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**MODELLING OCCUPANT EVACUATION
DURING FIRE EMERGENCIES IN BUILDINGS**

By

Derek F.H. Gruchy

**A thesis submitted to the faculty of Graduate Studies and Research in partial fulfillment
of the requirements of the degree of**

Master of Applied Science

**Department of Civil and Environmental Engineering
Carleton University
Ottawa, Ontario**

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MODELLING OCCUPANT EVACUATION DURING FIRE EMERGENCIES IN BUILDINGS

submitted by

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in partial fulfillment of the requirements for the degree of
Master of Applied Science in Civil Engineering

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September 2004

ABSTRACT

Computer models are becoming essential to the building design process, striving for better fire safety designs. One such model is being developed at Carleton University. It evaluates the most likely fire scenarios and their impact to life and property based on fire growth, smoke movement, building integrity, fire protection system effectiveness and occupant response and evacuation.

The occupant evacuation model developed uses environmental inputs and occupant response characteristics to simulate emergency evacuations. Experiments were conducted to quantify the effect of visibility on occupant speed and the findings are implemented in the model. It was found that gender was more influenced by smoke than age.

Case studies were conducted with the model to demonstrate its effectiveness in simulating building evacuations. The results indicate that alarm systems affect evacuation times significantly. Risk to life calculations indicate that fire services and sprinklers each reduce the probability of injury or death.

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1. INTRODUCTION

Risk modelling is very important to the fire safety industry as it allows a comparison of different designs leading to a selection of the optimal design for the building owner's needs. The fire safety design of a building cannot be based on a single fire scenario and considered to have an adequate fire safety design. An exhaustive set of scenarios must be evaluated together with the probability of each scenario occurring. This process allows the overall risk to the building's occupants and contents to be calculated.

Hadjisophocleous and Fu [1,2] outline a framework for a risk analysis model being developed at Carleton University. The model calculates the risk to life, as well as expected fire costs for four storey buildings. An example is done, in their paper, to show how each sub-model interacts with the others to calculate the life risk and economic loss.

Currently, there are few models that can be used to evaluate fire safety levels in a building. CESARE Risk [3,4], CRISP [4,5], FiRECAM [4,6], and FIERASystem [4,7] are a few examples, however, only FiRECAM is available to fire protection designers. The Fire Safety Engineering group at Carleton University is developing a comprehensive fire risk analysis model which considers the environmental progression of the fire, the impact of the fire on the building, the effectiveness and impact of the active fire protection systems and the response and evacuation of building occupants. The model calculates the economic impact of fires and the expected risk to life, by considering the most probable fire scenarios that may occur in the building.

One of the sub-models of the risk model is the occupant evacuation sub-model. The development of the evacuation model is one of the objectives of this work. In addition to the evacuation model, experiments were performed to determine the impact of visibility on the speed of occupants, and produce speed adjustment factors that are used in the model. This report provides a description of the experimental facility, and the methodology used for the tests. Data acquisition technology and procedures used to obtain speed values are also discussed. The evacuation tests were done using the SHEBA (SHip Evacuation Behaviour Assessment) facility of BMT Fleet Technology [8].

The effect of optical density during emergency lighting conditions was considered. Results are presented in a statistical manner assuming that the behaviour of each demographic follows a trend under given combinations of emergency conditions.

1.1 Objectives

The objective of this work is to develop an occupant evacuation computer model that will be easily integrated with other sub-models into a fire risk analysis model.

The overall objective of the experiments was to collect data suitable for incorporation in the occupant evacuation model. The data obtained were used to create speed adjustment factors to compensate for different levels of smoke an occupant may encounter.

Specifically, the objectives of this project were to:

- Develop an occupant evacuation computer model which can be integrated in a Risk Analysis framework.
- Collect speed and behaviour data for persons and groups of persons moving along a corridor and ascending/descending stairs.
- Determine the effect of optical density on the speeds and behaviours of persons and groups.
- Determine occupant characteristics that influence occupant evacuation.
- Determine statistically valid modification factors to apply to “normal” speeds in adverse visibility conditions.

1.2 Scope of Report

This report outlines the development of an occupant evacuation computer model and how it functions within the overall framework of the risk project. The model is designed to be as robust as possible but its primary focus is commercial buildings of a height not exceeding four storeys.

The literature review performed, found in Chapter 2, deals with models and theories of evacuation modelling, and general occupant evacuation considerations.

Chapter 3 and Chapter 4 describe the experimental facility and the results obtained, showing the effect of smoke levels and visibility on occupant evacuation speeds.

In Chapter 5, the modelling methodology used for the evacuation model is discussed. A brief introduction to the risk model is given to understand the scope of the model and the need for an occupant evacuation simulator within that model. The occupant response model is also discussed to show the behavioural aspect of the occupants that is being considered in a separate subroutine of the overall program.

The predictions of the evacuation model are shown in Chapter 6. A case study is done to show how it functions with the other programs developed at Carleton University.

All data and cursory information is placed in appendices for easy access and broader understanding of the overall project.

2. LITERATURE REVIEW

The study of occupant evacuation in fire situations is relatively new. Information is difficult to find on the topic because, in order for experiments to be done, people would have to be exposed to hazardous conditions. Thus, the only data that are obtained are from accidental fire situations where questionnaires can be handed out or through interviews of occupants involved in fire incidents. Evacuation drills can reveal limited data but these drills do not represent the actual conditions people will be exposed to during a fire. The literature review covered both occupant response and evacuation. In addition, the literature addresses research work in evacuation modelling techniques.

2.1 Introduction to the Evacuation Process

The evacuation process is the combination of several aspects and it begins as soon as the fire is started. In the BSI (British Standards Institution) [9], it is shown that the evacuation time is broken down into pre-movement time and travel time, seen in Equation 1.

$$\Delta t_{evac} = \Delta t_{pre} + \Delta t_{trav} \quad \text{Equation 1}$$

The pre-movement time is further divided into recognition time and response time. The recognition time is the time required for an occupant to become aware that there is a fire in the building. This time depends on the location of the occupant with respect to the fire source. The response time is the time period between the time of recognition of the fire source and the time when the occupant begins to evacuate the

building. After the occupants have responded, the travel time is the time required for the occupants to move from their position at the time of response to an area of safety. Δt_{evac} is also known as the Required Safe Egress Time (RSET), or the time occupants will need to evacuate the building in question. The time available for safe evacuation, which is the time when untenable conditions occur in the building, is referred to as the Available Safe Egress Time (ASET). This is the maximum time occupants will have to evacuate the building in question. In order for a design to be deemed safe for occupants, the Required Safe Egress Time (RSET) must be less than the Available Safe Egress Time (ASET). If this is the case, occupants will have more time than necessary to evacuate and will be less likely to incur injuries from the fire effects.

2.2 Occupant Response and Characteristics

It is the response of the occupants which is most crucial to the evacuation process, especially in the compartment of fire origin [10, 11]. The quicker occupants respond to the cues they are given, the more likely they are to have a safe egress. Response is based on the characteristics of cues offered to the occupants and the characteristics of the occupants [9].

In the BSI [9], eight major occupant characteristics are described. They are familiarity with the building, alertness, mobility, social affiliation, role and responsibility, location in the building, commitment and presence of focal points in the building. Familiarity with the building will determine whether the occupant knows where all the exits are located and which evacuation routes are best under the conditions. Alertness

will impact the occupant's ability to respond. Someone sleeping will respond much later than an occupant who is awake. Mobility is the ability of the person to move towards an exit. This can be altered in several ways, such as by the presence of smoke, high population density or physical disability. Each of these conditions would reduce the mobility of the occupant in question. Social affiliation means that an occupant will strive to remain with a group of individuals he is emotionally attached to. An example would be a father not leaving a building without his child. Role and responsibility will impact the occupant behaviour during the response period. A customer at a store will respond differently to a fire than the owner or an employee will. Location in the building will affect the occupant response because an occupant in the compartment of fire origin will receive cues sooner than all other occupants. Commitment is when an occupant is in a situation where they cannot stop the activity or they do not feel immediately threatened to cause them to stop their activity. An occupant using a restroom would likely be committed to finishing the activity before evacuating. Focal points are places in a building where most occupants will focus their attention. An example of this could be the stage at a theatre or the ice at a hockey arena. Occupants will be less likely to notice a fire in another part of these buildings because their attention is directed to a specific area of the building. Shields and Boyce [12] discuss results of four unannounced evacuations in three storey department stores and how the eight occupant characteristics impact the evacuation process.

Proulx [13] discusses the reasons for installing fire alarm systems in buildings.

The reasons given are as follows:

- Warn occupants of a fire
- Have prompt and immediate action
- Initiate evacuation movement
- Allow sufficient time to escape

Often, however, these objectives are not met because occupants ignore the alarm. This can be due to occupants not knowing what the alarm signal means or frustration with frequent false alarms and fire drills. Proulx states that research must be done in this area to determine the effect of false alarms or fire drills on an occupant's likelihood to evacuate when they hear an alarm. Another problem for occupant response can be the audibility of the alarm signal. In some high-rise buildings, Proulx found that some occupants could not hear the signal from inside their apartment. Combining other methods of alerting occupants and safety training with an alarm system will make it more reliable. These can include voice communication messages, training of occupants, fire drills and a complete fire safety plan. It will be the combination of these elements that will ensure the safety of occupants.

In addition to the work of Proulx, Bryan [14] explains the process behind the design of an alarm system and how voice alarm systems can increase the likelihood occupants will evacuate.

2.3 Effect of Environmental Conditions on Movement and Behaviour

In a fire, evacuation can be greatly impeded by the presence of smoke because the speeds of the occupants are reduced significantly. This is, in part, due to decreased visibility as well as irritation of the eyes and the respiratory systems of the occupants. Irritation and reduced visibility can have psychological as well as physiological effects on occupants

Tadahisa Jin [15, 16] did a great deal of work in the area of smoke effects on people. Obscuration, occupant visibility and the effect on behavioural patterns were part of his studies. These experiments were a great help to subsequent researchers in the field, giving quantitative values to these ideas. These tests were performed with actual irritant smoke to check for behaviour and visibility capability. The effect of increased smoke density was to create unrest or panic for the test subjects. Walking speeds were found to decrease with the increase in smoke density. Behavioural data were collected in the form of concentration tasks, where most of the subjects were housewives. While performing a task, the room was filled with smoke at a constant rate and the subject's efficiency at the task was observed at different levels of smoke. It was determined that for someone who is familiar with a building, the optical density of the smoke must not exceed 0.5 OD/m to allow for safe egress, while a person unfamiliar with the building would require less than 0.1 OD/m to ensure safe egress. The last test was conducted in a corridor filled with white, irritant smoke and heaters. The subjects had to answer arithmetic questions while moving from one end to the other. Their competence decreased at the beginning of the corridor when the smoke was first introduced.

Purser [17] discusses the behavioural impact of smoke-filled environments on the occupants of an aircraft. People are sceptical of moving through smoke to reach an exit and if these paths are chosen, the evacuation speeds are greatly reduced for optical densities greater than 0.5 OD/m. Different types of fires are considered, showing the impact each condition has on evacuation.

How a crowd moves can be important to the evacuation process in a large building or open area, such as a sport facility, where thousands of people try to evacuate simultaneously.

Fruin [18] developed correlations based on crowd density, which allow expected crowd movement speeds to be calculated. The research was done for walkways but is transferable to building cases. He refers to the population density as a level-of-service. There are six levels of service, ranging from A to F in his model. Level-of-service A is the least populated, where an occupant occupies about 35 square feet (3.25 m^2) in area. The levels of service then decrease in available area up to level-of-service F, where an occupant occupies about 5 square feet (0.46 m^2) in area. At this level, walking becomes quite restricted and only shuffling movement is attainable. These are the levels of service for a walkway. Fruin also discusses levels of service for stairways and queuing, which are also applicable to building design.

Algadhi and Mahmassani [19] state that more research is required for pedestrian movement in crowded situations. Three types of crowd movement models can be used: controlled uniform movement, disorderly movement and individual behaviour to the crowd phenomenon. It is shown that a turbulence model from fluid dynamics can model the disorderly movement exhibited by crowds effectively.

Okazaki and Matsushita [20] have developed a model in which people act as though they are particles within an electromagnetic field. Occupants and barriers are given positive charges so that they repel each other, while exits are given negative charges so that the occupants seek them out. This is more like the controlled, uniform movement of a crowd because the program only deals with office building evacuation and queuing behaviour.

Bradley [21] compares the similarity between flows in a crowd and those of a fluid. The proposed use is to predict dangerous situations created by crowd surges. These characteristics are only visible in densely packed crowds, where the population density is much higher than the norm.

Ketchell and Cole [22] have developed a program, EGRESS, which uses a movement model in tandem with a behavioural model to simulate an emergency evacuation process. It interprets the behaviour of the occupant, which led to decisions to select a specific evacuation route. Cellular automata techniques are used by splitting the floor plan into grid spaces which can either be occupied or unoccupied.

Stanton and Wanless [23] discuss the factors affecting pedestrian flow and methods to grade existing and future facilities. The six levels of service, as defined by Fruin [18], are discussed to show how different crowd densities will impede progress to different extents. In the absence of smoke, it isn't until the flow capacities of route elements are reached that evacuation problems occur. People become blocked from the exit and this is when dangerous circumstances arise.

Velastin and Yin [24] employ methods to automatically calculate crowd density and velocity through the use of video, rather than having human error involved in collecting data. Checking boundary fringes, the computer can calculate how many people are in a given area on the screen. By checking for head movements, forward motion can be discerned and general directions of each person can be ascertained.

Yamori [25] discusses macro and micro dynamics in crowd behaviour, revealing patterns that often emerge when two groups approach each other. The time of day and week were also altered to check the effect on subject behaviour. It was found that a critical crowd density is required in order for banded behaviour to occur. Banded behaviour is the phenomenon of people in a crowd moving together to make travelling through a crowd easier. The banded behaviour looks like a "river" of people moving through a crowd. Banded behaviour is rated with the Band Index to quantify the amount of this behaviour occurring in a crowd. The Band Index is rated from 0 to 1.0 in theory, but never exceeded 0.5 in practice. The banding process is dependent on the subjects at the head of the groups. If these people band together and form a wedge to break through

an oncoming group, the people behind them will follow this path. Otherwise, many smaller paths will be followed and the movement will be much more chaotic.

Clifford [26] investigates the usefulness of computer simulation to design sport facilities and other large buildings, to optimize crowd movement. The levels of service, determined by Fruin [18], are again employed. A corresponding population density is then given to each level of service. The levels of service are then broken down for each type of compartment so that walkways, stairways and queuing areas each have different expected population densities for the same level of service.

Pauls [27] discusses the relationship between the rate of flow of occupants and the width of the stairwell. The overall time to evacuate the building is discussed as well. The paper looks at the effects of population density in stairwells for high-rise office buildings. Correlations for expected speeds are made based on the effective width of the stairwell. In the paper, the effective width is 300mm less than the actual width of the stairwell. Using Fruin's levels of service [18], Pauls states that the optimal level of service for occupant evacuation of high-rise buildings is level-of-service E. It is hoped that data such as this will be used in future exit designs.

2.4 Evacuation Models

There have been many occupant evacuation models created and each one was developed for a specific purpose. Although, each program is designed to be as robust as possible, simplifications are inevitable so that the program may function efficiently.

Limitations include the environment in which the program may be used, the number of occupants or compartments allowed to be modelled and the detail of information given to the user.

The simplest method for modelling occupant evacuation is the use of correlations found in the SFPE Handbook [28]. These correlations will only yield an estimate of the time of evacuation of high-rise office buildings and should not be used for design purposes. The correlations are a quick method to see if a design makes sense, but the design should always be checked by a more accurate method.

EvacNET is one of the evacuation models available [29]. The model is a network model and it does not consider individual movements or decisions. The occupants within a given compartment are treated as a single group which moves together. The program yields the minimum time required to evacuate the given building because the program strives to optimize evacuation. This program is useful when planning evacuation routes of a building.

EXODUS [30, 31, 32, 33, 34, 35] and maritimeEXODUS [33, 35], a version of EXODUS used in the marine industry, are two of the more highly evolved programs for occupant evacuation. They consider independent occupant movements and allow diverse floor plans. The programs simulate evacuation of buildings or ships and are being updated to consider the impact of smoke on the evacuation process. Included in the program are Movement, Toxicity, Behaviour, Hazard and Occupant sub-models. The program is a standalone product.

Alterations to the functionality of EXODUS are discussed by Gwynne and Galea [34], to create buildingEXODUS. This model allows the occupants to make more realistic decisions when confronted with a fire situation. Using data from real fire situations, the model uses redirection probabilities to move occupants in a manner similar to that found in real fire situations. The model considers the probability of an exit's selection based on line-of-sight as well as crowding around doorways. If a door can not be seen from an occupant's location, they are less likely to use it. Also, if a doorway is more crowded than another, the occupant is less likely to use it. In order for an occupant to interact with the changing environment, the familiarity the occupant has with the building must be known. Familiarity may cause occupants to select an exit further away from them because it is the exit they use on a daily basis. The paper gives simulation examples of how buildingEXODUS represents these ideas.

Galea [35] discusses the requirements for proper validation of a simulation model. A reliable set of data to compare model predictions with is necessary but often hard to obtain. A set of data which tells where each occupant is at the beginning of a simulation, the path they chose to use and their time to evacuate is not readily available. This makes the task of validation difficult to complete with certainty, which means that it should be an ongoing process which should evolve as new data are available for comparison. The variability of human behaviour also makes this task increasingly difficult since tasks will seldom be replicated exactly in real life. There is a lack of realism in any test which is specifically designed to obtain all the relevant information because it becomes a fire drill rather than an accurate evacuation. Occupants will immediately begin to evacuate rather

than spending time gathering belongings or other tasks they may engage in when the threat of an actual fire is there. This is why validation must be an ongoing evaluation of the model.

Gwynne and Galea [4] discuss the importance of repeating suitability tests for building designs. When using full-scale evacuations, usually only one test is performed and this may not be representative of the building. To get accurate evacuation results, tests should be repeated several times. The cost and impracticality of such repetition usually limits the amount of actual evacuations performed in buildings. These tests can only be performed after the building is constructed, which makes any required alterations tedious and costly. This makes the use of evacuation models necessary in order to obtain optimal designs. The designers of evacuation models must make decisions as to how their model will operate. The nature of the model and methods of enclosure representation, population representation and behavioural perspective must all be selected. The choices will impact the accuracy, computational requirements and applicability of the model.

Evacuation models are divided into optimization, simulation and risk assessment tools. The optimization models assume that occupants will select the most efficient path to the outside and ignore non-evacuation activities. Flow characteristics of people and exits are also assumed to be optimal. These evacuation models are designed to handle large populations and do not consider individual characteristics of the occupants. An example of an optimization model would be EvacNET [29]. Simulation models allow representation of occupant behaviour observed in actual evacuations. This means that the

paths occupants select in these simulations will be more representative of an actual evacuation. An example of a simulation model is EXODUS. Risk assessment models are designed to reveal hazards which may be encountered during an evacuation, as well as quantifying the associated risk. Repeating multiple simulations with a risk assessment model allows statistical variations to be considered. These models incorporate the likelihood of a fire scenario and the dangers associated with that fire scenario, creating an overall risk calculation for the building. Examples of risk assessment models are CRISP and FIERA system.

Simulation models are subdivided based on how they represent the enclosure, population perspective and behavioural perspective. The enclosure can be represented by a fine network or a coarse network. A fine network allows a compartment to be divided into smaller sections that may have their own characteristics. This allows better representation of people to people interactions, such as crowd movement. A coarse network assumes that only compartments and their connections are important to the modelling atmosphere. An occupant's location is less accurate when using a coarse network.

The perspective of the population can either be individual or global. Individual perspective allows for a diverse population to be modelled and allows individual trajectories or histories to be investigated. The global perspective looks at the evacuation of a group. This yields the number of occupants evacuated over time but not the exact paths that were taken by each occupant. This type of model runs more quickly than the

individual perspective models but it also lacks the detailed results of the individual model.

Regarding the modelling of behavioural perspective, there are five methods that could be considered as follows: no behavioural rules, functional analogy behaviour, implicit behaviour, explicit behaviour (rule-based behaviour) and artificial intelligence behaviour. If a model has no behavioural perspective rules then it assumes that the movement of the population, as well as the enclosure representation, will influence and determine the evacuation process. Using a functional analogy behaviour model allows individuals to be defined separately although they will all be affected by the function in the same way. The function used to represent the occupants does not necessarily have to be from actual occupant behaviour experiments. The function can be from another scientific phenomenon that is assumed to be similar to the movement of occupants. An example of this is treating occupants and obstacles as magnets. The path the occupant will choose is the resulting magnetic field based upon the location of all other magnetic poles. Some models assume that the behavioural rules are implicitly represented by the physical model they have selected. The models are based on secondary data that is comprised of psychological and sociological effects. The models do not use functions or equations to represent these ideas but rely on the validity of the data to accurately model human behaviour. Models which use a rule-based behaviour system explicitly acknowledge that occupants have individual characteristics. These models allow the occupants to make decisions based on a set of rules. The rules may be triggered every time or only in some cases. An example of a rule could be, "If a compartment is filled

with a certain level of smoke, do not enter it”. Artificial intelligence behaviour is the last method of modelling the behavioural perspective. This allows each occupant to respond to the fire situation in a realistic manner. The occupants in these programs will make decisions based on all the information afforded to them, as a “real life” occupant would. In order to design an evacuation model, each of these components must be considered.

Gwynne and Galea [30] detail the four aspects of occupant evacuation performance which must be considered in order to have an accurate simulation. These include configuration, environmental, procedural and behavioural effects. The configuration of the enclosure includes the size of compartments such as rooms, exits, corridors and stairwells. The environmental effects include the heat, toxic gases and smoke or other irritants and how they affect the evacuation of the occupants. Procedures which are used during the evacuation process would impact the knowledge of the occupants. This includes the training of staff and knowledge of exit locations for unfamiliar occupants. Lastly, the behavioural aspect of the evacuation includes interaction, adopted roles, travel speeds and general responses to the situation. Each contributor to the evacuation process must be considered to some extent. Different models are more detailed in certain areas than others.

Galea and Lawrence [31] discuss changes to existing models in order to make them enclosure specific. The process shows how EXODUS was adapted for use in hospitals. New methods of evacuation are required due to the demographic of occupants. Occupants will likely be less than able-bodied and will require special attention from staff members. It becomes important to know which buildings a simulation is valid for

and whether or not it can be modified for use in others. Most buildings of interest are standard, public buildings but those requiring special consideration must be accurately modelled. Without the adaptations made to EXODUS, it would not be able to model the evacuation of a hospital accurately and provide realistic results.

Gwynne and Galea [32] adapted the EXODUS program to account for exit congestion. This makes the program more realistic since people may not wait in a line of hundreds of people to evacuate, if there is another exit less congested. The decision to select another exit is based upon line of sight information as well as cues from other occupants. The results show more distributed populations using each exit rather than congestion at several exits.

MacLennan and Regan [36] describe a method by which the Required Safe Egress Time (RSET) can be accurately modelled for each occupant within a building, depending on location and occupant state. This is the theory of occupant response which directly affects the occupant evacuation.

2.5 Research Pertaining to BMT Fleet Technology Limited Experimentation

In order to understand the experiments, which are included in this project, a cursory study was required on marine evacuations and previous work done by BMT Fleet Technology Limited.

Galea [33] shows the extension of the EXODUS model and how it can be applied to naval situations. There are several different considerations which must be looked at in this case compared to a building evacuation. One is that occupants will be evacuating up

stairs rather than down stairs most often, in order to reach the deck of the ship. Other differences include searching for and donning life jackets to improve survival after abandoning the vessel. Differences like these must be accounted for when designing an evacuation tool for the marine environment.

Galea and Filippidis [8] discuss the usefulness of maritimeEXODUS and how it is unique to the marine environment. The inclusion of SHEBA experimental data is discussed, and the methods used in the experiments are also explained. Details of the data are outlined. An example simulation is described to show how the program can deal with marine-specific environments.

2.6 Theories and Other Information

This section presents several ideas on methods of programming or concepts which need to be considered when modelling occupant evacuation. These papers discuss the reasons for including a theory rather than the implementation.

Purser [37] shows the technical reasons for the shift to performance-based codes from the standard prescriptive codes. Human tenability is of major concern for the engineering community so it must be considered accurately or conservatively. Knowing concentrations of potential toxicants or heat fluxes at any given time can yield the likelihood of a human surviving in these conditions. Not only is it important to consider the immediate effects of the fire environment but also the long term impact on an occupant's health. The problem in trying to obtain realistic data for a tenability model is that no direct experimentation can be carried out. Humans cannot be exposed to

dangerous conditions like a timber assembly can be. The paper goes over the equations used to calculate time of incapacitation or death to an occupant for different irritants.

Li and Ye [38] outline the considerations which must be made when simulating the evacuation of a high-rise building. Methods to calculate time until doorways are reached as well as population densities and flow curves are detailed.

Spearpoint [39] shows how population distributions prior to evacuation can affect the evacuation process. Examples are performed using the Simulex model [4] but the ideas can be used in other programs. The paper states that when pre-evacuation time distributions are large, it is the pre-evacuation time that dominates the overall time for those occupants to evacuate the building. When the distribution for pre-evacuation times is small, it is the travel time and queuing that will dominate the overall evacuation time for the occupants. Thus, if occupants all decide to leave at the same time, the evacuation process will be slow due to queuing effects. In this case, the queuing time will effect the total evacuation time more than the pre-evacuation time.

2.7 Literature Review Conclusions

The progression of understanding human behaviour in fire scenarios is shown in detail by the wide range of literature reviewed. Research in the field has developed correlations, patterns and important characteristics of occupants which all impact how they may evacuate a building.

Once a strong understanding was established, researchers began to model this occupant behaviour with computer models. This allowed new designs to be tested, aiming at reducing cost without decreasing the life safety of the building.

The evacuation model developed and described in this paper is different from the others found in the literature because it is compatible with multiple other programs being developed concurrently at Carleton University, which consider different aspects of the fire scenario. These programs combined calculate the risk from fires to building occupants. The risk model considers fire growth and spread, smoke movement, economic impact, reaction and impact of the fire department, fire protection system efficiency and effectiveness, occupant response and evacuation to arrive at an estimate of the risk to life and property damage for multiple scenarios. Different sub-models are integrated and run as an all-encompassing model that yields information on each aspect of a fire scenario and its impact. Having a model like this available to industry will be invaluable. Due to the lack of integrated models, designers are often forced to use a combination of models and to transfer data and outputs from one model to another, manually; an activity that is very prone to errors.

The evacuation model discussed in this report is a combination of different ideas on how human behaviour should be modelled. It uses nodal evacuation procedures, like EvacNET, but it considers each occupant separately rather than as part of a group. Since only the general position of the occupant is required to calculate the danger to each occupant, only the compartment the occupant occupies is required. An exact location within a compartment is not necessary, allowing the model to complete the simulation

more quickly. Not using the Cartesian location of each occupant means that crowding is not considered because exact location within the compartment is not known, however, occupant densities in compartments, corridors and egress routes are included.

This model lies between the nodal, hydraulic model and the occupant by occupant type models which consider position and interactions. This allows the user to obtain results which can be integrated easily into a complete building analysis.

There are few risk models that can simulate an entire fire scenario and yield results for every aspect of that scenario. The Carleton University risk assessment model will be able to calculate the risk to life as well as the damage to the building and its contents. It will simulate the fire and smoke spread through the building and use these results to calculate occupant response. The effect of sprinklers and fire services is also part of the model. The occupant evacuation model uses all of these results as inputs and computes a likely evacuation path for each occupant. These data are then used to determine the risk to life for the occupants based on the probability of each fire scenario occurring in the building.

3. EXPERIMENTAL WORK

In order to make the occupant evacuation model as realistic as possible, experiments were performed on the effect of visibility on evacuation speeds. These experiments were performed in conjunction with BMT Fleet Technology Limited (BMT FTL), using their SHip Evacuation Behaviour Assessment (SHEBA) facility. The tests focused on the effect of ship angle and smoke levels on evacuation speeds through a corridor and a set of stairs. The data without the effect of angle is the only data incorporated in the evacuation model so only these results will be discussed.

3.1 Introduction to Experiment

BMT FTL has developed the SHEBA facility that features a passageway and staircase designed to ship-like standards. The SHEBA facility has previously been used to observe and measure the behaviour of several hundred volunteers with the rig subjected to angles of static heel, representing a damaged (listing) vessel. This information has been incorporated into the evacuation analysis tool maritimeEXODUS developed by the University of Greenwich. With partial funding from Precarn Inc., BMT FTL has added the ability to subject volunteer test participants to simulated smoke. The tests were conducted from May through July of 2003, with varied smoke density, under emergency lighting conditions.

Groups of 15 to 20 participants took part in each test. During each test, four trials were performed using combinations of three angles and four levels of smoke density. Each trial included: individual runs through SHEBA in both directions (up and down the

corridor of the facility); group runs through SHEBA in both directions; and a counter-flow group run, all performed under repeatable conditions. The baseline trial for each test was at conditions of: normal lighting/level (0°)/no smoke conditions. This represents the basic familiarity with the environment that occupants could be expected to have gained prior to an emergency. After the baseline trial, there were trials which involved angles of 0° , 10° and 20° and optical densities of 0.1, 0.5 and 1.0 OD/metre (Note: optical density per metre is a logarithmic scale where 1.0 OD/m means that 90% of light is absorbed over one metre, 2 OD/m means 99% is absorbed over one metre, etc. At the lowest value of 0.1 OD/m, an occupant can see about 13 meters ahead. At the highest value of 1.0 OD/m, an occupant can see about one meter in front of them. Refer to Appendix A). The combination and order of these trials were changed for each test.

3.2 Experimental Layout

The SHEBA facility consists of a small room (3.65m x 2.4m) at one end, followed by an 11m long corridor. The corridor is connected to a flight of stairs ascending 2 metres to a platform and exit (see Figure 1 and Figure 2). The corridor and stair dimensions are based on standard dimensions found on passenger vessels. Railings were also fitted to the rig according to standard ship sizing. The corridor is 1.89m wide (1.63m between railings). The staircase is 1.53m wide (1.30m between railings) and has a total of 9 steps, each 200mm high, with a step run of 230mm. This staircase is raised from the corridor so that a participant walking along the corridor would have to ascend

the stairs once they were reached. Traversing in the opposite direction, the participant would first descend the stairs and then move along the corridor.

Figure 1 – SHEBA Test Rig

Figure 2 – Plan and Profile View of SHEBA

3.3 Modifications to SHEBA

3.3.1 Overview of Modifications

Before this set of tests could be undertaken, SHEBA had to be modified to create the desired environmental conditions and to observe and measure participants' behaviour in those conditions. This required smoke generators, new sensors, and optical density meters as well as infrared filters for the cameras. SHEBA also required a roof and curtains at each end to contain the smoke within the rig. Photographs of the features described in the following section can be found in Appendix B.

3.3.2 Description of Additional Features

a) Smoke Generators

The smoke machines used were Fog F/X Model 1741 by MultiMedia Electronics Inc., Farmingdale, NJ. The machines generate a fog by vaporizing a commercial product known as “Fog Juice”. A Material Safety Data Sheet was obtained for Fog Juice (see Appendix A) which showed the main ingredients to be Glycerin ($C_3H_8O_3$), Dipropylene Glycol ($C_6H_{14}O_3$) and Propylene Glycol ($C_3H_8O_2$). Various sources were checked to confirm that there are no health concerns relating to repeated exposure to glycerin-based fogs, including research on behalf of the Actors’ Union, EQUITY, whose members are sometimes exposed repeatedly to fog effects in stage shows. EQUITY’s studies showed that prolonged exposure had no adverse, permanent effects [40]. Short-term irritation from the fog is not unheard of, for which the remedy is fresh air.

Three Fog F/X machines were placed on the high side (when tilted) of SHEBA (see Figure 1 for view of the SHEBA apparatus tilted). On/off controls for each machine were located at the SHEBA control console. SHEBA’s operators found they could fill the rig to the desired smoke level and keep it (within tolerance) at that level by observing readings obtained from the two optical density meters, and manually adding bursts of smoke from the appropriate machines.

It was found that the “smoke” machines could produce a density of over 1.5 OD/m in SHEBA, well above the maximum level of 1.0 OD/m selected for the trials. (At the 1.0 OD/m level, 90% of incident light is absorbed over a path of one metre. Consequently, at this density, an outstretched hand almost disappears from view.)

b) Optical Density Meters

Two optical density meters, obtained under loan from the Fire Research Laboratories of the National Research Council (NRC), were placed in SHEBA near each end of the corridor and positioned perpendicular to each other. The meters were calibrated by NRC, and the calibration curves used in BMT FTL's in-house data acquisition software. The two meters took readings every second and values were plotted in the data acquisition software.

c) Optical Sensors

Optical sensors were used to monitor occupant movement during this set of tests. Sensors used in previous trials were single unit emitter/receivers, mounted in SHEBA's walls, that emitted beams to a reflective surface on the opposite wall causing the beam to return to the unit. When a person broke the beam the time was recorded. With the addition of smoke, too much of the light was absorbed for the sensors to be effective, and the units could not be modified. Sensors with separate emitters and receivers were purchased and mounted opposite each other, thus halving the beam path required. Initially, these units also had problems penetrating the thicker smoke but it was found that the source supply voltage could be increased from 12V to 120V. With the 120V supply, they were very effective even in the highest density of smoke tested (1.5 OD/m).

d) Infrared Camera Filters

The effectiveness of SHEBA's existing cameras in smoke was improved by the addition of infrared filters. Limiting the spectrum viewed by the cameras to the infrared spectrum reduced scattering by the fog, resulting in improved video visibility in SHEBA. Helmets worn by participants were fitted with an infrared Light Emitting Diode (LED) that could easily be seen with the infrared filters (although invisible to the human eye). For safety reasons, the trials personnel monitored live video displays of participants in the rig, and the LEDs showed participants' locations at all times. The LEDs showed up clearly on the videotape recordings, allowing human behaviour to be observed in post-trials analysis. Participants also wore a distinguishing number, which could be related to the individual when reviewing videotapes. (Such analysis is outside the scope of this report, but the tapes have been provided to the University of Greenwich for such review.)

e) Roof and Smoke Curtains

To contain the smoke created by the generators, SHEBA was fitted with a roof as well as plastic curtains at either end. The result was very effective. The curtains were placed before and after the first and last sensor beams so as not to impede participants. The curtains were sheets of plastic which hung from ceiling to floor at the entrance and exit to the SHEBA rig. Each opening was covered with 2 panels of plastic that each had Velcro strips on them to keep them sealed. The curtains were transparent so the participant could see the other side. Participants easily made their way through the curtains so that they were not held in the smoky conditions longer than was necessary.

Trial personnel were present at both ends of SHEBA to assist participants through the curtains, and to close the curtains between participants, keeping smoke levels constant.

3.4 Ethics Review

Since these tests involved human participants and conditions that could be viewed as potentially harmful or dangerous, the consent of the Carleton University Ethics Committee was obtained (see Appendix G). The ethics review included the data forms and consent forms that each participant would complete throughout the experimentation process.

3.5 Participants

Most participants for the tests were volunteers from the general public. BMT FTL repeated its “Abandon Ship for Charity” program, instituted for naval SHEBA trials in 2001, in which groups were encouraged to attend in exchange for a monetary donation to a charity of their choice. Abandon Ship for Charity was communicated by word of mouth, contacting groups who participated in previous trials, and local advertising. The administrator ensured that volunteer groups represented the demographic mix sought for the test program. At one stage, the number of over-50 year old participants was less than required so the monetary donation for 50+ was increased and service organizations and seniors’ clubs were successfully targeted.

A diverse range of participants was recruited including student groups, church groups, choirs, parents of Scouts and Guides, and active seniors groups.

3.6 Test Procedure

The test procedure was designed to obtain data in a safe manner for use in an evacuation simulation program. In Appendix A, the entire test matrix can be seen as well as a sample test form for a single test from the overall matrix. The methodology employed in establishing the test matrix is based on the considerations discussed in the following sections.

3.6.1 General Considerations

In developing the test procedures, the following factors were considered:

- a) test protocol was designed to ensure unbiased data was obtained consistently
- b) safety of all involved was paramount and steps were taken to ensure this
- c) each batch of volunteer participants would be available for a maximum of three hours
- d) requirements of the ethics committee

3.6.2 Test Matrix

An overall test plan (see Appendix A) was created based on the considerations from 3.6.1. (Note that in this discussion, “trial” means a configuration of angle and smoke held consistent for a batch of 15 to 20 participants. “Test” means a sequence of four trials using the same group of participants, carried out in a continuous session.)

A matrix of all possible combinations of smoke and angle was created. Since there were three angles and three optical densities being considered, this yielded nine unique combinations. (The additional combinations of three heel angles and zero smoke were available from the 2001 SHEBA data.) Once this was done, the order in which a smoke-angle combination appeared in the test was altered so that each combination was performed as the 2nd, 3rd and 4th trial at least once. In each case, the first trial was at zero heel, zero smoke and full lighting to simulate the likely familiarity occupants will have with a building prior to an emergency.

On the test matrix there is a column for test number. In each space there is a number followed by the number of the test this test is validating. Below this is a set number of 1, 2 or 3, denoting the non-repetitive combinations of 3 angles and 3 levels of smoke. Since there were 3 angles and 3 levels of smoke used, this yielded 3 non-repeating sets. Each set of combinations had 6 possible orders in which they could be performed, making 18 tests. After these 18 tests were performed the rest of the tests were performed to fill in areas that required additional data.

The order in the matrix, in which each singular test appeared, was also important. The test with the most diverse combinations was performed first because it was thought to be least susceptible to bias. The occupant would be exposed to such diverse conditions in this test that the impact of familiarity would be the lowest for this case. The next test always included a check on the previous test, which means the 2nd trial of the test had a similar condition to the 4th trial of the previous test. This was to minimize the effect of familiarity with the facility.

The sequence of tests was two tests from set 1, then two from set 2 and finally two from set 3. This way data were gathered evenly for each set of angle-smoke combinations.

This test matrix design allowed all data that were required to be collected in a logical manner, which reduced the effect of familiarity as much as possible. The learning curve of repeating a task several times is a natural occurrence but by performing each smoke-angle combination at different times during a test, this effect was reduced as much as possible in the final results for each condition.

3.6.3 Test Procedure

In general, only one test was performed in a day. On two occasions there was a test in the morning and one at night. Groups were required to be no less than 15 people to keep the number of tests required to a minimum.

The first task of each test was for the participants to don lifejackets while being videotaped so that the time taken could be extracted later. Participants wore the lifejackets through the entire test. This could represent the case of heavily dressed occupants in the winter season. Clearly numbered safety helmets were also worn for protection and identification purposes. The helmet number was recorded for each participant.

Each test comprised four trials. Each trial included individual runs through SHEBA in both directions; group runs through SHEBA in both directions; and a counter-flow group run, all performed under identical conditions. A baseline run of 0° and 0 OD

was performed in every test (except the last test, which was slightly different since to even up numbers, males and females were asked to perform different trials). The baseline run was done with the assumption that most passengers would become somewhat familiar with their surroundings on a ship. The baseline run was done at normal lighting conditions. All other trials that involved the addition of smoke were performed in emergency lighting conditions, simulated by dimming the lights in SHEBA to a marked setting on a dimmer switch. This was moderately repeatable. Light levels ranged from 7.96 to 15.91 LUX in the corridor, and a constant value of 5 LUX looking down from the top of the stairs (see Appendix A). Light levels were not recorded for each test.

For each trial condition, participants were first asked to line up at one end of SHEBA. They were called in, one at a time, and asked to briskly make their way to the other end. Once every participant had made it through, the task was repeated in the opposite direction. This tested the effect of ascending and descending stairs on the participants, as well as the effect of moving along the corridor towards stairs, with obscured vision. Once this was completed, the entire group was asked to make its way through SHEBA. The cue for this “group run” was a public address “emergency” announcement by the test director and ringing alarm bells to instil a sense of urgency in the participants. This was performed in both directions as well. Lastly, the group was split in half and the two halves started at opposite ends. Again, the test director made an evacuation announcement and sounded the alarm bell and both groups made their ways to the other end in a counter flow manner, having to manoeuvre past each other.

The group behaviour is captured on videotape for future analysis. An incidental benefit of the group runs was that the atmosphere was exciting for the participants and kept them interested in the task at hand.

3.6.4 Safety Monitoring

During all tests, BMT Fleet Technology Limited personnel were positioned in SHEBA at the following locations:

- outside of both sets of plastic curtains
- at the data acquisition console monitoring cameras
- following the participants through the smoke at high density (1.0 OD/m)

All personnel wore wireless headsets to communicate quickly and effectively within SHEBA.

Participants wore hard hats and a lifejacket for safety as well as identification (see Appendix B). They were also instructed that if they did not want to participate in any of the trials they could withdraw freely.

3.6.5 Measurements

All measurements of individual runs were taken with data acquisition software designed by BMT FTL specifically for SHEBA. As a participant broke the beam of a sensor it would record the time between the breaking of subsequent sensors. Each speed was recorded with the instantaneous level of smoke within SHEBA. Knowing the

distance between each sensor, speeds were automatically calculated for the participant between each sensor. An average speed was also calculated for the entire length of SHEBA.

The raw data collected from the sensors were saved and stored which allowed spot checks to be performed to ensure correct data were being presented by the program. Since it was not possible to maintain smoke levels at exactly 0.1, 0.5 or 1.0 OD/m, an acceptable range had to be decided upon. Table 1 shows the expected smoke level and the values that would be accepted. If points fell outside these ranges they were disregarded in the dataset.

Table 1 – Range of Optical Densities Accepted During Testing

Optical Density (OD/m)	
Expected	Accepted
0	0
0.1	0.085 - 0.24
0.5	0.35 - 0.64
1	0.85 - 1.14

For group runs, the sensors could not determine each person's speed since the beams have no way of knowing who has just passed and in what order. Since this was also data of value, the cameras inside SHEBA were fitted with infrared filters so that the participants could be seen. This will allow tapes to be viewed and behaviours and speeds of groups to be obtained. This has not been undertaken to date and will not be discussed in this report.

4. RESULTS AND ANALYSIS OF EXPERIMENTAL DATA

The results and analysis discussed in this Chapter are based on the raw data obtained from the tests described in Chapter 3. The data is not the entire set of data that was collected during the testing. Data pertaining to the effect of angle, or heel, is omitted in this report. In the analysis, extraneous points are removed and the format of the data is changed. The populations and their corresponding speeds, obtained from the experiments, sorted in demographic groups of gender and age, are shown next. These speeds are broken down into corridor speeds and stairwell speeds to make the data, and comparisons, more useful and to facilitate their use in the evacuation model.

4.1 Sample Population

The data shown in Table 2 is the demographic distribution of participants in the tests. These data include the people who participated in the tests which pertain to this report. The number of people, who performed each specific trial, is given. This is not the total number of participants who performed each trial because some data points have been removed due to irregularities or inconsistencies. For example, 59 men younger than 50 years of age performed the test with an optical density of 0.1 OD/m. Fourteen of these men were not included due to various irregularities, leaving 45 entries. One reason for excluding the results of a participant was speeds much greater than the average. This was done by checking if there were at least four other participants within ± 0.2 m/s of the

speed in question. So a participant that had a speed of 4.1 m/s in the corridor needed four other participants to have speeds between 3.9 m/s and 4.3 m/s to be included in the data used in this report. Another reason for exclusion was participants not having data recorded for all trials they performed. This ensured that comparisons between corridor and stairwell speeds were done with equal populations. Lastly, if the smoke during the trial was not at the optical density it should have been, the data was not used. Again, these optical density ranges are found in Table 1.

Table 2 – Demographic Distribution For Each Trial Combination

2003 Trials	Optical Density (OD/m)		
	0.1	0.5	1
Male < 50	45	53	21
Male 50+	25	18	22
Female < 50	39	35	27
Female 50+	24	22	21

0 Optical Density (OD/m)	2003	2001
Male < 50	116	44
Male 50+	55	26
Female < 50	107	33
Female 50+	59	12

It can be seen that in 2001 some tests were performed and these tests have been incorporated into the data gathered in 2003 to obtain a wider spectrum of data. Trials performed in 2001 only tested the effect of angle on an occupant's evacuation speed, so only the 0° data was used because this is the data relevant to building evacuations. Notice the value for females older than 49 from 2001. Each demographic was required to

have at least 18 people perform the trial so that the data had a sufficient population to have confidence in its use. This trial had 12 participants who performed it, but was combined with the data collected in 2003 and formed a group of 71 women older than 49. The data was checked to ensure it was not extremely different from the other data collected. This was done by checking the mean speed and standard deviation of common groups for both sets of tests. For example, comparing women less than 50 for both sets of tests, for speeds moving up the stairs, the numbers are similar. In 2001, the mean speed is 1.02 m/s with a standard deviation of 0.29 m/s. The sample population was 33 women. In 2003, the mean speed was 1.05 m/s with a standard deviation of 0.31 m/s. The sample population was 140 women. For further comparison, see Appendix D and Appendix E.

4.2 Corridor Speeds

In order to better understand the data described in the following sections, a description of the full data set is given.

Figure 3 is a graphical representation of the data collected for the group of males under the age of 50, moving along a corridor. For each optical density that was tested, the fraction of participants that attained each speed is shown. This creates a distribution of speeds so that the effect of smoke is visually represented.

Figure 3 – Corridor Speeds at Different Optical Densities for Men < 50

Table 3 shows the statistics of the data represented in Figure 3 and uses the same units for the data. The mean speed of the group at each smoke density is shown. To put the mean speed in perspective, the standard deviation of the data is given, along with the minimum and maximum values obtained. These values are in metres per second (m/s). The variance and sample populations are also given. For the complete set of data for the experiments, refer to Appendix D.

Table 3 – Results of Males < 50 Moving Along a Corridor in Varied Optical Densities

Speeds For Males Less Than 50 In a Corridor Exposed to Different Optical Densities						
Optical Density (OD/m)	Mean (m/s)	Minimum (m/s)	Maximum (m/s)	Standard Deviation (m/s)	Variance (m/s) ²	Sample Population
0	2.06	1.12	3.34	0.52	0.27	160
0.1	2.20	1.22	3.69	0.69	0.47	45
0.5	1.67	0.94	2.34	0.36	0.13	53
1	1.32	0.68	1.96	0.40	0.16	21

For ease of discussion in this report, only the mean speeds will be used to describe the visibility effects on evacuation speeds.

Data in Table 4 and Table 5 is graphically represented in Figure 4 and Figure 5. This data was collected from participants moving up the corridor (toward the stairs) and down the corridor (away from the stairs). From the graphs it can be seen that there tends to be a gender correlation for corridor speed, moving up or down the corridor. Females of any age tend to be affected similarly by the environment and the same is true for males. This is shown by the shapes of the graphs. The older women move at a slower pace than the younger women but the shape of their speed curves are similar.

Table 4 – Demographic Speed Breakdown Up Corridor

	Optical Density (OD/m)			
	0	0.1	0.5	1
Male < 50	2.32	2.65	1.79	1.42
Male >= 50	1.86	2.03	1.39	1.11
Female < 50	2.06	2.27	1.58	1.24
Female >= 50	1.58	1.55	0.91	0.95

Figure 4 – Graphical Representation of Table 4

Table 5 – Demographic Speed Breakdown Down Corridor

	Optical Density (OD/m)			
	0	0.1	0.5	1
Male < 50	2.42	2.68	1.85	1.58
Male >= 50	1.87	1.93	1.45	1.10
Female < 50	2.17	2.26	1.60	1.40
Female >= 50	1.61	1.49	0.95	0.99

Figure 5 – Graphical Representation of Table 5

In general, the introduction of minimal smoke (0.1 OD/m) increases egress speeds along the corridor. Corridor speeds tend to be faster after descending the stairs, than when participants are approaching the stairs. Since the first run for the participants was with no smoke, they knew there were stairs in the SHEBA facility. This likely made them cautious when approaching the stairs, so they had slower speeds.

4.3 Stair Speeds

Data in Table 6 and Table 7 is graphically represented in Figure 6 and Figure 7. This data was collected from participants moving up the staircase and down the staircase. From the graphs it can be seen that young males tend to be the fastest. They are followed by young women as the next fastest group. Older males are the third fastest group. Lastly, older women tend to be the slowest group.

The maximum speed for males less than 50 is 1.5 m/s when exposed to an optical density of 0.1 OD/m. This reduces to 1.0 m/s at an optical density of 1.0 OD/m. For females of the same age group, the maximum speed attained is 1.2 m/s at an optical density of 0.1 OD/m. This reduces to 0.9 m/s at an optical density of 1.0 OD/m. This shows the trend is common to people of similar age regardless of gender.

Table 6 – Demographic Breakdown Up Stairs

	Optical Density (OD/m)			
	0	0.1	0.5	1
Male < 50	1.37	1.53	1.22	1.00
Male >= 50	0.91	0.96	0.97	0.64
Female < 50	1.05	1.23	0.97	0.92
Female >= 50	0.72	0.71	0.59	0.62

Figure 6 – Graphical Representation of Table 6

Table 7 – Demographic Speed Breakdown Down Stairs

	Optical Density (OD/m)			
	0	0.1	0.5	1
Male < 50	1.24	1.32	1.12	1.00
Male >= 50	0.92	0.92	0.82	0.62
Female < 50	1.07	1.09	0.92	0.82
Female >= 50	0.71	0.61	0.52	0.53

Figure 7 – Graphical Representation of Table 7

The main objective in performing this set of experiments was to obtain an understanding of how different levels of smoke density, at low light levels, affected egress performance so that this phenomenon could be modelled accurately. The following analysis will show trends based on gender and age in a form that will be easily integrated into a computer simulation.

4.4 Previous Testing

A set of experiments were performed in 2001, prior to the experiments described in Chapter 3. This set of experiments only tested the effect of angle, commonly referred to as heel in the marine industry, on the evacuation speeds of occupants. These tests will henceforth be referred to as the Heel Tests. This data was then combined with the data collected with the procedures described in Chapter 3 so that the effect of angle could be separated from the effect of smoke density. For the purpose of this report, only the data obtained at 0° will be used because it is the data relevant to building evacuations. Data from both sets of experiments involving any amount of angle have been omitted because they do not pertain to the scope of this report. See Appendix E for the raw data from the Heel Tests and the demographic breakdown of the participants involved.

4.5 Tables of Heel Testing and Heel With Smoke Testing Data Merged

In Table 8 to Table 11, the combined data from the first 2 phases of SHEBA testing is shown. Data deemed unsatisfactory has been removed using the same criteria discussed in Section 4.1. The data found in Table 8 to Table 11 will be the data referred to for analysis or discussion of the model from this point forward.

4.6 Analysis of Corridor Speeds

Looking at the behaviour in the corridor alone, it appears that gender is a greater influence than participant age. Males tend to move at speeds higher than their female counterparts.

The following tables are speed factors for each demographic under each condition in SHEBA. All acquired speed data has been divided by the baseline value for that demographic. This yields a speed factor of 1.00 for the baseline trial. All other trials are relative to this value. A value less than 1.00 means that the effect of the environment was to slow the participant, while a value greater than 1.00 means it increased egress speed.

Table 8 – Speeds Up Corridor Relative to Baseline Trial

	Optical Density (OD/m)				<u>Baseline</u>
	0	0.1	0.5	1	
Male < 50	1.0	1.1	0.8	0.7	2.25
Male >= 50	1.0	1.1	0.8	0.6	1.93
Female < 50	1.0	1.2	0.8	0.6	2.09
Female >= 50	1.0	1.0	0.6	0.6	1.69

Table 9 – Speeds Down Corridor Relative to Baseline Trial

	Optical Density (OD/m)				<u>Baseline</u>
	0	0.1	0.5	1	
Male < 50	1.0	1.1	0.8	0.7	2.41
Male >= 50	1.0	1.1	0.8	0.7	2.00
Female < 50	1.0	1.1	0.8	0.7	2.24
Female >= 50	1.0	0.9	0.6	0.7	1.79

These speed factors are used in the occupant evacuation model to adjust speeds according to the levels of smoke the occupant is subjected to in a corridor or compartment. This is discussed in greater detail, in Chapter 5.

4.7 Analysis of Stair Speeds

Ascending and descending the stairs yielded different effects on participants. The rate of moving up the stairs was more age dependent, while the rate of descending the stairs tended to be more gender dependent. Since occupants will descend stairs more often than ascend them, in a fire emergency, this data was deemed more valuable.

An increase in optical density caused a decrease in participant speed. However, the addition of minimal smoke (0.1 OD/m) increased speeds up and down the staircase. Speeds on the staircase were slower than those along the corridor.

The following tables are speed factors for each group under each condition in SHEBA. All acquired speed data has been divided by the baseline value for that demographic. This yields a speed factor of 1.00 for the baseline trial. All other trials are relative to this value. A value less than 1.00 means that the effect of the environment was to slow the participant while a value greater than 1.00 means it hastened egress.

Table 10 – Speeds Ascending Stairs Relative to Baseline Trial

	Optical Density (OD/m)				<u>Baseline</u>
	0	0.1	0.5	1	
Male < 50	1.0	1.1	0.9	0.8	1.33
Male >= 50	1.0	1.0	1.0	0.7	0.95
Female < 50	1.0	1.1	1.0	0.9	1.05
Female >= 50	1.0	1.0	0.8	0.8	0.75

Table 11 – Speeds Descending Stairs Relative to Baseline Trial

	Optical Density (OD/m)				<u>Baseline</u>
	0	0.1	0.5	1	
Male < 50	1.00	1.00	0.91	0.81	1.23
Male >= 50	1.00	0.96	0.86	0.65	0.96
Female < 50	1.00	1.01	0.85	0.79	1.08
Female >= 50	1.00	0.83	0.70	0.71	0.74

These speed factors are used in the occupant evacuation model to adjust speeds according to the levels of smoke the occupant is subjected to while descending a stairwell. This is discussed in greater detail, in Section 5.

4.8 Effect of Trial Order

When considering the effect of trial order on the speed factors, the data from the SHEBA Heel Testing is not included. This is because the order of trials was not recorded for this phase of SHEBA testing, so the data can only be used in the average comparisons.

4.8.1 Standard Deviation Confidence Test

The values presented are averages for the total dataset. It was assumed that the range of values would fit a normal distribution. This hypothesis was then tested by means of the validity test for confidence intervals.

The following equation, found in [41], is used.

$$Z = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}} \quad \text{Equation 2}$$

Where:

$\bar{X}$ = sample value taken from the dataset.

μ = Mean of the dataset.

σ = Standard Deviation of the dataset.

N is the number of data points within the dataset.

For 99% confidence that the data will follow a normal distribution, the following must be true: $-2.58 \leq Z \leq 2.58$

If Z lies within this range, it can be assumed with 99% confidence that the data will follow a normal distribution. In the case of all the data collected in these tests, there were 215 possible datasets and only 12 were outside this range. This gives sufficient confidence that these anomalies could be rectified if more data points had been obtained for those conditions (see Appendix F for an example).

In Appendix F, the statistical breakdown of each dataset can be seen. The standard deviation (σ) is shown. Also minimum and maximum values are given to show

the range of the data spread. With this information, it is apparent that the graphs are only a single line in a band of possible results. By taking the value along this mean line, a statistical probability can then be added to this value. Since it has been shown that a normal distribution fit can be applied to the data with reasonable confidence, more accurate answers can be developed by means of a random number generator based on Standard Deviation Theory.

It has been assumed that the mean values are accurate enough for this report so that the results can be displayed neatly in table format.

4.9 Discussion and Comparison of Results

The results presented in this Chapter will now be compared to results previously obtained in the field by other researchers. Data collected by Jin, Proulx, Fruin and others will be compared to the results from these BMT Fleet Technology Limited (BMT FTL) experiments. The data of each researcher is shown in Table 12 to Table 16.

Table 12 – Occupant Speeds Based On Demographic and Location

Demographic	Horizontal (m/s)	Stairs (m/s)
Male	1.35	1.06
Female	0.98	0.77
Groups Children Seniors	0.65	0.40

Table 13 – Average Stair Speeds From Proulx

Building	Mean Decent Time	Speed (m/s)
A	15	0.52
B	20	0.54
C	21	0.62

Low Population Densities

Speed of small children was 0.45 m/s

Speed of occupants over 65 was 0.43 m/s

Table 14 – Average Stair Speeds From Fruin

Gender	Age	Down (m/s)	Up (m/s)
Male	< 30	1.01	0.67
Female	< 30	0.76	0.64
Male	30-50	0.86	0.63
Female	30-50	0.67	0.59
Male	>50	0.67	0.51
Female	>50	0.60	0.49

Table 15 – Corridor Speeds For Different Optical Densities From Jin

	0.1 OD/m	0.3 OD/m	0.5 OD/m	0.7 OD/m	0.9 OD/m	1.1 OD/m
Male Speed (m/s)	1.05	0.95	0.90	0.88	0.75	0.70
Female Speed (m/s)	1.05	0.95	0.80	0.85	0.45	0.55

Table 16 – Speeds From BMT FTL Experiments

Optical Density (OD/m)	Male		Female		Groups, Children, Seniors	
	Horizontal (m/s)	Stairs (m/s)	Horizontal (m/s)	Stairs (m/s)	Horizontal (m/s)	Stairs (m/s)
0.0	2.37	1.31	2.12	1.06	1.74	0.82
0.1	2.67	1.43	2.27	1.16	1.67	0.80
0.5	1.82	1.17	1.59	0.95	1.18	0.73
1.0	1.50	1.00	1.32	0.87	1.04	0.60

In Table 12, the results of research undertaken by Proulx, Hadjisophocleous and Liu are shown for horizontal and stairwell movements of occupants in emergency situations. Comparing these results to those found in the BMT FTL experiments, it can be seen that the experiments discussed in this Chapter yielded much higher speeds for the participants. Comparing horizontal speeds for males older than 50 years between Table 12 and Table 16, the results are 1.35 m/s and 2.37 m/s respectively. This is quite a difference in overall mean speed for an occupant of this group. The same phenomenon can be seen in all other categories between the two sets of experimental results.

In Table 13, the average speeds for occupants descending a set of stairs, as found by Proulx, are shown. The results from three different buildings are shown and the values of men and women are combined. The speeds of children and occupants older than 65 are reported separately from this data. Taking the average of the three values found in Table 16, the average speed for an occupant, male or female, will be 0.56 m/s in the stairwells, with a value of 0.45 m/s for children and 0.43 m/s for those over 65.

It is difficult to compare the results of Proulx to those discussed in this Chapter for several reasons. First, the male and female speeds have been grouped together and considered one demographic, where as the BMT FTL experiments use two separate demographics. Another reason is the age used to differentiate between younger and older participants, in each case. In Proulx's results the age used is 65 but in the BMT FTL experiments 50 is used. Lastly, there is no data for horizontal comparison in the Proulx data. This makes it is difficult to compare Proulx's results to the results described in this Chapter. A general conclusion, however, is that the BMT FTL speeds are higher than those found by Proulx. For a young person descending a set of stairs, Proulx found their speed to be about 0.56 m/s. Taking the average of the results for males and females from the BMT FTL tests, at the no smoke condition, a speed of 1.19 m/s is found. For elderly persons and children, Proulx found a value of 0.44 m/s while BMT FTL found a value of 0.82 m/s. This comparison is difficult because of the different way in which the data have been obtained, however, the conclusion again is that the BMT FTL results are higher than Proulx's results. Proulx's results are taken from actual high-rise evacuations so they are likely to be more accurate values to use for building evacuations.

In Table 14, the average stair speeds, as found by Fruin, are shown for males and females of different demographics. This data can be compared more easily to the data discussed in this Chapter, since the demographics are similar, but it is only for stairs. Comparing the data for occupants older than 50 years of age, in Table 14 and Table 16, it can be seen that the values from BMT FTL are, again, much higher. For males older than 50 years of age, Fruin found an average stair speed of 0.59 m/s while BMT FTL found

0.92 m/s. For females older than 50 years of age, Fruin found an average stair speed of 0.55 m/s while BMT FTL found 0.72 m/s. The average for this age group, combining men and women, is 0.57 m/s by Fruin and 0.82 m/s for the BMT FTL experimental data.

In Table 15, the corridor speeds, found by Jin, based on different optical densities, are given. The data does not differentiate between age groups, only gender. Comparing values for optical densities also used in the BMT FTL experimentation, found in Table 16, it is seen that the BMT FTL results are, again, higher. At 0.5 OD/m, Jin found that males travelled at a speed of 0.9 m/s. The BMT FTL experimentation found males travelled at a speed of 1.62 m/s under the same conditions.

The data discussed in this Chapter is summarized in Table 16. It shows the general trends of the experimental results, in a format similar to that used by other researchers in the field.

Since the developed evacuation model will be used for building evacuations, and given that the speeds obtained from the BMT FTL experiments are much higher than those found by other researchers, only the factors found in Section 4.6 and Section 4.7 will be used in the evacuation model.

The main reasons for the high speeds obtained in the BMT FTL experiments could be the following: firstly, participants were asked to walk “briskly” down the corridor. This could have encouraged them to move faster than they normally would have without instruction. Another reason for difference is that this set of data was collected over a short distance of thirteen metres. Most of the other researchers obtained results from full evacuations. The one exception was Jin, who had a geometrical setup

very similar to the one used at BMT FTL. The difference between the two experiments was that Jin used real smoke while the BMT FTL experiments were done with harmless theatrical smoke. There was no irritation to the participants, only a reduction in visibility.

For these reasons, the base speeds used for the occupants in the evacuation model are those found in Table 12. These results were found by Proulx, Hadjisophocleous and Liu, at the National Research Council (NRC). This set of data used the same demographic breakdowns as the data collected at BMT FTL and had results similar to those found by the other researchers, so it was selected for the evacuation model.

The impact of smoke on evacuation speeds is assumed to be similar no matter the distance of travel, so the factors obtained for speed adjustment at each optical density are assumed to be valid for building evacuations.

5. MODELLING

This Chapter describes the evacuation model developed as part of this work. The model was designed and developed using the Visual Basic programming language. It uses the experimental results from Chapter 4 to adjust occupant evacuation speeds for smoke levels in the building. A simple model was desired so that it could be integrated into the fire risk analysis model. The evacuation model was also required to be as accurate as possible so that it could be used as a standalone model.

As discussed earlier, the evacuation model developed in this work will be integrated into the fire risk analysis model of Carleton University. Some of the required features include the following:

- Use outputs of the occupant response model, which are the probabilities of evacuation commencing at different times depending on occupant location in the building
- Use outputs of the smoke model. These outputs include smoke concentrations and visibility which affect evacuation speeds.
- Create outputs that will be usable by the risk to life model so that injuries and deaths can be calculated for a given scenario.

As the risk analysis considers a large number of scenarios, the evacuation model is required to be as simple as possible to reduce computation time. The simplifications made will be discussed further in Section 5.2.1. The program was also required to be as robust as possible in case later changes are desired. Currently, the program does not

locate each occupant with Cartesian coordinates, but it has been designed to allow for this extension in the future. It would require additional programming but the architecture allows it to be done using grid spacing.

5.1 Life Hazard Model and Other Components

The life hazard model is the amalgamation of each aspect of the fire scenario to calculate the probability of death or injury to the occupants. By running simulations which represent the most probable fires and altering variables, the overall safety of a building can be calculated for the occupants. This value gives an idea of how many people are expected to be injured or killed when a fire occurs. The framework for the program can be seen in Figure 8.

The occupant evacuation sub-model shown in Figure 8 is part of the life risk model and requires inputs from the other sub-models. It can be seen that initially a fire scenario and design fire must be selected. After this, on the left hand side of Figure 8, the effects of the fire are calculated by other sub-models. Fire growth and spread, smoke movement and damage to the building are all calculated. The outputs of these sub-models impact the detection of the fire, the fire department response and the occupant response, as well as the evacuation of the occupants.

It can be seen that the risk model also calculates the expected costs of the fire scenarios but this is not the scope of this report so it will not be discussed here.

Figure 8 – Life Risk Model Framework

5.1.1 Occupant Response Model

The occupant response model calculates the probability of performing several actions such as calling the fire department, activating the pull bar, warning other occupants and deciding to evacuate the building. The probability of each action depends on occupant location relative to the compartment of fire origin. Probability of action will

be higher for someone within the compartment of fire origin than in compartments remote from the fire. Someone in an adjacent compartment will have the next highest probability of action and the occupants in all other compartments will have the lowest level of probability to respond at any given time during the fire.

This model calculates the probabilities that occupants will begin to egress at different times, which are used as input by the occupant evacuation model. Appendix I has sample input and output files for the occupant response model. Details of the occupant response model can be found in [1]. The output file becomes the input file for the occupant evacuation program.

5.1.2 Smoke Movement Model

Another sub-model of the risk assessment model is the smoke movement model. This model calculates the amount of smoke in each compartment of the building over each time step. This allows the amount of smoke at any location, at any time, to be known. This information is then taken as an input into the occupant evacuation simulation and used to adjust the speed at which the occupants travel, accounting for the loss of visibility due to amounts of smoke. This data is also used as a check to see whether an occupant would continue in a given direction or select a different exit. If the levels of smoke are too high, the occupant will try to move in a different direction to find a clearer path of egress. Appendix I has sample input and output files for the smoke movement model. Details of the smoke movement model can be found in [2]. The

output file of the smoke movement model becomes the input file for the occupant evacuation model.

5.1.3 Sprinkler Effectiveness, Fire Department and Other Sub-Models

Some models being developed by Carleton University do not directly affect the occupant evacuation program but they do affect some of the models which are directly connected to the occupant evacuation. This means that they will affect the input received by the smoke model and occupant response model.

The effectiveness of the sprinklers will impede the ability of the smoke and fire to propagate through the building, thus making levels of smoke and heat lower than they would be normally.

The fire department program calculates the time at which the fire department can be expected to arrive at the fire scene. Their effectiveness will be dependent on the time of their arrival. The fire department affects the evacuation process in a similar manner to the sprinklers.

5.2 Methodology

The evacuation model described in this report is a simulation model. This means that the model attempts to represent occupant behaviour and movement that might be seen in an actual evacuation of a building. The model can show the route taken by each occupant, revealing decisions made by the occupant.

It was decided that there was no need for the use of grid spacing in the compartments since the smoke movement model is a 2-zone model. This means that below the interface height of the smoke layer, ambient conditions are assumed. Above the interface height, in the smoke layer, the conditions are assumed uniform throughout the compartment. Occupants will be subjected to a uniform environment anywhere in a given compartment of the building. Properties will differ between compartments of the building but are uniform throughout the upper layer and lower layer of a compartment, for a given time interval. Thus, a coarse network was used in the model, rather than a fine network. This allows the occupant's position to be known by compartment numbers.

The population perspective for the model is an individual perspective rather than a global perspective. This allows for independent action for each occupant. It also allows each occupant to be tracked separately throughout the simulation so that decisions and evacuation routes can be analysed.

Lastly, a rule based behavioural system is used in the evacuation model. This allows the occupants to make decisions based on rules that are written in the model. The rules are based on comparison of random numbers so that not all occupants will make the same decision. There are some rules which supersede other rules so that occupants will not endanger themselves in a manner that would be unlikely to occur in an actual fire scenario.

Occupants can interact with other occupants, the building or the environment, creating a different behaviour in each case. Since the buildings considered in the evacuation model are assumed to be four storey commercial buildings, large crowds are

not of a great concern. This is because in most commercial buildings, the populations will be dispersed throughout the building in moderate numbers. Occupants will have different focal points throughout the building so their response times will differ as well, allowing for a staggered evacuation process. This allows physical pushing and shoving between occupants to be ignored, to simplify calculations. Some interaction, however, is considered implicitly by the use of the impact of population density on occupant speeds. Interaction between the occupant and the building is based on widths of exits and corridors which will impede the occupant's evacuation process. The interaction between the occupant and the environment is of the greatest concern since this will impact the risk to life significantly.

5.2.1 Assumptions

In order to simplify the process of modelling human behaviour, some assumptions were made. The assumptions are based on engineering judgement that will be explained. Whenever possible, the assumptions made were of a conservative nature so that any errors are in the benefit of design safety.

The first assumption was that occupants will egress in order rather than randomly. Each occupant is given an identification number (ID Number) depending on the order they were listed in the input file of the model. During each time step, the occupant with a lower ID number will always egress before another occupant who has also begun evacuation, based on their occupant response characteristics. This is repeated until all occupants have acted during the time step. All responding occupants act during the same

time step, but the program needs to calculate one occupant at a time. It was decided that selecting the occupants by a random number generator would require too much computational time. It would limit the usefulness of the tool for an effect that is minimal on the overall time to evacuate the building. If a random number was generated every time queuing was an issue, the program would run more slowly because currently the program simply selects the occupant with the lowest ID number. The increase in required time to run the simulation would be noticed as the population increases. The effect of this is that the occupants entered into the program later will have a higher probability of queuing at openings or exits. Since physical interactions between occupants, like shoving, are not considered in the program, only queuing will be affected by this assumption.

It was also decided that compartments within the building will be rectangular. This means that there are no complex geometries. This allows distances to be travelled to be calculated by simple geometric calculations. Circles and oddly shaped rooms, though plausible for a building, will not be considered. A circular room can be replaced with a rectangular equivalent in the building floor plan. Also, a room of complex geometry could be broken down into several rooms of rectangular geometry. The point where they meet is considered a doorway, although it will span the entire width of the room.

The previous assumption also allows wall avoidance to be ignored because in a rectangular room, a wall will never impede progress to an exit. Since the occupants will be travelling unobstructed to the doorway, only smoke and fire need to be considered as obstacles within the environment. With this assumption, obstacles in rooms such as

chairs or tables are also ignored since the time required to move around them will be small compared to the overall time to egress.

In each compartment, the position of the door is assumed irrelevant. Only the distance to be traversed is required because this will dictate how long it takes to reach the outside. The exact path taken within a compartment is not of immediate importance. If the exits the occupant evacuated through are known, then queuing effects and distances to be travelled can be considered. In the case of a compartment, the distance from the centre of the room to the furthest corner is used as the distance to the exit. For a corridor, the distance to travel is the entire length of the corridor. Lastly, the distance used in the stairwell movement is the length from one floor to another. All occupants in a given compartment travel the same distance but at different times, based upon the probability of response to fire cues obtained from the occupant response model.

Once an occupant has decided to leave the building, they will not alter this decision. Occupants may change their mind as to which exit they would like to use, but they will never decide to try to stay in one room after they have decided to exit the building.

The time which occupants may spend searching for keys or performing other pre-evacuation tasks not related to evacuation is accounted for in the initial time to react to the fire cues, obtained from the occupant response model.

There are preferred exits within the building. When given a choice of exit selection, there will be one which makes more sense to take. This could be an exit which is closer, or one which leads to a safer area. This “decision” is performed by means of

probability of exit selection based upon several factors discussed in Section 5.3.1. Each exit is given an associated probability of use, when comparing it to the other exits in the same room.

Each compartment of the building will only have two exits which the occupant will be able to choose from. This is a logical assumption for most buildings since most compartments and corridors will only have two exits in a typical building. The program is coded to allow for more than two doorways per compartment in case it is desired at a later date. For stairwells, doorways to other floors are not considered as highly usable exits. Their probabilities are limited to small values so that occupants will only use them if progress is impeded by smoke in the stairwell. A door must lead the occupant in the direction of the outside, at the bottom, unless there are severe conditions.

Once an optical density of 1.0 OD/m is reached in the program, speed reduction factors will be assumed to be 0.5 since tests were not done beyond this value. This is an arbitrary value, based on engineering judgement, which is hopefully on the conservative side and may be adjusted.

5.3 Occupant Evacuation Features

The occupant evacuation program has several subroutines which perform specific functions and the theory of important ones will be discussed here. The main flowchart of the model is shown in Figure 9. The complete set of flowcharts can be found in Appendix J.

Referring to Figure 9, it can be seen that the main subroutine of the evacuation model that considers each occupant and their movements begins reading inputs from several files, including a file that contains all the information about the occupants and a file that describes the building geometry. There are also input files with the results of other sub-models such as the occupant response and smoke movement models.

Next, the program begins considering each occupant for each time step. It generates a random number and compares this value to the probability of the occupant responding to fire cues at this time. If the generated number is lower than the probability of occupant response, then the occupant responds. Occupant response begins with a value of 0 initially, increasing over time as the fire grows until it reaches a maximum value of 1.0. This means that as the likelihood of occupant response increases with time, it will become more likely that the generated number is less than the response value. Once an occupant has decided to respond to the fire cues, the program no longer checks the occupant for response.

If the occupant responds to the fire cues during the time step in question, the program then calls a subroutine that determines what type of compartment the occupant is in (room, corridor or stairwell) and then calls the corresponding subroutine. Within each of these compartment subroutines, other subroutines are called. The complete set of flowcharts is included in Appendix J.

Figure 9 – Flowchart of Occupant Evacuation Methodology

After the occupant has been considered completely for the current time step, the program then checks to see if there are more occupants in the building. If this is the case, the next occupant is considered in the same manner, otherwise, the program increments the time steps. If the time the fire is expected to burn has not been reached, the program begins considering all the occupants still left in the building for the next time step.

Once the maximum scenario time has been reached, the program begins to create the output files. The files contain all the data of occupant location for each time step and times of evacuation for each occupant.

5.3.1 Exit Selection

In order to select the appropriate exit from a compartment of the building, this subroutine uses factors to associate a value to conditions the occupant is exposed to, using Equation 3.

$$P_{\text{door}}(\text{Adjusted}) = F_p F_s P_{\text{door}} \quad \text{Equation 3}$$

where F_p = factor associated with previous use of the exit. This factor ensures that an occupant is less likely to use a doorway they just came through, so that occupants do not get stuck walking back and forth in the building.

F_s = factor for the level of smoke in the compartment connected by the exit. This factor ensures that an occupant is less likely to use a doorway with high levels of smoke on the other side. It encourages the occupant to take the safer route.

P_{door} = probability of using the exit if all other conditions are equal. This is a compartment property that is equal for all occupants at all times. It is adjusted by the previous factors to yield a new probability of use.

Once the probability of each exit in the compartment is calculated, the model checks to see which exit has a lower probability of use. A random number is then generated between 0 and 1.0, representing the range of probabilities 0% to 100%. If the number generated is lower than the probability for the least likely exit then this door is selected. Otherwise, the more likely door is selected.

5.3.2 Speed Adjustment

There are several reasons for the necessity of speed adjustment. These reasons include levels of smoke, population density within a given compartment and an adjustment for the Standard Deviation (S.D.) of the speeds used in the program.

The speed data, from Chapter 4, obtained from the experiments, outlined in Chapter 3, had standard deviations for each set of data. These standard deviations are used to adjust the average speeds of each demographic to make a more realistic range of speeds in the population. A random number, from 0 to 1.0, is subtracted from a threshold value currently set at 0.5. The resulting number may be positive or negative, depending on the magnitude of the random number generated. This new value is then multiplied by the standard deviation of the data collected for the current occupant's demographic and

position. It is then added to the mean speed of the group the current occupant belongs to as shown in Equation 4.

$$Basespeed = Speed_{Demographic} + (0.5 - rand) * \sigma \quad \text{Equation 4}$$

where $Speed_{demographic}$ = average speed for the demographic of the occupant

$rand$ = random number between 0 and 1.0

σ = standard deviation of the data for the occupant demographic

For example, a male occupant less than 50 years old, moving up a set of stairs, was found to have a standard deviation of 0.49 m/s in the data collected. This number would be multiplied by the difference between 0.5 and a random number. This new value would be added to the mean speed used in the model for a male less than 50 years old and moving in a stairwell. This base speed is 1.06 m/s and would be adjusted higher or lower, depending on the magnitude of the random number generated.

Once the base speed has been calculated, the adjustments are done by factors relating to the severity of the condition, according to Equation 5.

$$Speed = F_s F_d BaseSpeed \quad \text{Equation 5}$$

where F_s = smoke adjustment factor

F_d = population density factor

$BaseSpeed$ = average speed of the occupant adjusted by a portion of the S.D.

The smoke factor is obtained through use of the experimental data discussed in Chapter 3 and calculated in Chapter 4. Equations were created from the data found in Table 8 to Table 11. Since the tests were only done for 0, 0.1, 0.5 and 1.0 OD/m optical densities, interpolation was required for values other than these. It is assumed that the behaviour between these points is linear. For optical densities greater than 1.0 OD/m, a factor of 0.5 is used. It is unlikely occupants will still be in an area of a building where the optical density is this high. Equation 6 to Equation 9 show the smoke factor adjustments for a male less than 50 years old, moving in a stairwell. Since the numbers are rounded values and not actual data points, the equations do not yield identical results for previous common points.

For the case where the optical density is less than or equal to 0.1 OD/m,

$$\text{SmokeFactor} = 1 \quad \text{Equation 6}$$

For the case where: $0.1 \text{ OD/m} < \text{optical density} \leq 0.5 \text{ OD/m}$,

$$\text{SmokeFactor} = 1 - 0.2375 * \text{OpticalDensity} \quad \text{Equation 7}$$

For the case where: $0.5 \text{ OD/m} < \text{optical density} \leq 1.0 \text{ OD/m}$,

$$\text{SmokeFactor} = 0.9 - 0.2 * \text{OpticalDensity} \quad \text{Equation 8}$$

For the case where the optical density is greater than 1.0 OD/m,

$$\text{SmokeFactor} = 0.5 \quad \text{Equation 9}$$

The factor that accounts for the population density of the compartment is computed by normalizing the result of the following standard density equation [42].

$$v = k - akD \text{ (m/s)} \quad \text{Equation 10}$$

where $k = 1.08$ for stairwells or 1.40 for any other compartment

$a = 0.266$, a constant

D = population density in the compartment (people / m^2)

This equation is valid only for the values of $D > 0.55$ people/ m^2 . The speed with a population density of 0.55 people/ m^2 is considered the maximum speed and it is used for values of population density less than 0.55 people/ m^2 . All values of speed were divided by this value to yield factors that could be multiplied with the known speed of the occupant. The entire set of factors can be seen in Table 17. Although there are different values for 'k' for stairwells and horizontal travel, the factors are equal for both, for a common population density. The speeds will be lower in the stairwell than anywhere else but the factor by which the speed is affected will be the same for any location in the building. This can be seen by looking at the first 3 entries in Table 17 for the stairs and the corridors or rooms. At a density of 0.55 people/ m^2 , the corridors and rooms have higher speeds than the stairwells, but the factor for both cases is the same, 1.0 . This is the case for the entire table.

Table 17 – Speed Correction Factors For Density

$v = k - akD$				
Corridor or Room			Stairs	
k	a		k	a
1.4	0.266		1.08	0.266
v (m/s)	Factor	D (ppl/m ²)	Factor	v (m/s)
1.19	1.00	0.00	1.00	0.92
1.19	1.00	0.55	1.00	0.92
1.12	0.94	0.75	0.94	0.86
1.05	0.88	0.95	0.88	0.81
0.97	0.82	1.15	0.82	0.75
0.90	0.75	1.35	0.75	0.69
0.82	0.69	1.55	0.69	0.63
0.75	0.63	1.75	0.63	0.58
0.67	0.57	1.95	0.57	0.52
0.60	0.50	2.15	0.50	0.46
0.52	0.44	2.35	0.44	0.40
0.45	0.38	2.55	0.38	0.35
0.38	0.32	2.75	0.32	0.29
0.30	0.25	2.95	0.25	0.23
0.23	0.19	3.15	0.19	0.18
0.15	0.13	3.35	0.13	0.12
0.08	0.07	3.55	0.07	0.06
0.00	0.00	3.75	0.00	0.00

The base speed of each occupant is based on their age, gender and location. Men tend to move faster than women and youth are faster than the elderly. Stairwell speeds will be lower than those in a compartment or corridor. The base speed is given based on the occupant's attributes.

5.3.3 Travel Distance Calculations

The distance travelled is calculated by multiplying the adjusted speed of the occupant by the increment of time being considered for the simulation. This value is then subtracted from the remaining distance the occupant needs to travel to exit the compartment. If the new remaining distance is a negative number the occupant has reached the doorway and entered a new compartment. The program then checks to see if the occupant is able to pass through the doorway or not. If this is the case, the occupant enters the new compartment. Otherwise, the occupant remains at the doorway and queues with all other occupants in the compartment.

5.3.4 Doorway Queuing

As explained in Section 5.3.3, the program decides if an occupant is able to pass through an exit once they have reached it. The number of occupants that are able to pass freely through the exit is based upon the size of the exit and is given by Equation 11.

$$F_c = F_{s\max} w_e \quad \text{Equation 11}$$

Effective width, w_e , is an adjusted width of the exit. This is based on the premise that there are invisible boundaries within a building so that occupants will not be brushing up against walls. If an exit is 1.0 m in width, this value will be reduced to account for the fact that people will not be touching the door frame on their way out.

Next, the maximum specific flow, F_{smax} , of the exit is used. This value represents the maximum amount of people that can pass through an exit per second, per metre of exit width. A maximum value of 1.3 people/s/m [39] is used in the program. In the occupant evacuation model, the effective width, w_e , of the exit is calculated first. It is then multiplied by the maximum specific flow, F_{smax} , to yield the calculated flow, F_c . The calculated flow is the number of people per second that can pass through the exit in question. Multiplying F_c by the increment of time being considered yields the number of occupants able to pass through the doorway before queuing is necessary.

The program checks to see if the number of people that have passed through the door is less than this number. If it is then the occupant is allowed to pass. Otherwise, the occupant is forced to remain and wait their turn to exit.

6. VALIDATION AND RESULTS OF OCCUPANT EVACUATION MODEL

To ensure all aspects of the evacuation program are working according to their design, a validation process was required. The scenarios used for validation were designed to emphasize whether certain subroutines in the program are functioning properly or not. Exaggerated cases were used that would not be seen in reality, but they allowed for any errors in the program to be found immediately.

To test the occupant evacuation program, the CTTC (Carleton Technology and Training Centre) was used as the building in all of the scenarios that will be discussed. The floor plans can be found in Appendix H, as well as the population distribution used. The CTTC is a four storey commercial building with an expected occupancy of 293 people.

All scenarios were run three times and averages of these three runs are the values shown. This makes the data more useful due to its probabilistic nature.

To determine whether the model can handle large populations, the CTTC was modelled with 100 occupants in each compartment, giving a total population of 1900 occupants. The program ran normally but took 1 hour and 45 minutes to run because of the high levels of queuing that occurred.

6.1 Validation of Exit Queuing

To test the effectiveness of the queuing subroutine, a test was designed to fully check its suitability. The entire expected population of the building, 293 persons, was placed inside Compartment 1 (see Appendix H for the floor plan) and an evacuation was

performed. Since occupants were in the same compartment for this scenario, they began evacuation at relatively similar times. This forced all occupants to compete for two exits, 50 and 51, in order to evacuate the compartment. The results are seen in Figure 10.

The graph shows the cumulative number of seconds that occupants were queued at each doorway. Notice that this graph shows the total time that was spent queuing at each doorway for the entire population. Thus, for exit 50, the population of 293 people was forced to queue about 1400 seconds over the course of the simulation. This averages to about five seconds of queuing per occupant for the simulation. The value of 1400 seconds does not represent an actual time associated with the evacuation process. It is only used as a magnitude comparison between exits to see which exits had high levels of queuing. It can be seen that exits 50 and 51 have the highest queuing rates. This is due to the fact that they are the two doorways leading from Compartment 1. Exit 61 leads into Compartment 9 and is used by most of the population that selected exit 51 initially. This causes another queue while occupants try to evacuate using the exit found in Compartment 9.

Figure 10 - Doorway Queuing With 293 Occupants In Compartment 1

From Figure 11, it can be seen that the evacuation times from a common compartment follow a normal distribution quite nicely. Slight variation occurs because occupants have different speeds and characteristics influencing their decision to evacuate. The high queuing rates at the two exits also shift the evacuation times to the right of the graph (an increase in the amount of time required to evacuate).

Figure 11 – Evacuation Time Distribution

Figure 12 shows the evacuation time of each occupant compared to the average evacuation time line.

Figure 12 – Evacuation Times of Each Occupant

This scenario shows that the program is equipped to adequately cope with the possibility of queuing situations, even in extreme situations where large populations are considered.

6.2 Validation of Exit Selection

For exit selection to be tested, a choice between two doorways was required. After this, a blockage at one of the doorways was necessary to ensure that occupants would decide to accept the other doorway as the next best alternative. This was done on Floor 1 by placing a fire in the hallway, outside of doorway 50. It can be seen that the only exits which lead from Compartment 1 are 50 and 51, which lead into Corridor 5 and Corridor 36 respectively. If passage to Corridor 5 is blocked or filled with smoke, so that

no one will decide to use it, then all occupants should enter Corridor 36. A worst case scenario was used by placing the fire directly in front of an exit from Compartment 1 and then placing all the occupants in this compartment. The occupants were blocked from using one exit from Compartment 1 and from exit 67, which leads to the outside.

It can be seen in the Figure 13 that all 293 occupants used exit 51 to leave Compartment 1. This is seen by the large queuing number at this doorway while no one was forced to queue at exit 50.

Figure 13 – Queuing Results From 293 Occupants Evacuating Compartment 1

This simulation shows that the door selection process and detection of hazards function properly. This is an extreme case, of course, with 293 occupants trying to move through a single doorway and using a single stairwell.

6.3 Validation of Population Density Effects

When occupants try to evacuate they may not be able to move at their natural speed because the number of people within the immediate vicinity has an impact. The larger the crowd, the slower occupants must travel.

To demonstrate this phenomenon, the entire population was placed within Compartment 4, creating a density of over five people per metre squared. This extreme case demonstrates the effect on evacuation speeds and times. Recalling Table 17, a population density of five people/m² would yield a velocity of zero metres per second to occupants within the compartment. This means that only the occupant directly at the doorway will be able to move through the doorway. All other occupants will remain in their position. Although Compartment 4 is closer to the outside than Compartment 1, the times to evacuate are much higher in this case. Comparing Figure 12 to Figure 16, the two mean evacuation times can be seen. The previous scenario had an average evacuation time of 325 seconds while the current scenario had an average evacuation time of 400 seconds, even though Compartment 4 is closer to the outside than Compartment 1 (see Appendix H). Comparing Figure 13 to Figure 14, the difference in queuing is quite obvious. Considering the effects of density on speed, the magnitude of the queuing in Figure 14 is over seven times that in Figure 13. Since both evacuations

are under identical conditions, except this scenario is closer to the exit, it seems that queuing is the reason for the larger evacuation times in this scenario

Having only one door to evacuate the room from also creates more problems for the evacuation. The effects can be seen in Figure 14, as the occupants have a very high queuing rate at the only available exit from Compartment 4.

Figure 14 – Queuing Results From 293 Occupants Evacuating Compartment 4

It can be seen in Figure 15 that the evacuation times are still quite evenly distributed although queuing is an issue. The queuing simply increases the mean evacuation time for the population.

Figure 15 – Evacuation Time Distribution For Population

Figure 16 shows the evacuation times of each occupant. It can be seen that the queuing effects are more apparent in the occupants reacting last (occupants 150 to 293). The bimodal behaviour of the graph is explained by the extreme queuing effects in the compartment. Since Compartment 4 only has a single exit and 293 occupants are all trying to use it, at the same time relatively, the queuing becomes very pronounced. The exit only allows one occupant at a time to evacuate so a diagonal line of occupant evacuation times materializes at this point, until the end of the evacuation. It can be seen that some of the occupants at the back of the room decided to leave earlier and evacuated in a normal pattern, but most of them were forced to queue as the entire population moved towards the exit.

Figure 16 – Evacuation Times For Each Occupant

6.4 Simulation Case Studies

This section discusses four scenarios that were investigated, representing likely fires in the building. Each scenario was then repeated eight more times to test the effect of different fire protection systems. A medium t^2 fire was used in the first three cases as it would be the most likely fire for an office type building. A t^2 fire grows exponentially with time. For the fire scenario on the fourth floor, a fast t^2 fire was used because the fuel source was a sofa.

These cases will be discussed individually and the results shown. Comparisons will be made to EvacNET, a known evacuation model, for one of the scenarios.

When it is stated that there is no alarm system in the simulation cases, this means that there are only smoke detectors to warn the occupants, unless otherwise stated. When it is stated that an alarm system is available this means that there is a central alarm system, smoke detectors and heat detectors in the building.

The scenarios pertaining to Compartment 3 (Scenarios 1 to 8) will be explained in detail, with results explained as well. Since the rest of the scenarios (9 to 32) are identical except for the location of the fire, only the results of these simulations will be given for comparison. The same procedures were used for all 32 scenarios. The scenarios are described in Table 18. In Table 18, each condition has an associated probability of occurrence noted in brackets. These probabilities indicate that although a system is installed it is not expected to be 100% reliable and effective in case of a fire. Following along a row, the multiplication of each of these values will yield the overall probability of that fire scenario occurring. For example, a fire on the 1st floor, with sprinklers, with the arrival of fire services and an alarm has a probability of 0.12825 of occurring. If the probabilities for each scenario are summed, it will result in a value of 1.0. This means that Table 18 is meant to represent all the most likely fire scenarios for the building.

In cases where sprinklers are present, they are expected to activate at 180 seconds after the ignition of the fire source. Fire services are expected to begin fire suppression after 300 seconds, in the cases where they are assumed to arrive. When the sprinklers and fire services are successful, they will impact the size of the fire and the smoke output for the scenario.

Table 18 – Scenarios Used in Occupant Evacuation Simulations

List of Scenarios For CTTC Building Case Study					
Fire Room	Sprinkler	Fire Dept	Alarm	Probability	Scenario No
1 st Floor Parking Office (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	1
			No (0.1)	0.01425	2
		No (0.4)	Yes (0.9)	0.0855	3
			No (0.1)	0.0095	4
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	5
			No (0.1)	0.00075	6
		No (0.4)	Yes (0.9)	0.0045	7
			No (0.1)	0.0005	8
2 nd Floor Restaurant (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	9
			No (0.1)	0.01425	10
		No (0.4)	Yes (0.9)	0.0855	11
			No (0.1)	0.0095	12
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	13
			No (0.1)	0.00075	14
		No (0.4)	Yes (0.9)	0.0045	15
			No (0.1)	0.0005	16
3 rd Floor THSAO (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	17
			No (0.1)	0.01425	18
		No (0.4)	Yes (0.9)	0.0855	19
			No (0.1)	0.0095	20
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	21
			No (0.1)	0.00075	22
		No (0.4)	Yes (0.9)	0.0045	23
			No (0.1)	0.0005	24
4 th Floor TEMPEST (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	25
			No (0.1)	0.01425	26
		No (0.4)	Yes (0.9)	0.0855	27
			No (0.1)	0.0095	28
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	29
			No (0.1)	0.00075	30
		No (0.4)	Yes (0.9)	0.0045	31
			No (0.1)	0.0005	32

6.5 Fire In Compartment 3 (Parking Office on 1st Floor)

The parking office is a typical office workplace with cubical dividers separating work spaces. Typical combustibles found in this type of compartment are binders, paper, desks and chairs. The fire used in this scenario is a medium t^2 fire [1], given by the equation, $Q = \alpha t^2$, where $\alpha = 40 \text{ kW/min}^2$ and t is the time in minutes. A maximum heat release rate, Q , of 5MW was used to level the fire off to a steady state condition, if the fire reached such intensity. The smoke model actually controls the magnitude of the heat release rate based on availability of oxygen.

Within the parking services, 5 employees and 12 visitors were assumed to be in the office at any given time. At the beginning of the year, when large populations may be trying to renew parking permits, this value may be higher. For the majority of the year, the number of visitors is much lower than this, so assuming 17 people in the compartment was a conservative estimate of the population. Occupants 31 to 47 are those situated in the parking services office.

The results of the eight scenarios in Compartment 3 are summarized in Table 19 and will be discussed in further detail throughout this section.

Table 19 – Results From Fire Compartment 3

Compartment 3				
Scenario #	Evacuation Time (seconds)			
	Mean	Minimum	Maximum	Std. Dev.
1	367	87	625	99
2	385	91	642	104
3	373	82	593	94
4	379	86	655	106
5	366	85	572	97
6	348	85	913	118
7	369	91	593	99
8	393	93	752	112
Average	373	88	668	104

6.5.1 Scenario 1

The first case should be the safest case for occupant egress since there are full alarm capabilities, sprinklers and the fire department is expected to arrive.

For this scenario, graphs of the occupant response and smoke levels, as functions of time, will be explained to visually give an idea of inputs used by the program. Every scenario used similar data adjusted for the conditions being tested in each case.

It can be seen in Figure 17, the response of occupants in adjacent compartments to the compartment of fire origin is quite similar to that of other compartments in the building. The occupants in the compartment of fire, however, react to the fire conditions much quicker. At about 300 seconds (5 minutes), occupants in the fire compartment have a 100% likelihood of responding to the cues and beginning their evacuation. It is not until about 600 seconds (10 minutes) that all other occupants have the same likelihood of response.

Figure 17 – Probability of Occupant Response During Scenario 1

OFC is an occupant in the compartment of fire origin.

OAC is an occupant in compartments on the floor of fire origin.

OOC is an occupant on any other floor.

In Figure 18 and Figure 19, the levels of smoke for several compartments in the building are shown. Compartment 3 is the compartment of fire origin so it is expected that the optical density and depth of the smoke layer will be higher than in the other compartments. Corridor 34 and Corridor 36 are the two corridors closest to Compartment 3, as seen in the floor plans (Appendix H). Corridor 36 is directly connected to Compartment 3 by a doorway and does not have a smoke layer until Compartment 3 is filled to the top of the exit. Corridor 34 is directly connected to Corridor 36 and so it does not have high levels of smoke until the smoke layer in Corridor 36 lowers to the top of the exits. Notice that the optical density found in

Corridor 34 is much less than in Compartment 3 and Corridor 36. Since the smoke must fill Corridor 36 and then move into all other compartments afterwards, the optical density is greatly reduced. It can be seen in the floor plans in Appendix H that there are many compartments attached to Corridor 36, so smoke is not only flowing into Corridor 34 but also to the other compartments.

Figure 18 – Optical Densities For Several Compartments During Scenario 1

Figure 19 – Interface Height For Several Compartments During Scenario 1

In Figure 20 the temperatures of the three compartments are shown for this scenario. It is interesting to point out that the reason the smoke layer descends so close to the ground in Compartment 34, as shown in Figure 19, is because the temperature of the hot layer is that of room temperature. The smoke has no buoyancy hence it mixes with air of the lower layer and the interface descends almost to the floor.

Figure 20 – Hot Layer Temperatures For Several Compartments During Scenario 1

It is apparent that the sprinklers in this case have a large effect on the temperature attained by the fire. A maximum value of 170°C is reached, which is quite cool for a fire situation. This is due to the fact that the sprinklers cool and control the fire.

The mean egress time for this scenario was 363 seconds with a minimum value of 87 seconds and a maximum of 625 seconds. The evacuation results can be seen graphically in Figure 21 to Figure 23. Figure 22 shows that the distribution of the evacuations is normal. From Figure 23, it can be seen that occupants 31 to 47 evacuate earlier than all other occupants. This is expected since they are in the compartment of fire origin where the probability of response is higher, as seen in Figure 17.

Figure 21 – Percentage of Population Remaining in Scenario 1

Figure 22 – Number of Occupants Evacuated in Scenario 1

Figure 23 – Evacuation Times For Each Occupant in Scenario 1

6.5.2 Scenario 2

The second case is the same scenario as the first, but now the alarm system is not activated. The fire services arrive and sprinklers help control the fire, but there are no alarms to warn the occupants except for localized smoke detectors.

Figure 24 shows the probability of response of occupants for this scenario. Comparing to the curve for the previous scenario, it is obvious that the absence of an alarm system greatly reduces the likelihood of occupant response. At about 360 seconds (6 minutes), the occupants in the compartment of fire origin have a 100% likelihood of responding to the cues they are given. At 700 seconds (11.5 minutes), occupants in adjacent and other compartments have only a 90% likelihood of responding.

Figure 24 – Probability of Occupant Response During Scenario 2

The smoke conditions for this scenario are identical to those of Scenario 1, shown in Figure 18 to Figure 20. The only difference in the scenarios is that in this case, alarms are not functioning.

Figure 25 shows the total population evacuation as a function of time. Figure 26 shows the distribution of the evacuations for each time period. A mean evacuation time of 385 seconds was found. 91 seconds was found to be the minimum while 642 seconds was the maximum time taken to evacuate. Figure 27 shows the time of evacuation for each occupant. It is noticed, again, that occupants from the compartment of fire origin are the first to evacuate the building.

Figure 25 – Percentage of Population Remaining in Scenario 2

Figure 26 – Number of Occupants Evacuated in Scenario 2

Figure 27 – Evacuation Times For Each Occupant in Scenario 2

Comparing the results of Scenario 2 to those of Scenario 1, it appears that when the alarm system does not activate occupant evacuation times are increased. The occupants in the compartment of fire origin are not greatly affected by the absence of the alarm system because they receive direct cues from the fire so their evacuation times are still quite low.

6.5.3 Scenario 3

The third simulation has sprinklers to suppress the fire, alarms to warn occupants but it is assumed that the fire service does not arrive.

The mean egress time for the occupants was 373 seconds with a minimum of 82 seconds and a maximum of 593 seconds.

Figure 28 to Figure 30 show the distributions of occupant evacuation times.

Figure 28 – Percentage of Population Remaining in Scenario 3

Figure 29 – Number of People Evacuated in Scenario 3

As before, the occupants in the compartment of fire origin respond and evacuate earlier than those in the other compartments of the building. Figure 29 shows the distribution of the occupants initially in the compartment of fire origin is separate from the other occupants of the building because they respond quicker to the situation.

Looking at Figure 30, it seems that the evacuation process is quite close to the average evacuation time line. Ignoring the occupants of the fire compartment, almost the entire population is represented by the average evacuation time within 100 seconds (between 300 and 500 seconds).

Figure 30 – Evacuation Times For Each Occupant in Scenario 3

6.5.4 Scenario 4

The fourth scenario has sprinklers to suppress the fire but fire services do not arrive and there are no alarms to warn occupants of any danger, except for smoke detectors.

The percentage of the population evacuated as a function of time can be seen in Figure 31. The slight dip in the curve at the beginning is when the occupants from the compartment of fire origin evacuate the building.

The mean egress time is 379 seconds with a minimum value of 86 seconds and a maximum of 655 seconds. The evacuation results can be seen graphically in Figure 31 to Figure 33.

The times of evacuation for each occupant are shown in Figure 33 and it can be seen that the occupants in the fire compartment egress earlier than all others. In this scenario, there are many more occupants who evacuate at a later time. This makes sense since the alarms do not activate in this case.

Figure 31 – Percentage of Population Remaining in Scenario 4

Figure 32 – Number of Occupants Evacuated in Scenario 4

Figure 33 – Evacuation Times For Each Occupant in Scenario 4

This evacuation appears to be more spread out than the previous scenario. This is because there is no central alarm and occupants do not receive warning about the fire.

6.5.5 Scenario 5

The fifth simulation has no sprinklers available, but fire services are expected to arrive and the alarm system activates and warns the occupants.

A comparison between this scenario and Scenario 1 can be done to see the effects of sprinklers on the smoke levels expected within the building during the simulation. The results of the smoke model for this scenario are shown in Figure 34 to Figure 36.

Figure 34 – Optical Densities For Several Compartments in Scenario 5

Figure 35 – Smoke Layer Heights For Several Compartments in Scenario 5

Figure 36 – Temperature Profiles For Several Compartments in Scenario 5

Comparing the temperatures for the compartments in this case to those found in Scenario 1, the compartment of fire origin reaches around 400°C compared to the 170°C with the sprinklers. This shows that the sprinklers will help reduce the heat in the building and also the levels of smoke.

The mean egress time for evacuation in this scenario was 366 seconds, with a minimum value of 85 seconds and a maximum of 572 seconds.

Figure 37 to Figure 39 show the results of the evacuation model for this scenario.

Figure 37 – Percentage of Population Remaining in Scenario 5

Figure 38 – Number of Occupants Evacuated in Scenario 5

Figure 39 – Evacuation Times For Each Occupant in Scenario 5

6.5.6 Scenario 6

The sixth scenario is the same as the fifth scenario except that there are no alarms available.

This scenario has the longest time to evacuation when compared to the first eight scenarios. The mean evacuation time for this scenario was 348 seconds with a minimum value of 85 seconds and a maximum evacuation time of 913 seconds. This happens because there are no alarms but also because of the increased optical densities for this scenario that reduce evacuation speeds. Figure 40 to Figure 42 show the results of the evacuation model for this scenario.

Figure 40 – Percentage of Population Remaining in Scenario 6

Figure 41 – Number of Occupants Evacuated in Scenario 6

Figure 42 – Evacuation Times For Each Occupant in Scenario 6

6.5.7 Scenario 7

The seventh fire scenario has only an alarm system available to warn occupants and increase evacuation times. There are no sprinklers and no fire services available.

The average evacuation time for this scenario was 369 seconds with the quickest time being 91 seconds and the slowest being 593 seconds. Figure 44 shows that the distribution of speeds is quite normal.

Figure 43 to Figure 45 show results of the evacuation model for this scenario. Figure 45 shows the evacuation time of each occupant and the mean value of evacuation time. Occupants 31 to 47 are situated in the parking services office and can be seen to evacuate noticeably quicker than the rest of the occupants in the building, since it is the compartment of fire.

Figure 43 – Percentage of Population Remaining in Scenario 7

Figure 44 – Number of Occupants Evacuated in Scenario 7

Figure 45 – Evacuation Times For Each Occupant in Scenario 7

Notice that the maximum time for evacuation has been reduced below 600 seconds with the presence of alarms, while for previous scenarios without alarms the time to evacuate was over 900 seconds.

6.5.8 Scenario 8

The last case for the parking office is the worst case scenario for this compartment. There are no sprinklers, no alarms, and the fire services are not expected to arrive.

The mean evacuation time for this simulation was 393 seconds, with a minimum of 93 seconds and a maximum of 752 seconds. Notice that the 752 seconds is lower than the 913 seconds from Scenario 6. The difference between the two scenarios is that this scenario assumes no fire safety features to function properly while Scenario 6 assumes fire services will arrive. It would appear that Scenario 8 should have a higher maximum evacuation time or a similar evacuation time to Scenario 6. The two scenarios actually have very similar evacuation times if the occupant who took 913 seconds to evacuate is ignored. This occupant was an anomaly in the data which happens from time to time due to the probabilistic nature of the program.

The evacuation model results for Scenario 8 are shown in Figure 46 to Figure 48.

Figure 46 – Percentage of Population Remaining in Scenario 8

Figure 47 – Number of Occupants Evacuated in Scenario 8

Figure 48 – Evacuation Times For Each Occupant in Scenario 8

6.6 Fire in Compartment 15 (Restaurant on 2nd Floor)

For this scenario, the fire takes place in a restaurant. The most likely fire is in the kitchen during a cooking accident. The fire will likely be a grease fire that has been left unattended. This is represented by a medium t^2 fire ($\alpha = 40 \text{ kW/min}^2$), just like the fires considered in Section 6.5. The population in the restaurant is expected to be 12 people, comprised of four employees and eight customers. This is a typical population size during the day in the small café. The occupants in this compartment are occupants 143 to 154.

The same eight scenarios will be considered for this compartment but only the results will be given. Graphs of data appeared similar to those in Section 6.5. Table 20 gives the details of the eight scenarios considered with the fire in Compartment 15 and Table 21 shows the summarized results of the eight scenarios.

Table 20 – Simulations Performed With Fire in Compartment 15

Fire Room	Sprinkler	Fire Dept	Alarm	Probability	Scenario No
2 nd Floor Restaurant (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	9
			No (0.1)	0.01425	10
		No (0.4)	Yes (0.9)	0.0855	11
			No (0.1)	0.0095	12
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	13
			No (0.1)	0.00075	14
		No (0.4)	Yes (0.9)	0.0045	15
			No (0.1)	0.0005	16

Table 21 – Results From Fire in Compartment 15

Compartment 15				
Scenario #	Evacuation Time (seconds)			
	Mean	Minimum	Maximum	Std. Dev.
9	337	73	561	87
10	352	78	661	98
11	344	74	572	85
12	354	67	670	102
13	346	80	574	89
14	353	72	666	102
15	331	77	529	89
16	353	72	666	105
Average	346	74	612	95

6.6.1 Scenario 9

Scenario 9 will be looked at in detail so that it can be compared to a similar simulation performed using EvacNET.

Scenario 9 should be the safest case for Compartment 15 since there are sprinklers, alarm systems and fire services all available.

The mean evacuation time for occupants was 337 seconds with minimum and maximum values of 73 and 561 seconds respectively.

A simulation almost identical to this one was performed by Hadjisophocleous and Fu [1] using the evacuation model EvacNET. The results showed that the evacuation was completed in 550 seconds. This compares well with the results of this occupant evacuation simulation which yielded a total evacuation time of 561 seconds. The population remaining in the building at different times can be seen in Figure 49.

Figure 49 – Percentage of Population Remaining in Scenario 9

6.6.2 Scenario 15

Scenario 15 will be looked at in detail because it is the most obvious threat in the building, a fire in the restaurant on the 2nd level. This is Compartment 15 on the floor plans (Appendix H). It is a medium t^2 fire with only an alarm system available.

It can be seen from Figure 50 to Figure 52 that the times of evacuation were quite evenly distributed about the mean value of 331 seconds. The quickest evacuation was 77 seconds while the slowest was 529 seconds.

Distribution of each occupant's evacuation time is shown in Figure 52. The scatter plot shows how each occupant's evacuation time relates to the mean value. Noticing in the middle of the plot, occupants 143 to 154 evacuate substantially quicker than the rest of the occupants in the building. These are the occupants within Compartment 15, the compartment of fire origin, so this makes sense since they receive cues other occupants do not.

Figure 50 – Percentage of Population Remaining in Scenario 15

Figure 51 – Number of Occupants Evacuated in Scenario 15

Figure 52 – Evacuation Times For Each Occupant in Scenario 15

6.7 Fire In Compartment 22 (THSAO on 3rd Floor)

This fire is in the office of the THSAO company. The fire load is similar to the fire load of the parking office, with lots of paper and office furniture. The fire is represented in this scenario by a medium t^2 fire. The population is expected to be eight people, comprised solely of employees. Occupants 211 to 218 are initially in this compartment.

The same eight scenarios are considered for this compartment, as in Section 6.5, but only the overall results will be given. Graphs of data appeared similar to those in Section 6.5. Table 22 gives the details of the eight scenarios considered for this fire. Table 23 shows the results of the scenarios for this compartment.

Table 22 – Simulations Performed With Fire in Compartment 22

Fire Room	Sprinkler	Fire Dept	Alarm	Probability	Scenario No
3 rd Floor THSAO (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	17
			No (0.1)	0.01425	18
		No (0.4)	Yes (0.9)	0.0855	19
			No (0.1)	0.0095	20
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	21
			No (0.1)	0.00075	22
		No (0.4)	Yes (0.9)	0.0045	23
			No (0.1)	0.0005	24

Table 23 – Results From Fire in Compartment 22

Compartment 22				
Scenario #	Evacuation Time (seconds)			
	Mean	Minimum	Maximum	Std. Dev.
17	334	138	564	72
18	403	109	663	98
19	379	151	616	89
20	411	150	703	96
21	392	133	659	87
22	393	161	670	108
23	384	134	654	87
24	399	128	852	105
Average	387	138	673	93

6.7.1 Scenario 23

The twenty-third scenario is a fire which occurs in the THSAO compartment on the 3rd floor. This is Compartment 22 on the floor plans (Appendix H). It is a medium t^2 fire with only an alarm system available.

Figure 53 shows the percentage of occupants evacuated over time. Figure 54 shows the number of occupants evacuated per interval of time. It can be seen that the mean time for evacuation was 332 seconds with a minimum of 135 seconds and a maximum of 535 seconds. A trend tends to be that as the fire is started on higher levels of the building, the minimum time to evacuate is increased. Since the occupants who are in the compartment of fire origin, and are usually the first to begin evacuation, have a longer distance to travel, this makes sense.

Queuing in this scenario tends to be in the stairwell and especially at the final exits of the stairwells. It is also apparent at the exits to the outside where people must use the exit.

In Figure 55, the distribution of speeds for each occupant is given. The times of evacuation tend to be close to the mean value of egress. The exceptions are occupants 211 to 218 who are in the compartment of fire origin, Compartment 22. These occupants exit the building quicker than all others since they receive extra cues from the immediate fire.

Figure 53 – Percentage of Population Remaining in Scenario 23

Figure 54 – Number of Occupants Evacuated in Scenario 23

Figure 55 – Evacuation Times For Each Occupant in Scenario 23

6.8 Fire In Compartment 26 (Tempest Office on 4th Floor)

The final fire location is the Tempest office on the top floor of the building. There is a lounge area when the office is first entered and the fire is assumed to be started on the sofa that is found there. This type of fire, with upholstered furniture as the fuel source will grow quickly and will be represented in this scenario by a fast t^2 fire. This means that α will be 146 kW/min^2 rather than 40 kW/min^2 as used when the fire grew in the slower medium t^2 fashion. The maximum Heat Release Rate (HRR) is 5.0 MW so that if the fire reached this value it would remain there until the cooling phase. The population is expected to be 30 people, comprised solely of 30 employees. Occupants 219 to 248 will represent these employees in the simulation.

The same eight scenarios are considered for this compartment but only the overall results will be given. Graphs of data appeared similar to those in Section 6.5. Table 24 gives the details of the eight scenarios considered for this fire. Table 25 shows the results of the scenarios modelled for this compartment.

Table 24 – Simulations Performed With Fire in Compartment 26

Fire Room	Sprinkler	Fire Dept	Alarm	Probability	Scenario No
4 th Floor TEMPEST (0.25)	Yes (0.95)	Yes (0.6)	Yes (0.9)	0.12825	25
			No (0.1)	0.01425	26
		No (0.4)	Yes (0.9)	0.0855	27
			No (0.1)	0.0095	28
	No (0.05)	Yes (0.6)	Yes (0.9)	0.00675	29
			No (0.1)	0.00075	30
		No (0.4)	Yes (0.9)	0.0045	31
			No (0.1)	0.0005	32

Table 25 – Results From Fire in Compartment 26

Compartment 26				
Scenario #	Evacuation Time (seconds)			
	Mean	Minimum	Maximum	Std. Dev.
25	330	144	710	91
26	345	143	740	98
27	334	141	729	91
28	337	137	768	90
29	337	135	786	96
30	349	132	931	104
31	340	130	745	97
32	345	140	770	99
Average	340	138	772	96

6.8.1 Scenario 31

The thirty-first case is a fire which occurs in the Tempest office on the 4th floor. This is Compartment 26 on the floor plans (Appendix H). It is a fast t^2 fire with only an alarm system available for detection.

Figure 56 to Figure 58 show the results of an evacuation based on a fast fire on the top floor of the CTTC. The mean time of evacuation was 340 seconds, which can be seen in Figure 58 below. The minimum evacuation time was 130 seconds and the maximum time was 770 seconds. Again, it is noted that on the higher levels of the building, the minimum evacuation time for this scenario is larger than the other scenarios with similar conditions, on lower floors.

It is seen in Figure 57 and Figure 58 that the occupants within the compartment of fire origin, 219 to 248, evacuate sooner than all other occupants because of additional cues they receive.

Figure 56 – Percentage of Population Remaining in Scenario 31

Figure 57 – Number of Occupants Evacuated in Scenario 31

Figure 58 – Evacuation Times For Each Occupant in Scenario 31

From Figure 58 it is seen that within the collection of occupants, 249 to 293, the occupants tend to take longer to evacuate in this case. This case has no fire suppression but it does have alarms to warn occupants. This group of occupants is on the same floor as the compartment of fire but they are not from the compartment of fire. When this group of occupants attempts to evacuate the building they find smoke from the fast growing fire that is not being suppressed. This causes the occupants to try and find an alternate route and increases their overall evacuation time as shown.

6.9 Life Hazard Calculations

Life hazard calculations for each scenario were done using the life hazard sub-model of the risk model. The life hazard sub-model uses the levels of toxicants in the air to determine whether an occupant has been injured or killed. The Fractional Incapacitating Dose (FID) is the summation of values based upon the levels of all toxic gases in a compartment at any given time. In the life hazard model it is assumed that if the FID value is larger than 0.2 then an occupant is considered injured and if the FID value reaches 0.8, the occupant is considered dead. Normally, the FID value for death is assumed to be 1.0 so using 0.8 is a conservative estimate.

The results of the life hazard calculations are given in Table 26. In Table 26 the overall results can be seen for each scenario. It can be seen that there were a few injuries and deaths in the simulations that were run. There were five deaths, one in Scenario 22, one in Scenario 24, one in Scenario 30 and two in Scenario 32.

To provide a quick assessment of the effect of sprinklers, alarms and fire services on the life hazard results, Table 27 to Table 29 show the average values for all scenarios corresponding to a particular system. These numbers do not consider the likelihood of the scenario occurring. This will be accounted for in Section 6.10, where a risk analysis will be performed.

Table 26 – Complete Results of Fire Scenarios For CTTC Building

CTTC BUILDING						
Scenario #	Evacuation Time (seconds)				Life Hazard	
	Mean	Minimum	Maximum	Std. Dev.	Injuries	Deaths
1	367	87	625	99	0	0
2	385	91	642	104	0	0
3	373	82	593	94	0	0
4	379	86	655	106	0	0
5	366	85	572	97	0	0
6	348	85	913	118	0	0
7	369	91	593	99	0	0
8	393	93	752	112	0	0
9	337	73	561	87	0	0
10	352	78	661	98	0	0
11	344	74	572	85	0	0
12	354	67	670	102	0	0
13	346	80	574	89	0	0
14	353	72	666	102	1	0
15	331	77	529	89	0	0
16	353	72	666	105	1	0
17	334	138	564	72	0	0
18	403	109	663	98	0	0
19	379	151	616	89	0	0
20	411	150	703	96	0	0
21	392	133	659	87	0	0
22	393	161	670	108	0	1
23	384	134	654	87	0	0
24	399	128	852	105	0	1
25	330	144	710	91	0	0
26	345	143	740	98	2	0
27	334	141	729	91	0	0
28	337	137	768	90	0	0
29	337	135	786	96	1	0
30	349	132	931	104	0	1
31	340	130	745	97	3	0
32	345	140	770	99	1	2
Average	361	109	681	97		

Table 27 shows the average values of the 16 scenarios with alarms and the 16 scenarios without alarms. It can be seen that the addition of alarms to a building helps decrease the time required to evacuate and decreases the number of deaths although the number of injuries increases slightly. These results make sense since the occupants are warned of danger earlier with the presence of alarms in the building. Occupants are more likely to evacuate with the alarms and may enter areas that are smoke filled, so injuries may slightly increase. Deaths per scenario are reduced from 0.31 to 0 when alarms are assumed to activate.

Table 27 – Effect of Alarms on Evacuation Times and Life Safety

Scenario	Evacuation Time (seconds)				Life Hazard	
	Mean	Minimum	Maximum	Std. Dev.	Injuries	Deaths
With Alarms	354	110	630	91	0.25	0.00
Without Alarms	369	109	733	103	0.31	0.31

Table 28 shows the effect of fire services arriving to the building in time to fight the fire. It appears that the fire services have no effect on the evacuation times but they do help decrease the number of deaths and injuries in the building. The effect appears to be less than that of the alarms since the fire department isn't assumed to begin fighting the fire until 300 seconds after the fire has begun. Deaths per scenario are reduced from 0.19 to 0.13 when the fire department is assumed to arrive in time to help contain the fire.

Table 28 – Effect of Fire Services on Evacuation Times and Life Safety

Scenario	Evacuation Time (seconds)				Life Hazard	
	Mean	Minimum	Maximum	Std. Dev.	Injuries	Deaths
With Fire Services	359	109	684	97	0.25	0.13
Without Fire Services	364	110	679	97	0.31	0.19

Table 29 shows the effect of having sprinklers to help suppress the fire as it begins to grow larger. It can be seen that the sprinklers have slightly reduced the maximum evacuation times of the occupants. More importantly, the sprinklers greatly reduce the likelihood of death and injury to the occupants. Deaths are reduced from 0.31 deaths per scenario to zero, when sprinklers are activated.

Table 29 – Effect of Sprinklers on Evacuation Times and Life Safety

Scenario	Evacuation Time (seconds)				Life Hazard	
	Mean	Minimum	Maximum	Std. Dev.	Injuries	Deaths
With Sprinklers	360	109	655	94	0.13	0.00
Without Sprinklers	362	109	708	100	0.44	0.31

6.10 Expected Risk to Life Analysis

Now that all the scenarios have been discussed and the results for each shown, a closer look at the Expected Risk to Life (ERL) for the occupants can be undertaken. The ERL is computed using Equation 12. As it can be seen from Equation 12, the ERL is the

sum of the product of the number of deaths for each scenario and the probability of each scenario occurring.

$$ERL = \left(\sum_i^N D_i P_i \right) * P_A A \quad \text{Equation 12}$$

where: D_i = number of deaths for scenario i

P_i = probability of the scenario occurring

P_A = annual likelihood of a fire occurring in the building. This is given in units of fire/m²/year.

A = area of the building in metres squared.

N = number of scenarios to be considered

i = counter variable used for the summation

Equation 12 also uses the expected frequency of fires for the building. It was found that the frequency of fires, P_A , occurring in office buildings is 7.68×10^{-6} fires/m²/year [43]. The floor area of the CTTC, the building considered in all scenarios, has been calculated as 5240 m².

To compare the ERL of different alternative design options for this building the risk model was used to perform the risk analysis for the following options.

Option A is the current design.

Option B assumes that the fire department will not respond to fires.

Option C considers the building without sprinklers installed.

Option D considers the building without an alarm system installed.

Option E has sprinklers installed but no alarm system installed and fire services will not respond to fires.

Option F has no sprinklers installed and no alarm system installed but fire services are expected to respond to fires.

Option G has an alarm system but no sprinklers are installed and fire services are not expected to respond to fires.

Option H has no sprinklers or alarms installed and the fire services are not expected to respond to fires.

The possible scenarios and the probabilities for each of the design options are shown in Table 30 to Table 37.

Table 30 shows the scenarios and probabilities for Design Option A which includes sprinklers, alarms and assumes fire services will respond to fires.

Table 30 – Option A: Risk to Life Calculations With All Services Available

CTTC BUILDING With All Services Available				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
1	0	0	0.12825	0
2	0	0	0.01425	0
3	0	0	0.0855	0
4	0	0	0.0095	0
5	0	0	0.00675	0
6	0	0	0.00075	0
7	0	0	0.0045	0
8	0	0	0.0005	0
9	0	0	0.12825	0
10	0	0	0.01425	0
11	0	0	0.0855	0
12	0	0	0.0095	0
13	0	0	0.00675	0
14	1	0	0.00075	0
15	0	0	0.0045	0
16	1	0	0.0005	0
17	0	0	0.12825	0
18	0	0	0.01425	0
19	0	0	0.0855	0
20	0	0	0.0095	0
21	0	0	0.00675	0
22	0	1	0.00075	0.00075
23	0	0	0.0045	0
24	0	1	0.0005	0.0005
25	0	0	0.12825	0
26	2	0	0.01425	0
27	0	0	0.0855	0
28	0	0	0.0095	0
29	1	0	0.00675	0
30	0	1	0.00075	0.00075
31	3	0	0.0045	0
32	1	2	0.0005	0.001
Total	9	5	1.00	0.003
ERL	0.00012073			

Table 31 presents the scenarios and probabilities for Design Option B, which includes sprinklers and alarms but assumes that the fire department does not respond to fires.

Table 31 – Option B: Risk to Life Calculations With No Fire Department

CTTC BUILDING With No Fire Department				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
3	0	0	0.21375	0
4	0	0	0.02375	0
7	0	0	0.01125	0
8	0	0	0.00125	0
11	0	0	0.21375	0
12	0	0	0.02375	0
15	0	0	0.01125	0
16	1	0	0.00125	0
19	0	0	0.21375	0
20	0	0	0.02375	0
23	0	0	0.01125	0
24	0	1	0.00125	0.00125
27	0	0	0.21375	0
28	0	0	0.02375	0
31	3	0	0.01125	0
32	1	2	0.00125	0.0025
Total	5	3	1.00	0.00375
ERL	0.000150912			

Table 32 is for Design Option C, which has no sprinklers installed but includes alarms and assumes the fire department responds to fires.

Table 32 – Option C: Risk to Life Calculations With No Sprinklers

CTTC BUILDING With No Sprinklers				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
5	0	0	0.135	0
6	0	0	0.015	0
7	0	0	0.09	0
8	0	0	0.01	0
13	0	0	0.135	0
14	1	0	0.015	0
15	0	0	0.09	0
16	1	0	0.01	0
21	0	0	0.135	0
22	0	1	0.015	0.015
23	0	0	0.09	0
24	0	1	0.01	0.01
29	1	0	0.135	0
30	0	1	0.015	0.015
31	3	0	0.09	0
32	1	2	0.01	0.02
Total	7	5	1.00	0.06
ERL	0.002414592			

Table 33 shows scenarios and corresponding probabilities for Design Option D, which includes sprinklers, no alarm system and assumes fire services will respond to fires.

Table 33 – Option D: Risk to Life Calculations With No Alarm System

CTTC BUILDING With No Alarm Systems				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
2	0	0	0.1425	0
4	0	0	0.095	0
6	0	0	0.0075	0
8	0	0	0.005	0
10	0	0	0.1425	0
12	0	0	0.095	0
14	1	0	0.0075	0
16	1	0	0.005	0
18	0	0	0.1425	0
20	0	0	0.095	0
22	0	1	0.0075	0.0075
24	0	1	0.005	0.005
26	2	0	0.1425	0
28	0	0	0.095	0
30	0	1	0.0075	0.0075
32	1	2	0.005	0.01
Total	5	5	1.00	0.03
ERL	0.001207296			

The scenarios and probabilities for Design Option E are shown in Table 34. This option has sprinklers, no alarm system and no fire services.

Table 34 – Option E: Risk to Life Calculations With Only Sprinklers

CTTC BUILDING With Only Sprinklers				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
4	0	0	0.2375	0
8	0	0	0.0125	0
12	0	0	0.2375	0
16	1	0	0.0125	0
20	0	0	0.2375	0
24	0	1	0.0125	0.0125
28	0	0	0.2375	0
32	1	2	0.0125	0.025
Total	2	3	1.00	0.0375
ERL	0.00150912			

Table 35 is for Design Option F, which has no sprinklers, no alarm system but the fire department responds to fires.

Table 35 – Option F: Risk to Life Calculations With Only Fire Department

CTTC BUILDING With Only Fire Department				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
6	0	0	0.15	0
8	0	0	0.1	0
14	1	0	0.15	0
16	1	0	0.1	0
22	0	1	0.15	0.15
24	0	1	0.1	0.1
30	0	1	0.15	0.15
32	1	2	0.1	0.2
Total	3	5	1.00	0.6
ERL	0.02414592			

Design Option G has no sprinklers, has an alarm system and fire services will not respond to fires. This Design Option is found in Table 36.

Table 36 – Option G: Risk to Life Calculations With Only Alarm System

CTTC BUILDING With Only Alarms				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
7	0	0	0.225	0
8	0	0	0.025	0
15	0	0	0.225	0
16	1	0	0.025	0
23	0	0	0.225	0
24	0	1	0.025	0.025
31	3	0	0.225	0
32	1	2	0.025	0.05
Total	5	3	1.00	0.075
ERL	0.00301824			

Table 37 shows the scenarios and probabilities for Design Option H, which has no sprinklers, no alarm system and fire services will not respond to fires.

Table 37 – Option H: Risk to Life Calculations With Nothing

CTTC BUILDING With Nothing				
Scenario #	Risk to Life			
	Injuries	Deaths	Probability	Deaths*Probability
8	0	0	0.25	0
16	1	0	0.25	0
24	0	1	0.25	0.25
32	1	2	0.25	0.5
Total	2	3	1.00	0.75
ERL	0.0301824			

The computed ERLs for all Design Options are shown in Table 38. Since the ERL values are very small, and to facilitate comparison, the values are normalized using the ERL value of Design Option H. This gives a value of 1.0 for Design Option H. A number smaller than 1.0 means the design is safer than Option H.

Table 38 – Expected Risk to Life Results

Design Option	Systems Included	Risk to Life	
		ERL	Normalized ERL
A	Alarm, Sprinkler, Dept.	0.000121	0.004
B	Alarms, Sprinklers	0.000151	0.005
C	Alarms, Fire Dept.	0.002415	0.08
D	Sprinklers, Fire Dept.	0.001207	0.04
E	Sprinklers	0.001509	0.05
F	Fire Department	0.024146	0.8
G	Alarms	0.003018	0.1
H	Nothing	0.030182	1

The results show that Design Option A, which has all systems present, is the safest. Adding all three protection systems reduces the normalized ERL from 1.0 to 0.004. Closely behind is design Option B which has alarms and sprinklers, with a normalized ERL of 0.005. The results show that sprinklers are the most effective in reducing risk to life. The results indicate that alarms help reduce risk to life as well. This can be seen by looking at the ERL of Design Option G which only has alarms. This option reduces the normalized ERL from 1.0 to 0.1. Design Option F, with the fire department, only reduces the normalized ERL from 1.0 to 0.8. Of course, not all of the fire department's duties are considered in the model. The fire department is only considered to fight the fire excluding their rescue efforts which, in reality, may help to further reduce risk.

These results are preliminary and used to demonstrate how the occupant evacuation model can be used in the risk model. More accurate results will be obtained when all sub-models of the risk model are completed. Additionally, these results pertain only to the CTTC. For a different design or building, the results may differ.

7. CONCLUSIONS

Using the SHEBA facility, 389 participants were used to generate a useful dataset of speeds in various smoke-filled environments. Men accounted for 52% of the population while women accounted for 48%. A third of both of these populations were over the age of 50. This made for a good range of data to represent the general public. Some data were used from a previous set of experiments and had similar population demographics.

It was found that gender was the dominant variable affecting movement speeds, when participants were moving along the corridor of SHEBA, in both directions. The speed of people descending the staircase was also gender dependent.

The general effect of smoke introduction to SHEBA was to decrease egress speeds. The only exception was the minimal level (0.1 OD/m), which increased participants' speeds slightly.

An occupant evacuation computer model has been developed to simulate occupant evacuation from buildings. The model predicts realistic times for occupant egress. The model uses data gathered from the SHEBA trials on the speed capabilities of the general public in different levels of smoke.

The occupant evacuation computer model accounts for crowd density and smoke levels to influence the speeds of the occupants. Exit selection is performed with likely familiarity and is affected by the levels of smoke in the building. The program handles the effects of queuing and stairwell movements. The occupant evacuation model can handle high numbers of occupants and large buildings. It was tested for a building with

40 rooms and 1900 occupants. The model takes longer to run as more occupants are considered but it still completes the evacuation simulation.

The Carleton Training and Technology Center (CTTC) was used to perform hazard and risk analysis calculations, to compare the impact of sprinklers, alarms and fire services on life hazard. It was found from the simulations performed that alarm systems decrease egress times significantly for occupants. The average evacuation time is reduced by about 100 seconds when alarms are introduced. Sprinklers were found to have a minor effect on the evacuation times. When sprinklers were introduced, evacuation times were reduced by about 50 seconds. It was also found that fire services, which are assumed to engage solely in firefighting activities, had a negligible effect on egress times.

Risk to life calculations revealed that alarm systems, fire services and sprinklers all contribute to reducing the risk to life for occupants of a building. Sprinklers had the highest impact on risk to life by reducing the normalized ERL from 1.0 to 0.05. Alarms had the next desirable effect on the normalized ERL by reducing it from 1.0 to 0.1. Lastly, the fire department reduced the normalized ERL from 1.0 to 0.8.

The ideal combination was found to be the combination of all three systems which reduced the normalized ERL from 1.0 to 0.004. If only two systems could be implemented, sprinklers and alarms would be the best selection followed by a combination of sprinklers and fire services.

Although these results are preliminary and are only applicable to the CTTC, they demonstrate the usefulness of risk assessment models in evaluating alternative fire protection designs for buildings, and the importance of the occupant evacuation model in the analysis.

7.1 Future Work

The evacuation model simulates occupant behaviour quickly and accurately but there are still several additions to the program that could be implemented.

The current model does not allow disabled people to be modelled. Blind occupants, deaf occupants, occupants in wheelchairs and even occupants with canes have special needs that must be considered in a fire situation. For example, deaf occupants will not hear an alarm system, so the system should incorporate visual cues as well as the standard audio cues.

Another occupant characteristic that is important to accurately modelling human behaviour is familiarity of the occupant with the building. Adding a familiarity factor that will influence the occupant's exit selections would make a more realistic evacuation process. Currently, the probability of using a door is a building characteristic with no adjustment for occupant familiarity with the building. Having a familiarity factor associated with the occupant, like gender or speed, would allow each doorway probability to be adjusted according to the occupant's own familiarity with the building.

Adding grid spacing to the program so that more accurate locations of each occupant will be known would allow occupant to occupant interactions to be modelled. Crowding and obstacle avoidance could be modelled easier with this type of enclosure representation.

A visual method of displaying the results would also be a beneficial extension of the program. Having the floor plan of the building with an occupant's egress route highlighted would make the program more user-friendly. Having moving dots on the floor plan may also be beneficial with low populations. Higher populations would become too cluttered on the floor plan and it would be difficult to see what is occurring as each occupant moves around.

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APPENDIX A
TEST PLAN AND OTHER FORMS

Table 39 – Test Plan For SHEBA Smoke Trials

Test Number	Angle	No Smoke	Smoke Density 1 (0.1)	Smoke Density 2 (0.5)	Smoke Density 3 (1.0)
1 (Check of 14) SET 1	0	1			
	0		1		
	20				1
	10			1	
2 (Check of 1) SET 1	0	1			
	10			1	
	0		1		
	20				1
3 (Check of 16) SET 2	0	1			
	20		1		
	10				1
	0			1	
4 (Check of 3) SET 2	0	1			
	0			1	
	20		1		
	10				1
5 (Check of 18) SET 3	0	1			
	10		1		
	20			1	
	0				1
6 (Check of 5) SET 3	0	1			
	0				1
	10		1		
	20			1	

Tests are placed vertically in order of completion. This is also true for the trials within each test. The highlighted box is the combination of smoke and angle used for that particular trial.

Test Number	Angle	No Smoke	Smoke Density 1 (0.1)	Smoke Density 2 (0.5)	Smoke Density 3 (1.0)
7 (Check of 2) SET 1	0	1			
	0		1		
	10			1	
	20				1
8 (Check of 7) SET 1	0	1			
	10			1	
	20				1
	0		1		
9 (Check of 4) SET 2	0	1			
	20		1		
	0			1	
	10				1
10 (Check of 9) SET 2	0	1			
	0			1	
	10				1
	20		1		
11 (Check of 6) SET 3	0	1			
	10		1		
	0				1
	20			1	
12 (Check of 11) SET 3	0	1			
	0				1
	20			1	
	10		1		
13 (Check of 8) SET 1	0	1			
	20				1
	10			1	
	0		1		
14 (Check of 13) SET 1	0	1			
	20				1
	0		1		
	10			1	
15 (Check of 10) SET 2	0	1			
	10				1
	0			1	
	20		1		
16 (Check of 15) SET 2	0	1			
	10				1
	20		1		
	0			1	
17 (Check of 12) SET 3	0	1			
	20			1	
	0				1
	10		1		
18 (Check of 17) SET 3	0	1			
	20			1	
	10		1		
	0				1

Test Number	Angle	No Smoke	Smoke Density 1 (0.1)	Smoke Density 2 (0.5)	Smoke Density 3 (1.0)
19 (Test 1) SET 1	0	1			
	0		1		
	20				1
	10			1	
20 (Test 7) SET 2	0	1			
	20		1		
	10				1
	0			1	
21 (Test 13) SET 3	0	1			
	10		1		
	20			1	
	0				1
22 (Test 1) SET 1	0	1			
	0		1		
	20				1
	10			1	
23 (Test 7) SET 2	0	1			
	20		1		
	10				1
	0			1	
24 (Test 13) SET 3	0	1			
	10		1		
	20			1	
	0				1

* Tests are designed such that 1/day can be performed (2hours 5min) with 55min leeway

** Completing the 6 test combinations 3 times yields 18 tests, with 288 participants

*** Completing the 3 major tests twice more, after validation, yields 384 participants

Typical Daily Test Plan

TEST DIRECTOR CHECKLIST

Test Number: _____

	Angle	OD
Reference:	0 deg	0 OD/m
Scenario 1:		
Scenario 2:		
Scenario 3:		

#	Reference		Scenario 1		Scenario 2		Scenario 3	
	1 to 4	4 to 1	1 to 4	4 to 1	1 to 4	4 to 1	1 to 4	4 to 1
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
GRP								

*1 to 4 (refer to map for details)

*4 to 1 (refer to map for details)

*Place **checkmark** in box once participant has completed task

*Place **circle** in box if participant declined to perform task, quit before finishing task, or if data record incomplete. (Circle and checkmark signifies data successfully recorded on a repeat run.)

It can be seen that on every day 0° and 0.0 OD was performed as the first test. The other three tests were different every day but always contained a test of 0°, 10° and 20°. With each angle, either 0.1, 0.5 or 1.0 OD of smoke was added to SHEBA.

The test plans and the test matrix were designed to minimize participant learning curves from moving through SHEBA for 3 hours. Thus each combination of angle and smoke was done in a different order from day to day. For example, one day, 20° and 1.0 OD would be the 2nd test and the next day it would be the 4th test, so if there was a learning curve, the data would be spread so that the effect would be minimal.

Test Director Procedure

During Test

- data collection is done by 2 employees at position 5
- volunteers gather outside SHEBA, wait to be called in order (position 1)
 - get lifejackets on and record the time it takes
- Subjects called one at a time to the test director (position 2)
- Subjects waits by test director (position 2) until instructed to begin traversing SHEBA
- Subject is followed by safety personal, from behind, so they do not affect data
- once subject reaches stairs, safety personal return to the test director so that they know they can send the next evacuee through
- safety personal at top of stairs (position 3) guide evacuee out to ensure no injury on steep angles.
- evacuee is instructed by position 3 safety personal to gather along side of SHEBA (position 4)
- REPEAT STEPS 2-7 UNTIL ALL PARTICIPANTS ARE COLLECTED AT POSITION 4
- test director moves to position 3
 - safety personal at top of stairs then becomes the safety personal who will follow the participants through SHEBA
 - safety personal who was following participants now remains at position 2 and becomes the guide safety personal at the end of the corridor
- same test is repeated from position 4 to position 1
- once participants traverse SHEBA and reach position 2, they are directed to position 1 to await the end of the test

Before Test

- gather in kitchen/boardroom
- briefing on experiment and what is expected
- sign consent forms / medical forms
- activate LED's on helmets for the night
- subjects are shown SHEBA

In Between Tests

- take volunteers to kitchen for refreshments
- SHEBA is filled to next smoke density and then set to appropriate angle
 - Helps smoke fill more evenly (tends to roll to 1 side when filled at angle)
- ensure all test subjects are feeling well and want to continue

After Tests

- gather for post-questionnaire
- charity donation
- finish all the paperwork (donation form)
 - filled out and signed by test director and lead volunteer

MSDS For Fog Fluid

Material Safety Data Sheet

May be used to comply with

OSHA's Hazard Communication Standard,
29 CFR 1910.1200. Standard must be
consulted for specific requirements.

U.S. Department of Labor

Occupational Safety and Health
Administration

(Non-Mandatory Form)

Form Approved

OMB No. 1218-0072

IDENTITY (As Used on Label and List) For all types of Fog Fluid and Water-Based Haze	Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.
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Section I

Manufacturer's Name Multi Media Electronics, Inc.	Emergency Telephone Number 631-847-7711
Address (Number, Street, City, State, and ZIP Code) 295 Adams Blvd	Telephone Number for Information 631-847-7711
Farmingdale, NY 11735	Date Prepared 05-06-2002
	Signature of Preparer (optional)

Section II - Hazard Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity, Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended
Multi Media Inc. Fog Fluids are a filtered blend of polyfunctional alcohol regularly used by the food and cosmetics industries. The largest single component of these formulations is H ₂ O. This product does NOT contain any ethylene glycol, triethylene glycol, diethylene glycol, polyethylene CAS# 56-81-5 Glycerin (C ₃ H ₈ O ₃) C ₃ H ₈ O ₃ CAS# 7732-18-5 Water (H ₂ O) CAS# 25265-71-8 Dipropylene Glycol (C ₆ H ₁₄ O ₃) C ₆ H ₁₄ O ₃ CAS# 57-55-6 Propylene Glycol (C ₃ H ₈ O ₂) C ₃ H ₈ O ₂			
This product does not contain any hazardous components.			
Caution: Known asthmatics or people having a low tolerance to fog products may be temporarily affected by a fog-filled environment. Use responsible levels of concentration in well-ventilated areas. Liquid not for internal consumption. Keep out of the reach of children.			

Section III - Physical/Chemical Characteristics

Boiling Point:	N/E	Specific Gravity (H ₂ O = 1) @25/25C	1.12
Vapor Pressure (mm Hg.)	N/A	Melting Point	N/A
Vapor Density (AIR = 1)	N/A	Evaporation Rate (Butyl Acetate = 1)	N/E
Solubility in Water Completely miscible.			
Appearance and Odor Transparent colorless, slight vanilla scent			

Fog

Section IV - Fire and Explosion Hazard Data

Flash Point (Method Used) Min. 270°F	Flammable Limits	LEL N/D	UEL N/D
Extinguishing Media Water fog, alcohol foam, dry chemical.			
Special Fire Fighting Procedures Do not direct a solid stream of water or foam into hot, burning pool; this may cause frothing and increase fire intensity. Use self-contained breathing apparatus and protective clothing.			
Hazardous Combustion Products May include and are not limited to oxides of carbon.			
Means of Extinction Carbon dioxide, dry chemical, alcohol foam, water fog.			
Unusual Fire and Explosion Hazards Spontaneous combustion in porous insulation leaks into porous insulation material may ignite at temperatures far below published autoignition or ignition temperatures, potentially even below the normal flash point.			

Section V - Reactivity Data

Stability:	Stable	X	
	Unstable		
Incompatibility (Materials to avoid) Oxidizing materials.			
Hazardous Decomposition or Byproducts May include and are not limited to oxides of carbon when heated to decomposition.			
Hazardous Polymerization	May Occur		Conditions to Avoid Product degrades when stored at elevated temperatures in presence of air. Degradation occurs rapidly at temperatures approaching the flash point.
	Will Not Occur	X	

Section VI - Health Hazard Data**Route(s) of Entry:**

Eyes: Flush with water for at least 15 minutes.	Inhalation: Exhale contaminated air - inhale fresh air.	Skin: Wash with soap and water.	Ingestion: Consult Physician
Effects of Chronic Exposure: None Known.			
Effects of Acute Exposure: Eye: May cause irritation. Ingestion: May cause stomach irritation.			
Carcinogenicity: Non-hazardous	NTP? Not listed	IARC Monographs? Not listed	OSHA Regulated? Not listed
Medical Conditions Generally Aggravated by Exposure A knowledge of the available toxicology information and of the physical and chemical properties of the material suggests that overexposure is unlikely to aggravate existing medical conditions.			
Emergency and First Aid Procedures: See above			

Fog

Section VII - Precautions for Safe Handling and Use**Steps to Be Taken in Case Material is Released or Spilled**

Small spills can be flushed with large amounts of water; larger spills should be collected for disposal.

Waste Disposal Method

Incinerate in a furnace where permitted under Federal, State, and local regulations.

Precautions to Be taken in Handling and Storing

Keep out of reach of children. Store in closed container away from incompatible materials.

Section VIII - Control Measures**Respiratory Protection (Specify Type)**

At ambient temperature none needed for vapor.

Ventilation	Local Exhaust	Special
General room		
	Mechanical (General)	Other

Protective Gloves**Eye Protection**

Safety Goggles.

Work/Hygienic Practices: Good hygiene practices

This information is to the best of our knowledge and belief, accurate and reliable as of the date compiled. However, no representation, warranty or guarantee is made as to its accuracy, reliability or completeness. It is the user's responsibility to satisfy himself as to the suitability and completeness of such information for his own particular use. We do not accept liability for any loss or damage that may occur from the use of this information nor do we offer warranty against patent infringement.

LIGHT READINGS FOR SHEBA AND POSSIBLE VARIANCE

Condition	EV Reading (Exposure Value - ISO 100)		
	Light Source	Ambient from Cabin	Ambient from Stair Top
	EV = $\log(\text{LUX}/2.5) / \log(2)$		
Full Light in Sheba Full Ambient Light	17.00	8.00	6.33
Expected Light Conditions	9.67	2.00	1.00
Less Light in Sheba Low Ambient Light	8.67	2.00	1.00
<< Light in Sheba Low Ambient Light	4.00	1.67	1.00
More Light in Sheba Low Ambient Light	10.33	2.00	1.00
>> Light in Sheba Low Ambient Light	11.33	2.67	1.00

Condition	LUX Conversions		
	Light Source	Ambient from Cabin	Ambient from Stair Top
	Light Intensity (LUX) = $2.5 \cdot 2^{\text{EV}}$		
Full Light in Sheba Full Ambient Light	327680.00	640.00	201.12
Expected Light Conditions	2036.57	10.00	5.00
Less Light in Sheba Low Ambient Light	1018.29	10.00	5.00
<< Light in Sheba Low Ambient Light	40.00	7.96	5.00
More Light in Sheba Low Ambient Light	3217.95	10.00	5.00
>> Light in Sheba Low Ambient Light	6435.91	15.91	5.00

Table of all possible light levels in SHEBA during testing, given in EV and LUX readings.

APPENDIX B

SHEBA EQUIPMENT AND MODIFICATIONS

Figure B.59 – Hydraulic controls for SHEBA to alter angle of heel

Figure B.60 – Console with monitors to watch participants

Figure B.61 – Smoke generators on the side of SHEBA

Figure B.62 – Close-up of one smoke generator

Figure B.63 – Laser sensor on outside wall of SHEBA

Figure B.64 – View of same sensor inside SHEBA

Figure B.65 – Helmets with LED and life jackets worn by participants

Figure B.66 – Close-up of helmet and LED

Figure B.67 – Plastic barrier at end of SHEBA to contain smoke inside corridor

Figure B.68 – Cameras along ceiling of SHEBA corridor

Figure B.69 – Smoke meter for reading current level of smoke in SHEBA

APPENDIX C
SHEBA VIEWS

Figure C.70 – SHEBA corridor under normal conditions

Figure C.71 – SHEBA stairs under normal conditions

Figure C.72 – Hydraulics holding SHEBA at 20°

Figure C.73 – Hydraulic on SHEBA

Figure C.74 – SHEBA at 20° viewed from outside

Figure C.75 – SHEBA at 20° and OD = 0.5 OD/m from the outside

APPENDIX D

HEEL WITH SMOKE TESTING - RAW DATASET

Average Demographic Values Combining 2nd, 3rd And 4th Runs

0 Degree Values

Up Stairs - Speed 3-4 (m/s) 1

0 OD Men < 50		0 OD Men >= 50		0 OD Women < 50		0 OD Women >= 50	
Mean	1.328118	Mean	0.950732	Mean	1.045734	Mean	0.745915
Stand. Dev.	0.493297	Stand. Dev.	0.371376	Stand. Dev.	0.306136	Stand. Dev.	0.224954
Variance	0.243342	Variance	0.13792	Variance	0.093719	Variance	0.050605
Min. Value	0.59	Min. Value	0.41	Min. Value	0.58	Min. Value	0
Max. Value	2.76	Max. Value	2.3	Max. Value	2.29	Max. Value	1.32
Sample #	170	Sample #	81	Sample #	140	Sample #	71

0.1 OD Men < 50		0.1 OD Men >= 50		0.1 OD Women < 50		0.1 OD Women >= 50	
Mean	1.398444	Mean	0.9624	Mean	1.185385	Mean	0.709167
Stand. Dev.	0.609493	Stand. Dev.	0.254972	Stand. Dev.	0.405027	Stand. Dev.	0.232695
Variance	0.371482	Variance	0.065011	Variance	0.164047	Variance	0.054147
Min. Value	0.58	Min. Value	0.61	Min. Value	0.63	Min. Value	0.38
Max. Value	3.09	Max. Value	1.45	Max. Value	2.29	Max. Value	1.31
Sample #	45	Sample #	25	Sample #	39	Sample #	24

0.5 OD Men < 50		0.5 OD Men >= 50		0.5 OD Women < 50		0.5 OD Women >= 50	
Mean	1.213962	Mean	0.966667	Mean	1.006571	Mean	0.593636
Stand. Dev.	0.443809	Stand. Dev.	0.495212	Stand. Dev.	0.258092	Stand. Dev.	0.191723
Variance	0.196967	Variance	0.245235	Variance	0.066611	Variance	0.036758
Min. Value	0.52	Min. Value	0.41	Min. Value	0.59	Min. Value	0.31
Max. Value	2.49	Max. Value	2.53	Max. Value	1.83	Max. Value	1.06
Sample #	53	Sample #	18	Sample #	35	Sample #	22

1.0 OD Men < 50		1.0 OD Men >= 50		1.0 OD Women < 50		1.0 OD Women >= 50	
Mean	0.998846	Mean	0.640455	Mean	0.907143	Mean	0.627273
Stand. Dev.	0.376301	Stand. Dev.	0.194703	Stand. Dev.	0.254091	Stand. Dev.	0.220695
Variance	0.141603	Variance	0.037909	Variance	0.064562	Variance	0.048706
Min. Value	0.59	Min. Value	0.27	Min. Value	0.51	Min. Value	0.19
Max. Value	1.99	Max. Value	1.06	Max. Value	1.53	Max. Value	1.06
Sample #	21	Sample #	22	Sample #	27	Sample #	21

ANGLE 0 - Down Stairs - Speed 4-3 (m/s)

0 OD Men < 50		0 OD Men >= 50		0 OD Women < 50		0 OD Women >= 50	
Mean	1.234118	Mean	0.955	Mean	1.082727	Mean	0.741972
Stand. Dev.	0.231807	Stand. Dev.	0.246543	Stand. Dev.	0.223166	Stand. Dev.	0.258726
Variance	0.053734	Variance	0.060783	Variance	0.049803	Variance	0.066939
Min. Value	0.64	Min. Value	0.35	Min. Value	0.59	Min. Value	0.2
Max. Value	1.99	Max. Value	1.38	Max. Value	1.63	Max. Value	1.46
Sample #	160	Sample #	81	Sample #	140	Sample #	71

0.1 OD Men < 50		0.1 OD Men >= 50		0.1 OD Women < 50		0.1 OD Women >= 50	
Mean	1.238222	Mean	0.9168	Mean	1.090513	Mean	0.613333
Stand. Dev.	0.298232	Stand. Dev.	0.19557	Stand. Dev.	0.262437	Stand. Dev.	0.225941
Variance	0.088942	Variance	0.038248	Variance	0.068873	Variance	0.051049
Min. Value	0.77	Min. Value	0.63	Min. Value	0.62	Min. Value	0.27
Max. Value	1.97	Max. Value	1.31	Max. Value	1.62	Max. Value	1.21
Sample #	45	Sample #	25	Sample #	39	Sample #	24

0.5 OD Men < 50		0.5 OD Men >= 50		0.5 OD Women < 50		0.5 OD Women >= 50	
Mean	1.118491	Mean	0.823889	Mean	0.920571	Mean	0.522273
Stand. Dev.	0.256571	Stand. Dev.	0.232964	Stand. Dev.	0.219625	Stand. Dev.	0.151373
Variance	0.065828	Variance	0.054272	Variance	0.048235	Variance	0.022914
Min. Value	0.59	Min. Value	0.49	Min. Value	0.51	Min. Value	0.16
Max. Value	1.73	Max. Value	1.32	Max. Value	1.54	Max. Value	0.77
Sample #	53	Sample #	18	Sample #	35	Sample #	22

1.0 OD Men < 50		1.0 OD Men >= 50		1.0 OD Women < 50		1.0 OD Women >= 50	
Mean	0.999231	Mean	0.624091	Mean	0.850571	Mean	0.526364
Stand. Dev.	0.305705	Stand. Dev.	0.237279	Stand. Dev.	0.287984	Stand. Dev.	0.226138
Variance	0.093455	Variance	0.056302	Variance	0.082935	Variance	0.051139
Min. Value	0.6	Min. Value	0.26	Min. Value	0.29	Min. Value	0.17
Max. Value	1.63	Max. Value	1.11	Max. Value	1.72	Max. Value	1.15
Sample #	21	Sample #	22	Sample #	27	Sample #	21

ANGLE 0 - Up Corridor - Corridor Speed Up

0 OD Men < 50		0 OD Men >= 50		0 OD Women < 50		0 OD Women >= 50	
Mean	2.253999	Mean	1.932556	Mean	2.089251	Mean	1.694412
Stand. Dev.	0.533393	Stand. Dev.	0.458656	Stand. Dev.	0.512179	Stand. Dev.	0.426193
Variance	0.284508	Variance	0.210366	Variance	0.262327	Variance	0.181641
Min. Value	0.893304	Min. Value	1.156569	Min. Value	1.192649	Min. Value	0.830768
Max. Value	4.070111	Max. Value	3.739789	Max. Value	3.951896	Max. Value	2.803995
Sample #	160	Sample #	81	Sample #	140	Sample #	71
0.1 OD Men < 50		0.1 OD Men >= 50		0.1 OD Women < 50		0.1 OD Women >= 50	
Mean	2.566828	Mean	2.12032	Mean	2.456322	Mean	1.646175
Stand. Dev.	0.784371	Stand. Dev.	0.457618	Stand. Dev.	0.744499	Stand. Dev.	0.491055
Variance	0.615238	Variance	0.209414	Variance	0.554279	Variance	0.241135
Min. Value	1.412256	Min. Value	1.394538	Min. Value	1.347487	Min. Value	1.019015
Max. Value	3.949705	Max. Value	3.22075	Max. Value	3.83691	Max. Value	2.953557
Sample #	45	Sample #	25	Sample #	39	Sample #	24
0.5 OD Men < 50		0.5 OD Men >= 50		0.5 OD Women < 50		0.5 OD Women >= 50	
Mean	1.879997	Mean	1.477511	Mean	1.641898	Mean	0.985517
Stand. Dev.	0.401543	Stand. Dev.	0.315502	Stand. Dev.	0.38191	Stand. Dev.	0.356107
Variance	0.161237	Variance	0.099541	Variance	0.145855	Variance	0.126812
Min. Value	1.046269	Min. Value	0.997736	Min. Value	0.87763	Min. Value	0.390496
Max. Value	2.650222	Max. Value	2.080044	Max. Value	2.700097	Max. Value	1.706285
Sample #	53	Sample #	18	Sample #	35	Sample #	22
1.0 OD Men < 50		1.0 OD Men >= 50		1.0 OD Women < 50		1.0 OD Women >= 50	
Mean	1.524486	Mean	1.210503	Mean	1.350511	Mean	1.07111
Stand. Dev.	0.512959	Stand. Dev.	0.390596	Stand. Dev.	0.543473	Stand. Dev.	0.455179
Variance	0.263127	Variance	0.152565	Variance	0.295363	Variance	0.207188
Min. Value	0.798909	Min. Value	0.626636	Min. Value	0.401063	Min. Value	0.412702
Max. Value	2.649888	Max. Value	2.052483	Max. Value	2.552691	Max. Value	2.399284
Sample #	21	Sample #	22	Sample #	27	Sample #	21

ANGLE 0 - Down Corridor - Corridor Speed Down

0 OD Men < 50		0 OD Men >= 50		0 OD Women < 50		0 OD Women >= 50	
Mean	2.405336	Mean	1.999689	Mean	2.236817	Mean	1.794656
Stand. Dev.	0.625801	Stand. Dev.	0.469976	Stand. Dev.	0.554797	Stand. Dev.	0.52891
Variance	0.391627	Variance	0.220878	Variance	0.307799	Variance	0.279746
Min. Value	1.49	Min. Value	1.115422	Min. Value	1.463516	Min. Value	1.021785
Max. Value	4.529061	Max. Value	3.726103	Max. Value	4.292987	Max. Value	3.492703
Sample #	160	Sample #	81	Sample #	140	Sample #	71
0.1 OD Men < 50		0.1 OD Men >= 50		0.1 OD Women < 50		0.1 OD Women >= 50	
Mean	2.632424	Mean	2.104487	Mean	2.4553	Mean	1.664253
Stand. Dev.	0.86128	Stand. Dev.	0.524374	Stand. Dev.	0.765472	Stand. Dev.	0.495175
Variance	0.741803	Variance	0.274968	Variance	0.585947	Variance	0.245199
Min. Value	1.437523	Min. Value	1.199344	Min. Value	1.259034	Min. Value	1.017007
Max. Value	4.178758	Max. Value	3.757061	Max. Value	4.051338	Max. Value	2.753383
Sample #	45	Sample #	25	Sample #	39	Sample #	24
0.5 OD Men < 50		0.5 OD Men >= 50		0.5 OD Women < 50		0.5 OD Women >= 50	
Mean	2.00251	Mean	1.647836	Mean	1.752049	Mean	1.145115
Stand. Dev.	0.425761	Stand. Dev.	0.363111	Stand. Dev.	0.348221	Stand. Dev.	0.310076
Variance	0.181272	Variance	0.13185	Variance	0.121258	Variance	0.096147
Min. Value	1.202267	Min. Value	1.107169	Min. Value	1.078453	Min. Value	0.640018
Max. Value	3.206229	Max. Value	2.4	Max. Value	2.745127	Max. Value	1.749864
Sample #	53	Sample #	18	Sample #	35	Sample #	22
1.0 OD Men < 50		1.0 OD Men >= 50		1.0 OD Women < 50		1.0 OD Women >= 50	
Mean	1.756898	Mean	1.341082	Mean	1.594162	Mean	1.226526
Stand. Dev.	0.558239	Stand. Dev.	0.330715	Stand. Dev.	0.520382	Stand. Dev.	0.412388
Variance	0.311631	Variance	0.109373	Variance	0.270797	Variance	0.170064
Min. Value	1.009034	Min. Value	0.79773	Min. Value	0.590202	Min. Value	0.696324
Max. Value	2.852924	Max. Value	1.944293	Max. Value	3.072372	Max. Value	2.366442
Sample #	21	Sample #	22	Sample #	27	Sample #	21

APPENDIX E

HEEL TESTING - RAW DATASET

Number of Participants in Demographic Participating

O° Angle	
Male 18-49	44
Male 50+	26
Female 18-49	33
Female 50+	12

0 Angle Dataset Statistical Breakdown

ANGLE 0 - Up Stairs - Speed 3-4

Men < 50		Men >= 50		Women < 50		Women >= 50	
Mean	1.247045	Mean	1.029231	Mean	1.020606	Mean	0.853333
Stand. Dev.	0.45079	Stand. Dev.	0.413917	Stand. Dev.	0.29314	Stand. Dev.	0.198601
Variance	0.203212	Variance	0.171327	Variance	0.085931	Variance	0.039442
Min. Value	0.67	Min. Value	0.41	Min. Value	0.58	Min. Value	0.63
Max. Value	2.76	Max. Value	2.3	Max. Value	1.85	Max. Value	1.32
Sample #	44	Sample #	26	Sample #	33	Sample #	12

ANGLE 0 - Down Stairs - Speed 4-3

Men < 50		Men >= 50		Women < 50		Women >= 50	
Mean	1.225455	Mean	1.030385	Mean	1.12	Mean	0.921667
Stand. Dev.	0.195263	Stand. Dev.	0.232094	Stand. Dev.	0.214403	Stand. Dev.	0.190303
Variance	0.038128	Variance	0.053868	Variance	0.045969	Variance	0.036215
Min. Value	0.64	Min. Value	0.53	Min. Value	0.66	Min. Value	0.63
Max. Value	1.63	Max. Value	1.38	Max. Value	1.53	Max. Value	1.27
Sample #	44	Sample #	26	Sample #	33	Sample #	12

ANGLE 0 - Up Corridor - Corridor Speed Up

Men < 50		Men >= 50		Women < 50		Women >= 50	
Mean	1.997832	Mean	1.943051	Mean	1.90227	Mean	1.763962
Stand. Dev.	0.297438	Stand. Dev.	0.322629	Stand. Dev.	0.338629	Stand. Dev.	0.238956
Variance	0.08847	Variance	0.104089	Variance	0.11467	Variance	0.0571
Min. Value	0.893304	Min. Value	1.410379	Min. Value	1.192649	Min. Value	1.112703
Max. Value	2.629298	Max. Value	2.610482	Max. Value	2.549458	Max. Value	2.048411
Sample #	44	Sample #	26	Sample #	33	Sample #	12

ANGLE 0 - Down Corridor - Corridor Speed Down

Men < 50		Men >= 50		Women < 50		Women >= 50	
Mean	2.052216	Mean	1.966206	Mean	2.034299	Mean	1.880661
Stand. Dev.	0.199356	Stand. Dev.	0.310984	Stand. Dev.	0.240082	Stand. Dev.	0.28523
Variance	0.039743	Variance	0.096711	Variance	0.05764	Variance	0.081356
Min. Value	1.631153	Min. Value	1.415503	Min. Value	1.632912	Min. Value	1.606784
Max. Value	2.624912	Max. Value	2.930322	Max. Value	2.709589	Max. Value	2.662953
Sample #	44	Sample #	26	Sample #	33	Sample #	12

APPENDIX F
DATA ANALYSIS METHODS

Data Analysis Validation

Using the equation,

$$Z = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}}$$

The following tables were checked to ensure that the data was valid. This is known as the Z test so beside each table you will see Z2-Avg, Z3-Avg. and Z4-Avg. which means that in each Z test, the 2nd, 3rd and 4th trials of a condition were compared to the average of that condition. If the value is $-2.58 \leq Z \leq 2.58$ than the assumption that the data fits a normal distribution is valid. If the value is outside this region then the assumption cannot be validated.

When the validation fails, the Z value is coloured either yellow or red. If it is coloured yellow it is because based on the amount of data points in that specific trial, the Z test cannot be trusted. If it is coloured red, this means the Z test can be trusted because there are sufficient data points, and it has yielded a failing result to the standard deviation assumption.

In the collection of data for these tests, the following was observed:

		%
	0	0.00%
Caution	5	20.83%
Tests	24	

Based on this table it appears that in general, the assumption of normal distribution is a valid one since none of the trials call for concern. 21% of the trials have been marked as not fitting the norm with which the others follow but upon examination it is most likely due to small sample populations used.

EFFECT OF BEING 2ND, 3RD OR 4TH RUN IN TEST ON DATA OBTAINED

Up Stairs		Mean (m/s)	Standard Deviation	Variance	Minium Value (m/s)	Maximum Value (m/s)	Sample Size (N)	Z = Mean1 -Mean2 - (mean1-mee Z <= 2.58 (+ or -) to be valid Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.94031 1.151546 0.170364 Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.18077 1.262071 -3.49064 Z 2-Avg. Z 3-Avg. Z 4-Avg. -0.95421 1.696449 -1.26805 Z 2-Avg. Z 3-Avg. Z 4-Avg. 0.044703 2.663237 -1.86857 Z 2-Avg. Z 3-Avg. Z 4-Avg. 0.162587 -0.99607 0.675107 Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.98644 0.88531 0.450266 Z 2-Avg. Z 3-Avg. Z 4-Avg. -0.33048 -0.73809 1.108039 Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.38805 1.031406 1.539703 Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.71252 0.987179 0.520302 Z 2-Avg. Z 3-Avg. Z 4-Avg. -2.51348 0.822741 0.825788 Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.38641 1.323315 -0.34133 Z 2-Avg. Z 3-Avg. Z 4-Avg. -2.6441 3.123307 1.182334
M<50 OD = 0	Average	1.33	0.4933	0.2433	0.59	2.76	160	
M>=50 OD = 0	Average	0.95	0.3714	0.1379	0.41	2.30	81	
W<50 OD = 0	Average	1.05	0.3061	0.0937	0.58	2.29	140	
W>=50 OD = 0	Average	0.75	0.2250	0.0506	0.00	1.32	71	
Men < 50	2nd Run	1.15	0.3513	0.1234	0.75	1.98	15	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.94031 1.151546 0.170364
	3rd Run	1.63	0.6608	0.4366	0.73	3.09	14	
	4th Run	1.43	0.6957	0.4840	0.58	3.04	16	
	Average	1.40	0.6095	0.3715	0.58	3.09	45	
Men >= 50	2nd Run	0.84	0.2587	0.0669	0.61	1.31	8	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.18077 1.262071 -3.49064
	3rd Run	1.06	0.2252	0.0507	0.68	1.45	15	
	4th Run	0.73	0.0636	0.0040	0.68	0.77	2	
	Average	0.96	0.2550	0.0650	0.61	1.45	25	
Women < 50	2nd Run	1.07	0.2974	0.0885	0.71	1.46	8	Z 2-Avg. Z 3-Avg. Z 4-Avg. -0.95421 1.696449 -1.26805
	3rd Run	1.40	0.4207	0.1770	0.79	2.29	15	
	4th Run	1.04	0.3662	0.1341	0.63	2.01	16	
	Average	1.19	0.4050	0.1640	0.63	2.29	39	
Women > 49	2nd Run	0.71	0.2648	0.0701	0.38	1.31	13	Z 2-Avg. Z 3-Avg. Z 4-Avg. 0.044703 2.663237 -1.86857
	3rd Run	0.91	0.1195	0.0143	0.77	1.06	4	
	4th Run	0.59	0.1215	0.0148	0.39	0.75	7	
	Average	0.71	0.2327	0.0541	0.38	1.31	24	
Men < 50	2nd Run	1.23	0.2887	0.0834	0.96	1.85	7	Z 2-Avg. Z 3-Avg. Z 4-Avg. 0.162587 -0.99607 0.675107
	3rd Run	1.11	0.4035	0.1628	0.52	1.97	20	
	4th Run	1.29	0.5001	0.2501	0.64	2.49	26	
	Average	1.21	0.4438	0.1970	0.52	2.49	53	
Men >= 50	2nd Run	0.67	0.2083	0.0434	0.41	0.99	5	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.98644 0.88531 0.450266
	3rd Run	1.09	0.1521	0.0231	0.89	1.26	4	
	4th Run	1.08	0.6438	0.4145	0.57	2.53	9	
	Average	0.97	0.4952	0.2452	0.41	2.53	18	
Women < 50	2nd Run	0.99	0.1017	0.0103	0.81	1.07	6	Z 2-Avg. Z 3-Avg. Z 4-Avg. -0.33048 -0.73809 1.108039
	3rd Run	0.95	0.2479	0.0615	0.59	1.54	20	
	4th Run	1.14	0.3238	0.1048	0.68	1.83	9	
	Average	1.01	0.2581	0.0666	0.59	1.83	35	
Women > 49	2nd Run	0.52	0.1339	0.0179	0.31	0.86	15	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.38805 1.031406 1.539703
	3rd Run	0.72	0.2207	0.0487	0.43	0.93	4	
	4th Run	0.80	0.2250	0.0506	0.64	1.06	3	
	Average	0.59	0.1917	0.0368	0.31	1.06	22	
Men < 50	2nd Run	0.82	0.1825	0.0333	0.59	1.20	8	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.71252 0.987179 0.520302
	3rd Run	1.16	0.4311	0.1858	0.59	1.99	9	
	4th Run	1.13	0.4929	0.2429	0.81	1.98	4	
	Average	1.00	0.3763	0.1416	0.59	1.99	21	
Men >= 50	2nd Run	0.47	0.1272	0.0162	0.27	0.61	6	Z 2-Avg. Z 3-Avg. Z 4-Avg. -2.51348 0.822741 0.825788
	3rd Run	0.70	0.1572	0.0247	0.50	0.95	6	
	4th Run	0.70	0.2003	0.0401	0.44	1.06	10	
	Average	0.64	0.1947	0.0379	0.27	1.06	22	
Women < 50	2nd Run	0.80	0.1830	0.0335	0.51	1.26	9	Z 2-Avg. Z 3-Avg. Z 4-Avg. -1.38641 1.323315 -0.34133
	3rd Run	1.02	0.2887	0.0833	0.55	1.53	16	
	4th Run	0.87	0.1375	0.0189	0.75	1.02	2	
	Average	0.91	0.2541	0.0646	0.51	1.53	27	
Women > 49	2nd Run	0.48	0.1070	0.0115	0.19	0.63	13	Z 2-Avg. Z 3-Avg. Z 4-Avg. -2.6441 3.123307 1.182334
	3rd Run	0.87	0.1567	0.0246	0.58	1.06	7	
	4th Run	0.77	0.1061	0.0113	0.69	0.84	1	
	Average	0.63	0.2207	0.0487	0.19	1.06	21	

Down Stairs		Mean (m/s)	Standard Deviation	Variance	Minium Value (m/s)	Maximum Value (m/s)	Sample Size (N)			
M<50 OD = 0	Average	1.23	0.2318	0.0537	0.64	1.99	160			
M>=50 OD = 0	Average	0.96	0.2465	0.0608	0.35	1.38	81			
W<50 OD = 0	Average	1.08	0.2232	0.0498	0.59	1.63	140			
W>=50 OD = 0	Average	0.74	0.2587	0.0669	0.20	1.46	71			
Men < 50	2nd Run	1.12	0.2244	0.0504	0.81	1.46	15	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	1.44	0.3188	0.1016	0.96	1.97	14			
	4th Run	1.17	0.2587	0.0669	0.77	1.74	16			
	Average	1.24	0.2982	0.0889	0.77	1.97	45			
OD = .1										
Men >= 50	2nd Run	0.91	0.1988	0.0395	0.63	1.21	8	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.96	0.1857	0.0345	0.63	1.31	15			
	4th Run	0.66	0.0283	0.0008	0.64	0.68	2			
	Average	0.92	0.1956	0.0382	0.63	1.31	25			
OD = .1										
Women < 50	2nd Run	0.96	0.1881	0.0354	0.68	1.26	8	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	1.25	0.2038	0.0415	0.92	1.62	15			
	4th Run	1.01	0.2792	0.0779	0.62	1.46	16			
	Average	1.09	0.2624	0.0689	0.62	1.62	39			
OD = .1										
Women > 49	2nd Run	0.60	0.2259	0.0510	0.38	1.15	13	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.82	0.2829	0.0800	0.57	1.21	4			
	4th Run	0.53	0.1332	0.0177	0.27	0.71	7			
	Average	0.61	0.2259	0.0510	0.27	1.21	24			
OD = .1										
Men < 50	2nd Run	1.14	0.0983	0.0097	0.99	1.32	7	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	1.09	0.2361	0.0557	0.59	1.53	20			
	4th Run	1.14	0.3020	0.0912	0.59	1.73	26			
	Average	1.12	0.2566	0.0658	0.59	1.73	53			
OD = .5										
Men >= 50	2nd Run	0.73	0.1494	0.0223	0.61	0.99	5	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.99	0.1878	0.0353	0.82	1.19	4			
	4th Run	0.80	0.2673	0.0715	0.49	1.32	9			
	Average	0.82	0.2330	0.0543	0.49	1.32	18			
OD = .5										
Women < 50	2nd Run	1.01	0.2925	0.0855	0.71	1.54	6	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.88	0.1807	0.0327	0.52	1.26	20			
	4th Run	0.95	0.2526	0.0638	0.51	1.26	9			
	Average	0.92	0.2196	0.0482	0.51	1.54	35			
OD = .5										
Women > 49	2nd Run	0.48	0.1397	0.0195	0.16	0.68	15	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.65	0.1144	0.0131	0.50	0.75	4			
	4th Run	0.56	0.1890	0.0357	0.41	0.77	3			
	Average	0.52	0.1514	0.0229	0.16	0.77	22			
OD = .5										
Men < 50	2nd Run	0.86	0.2066	0.0427	0.63	1.26	8	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	1.28	0.2772	0.0769	0.84	1.63	9			
	4th Run	0.84	0.2189	0.0479	0.60	1.11	4			
	Average	1.00	0.3057	0.0935	0.60	1.63	21			
OD = 1.0										
Men >= 50	2nd Run	0.46	0.1038	0.0108	0.33	0.60	6	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.78	0.2975	0.0885	0.33	1.11	6			
	4th Run	0.63	0.2033	0.0413	0.26	0.99	10			
	Average	0.62	0.2373	0.0563	0.26	1.11	22			
OD = 1.0										
Women < 50	2nd Run	0.72	0.2077	0.0432	0.29	0.99	9	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.99	0.3113	0.0969	0.51	1.72	16			
	4th Run	0.77	0.2380	0.0566	0.56	1.03	2			
	Average	0.85	0.2880	0.0829	0.29	1.72	27			
OD = 1.0										
Women > 49	2nd Run	0.38	0.1033	0.0107	0.17	0.54	13	Z 2-Avg.	Z 3-Avg.	Z 4-Avg.
	3rd Run	0.76	0.2074	0.0430	0.54	1.15	7			
	4th Run	0.62	0.0990	0.0098	0.55	0.69	1			
	Average	0.53	0.2261	0.0511	0.17	1.15	21			
OD = 1.0										

Up Corridor		Mean (m/s)	Standard Deviation	Variance	Minium Value (m/s)	Maximum Value (m/s)	Sample Size (N)
M<50 OD = 0	Average	2.25	0.5334	0.2845	0.89	4.07	160
M>=50 OD = 0	Average	1.93	0.4587	0.2104	1.16	3.74	81
W<50 OD = 0	Average	2.09	0.5122	0.2623	1.19	3.95	140
W>=50 OD = 0	Average	1.69	0.4262	0.1816	0.83	2.80	71
M<50 OD = .1	Average	2.57	0.7844	0.6152	1.41	3.95	45
M>=50 OD = .1	Average	2.12	0.4576	0.2094	1.39	3.22	25
W<50 OD = .1	Average	2.46	0.7445	0.5543	1.35	3.84	39
W>=50 OD = .1	Average	1.65	0.4911	0.2411	1.02	2.95	24
M<50 OD = .5	Average	1.88	0.4015	0.1612	1.05	2.65	53
M>=50 OD = .5	Average	1.48	0.3155	0.0995	1.00	2.08	18
W<50 OD = .5	Average	1.64	0.3819	0.1459	0.88	2.70	35
W>=50 OD = .5	Average	0.99	0.3561	0.1268	0.39	1.71	22
M<50 OD =1.0	Average	1.52	0.5130	0.2631	0.80	2.65	21
M>=50 OD =1.0	Average	1.21	0.3906	0.1526	0.63	2.05	22
W<50 OD =1.0	Average	1.35	0.5435	0.2954	0.40	2.55	27
W>=50 OD =1.0	Average	1.07	0.4552	0.2072	0.41	2.40	21
Down Corridor		Mean (m/s)	Standard Deviation	Variance	Minium Value (m/s)	Maximum Value (m/s)	Sample Size (N)
M<50 OD = 0	Average	2.41	0.6258	0.3916	1.49	4.53	160
M>=50 OD = 0	Average	2.00	0.4700	0.2209	1.12	3.73	81
W<50 OD = 0	Average	2.24	0.5548	0.3078	1.46	4.29	140
W>=50 OD = 0	Average	1.79	0.5289	0.2797	1.02	3.49	71
M<50 OD = .1	Average	2.63	0.8613	0.7418	1.44	4.18	45
M>=50 OD = .1	Average	2.10	0.5244	0.2750	1.20	3.76	25
W<50 OD = .1	Average	2.46	0.7655	0.5859	1.26	4.05	39
W>=50 OD = .1	Average	1.66	0.4952	0.2452	1.02	2.75	24
M<50 OD = .5	Average	2.00	0.4258	0.1813	1.20	3.21	53
M>=50 OD = .5	Average	1.65	0.3631	0.1318	1.11	2.40	18
W<50 OD = .5	Average	1.75	0.3482	0.1213	1.08	2.75	35
W>=50 OD = .5	Average	1.15	0.3101	0.0961	0.64	1.75	22
M<50 OD =1.0	Average	1.76	0.5582	0.3116	1.01	2.85	21
M>=50 OD =1.0	Average	1.34	0.3307	0.1094	0.80	1.94	22
W<50 OD =1.0	Average	1.59	0.5204	0.2708	0.59	3.07	27
W>=50 OD =1.0	Average	1.23	0.4124	0.1701	0.70	2.37	21

APPENDIX G

CONSENT FROM CARLETON UNIVERSITY ETHICS COMMITTEE

5296
Proj File

Office of Research Services
Faculty of Graduate Studies and Research
1125 Colonel By Drive
Ottawa, ON Canada K1S 5B6
Tel: (613) 520-2516
Fax: (613) 520-2521

2 July 2003

Mr. Derek Gruchy & Mr. Andrew Carran
BMT Fleet Technology Ltd.
311 Legget Drive
Kanata, Ontario
K2K 1Z8

Re.: Ethics Clearance

Dear Mr. Gurchy & Mr. Carran,

The Carleton University Research Ethics Committee has reviewed the application for the research project *Advanced Ship Evacuation Simulation Reduced Visibility Trials* and given it approval.

The guidelines governing ethics approval are as follows:

1. Ethics clearance is valid for one-year (from date of this letter). If you do not complete the research portion involving human participants indicated in your proposal within that time frame you must contact the Research Ethics Committee so the research project can be considered for an extension.
2. Should there be any significant changes to the proposal you are obligated to contact the Research Ethics Committee with the changes.
3. Should any participant suffer negatively from the research please report this to the Research Ethics Committee and indicate what steps you have taken to resolve the situation.
4. Finally, this office will contact you annually to review the status of the research project, and if necessary the Research Ethics Committee will convene to review any problems that have occurred over the course of the year.

Please note that the authority of the Carleton University Ethics Committees is in accordance with Article 1.2 of the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*. The Carleton University policy states: **"Carleton University Ethics Committees are mandated to approve, reject, propose modifications to, suspend, or terminate any proposed or ongoing research that is subject to ethics review pursuant to this policy."**

If you have any questions please do not hesitate to contact me. On behalf of the Carleton University Research Ethics Committee I wish you the best of luck with your research.

Yours truly,

Leslie J. MacDonald-Hicks
Research Ethics Committee Coordinator
511A Tory Building
613-520-2517
Leslie_MacDonald-Hicks@carleton.ca

cc/G. Hadjisophocleous

APPENDIX H
CASE STUDY DATA

Figure H.76 – First Floor of the CTTC

Figure H.77 – Second Floor of the CTTC

Figure H.78 – Third Floor of the CTTC

Figure H.79 – Fourth Floor of the CTTC

Description of Compartments In CTTC Building 1 st Floor						
Description	Room ID	Width (m)	Depth (m)	Expected # of Employees	Expected # of Visitors	Total Population
Co-op office	1	19	20	14	6	20
E-Academy Inc.	2	12	13	10	0	10
Parking services	3	15	10	5	12	17
Prescription	4	8	7	2	4	6
South corridor	5	11	3	0	0	0
East corridor	36	18	3	0	0	0
West corridor	35	12	3	0	0	0
Landing area	6	1.3	11	0	0	0
Landing area	7	1.3	11	0	0	0
Entrance 1	33	1.3	12	0	0	0
Entrance 2	34	1.3	21	0	0	0
Atrium1-3	8	6	5	0	0	0
Atrium1-2	9	10	3	0	0	0

Description of Compartments In CTTC Building 2 nd Floor						
Description	Room ID	Width (m)	Depth (m)	Expected # of Employees	Expected # of Visitors	Total Population
Health & Counsel	10	28	20	44	6	50
Soft Capital Inc.	11	13	10	2	1	3
Office	12	10	16	11	0	11
Dental Clinic	13	12	11	15	4	19
Virtual Wave Inc.	14	14	9	6	0	6
Treats Coffee	15	8	12	4	8	12
South corridor	16	11	3	0	0	0
West corridor	37	19	3	0	0	0
East corridor	38	19	3	0	0	0
North corridor	39	11	3	0	0	0
Landing area	17	1.3	11	0	0	0
Landing area	18	1.3	11	0	0	0

Description of Compartments In CTTC Building 3 rd Floor						
Description	Room ID	Width (m)	Depth (m)	Expected # of Employees	Expected # of Visitors	Total Population
CAOT	19	19	21	14	18	32
Bayer Inc.	20	13	20	6	0	6
IAPA Training	21	9	11	18	0	18
THSAO	22	11	21	8	0	8
South corridor	23	11	3	0	0	0
West corridor	40	19	3	0	0	0
East corridor	41	19	3	0	0	0
North corridor	42	11	3	0	0	0
Landing area	24	1.3	11	0	0	0
Landing area	25	1.3	11	0	0	0

Description of Compartments In CTTC Building 4 th Floor						
Description	Room ID	Width (m)	Depth (m)	Expected # of Employees	Expected # of Visitors	Total Population
Tempest	26	14	21	30	0	30
Building Manager	27	16	21	5	0	5
Biology Dept. East	28	12	12	9	3	12
Biology Dept. North	45	29	13	17	3	20
Forintek	29	10	15	8	0	8
South corridor	30	11	3	0	0	0
West corridor	43	19	3	0	0	0
East corridor	44	19	3	0	0	0
Landing area	31	1.3	11	0	0	0
Landing area	32	1.3	11	0	0	0

Description of Exits For Building 1 st Floor			
Exit Number	1 st Compartment	2 nd Compartment	Width of Exit
50	1	5	0.9
51	1	36	0.9
52	2	36	0.9
53	3	36	0.9
54	4	8	0.9
55	5	35	3.0
56	5	36	3.0
57	6	33	1.3
58	7	34	1.3
59	8	35	5.0
60	8	46	5.0
61	9	36	0.9
62	9	OUTSIDE	0.9
63	33	OUTSIDE	0.9
64	36	34	0.9
65	34	OUTSIDE	0.9
66	35	46	3.0
67	46	OUTSIDE	0.9

Description of Exits For Building 2 nd Floor			
Exit Number	1 st Compartment	2 nd Compartment	Width of Exit
68	10	37	0.9
69	10	38	0.9
70	11	38	0.9
71	12	38	0.9
72	13	38	0.9
73	14	37	0.9
74	15	37	0.9
75	16	37	3.0
76	16	38	3.0
77	17	38	0.9
78	18	37	0.9
79	37	39	3.0
80	37	47	3.0
81	38	39	3.0
82	47	OUTSIDE	0.9

Description of Exits For Building 3 rd Floor			
Exit Number	1 st Compartment	2 nd Compartment	Width of Exit
83	19	40	0.9
84	19	41	0.9
85	20	41	0.9
86	21	42	0.9
87	22	40	0.9
88	23	40	3.0
89	23	41	3.0
90	24	40	0.9
91	25	41	0.9
92	40	42	3.0
93	41	42	3.0

Description of Exits For Building 4 th Floor			
Exit Number	1 st Compartment	2 nd Compartment	Width of Exit
94	26	30	0.9
95	26	43	0.9
96	27	48	0.9
97	28	44	0.9
98	29	43	0.9
99	30	43	3.0
100	30	44	3.0
101	31	44	0.9
102	32	43	0.9
103	43	45	0.9
104	44	48	3.0
105	28	45	2.0

Description of Exits For Building Stairwells			
Exit Number	1st Compartment	2nd Compartment	Width of Exit
106	32	25	1.3
107	25	18	1.3
108	18	7	1.3
109	31	24	1.3
110	24	17	1.3
111	17	6	1.3
49	OUTSIDE		

APPENDIX I

INPUT / OUTPUT FILES USED IN SIMULATIONS

SAMPLE OCCUPANT RESPONSE INPUT FILE (USED TO CREATE OCCUPANT RESPONSE OUTPUT FILE)

Lines 1 to 9 are used for description

 Occupant Response Model Input File

----- A Test Case -----

----From next line, data retrieval begins----

(1)TIME FOR FIVE FIRE STATES IN SECONDS(>0)

State0(Start)

0

State1(Cues)

129

State2(Smoke)

200

State3(Heat)

296

State4(Flashover)

1441

(2)SIMULATION TIME IN SECONDS

1800

(3)OUTPUT STEP SIZE IN SECONDS

60

(4)RELIABILITIES OF DETECTION AND ALARM SYSTEMS(0~1)

Local Alarm

0.6

Sprinkler

0.95

Heat Detector

0.9

Smoke Detector

0.9

Central Alarm

0.9

Voice Alarm

0.9

(5)INTERPRETATION PROBABILITIES OF CENTRAL AND VOICE ALARMS(0~1)

Central Alarm

0.9

Voice Alarm

0.9

(6)AVAILABILITY OF DETECTION AND ALARM SYSTEMS(#TRUE# or #FALSE#)**Local Alarm(Fire Room)****#TRUE#****Local Sprinkler(Fire Room)****#FALSE#****Local Heat Detector(Fire Room)****#TRUE#****Other Heat Detector****#TRUE#****Local Smoke Detector(Fire Room)****#TRUE#****Corridor/HVAC Smoke Detector****#TRUE#****Stairwell/Elevator Smoke Detector****#TRUE#****Central Alarm****#TRUE#****Voice Alarm****#FALSE#****Central Alarm Connected to Fire Dept****#TRUE#****Considering Factor of Remaining Occupants****#TRUE#****(7)INTERPRETIVE RESPONSE DELAY TIMES IN SECONDS****Level1(FIRE Cues/Voice Alarm/Fire Department/Sprinklers)****40****Level2(Other Occupants)****80****Level3(Central Alarm/Local Alarm)****160****(8)DETECTION DELAY TIMES IN SECONDS****Level1****40****Level2****80****(9)FIRE DEPARTMENT RESPONSE AND VOICE DELAY TIME IN SECONDS****Fire Dept Response****180****Voice Delay****60****(10)PROBABILITIES OF DIRECT PERCEPTION OF FIRE CUES****Occupants in the Fire Compartment(OFC)****1.0****Occupants in Adjacent Compartments(OAC)****0.5****Occupants in Other Compartments(OOC)****0.3**

(11)DETECTION DEVICE ACTIVATION TIME RANGE IN SECONDS (Default 60)**Local Alarm****60****Sprinkler****60****Heat Detector****60****Smoke Detector****60****(12)PROBABILITIES FOR ACTIONS TAKEN BY OCCUPANTS IN THE FIRE COMPARTMENT****Direct Perception(STATE 0-1): Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.8, .2, .2, .2****Direct Perception(STATE 1-2): Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.8, .4, .3, .2****Direct Perception(STATE 2-4): Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.8, .6, .5, .2****Warning From Local Alarm : Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.6, .5, .3, .2****Warning From Central Alarm : Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.4, 0, 0, 0****Warning From Voice Alarm : Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****0, 0, 0, 0****Warning From Fire Dept. : Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****0, 0, 0, 0****Warning From Sprinkers : Call Fire Dept., Activate Pullbar, Warn OAC, Warn OOC****.4, 0, .2, .1****(13)PROBABILITIES FOR ACTIONS TAKEN BY OCCUPANTS IN ADJACENT COMPARTMENTS****Direct Perception : Call Fire Dept., Warn OOC****.6, 0.1****Warning From Local Alarm : Call Fire Dept., Warn OOC****0, 0****Warning From Central Alarm : Call Fire Dept., Warn OOC****.4, 0****Warning From Voice Alarm : Call Fire Dept., Warn OOC****0, 0****Warning From Other Occupant: Call Fire Dept., Warn OOC****.1, 0.1****Warning From Fire Dept. : Call Fire Dept., Warn OOC****0, 0****Warning From Sprinkers : Call Fire Dept., Warn OOC****0, 0**

(14)PROBABILITIES FOR ACTIONS TAKEN BY OCCUPANTS IN OTHER COMPARTMENTS

Direct Perception	:	Call Fire Dept	.6
Warning From Local Alarm	:	Call Fire Dept	.6
Warning From Central Alarm	:	Call Fire Dept	.4
Warning From Voice Alarm	:	Call Fire Dept	0
Warning From Other Occupant:		Call Fire Dept	.1
Warning From Fire Dept.	:	Call Fire Dept	0
Warning From Sprinklers	:	Call Fire Dept	0

(15)NUMBER OF GROUPS IN THE BUILDING

Number of Groups In OFC

1

Number of Groups In OAC

5

Number of Groups In OOC

12

(16)NUMBER OF OCCUPANTS AND THEIR AVERAGE RESPONSE ABILITY OF EACH GROUP

ID, Number of Occupants, and Response Ability In OFC

1, 12, 0.9

ID, Number of Occupants, and Response Ability In OAC

1, 50, 0.8

2, 3, 0.9

3, 11, 0.9

4, 19, 0.8

5, 6, 0.9

ID, Number of Occupants, and Response Ability In OOC

1, 20, 0.9

2, 10, 0.9

3, 17, 0.9

4, 6, 0.9

5, 32, 0.9

6, 6, 0.9

7, 18, 0.9

8, 8, 0.9

9, 30, 0.9

10, 5, 0.9

11, 32, 0.9

12, 8, 0.9

**SAMPLE OCCUPANT RESPONSE OUTPUT FILE
(USED AS INPUT IN OCCUPANT EVACUATION SIMULATIONS)**

Cumulative Probabilities of Actions Taken by OFC

**Time, CallFire, Pull Bar, Warn OAC, Warn OOC, Evacuate
(s) (0 to 1) (0 to 1) (0 to 1) (0 to 1) (0 to 1)**

00000,	0.000000,	0.000000,	0.000000,	0.000000,	0.000000
00030,	0.000000,	0.000000,	0.000000,	0.000000,	0.000000
00060,	0.012311,	0.003078,	0.003078,	0.003078,	0.015389
00090,	0.076947,	0.019237,	0.019237,	0.019237,	0.096183
00120,	0.196984,	0.049246,	0.049246,	0.049246,	0.246230
00150,	0.372422,	0.133203,	0.113154,	0.093106,	0.465528
00180,	0.561650,	0.227816,	0.184114,	0.140412,	0.702062
00210,	0.696461,	0.328924,	0.268371,	0.174115,	0.870576
00240,	0.775870,	0.388481,	0.318002,	0.193967,	0.969837
00270,	0.800000,	0.406579,	0.333083,	0.200000,	1.000000

Cumulative Probabilities of Actions Taken by OAC

Time, (s)	CallFire, (0 to 1)	Warn OOC, (0 to 1)	Evacuate (0 to 1)
00000,	0.000000,	0.000000,	0.000000
00030,	0.000000,	0.000000,	0.000000
00060,	0.000000,	0.000000,	0.000000
00090,	0.000000,	0.000000,	0.000000
00120,	0.000000,	0.000000,	0.000000
00150,	0.000331,	0.000331,	0.003306
00180,	0.001322,	0.001322,	0.013223
00210,	0.003094,	0.002975,	0.030041
00240,	0.007183,	0.005289,	0.057401
00270,	0.014912,	0.009064,	0.103883
00300,	0.026676,	0.014372,	0.169052
00330,	0.040310,	0.019034,	0.230541
00360,	0.065970,	0.024768,	0.320259
00390,	0.098017,	0.029290,	0.408429
00420,	0.260184,	0.032255,	0.717941
00450,	0.344080,	0.040151,	0.874504
00480,	0.363488,	0.047308,	0.913679
00510,	0.368095,	0.048077,	0.927958
00540,	0.371758,	0.048942,	0.944386
00570,	0.375672,	0.049902,	0.960851
00600,	0.379955,	0.050958,	0.986921
00630,	0.384627,	0.052110,	0.996188
00660,	0.389687,	0.053357,	0.997820
00690,	0.395135,	0.054701,	0.998345
00720,	0.400972,	0.056140,	0.998957
00750,	0.407196,	0.057674,	0.999371
00780,	0.413809,	0.059305,	0.999653

Cumulative Probabilities of Actions Taken by OOC

Time, (s)	CallFire, (0 to 1)	Evacuate (0 to 1)
00000,	0.000000,	0.000000
00030,	0.000000,	0.000000
00060,	0.000000,	0.000000
00090,	0.000000,	0.000000
00120,	0.000000,	0.000000
00150,	0.000331,	0.003306
00180,	0.001322,	0.013223
00210,	0.003097,	0.030076
00240,	0.007239,	0.057955
00270,	0.014272,	0.097737
00300,	0.024310,	0.147479
00330,	0.036376,	0.196868
00360,	0.058989,	0.263038
00390,	0.088690,	0.337925
00420,	0.251011,	0.678129
00450,	0.333241,	0.848674
00480,	0.350432,	0.889726
00510,	0.354365,	0.908045
00540,	0.357564,	0.929578
00570,	0.360577,	0.950458
00600,	0.363718,	0.983405
00630,	0.367145,	0.995148
00660,	0.370856,	0.997217
00690,	0.374853,	0.997880
00720,	0.379135,	0.998657
00750,	0.383701,	0.999187
00780,	0.388552,	0.999550

**SAMPLE SMOKE MODEL INPUT FILE
(USED TO CREATE SMOKE MOVEMENT OUTPUT FILE)**

01):ReCT03, CT0304, BY05, DV06, CCV07, RCV08, SCV8A, MV09, FS10, TsimuS, TmaxS, StepSizeS
1, 1, 2, 60, 0, 0, 6, 0, 1, 1800, 3600, 1
02):HrefM, PambPa, Tamb, LoopSize|L|M|S|, |Tc|Tk|, |Ckg|Cmol|, |kg/S|m3/S|cfm|, |Mc|He|
0, 101325, 20, M, Tc, Cmol, m3/S, Mc
03):CTid, Tini, WidtM, DeptM, CeilM, FlooM, Cc, Ff, We, Ws, Ww, Wn
1, 20, 19, 20, 3, 0, 1, 2, 1, 1, 1, 1
04):CTid, Tini, PeriM, AreaM, CeilM, FlooM, Cc, Ff, We, Ws, Ww, Wn
05):BYid, BYdesc, BYthic, BYcond, BYdens, BYspec, BYemis, OTdept
1, Gypsum, 0.1, 0.16, 790, 900, 0.9, 0
2, Concrete, 0.2, 0.76, 1900, 880, 0.9, 0
06A):DVid,DVno1,DVno2,DVsoff,DVsill,DVwidt,DVwindV, DVbreakTempC, DVtimePointNo
1, 1, 2, 2, 0, 0.9, 0, 10000, 2
06B):DVtime(S)
0, 1800
06C):OpeningFactor
1, 1
07):CCVid, CnoTop, CnoBot, Cthic, Cdiam
08):RCVid, RnoTop, RnoBot, Rthic, Rwidt, Rdept
08A):SCVid, SCVctNo, SCVtopNo, Sdensity, |Open|Closed|
1, 6, 17, 1.3, Closed
09A):MVID, CTid, OpenExtM, TstartS, TendS, DotNo, |Dis|Con|
09B):TimeDot(S)
09C):(Out+)|m3/S|kg/S|cfm|
10A):FSct, |CeWaCo|,FuName, Xwidt, Ydept, Zheig, |Dis|Equ|, TstartS, TendS, DotNo
3, Ce, Sofa, 7.5, 5, 0.50, Equ, 0, 1800, 10
10B):RAD%,HeatMJ, CarbF,HydrF,OxygF, Tox1F,Tox2F,Tox3F, SOOTcrp, COcrp, MaxHRR(MW)
0.536, 15.4, 0.62, 0.09, 0.25, 0.04, 0, 0, 0.117, 0.0089, 5
10C):Time(S)
10D):HRR(kW)
10E):SquaA(kW/Minute2), LineB(kW/Minute), ConsC(kW)
40, 0, 0
11):SprinklerAvailable|Yes|No|,ActTemperature(C), SprayDensity(mm/S), Effectiveness
No, 150, 0.1, 0.9
12):FireDeptNotificationTime(S), FireDeptResponseTime(S), FireDeptSetUpTime(S)
1800, 1800, 1800

SAMPLE SMOKE MODEL OUTPUT FILE **(USED AS AN INPUT IN THE OCCUPANT EVACUATION MODEL)**

Number of Compartments 48

Compartment ID Number

1

Time (s)	UppT (C)	LowerT (C)	UppO2 (m3%)	LowO2 (m3%)	UppCO2 (m3%)	LowCO2 (m3%)	SmokeCO (ppm m3)	LowerCO (ppm m3)	SmokeSoot (1/m)	SmokeOD (m)	InterH (kW/m2)	Radiate (KW)	HRR
00000	0020.0	0020.0	20.72	20.72	00.000	00.000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	002.95	000.00	0.00E+00
00060	0020.0	0020.0	20.72	20.72	00.000	00.000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	002.90	000.00	0.00E+00
00120	0020.0	0020.0	20.72	20.72	00.000	00.000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	002.90	000.00	0.00E+00
00180	0020.0	0020.0	20.72	20.72	00.000	00.000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	002.90	000.00	0.00E+00
00240	0020.0	0020.0	20.72	20.72	00.000	00.000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	002.90	000.00	0.00E+00
00300	0020.3	0020.0	20.71	20.72	00.009	00.000	1.48E+00	5.05E-06	1.36E-02	0.00E+00	002.90	000.00	0.00E+00
00360	0023.0	0020.0	20.53	20.72	00.135	00.000	2.16E+01	1.08E-05	1.99E-01	1.30E-01	002.90	000.42	0.00E+00
00420	0023.1	0020.0	20.34	20.73	00.261	00.000	4.17E+01	1.22E-03	3.84E-01	1.69E-01	002.85	000.42	0.00E+00
00480	0023.0	0020.0	20.23	20.73	00.342	00.000	5.46E+01	3.82E-03	5.03E-01	1.88E-01	002.82	000.42	0.00E+00
00540	0023.0	0020.0	20.18	20.73	00.375	00.000	6.00E+01	4.75E-03	5.52E-01	1.88E-01	002.77	000.42	0.00E+00
00600	0023.0	0020.0	20.15	20.73	00.391	00.000	6.25E+01	4.75E-03	5.75E-01	1.83E-01	002.72	000.42	0.00E+00
00660	0023.0	0020.0	20.13	20.73	00.406	00.000	6.50E+01	4.75E-03	5.98E-01	1.80E-01	002.65	000.42	0.00E+00
00720	0023.0	0020.0	20.10	20.73	00.426	00.000	6.81E+01	4.75E-03	6.27E-01	1.80E-01	002.59	000.42	0.00E+00
00780	0023.0	0020.0	20.07	20.73	00.448	00.000	7.16E+01	4.75E-03	6.59E-01	1.80E-01	002.52	000.42	0.00E+00
00840	0023.0	0020.0	20.04	20.73	00.467	00.000	7.47E+01	4.75E-03	6.87E-01	1.81E-01	002.45	000.42	0.00E+00
00900	0023.0	0020.0	20.01	20.73	00.485	00.000	7.76E+01	4.75E-03	7.14E-01	1.82E-01	002.37	000.42	0.00E+00
00960	0023.0	0020.0	19.98	20.73	00.503	00.000	8.05E+01	4.75E-03	7.41E-01	1.83E-01	002.29	000.43	0.00E+00
01020	0023.0	0020.0	19.95	20.73	00.528	00.000	8.45E+01	4.75E-03	7.77E-01	1.87E-01	002.21	000.43	0.00E+00
01080	0023.0	0020.0	19.91	20.73	00.550	00.000	8.80E+01	4.75E-03	8.10E-01	1.90E-01	002.13	000.43	0.00E+00
01140	0023.0	0020.0	19.88	20.74	00.574	00.000	9.18E+01	4.75E-03	8.44E-01	1.93E-01	002.04	000.43	0.00E+00
01200	0023.0	0020.0	19.85	20.74	00.592	00.000	9.46E+01	4.92E-03	8.71E-01	1.95E-01	001.96	000.43	0.00E+00
01260	0023.0	0020.0	19.83	20.74	00.609	00.000	9.75E+01	4.92E-03	8.97E-01	1.97E-01	001.87	000.43	0.00E+00
01320	0023.0	0020.0	19.80	20.74	00.624	00.000	9.98E+01	4.92E-03	9.18E-01	1.98E-01	001.79	000.43	0.00E+00
01380	0023.0	0020.1	19.79	20.74	00.633	00.000	1.01E+02	4.92E-03	9.32E-01	1.98E-01	001.70	000.43	0.00E+00
01440	0023.0	0020.1	19.78	20.74	00.641	00.000	1.03E+02	4.92E-03	9.44E-01	1.98E-01	001.61	000.43	0.00E+00
01500	0023.0	0020.1	19.77	20.74	00.645	00.000	1.03E+02	4.92E-03	9.50E-01	1.97E-01	001.52	000.43	0.00E+00
01560	0023.0	0020.1	19.76	20.74	00.650	00.000	1.04E+02	4.92E-03	9.57E-01	1.96E-01	001.43	000.43	0.00E+00
01620	0023.1	0020.1	19.76	20.74	00.656	00.000	1.05E+02	4.92E-03	9.65E-01	1.96E-01	001.34	000.43	0.00E+00
01680	0023.1	0020.1	19.74	20.74	00.663	00.000	1.06E+02	4.92E-03	9.76E-01	1.96E-01	001.24	000.43	0.00E+00
01740	0023.2	0020.1	19.73	20.74	00.670	00.000	1.07E+02	4.92E-03	9.86E-01	1.96E-01	001.15	000.43	0.00E+00
01800	0023.2	0020.1	19.72	20.74	00.676	00.000	1.08E+02	4.92E-03	9.95E-01	1.95E-01	001.05	000.43	0.00E+00

OCCUPANT CHARACTERISTIC INPUT FILE

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1 .....
2 .....
3 "OCCUPANT INPUT FILE"
4 .....
5 .....
6
7
  Number of Occupants
  293
1
2
1 .....
2 .....
5 "OCCUPANT PROPERTIES"
6 .....
7 .....
Occupant 1
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  F, 25, 0.84, 01, False, False, 1, 50, 51
Occupant 2
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  F, 69, 0.17, 01, False, False, 1, 50, 51
Occupant 3
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  F, 21, 0.83, 01, False, False, 1, 50, 51
Occupant 4
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 65, 0.53, 01, False, False, 1, 50, 51
Occupant 5
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 65, 0.61, 01, False, False, 1, 50, 51
Occupant 6
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 30, 0.94, 01, False, False, 1, 50, 51
Occupant 7
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 64, 0.22, 01, False, False, 1, 50, 51
Occupant 8
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 31, 0.87, 01, False, False, 1, 50, 51
Occupant 9
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  F, 29, 0.77, 01, False, False, 1, 50, 51
Occupant 10
Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
  M, 67, 0.54, 01, False, False, 1, 50, 51

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Occupant 11

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.50, 01, False, False, 1, 50, 51

Occupant 12

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.62, 01, False, False, 1, 50, 51

Occupant 13

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 20, 1.21, 01, False, False, 1, 50, 51

Occupant 14

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 32, 0.89, 01, False, False, 1, 50, 51

Occupant 15

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.43, 01, False, False, 1, 50, 51

Occupant 16

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 24, 0.64, 01, False, False, 1, 50, 51

Occupant 17

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.71, 01, False, False, 1, 50, 51

Occupant 18

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 23, 0.65, 01, False, False, 1, 50, 51

Occupant 19

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 1.12, 01, False, False, 1, 50, 51

Occupant 20

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.22, 01, False, False, 1, 50, 51

Occupant 21

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 18, 0.82, 02, False, False, 1, 52, 0

Occupant 22

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.09, 02, False, False, 1, 52, 0

Occupant 23

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.64, 02, False, False, 1, 52, 0

Occupant 24

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.69, 02, False, False, 1, 52, 0

Occupant 25

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 25, 0.74, 02, False, False, 1, 52, 0

Occupant 26

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 0.89, 02, False, False, 1, 52, 0

Occupant 27

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 0.87, 02, False, False, 1, 52, 0

Occupant 28

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.32, 02, False, False, 1, 52, 0

Occupant 29

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.47, 02, False, False, 1, 52, 0

Occupant 30

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 38, 0.54, 02, False, False, 1, 52, 0

Occupant 31

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.35, 03, False, False, 1, 53, 0

Occupant 32

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.20, 03, False, False, 1, 53, 0

Occupant 33

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.68, 03, False, False, 1, 53, 0

Occupant 34

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.55, 03, False, False, 1, 53, 0

Occupant 35

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 26, 0.67, 03, False, False, 1, 53, 0

Occupant 36

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.41, 03, False, False, 1, 53, 0

Occupant 37

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.45, 03, False, False, 1, 53, 0

Occupant 38

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 64, 0.54, 03, False, False, 1, 53, 0

Occupant 39

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 67, 0.56, 03, False, False, 1, 53, 0

Occupant 40

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.88, 03, False, False, 1, 53, 0

Occupant 41

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.62, 03, False, False, 1, 53, 0

Occupant 42

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 25, 1.04, 03, False, False, 1, 53, 0

Occupant 43

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.92, 03, False, False, 1, 53, 0

Occupant 44

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.51, 03, False, False, 1, 53, 0

Occupant 45

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 66, 0.44, 03, False, False, 1, 53, 0

Occupant 46

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 31, 1.15, 03, False, False, 1, 53, 0

Occupant 47

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.69, 03, False, False, 1, 53, 0

Occupant 48

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 22, 0.89, 04, False, False, 1, 54, 0

Occupant 49

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 25, 1.01, 04, False, False, 1, 54, 0

Occupant 50

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.53, 04, False, False, 1, 54, 0

Occupant 51

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 29, 0.96, 04, False, False, 1, 54, 0

Occupant 52

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.61, 04, False, False, 1, 54, 0

Occupant 53

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 65, 0.42, 04, False, False, 1, 54, 0

Occupant 54

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.60, 10, False, False, 2, 68, 69

Occupant 55

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 1.27, 10, False, False, 2, 68, 69

Occupant 56

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 0.95, 10, False, False, 2, 68, 69

Occupant 57

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.58, 10, False, False, 2, 68, 69

Occupant 58

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.57, 10, False, False, 2, 68, 69

Occupant 59

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.22, 10, False, False, 2, 68, 69

Occupant 60

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 0.90, 10, False, False, 2, 68, 69

Occupant 61

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 21, 1.01, 10, False, False, 2, 68, 69

Occupant 62

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 36, 0.93, 10, False, False, 2, 68, 69

Occupant 63

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 0.98, 10, False, False, 2, 68, 69

Occupant 64

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 21, 1.09, 10, False, False, 2, 68, 69

Occupant 65

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.52, 10, False, False, 2, 68, 69

Occupant 66

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 67, 0.44, 10, False, False, 2, 68, 69

Occupant 67

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 18, 0.97, 10, False, False, 2, 68, 69

Occupant 68

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.00, 10, False, False, 2, 68, 69

Occupant 69

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.00, 10, False, False, 2, 68, 69

Occupant 70

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.12, 10, False, False, 2, 68, 69

Occupant 71

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 36, 0.82, 10, False, False, 2, 68, 69

Occupant 72

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.14, 10, False, False, 2, 68, 69

Occupant 73

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 26, 0.92, 10, False, False, 2, 68, 69

Occupant 74

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 0.92, 10, False, False, 2, 68, 69

Occupant 75

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 26, 0.77, 10, False, False, 2, 68, 69

Occupant 76

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 38, 1.10, 10, False, False, 2, 68, 69

Occupant 77

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.28, 10, False, False, 2, 68, 69

Occupant 78

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.66, 10, False, False, 2, 68, 69

Occupant 79

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 38, 0.53, 10, False, False, 2, 68, 69

Occupant 80

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.82, 10, False, False, 2, 68, 69

Occupant 81

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 30, 0.86, 10, False, False, 2, 68, 69

Occupant 82

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.29, 10, False, False, 2, 68, 69

Occupant 83

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.52, 10, False, False, 2, 68, 69

Occupant 84

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 38, 1.19, 10, False, False, 2, 68, 69

Occupant 85

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.26, 10, False, False, 2, 68, 69

Occupant 86

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 32, 0.49, 10, False, False, 2, 68, 69

Occupant 87

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.11, 10, False, False, 2, 68, 69

Occupant 88

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 27, 1.33, 10, False, False, 2, 68, 69

Occupant 89

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.29, 10, False, False, 2, 68, 69

Occupant 90

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.46, 10, False, False, 2, 68, 69

Occupant 91

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.06, 10, False, False, 2, 68, 69

Occupant 92

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 38, 1.29, 10, False, False, 2, 68, 69

Occupant 93

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.24, 10, False, False, 2, 68, 69

Occupant 94

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.18, 10, False, False, 2, 68, 69

Occupant 95

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 64, 0.62, 10, False, False, 2, 68, 69

Occupant 96

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 33, 0.89, 10, False, False, 2, 68, 69

Occupant 97

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 26, 1.32, 10, False, False, 2, 68, 69

Occupant 98

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 25, 0.94, 10, False, False, 2, 68, 69

Occupant 99

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.31, 10, False, False, 2, 68, 69

Occupant 100

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.52, 10, False, False, 2, 68, 69

Occupant 101

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.22, 10, False, False, 2, 68, 69

Occupant 102

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 38, 0.64, 10, False, False, 2, 68, 69

Occupant 103

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.33, 10, False, False, 2, 68, 69

Occupant 104

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 26, 0.66, 11, False, False, 2, 70, 0

Occupant 105

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 31, 1.26, 11, False, False, 2, 70, 0

Occupant 106

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.94, 11, False, False, 2, 70, 0

Occupant 107

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 70, 0.37, 12, False, False, 2, 71, 0

Occupant 108

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.61, 12, False, False, 2, 71, 0

Occupant 109

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.21, 12, False, False, 2, 71, 0

Occupant 110

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 64, 0.63, 12, False, False, 2, 71, 0

Occupant 111

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.54, 12, False, False, 2, 71, 0

Occupant 112

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 1.08, 12, False, False, 2, 71, 0

Occupant 113

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.20, 12, False, False, 2, 71, 0

Occupant 114

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.48, 12, False, False, 2, 71, 0

Occupant 115

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 26, 0.86, 12, False, False, 2, 71, 0

Occupant 116

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.29, 12, False, False, 2, 71, 0

Occupant 117

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 20, 1.30, 12, False, False, 2, 71, 0

Occupant 118

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 30, 1.24, 13, False, False, 2, 72, 0

Occupant 119

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.25, 13, False, False, 2, 72, 0

Occupant 120

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 25, 0.85, 13, False, False, 2, 72, 0

Occupant 121

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 27, 1.22, 13, False, False, 2, 72, 0

Occupant 122

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.34, 13, False, False, 2, 72, 0

Occupant 123

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 20, 0.62, 13, False, False, 2, 72, 0

Occupant 124

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.39, 13, False, False, 2, 72, 0

Occupant 125

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.59, 13, False, False, 2, 72, 0

Occupant 126

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.70, 13, False, False, 2, 72, 0

Occupant 127

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 67, 0.46, 13, False, False, 2, 72, 0

Occupant 128

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 31, 1.27, 13, False, False, 2, 72, 0

Occupant 129

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 31, 1.16, 13, False, False, 2, 72, 0

Occupant 130

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.33, 13, False, False, 2, 72, 0

Occupant 131

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.15, 13, False, False, 2, 72, 0

Occupant 132

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.49, 13, False, False, 2, 72, 0

Occupant 133

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.57, 13, False, False, 2, 72, 0

Occupant 134

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 0.89, 13, False, False, 2, 72, 0

Occupant 135

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.59, 13, False, False, 2, 72, 0

Occupant 136

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 24, 0.54, 13, False, False, 2, 72, 0

Occupant 137

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 1.10, 14, False, False, 2, 73, 0

Occupant 138

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 20, 1.19, 14, False, False, 2, 73, 0

Occupant 139

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 0.91, 14, False, False, 2, 73, 0

Occupant 140

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.58, 14, False, False, 2, 73, 0

Occupant 141

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.55, 14, False, False, 2, 73, 0

Occupant 142

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.22, 14, False, False, 2, 73, 0

Occupant 143

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 1.17, 15, False, False, 2, 74, 0

Occupant 144

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.60, 15, False, False, 2, 74, 0

Occupant 145

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 27, 1.13, 15, False, False, 2, 74, 0

Occupant 146

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.36, 15, False, False, 2, 74, 0

Occupant 147

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 70, 0.46, 15, False, False, 2, 74, 0

Occupant 148

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.18, 15, False, False, 2, 74, 0

Occupant 149

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 66, 0.53, 15, False, False, 2, 74, 0

Occupant 150

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.76, 15, False, False, 2, 74, 0

Occupant 151

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 0.88, 15, False, False, 2, 74, 0

Occupant 152

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.10, 15, False, False, 2, 74, 0

Occupant 153

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 1.07, 15, False, False, 2, 74, 0

Occupant 154

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 26, 0.97, 15, False, False, 2, 74, 0

Occupant 155

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 25, 0.96, 19, False, False, 3, 83, 84

Occupant 156

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.27, 19, False, False, 3, 83, 84

Occupant 157

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 65, 0.51, 19, False, False, 3, 83, 84

Occupant 158

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 0.96, 19, False, False, 3, 83, 84

Occupant 159

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.72, 19, False, False, 3, 83, 84

Occupant 160

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.79, 19, False, False, 3, 83, 84

Occupant 161

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 1.01, 19, False, False, 3, 83, 84

Occupant 162

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 22, 0.84, 19, False, False, 3, 83, 84

Occupant 163

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 20, 0.71, 19, False, False, 3, 83, 84

Occupant 164

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.37, 19, False, False, 3, 83, 84

Occupant 165

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 21, 1.11, 19, False, False, 3, 83, 84

Occupant 166

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 1.28, 19, False, False, 3, 83, 84

Occupant 167

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 38, 1.30, 19, False, False, 3, 83, 84

Occupant 168

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 1.30, 19, False, False, 3, 83, 84

Occupant 169

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.03, 19, False, False, 3, 83, 84

Occupant 170

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 18, 1.08, 19, False, False, 3, 83, 84

Occupant 171

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.25, 19, False, False, 3, 83, 84

Occupant 172

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 68, 0.47, 19, False, False, 3, 83, 84

Occupant 173

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 19, 0.72, 19, False, False, 3, 83, 84

Occupant 174

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.74, 19, False, False, 3, 83, 84

Occupant 175

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.01, 19, False, False, 3, 83, 84

Occupant 176

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.48, 19, False, False, 3, 83, 84

Occupant 177

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 0.97, 19, False, False, 3, 83, 84

Occupant 178

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.25, 19, False, False, 3, 83, 84

Occupant 179

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 22, 1.00, 19, False, False, 3, 83, 84

Occupant 180

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 68, 0.56, 19, False, False, 3, 83, 84

Occupant 181

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.37, 19, False, False, 3, 83, 84

Occupant 182

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 64, 0.23, 19, False, False, 3, 83, 84

Occupant 183

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.52, 19, False, False, 3, 83, 84

Occupant 184

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 22, 0.99, 19, False, False, 3, 83, 84

Occupant 185

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 0.91, 19, False, False, 3, 83, 84

Occupant 186

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 1.23, 19, False, False, 3, 83, 84

Occupant 187

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.56, 20, False, False, 3, 85, 0

Occupant 188

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.16, 20, False, False, 3, 85, 0

Occupant 189

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.36, 20, False, False, 3, 85, 0

Occupant 190

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 30, 1.34, 20, False, False, 3, 85, 0

Occupant 191

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.23, 20, False, False, 3, 85, 0

Occupant 192

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 1.04, 20, False, False, 3, 85, 0

Occupant 193

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 28, 0.56, 21, False, False, 3, 86, 0

Occupant 194

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 20, 1.10, 21, False, False, 3, 86, 0

Occupant 195

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 25, 0.56, 21, False, False, 3, 86, 0

Occupant 196

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.26, 21, False, False, 3, 86, 0

Occupant 197

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.34, 21, False, False, 3, 86, 0

Occupant 198

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.80, 21, False, False, 3, 86, 0

Occupant 199

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.45, 21, False, False, 3, 86, 0

Occupant 200

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.81, 21, False, False, 3, 86, 0

Occupant 201

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 32, 0.50, 21, False, False, 3, 86, 0

Occupant 202

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.26, 21, False, False, 3, 86, 0

Occupant 203

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.18, 21, False, False, 3, 86, 0

Occupant 204

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.35, 21, False, False, 3, 86, 0

Occupant 205

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 65, 0.32, 21, False, False, 3, 86, 0

Occupant 206

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 0.99, 21, False, False, 3, 86, 0

Occupant 207

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.16, 21, False, False, 3, 86, 0

Occupant 208

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 27, 1.24, 21, False, False, 3, 86, 0

Occupant 209

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 37, 1.31, 21, False, False, 3, 86, 0

Occupant 210

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.63, 21, False, False, 3, 86, 0

Occupant 211

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 27, 1.35, 22, False, False, 3, 87, 0

Occupant 212

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.45, 22, False, False, 3, 87, 0

Occupant 213

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.55, 22, False, False, 3, 87, 0

Occupant 214

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 38, 0.95, 22, False, False, 3, 87, 0

Occupant 215

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.37, 22, False, False, 3, 87, 0

Occupant 216

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.92, 22, False, False, 3, 87, 0

Occupant 217

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 28, 0.97, 22, False, False, 3, 87, 0

Occupant 218

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 22, 0.74, 22, False, False, 3, 87, 0

Occupant 219

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 22, 0.73, 26, False, False, 4, 94, 95

Occupant 220

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.55, 26, False, False, 4, 94, 95

Occupant 221

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 0.90, 26, False, False, 4, 94, 95

Occupant 222

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.44, 26, False, False, 4, 94, 95

Occupant 223

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 0.86, 26, False, False, 4, 94, 95

Occupant 224

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 26, 0.93, 26, False, False, 4, 94, 95

Occupant 225

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.91, 26, False, False, 4, 94, 95

Occupant 226

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 0.98, 26, False, False, 4, 94, 95

Occupant 227

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 30, 0.90, 26, False, False, 4, 94, 95

Occupant 228

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.64, 26, False, False, 4, 94, 95

Occupant 229

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.18, 26, False, False, 4, 94, 95

Occupant 230

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 31, 1.05, 26, False, False, 4, 94, 95

Occupant 231

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.07, 26, False, False, 4, 94, 95

Occupant 232

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 0.98, 26, False, False, 4, 94, 95

Occupant 233

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.85, 26, False, False, 4, 94, 95

Occupant 234

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.15, 26, False, False, 4, 94, 95

Occupant 235

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 1.02, 26, False, False, 4, 94, 95

Occupant 236

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.24, 26, False, False, 4, 94, 95

Occupant 237

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.16, 26, False, False, 4, 94, 95

Occupant 238

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 0.88, 26, False, False, 4, 94, 95

Occupant 239

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 36, 0.91, 26, False, False, 4, 94, 95

Occupant 240

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 25, 0.75, 26, False, False, 4, 94, 95

Occupant 241

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.87, 26, False, False, 4, 94, 95

Occupant 242

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 1.13, 26, False, False, 4, 94, 95

Occupant 243

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.28, 26, False, False, 4, 94, 95

Occupant 244

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.34, 26, False, False, 4, 94, 95

Occupant 245

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.65, 26, False, False, 4, 94, 95

Occupant 246

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.83, 26, False, False, 4, 94, 95

Occupant 247

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.63, 26, False, False, 4, 94, 95

Occupant 248

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 1.18, 26, False, False, 4, 94, 95

Occupant 249

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 33, 0.81, 27, False, False, 4, 96, 0

Occupant 250

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 21, 0.63, 27, False, False, 4, 96, 0

Occupant 251

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 27, 0.57, 27, False, False, 4, 96, 0

Occupant 252

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 65, 0.43, 27, False, False, 4, 96, 0

Occupant 253

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.79, 27, False, False, 4, 96, 0

Occupant 254

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.49, 28, False, False, 4, 97, 105

Occupant 255

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 32, 0.66, 28, False, False, 4, 97, 105

Occupant 256

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.14, 28, False, False, 4, 97, 105

Occupant 257

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 1.03, 28, False, False, 4, 97, 105

Occupant 258

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.50, 28, False, False, 4, 97, 105

Occupant 259

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 68, 0.33, 28, False, False, 4, 97, 105

Occupant 260

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 1.06, 28, False, False, 4, 97, 105

Occupant 261

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.14, 28, False, False, 4, 97, 105

Occupant 262

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 24, 0.90, 28, False, False, 4, 97, 105

Occupant 263

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 34, 0.88, 28, False, False, 4, 97, 105

Occupant 264

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 25, 1.20, 28, False, False, 4, 97, 105

Occupant 265

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 23, 0.97, 28, False, False, 4, 97, 105

Occupant 266

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 39, 1.06, 29, False, False, 4, 98, 0

Occupant 267

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 23, 0.82, 29, False, False, 4, 98, 0

Occupant 268

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 1.15, 29, False, False, 4, 98, 0

Occupant 269

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 68, 0.34, 29, False, False, 4, 98, 0

Occupant 270

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 26, 1.09, 29, False, False, 4, 98, 0

Occupant 271

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 0.96, 29, False, False, 4, 98, 0

Occupant 272

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 70, 0.64, 29, False, False, 4, 98, 0

Occupant 273

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 28, 0.91, 29, False, False, 4, 98, 0

Occupant 274

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 69, 0.65, 45, False, False, 4, 103, 105

Occupant 275

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 70, 0.25, 45, False, False, 4, 103, 105

Occupant 276

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.25, 45, False, False, 4, 103, 105

Occupant 277

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 66, 0.32, 45, False, False, 4, 103, 105

Occupant 278

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 29, 0.55, 45, False, False, 4, 103, 105

Occupant 279

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 36, 1.17, 45, False, False, 4, 103, 105

Occupant 280

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 0.89, 45, False, False, 4, 103, 105

Occupant 281

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 19, 0.94, 45, False, False, 4, 103, 105

Occupant 282

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.51, 45, False, False, 4, 103, 105

Occupant 283

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 67, 0.50, 45, False, False, 4, 103, 105

Occupant 284

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 35, 1.35, 45, False, False, 4, 103, 105

Occupant 285

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.30, 45, False, False, 4, 103, 105

Occupant 286

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 32, 1.24, 45, False, False, 4, 103, 105

Occupant 287

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 37, 0.51, 45, False, False, 4, 103, 105

Occupant 288

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 69, 0.33, 45, False, False, 4, 103, 105

Occupant 289

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 24, 0.88, 45, False, False, 4, 103, 105

Occupant 290

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 65, 0.38, 45, False, False, 4, 103, 105

Occupant 291

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 20, 0.87, 45, False, False, 4, 103, 105

Occupant 292

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 M, 34, 0.94, 45, False, False, 4, 103, 105

Occupant 293

Gender, Age, Speed, Location, Evacuated?, Initiated?, Floor, Target Exit, 2nd Exit
 F, 64, 0.28, 45, False, False, 4, 103, 105

BUILDING CHARACTERISTICS INPUT FILE

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.....
"BUILDING INPUT FILE"
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Height Between Floors

3

Number of Compartments (includes the Outside as a compartment)

111

Room of Fire Origin

22

Outside Number (Must be put in the file before all doorways)

49

Time Increment (seconds)

1

Time to Flashover (seconds) - ASSUME THIS IS THE TOTAL LENGTH OF THE FIRE FOR NOW!!!! so 1800 instead of 1441

1800

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COMPARTMENT PROPERTIES

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1 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 19 , 20 , False , False , 0 , 0 , 50 , 51 , 1 , 0.50 , 0.50

2 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 12 , 13 , False , False , 0 , 0 , 52 , X , 1 , 1.00 , 0

3 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 15 , 10 , False , False , 0 , 0 , 53 , X , 1 , 1.00 , 0

4 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 8 , 7 , False , False , 0 , 0.0 , 54 , X , 1 , 1.00 , 0

5 Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
C , 3 , 11 , False , False , 0.2 , 0.0 , 55 , 56 , 1 , 0.60 , 0.40

6 Stairwell 1 Landing on Floor 1

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
S , 1.3 , 11 , True , False , 0.15 , 0.09 , 57 , 108 , 1 , 1.00 , 0.00

7 Stairwell 2 Landing on Floor 1

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
S , 1.3 , 11 , True , False , 0.15 , 0.09 , 58 , 111 , 1 , 1.00 , 0.00

8 Atrium Room

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 6 , 5 , False , False , 0.0 , 0 , 60 , 59 , 1 , 0.75 , 0.25

9 Atrium Room

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 3 , 10 , False , False , 0.0 , 0 , 62 , 61 , 1 , 0.90 , 0.10

10 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 20 , 28 , False , False , 0.0 , 0 , 68 , 69 , 2 , 0.75 , 0.25

11 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
R , 10 , 13 , False , False , 0.0 , 0 , 70 , 11 , 2 , 1.00 , 0

12 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 16 , 10 , False , False , 0.0 , 0 , 71 , 12 , 2 , 1.00 , 0

13 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 12 , 11 , False , False , 0.0 , 0 , 72 , X , 2 , 1.00 , 0

14 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 9 , 14 , False , False , 0.0 , 0 , 73 , X , 2 , 1.00 , 0

15 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 12 , 8 , False , False , 0.0 , 0 , 74 , X , 2 , 1.00 , 0

16 Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 11 , False , False , 0.2 , 0 , 75 , 76 , 2 , 0.50 , 0.50

17 Stairwell 1 Landing Area on Floor 2

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 108 , 77 , 2 , 1.00 , 0.00

18 Stairwell 2 Landing Area on Floor 2

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 111 , 78 , 2 , 1.00 , 0.00

19 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 21 , 19 , False , False , 0.0 , 0 , 83 , 84 , 3 , 0.50 , 0.50

20 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 20 , 13 , False , False , 0.0 , 0 , 85 , X , 3 , 1.00 , 0

21 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 11 , 9 , False , False , 0.0 , 0 , 86 , X , 3 , 1.00 , 0

22 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 21 , 11 , False , False , 0.0 , 0 , 87 , X , 3 , 1.00 , 0

23 Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 11 , False , False , 0.2 , 0 , 88 , 89 , 3 , 0.50 , 0.50

24 Stairwell 1 Landing Area on Floor 3

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 107 , 90 , 3 , 1.00 , 0.00

25 Stairwell 2 Landing Area on Floor 3

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 110 , 91 , 3 , 1.00 , 0.00

26 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 21 , 14 , False , False , 0.0 , 0 , 94 , 95 , 4 , 0.50 , 0.50

27 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 21 , 16 , False , False , 0.0 , 0 , 96 , X , 4 , 1.00 , 0

28 Part 1 of the Biology Department

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 15 , 15 , False , False , 0.0 , 0 , 97 , 105 , 4 , 0.95 , 0.05

29 Compartment

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 15 , 10 , False , False , 0.0 , 0 , 98 , X , 4 , 1.00 , 0

30 Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 11 , False , False , 0.2 , 0 , 99 , 100 , 4 , 0.50 , 0.50

31 Stairwell 1 Landing Area on Floor 4

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 106 , 101 , 4 , 1.00 , 0.00

32 Stairwell 2 Landing Area on Floor 4

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 S , 1.3 , 11 , True , False , 0.15 , 0.09 , 109 , 102 , 4 , 1.00 , 0.00

33 Entrance Way Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 1.3 , 12 , False , False , 0.20 , 0.0 , 63 , 57 , 1 , 0.90 , 0.10

34 Entrance Way Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 1.3 , 21 , False , False , 0.20 , 0.0 , 65 , 64 , 1 , 0.90 , 0.10

35 Part 2 of Corridor 5

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 12 , False , False , 0.20 , 0.0 , 66 , 55 , 1 , 0.75 , 0.25

36 Part 3 of Corridor 5

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 18 , False , False , 0.20 , 0.0 , 61 , 64 , 1 , 0.75 , 0.25

37 Part 2 of Corridor 16

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 80 , 78 , 2 , 0.75 , 0.25

38 Part 3 of Corridor 16

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 76 , 77 , 2 , 0.30 , 0.70

39 Part 4 of Corridor 16

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 11 , False , False , 0.20 , 0.0 , 79 , 81 , 2 , 0.50 , 0.50

40 Part 2 of Corridor 23

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 90 , 88 , 3 , 1.00 , 0.00

41 Part 3 of Corridor 23

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 91 , 93 , 3 , 1.00 , 0.00

42 Part 4 of Corridor 23

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 11 , False , False , 0.20 , 0.0 , 92 , 93 , 3 , 0.50 , 0.50

43 Part 2 of Corridor 30

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 102 , 99 , 4 , 1.00 , 0.00

44 Part 3 of Corridor 30

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 19 , False , False , 0.20 , 0.0 , 101 , 100 , 4 , 0.95 , 0.05

45 Part 2 of the Biology Department

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 R , 29 , 13 , False , False , 0.00 , 0.0 , 103 , 105 , 4 , 0.95 , 0.05

46 1st Floor Exit Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 5 , False , False , 0.20 , 0.0 , 67 , 66 , 1 , 0.90 , 0.10

47 2nd Floor Exit Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 5 , False , False , 0.20 , 0.0 , 82 , 80 , 2 , 0.90 , 0.10

48 4th Floor Extra Corridor

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 C , 3 , 15 , False , False , 0.20 , 0.0 , 104 , X , 4 , 1.00 , 0

49 Outside

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 Out , 0.0 , 0 , False , False , 0.00 , 0.0 , X , X , 1 , 0 , 0

50 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 D , 0.9 , 0 , False , False , 0.15 , 0.0 , 5 , 1 , 1 , 0 , 0

51 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 D , 0.9 , 0 , False , False , 0.15 , 0.0 , 36 , 1 , 1 , 0 , 0

52 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 D , 0.9 , 0 , False , False , 0.15 , 0.0 , 36 , 2 , 1 , 0 , 0

53 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
 D , 0.9 , 0 , False , False , 0.15 , 0.0 , 36 , 3 , 1 , 0 , 0

54 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	8	4	1	0	0

55 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	35	5	1	0	0

56 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	36	5	1	0	0

57 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	1.3	0	False	False	0.15	0.0	33	6	1	0	0

58 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	34	7	1	0	0

59 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	5.0	0	False	False	0.15	0.0	46	8	1	0	0

60 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	5.0	0	False	False	0.15	0.0	35	8	1	0	0

61 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	9	36	1	0	0

62 Doorway

Type, Width, Length, Railing?, 2 Rallings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , Out , 9 , 1 , 0 , 0

63 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	Out	33	1	0	0

64 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.34	.36	.1	0	0

65 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	Out	34	1	0	0

66 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	46	35	1	0	0

67 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	Out	.46	1	0	0

68 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	0.37	0.10	2	0	0

69 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	38	10	2	0	0

70 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	38	11	2	0	0

71 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	38	12	2	0	0

72 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	38	13	2	0	0

73 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	0.37	0.14	2	0	0

74 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	0.37	0.15	2	0	0

75 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	37	16	2	0	0

76 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	38	16	2	0	0

77 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	17	38	2	0	0

78 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	18	37	2	0	0

79 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	37	39	2	0	0

80 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	.47	.37	.2	0	0

81 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	.38	.39	.2	0	0

82 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	Out	47	2	0	0

83 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.40	.19	.3	0	0

84 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.41	.19	.3	0	0

85 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.41	.20	3	0	0

86 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.42	.21	.3	0	0

87 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	.40	.22	.3	0	0

88 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	.40	.23	.3	0	0

89 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	.41	.23	.3	0	0

90 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.24	.40	.3	0	0

91 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	.25	.41	3	0	0

92 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0.0	False	False	0.15	0.0	40	42	3	0	0

93 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	3.0	0	False	False	0.15	0.0	41	42	3	0	0

94 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	30	26	4	0	0

95 Doorway

Type	Width	Length	Railing?	2 Railings?	B.Layer Size	Railing B.Layer Size	Exit1	Exit2	Floor	Prob1	Prob2
D	0.9	0	False	False	0.15	0.0	43	26	4	0	0

96 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 48 , 27 , 4 , 0 , 0

97 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 44 , 28 , 4 , 0 , 0

98 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 43 , 29 , 4 , 0 , 0

99 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 3.0 , 0 , False , False , 0.15 , 0.0 , 43 , 30 , 4 , 0 , 0

100 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 3.0 , 0 , False , False , 0.15 , 0.0 , 44 , 30 , 4 , 0 , 0

101 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 31 , 44 , 4 , 0 , 0

102 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 32 , 43 , 4 , 0 , 0

103 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 0.9 , 0 , False , False , 0.15 , 0.0 , 43 , 45 , 4 , 0 , 0

104 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 3.0 , 0 , False , False , 0.15 , 0.0 , 44 , 48 , 4 , 0 , 0

105 Doorway

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 2 , 0 , False , False , 0.15 , 0.0 , 28 , 45 , 4 , 0 , 0

106 Stairwell Imaginary Doorway for 31 to 24

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 24 , 31 , 3 , 0 , 0

107 Stairwell Imaginary Doorway for 24 to 17

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 17 , 24 , 2 , 0 , 0

108 Stairwell Imaginary Doorway for 17 to 6

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 6 , 17 , 1 , 0 , 0

109 Stairwell Imaginary Doorway for 32 to 25

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 25 , 32 , 3 , 0 , 0

110 Stairwell Imaginary Doorway for 25 to 18

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 18 , 25 , 2 , 0 , 0

111 Stairwell Imaginary Doorway for 18 to 7

Type, Width, Length, Railing?, 2 Railings?, B.Layer Size, Railing B.Layer Size, Exit1, Exit2, Floor, Prob1, Prob2
D , 1.3 , 0 , False , False , 0.15 , 0.0 , 7 , 18 , 1 , 0 , 0

APPENDIX J

FLOWCHART OF OCCUPANT EVACUATION MODEL