1993 World Trade Centre attack, with relevant data collated in terms of occupant behaviour during the event. Of relevance to the UCL study are the questionnaires provided to fire wardens following the event. Key points include perception of seriousness, experience of prior alarms and previous training. These are all aspects which can be considered to impact on pre-movement times. Other aspects of their survey are arguably not as relevant, as the WTC attacks represented a genuine incident, and the UCL exercise will take the form of (non-emergency) egress drills.

Bishop et al. **(Bishop, et al., 2018)** conclude their study by noting that a pre-movement time for wardens is a critical stage in the overall pre-movement time, instigating evacuation of other occupants. This pre-warning time, where staff respond either due to procedure or behaviourally, and then act as a cue, was also noted by Gwynne et al. **(Gwynne, et al., 2012)**.

Rogsch et al. **(Rogsch, et al., 2014)** note that, at a certain point in their studies, a longer pre-movement time had a disproportionate impact on the overall building evacuation time, prior to which there was little impact. This was primarily due to occupant numbers and therefore density, which is considered unlikely to be a significant factor in the case of the UCL study, due to lower occupant numbers anticipated to be present.

Fahy and Proulx **(Proulx & Fahy, 2001)** state that the type of cue received influences the pre-movement time, although in one study, 90% of occupants left their room within 90 seconds, but delays lasted as long as five minutes. Hamilton et al. **(Hamilton, et al., 2018)** note that the role of the teacher is critical in reducing pre-movement times in schools. Guide E also recognizes the criticality of the type of cue in generating a response **(CIBSE, 2010, p. 7.9)**.

Brennan **(Brennan, 1997)** carried out studies of real fires in high-rise buildings, noting that office occupants move as a single unit, with quick responses influenced by training, ease of communication and unity in response. Pre-movement times for the office in this study ranged between one to six minutes. There is a difference between Brennan's study this dissertation research relates, is that Brennan examined real fires, which may have provided additional cues.

Lawrence Webster Forrest **(Lawrence Webster Forrest, 2018)** suggest that pre-movement times of less than 20 seconds could be expected in offices. This figure is seconded in Guide E **(CIBSE, 2010)**.

Vistnes et al. **(Vistnes, et al., 2005)** describe a range of delay actions carried out by occupants within the pre-movement phase. These vary depending on occupancy, but, relevant to this study, include notifying others, shutting down of equipment, inaction, collection of belongings, etc. It may be reasonable to expect that the UCL drills would incorporate some of these delay actions.

Gwynne et al. **(Gwynne, et al., 2011)** go further by arguing that delay actions can be procedural and/or cognitive. This may include "*the time between the fire being noted by staff and the eventual raising of a public alarm*" **(Gwynne, et al., 2011, p. 245)**. It is also noted that:

"*An individual will process this information in accordance with their abilities, attributes, experience, expertise, the situation, the surrounding environment…and their objectives to* *formulate a response given the time available…Training can help make this process more efficient and even make it more likely to arrive at an appropriate outcome; however, it does not alter or remove the process entirely…it will still exist and delay the final action*" **(Gwynne, et al., 2011, p. 246)**.

Thus, the argument of Gwynne et al. may suggest that, if pre-movement times are relatively short in the initial round of UCL drills, further training may have limited impact when measured in the course of the second round of drills.

2.3 Risk Perception (RP)

Kinateder et al. **(Kinateder, et al., 2015)** write extensively about the concept of risk perception in the context of changing from pre-evacuation to evacuation behaviour. Risk perception is considered to be a psychological, subjective risk assessment process, carried out by individuals in evacuation scenarios. Critically, Kinateder notes that:

"'risk' has various meanings in everyday usage, such as hazard…, consequence…,probability…,or potential adversity or threat…This highlights a critical aspect in many questionnaire studies on evacuation and RP in which participants were simply asked, 'how much risk they felt'…It is possible that participants had different concepts about the term 'risk' when they rated their perceived risk" **(Kinateder, et al., 2015, p. 7)**.

This highlights a potential weakness in the questionnaire provided to occupants following the UCL evacuation exercises, due to it using this ambiguous and ill-defined term 'risk'. In this connection, the concept of risk is sometimes regarded as probability of an undesirable event occurring. For many years, the definition of 'fire risk' in BS 4422 was the "*likelihood of a fire occurring*" **(British Standards Institution, 1987, p. 2)**; even today, some fire safety practitioners use the term 'risk' in this manner.

However, in the absence of any consideration of 'consequences', this concept of risk is unhelpful in management of fire safety. The modern concept of 'fire risk' (e.g. as now given in BS 4422 **(British Standards Institution, 2005, p. 34)**) is a combination of the probability of fire and the consequences (severity) of fire occurring. Nevertheless, the ambiguity of the term ‘risk’ remains prevalent in the fire safety profession, for example, the guides produced by the then DCLG on compliance with the Fire Safety Order defines fire risk as “*the chance of harm occurring*” **(HM Government, 2007, p. 9)**; however, in contrast, the Scottish Government guides on compliance with the Fire (Scotland) Act use the more appropriate and modern definition of ‘fire risk’ **(Scottish Government, 2017)**.

Kinateder et al. **(Kinateder, et al., 2015)** also note the role of previous fire experience, safety climate, safety culture, safety training and credibility and trust of fire cues and authorities in forming risk perception and evacuation decision-making.

Sime et al. **(Sime, et al., 1992)** found that most people interviewed assumed that an alarm indicated a drill and not a real emergency.

Todd notes that:

“*most people’s experience of fire is almost entirely limited to controlled, ‘beneficial’ fires…It is, therefore, little wonder that they are ill prepared for an uncontrolled fire within a building; their expectation is that this fire will behave in a similar manner to the only other fires that they have experienced*” **(Todd, 2008, p. 285)**.

Therefore, it is suggested that the lack of experience of uncontrolled fire relates directly to the response of individuals. This view is accepted by a number of authors whose work has been reviewed within the literature review, including the SFPE **(Society of Fire Protection Engineers, 2019)**. The implication is that effective training can, in part at least, provide better understanding of uncontrolled fire to building occupants, and the next section of the literature review explores training in further detail, as this is directly related to the UCL study.

2.4 Training

Canter notes that "*staff need effective training in what to do in a fire to reduce delay in evacuation*" **(Canter, 1985, p. 21)**. This is a common theme throughout the relevant literature and indeed correlates directly with requirements prescribed by the Regulatory Reform (Fire Safety) Order 2005 **(HM Government, 2006)**.

Sinclair et al. describe training as:

"*the systematic acquisition of knowledge, skills, and attitudes with the goal of developing competencies necessary for effective performance in work environments…Emergency management training is intended to develop people's capacity to respond to the new and atypical demands presented by a disaster, as well as developing norms of carrying out a job or exercising a specific skill. Training should incorporate key officials and must focus on the procedures that will take place…*" **(Sinclair, et al., 2012, p. 509)**.

Sinclair et al. therefore inherently recognize the need for training to be relevant to the demands of a specific scenario. This view is expanded by Gwynne et al., who view egress drills as a type of model with a training purpose at the heart of the exercise (in conjunction with an effort to assess performance) **(Gwynne, et al., 2017)**.

Bishop et al. recognize the importance of training and situation awareness through accurate information in creating correct and adequate behavioural responses to incidents. This research also used fire drills to assess the adequacy of training, which is relevant to this study. Critical features of this training and awareness related to recognizing the fire alarm as a trustworthy cue and the need for fire marshals to take leadership in an incident to circumvent the information seeking process. A three-part training programme was devised, which is relevant to the fundamental nature of this study dissertation study at UCL **(Bishop, et al., 2018)**.

Recent research shows that virtual reality and serious games can be effective tools in providing effective training, arguably with greater success than traditional training and drills, by improving engagement with the learning environment **(Feng, et al., 2018)**. Cha et al. **(Cha, et al., 2010)** note that virtual reality incorporating volume rendered fire models are the most simple for non-specialists to interpret, and there is implied criticism of using FDS CFD models. However, Xu et al. **(Xu, et al., 2014)** note that the accuracy of the FDS model, being to within 5-20% margin of error of experimental values, is a safe, low-cost means of providing simulated fire behavior model data as part of an immersive training package. In the case of the UCL study, FDS was used for CFD modelling. The CFD model is therefore used to generate representative fire conditions to make training material presented participants more effective.

Indeed, even more historic research by Sime et al. **(Sime, et al., 1992)** recognized that simulation was "*valid as a training aid as well as a research tool*". Canter **(Canter, 1985)** notes the potential of computer models to simulate some aspect of the fire. Developments in technology and, in particular, CFD, whilst still having the issues associated with establishing validity, do allow various aspects of the fire to be modelled with reasonable accuracy.

2.5 Drills

Gwynne et al. **(Gwynne, et al., 2017)** describes egress drills as a form of model, with inherent simplifications and limitations as with all models, although still being very useful for real-world approximation. They note:

"*Egress drills have provided a convenient field laboratory for evacuation researchers…above and beyond their original purpose of enhancing life safety. This research involved the observation of routine and modified drills performed to satisfy specific research objectives …collecting data on specific elements of evacuee performance…eg, pre-evacuation times…*" **(Gwynne, et al., 2017)**.

This is relevant to the UCL study, as the method of assessing and recording pre-evacuation times will involve modified egress drills. Also of relevance are the notes on observers needing to exercise care in not influencing the outcome of the drill in the course of the observation process, requiring suitable resource and planning to execute correctly for the purposes of research. It is also noted that the drill produces a single and limited result, and may not be an indicator of real-world performance. It may also not provide indication of the underlying reasons for particular performance. **(Gwynne, et al., 2017)**. This will be relevant to consider in the course of analyzing the data output from the UCL drills.

Similar studies have included those conducted by University of Greenwich, at which eight researchers were appointed to monitor various aspects of evacuee pre-movement time at hospital and research facilities **(Fire Safety Engineering Group, University of Greenwich, 2018)**.

Proulx and Fahy **(Proulx & Fahy, 1997)** carried out fire drills at buildings to examine pre-evacuation times. This research involved buildings with a similar number of storeys to those at UCL, although significantly more occupants. Drills were carried out on an unannounced basis. Pre-movement times on average were between 0:36 and 1:03. and critical factors were considered to be fire alarm audibility, staff training and presence of fire marshals. This is relevant to the UCL study, as fire alarm sound pressure levels, staff training and checks by fire marshals are to be considered in the study.

2.6 Fire Detection and Alarm Systems

Within the literature, there is common acceptance that fire alarm signals have a direct bearing on the response of occupants. Indeed, this is recognized within the material on 'cues' described by the SFPE **(Society of Fire Protection Engineers, 2019)**.

CIBSE note "*traditional fire alarm sounders cannot always be relied upon to prompt people to move immediately to safety*" **(CIBSE, 2010, p. 7.8)**.

Purser notes that

"*voice alarms provided more reliable and shorter PTAT response times than sounders, especially in "awake and unfamiliar" behavioural scenarios. Occupants tended to listen to the full voice message and sometimes the first repeat before starting to travel. The short voice message produced a shorter but less reliable PTAT response. Group interactions had a major effect on response behaviours and times*" **(Purser, 2010)**.

Work carried out by Canter **(Canter, 1985)** historically recognized the potential for reduction in response times afforded by "*alarms which give good information rather than loud signals*".

Canter notes

"*emphasis on loud warning bells is based on the assumption that people will respond immediately to these without further information, it does not take account of an* *'interpretation' stage in the behavioural sequence. Such bells may, therefore, actually encourage people to investigate their cause rather than leave the building*" **(Canter, 1985, p. 22)**.

This is relevant, as it may be expected that investigation will take place in the early stages of the egress drills. Again, research carried out since that of Canter has suggested that this view is correct, and the investigation and information gathering features of pre-movement are now well accepted **(Society of Fire Protection Engineers, 2019)**.

Whilst not directly relevant, the sound pressure level and frequency of fire alarm signals was also found to be important in research carried out in sleeping accommodation, by Bruck and Thomas **(Thomas & Bruck, 2008)**. Critical factors in the studies of Proulx and Fahy were also considered to be fire alarm audibility, staff training and presence of fire marshals. This is relevant to the UCL study, as fire alarm sound pressure levels, staff training and checks by fire marshals are to be considered in the study **(Proulx & Fahy, 1997)**.

2.7 Unwanted Fire Signals

Rutimann **(Rutimann, 2014)** finds that approximately 95% of automatically transmitted alarm activations in Europe, with the exception of Switzerland, are false. Two main issues are found to impact on false alarm rates, being regular maintenance of existing systems and modernization and upgrade of older technologies. This is relevant to the UCL study, as many of the systems in place within the Georgian townhouses are older systems.

As Todd notes

"*Occupants' response to alarm signals may be determined in part by the rate at which false alarms occur. Research has shown that, in this respect, response is governed less by the rate of false alarms (e.g. number per annum) than the time since the last false alarm occurred*" **(Todd, 2008, p. 284)**.

This is relevant to this dissertation, as data relating to numbers of false alarms are available. If the findings in relation to UCL fire alarm statistics were that false alarms occurred frequently, this would be expected to have a delaying effect on occupant evacuation, increasing pre-movement times.

BS 5839-1 also describes an '*acceptable*' rate of false alarms, based on various factors, including number of detectors. Notably, BS 5839-1 also describes a rate of false alarms which is not acceptable. As, generally, the UCL Heritage buildings to which this research relates are small, and in most cases will have under 40 detectors, "*two false alarms per annum is to be regarded as unacceptable*" **(British Standards Institution, 2017, p. 95)**.

2.8 Key Findings from Literature Review

Some key points from the review, in relation to this dissertation project, are as follows:

- Various factors may influence pre-movement times.
- Risk perception, management and training are all areas relevant to this dissertation.
- There is a need for researchers to avoid influencing the results of egress drills carried out for research purposes.
- Questionnaire responses can be considered in the context of earlier research.
- Questionnaires should be kept short to make them practicable.
- Training and CFD models can be useful, particularly if they are as immersive, relevant and realistic as possible.
- Unwanted fire signals may impact on pre-movement times and are a key topic within the research.
- The age, type and maintenance quality of fire detection and alarm systems may directly relate to the number of unwanted fire signals.

Chapter 3 Methodology

3.1 Rationale

The methodology selected to complete the initial drills involved selection of 10 single-staircase Georgian townhouse buildings, with occupancy as educational premises. The data collection methodology is based on the work reviewed in Chapter 2.

These were selected on the basis of being of similar size and occupancy, in similar geographical location, having similar fire detection and alarm systems, being subject to the same fire safety management policy and procedures, and having similar configurations and layouts. Details of the premises are contained in **Table 3. 1**. From an ethical perspective, it is worth noting that fire drills are required by legislation **(HM Government, 2006)** and therefore the exercise was used for research purposes and legislative requirements, with which there would have been compliance in any case.

Showing building occupants the CFD simulation as face-to-face training also has some inherent ethical implications. However, as with drills, training is required by legislation. Critically, the requirement for training to be provided at the time of first employment is supplemented by the requirement for training to be repeated 'periodically'. Training is required on "*the appropriate precautions and actions to be taken…to safeguard…relevant persons on the premises*" and "*be provided in a manner appropriate to the risk identified by the risk assessment*" **(HM Government, 2006, p. 15)**.

It can be seen that an appropriate action to safeguard relevant persons would be to respond quickly to an alarm. Additionally, in terms of the scenario modelled for the CFD simulation, the importance of not interfering with fire precautions by wedging open fire doors could be seen as training on taking appropriate precautions. Both of these aspects are inherently important to the risk assessment that allows use of the single stair building as office accommodation and therefore ethically the training can be considered to be reasonable in the circumstances.

Repeating the egress drill on a further occasion, some six months later, can also be considered to be reasonable, as recognized guidance to the Fire Safety Order states that "*there should be a fire drill at least once a year and preferably one a term/semester*" **(HM Government, 2007, p. 112)**.

Property	**Date**	**Listed Status**	**No. of floors**	**Gross Area (m^2)**
33 Bedford Place	1815	Grade II	LG, G + 3	568.4
11 Woburn Square	1829	Grade II	LG, G + 3	359.1
15 Woburn Square	1829	Grade II	LG, G + 3	361.9

2 Taviton Street	1824	Grade II	LG, G + 4	497.2
35 Tavistock Square	1825	Grade II*	LG, G + 4	579.1
34 Tavistock Square	1826	Grade II*	LG, G + 4	542.8
22 Gordon Square	1850	Grade II	LG, G + 4	502.5
19 Gordon Square	1850	Grade II	LG, G + 4	469.5
10 Woburn Square	1829	Grade II	LG, G + 3	335.4
18 Woburn Square	1829	Grade II	LG, G + 3	353.4

Table 3. 1 Details of buildings used for egress drills.

The research work is fundamentally split into two phases, namely initial egress drills, questionnaires and fire safety management review (Phase 1), followed by the CFD model preparation, training of staff, second egress drill and questionnaires (Phase 2).

Phase 1

3.2 Initial Egress Drills

A team of eight observers was assembled, comprising staff who perform the following roles at UCL:

1. UCL Fire Safety Officer
2. UCL Fire Safety Officer
3. UCL Safety Adviser
4. UCL Safety Adviser
5. UCL Area Facilities Manager
6. UCL Building Surveyor
7. UCL Business Continuity Adviser
8. UCL Administrator

Prior to engaging in the evacuation exercise, all team members were provided with a briefing on the exercise, with both written and verbal instructions. Of primary importance was the need for the observers to not adversely affect the outcome of the research by becoming involved in the pre-evacuation decisions of occupants. As such, clear instructions were provided on information to be given to occupants in the case of occupants seeking such information or instructions from members of the research team. These instructions are contained as **Appendix A** to this dissertation.

Data sheets, returned copies of which are contained in **Appendix C**, were provided to each observer, to record specific features of the evacuation. Each observer took up position within the staircase. It is worth noting that doors between occupied rooms and the staircase are all solid panel doors, with no vision panels. The observers could therefore not be seen by the occupants of the rooms. The time at which the first occupant opened the door was to be recorded. It is noted that this time could actually represent part of an information gathering exercise by the occupant, rather than presentation to commence evacuation. In this regard, the observer was instructed not to provide instructions to occupants, and merely to observe their behaviour.

If the occupant(s) sought information but did not evacuate, following opening the door to their office, the observer was to note this down. In general, if the arrival of the occupant at the door signalled the commencement of their evacuation, this was considered to be the 'presentation time' (which would be likely to be extremely close to the pre-movement time, given the very short travel distances from any point within the room to the staircase enclosure).

At the time of the research exercise, a suspected gas leak occurred, which affected buildings in Woburn Square. London Fire Brigade evacuated a number of UCL buildings, including those on Woburn Square, after completion of the egress drills at 11 and 15 Woburn Square, but prior to 10 and 18 Woburn Square having been undertaken. As it was considered that this would have a potentially undesired impact on any research findings that could be obtained, these two buildings were removed from the programme.

3.3 Questionnaires Following Initial Egress Drills

Following each egress drill, all occupants were asked if they would be willing to complete a questionnaire). The response to this request was universally positive and 101 questionnaires were completed and returned. Questions aimed to determine the following:

1. Did occupants trust the fire alarm.
2. How long occupants believed they had to escape in fire.
3. How frequently they considered that the fire alarm activated.
4. How relevant they thought existing UCL training was.
5. Did they have experience of fire.
6. How long they had worked in the premises.
7. How they would rate the fire risk, from high to low.
8. Were they interested in further training.

Space was provided for any additional comments. Completed questionnaire returns are contained in **Appendix E**.

Two particular issues are notable with the questionnaire which potentially undermine some of its usefulness. These are the definitions of ‘fire risk’ and ‘fire drills’ contained in questions seven and three respectively.

The questionnaires were prepared, distributed and completed in advance without perhaps clearly defining these. As such, there exists the potential for respondents to have been providing answers in a different manner to one another. Care is also required in analysis of the statistics of small numbers **(Dean & Dixon, 1951)**.

Property	**No of PMT Sheets**	**No of Surveys Returned**
33 Bedford place	Eight	12
11 Woburn Square	Eight	Four
15 Woburn Square	Eight	Six
2 Taviton Street	Seven	19
35 Tavistock Square	Seven	10
34 Tavistock Square	Seven	12
22 Gordon Square	Seven	10
19 Gordon Square	Seven	28
Total		**101**

Table 3. 2 Data collected from initial egress drills.

Data collected following the drills, from both observers and occupant questionnaires, can be summarized as in **Table 3. 2**.

3.4 Fire Safety Management and Unwanted Fire Signal Analysis

It is also considered relevant to attempt to derive relevant fire safety management features that may impact on the results. In particular, the following aspects are considered to be relevant:

- Appointment and presence of fire marshals
- Fire safety training of staff
- Fire safety management culture
- Numbers of unwanted fire signals in the building

Data is recorded and available on UCL systems. In particular, UCL operates an electronic safety management tool, riskNET. UCL's Organization and Arrangements for Safety **(University College London, 2018)** require that each department records the names and locations of appointed persons (including fire evacuation marshals) on the Responsible Persons Register module. This information was found to be reasonably complete on the Register.

UCL requires that all staff completed *Basic Fire Safety* e-learning training on the Moodle platform. There is also *Fire Evacuation Marshal* e-learning. Each training package is to be completed in the buildings covered by the research in periods not exceeding three years. Data relating to completion of this training is maintained electronically on Moodle. However, on review of these data, it was not deemed reliable enough to analyze, as an issue with the recording system meant that much of the information was incomplete or missing entirely.

A review of fire risk assessments held on the UCL riskNET database revealed that wedging of fire doors was universally recorded in these buildings. It was considered therefore that no further analysis of this data was particularly relevant, although this practice was worth incorporating in the second phase of research work in terms of preparation of the CFD model.

All UCL fire detection and alarm systems are automatically linked to a central security control room. On activation of any fire alarm system, an electronic record is immediately made on riskNET. Details of all fire detection and alarm system hardware are maintained by UCL Estates in the form of asset registers. All unwanted fire signals are therefore recorded and investigated. There was, therefore, good data available in this regard.

Whilst information relating to general staff training was not considered to be reliable, other available data provides a useful resource for determining fire safety management levels and factors relating to the fire alarm systems present in the buildings to which the research relates.

Phase 2

3.5 Preparation of CFD Model

A CFD model was prepared, using Fire Dynamics Simulator (FDS) via the Pyrosim software. The purpose of the model was primarily to illustrate the time to critical events to non-specialists. As such, the visual smoke models, with slice files to represent temperature and visibility criteria, were of primary interest. 34 Tavistock Square was selected as the building for the focus of the second phase of research. This building was selected due to having presentation times between 12 seconds and 148 seconds, with a range of mean average presentation time (between first and last presentation times) ranging from 34 seconds to 89.5 seconds.

Whilst it is noted that 19 Gordon Street had a far longer pre-movement time on ground floor, this related to a student common room in which no staff provided evacuation instructions. It was not considered practicable to provide the training to students. Additionally, 34 Tavistock Square appeared to have good numbers of appointed floor wardens, who did check most areas during the initial drill. As such, 34 Tavistock Square was considered to offer a reasonable case study for the second phase.

The model created was an approximation of the premises at 34 Tavistock Square. Dimensions were measured on site using a LASER measure, as well as from CAD record drawings held by the UCL Estates department.

The mesh was created at 0.1m x 0.1m x 0.1m. The fire was based on a 't^2 ramp up time' of 150 seconds, with a heat release rate per unit area of 2500 kW / m^2, with yields as per polyurethane foam. The fire was placed in a kitchen located between ground and first floors. For the purposes of the model, the kitchen door was modelled to be open, allowing fire products to enter the stair enclosure. Obstructions were placed in rooms within the model for the purposes of computational efficiency. The fire surface accounted for one square metre, with a vent above the affected surface to allow combustion. The model was run for 300 seconds and slice files were input as per **Figure 3. 1** and visually appeared as per **Figure 3. 2**. Full details of the FDS model are contained within **Appendix F**.

Whilst the construction of the model has some limitations in terms of accuracy, this was considered to be reasonable on account of its purpose primarily as a training tool and not as a scientific analysis of fire and smoke spread. The 'worst-case-scenario' created adheres to the "what if" principles that are embodied within fire safety engineering **(British Standards Institution, 2002)**.

Animated Planar Slices

	XYZ Plane	Plane Value	Gas Phase Quantity	Use Vector?	Cell Centered?
1	X	7.0 m	Temperature	YES	YES
2	X	7.0 m	Visibility	YES	YES
3	X	6.0 m	Temperature	YES	YES
4	X	6.0 m	Visibility	YES	YES
5	Z	16.5 m	Temperature	YES	YES
6	Z	16.2 m	Visibility	YES	YES
7	Z	13.5 m	Temperature	YES	YES
8	Z	13.0 m	Visibility	YES	YES
9	Z	9.6 m	Temperature	YES	YES
10	Z	9.1 m	Visibility	YES	YES
11	Z	5.8 m	Temperature	YES	YES
12	Z	5.3 m	Visibility	YES	YES
*					

Figure 3. 1 Slice files in FDS model.

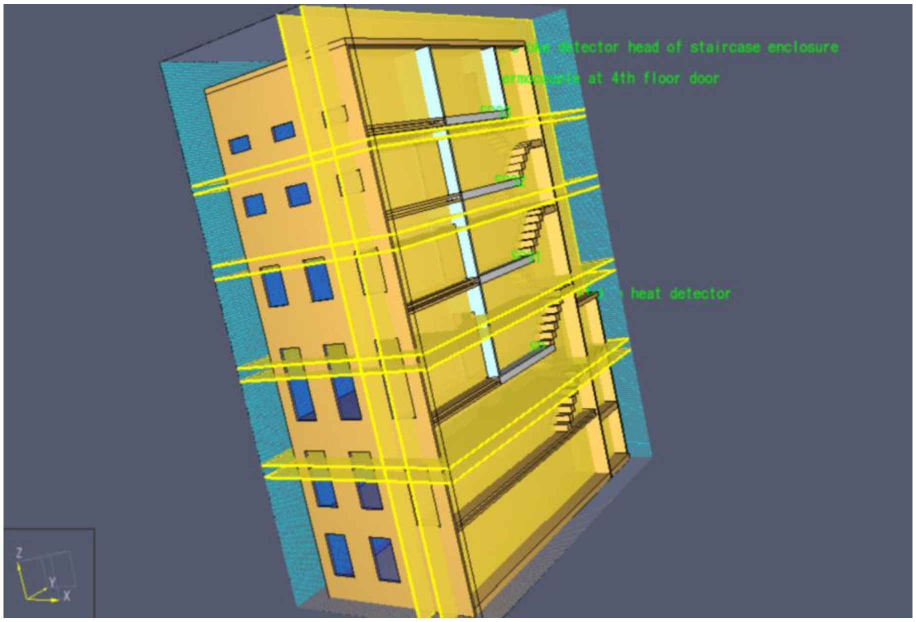

Figure 3. 2 Slice files displayed in Pyrosim.

3.6 Delivery of CFD Simulation as Part of Training Package

3.6.1 Simulation

A basic accompanying training package was developed to explain key tenability criteria to occupants. For the purposes of the simulation, a Windows Media Player video file was created, using the graphics associated with 3D smoke available on Pyrosim. The focus of the video was the staircase enclosure, viewed from the perspective indicated in **Figure 3. 3**.

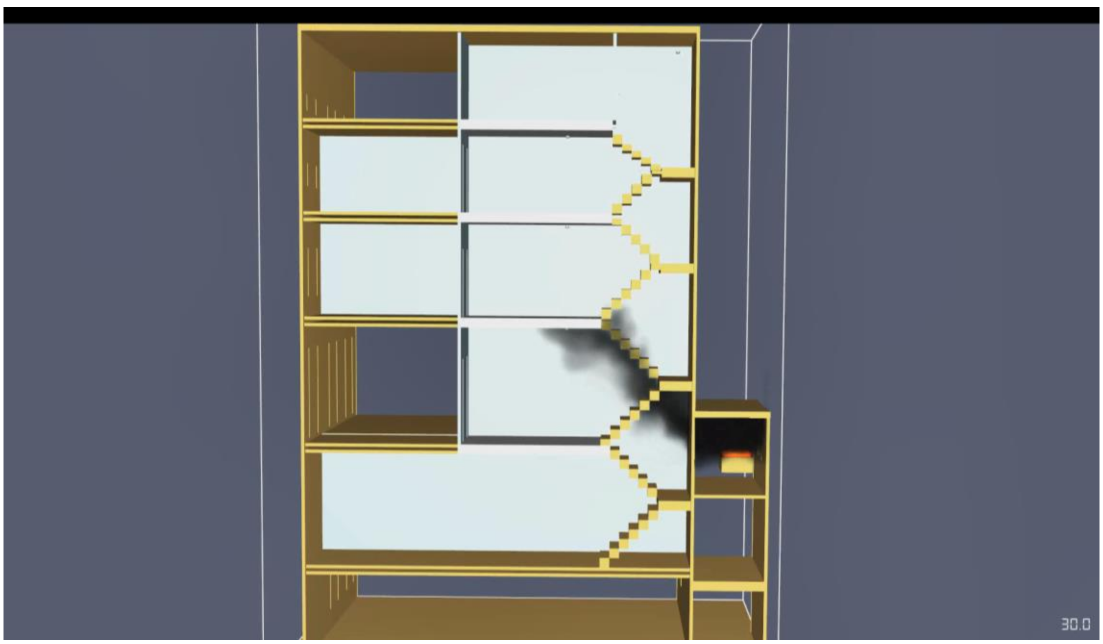

Figure 3. 3 Video simulation file showing 3D smoke at 30 seconds**.**

Delivery of the training was interactive; delegates were shown the CFD model running in real time. The training was supplemented with a handout, detailing conditions shown in slice files at different points in time. The attention of the delegates was drawn to the handout at critical points during the simulation. The training handout returns (containing the questionnaire responses) are contained as **Appendix G**.

A number of sessions were held and, in total, 13 occupants participated. It was not possible to show all occupants the simulation due to time constraints and the transient nature of the occupancy within the building. However, it was possible to ensure that at least one occupant per floor undertook the training, and this in itself presents some useful fundamental points that can be examined in the course of the second egress drill. Indeed, there were 12 occupants present at the time of the first egress drill, so the number of persons to whom the training was delivered was considered reasonable.

Details of those who completed the training are contained in **Table 3. 3**. Floor plans for 34 Tavistock Square are contained as **Appendix J**.

Floor	Room no.	No. of occupants shown simulation
4	401	One
4	403	Two
3	301	Two
2	201	One
1	102	Two
Ground	G01	Three
Lower ground	B01	Two

Table 3. 3 Locations of occupants shown simulation.

3.6.2 Questionnaire Before Simulation

Prior to watching the simulation, delegates filled out a questionnaire comprising five questions to determine:

1. Where their general work area was.
2. How often they were based on or visit upper floors.
3. Whether they believed that heat, visibility or toxic products would impair escape first.
4. How long they thought each floor would take to become unpassable.
5. How long they believed it would take for the fire alarm to activate.

Completed questionnaires are contained within **Appendix G**.

The purpose of the questionnaire was designed to identify whether occupant expectations of conditions that the simulation may show were accurate, whether this was changed following the simulation, and whether answers related to risk perception developed from either working on upper floors or visiting upper floors on a routine basis.

Part of the ethos of presenting the first part of the questionnaire was to generate thought and discussion as part of the interactive and immersive training programme.

3.6.3 Questionnaire After Simulation

Following completion of the 300 second simulation and briefing, delegates filled out a second questionnaire, answering an additional five questions to determine:

1. Whether the simulation changed their view on fire and smoke development.
2. Whether they would be less likely to wedge fire doors in the open position.
3. Whether they would be more likely to remove wedges, where they found them.
4. Whether they would evacuate more quickly on activation of the fire alarm, after watching the simulation.
5. How they rated the training exercise on a scale of five to one, where five was 'extremely useful' and one was 'not useful at all'.

Again, the completed questionnaires are contained within **Appendix G**.

In particular, data gathered from this part of the exercise allows some degree of analysis against whether expectations of tenability times changed following the training, and whether any changes could be observed within the second drill performance.

3.7 Carrying Out of Further Egress Drill

Following delivery of the training, a further unannounced egress drill was carried out and monitored at 34 Tavistock Square. For the purposes of continuity, the same team of observers participated. Given that the initial round of egress drills were carried out in dry, overcast but mild weather conditions, the date was set for 3 April 2019. The weather conditions were similar on this date so the drill proceeded as planned. It is considered that bad weather may contribute to a decision to delay evacuation in some circumstances.

The research team of observers of the egress drill were given a modified record sheet (returns of which are contained within **Appendix H**). As with the previous drill, care was taken to brief observers on the need to try to avoid influencing the result of the drill.

Specifically, rather than recording the first and last presentation times for the floor as a whole, observers were asked to record the first and last presentation times for each individual room. This was considered achievable on the basis that floors had a maximum of three occupied rooms and low numbers of occupants present within each, with some rooms anticipated to have no occupants due to the transient nature of occupation. Again, observers were asked to confirm whether rooms were checked by fire marshal.

By checking the individual rooms and recording results relating to presentation times as well as occupant numbers, some correlation with occupants that participated in the training was considered to be possible.

3.8 Questionnaires Following Second Drill

A reduced-scope questionnaire was prepared for the second egress drill. The questionnaire was intended to determine:

1. Whether occupants had been involved in the simulation training.
2. Whether they were a visitor or regular occupant.
3. Where in the building they were located when the fire alarm sounded.
4. Whether they took the decision to evacuate themselves, or awaited instructions.

Again, the data from these questionnaires allow a degree of correlative analysis, particularly in terms of whether occupants had received the training and whether this influenced their decision to evacuate, or indeed whether they awaited instructions.

3.9 Approach to Phase 1 Data Analysis

3.9.1 Pre-Movement Times from Initial Egress Drills

Of specific interest in the case of pre-movement times collated from the initial eight egress drills are the presentation times of the first and last occupants on each floor, and whether fire marshals checked these areas. To analyze the results of the pre-movement time, it has been decided to use the approach detailed in PD 7974-6 **(British Standards Institution, 2004, p. 25)**, where pre-movement time is calculated as:

$$\boldsymbol{total\ premovement\ time} = \Delta \boldsymbol{t}_{\boldsymbol{pre}\ (\boldsymbol{1st\ percentile})} + \Delta \boldsymbol{t}_{\boldsymbol{pre}\ (\boldsymbol{99th\ percentile})}$$

Whilst the CFD model relates specifically to 34 Tavistock Square, there may be some merit to comparing this pre-movement time to the tenability results determined by the model.

Additionally, the times associated with first and last occupants can be considered in the context of those detailed within PD 7974-6, as replicated in **Table 3. 4**.

Scenario category and modifier A: Awake and familiar	First occupants $\Delta t_{pre\ (1st\ percentile)}$	Occupant distribution $\Delta t_{pre\ (99th\ percentile)}$
M1 B1-B2 A1-A2	0.5	1.0
M2 B1-B2 A1-A3	1	2
M3 B1-B2 A1-A3	>15	>15

Table 3. 4 Pre-movement times for awake and familiar premises, adapted from PD 7974-6 Table C.1.

3.9.2 Questionnaire Responses Following Initial Egress Drill

The methodology for scoring responses for quantitative analysis is based on the following:

Question 1 Did occupants trust the fire alarm.

For the purposes of analyzing the data, ‘yes’ will be considered to have a score of ‘1’, ‘no’ a score of ‘0’, and don’t know or leaving the answer blank will attract a ‘not applicable’ to the dataset for analysis purposes.

Question 2 How long did occupants believe they had to escape safely.

Occupants are able to record a response of their choice in terms of minutes.

For the purposes of data analysis, the recorded answer can be used. The data obtained from answers to this question can be compared to the results obtained from the CFD model for analysis purposes.

Question 3 With what frequency did occupants consider fire alarms to activate.

For the purposes of data analysis, ‘very regularly’ will attract a score of ‘4’, ‘regularly’ - ‘3’, ‘sometimes’ - ‘2’, ‘rarely’ - ‘1’ and ‘never’ - ‘0’.

It is noted that occupants may have differing views on the definition of what constitutes either a false alarm or a fire drill. In particular, UCL carries out weekly functional testing of fire alarm systems in accordance with guidance **(British Standards Institution, 2017)** which may lead to some ambiguity in this definition.

Question 4 How relevant did occupants believe UCL fire safety training was.

For the purposes of data analysis, these, ‘very relevant’ to ‘very irrelevant’ will attract scores from ‘5’ to ‘1’ respectively.

Occupants are able to record further comments in relation to this question, which will be recorded and analyzed qualitatively. This is in addition to other comments that can be freely recorded on the second page of the questionnaire.

Question 5 Did occupants have experience of fires.

For the purposes of analyzing the data, ‘yes’ will be considered to have a score of ‘1’, ‘no’ a score of ‘0’, and ‘would rather not say’ or leaving the answer blank will attract a ‘not applicable’ to the dataset for analysis purposes.

Occupants are able to record further comments in relation to this question, which will be recorded and analyzed qualitatively. This is in addition to other comments that can be freely recorded on the second page of the questionnaire.

Question 6 How long had occupants worked in the premises.

For the purposes of analyzing the data, ‘less than one year’ will attract a score of ‘1’, ‘one to five years’ a score of ‘2’, and ‘five years or more’ a score of ‘3’. This provides a quantified approach to determining familiarity with the building or similar buildings.

Question 7 How would occupants class the fire risk within the premises.

For the purposes of analyzing the data, 'high' will attract a score of '3', 'normal' a score of '2', 'low' a score of '1', and don't know or leaving the answer blank will attract a 'not applicable'.

Question 8 Were occupants interested in further training.

For the purposes of analyzing the data, 'yes' will be considered to have a score of '1', 'no' a score of '0'.

By using these quantitative values, it will be possible to explore some correlations between the datasets. In particular, some analysis will be possible between the time worked in a Heritage building and the risk perception / perception of available escape time, correlation between experience of fire and perception of risk, trust in fire alarm systems and perception of frequency of false alarms and fire drills, and links between relevance of fire safety training and perception of risk and available safe egress time.

3.9.3 Fire Safety Management Data

The data relating to numbers of fire marshals recorded in riskNET will be compared to data collected in the course of the initial egress drills. Specifically, the recorded data will be compared to whether fire marshals carried out checks during those drills, and of which areas.

Data relating to unwanted fire signals and age of fire detection and alarm systems will also be examined. This will be compared to responses in questionnaires relating to numbers of fire alarm activations to determine whether there is particular correlation in the data.

3.10 Approach to Phase 2 Data Analysis

3.10.1 CFD Model

Slice file data will be examined against occupant expectation of available safe egress time determined within the Phase 1 questionnaires. Primarily, the model was created to provide a visual simulation for the purposes of training occupants, rather than being a 'scientific' model whose sole purpose was to explore tenability conditions.

However, there is some merit in determining whether occupants in the range of Heritage buildings could benefit from the simulation training that was delivered to occupants of 34 Tavistock Square.

3.10.2 Simulation Training

Given the lower number of data-points, these can be presented and analyzed individually, exploring the responses in the context of information obtained from the CFD model as well as the second egress drill. Specifically, the key analysis will relate to whether the simulation changes occupant risk perception, and whether they feel it is an effective means of training in relation to both pre-movement times and participating actively in fire safety management at the premises.

This is considered to be useful in determining whether provision of such training would be considered by occupants to be of benefit as part of a building-specific training regime.

3.10.3 Second Egress Drill

Data collected at the time of the second drill can be compared to the data collected during the first at the same building. Whilst there is slightly more data recorded for the second drill (on account of presentation times for individual rooms being recorded, rather than just the floor, as per the first egress drill), it is of course still possible to determine a floor pre-movement time based on the recorded data.

Again, the recording of whether a fire marshal check of areas was carried out can be compared to recorded riskNET data and the data from the first drill, to determine whether there are any substantial departures in performance, or whether the drill could be considered to be directly comparable to performance during that first drill.

3.10.4 Questionnaire Responses Following Second Egress Drill

The primary purpose of the post-drill questionnaire was to determine whether occupants participating in the second drill had received the simulation training. This data can be analyzed to determine whether those that received the training behaved in a different manner to those who did not, and to identify any differences in performance that may have resulted from this.

The responses to these questionnaires will help to categorize any performance data, to align it with other data relating to the pre-movement times in the second drill and the simulation training.

As such, responses will be explored in the context of the data collected in the course of the training and the second drill.

Chapter 4 Phase 1 Results and Analysis

4.1 Egress Drills

The initial eight egress drills provided a range of useful data. A quantitative analysis of pre-movement data is contained within **Appendix B**. Copies of all record sheets received from observers are contained within **Appendix C**.

4.1.1 Pre-Movement Times

As can be seen from the data within **Appendices B1 – B8**, presentation times ranged from two seconds (2 Taviton Street) to 620 seconds (19 Gordon Square). It is considered unlikely that the two second presentation time is a valid result, and is more likely to have related to an occupant that was already travelling to the door of the room when the fire alarm sounded. However, presentation times for first occupants were generally quite short, including 22 Gordon Street (13 seconds), 2 Taviton Street (13 seconds for the next occupant after exiting after the two second presentation time), 34 Tavistock Square (12 seconds), 35 Tavistock Square (11 seconds), 33 Bedford Place (16 seconds), 15 Woburn Square (21 seconds) and 19 Gordon Square (17 seconds). Even the longest presentation time for the first occupant in the drill programme, at 11 Woburn Square, presented at 45 seconds. As such, these times are significantly under the 'one minute' figure suggested in PD 7974-6 for first occupant pre-movement time **(British Standards Institution, 2004)**.

In the case of the long presentation time at 19 Gordon Square, 620 seconds was the time that the last person evacuated following re-entry by a member of staff, who had re-entered the building to instruct students to evacuate from the ground floor common room. During the initial evacuation of the premises, there were no fire marshal checks, so the evacuation relied (unsuccessfully) on occupants making the decision to evacuate. Indeed, there were only two staff present within the building. All occupants filled in a questionnaire, which is discussed in further detail in Section 4.2, although it is perhaps worth noting that two people made specific comments in relation to training, both stating that they had not had training. It is entirely possible, however, that these comments were made by students filling in the questionnaire, as students do not receive fire safety training under UCL arrangements.

The long presentation time for the last occupant would be expected, if basing analysis on PD 7974-6 **(British Standards Institution, 2004)**. This is because, unlike the remainder of the premises at 22 Gordon Square, and, indeed, the other seven buildings, in which, whilst floor wardens may not always be present (as demonstrated at these drills), all staff receive at least some level of fire safety training. As such, the level of management for these other spaces could be considered to be M2 **(British Standards Institution, 2004, p. 11)**. Whilst occupants of the common room would be categorized as 'awake and familiar', due to this being a departmental common room and a space allocated specifically for the students present, the lack of training of students, coupled with the lack of fire marshal checks, would be more in accordance with a management level of M3 **(British Standards Institution, 2004, p. 11)**.

As such, pre-movement times for the first and 99th percentile occupants would both be over 15 minutes as per **Table 3. 4**. Indeed, times in excess of 15 minutes may have occurred had the member of staff not re-entered the building when they realized that a drill was taking place and their return to work was being delayed by students remaining in place.

The next longest presentation time was within 34 Tavistock Square (the building consequently selected for Phase 2 research). Interestingly, this occurred on the lower ground floor, which was checked by a fire marshal at some point during the evacuation. The observer noted that "*lower ground floor did not evacuate at presentation time – 3 min 45 s elapsed prior to floor being fully evacuated*" as noted in **Appendix B3**. No further notes are recorded, although it is possible that a fire marshal had to travel down from one of the upper floors to check this area. Indeed, the occupant may have been seeking additional information rather than presenting themselves for evacuation, which is a recognized possibility **(Society of Fire Protection Engineers, 2019, p. 35)**. It is entirely possible that they realized that the alarm represented a drill rather than a genuine emergency and therefore re-engaged with tasks prior to evacuating.

Examining the whole eight drills as a single entity can simplistically be carried out, after discounting the two second and 620 second times at each extremity, by adding together the fastest (11 seconds) and slowest (148 seconds) presentation times, provides a figure of 159 seconds. This is above the 90 seconds associated with M1 but below the 180 seconds associated with M2 management levels **(British Standards Institution, 2004, p. 25)**. Indeed, numerous results recorded at the drills suggest that occupants move much more quickly in general than would be anticipated in PD 7974-6, as is demonstrated in **Table 4. 1**.

Building	$\Delta t_{pre\ (1st\ percentile)} + \Delta t_{pre\ (99th\ percentile)}$
22 Gordon Square	13 + 38 = 51 seconds
2 Taviton Street	13 + 65 = 78 seconds (discounting 2 sec time)
34 Tavistock Square	12 + 148 = 160 seconds
35 Tavistock Square	11 + 80 = 91 seconds
33 Bedford Place	16 + 62 = 78 seconds
11 Woburn Square	45 + 94 = 139 seconds
15 Woburn Square	21 + 40 = 61 seconds
19 Gordon Square	17 + 620 = 637 seconds

Table 4. 1 Pre-movement times as calculated using PD 7974-6 method.

4.1.2 Fire Marshal Checks

It is very likely that the relatively short pre-movement times discussed in Section 4.1.1 relate at least in part to the checks carried out by fire marshals. It is also likely that the mandatory fire safety training plays an important role in ensuring that staff understand what is expected of them when the fire alarm sounds.

It is noted that the two buildings at which no fire marshal checks were carried out (11 Woburn Square and 19 Gordon Square) had relatively long pre-movement times. In the case of 19 Gordon Square, the lack of fire marshal check is considered to be directly related to the very long pre-movement time in the common room. This is demonstrated by the fact that all occupants evacuated as soon as instructed by the member of staff who re-entered the building.

The only building in which all floors were checked by a fire marshal was 35 Tavistock Square. The pre-movement time in this building was lower than that stated in PD 7974-6 for level M1 management **(British Standards Institution, 2004)**. In the case of 15 Woburn Square, all upper floors were checked, although the lower ground floor was not checked. However, the lower ground floor in this particular building only contains meeting rooms. Given the nature of the use of the building, it is likely that the fire marshals knew that these were unoccupied at the time, and therefore it could be argued that all relevant checks were carried out. In this building, again, the pre-movement time was shorter than the time associated with M1.

4.2 Questionnaires

Quantitative analysis of questionnaire responses is contained within Appendix D (D1 – D8), with survey responses contained in Appendix E.

4.2.1 Experience of Fire, Fire Safety Training and Fire Risk Rating (Risk Perception)

In total, seven occupants reported that they had experience of fire. There were two occupants at 22 Gordon Square who reported experience of fire (one noting that this was a "*kitchen fire at home*" and the other at "*Cruciform Libraries* (sic)") (**Appendix D.1**). Both occupants recorded that they believed the fire risk rating to be 'low'. This could relate to the environment being different to that in which they previously experienced fire. It is noted that both occupants had worked in the building for over a year, and appeared rated fire safety training as 'relevant' and 'very relevant'.

At 2 Taviton Street, three occupants reported experience of fire, two of whom rated the fire risk as 'normal' and the other who rated the risk as 'high' (**Appendix D.2**). The occupant who rated the risk as 'high' recorded that they felt 'indifferent' about fire safety training. The other two occupants felt that training was 'relevant'. It may be the case that the occupant who perceived the risk was 'high' was not confident in management of fire safety due to their experience of the training. However, equally, the risk perception could relate to the severity of the fire that they experienced, the premises that they experienced it in, or, indeed, relate purely to how the individual processes the threat **(Society of Fire Protection Engineers, 2019, p. 22)**.

At 34 Tavistock Square, one occupant recorded that they had experience of fire. They left most of the questionnaire blank, although, interestingly, recorded that they did trust the fire alarm system, and estimated an available safe egress time of 20 seconds (**Appendix D.3**). This was by far the shortest time recorded in all surveys, which may imply that the perception of risk was, by virtue of this time, to be 'high'.

The final occupant to record experience of fire was within 35 Tavistock Square. This occupant again recorded that training was 'relevant' and the risk was 'normal' (**Appendix D.4**). The occupant was one of only two in the building who recorded that they did not trust the fire alarm system. This occupant recorded that they had been working within the premises for over five years. Again, this may have a bearing on the responses provided, due to familiarity and consequent de-sensitizing following exposure to fire alarm testing and drills **(Society of Fire Protection Engineers, 2019, p. 38)**.

4.2.2 Fire Safety Training Relevance and Interest in Further Training

On the basis that all buildings in the sample have the same training delivered to all occupants, it is considered appropriate to analyze the entire sample collectively. Quantitatively examining the responses provides an average score of 3.74 (which places it close to 'relevant'). It is noted that poor responses to this question in the case of 19 Gordon Square reduced this rating. Discounting the results of 19 Gordon Square provides an average score of 4.08 (which is 'relevant'). Indeed, it is appropriate to discount this dataset on the basis that it comprised mainly responses from students, who do not receive training.

Looking at occupants who wanted further training (again discounting 19 Gordon Square), 34.3% of occupants expressed an interest in further training.

Based on these data, it is considered that occupants are mainly satisfied with current training arrangements.

4.2.3 Trust in Fire Alarms and False Alarms

It is noted that "*lower confidence…leads to longer response delays*" **(Society of Fire Protection Engineers, 2019, p. 30)**. On that basis, **Table 4. 2** provides data on occupant trust within fire alarms in each of the buildings. Again, responses from students appear to suggest low trust in the alarm in 19 Gordon Square. This tallies with the very long pre-movement time in this building caused by delayed evacuation. However, in general, the high level of trust in the alarms can potentially, at least in part, be linked to the low number of unwanted fire signals recorded in **Table 4. 5**.

Building	**Percentage trust in fire alarm system**
22 Gordon Square	90.9%
2 Taviton Street	94.7%
34 Tavistock Square	100%
35 Tavistock Square	80%
33 Bedford Place	100%
11 Woburn Square	100%

15 Woburn Square	100%
19 Gordon Square	43.5%

Table 4. 2 Percentage of persons who trust fire alarm system determined in surveys.

4.2.4 Expectations of Time to Escape (ASET)

The approach to calculating an average time for ASET from questionnaire responses involved removing responses that stated a maximum time (i.e. those that said "under one minute"), and selecting a middle value where a range was stipulated (i.e. where occupants stated three to five minutes, a value of four minutes was used). Those that did not respond were not included and not counted for division of the sum total for calculating of the mean average value.

On this basis, mean averages were calculated as per **Table 4. 3**.

Building	**Mean anticipated ASET (minutes)**
22 Gordon Square	3.125
2 Taviton Street	2.638
34 Tavistock Square	2.736
35 Tavistock Square	1.9
33 Bedford Place	3.81
11 Woburn Square	2
15 Woburn Square	2.25
19 Gordon Square	5.05
All	**2.939**

Table 4. 3 Mean anticipated ASETs as per questionnaire returns.

This is a reasonable estimate of occupant expectation of ASET in this instance, as many occupants responded in the range of two to three minutes. Again, values associated with 19 Gordon Square were higher, although, again, this could relate to students completing the questionnaire (who have not received fire safety training). It is possible that values between two and three minutes related in part to occupant awareness of the traditional 2 ½ minute evacuation time through historical training **(Todd, 2008, p. 128)**.

4.3 Fire Safety Management Data Analysis

Recorded data on UCL systems demonstrates a mixed standard of department fire safety management, which was reflected in the findings of the egress drills. In particular, as is shown in **Table 4. 4**, the requirement to maintain up-to-date records of fire marshals is not universally met. That does not directly translate to poor on-site management (for example, fire marshals checked all floors of 35 Tavistock Square during the drill, although none were recorded on riskNET).

However, it can be seen that fire marshal numbers are low generally, and where one fire marshal was recorded on riskNET, no checks were carried out during the drill, demonstrating a probable lack of adequate contingency arrangements. Conversely, where no fire marshals were recorded on riskNET, at least some parts of the premises were checked during the drill.

Property	**Number of fire marshals***	**Floors checked by FEMs during egress drill**
33 Bedford place	None recorded	2nd, ground, lower ground
11 Woburn Square	One recorded	None

15 Woburn Square	Two recorded	3^{rd}, 2^{nd}, 1^{st}, ground
2 Taviton Street	Three recorded	Ground floor only
35 Tavistock Square	None recorded	All floors checked
34 Tavistock Square	Five recorded	4^{th}, 3^{rd}, 1^{st}, lower ground
22 Gordon Square	None recorded	Ground floor only
19 Gordon Square	One recorded	None
**Fire evacuation marshals as recorded on riskNET Responsible Persons Register*		

Table 4. 4 Fire marshal data per building.

In terms of fire alarm systems, detection is provided universally to a high standard. Numbers of unwanted fire signals are low across all premises. The fire alarm system was replaced in 15 Woburn Square part way through the analysis, following which point no further unwanted alarms occurred. These data tend to suggest well-managed systems which would be expected to maintain a high degree of occupant trust, reflect in the questionnaire responses.

Property	**Category of FDAS**	**Date of Installation**	**Number of Unwanted Fire Signals Between 01/09/2015 & 31/08/2018**
33 Bedford place	L2	2014	None
11 Woburn Square	L2	1997	One (08/06/2016)
15 Woburn Square	L2	Mid-2017	Two (16/12/2016 & 10/01/2017)
2 Taviton Street	L2	2007	One (21/11/2017)

35 Tavistock Square	L2	1999	None
34 Tavistock Square	L2	1999	One (08/06/2016)
22 Gordon Square	L2	2010	None
19 Gordon Square	L2	2006	None

Table 4. 5 Fire alarm system data.

4.4 Summary of Phase 1 Key Findings

A number of key points have been identified within the Phase 1 research:

- There were a range of calculated pre-movement times. Five of the buildings had times generally associated with a high standard of management, M1, two were more in line with M2, and 19 Gordon Square was more comparable to M3, on the basis of delayed student evacuation from the common room.
- Departmental adherence to UCL arrangements in terms of maintaining up-to-date records varied across the buildings. However, failure to comply did not directly translate to a lack of fire marshals present in the buildings.
- Fire marshal checks of areas were not universal. That said, occupants still acted relatively appropriately in terms of self-evacuating, indicating acceptance of procedures instructed to them through training.
- Satisfaction with current training was relatively high, and only approximately a third of participants wanted further training.
- Risk perception of occupants did not necessarily relate to experience of fires in this dataset.
- Trust in fire alarm systems was generally high. This may have been associated with low rates of false alarms.

Chapter 5 Phase 2 Research Results and Analysis

5.1 CFD Model Results

The CFD model results were designed to indicate worst-case-scenario conditions within the escape route based on the kitchen door being open. Tenability would be expected to be affected in terms of visibility first, followed by toxic products and then heat **(Purser, 2018)**. Indeed, the model results reflected this expectation, as is shown in **Figures 5.1 - 5.4**.

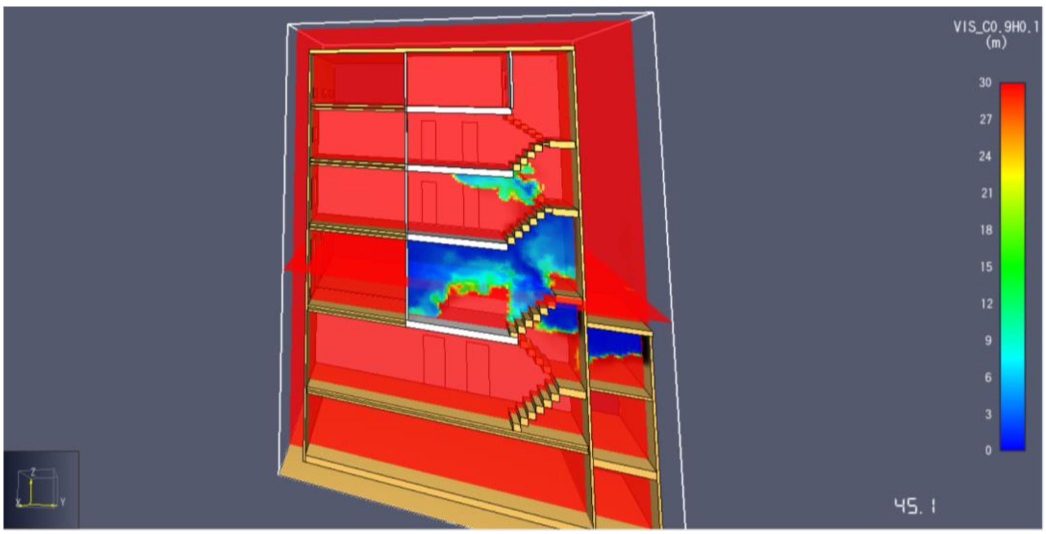

Figure 5. 1 Visibility (m) at 45 seconds.

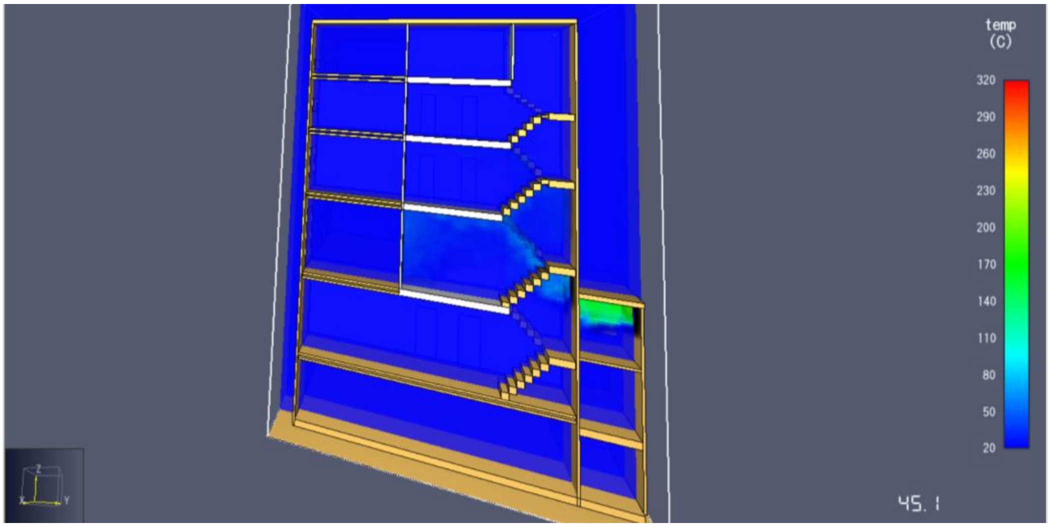

Figure 5. 2 Temperature (C) at 45 seconds.

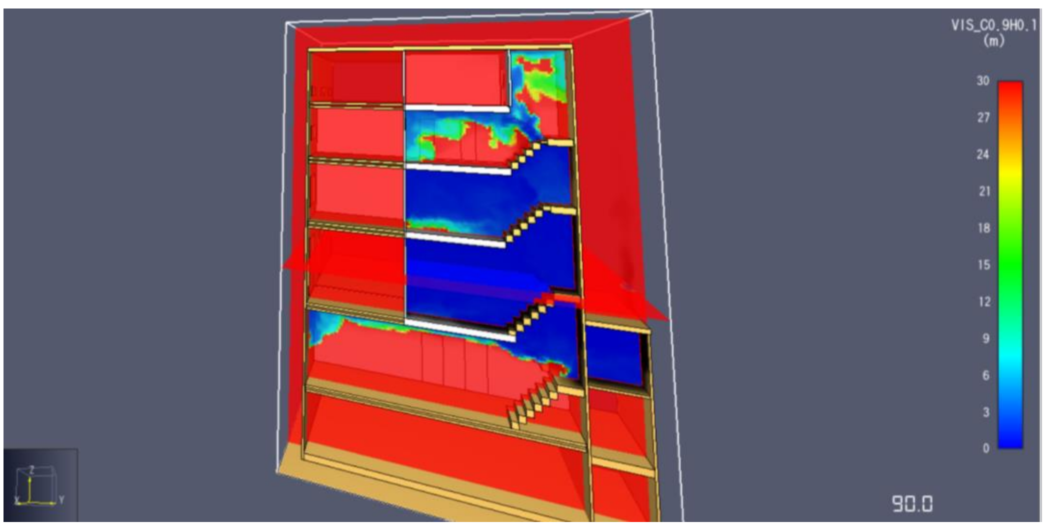

Figure 5. 3 Visibility (m) at 90 seconds.

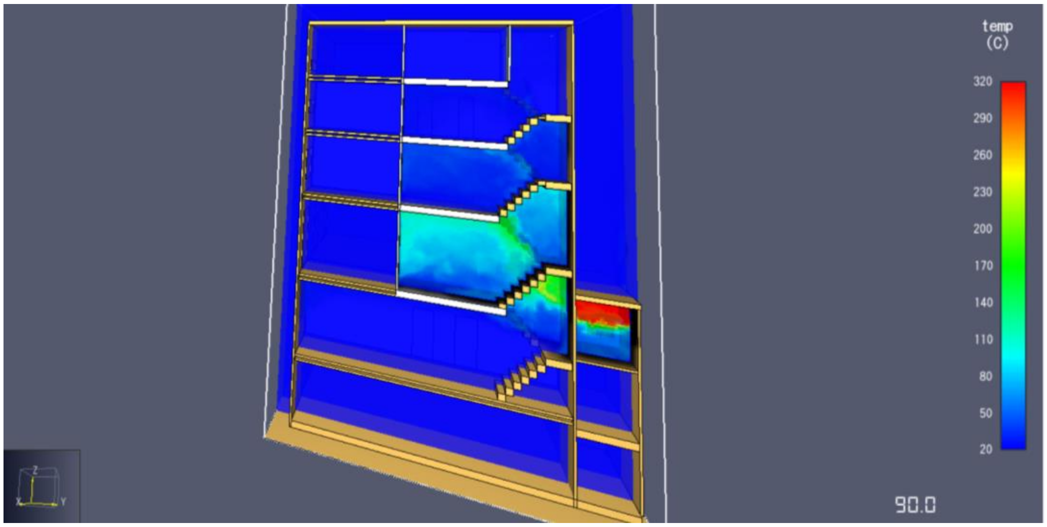

Figure 5. 4 Temperature (C) at 90 seconds.

When compared to the approximate mean average expectation of ASET of three minutes determined in **Table 4. 3**, it can be seen in the model that visibility is compromised through most of the escape route for upper floors in half that time as per **Figure 5. 3**. This implies that the model results would challenge the expectations of a number of occupants within the eight buildings studied in Phase 1.

5.2 Simulation Training and Questionnaires

5.2.1 Expectations Beforehand

Responses to questionnaires are contained within **Appendix G**. From these, nine of the delegates were found to be based routinely on floors above ground. Of the conditions to challenge tenability, eight occupants selected visibility, six selected heat and four selected toxic products. It is worth noting that three occupants selected multiple conditions which have been counted in the above statistics. Two of these selected all three values as being the conditions that would affect tenability, whilst the further occupant selected visibility and toxic products. It is possible that this demonstrates the effectiveness of well-publicized community fire safety activities **(Todd, 2008, p. 356)**.

In response to the question asking about available safe egress times for each floor area, four occupants responded 'don't know' to all areas. A range of responses were given by those who did participate, from two seconds to 20 minutes, although most occupants identified that tenability limits would be reached in considerably under this maximum response, with some simply ticking the boxes in the columns designated 'seconds'. It is worth noting the mean ASET of 2.736 minutes in **Table 4. 3**, which was formed of a range of responses, from 20 seconds to 10 minutes. Specifically, it is possible that, in the second questionnaire, there were too many options available to delegates, and the simpler criteria afforded in the first questionnaire was simpler to estimate.

In terms of anticipated times to detector activation, three of the occupants did not respond to estimate a time. Of the remaining responses, these ranged between two seconds and three minutes.

5.2.2 Responses After Training

More critical to this research were the questionnaire responses following the training. The majority (12 to one) of delegates reported that the simulation changed their view on fire and smoke spread. A lower ratio (nine to one) stated that they would be less likely to wedge fire doors in the open position. However, anecdotally, delegates reported, at the time of filling out the questionnaire, that they would not do so anyway, so this may be part of the rationale for these responses.

A majority of 11 to two responded to both the question relating to being likely to remove wedges where found and to evacuate more quickly in the positive. As such, occupants suggested that the training positively reinforced fire safety management messages, in terms of encouraging active participation in management of means of escape protection, as well as the need to reduce pre-movement times.

Critically, the mean average value for ‘usefulness’ of training was 4.69 (where five was termed ‘extremely useful’). Indeed, 10 of the 13 delegates rated the training as ‘extremely useful’. Of note are the following comments that were recorded by delegates as per **Table 5. 1**.

No.	Comments recorded by delegates following training
1	*It was a great exercise and should be incorporated with online fire safety training modules.*
2	*Really quick + useful exercise.*
3	*Very useful information. Good to see the simulation & see how it affects our building.*
4	*Would be more useful having the fire exit by the window shown, differentiating escape time depending on fire development. Would be useful to not just see the smoke but heat too, to understand better what you were talking to us.*
5	*Use for future H&S planning / website.*
6	*Very useful to know how the fire travels and which areas would remain relatively safe. Good to see as visual representation.*
7	*Very interesting to note how quickly smoke spreads, especially in a single staircase scenario. Think it would be very useful to feature in a training session / Moodle.*

Table 5. 1 Comments recorded by delegates following training.

Of note are the comments detailed as No. 4. The building had an historical roof escape which was no longer designated as part of the escape strategy. The delegate discussed their comments after in relation to visual representations of heat, and realized that they had not referred to the handout as instructed during the simulation.

However, overall, it can be seen that the training was extremely well received. The fact that over half of occupants recorded comments demonstrates that they were engaged with the training, and their quantitative and qualitative feedback reflects this.

5.3 Second Egress Drill Data

For the purposes of results and analysis relating to the second drill, it is considered to be reasonable to explore both the recorded pre-movement data (contained in **Appendix H**) and questionnaire data (contained in **Appendix I**) together in **Table 5. 2**. In total, nine occupants were present at the time of the drill, and all of them completed a questionnaire. Of the nine persons present, seven had participated in the simulation training. At this drill, fire marshal checks were carried out of all floors, with the final check being completed at 1 minute 46 seconds (lower ground floor).

Floor	**Room number**	**No. of persons**	**No. of persons that received training**	$\Delta t_{pre\ (1st\ percentile)} + \Delta t_{pre\ (99th\ percentile)}$
4	401	1	1	40 s -
4	403	1	0	35 s -
2	201	2	1	27 s + 28 s = 55 s
1	102	2	2	24 s + 67 s = 91 s
G	G01	2	2	37 s + 40 s = 77 s
G	G04	1	1	Unknown – observer did not record occupants in this room

Table 5. 2 Second egress drill data.

From the above Table, there is perhaps no clear link between the simulation training and pre-movement times. This is certainly the case on fourth floor, where the occupant who did not receive the training evacuated prior to the trained occupant. There are a number of possible of reasons for this, including, potentially, engagement in tasks or previous experience.

As there were two occupants present in room 201, the decision taken by the first occupant to present for evacuation may well have influenced the decision of the second occupant. The data is fairly limited so this cannot be said with certainty, although it would be expected to have an effect, based on information detailed in the literature review.

The widest range of pre-movement times was on first floor, and this would consequently constitute the pre-movement time for the entire population, using the method detailed in PD 7974-6 **(British Standards Institution, 2004)**. The calculated pre-movement time would be expected of a very well-managed building as per **Table 3. 4**. Comparing the calculated 91 second egress drill pre-movement time with the initial drill, on face value, this suggests significant improvement on the 160 second time previously recorded. Population sizes were slightly greater in the first drill (12 persons compared to nine for the second drill), although evidently the numbers in both cases are small, and therefore significance of statistical analysis to form an argument is perhaps undermined.

Of interested was that five occupants recorded that they left without instruction from a fire marshal, with the other four reporting that they awaited instruction prior to leaving. Three of the four that awaiting instructions had received the training. As such, it could not be stated that the training was universally successful in improving occupant response. That said, it is entirely possible that occupants were more willing to abide by instructions on receipt of them and had a greater trust in the need to take action once instructed.

5.4 Summary of Phase 2 Results and Analysis

A number of key points have been determined in the course of the Phase 2 research:

- Tenable escape conditions were compromised more quickly than was reported by those surveyed in Phase 1.
- The majority of occupants that participated in the simulation training reported that the simulation had changed their view on fire development.
- Occupants that participated in the simulation training responded to questionnaires to indicate that they would generally participate more actively in fire safety management of the premises.
- The training was received extremely well, with positive feedback and high satisfaction rates.
- However, forming direct correlations between the training and the results of the second drill is challenging. On face value, the pre-movement time was reduced at the second drill, although evidence in support of this is potentially slightly unreliable due to the size of the dataset.
- It is difficult to confirm that any improvements came as a direct result of the provision of the simulation training.

Chapter 6 Conclusions and Recommendations

To conclude this dissertation, this chapter sets out conclusions in respect of the objectives of the dissertation. Following this, the work is concluded, and relevant recommendations are made. Recommendations are relevant to UCL as an institution, but are also relevant to other operators of similar buildings. The research carried out in this dissertation has produced a large amount of data, some of which has not been analyzed in detail based on the constraints of the scope of an undergraduate dissertation.

6.1 Objectives

The objectives of this dissertation were:

6.1.1 To carry out a literature review of the subject area.

The literature review carried out identified that there was a significant amount of material with relevance to the topic. Specifically, a range of research had been conducted in relation to human behaviour in fire and alarm situations, factors influencing pre-movement times, risk perception, training, drills, fire alarm systems and unwanted fire signals.

The literature review identified a number of points that informed construction of the research programme, particularly in respect of preparation of occupant questionnaires, and data to be examined in relation to pre-movement time. In particular, it is clear that large amounts of research work continues to take place in the profession across the world, and this is directly informing changes to in practical application of fire safety principles under various legislative regimes. However, human behaviour, and the factors which make up pre-evacuation behaviours, remains challenging, and a developing science. It was, therefore, clear that proceeding with this dissertation had the potential to add to this developing field.

6.1.2 To determine measurable pre-movement times by carrying out monitored evacuations.

This phase of the work involved recording of data from eight egress drills. Whilst this was a smaller sample than the originally intended 10 drills, it provided a large amount of relevant quantitative data in respect of pre-movement times on each floor of the eight buildings, as well as whether fire marshals carried out checks. Indeed, there was a range of results present within the data that allowed qualitativeexamination based on factors and principles identified within the literature review.

6.1.3 To examine data relating to fire safety training, fire marshals and unwanted fire signals in the relevant Heritage buildings.

Meeting this objective was made possible by existing means of recording data in place at UCL. There were a number of factors relating to recorded data that were relevant to analysis of the Phase 1 work, particularly the link between unwanted fire signals (which were low) and trust in the fire alarm system (which was high). These links were recognized in the material subject to the literature review.

Additionally, departmental adherence to UCL policy, whereby all departments are required to maintain up-to-date records, was not universal; however, this did not mean that on site arrangements were necessarily absent. It was noted that, where low numbers of fire marshals were recorded on riskNET, the buildings were more likely to not have a fire marshal present during the drill.

6.1.4 To determine occupant understanding of available safe egress time through use of questionnaires.

In working towards this objective, questionnaires were prepared, the return rate of which was universally high. This may be due to the nature of UCL's business as a leading research institution, and consequently staff and students being willing to participate as they are involved in such activities themselves.

The questionnaire responses provided excellent data, not just of occupant understanding and estimation of available safe egress time, but also of peripheral topics, such as factors relating to risk perception, fire safety training, duration of working within the premises, etc. Indeed, there is much more data contained within the questionnaires than can practicably be analyzed within the constraints of this undergraduate dissertation.

6.1.5 To prepare a CFD model of a typical UCL Heritage education building.

To meet this objective, a CFD model was created of 34 Tavistock Square. The scenario created for the model represented a worst-case-scenario that was arguably more severe than would generally be expected. However, the purpose of the model was primarily to act as a training tool in support of improving occupant response and, as such, was considered to be fit-for-purpose. Specifically, as the scenario represented a fire door being wedged in the open position, there were potential learning outcomes associated with fire safety management as well as simple pre-evacuation considerations.

The results of the model were very much as expected, in that visibility was compromised prior to heat affecting tenability within the staircase enclosure. The model results also afforded a comparison with data obtained in support of meeting the previous objective.

6.1.6 To provide CFD model results to occupants as face-to-face training.

The work carried out in support of this objective was possibly some of the most relevant within the dissertation project. Whilst it proved quite difficult to arrange training in a manner that ensure that all occupants received it, given the time constraints associated with the project, a reasonable sample of occupants did undertake the training, with whom it was extremely well-received. Indeed, questionnaire responses suggested incorporating the simulation as part of general fire safety training, which is relevant to note.

Given further time, it would have been useful to extend the sample of occupants to whom the simulation training was provided. This would have expanded the dataset within the Phase 2 work and potentially offered additional validation of results.

6.1.7 To evaluate any improvements in pre-movement times by carrying out further monitored evacuations.

The final egress drill and questionnaire again provided good data, albeit relating only to a small group of occupants. Quantitatively, it was suggested from the data that an improvement had been achieved. However, given the size of the dataset, care should be taken in forming such a conclusion. Again, extension of the scope of the project to include additional buildings in the Phase 2 work, had time been available, would have provided more robustness to the data and its subsequent analysis.

6.2 Conclusion

It can be concluded from this work that fire safety management standards across these buildings at UCL is fairly high. Occupants are relatively well trained and generally act appropriately during fire alarm activations. Where students are left alone, without supervision, and without appropriate fire marshal procedures, this has the potential to be undermined.

Occupant understanding of the risk from fire varies across the population. That said, many occupants believe the time available to them to escape safely in case of fire to be reasonably short. This was confirmed within the questionnaires, and validated in the CFD model results.

Occupants also expressed that they were more likely to assist in managing fire safety by removing wedges from fire doors.

Whilst, generally, occupants are satisfied with current training arrangements, simulation training was found to be extremely well received. It may be difficult to directly link this to improved evacuation results, although the comments and feedback received from this method of bespoke training implies that it was at least to some degree successful.

6.3 Recommendations

6.3.1 Simulation Training

UCL should incorporate the CFD simulation video and handout into online Moodle training and/or local induction training for occupants of all single staircase Heritage buildings. This recommendation may be relevant to other universities, as well as other office-based companies, who operate similar Heritage buildings with single staircase escape conditions.

6.3.2 Fire Drills

UCL (and estate operators, more broadly) should more effectively utilize fire drill exercises as a training tool as well as a tool for evaluating the effectiveness of training. Specifically, exploring pre-evacuation behaviours, and seeking to improve them, in the course of fire drills, is considered to be a worthwhile component of a fire drill.

6.3.3 Further Research

Given the amount of relevant information collected for this dissertation project, further data are available to support future research on this specific topic. This could include examining the data differently to generate distributions for use in modelling. This may include further research on occupant responses and risk perception, in which further correlative analysis is considered possible. Additionally, it would be a worthwhile exercise to expand on the research conducted within this dissertation by providing the simulation training to occupants of all other similar UCL buildings, and evaluating the effectiveness of this training in the course of a further programme of unannounced egress drills. If this was repeated at a suitable future date, the results may provide a useful additional dataset for further analysis.

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LIST OF APPENDICES