ABSTRACT

Title of Document: POTENTIAL EFFECTS OF INCREASED INDIVIDUAL SIZE ON STAIRWAY EGRESS TIME

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In the United States and worldwide, the prevalence of overweight and obese individuals is on the rise. The potential effects of increased individual size on egress time of stairways are analyzed through the use of Pathfinder for one and three floor evacuation scenarios. Six different normal distributions of body size with mean occupant diameter increasing at five centimeter intervals are considered. It is found that as body size increases, the time necessary for egress increases by up to 62.7%. To better classify this information, stair width, number of exiting occupants, and evacuation floor height are examined in combination with increasing occupant size to gather the effect of secondary variables. Causes and influencing elements regarding the impact of increasing individual size within stair egress are proposed.

POTENTIAL EFFECTS OF INCREASED INDIVIDUAL SIZE ON STAIRWAY EGRESS TIME

By

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Submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2021

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ACKNOWLEDGEMENTS

I am incredibly grateful for all the encouragement and guidance I received throughout my time on this project. I would first like to express my sincere thanks to Dr. Milke for supporting me through the development of this thesis; I cannot convey how appreciative I am for allowing me the freedom to design and shape my research into what it is.

I would like to extend thanks to the Coast Guard for helping me to discover fire protection engineering and funding my graduate studies. Additionally, I would like to express acknowledgement and special thanks to Thunderhead Engineering for allowing me to use Pathfinder.

Thank you to my thesis committee members, Dr. Trouve and Dr. Gwynne, for your time and input on this research. Thank you to my classmates Anna Wright, Joe Decker, Kate Donlin, and Libby Norwood for shaping my graduate experience into something truly special. You are all powerful, amazing, and a great support system.

Lastly, I would like to thank my family. I owe many thanks to my sister, Sami, for believing in me so much that I cannot help but believe in myself. Thank you to my parents for their endless love and support. I could not have asked for two more wonderful role models, cheerleaders, and confidants; you're the best (around).

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CHAPTER 1: INTRODUCTION

Between 2009 and 2013, United States fire departments responded to an estimated average of 14,500 reported structure fires in high-rise buildings per year (NFPA 2021); while this is a small percentage of overall fire department responses to fire, the event of a high rise fire emergency may pose a significant threat to life safety.

When an evacuation is required, an egress system needs to be designed to allow affected occupants to exit and reach safety before conditions in the building reach a state where they are no longer tenable. The fundamental component when conducting an evacuation analysis is that Required Safe Egress Time is lower than Available Safe Egress Time. There are multiple variables that can affect these two values, so their calculation can be complex and have an inherent amount of uncertainty.

Overweight and obesity persists as a major health issue in the United States caused by the increase in size and number of fat cells in the body. The epidemic of excess weight is considered to be both a critical and common health problem. During egress from a high-rise building, occupants use the stairwell as their primary path to exit the building. The physiological burden of obesity is known to impact health in the form of increased risk of diseases such as high blood pressure, high cholesterol, type 2 diabetes, and coronary heart disease; however, few studies have been conducted regarding the impact of physical size on movement time through different components of egress.

The goal of this report is to better understand the effect of increased individual size on stairwell egress. It should be recognized that increased individual size is only one consequence of the epidemic of excess weight; therefore, its effect on evacuation time does not encompass the total effect of overweight and obesity on stairwell egress. One floor and three floor evacuations were examined for a variety of body sizes; additional considered variables included stair width and number of occupants evacuating per floor.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1: OBESITY AND BMI DATA

Despite increased acknowledgement of the problem, the obesity epidemic continues in the United States and around the world. Worldwide obesity has nearly tripled since 1975 (WHO 2021). The most recent Center for Disease Control (CDC) data estimates that 42.4% of adults and 18.5% of children and adolescents in the United States are obese. As of 2017-2018, the percentage of adults who are either overweight or obese is 73.6% (CDC 2021). The prevalence of obesity among adults aged 20 and over by sex and age in the United States from 2017-2018 is shown in Figure 2.1 (CDC 2021).

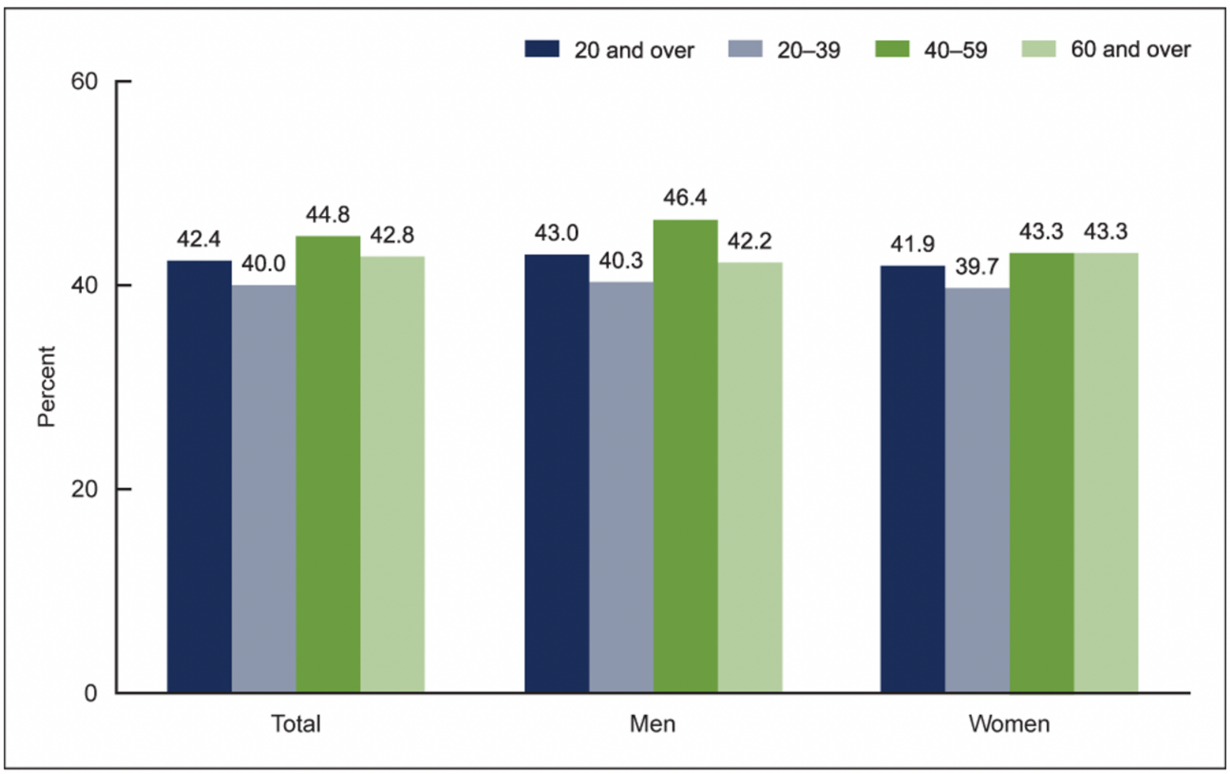

Figure 2.1: Prevalence of Obesity Among Adults as Related to Sex and Age Demographics

The terms overweight and obesity are defined based on body mass index (BMI), which can be calculated using the following formula:

$$BMI = \frac{W}{H^2} \quad (1)$$

where W = weight in kilograms and H = height in meters. Table 2.1 shows the categories of BMI that make up the weight classes of underweight, normal, overweight, obesity class I, obesity class II, and obesity class III (extreme obesity) (CDC 2021).

Table 2.1: BMI Classification

BMI (kg/m^2)	Classification
<18.5	Underweight
18.5-24.9	Normal
25.0-29.9	Overweight
30.0-34.9	Obesity Class I
35.0-39.9	Obesity Class II
40+	Obesity Class III (Extreme Obesity)

BMI is a simple tool designed to use at the population level to measure overweight and obesity; however, due to its limited input variables, it is not a perfect measure of body fat or body size. It does not distinguish between weight from muscle and weight from fat, so persons of very different body composition of the same height can have the same BMI.

Table 2.2 depicts the average height, weight, and BMI of men and women in 1962 and 2018. The average increase in height for both genders is less than 0.03 meters (one inch), but the increase in weight is dramatic for both men and women during this time period (CDC 2021).

Table 2.2: Height, Weight, and BMI Changes from 1962 to 2018

	Men			Women		
	Height (m/in)	Weight (kg/lb)	BMI	Height (m/in)	Weight (kg/lb)	BMI
1962	1.73/68.2	76.2/168.0	26.4	1.60/63.0	64.4/142.0	26.1
2018	1.75/69.0	90.6/199.8	30.6	1.61/63.5	77.5/170.8	30.9
% Increase	1.17	18.93	16.19	0.79	20.28	18.39

The information in Table 2.2 would suggest that people are heavier, and therefore larger (and taking up more physical space) than in previous years. Additionally, between 1962 and 2014, the average female BMI increased from 25.2 to 29.2 (15.9%), and the average male BMI increased from 25.4 to 28.7 (13.0%) (Ahrens 2018); this implies that over just four years, the average male BMI increased by 1.4 and the average female BMI increased by 1.7. It should be noted that the percent of obese adults varied little from 1960 to 1980, but then increased considerably after 1980 (NHANES 2003).

Average reported BMIs have significantly increased since 1962; the curve associated with the distribution of BMIs has also changed over time. Initially the curve was assumed to follow a normal distribution, while currently it is believed that there is likely a skewing to the right or that the curve now follows a log normal distribution (Penman 2006).

2.2: FIRE PROTECTION LITERATURE

2.2.1: EGRESS SYSTEM REQUIREMENTS

An egress system design should consider the number of occupants, the egress path components available, and any potential hazards (Hoskins 2012). A means of egress is a continuous and unobstructed way of exit travel from any point in a building or structure to a public way (NFPA 101 2018). It is composed of vertical and horizontal ways of travel including room spaces, doorways, hallways, corridors, passageways, balconies, ramps, stairs, enclosures, lobbies, escalators, horizontal exits, courts, and yards.

To conduct an evacuation analysis, the Required Safe Egress Time (RSET) is calculated in order to determine how long it will take all occupants to safely exit the building. RSET considers the time it takes for occupants to become aware of the need to evacuate a building, pre-evacuation time (or the time it takes for individuals to actually begin evacuating), and the time to physically evacuate to a point of safety. RSET differs for each individual, and is affected by factors such as individual characteristics, interactions with physical components of the building, and interactions with other occupants (Hoskins 2012). When calculating the RSET of a structure, the largest value available, or the value associated with the last occupant to evacuate, is what is considered.

Available Safe Egress Time (ASET) is determined to see how long tenable conditions will be present in a building or structure. ASET can be affected by loss of visibility, concentrations of irritant and asphyxiant gasses, heat exposure, and the structural strength of the building when occupant interaction with these deteriorating conditions occurs.

A fundamental component of effective evaluation of life safety is that RSET is lower than ASET. Due to the numerous and changing variables that are associated with these two values, their calculation is very complex and can have a large uncertainty (Ahrens 2018). As the values of ASET and RSET approach each other, the accompanying factor of safety decreases, and the occupant risk increases.

2.2.2: FACTORS IMPACTING RSET

There are multiple factors that can impact RSET time; several of these factors are characterized and described in the following section. It should be noted that RSET is the sum of three components: the time until an occupant is aware of the need to evacuate, the time until the occupant actually starts moving toward an exit (pre-evacuation time), and the time required by an occupant to physically reach safety after beginning movement. The focus of this study is the third component of RSET and thus it is the concentration of this subsection; however, there is a possibility that the increased likelihood of health issues that accompany overweight and obesity could require additional preparatory tasks or create impairments that extend pre-evacuation time.

2.2.2.1: CAPACITY OF EGRESS COMPONENTS

The egress capacity for each means of egress component is based on the clear width of the component and its overall design.

EFFECTIVE WIDTH/BOUNDARY LAYER

When occupants are evacuating a building, they maintain a boundary layer clearance (or distance between themselves and the object in question) from walls and other stationary objects (Pauls et al. 2007). This clearance is necessary to accommodate lateral body sway; additionally, personal preference dictates that persons attempt to maintain space around themselves when the population density is sufficiently low.

Originally, building codes used an "exit unit" to address the relationship between flow and stairwell width (one exit unit = 0.56 m) (Pauls 1980). Currently, the effective width of a component is considered its usable width and can be calculated using the following equation:

$$w_e = w - 2 * (boundary\ layer\ width) \tag{2}$$

Where w_e = effective width and w = width.

STAIR RISER HEIGHT/TREAD DEPTH

The impact of stair riser height can differ depending on the direction of travel of occupants; for normal stride patterns, steeper riser heights are preferred for ascent and shallower riser heights are preferred for descent (Templer 1975). During descent, steep riser height can decrease the speed of occupants due to fatigue or fear of falling (Templer 1974); however, fewer steps are required due to the increased height of each step, so ascent time tends to be faster.

Tread depth can also alter an occupant's speed during evacuation. When moving down stairs, individuals prefer to place the ball of their foot on the stair tread. If a stair is too narrow to fit the entire foot of an individual (and the ball of the foot will not be on the tread), the foot will be placed at an angle at which it can fit in its entirety on the step. This foot positioning is unnatural, and can increase the amount of time required for descension (Templer, 1975). Conversely, if the tread of a step is too long, an individual may slow down in order to take a step with both the left and right foot on each stair (rather than utilizing one foot for each step) (Templer 1975).

2.2.2.2: OCCUPANT CHARACTERISTICS

AGE

The level of impact of occupant age on speed of evacuation is not always clear. Some studies have found that senior and younger occupants move significantly slower than other age groups at normal speeds (Proulx et al. 1995, Fruin 1971), while others found that this only occurred when individuals are asked to move at a heightened pace. Additional literature reports that in some case studies the evacuation time required for seniors is not significantly different than the evacuation time required for other age groups (Proulx et all 1995). In further studies, it was reported that older individuals tended to begin their evacuation earlier (Proulx 1995).

GENDER

While some studies have found that gender is not statistically significant when determining egress speeds (Templer 1975, Proulx 1995), others have found that the average male movement speed is greater than average female speed (Fruin 1971).

PHYSICAL ABILITY

61 million, or 26 percent of, adults in the United States live with a disability. Of these, 13.7 percent include aspects associated with mobility (serious difficulty walking or climbing stairs), and 10.8 percent include aspects associated with cognition (serious difficulty concentrating, remembering, or making decisions) (CDC 2021). Mobility or

cognitive impaired individuals may require assistance during egress or additional time to traverse different components of egress. Additionally, occupants behind impaired individuals may be reluctant to pass.

When traveling down stairs, it was found that in comparison to individuals with no disability, mobility impaired individuals who do not require a walking aid moved at approximately 51% of the velocity of unimpaired individuals, mobility impaired individuals using a walking stick moved at approximately 46% of the velocity of unimpaired individuals, mobility impaired individuals using a rollator (wheeled walker) moved at approximately 23% of the velocity of unimpaired individuals, and mobility impaired individuals using crutches moved at approximately 31% of the velocity of unimpaired individuals (Boyce et al. 1999).

BODY SIZE (AREA OF A PERSON)

Fruin and Templer examined the use of body ellipses to model people movement on stairs; this shape estimate is generally accepted in the fire protection field. Daman estimated the breadth of shoulders of civilians to be 0.51 m and the breadth of shoulders of soldiers to be 0.55 m, and Fruin established the realistic dimension of humans to be 0.61 m by 0.46 m based on the desire to avoid interactions (Fruin 1987). Additionally, Fruin noted that 0.1 m should be added to the estimated body ellipse on stairs because body sway is more pronounced. Templer stated that an additional 0.05 m should be utilized to account for clearance between clothes and stairs. The following formula can be used to find the area of a body in square meters:

$$f = \frac{\pi}{4} ac \qquad (3)$$

where f = area in m^2, a = depth in m, and c = breadth in meters. Pauls examined ellipses at a range of densities, and concluded people behaved more like circles at low densities.

FATIGUE

In high-rise buildings, it is possible for fatigue to occur as a result of physical effort and impact RSET; fatigue can cause a decrease in physical performance (speed) during an evacuation as well as a decrease in mental performance (motivation).

Studies have reported different impacts regarding fatigue. Some research based on occupant speed indicates fatigue is not an issue in building evacuation (Pauls and Jones 1980, Khisty 1985); other studies have reported fatigue being present (Peacock et al. 2009, Proulx et al 1999) (Hoskins 2012).

In the National Institute of Standards and Technology (NIST) investigation of the 2001 World Trade Center disaster, it was found that in some cases occupants chose to rest on stairs or stair landings during their evacuation. The UK World Trade Center investigation reported 85% of the sample studied in the stair evacuation in the North Tower stopped during their descent, and of those stoppages at least 8% were due to the need of evacuees to rest (Ronchi et al. 2015).

While it is recognized that fatigue can impact RSET, this study does not aim to investigate its correlation with increased body size, relationship to travel speed, or impact on stairwell egress.

2.2.2.3: OCCUPANT INTERACTION

MERGING FLOWS

During evacuation of a space, flow from a floor has priority to flow in a stair (Kagawa et al. 1986). Additionally, the flow rate onto a stair decreases as stair population increases and flow from a floor is maximized if a stair is adjacent to the incoming stair (Galea et al. 2008). The hydraulic model states that the flow rate into a merging scenario should be equal to the outflow rate; however, when evacuation data from stairwells was examined, it was found that on average the outflow rate was equal to 0.75 times the inflow rate (Campbell 2012). During merging events, occupants tend to hesitate (specifically when approaching another flow of occupants). Due to this behavior, there is inefficiency in merging (Campbell 2012).

QUEUES

Queues form if the flow into a space is greater than the flow capacity out of that space. A common reason for queues to form is the presence of obstructions and transitions. The time for a que to dissipate is equal to the population in a queue divided by the net flow rate from the queue (Hoskins 2012).

PLATOONS

Occupants tend to form platoons, or groups of individuals that are spatially close to each other, when egressing from a building. It has been noted that during an evacuation, the flow of evacuating people reached the exit in groups headed by their leaders; 62% of people traveled in groups of two to three people, groups tended to be single-sex groups or families, and all groups traveled at a speed associated with their slowest member (Proulx et al. 1995).

In a more recent study of platoon behavior, it was discovered that in stairwells platoons most frequently remain unchanged. Of the identified platoons, 39% were one-person platoons, 21% contained two occupants, 14% had between 3 and 5 occupants, 10%

contained between 6 and 10 occupants, and 16% contained 11 or more occupants (Baker 2012). Additionally, larger platoons lead to longer evacuation times (Baker 2012).

PASSING

Passing is infrequently observed (Hoskins 2011). Of the cases observed in Hoskins' study, passing only occurred in 7%, and of those 7% only 1% were scenarios where a faster moving person passed a slower moving person.

2.2.3: MOVEMENT/MOBILITY

This subsection presents the calculations and models that are used to determine the speed and flow of occupants during egress. Additionally, it discusses how occupant density can impact movement in an egress component.

2.2.3.1: DENSITY

Occupant walking speed has been found to be greatly affected by density (Fruin 1987). Density is expressed using the following three equations (Predtechenskii and Milinskii 1978):

$$D_1 = \frac{P}{Lw} \ (\frac{P}{m^2}) \tag{4}$$

$$D_2 = \frac{Lw}{P} \ (\frac{m^2}{P}) \tag{5}$$

$$D_3 = \frac{\Sigma f_j}{Lw} \ (\frac{m^2}{m^2}) \tag{6}$$

where D_i = density, P = number of persons, L = length of space, w = width of space, and f_j = area occupied by each person.

2.2.3.2: SPEED/VELOCITY

Speed is defined as the movement velocity of evacuating individuals and is denoted by the variable S; observations and experiments have shown that the speed of a group or an individual in a group is a function of the population density. If the population density is less than 0.54 persons/m^2, speed will be maximized because individuals will move at their own pace independent of the pace of others (Gwynne and Rosenbaum 2016). Conversely, if the population density exceeds 3.8 persons/m^2, it is assumed that no movement will occur until the density decreases. Between these population density limits, speed can be estimated using the following formula:

$$S = k - akD_1 \tag{7}$$

where S = speed (m/s), a = constant (.266), k = constant for egress component, and D_1 = density (p/m^2). Figure 2.2 below shows the reported average speeds during experiments and observations from 1971 to 2004 (Hoskins 2012).

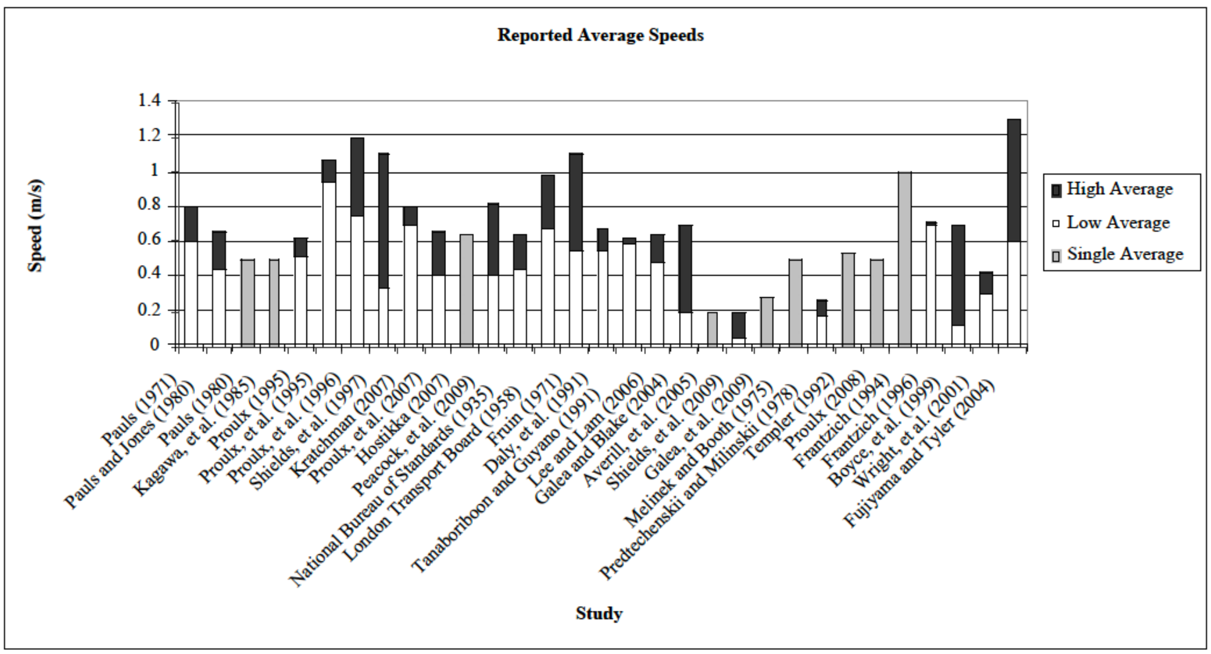

Figure 2.2: Reported Average Speeds During Experiments and Observations

2.2.3.3: FLOW RATE

Flow rate is defined as the number of persons that pass a specific position per unit time, and can be calculated using the following formulas:

$$F_c = SD_1w_e \tag{8}$$

$$F_c = (k - akD_1)D_1w_e \tag{9}$$

where S = speed (m/s), a = constant (.266), D_1 = density (p/m^2), k = constant for egress component, w_e = effective width (m).

2.2.3.4: SPECIFIC FLOW

Specific flow is defined as the number of persons that pass a specific position per unit time and per unit width of the path, and can be found using the following formula:

$$F_s = \frac{F_c}{w_e} \tag{10}$$

Where F_s = specific flow, F_c = flow rate (defined later in this chapter), and w_e = effective width. Specific flow is maximized when density = 1/2a, or 1.88 p/m^2.

2.2.3.5: LEVEL OF SERVICE

As shown in Section 2.2.3.2, movement on stairs can vary from individual movement and speed of each individual at low densities to no movement at high densities. Fruin's level of service concept defines six different cases relating density to flow conditions (Fruin 1971). Each case is assigned a letter and quantitatively defined; Table 2.3 summarizes Fruin's levels of service.

Table 2.3: Fruin's Levels of Service

Level of Service	Level Ground Space (m^2/person)	Stair Space (m^2/person)	Behavior
A	>3.25	>1.86	Occupants can move freely at their own speed; presence of other occupants has no effect on egress time
B	2.32-3.25	1.39-1.86	Occupants move freely in the main flow direction; bulk flow will slow down when counter flows are present
C	1.39-2.32	0.93-1.39	Ability for occupant to walk at desired speed is restricted
D	0.93-1.39	0.65-0.93	Walking speeds of most occupants are reduced; passing other occupants is limited

E	0.46-0.93	0.37-0.65	Occupants move at speed of slowest member; passing is severely limited
F	<0.46	<0.37	Occupants are in contact with one another and movement is reduced to shuffling; not recommended for design

2.2.4: RSET CALCULATION METHODS

Two general methods are used in order to calculate RSET: algebraic hand calculations and computer simulations.

2.2.4.1: HAND CALCULATIONS

Hand calculations are fundamental for egress calculation; equations utilized in the hydraulic model are the foundation for many computer models.

PAULS' CORRELATIONS

Early correlations for egress time were based on the analysis of the evacuation of 56 office buildings during fire drills; Pauls proposed that when the normalized population was less than 800 persons per meter of effective width, the total evacuation time could be calculated using the following two models:

$$t = 0.68 + 0.081\left(\frac{P}{w_e}\right)^{0.73} \quad (11)$$

$$t = 2.0 + 0.0117\left(\frac{P}{w_e}\right) \quad (12)$$

where t = evacuation time (min), p = population using stair, and w_e = effective width (m). Figure 2.3 shows the observed population data used to find these two correlations.

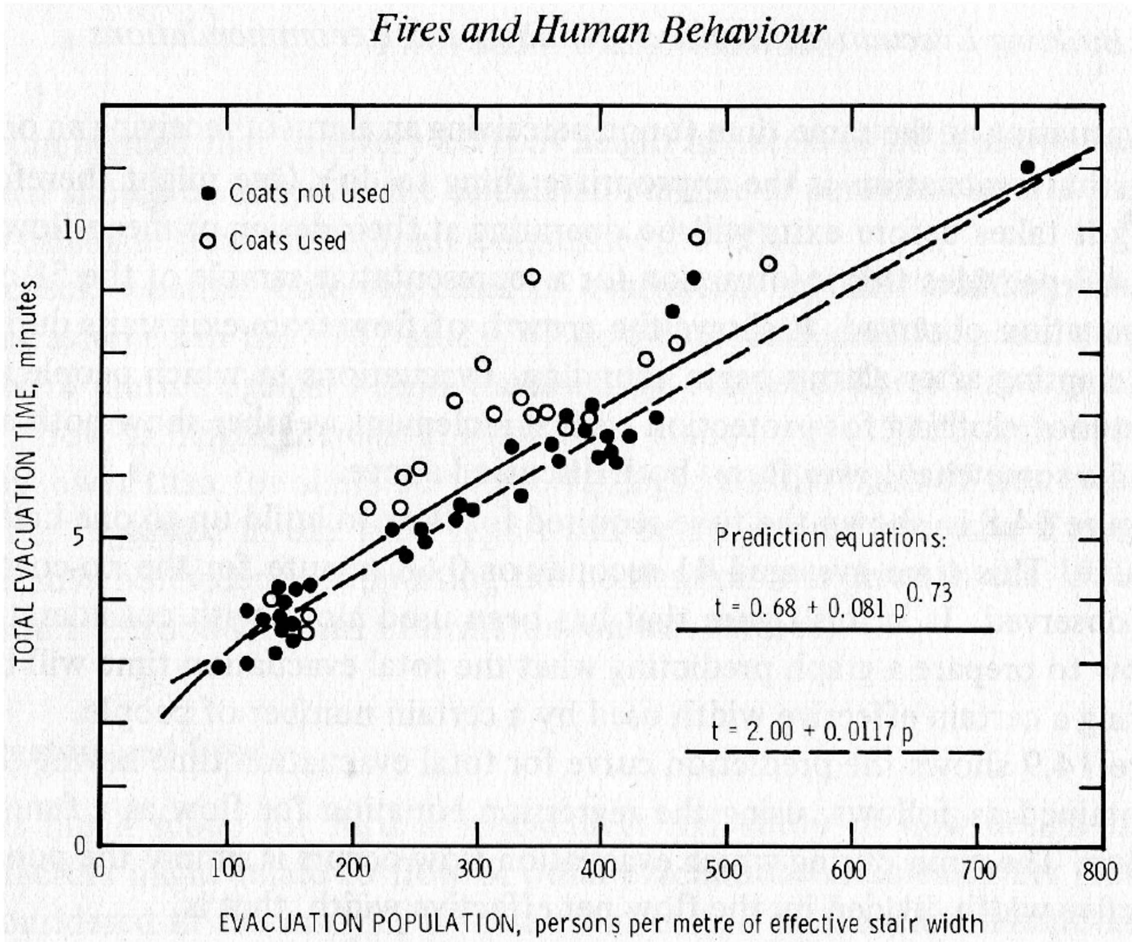

Figure 2.3: Data Points Used to Create Pauls' Evacuation Time Model

HYDRAULIC MODEL: FIRST ORDER ANALYSIS

The first order hydraulic model focuses on evacuation through a critical, or controlling, component. It utilizes the maximum specific flow, flow rate, and speed previously described in this report in order to calculate egress time (Gwynne and Rosenbaum 2016).

MODEL LIMITATIONS

While the hydraulic model is a good representation of the average population, it fails to consider individual characteristics that may impact evacuation speed. Additionally, when platoons form, individuals may not experience average behavior, and this can affect egress time.

2.2.4.2: COMPUTER SIMULATIONS/MODELS

Several evacuation models have been developed to determine egress times; computer simulations (models) quantify human movement and behavior during egress. Computer simulation outputs include evacuation time, flow rates through building components, congestion areas, individual movement from one area to another, and risk to occupants.

Current models can be categorized by their characteristics: modeling method, scope of representation, output, distribution and cost, age/generation of model, and refinement of representation (Gwynne et al., 2005). Pathfinder was used for the purpose of this thesis, so it is discussed in greater detail in the next subsection.

PATHFINDER

Pathfinder is an agent-based egress and human movement simulator (Thunderhead Engineering 2015); it is a partial behavioral model available for a set cost to the public through Thunderhead Engineering. This computer model provides two primary options for occupant motion: SFPE mode and Steering mode.

SFPE mode implements the concepts in the *SFPE Handbook of Fire Protection Engineering*. This mode is a flow model, where walking speeds are determined by occupant density within each room and flow through doors is controlled by door width. It utilizes straight line paths and constant speeds; as a result, it is considered to be more of a movement model rather than a partial behavior model.

Steering mode is based on the idea of inverse steering behaviors. It allows more complex behavior to naturally emerge as a byproduct of movement algorithms (such as utilization of curved paths and the ability for occupants to accelerate and decelerate) eliminating the need for explicit door queues and density calculations.

Pathfinder uses cylinders to represent occupant bodies, and therefore the projected body area is circular. The default setting in Pathfinder assumes a constant value for a shoulder width of 45.57 cm which is slightly smaller than, but close in value to, person widths established by literature previously referenced in this report. In Pathfinder, the user is able to change the body size distribution from constant to uniform, normal, or log-normal (Ahrens 2018).

The verification and validation for this software consists of a detailed set of test cases designed to ensure that the simulations capture realistic behavior. The verification tests are synthetic tests specifically designed to examine the ability of the software to implement a particular evacuation mode or occupant behavior. These validation tests are based on published experimental data from literature (Kodur 2020).

CHAPTER 3: METHODOLOGY

3.1: PURPOSE

This research is designed to quantify the effect of increased individual size during stairwell egress. One floor and three floor evacuations were examined for a variety of body sizes; additional considered variables included stair width and number of occupants evacuating per floor.

Testing performed simulated evacuations using one stairwell and one exit; all occupants began their evacuation from the stairwell landing in order to isolate the time of evacuation to the stair component.

3.2: SOFTWARE

Pathfinder was chosen for this research due to its successful meeting of the guidance of component testing and its availability during the global pandemic (Thunderhead Engineering 2015, Kodur 2020).

Verification tests are synthetic test cases designed to ensure that the simulator is performing as specified by the Pathfinder Technical Reference, while validation tests are designed to measure how well Pathfinder's implementation of simulation captures real behavior. Pathfinder is subject to an ongoing verification and validation process, and results of these tests are presented in Pathfinder's Verification and Validation document. In this document, the results of a series of performed International Maritime Organization (IMO) tests and NIST evacuation tests are presented to validate Pathfinder's modeling ability.

3.2.1: SOFTWARE SETTINGS

In order to best isolate the variable of increased individual size, parameters in Pathfinder not associated with individual size or stairwell geometry remained constant for each test. Table 3.1 shows occupant parameters that remained constant during testing:

Table 3.1: Constant Occupant Characteristic Inputs

Occupant Characteristic	Value
Speed	1.19 m/s (3.90 ft/s)
Shape	Cylinder
Height	1.83 m (6.00 ft)
Comfort Distance	0.080 m (0.263 ft)

Steering mode was utilized for this research. This mode allows for more complex behavior during egress; occupants proceed independently to their goal while avoiding other occupants and obstacles.

3.3: TEST DESIGN

The series of tests designed for this thesis was created to isolate the egress time required in a staircase. Evacuation from multiple floors was evaluated using different stair geometries and occupant characteristics. The following sections describe each facet of the assigned stair geometry, occupant exit conditions, and occupant characteristics for this testing.

The U-shaped stair created for this series of tests was designed to be representative of the exit stair shape used in multiple high rise structures. This prevented the obtained results from only being applicable to a single building's layout and from artificially amplifying the impact of occupant size on egress time.

Occupant size was selected as the focus of this experiment because it is a variable associated with overweight and obesity that cannot be changed; it must remain constant during the course of an egress scenario. While it is not the only possible aspect associated with increase in BMI that could affect egress time, increasing body size is an important factor worthy of exploration. Utilizing a computer model allowed this research to isolate this particular factor that could not be isolated during the observation of human subjects.

3.3.1: STAIR GEOMETRY

The different elements of the stairwell geometry are described in this subsection.

3.3.1.1: EXIT

The exit, or end, of this simulation was two feet after where the bottom floor landing met the lowest step in the stairway. The width of this exit was considered to be the entire length of the stair.

3.3.1.2: FLOOR HEIGHT

Floor height was designed to be 3.05 m (10.0 feet). This height remined constant for every floor in each test.

3.3.1.3: LANDING DIMENSIONS

Each landing in the stairwell had a width of two times the width of the stair and a depth of the width of the stair. Figure 3.1 below illustrates this concept on the Pathfinder model.

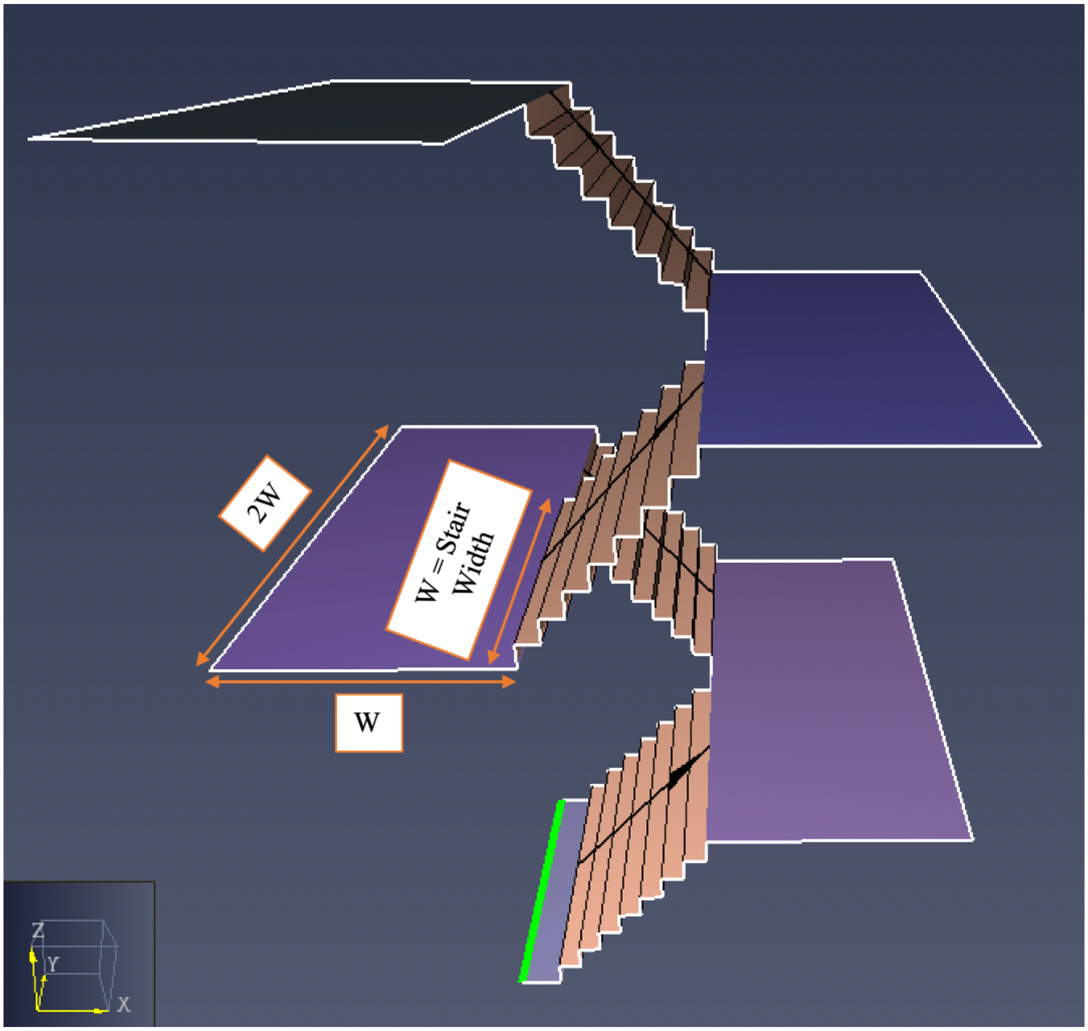

Figure 3.1: Visual Representation of Landing Dimensions

Landings were placed on floor levels and intermediate landings were placed between floor levels.

3.3.1.4: STAIR DIMENSIONS

The rise and run properties of each stair were kept constant throughout this series of tests (19.1 cm rise, 25.4 cm run). This step dimension was chosen because it has the lowest associated k value of the four different stair geometries considered in Chapter 59 of the *SFPE Handbook*. This, in combination with the previously stated notion that steeper stair rise can require a greater time for descent, would imply that 19.1 cm/25.4 cm stair geometry would lead to the longest evacuation time. In Pathfinder, the rise and run does not have to match the geometric slope of each stair in order for a simulation model to run; however, the stairs in this research were designed so that the geometric slope of each stair did match the chosen rise and run. In accordance with this geometry, the height between each floor landing and intermediate landing was 152.4 cm, and eight 19.1 cm tall steps were utilized to fit this distance. The vertical distance between landings was 203 cm (8 steps x 25.4 cm per step).

3.3.1.5: STAIR WIDTHS

Two stair widths were examined for this research: 188 cm and 152 cm. These stair dimensions were chosen because of their large clear widths; this additional open space on each horizontal plane allows for the potential for multiple occupants to be on the same stair at the same time.

3.3.2: OCCUPANT EXIT CONDITIONS

The exit occupant conditions, or the number of occupants who exited and their starting locations, are discussed below.

3.3.2.1: EVACUATING FLOORS

Two different egress scenarios were tested: the evacuation of one floor and the evacuation of three floors. The evacuation simulations conducted assumed there was only one effected floor, or fire floor. A single floor egress was tested for data comparison purposes; a three floor evacuation was tested because it better simulates an actual building egress scenario. The fire and life safety systems installed in high rise buildings are designed to control a fire, and therefore lessen the need to evacuate all occupants. Typically, the occupants of the fire floor and the floors immediately above and below it are the only occupants required to egress in the event of a fire scenario (NFPA 2021).

Different scenarios were tested by setting the fire floor as floor 5, 10, 15, 25, 35, 50, 75, or 100. In the United States, only three buildings have more than 100 floors (the Willis Tower in Chicago, the One World Trade Center in New York City, and the Empire State Building in New York City), so the maximum number of floors used during this testing was 100 (CTBUH 2021). Fire floors below 100 were chosen for testing to represent a variety of evacuation floor heights; the distance between selected fire floors was smaller for lower floors and larger for higher floors. This interval pattern was utilized because the higher the fire floor, the lower the number of buildings that will contain that floor. While this research was designed to focus on high rise buildings, the lower floors selected for testing also allow the results to be applied to shorter structures with lower numbers of total floors.

3.3.2.2: EXITING OCCUPANTS

The number of occupants egressing from each floor was a secondary independent variable for this research. Each test was run with 25, 50, 75, or 100 occupants evacuating from each floor. The numbers of occupants per floor included in the simulations were selected randomly. In tests where only one floor was egressing, this was the total number of occupants evacuating; in tests where three floors were egressing, the total number of occupants evacuating was 75, 150, 225, or 300 (respectively).

3.3.3: OCCUPANT BODY SIZE

Fruin found the standard body size to be 0.25 m to 0.35 m (Fruin 1980). For the purposes of this research, the standard size considered was from 0.25 m to 0.4 m; this 15 percent increase was considered because the reported Fruin body size was based on research conducted on New York City commuters. Persons in cities tend to have significantly lower rates of obesity and overweight individuals (CDC 2021, NYC.gov 2021, Ahrens 2018), and the increased upper bound helps to compensate for this statistic.

Occupant dimensions are inputted into Pathfinder as diameters. Using the more conservative value of a 16.2% increase in BMI from 1962 to 2018 and assuming that increase in BMI directly correlates to increase in body diameter, Table 3.2 was constructed to depict the increased occupant diameter values.

Table 3.2: Increased Diameter Values

Radius (cm)	Diameter (cm)	16.2 % Increased Diameter (cm)
25	50	58.1
27.5	55	63.9
30	60	69.7
32.5	65	75.5
35	70	81.3
37.5	75	87.2
40	80	93.0

This table was used to create the input parameters of testing size ranges for this research; Table 3.3 depicts the different size ranges used for testing. The minimum size was selected in order to create a larger range of occupant size values to be used in the normal distribution; the maximum size was chosen based on the 16.2% diameter increased values described in Table 3.2. The Group A mean is representative of the lower end diameter of 0.5 m found by Fruin, and the mean value of each group increases in comparison to Group A by the same number of centimeters that the maximum value increases in comparison to Group A. Standard deviation is a measure of the amount or variation of a set of values; the standard deviation remained constant for the purposes of this research.

Table 3.3: Input Group Occupant Diameter Ranges and Distributions

Individual Size Range Name	Min (cm)	Max (cm)	Mean (cm)	Standard Deviation (cm)
A	25	70	50	12.5
B	25	75	55	12.5

C	25	80	60	12.5
D	25	85	65	12.5
E	25	90	70	12.5
F	25	95	75	12.5

3.4: PROCEDURE

Simulations were run in Pathfinder for each of the previously described stair geometries, occupant exit conditions, and occupant characteristics. Each test was named in the following manner: test name = (Occupant Characteristic Group).(Stair Width).(Number of Evacuating Floors).(Central Evacuating Floor).(Occupants Per Floor). Table 3.4 below shows different simulation inputs; for each test, one variable was selected from each column. Every possible combination of variables was tested and, in total, 768 simulations were conducted.

Table 3.4: Test Input Value Overview

Occupant Characteristic Group	Stair Width (cm)	Evacuating Floor(s)	Occupants Per Floor
A	188	5	25
B	152	10	50
C		15	75
D		25	100
E		35	
F		50	
		75	
		100	
		4,5,6	
		9,10,11	
		14,15,16	
		24,25,26	
		34,35,36	
		49,50,51	
		74,75,76	
		99,100,101	

To supplement the Pathfinder computer simulation and provide a basis for comparison, hand calculations were completed using the previously described first order hydraulic model.

These calculations were not performed on every test, but on a random series of tests with different independent variables for reference purposes.

3.5: DATA COLLECTION

Pathfinder provides a graphic interface that allows the user to see the evolution of how occupants exit a stairwell (occupant paths and the number of occupants that have exited at particular time stamps). The recorded data for this research was the time at which the total population had exited the stairwell.

3.6: DATA ANALYSIS

The focus of the analysis of this data is the impact of increased occupant size on the time necessary for stairwell egress. At each stair geometry and exit condition, the difference in time of egress (in seconds) between Group A – F and the overall egress time (in terms of percent change) were analyzed.

CHAPTER 4: RESULTS AND ANALYSIS

Numerical results of each test performed are presented in Appendix A. This section works to break down these raw results and discover patterns and trends. Due to its higher applicability to actual evacuation scenarios, the research conducted using the egress of three floors is the focus of this chapter.

4.1 THREE FLOOR EGRESS

4.1.1 EGRESS TIME DIFFERENCE IN SECONDS

Figure 4.1 depicts the time for groups A, B, C, D, E, and F to egress from three evacuating floors (4, 5, and 6) with 100 occupants per floor; Figure 4.2 shows the time for groups A, B, C, D, E, and F to egress from three evacuating floors (99, 100, and 101) with 100 occupants per floor. From these figures, it can be seen that as the mean diameter size of each egressing group gets larger, the time required for egress increases. Although these graphs do not depict every evacuated floor or every number of egressing occupants per floor, the observed trend between group and egress time is representative of all data.

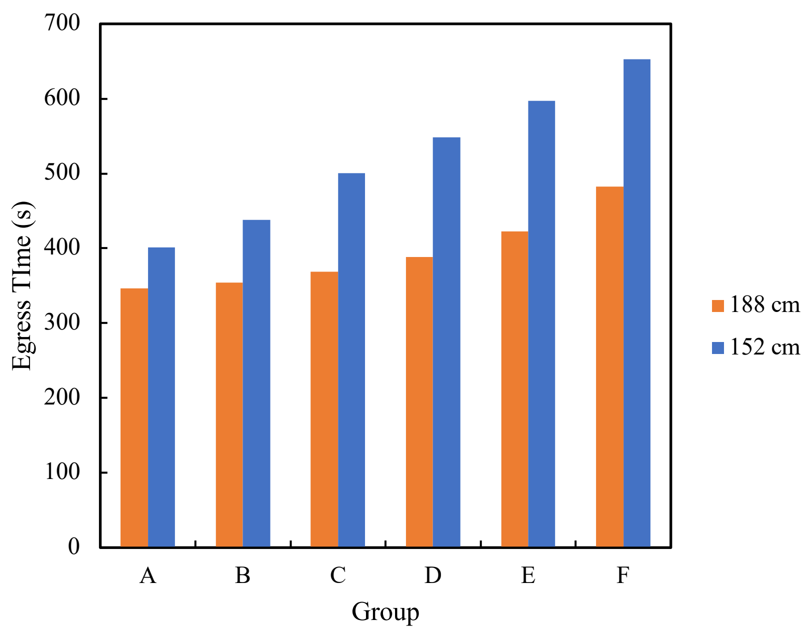

Figure 4.1: Egress Time by Group for Evacuation of Floors 4, 5, and 6 with 100 Occupants per Floor

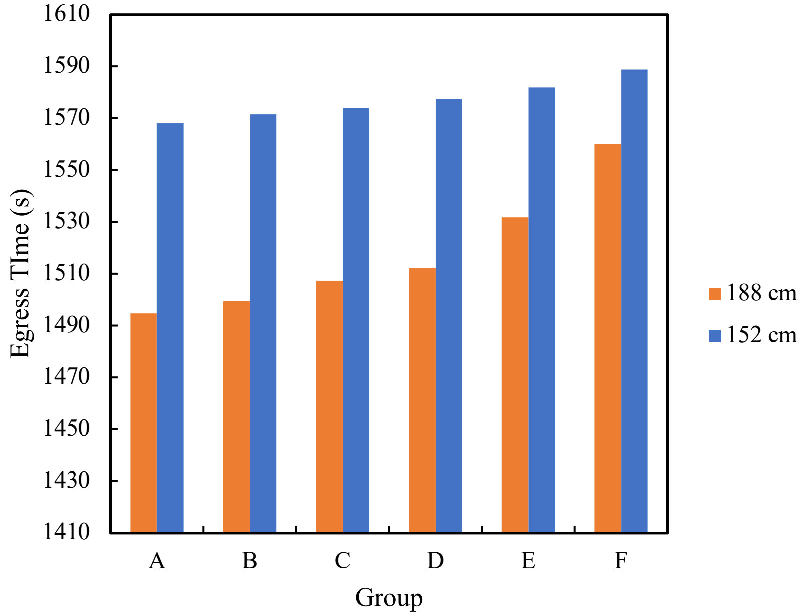

Figure 4.2: Egress Time by Group for Evacuation of Floors 99, 100, and 101 with 100 Occupants per Floor

Figure 4.3 depicts the egress time difference in seconds based on the central evacuating floor for a three story egress utilizing 188 cm stairwell, Figure 4.4 depicts the egress time difference in seconds based on the central evacuating floor for a three story egress utilizing 152 cm stairwell, and Figure 4.5 provides a comparison of 25 occupant per floor and 100 occupant per floor data from both stair widths. All three figures compare the egress time of Group A and Group F (accounting for the 16.2% BMI increase).

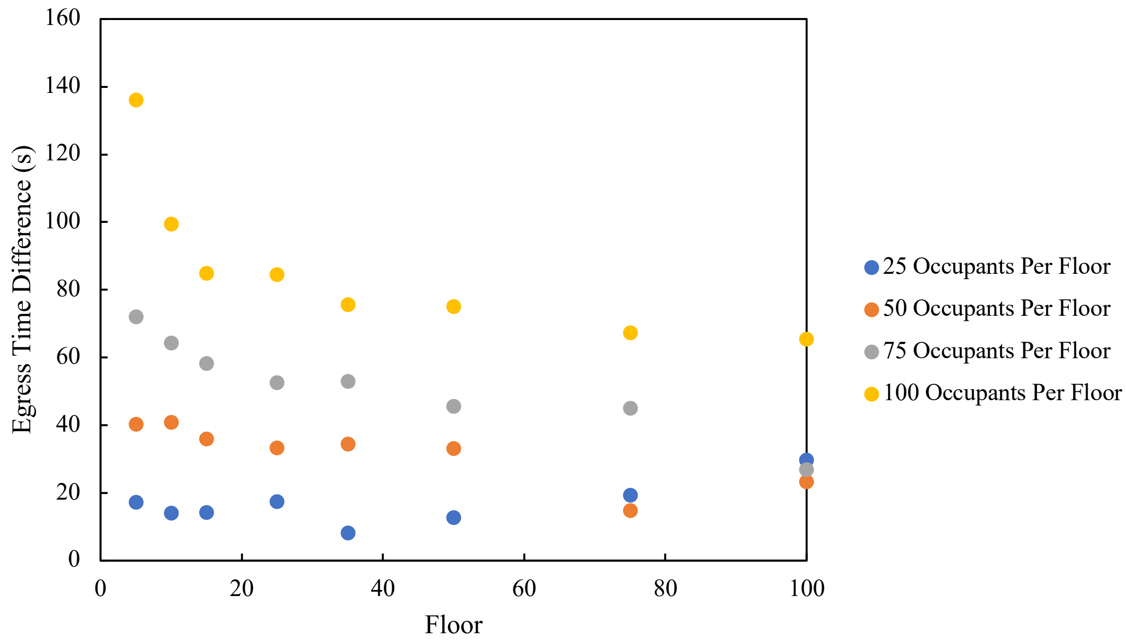

Figure 4.3: Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 188 cm Stair

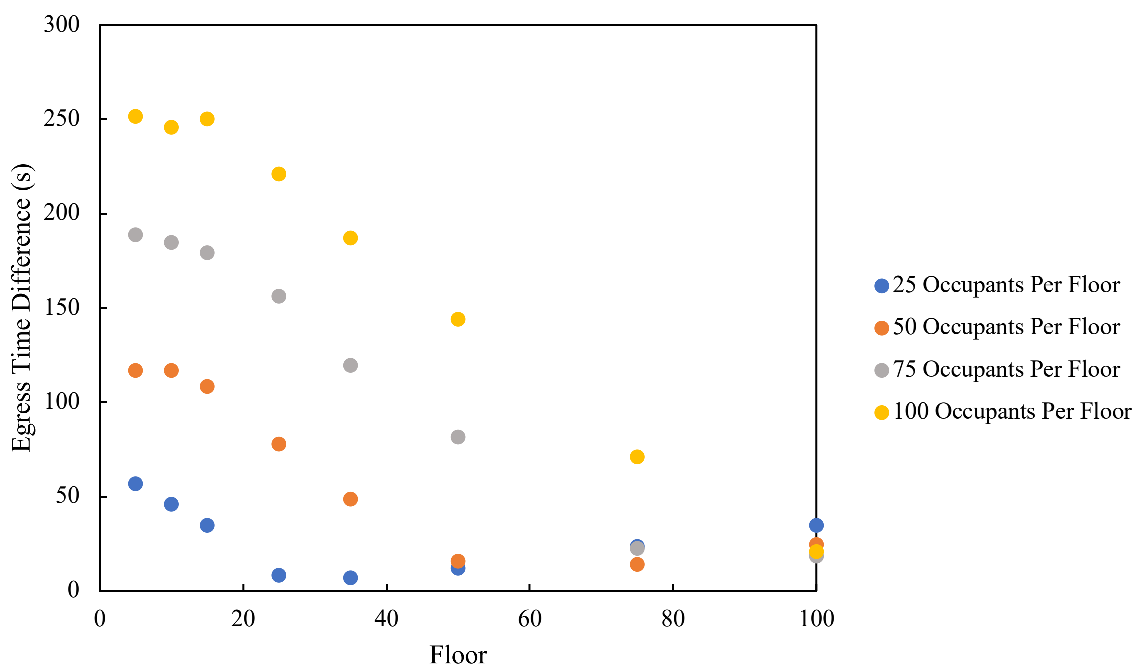

Figure 4.4: Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 152 cm Stair

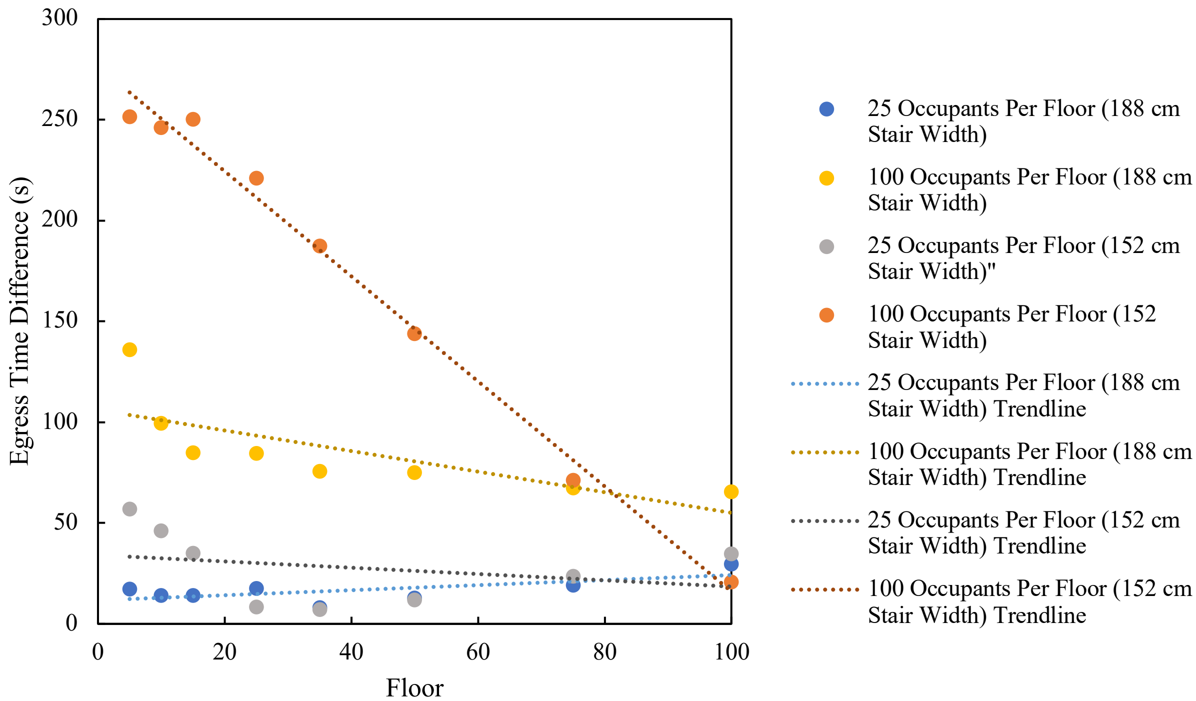

Figure 4.5: Comparison of Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 188 cm Stair and 152 cm Stair

The data presented in Figures 4.3, 4.4, and 4.5 follow relatively steady downward trends. This indicates that the impact of enlarged body size decreases with the increase of evacuation floor height. It should be noted that the three floor, 25 occupant per floor evacuation utilizing 188 cm wide stairs does not comply with this pattern; it appears that when a fewer number of occupants egress over a large number of floors, the occupant density decreases to a point where all occupants can egress at their ideal speed. For the three floor, 25 occupant per floor evacuation utilizing 188 cm wide stairs, this density point appears to occur between floors 15 and 25.

The data associated with 188 cm stair width has a more shallow slope than data associated with 152 cm stair width. This shows that of the two studied stair widths, the effect of increased occupant size has a larger impact on the more narrow stair.

In the comparison figure, the data shows that the average egress time increase was greater for larger number of occupants exiting per floor.

4.1.2 EGRESS TIME DIFFERENCE IN PERCENTAGES

Data from the previous three figures presents egress time differences in seconds; however, this information is not optimum without an appropriate frame of reference. Figure 4.6 depicts the egress time difference in percentage based on the central evacuating floor for a three story egress utilizing 188 cm stairwell, Figure 4.7 depicts the egress time difference in percentage based on the central evacuating floor for a three story egress utilizing 152 cm stairwell, and Figure 4.8 provides a comparison of 25 occupant per floor and 100 occupant per floor data from both stair widths. All three figures compare the egress time of Group A and Group F (accounting for the 16.2% BMI increase).

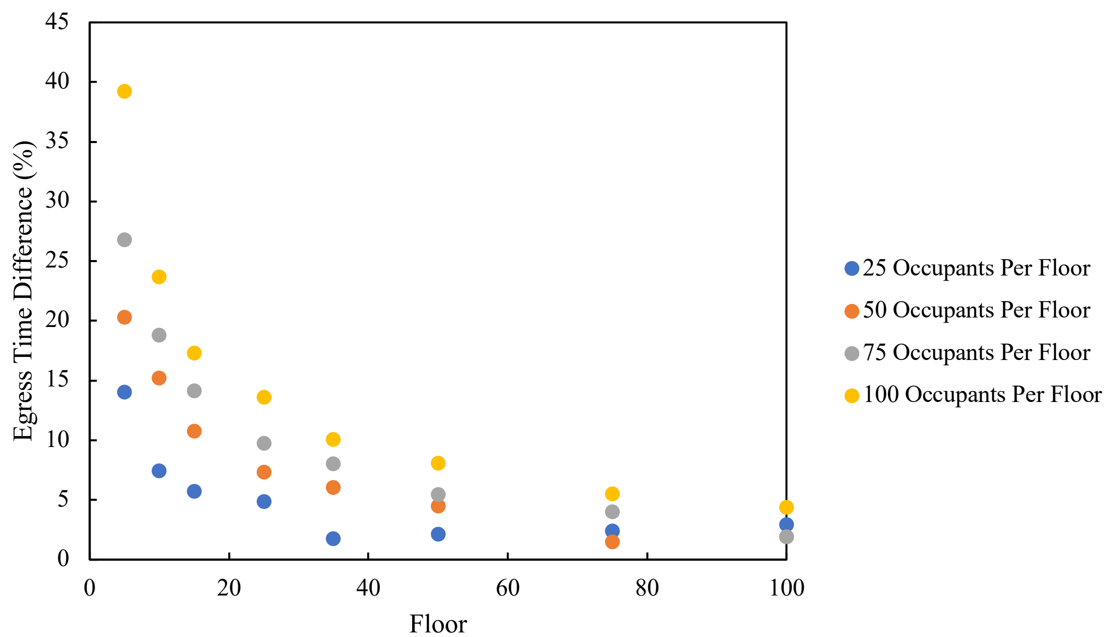

Figure 4.6: Difference in Egress Time in Percentage Between Group A and F for 3 Story Egress Using 188 cm Stair

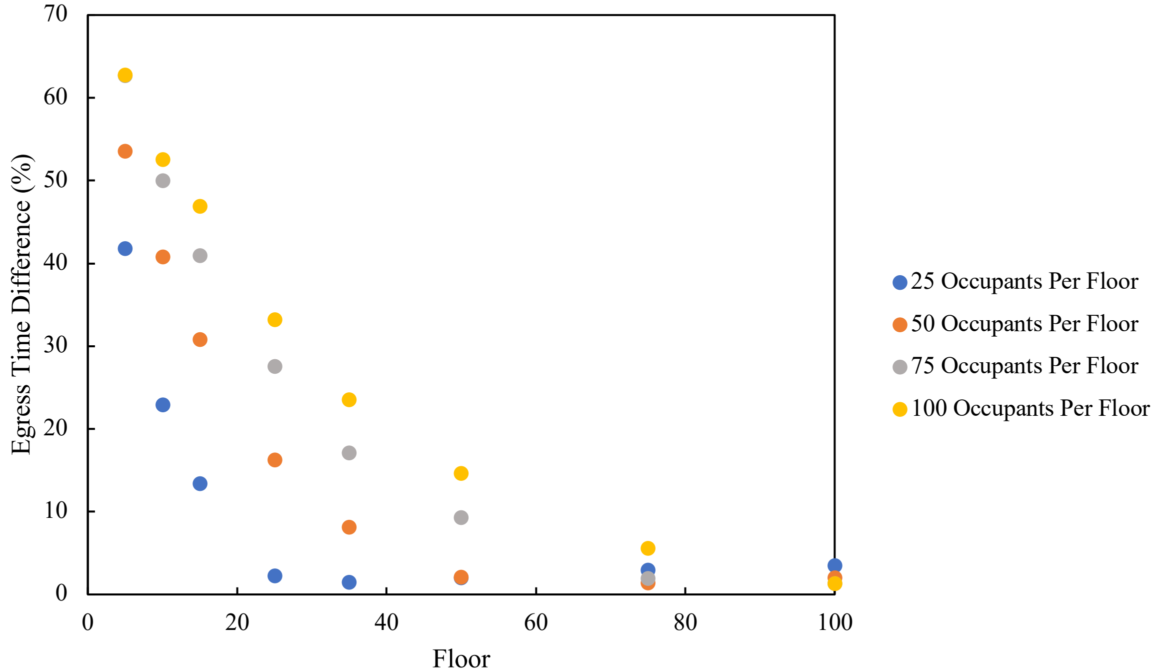

Figure 4.7: Difference in Egress Time in Percentage Between Group A and F for 3 Story Egress Using 152 cm Stair

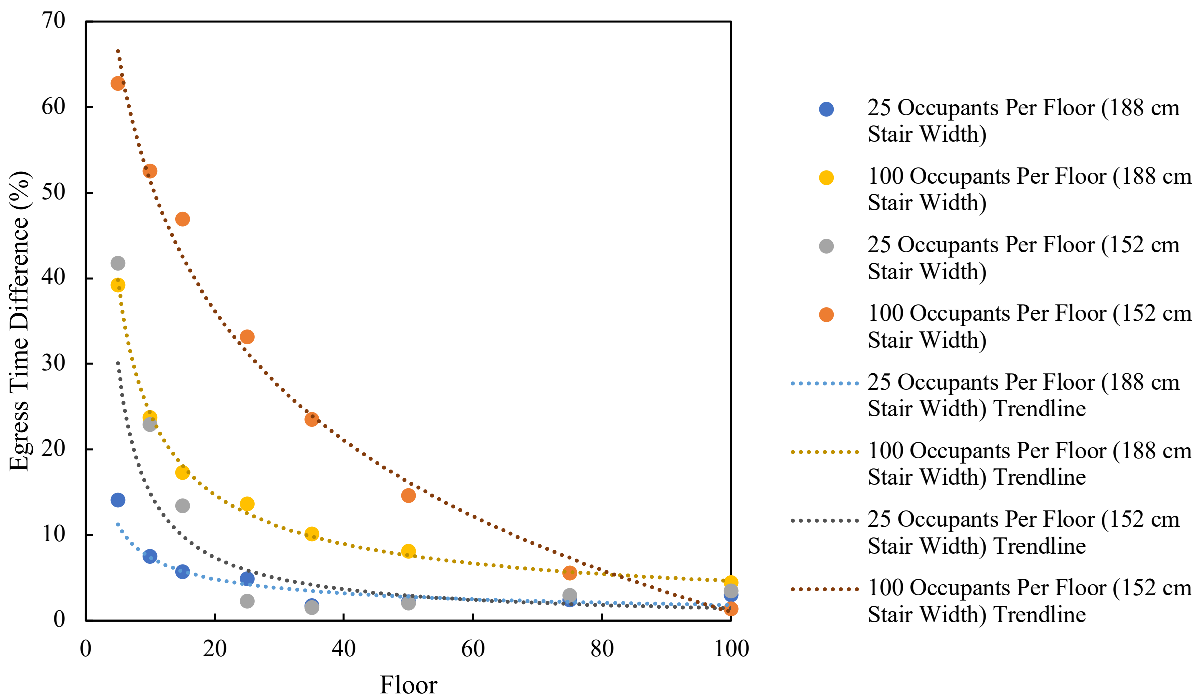

Figure 4.8: Comparison of Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 152 cm Stair and 188 cm Stair

The curves presented in Figures 4.6, 4.7, and 4.8 follow a downward trend and appear to reach a horizontal asymptote when the egress time difference percentage is equal to zero. In both the 188 cm and 152 cm stair width cases, the larger the number of occupants involved in egress, the larger the percentage increase of egress time.

In most cases, the lower the floor, the greater the percentage of egress time change. As previously observed when doing a time comparison in seconds, the 25 occupant per floor evacuation utilizing 188 cm wide stairs does not comply with the pattern based on time comparison in percentage. It appears that when a lesser number of occupants egress (and therefore the occupant density is less), at some point the percentage change of mean egress time alters from decreasing as floor level increases to increasing as floor level increases. One possible reason behind this change in behavior is that regardless of increased occupant size, the occupant density becomes low enough to allow occupants to move at their desired speed.

4.1.3 OCCUPANT SIZE PERCENTAGE INCREASE RELATION TO EGRESS TIME CHANGE

Figures 4.9, 4.10, 4.11, and 4.12 show the correlation between the size range mean value increase and egress time change for different occupant loads and location of the evacuating levels. These figures depict the egress time change of a three story evacuation using a 188 cm stair. The size range mean value increase was found using the mean occupant width of Groups A – F compared to the mean occupant width of Group A, and the egress time change was found using the mean egress time of Groups A – F compared to the mean egress time of Group A. As the percentage of mean value of the size range increases, the egress time change also increases.

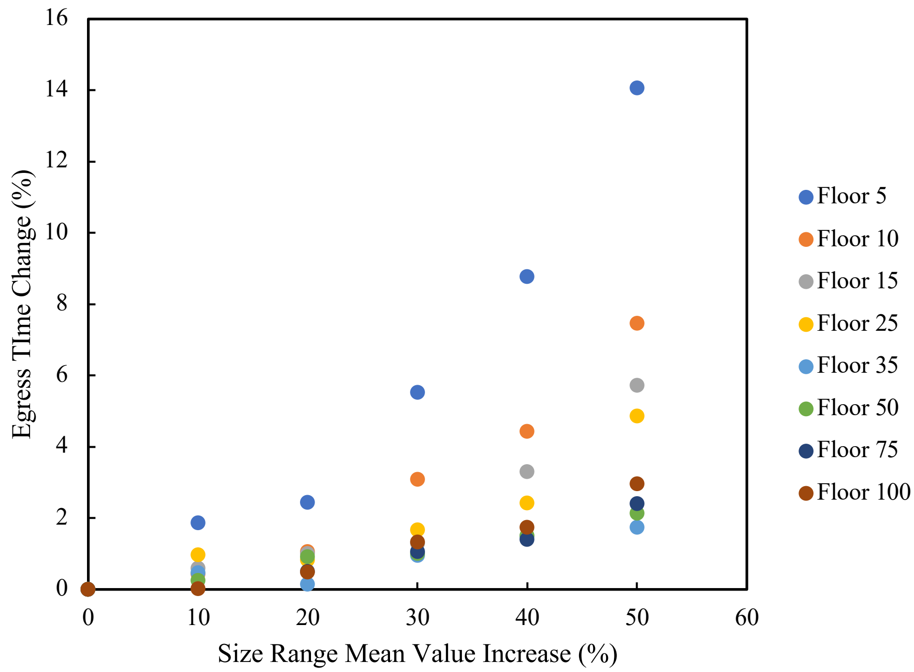

Figure 4.9: 25 Occupants Per Floor, 3 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

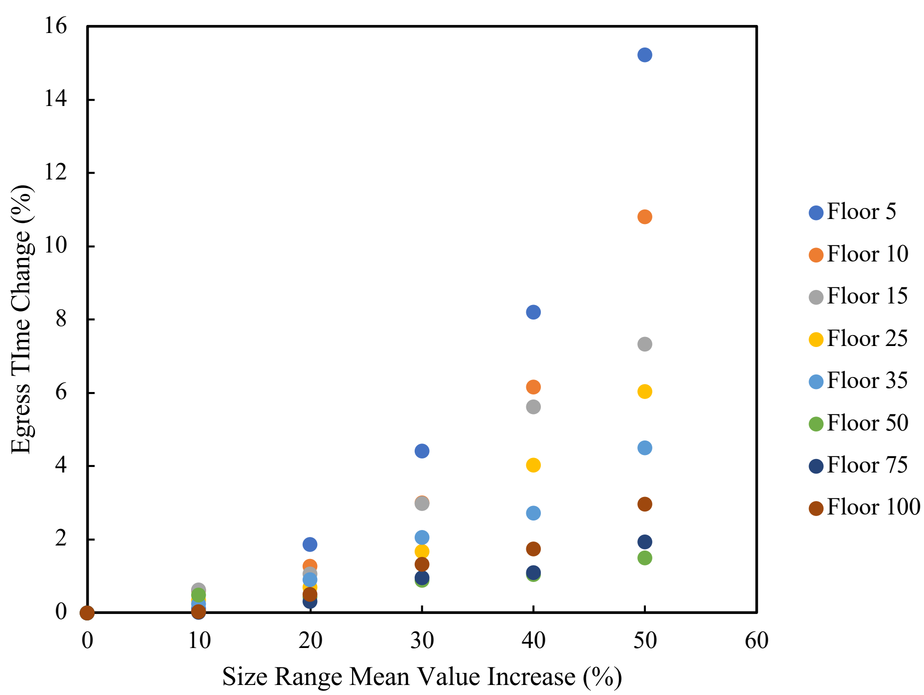

Figure 4.10: 50 Occupants Per Floor, 3 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

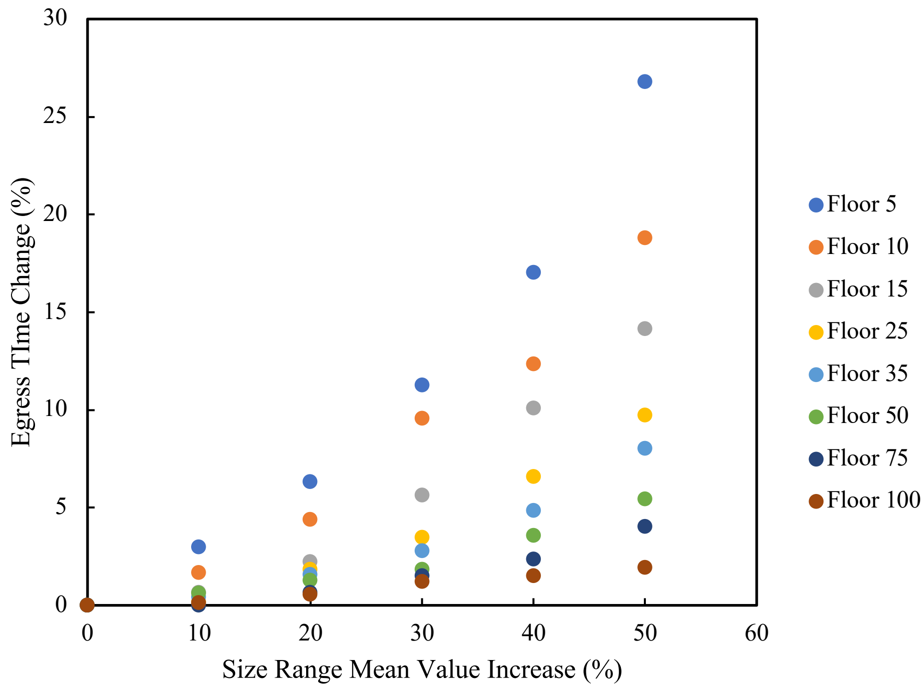

Figure 4.11: 75 Occupants Per Floor, 3 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

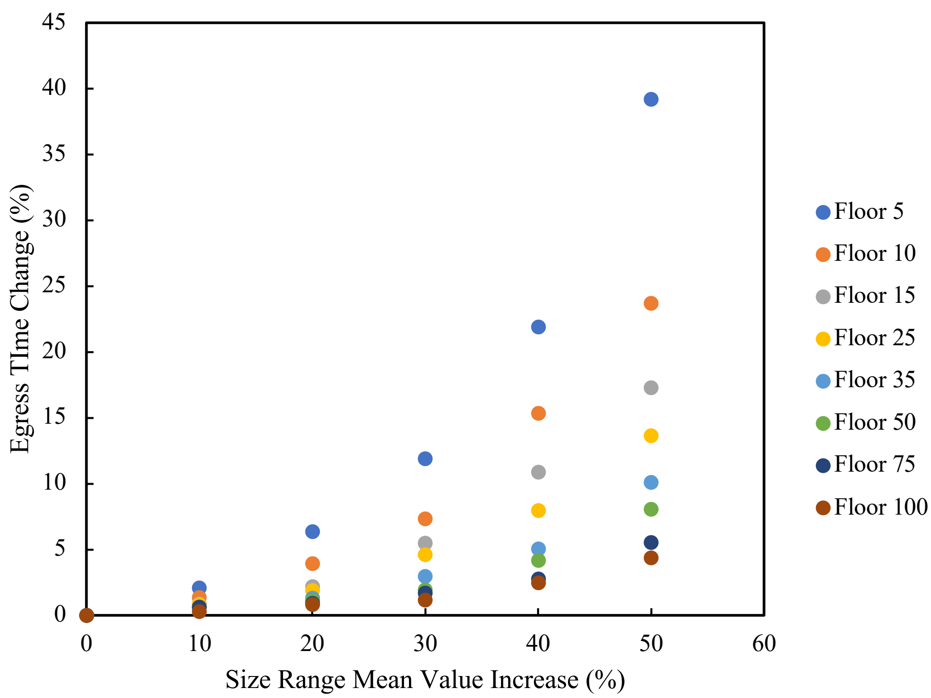

Figure 4.12: 100 Occupants Per Floor, 3 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

In most cases, the rate of egress time change was greater for lower floors; however, when 25 occupants per floor were egressing, Floors 35, 50, 75, and 100 did not follow this pattern and when 50 occupants per floor were egressing, floors 50, 75, and 100 did not follow this pattern. It appears that the behavior previously observed when a lower number of occupants egress occurred, i.e. after a particular threshold of the elevation of the floors evacuating is reached, the percentage change of mean egress time alters from decreasing as floor level increases to increasing as floor level increases. The location of this change will be referred to as the "critical floor" for the remainder of this report. As previously noted in this chapter, the reasoning behind this change in behavior is that the occupant density has decreased to a rate where occupants can move at their own speed, and therefore the egress of a low number of occupants over a long distance is no longer hindered by occupant size.

4.2 ONE FLOOR EGRESS

4.2.1 EGRESS TIME DIFFERENCE IN SECONDS

Figure 4.13 depicts the time for groups A, B, C, D, E, and F to egress from one evacuating floor (floor 5) with 100 occupants per floor; Figure 4.14 shows the time for groups A, B, C, D, E, and F to egress from one evacuating floor (floor 100) with 100 occupants per floor. From these figures, it can be seen that as the mean occupant size in the group gets larger, the time required for egress increases. Although these graphs do not depict every evacuated floor or every number of egressing occupants per floor, the observed trend between group and egress time is representative of all data.

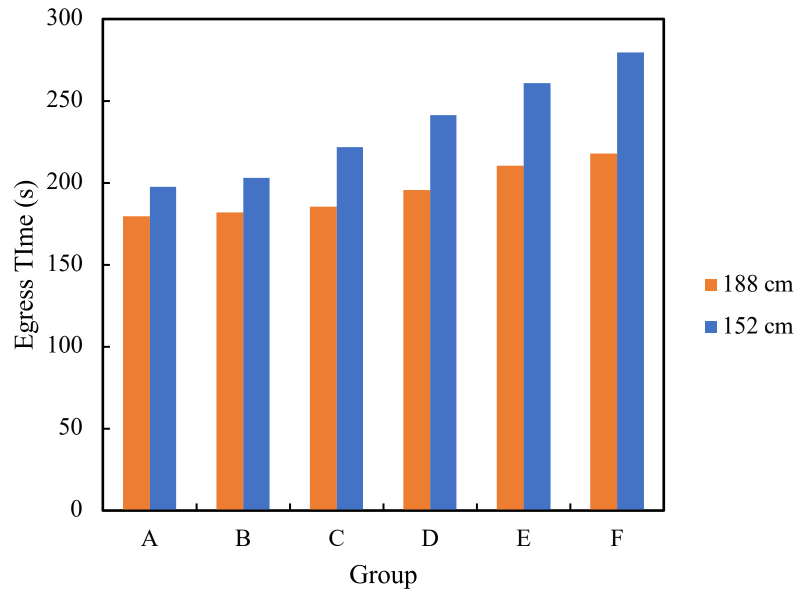

Figure 4.13: Egress Time by Group for Evacuation of Floor 5 with 100 Occupants per Floor

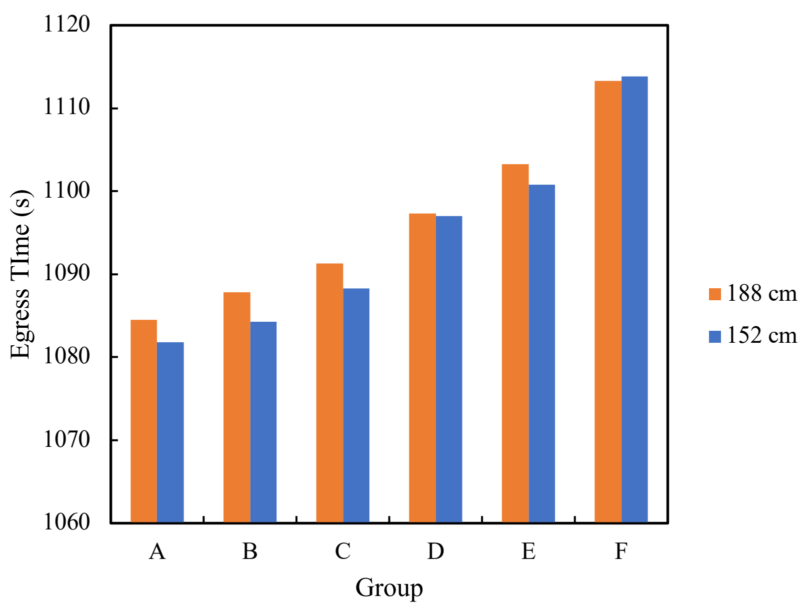

Figure 4.14: Egress Time by Group for Evacuation of Floor 100 with 100 Occupants per Floor

Figure 4.15 depicts the egress time difference in seconds based on the evacuating floor for a one story egress utilizing 188 cm stairwell, Figure 4.16 depicts the egress time difference in seconds based on the evacuating floor for a one story egress utilizing 152 cm stairwell, and Figure 4.17 provides a comparison of 25 occupant per floor and 100 occupant per floor data from both stair widths. All three figures compare the egress time of Group A and Group F (accounting for the 16.2% BMI increase).

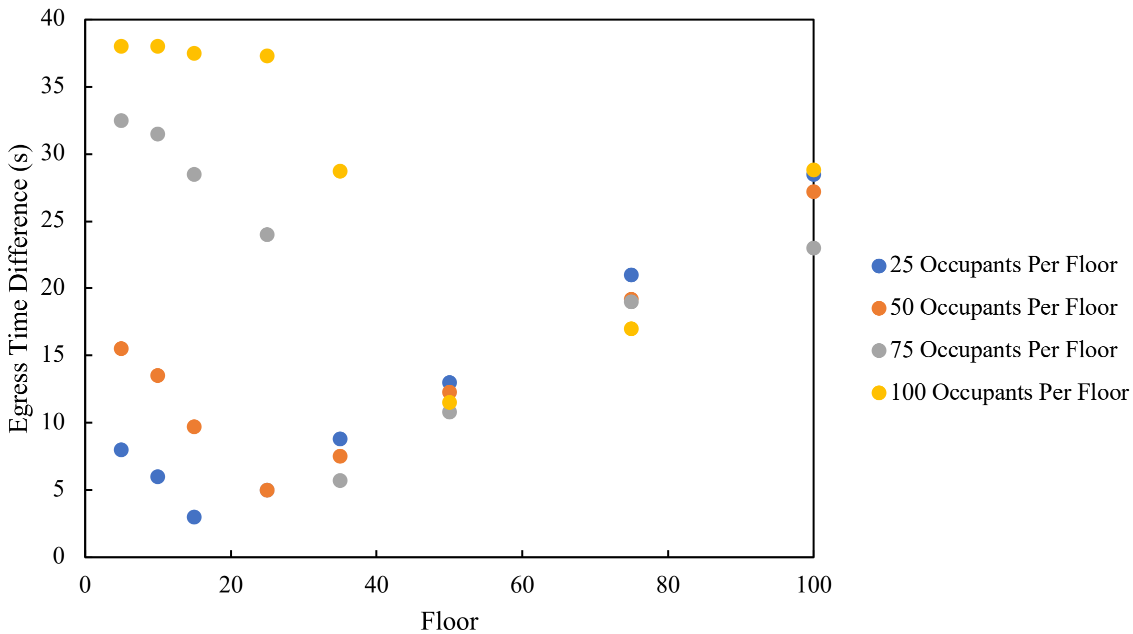

Figure 4.15: Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 188 cm Stair

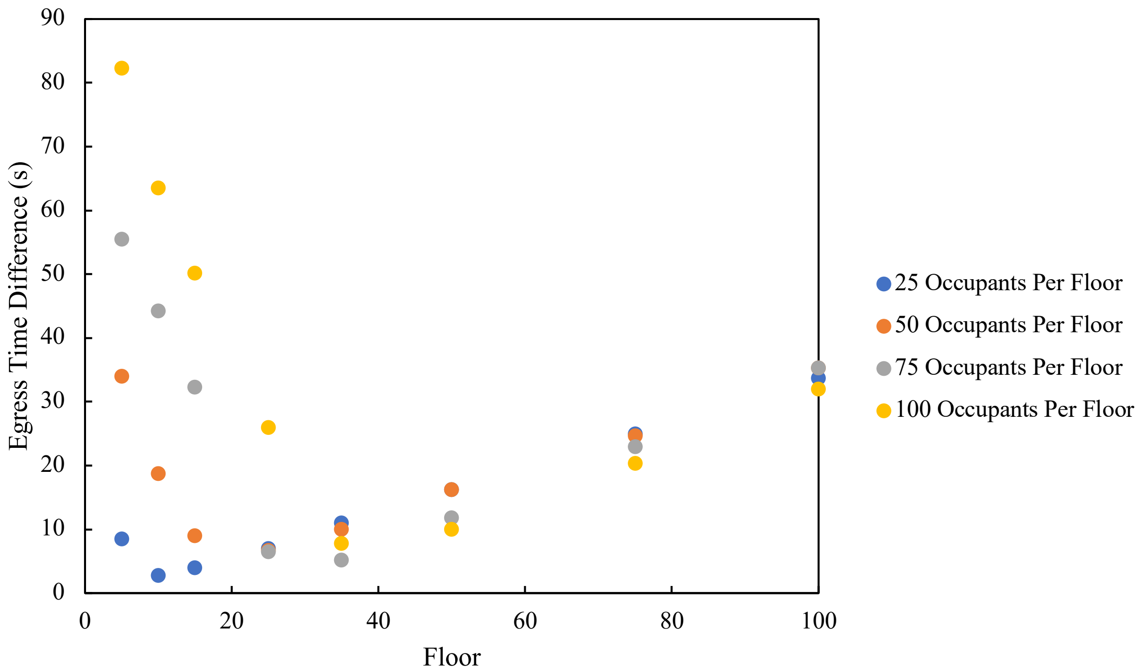

Figure 4.16: Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 152 cm Stair

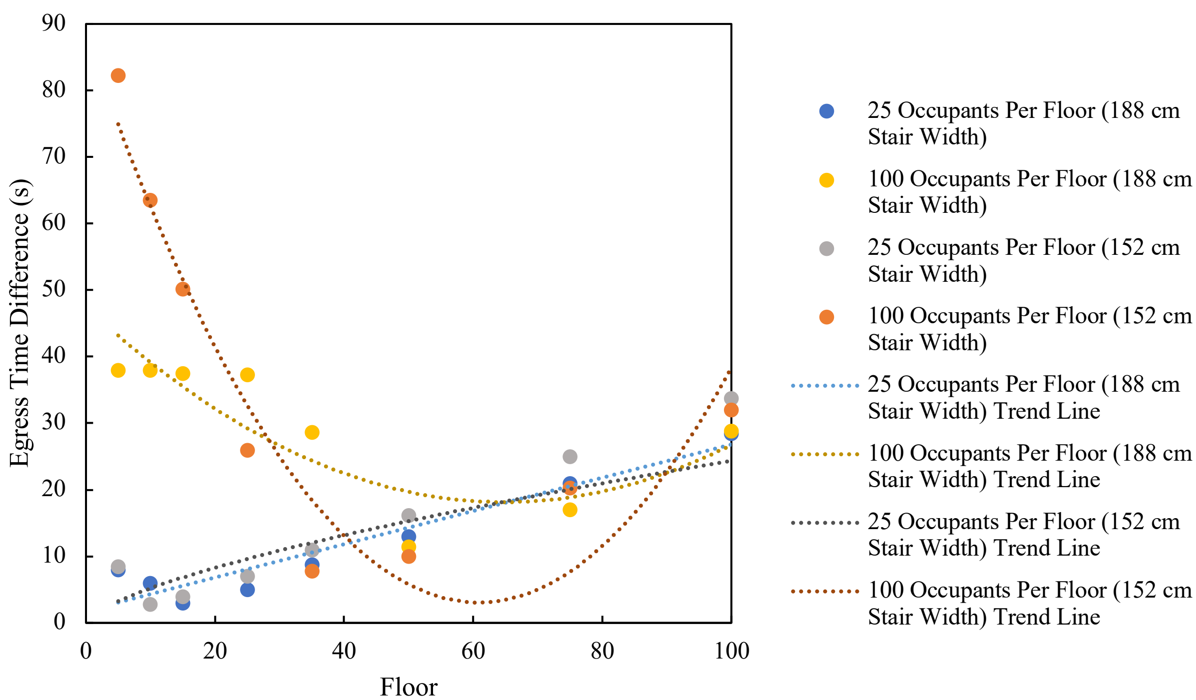

Figure 4.17: Comparison of Difference in Egress Time in Seconds Between Group A and F for 3 Story Egress Using 188 cm Stair and 152 cm Stair

The data presented in Figures 4.15, 4.16, and 4.17 depict the previously presented idea that the impact of enlarged body size decreases with the increase of evacuation floor height until a critical floor is reached. During one story egress, there is no merging from different floors; when occupants begin their stair descent, they take different paths of travel. Due to their initially tight grouping, some occupants egress close to the inside of the stair while others egress utilizing the outside of the stair. Occupants using the outside of the stair have a longer path of travel to the exit, so it takes them a longer time period to travel down the stairs than occupants on the inside of the stair. As a result, over time the distance between the first and last occupant to exit the stairs becomes greater as persons traveling on the inside of the stair distance themselves from those traveling on the outside of the stair. The critical floor occurs due to a combination of floor height and number of evacuating occupants; at this floor, there is a long enough egress route to allow occupants to spread out over time and utilize the optimum path of travel (the inside of the stairs) at their maximum speed.

When 25 occupants egress from one floor, this point is reached on a very low floor making the overall trend between floor height and egress time difference (in seconds) appear positive.

Before the critical floor is reached, the data associated with 188 cm stair width has a more shallow slope than data associated with 152 cm stair width. This confirms the idea presented earlier in this chapter that of the two studied stair widths, the effect of increased occupant size has a larger impact on the more narrow stair.

4.2.2 EGRESS TIME DIFFERENCE IN PERCENTAGES

Data from the previous three figures presents egress time differences in seconds; however, this information is not optimum without an appropriate frame of reference. Figure 4.18

depicts the egress time difference in percentage based on the evacuating floor for a one story egress utilizing 188 cm stairwell, Figure 4.19 depicts the egress time difference in percentage based on the evacuating floor for a one story egress utilizing 152 cm stairwell, and Figure 4.20 provides a comparison of 25 occupant per floor and 100 occupant per floor data from both stair widths. All three figures compare the egress time of Group A and Group F (accounting for the 16.2% BMI increase).

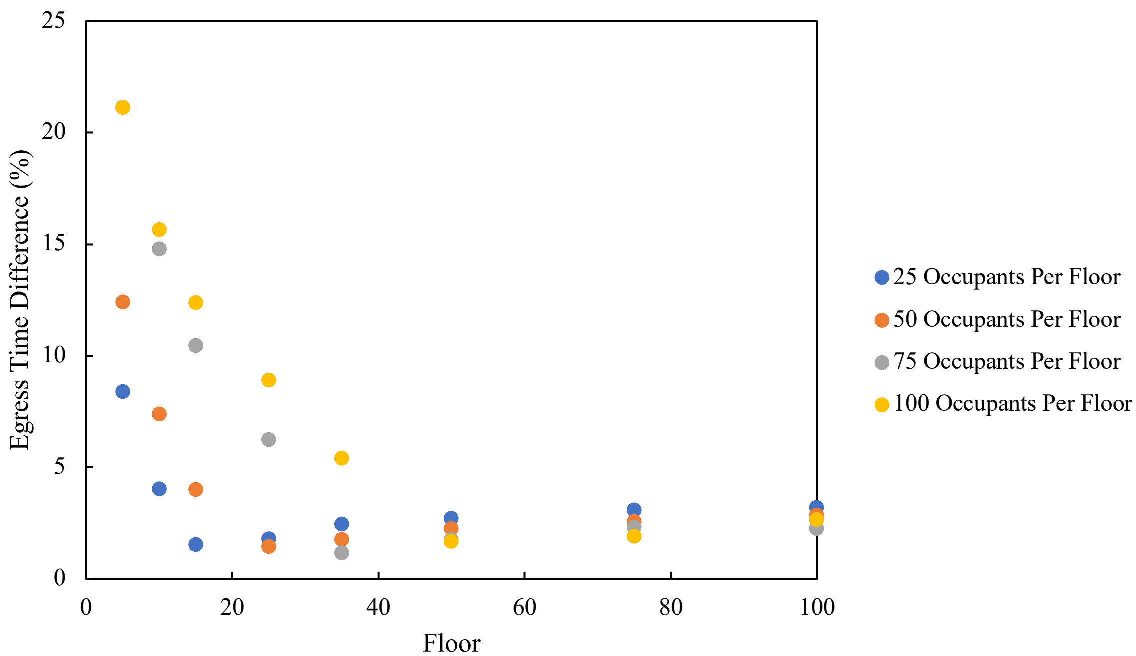

Figure 4.18: Difference in Egress Time in Percentage Between Group A and F for 1 Story Egress Using 188 cm Stair

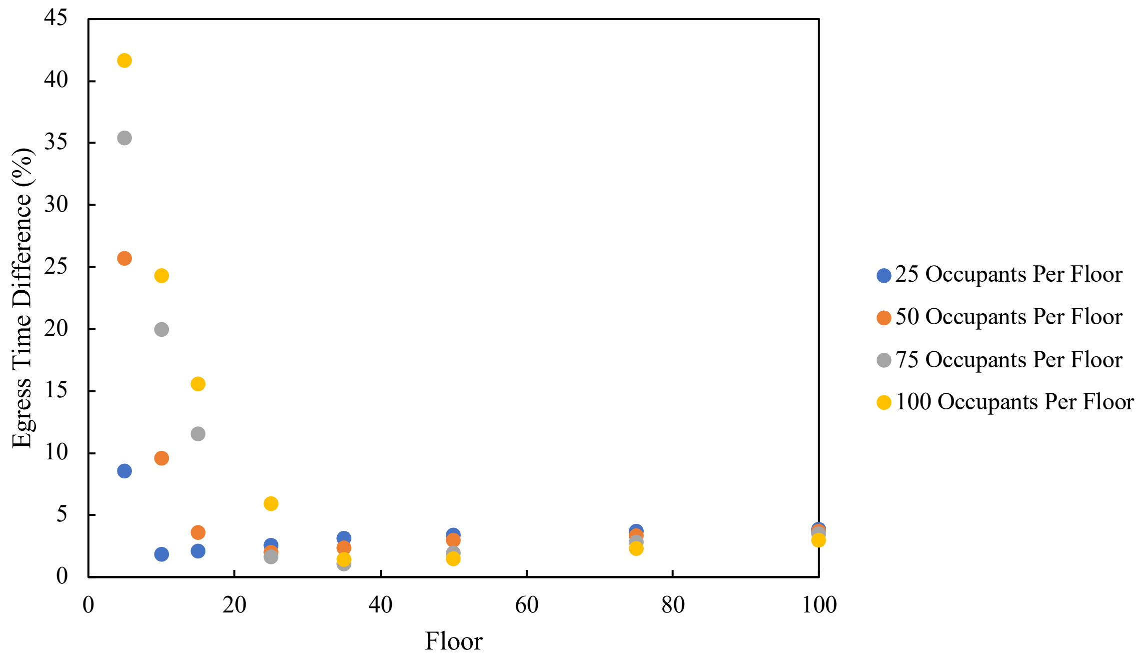

Figure 4.19: Difference in Egress Time in Percentage Between Group A and F for 1 Story Egress Using 152 cm Stair

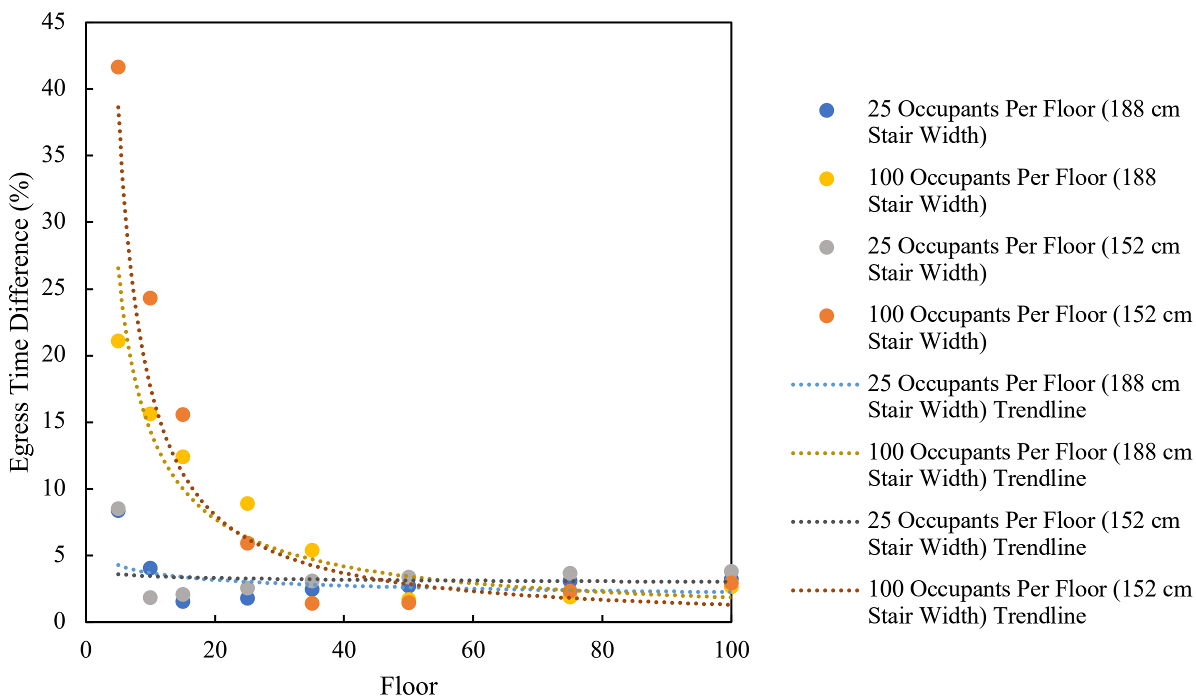

Figure 4.20: Comparison of Difference in Egress Time in Seconds Between Group A and F For 1 Story Egress Using 152 cm Stair and 188 cm Stair

The curves presented in Figures 4.18, 4.19, and 4.20 follow a downward trend until the critical floor is reached, and then begin to increase at a slow rate. This implies that until this point is reached, the higher the evacuating floor, the smaller the egress time difference (in percentage). In both the 188 cm and 152 cm stair width cases, the larger the number of occupants involved in egress, the larger the percentage increase of egress time.

4.2.3 OCCUPANT SIZE PERCENTAGE INCREASE RELATION TO EGRESS TIME CHANGE

Figures 4.21, 4.22, 4.23, and 4.24 show the correlation between the size range mean value increase and egress time change for different occupant loads and location of the evacuating levels. These figures depict the egress time change of a one story evacuation using a 188 cm stair. The size range mean value increase was found using the mean occupant width of Groups A – F compared to the mean occupant width of Group A, and the egress time change was found using the mean egress time of Groups A – F compared to the mean egress time of Group A. As the percentage of mean value of the size range increases, the egress time change also increases.

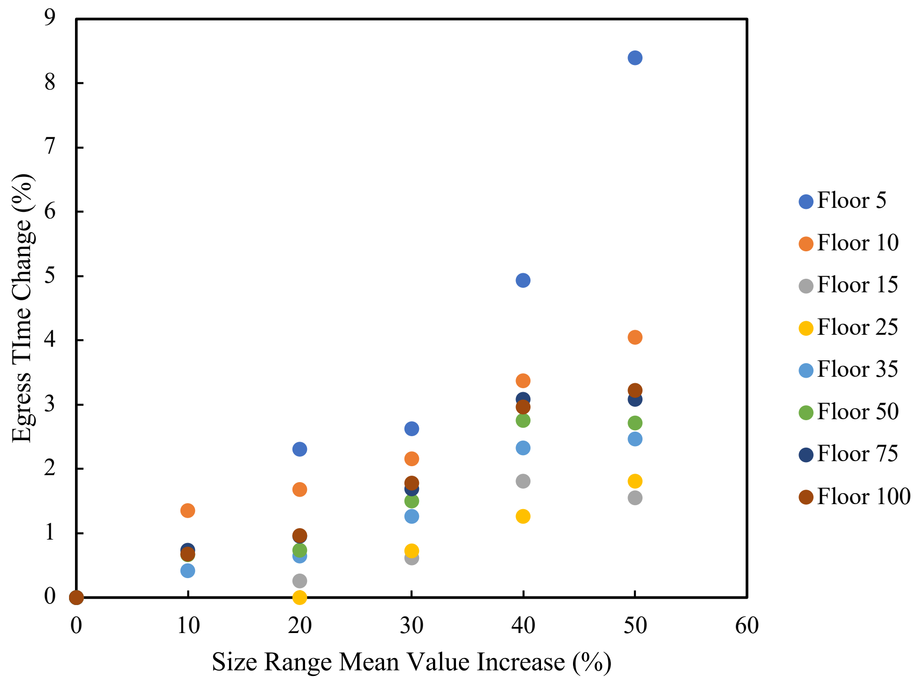

Figure 4.21: 25 Occupants Per Floor, 1 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

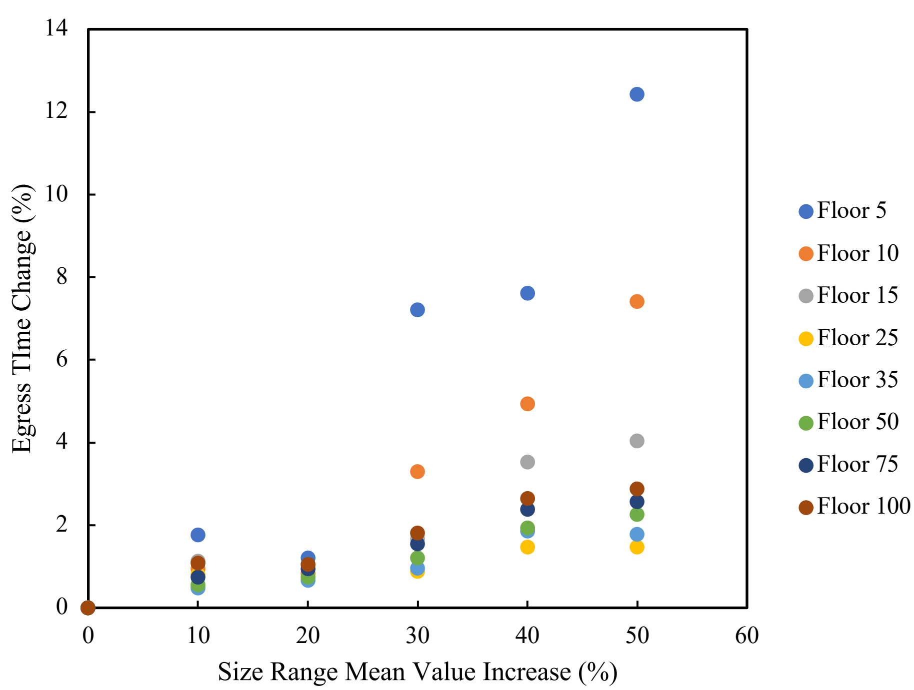

Figure 4.22: 50 Occupants Per Floor, 1 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

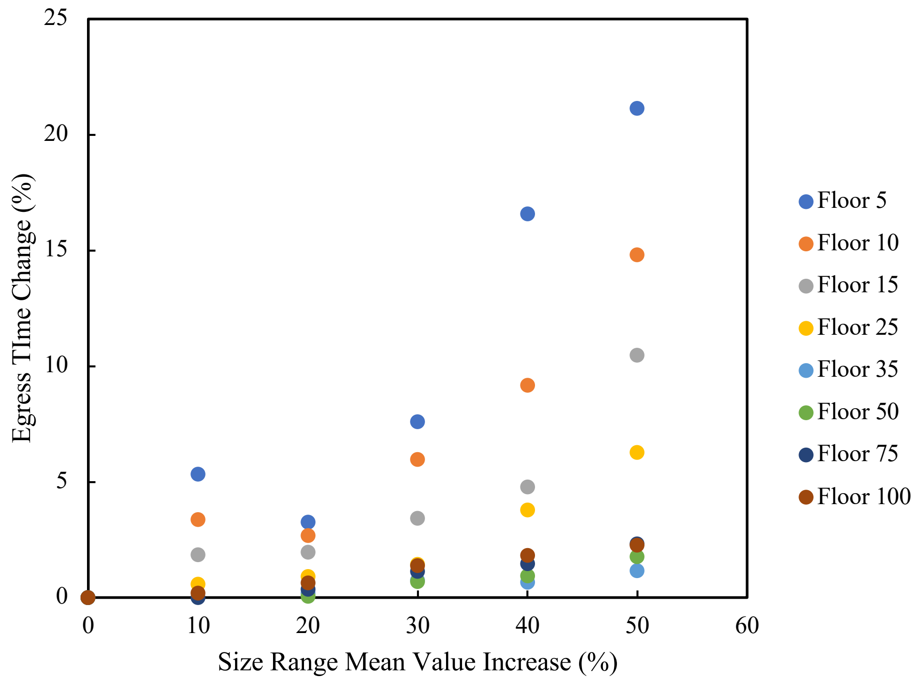

Figure 4.23: 75 Occupants Per Floor, 1 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

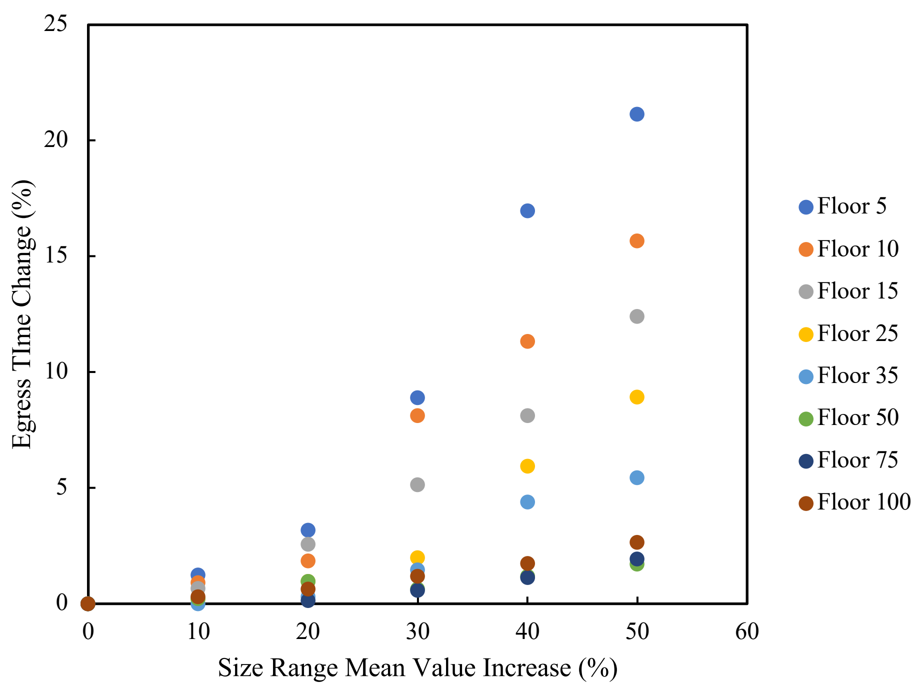

Figure 4.24: 100 Occupants Per Floor, 1 Floor Egress, Size Range Mean Value Change (%) Increase vs. Egress Time Change (%)

In all floor and number of egressing occupant scenarios, there was an upward trend between size range mean value increase and egress time change, meaning that larger individuals required an increased amount of time for egress.

With a fewer number of occupants egressing during a one floor evacuation, a critical floor was reached for all occupant number cases. For the 25 occupant case, this point was reached between floors 10 and 15; for the 50 occupant case, this point was reached between floors 15 and 25; for the 75 occupant case, this point was reached between floors 25 and 35; and for the 100 occupant case, this point was reached between floors 25 and 50. When this point, or floor, is reached the percentage change of mean egress time alters from decreasing as floor level increases to increasing as floor level increases. When a higher number of occupants are egressing, the height of the critical floor increases.

4.3 THREE FLOOR AND ONE FLOOR EGRESS COMPARISON

This section aims to compare the egress time percentage changes between one and three floor egress scenarios. Figures 4.25, 4.26, 4.27, and 4.28 compare the egress time difference in percentage between Groups A and F based on number of occupants egressing per floor.

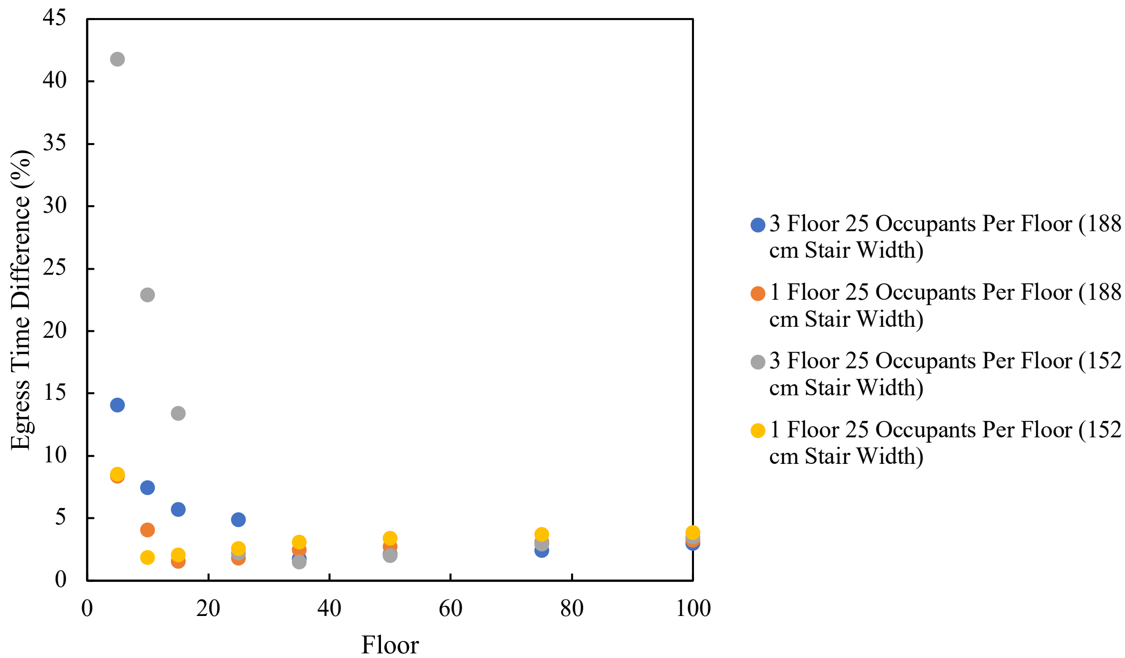

Figure 4.25: Difference in Egress Time in Percentage Between Group A and F for 25 Occupant per Floor Egress

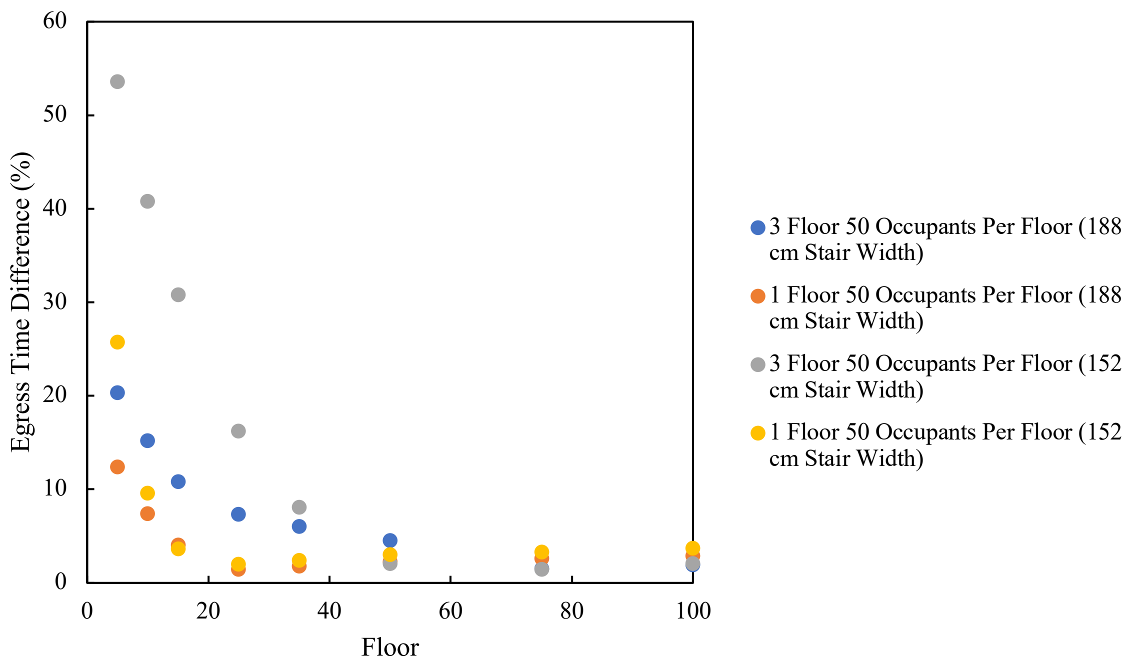

Figure 4.26: Difference in Egress Time in Percentage Between Group A and F for 50 Occupant per Floor Egress

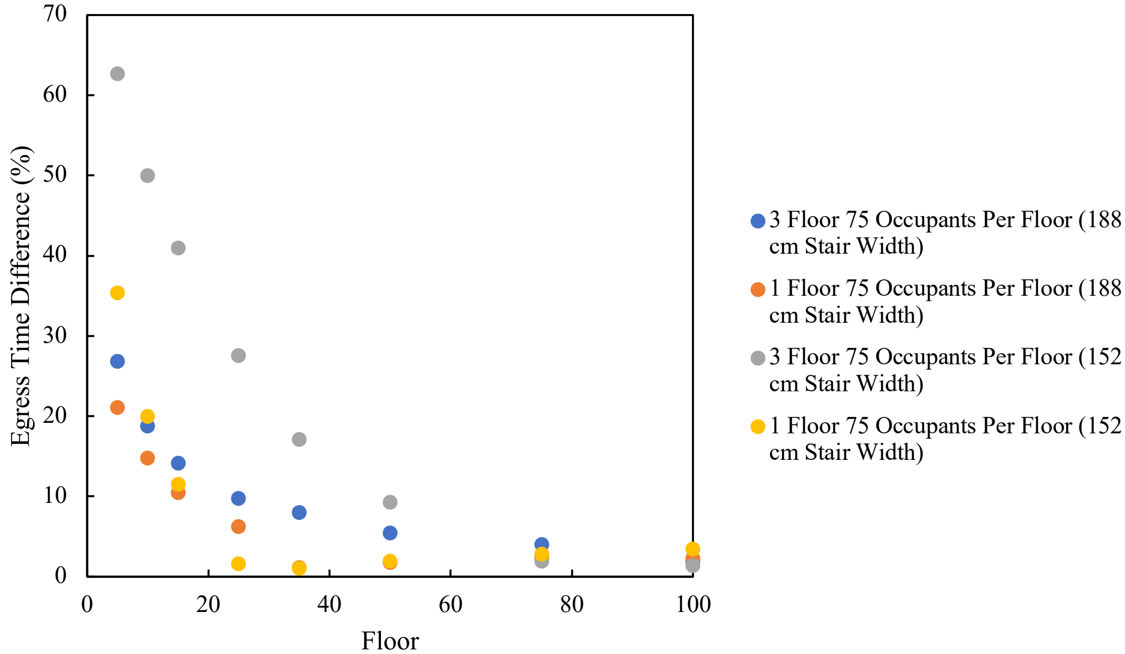

Figure 4.27: Difference in Egress Time in Percentage Between Group A and F for 75 Occupant per Floor Egress

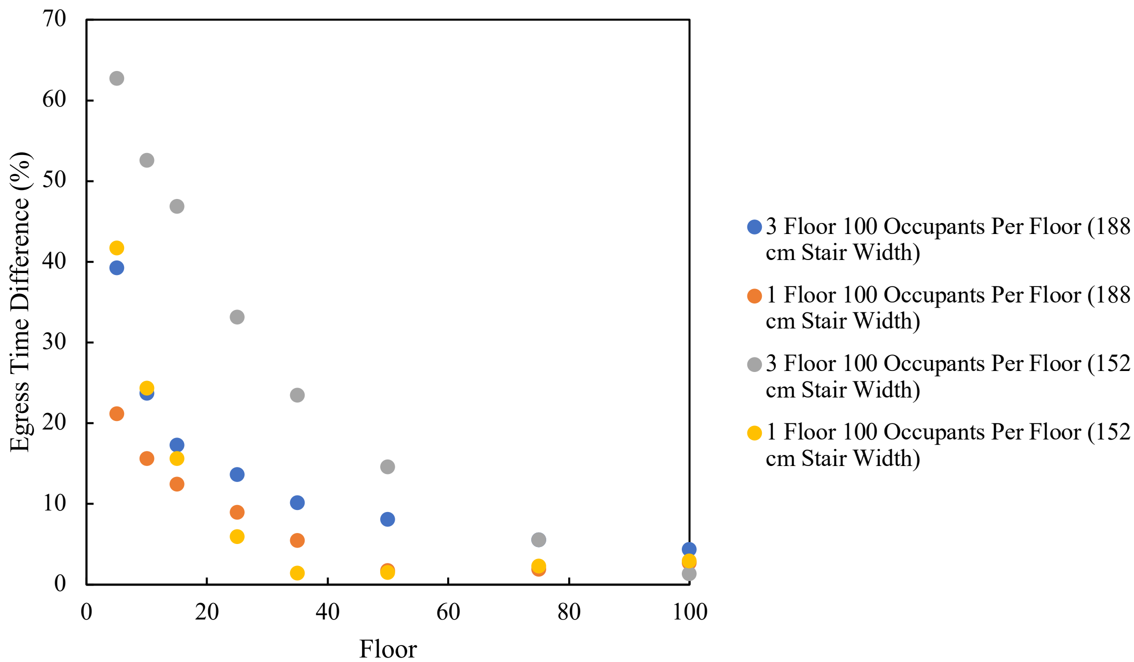

Figure 4.28: Difference in Egress Time in Percentage Between Group A and F for 100 Occupant per Floor Egress

From these figures, it can be observed that the egress time percentage difference between groups A and F is greater for three floor evacuations than for one floor evacuations until a critical floor is reached. The exact reasoning behind these results is difficut to pinpoint; this trend could be due to the larger number of people exiting during a three floor evacuation or the impact of merging versus not merging in three and one floor evacuation scenarios.

When the critical floor is reached, the egress time difference percentages are very similar for one and three floor evacuations. This critical floor is higher when the number of ocupants per floor greater; as previously mentioned in this chapter, a higher population density impacts the height of the critical floor. It should also be noted that the difference between egress times (in percentage) increases between one and three floor evacuations when the number of occupants evacuating per floor increaes. This pattern aligns with the notion that in this simulation, the egress time of a larger number of occupants exiting per floor is more greatly affected by an increase in occupant size.

Based on the number of occupants chosen to exit per floor in this series of tests, a specific comparison can be made between the same total number of occupants exiting from one floor as exiting from three floors. Figures 4.29 and 4.30 depict the percentage of egress time difference between one evacuating floor with 75 occupants per floor, three evacuating floors with 25 occupants per floor, and one evacuating floor with 25 occupants per floor. Both figures compare the egress time of Group A and Group F (accounting for the 16.2% BMI increase).

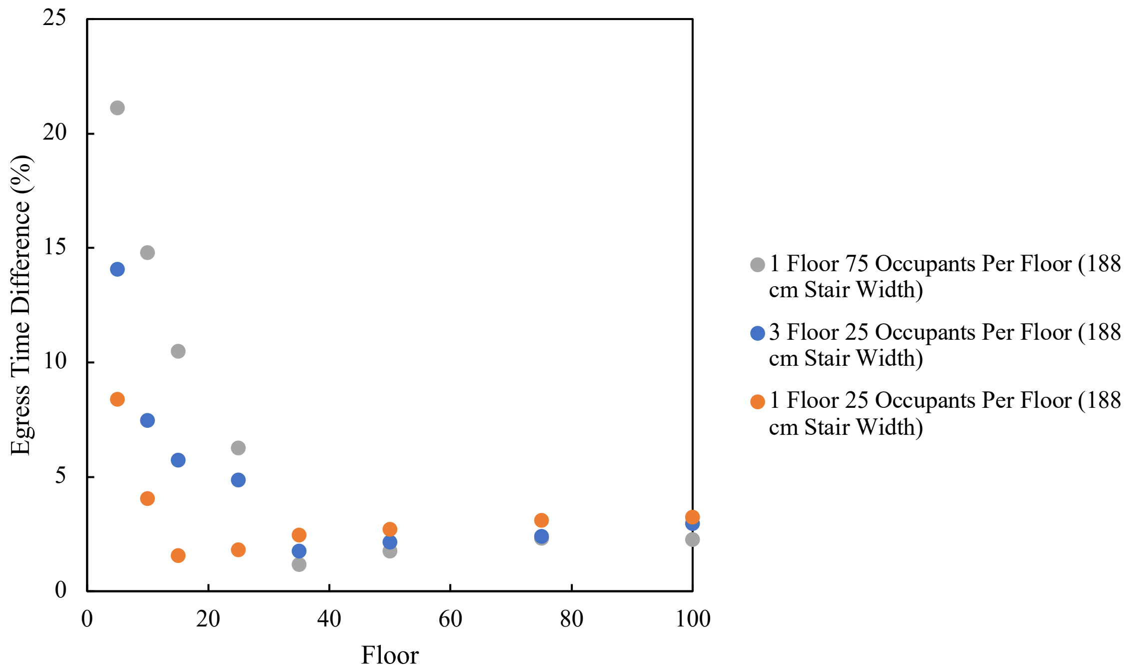

Figure 4.29: Difference in Egress Time in Percentage Between Group A and F Based on Floor for Select 188 cm Stair Width Egress

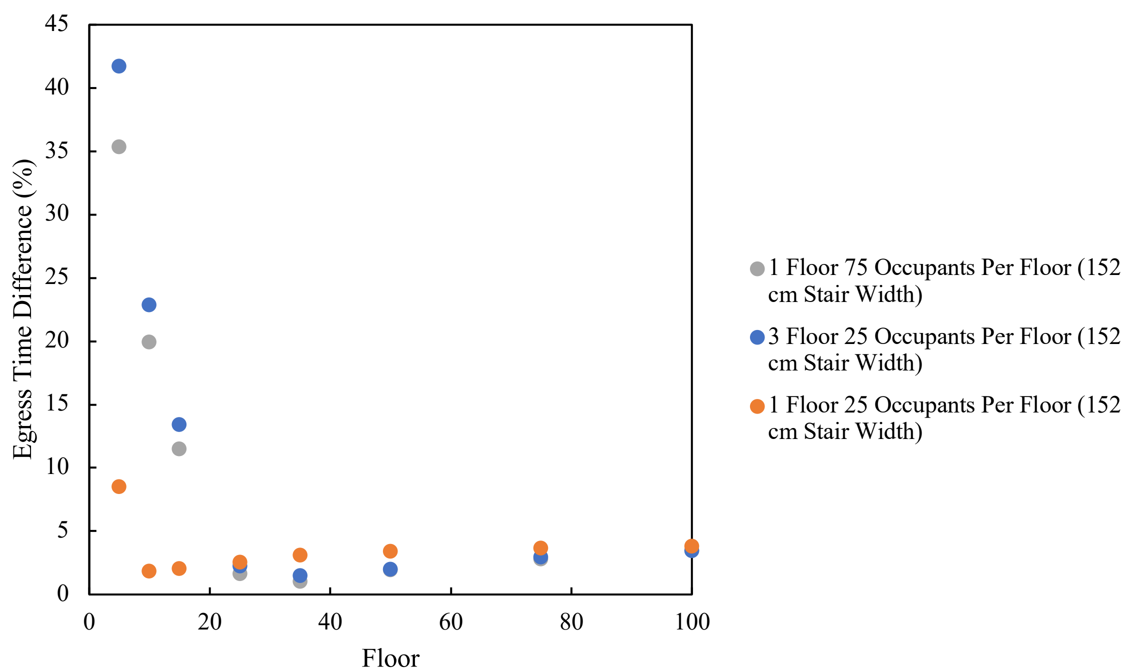

Figure 4.30: Difference in Egress Time in Percentage Between Group A and F Based on Floor for Select 152 cm Stair Width Egress

When egressing using a 188 cm wide stair, the difference in egress time (by percentage) is larger when 75 total occupants are exiting from one floor than when exiting from three floors until the critical floor is reached; when egressing using a 152 cm wide stair, the difference in egress time (by percentage) is larger when 75 total occupants are exiting from three floors than when exiting from one floor until the critical floor is reached. This opposition of results may be due to the low number of occupants on each floor; there is initially a low occupant density in the larger stair width scenario.

It can also be observed that the critical floor, or location where the egress time difference changes from decreasing to increasing as floor number increases, occurs at floor 35 for all 75 total occupant egress scenarios regardless of stair width. When the critical floor is reached, the egress time difference (in percentage) is very similar for the one and three floor evacuation scenarios.

4.4 HAND CALCULATION COMPARISON

Table 4.1 and 4.2 show a series of first order hydraulic model hand calculation times compared to the egress times found using Pathfinder for groups A and F.

Table 4.1: Three Floor Egress Hand Calculation Comparison

Number of Egressing Floors	Central Egress Floor	Stair Width (cm)	Each Floor Population (persons)	Hand Calc Egress Time (s)	Pathfinder Group A Egress Time (s)	Pathfinder Group F Egress Time (s)
3	5	188	75	130	123	140
3	5	188	150	181	199	239
3	5	188	225	232	269	341
3	5	188	300	283	347	483
3	35	188	75	744	469	478
3	35	188	150	795	572	606
3	35	188	225	846	660	713
3	35	188	300	897	749	825
3	75	188	75	1540	801	820

3	75	188	150	1590	995	1010
3	75	188	225	1640	1120	1160
3	75	188	300	1690	1220	1290
3	5	152	75	135	136	193
3	5	152	150	201	218	335
3	5	152	225	267	302	491
3	5	152	300	333	401	652
3	35	152	75	674	468	475
3	35	152	150	739	601	650
3	35	152	225	805	699	818
3	35	152	300	871	798	985
3	75	152	75	1370	796	819
3	75	152	150	1430	991	1000
3	75	152	225	1500	1170	1190
3	75	152	300	1570	1290	1360

Table 4.2: One Floor Egress Hand Calculation Comparison

Number of Egressing Floors	Central Egress Floor	Stair Width (cm)	Each Floor Population (persons)	Hand Calc Egress Time (s)	Pathfinder Group A Egress Time (s)	Pathfinder Group F Egress Time (s)
1	5	188	25	96.2	95.3	103
1	5	188	50	113	125	140
1	5	188	75	130	154	186
1	5	188	100	147	180	218
1	35	188	25	711	357	365
1	35	188	50	728	422	430
1	35	188	75	744	488	494
1	35	188	100	761	529	558
1	75	188	25	1500	681	702
1	75	188	50	1520	747	766
1	75	188	75	1540	816	835
1	75	188	100	1550	883	900
1	5	152	25	91.4	99.5	108
1	5	152	50	113	132	166
1	5	152	75	135	157	212
1	5	152	100	157	198	280
1	35	152	25	630	354	365
1	35	152	50	652	421	431
1	35	152	75	674	485	490

1	35	152	100	695	546	553
1	75	152	25	1320	676	701
1	75	152	50	1350	745	770
1	75	152	75	1370	811	834
1	75	152	100	1390	878	898

The hand calculated egress times for these select scenarios vary in comparison to the values found using Pathfinder; there is no discernable trend. However, in the majority of cases, the hand calculation time exceeds both the Pathfinder Group A egress time and the Pathfinder Group F egress time. One reason this could have occurred is that the formulas for had calculations require the assumption of a density; this chosen density is not necessarily indicative of actual density. Additionally, Pathfinder simulations were run in Steering mode, which allowed for more complex behaviors. First order hand calculations make multiple assumptions and generalize the behavior and characteristics of all occupants.

4.4 GENERAL ANALYSIS

Data collected in Pathfinder showed increased evacuation time changes in all egress scenarios tested when occupant diameter was increased; this implies the model's ability to make differing predictions based on occupant size.

The largest and smallest percent increases in egress time for each size group in comparison to Group A are depicted in Tables 4.3 and 4.4.

Table 4.3: Egress Time Increase Extremes for Three Floor Evacuation

Group	Data Extreme	Central Egress Floor	Stair Width (in)	Each Floor Population	Egress Time Increase (%)
B	High	5	60	100	9.28
B	Low	100	74	75	0.00
C	High	5	60	100	24.9
C	Low	100	74	50	0.31

D	High	5	60	100	36.7
D	Low	100	60	75	0.63
E	High	5	60	100	49.0
E	Low	100	60	75	0.83
F	High	5	60	100	62.7
F	Low	100	60	100	1.32

Table 4.4: Egress Time Increase Extremes for One Floor Evacuation

Group	Data Extreme	Central Egress Floor	Stair Width (in)	Each Floor Population	Egress Time Increase (%)
B	High	5	60	75	6.06
B	Low	25	74	25	-0.25
C	High	5	60	75	13.8
C	Low	15	74	50	-0.54
D	High	5	60	100	22.2
D	Low	35	60	75	0.10
E	High	5	60	100	32.2
E	Low	35	74	75	0.66
F	High	5	60	100	41.7
F	Low	35	60	75	1.07

As seen in the three floor evacuation data, the highest percentage of egress time increase occurred on the 60 inch stair evacuation of three floors with 100 people each with the central evacuation floor of 5. This data follows the trends established in the previous section: egress from a lower floor is more greatly affected by increase in body size, egress using stairs with a more narrow width is more greatly affected by increase in body size, and stair egress of a higher exiting population are more greatly affected by increase in body size. The lowest percentage of egress time increase occurred for each group from the central egress floor of 100, but the stair width and floor population values for this statistic varied. As stated earlier in this report, a possible explanation for this inconsistency is that decreased density over the course of a large number of floors allows a fewer total number of occupants to move at their own speed, and therefore the egress of these occupants is no longer hindered by occupant size.

The one floor evacuation data extremes are not as consistent as the three floor evacuation data due to the fewer number of total egressing occupants for each scenario. For the larger occupant size groups (D, E, and F), the highest percentage of egress time increase occurred on the 152 cm stair evacuation of one floor with 100 occupants from the central egress floor of 5. This data follows the trends established in the previous section: egress from a lower floor is more greatly affected by increase in body size, egress using stairs with a more narrow width is more greatly affected by increase in body size, and stair egress of a higher exiting population are more greatly affected by increase in body size. Groups B and C closely followed this trend; the only difference was that the population that created the largest egress time increase was 75 occupants per floor rather than 100. The lowest percentage of egress time increase for one floor evacuations occurred for each group from central egress floors of 15 to 35; this may be due to the critical floor density occurring on lower floors when lower numbers of occupants are evacuating.

This data also conveys that as occupant width increases, egress time also increases; nearly all high and low extreme data followed this trend.

CHAPTER 5: UNCERTAINTY

This research was completely based on the use of one model (Pathfinder); therefore, there is inherent uncertainty in the data. A model is a tool, and the accuracy of inputted information has a large impact on its results. Many default settings of Pathfinder, such as walking speeds and behavior, remained constant throughout this experiment. While these constant values made comparison of the independent variables more clear, they were not necessarily accurate representations so the results found have relative (rather than absolute) value.

Additionally, although the composition of the occupant widths in the test groups was created with the most recent CDC data, it relies on the assumption that increase in BMI directly relates to increase in occupant body width.

CHAPTER 6: CONCLUSIONS AND FUTURE RESEARCH

In this study, Pathfinder was used to study one floor and three floor evacuations for a variety of body sizes. The purpose of this research was to better understand the effect of increasing body size on stairwell egress. Testing performed simulated evacuations using one stairwell and one exit; all occupants began their evacuation from the stairwell landing in order to isolate the time of evacuation to the stair component. As the mean size of occupants increased, the change in egress time by percentage also increased.

In the simulations performed, it was found that the impact of enlarged body size decreases with the increase of evacuation floor height until a critical floor was reached. At this critical floor, the population density was low enough for occupants to move at their desired speed, and the impact of increased body size altered to increasing as floor level increased. At this floor there is a long enough egress route to allow occupants to spread out over time and utilize the optimum path of travel (the inside of the stairs) at their maximum speed.

The location of the critical floor was higher when the number of occupants per floor was higher.

Of the two different stair widths examined, the effect of increased occupant size had a larger impact on the more narrow stair width. Additionally, the average egress time increase was larger when a larger number of occupants were exiting per floor.

In order to help mitigate the uncertainty in this thesis for future research, a relation of body size to BMI should be studied using human subjects. With a better understanding of the correlation between BMI and body size, occupant width can be estimated with more precision. Human subjects of varying sizes should also be studied during egress; although there have been multiple studies of occupant egress, the physical size of evacuating personnel has not been a topic of focus.

The data in this study isolates the variable of increased body size, so the results found are representative of the "best case scenario" impact of increasing number of individuals affected by overweight and obesity. In order to properly account for the effects of the obesity epidemic on egress time, research must be conducted to find if there are correlations between speed and fatigue with body size. Obese individuals are at an increased risk for high blood pressure, high cholesterol, type 2 diabetes, coronary heart disease, osteoarthritis, sleep apnea and breathing problems, many types of cancers, depression, anxiety, and body pain and difficulty with physical functioning (CDC 2021). These obesity related health consequences have the potential to impact more than just body size, and could increase the amount of time required by obese individuals to physically egress as well as negatively affect pre-evacuation time.

APPENDIX A: RAW DATA

Occupant Characteristic Group	Stair Width (cm)	Evacuating Floor(s)	Occupant Per Floor	Egress Time (s)
A	152	4,5,6	25	136
A	152	9,10,11	25	200.8
A	152	14,15,16	25	260.8
A	152	24,25,26	25	379
A	152	34,35,36	25	468.3
A	152	49,50,51	25	592
A	152	74,75,76	25	795.8
A	152	99,100,101	25	999.5
B	152	4,5,6	25	139.8
B	152	9,10,11	25	209.3
B	152	14,15,16	25	270.3
B	152	24,25,26	25	382.3
B	152	34,35,36	25	468.8
B	152	49,50,51	25	593.5
B	152	74,75,76	25	798.5
B	152	99,100,101	25	1004.3
C	152	4,5,6	25	152.8
C	152	9,10,11	25	216.8
C	152	14,15,16	25	279.8
C	152	24,25,26	25	383.3
C	152	34,35,36	25	469.5
C	152	49,50,51	25	595.3
C	152	74,75,76	25	803
C	152	99,100,101	25	1010.8
D	152	4,5,6	25	163.3
D	152	9,10,11	25	229.3
D	152	14,15,16	25	289.8
D	152	24,25,26	25	384.5
D	152	34,35,36	25	471.3
D	152	49,50,51	25	597.5
D	152	74,75,76	25	806.3
D	152	99,100,101	25	1013.8
E	152	4,5,6	25	179.3
E	152	9,10,11	25	245.3
E	152	14,15,16	25	293.3

E	152	24,25,26	25	385.8
E	152	34,35,36	25	473.3
E	152	49,50,51	25	600
E	152	74,75,76	25	810.8
E	152	99,100,101	25	1020.8
F	152	4,5,6	25	192.8
F	152	9,10,11	25	246.8
F	152	14,15,16	25	295.8
F	152	24,25,26	25	387.5
F	152	34,35,36	25	475.3
F	152	49,50,51	25	604
F	152	74,75,76	25	819.3
F	152	99,100,101	25	1034.3
A	188	4,5,6	25	123
A	188	9,10,11	25	187.5
A	188	14,15,16	25	248.3
A	188	24,25,26	25	359.8
A	188	34,35,36	25	469.3
A	188	49,50,51	25	593.8
A	188	74,75,76	25	801
A	188	99,100,101	25	1005
B	188	4,5,6	25	125.3
B	188	9,10,11	25	188.3
B	188	14,15,16	25	249.8
B	188	24,25,26	25	363.3
B	188	34,35,36	25	471.5
B	188	49,50,51	25	595.3
B	188	74,75,76	25	800.8
B	188	99,100,101	25	1005.3
C	188	4,5,6	25	126
C	188	9,10,11	25	189.5
C	188	14,15,16	25	250.8
C	188	24,25,26	25	362.8
C	188	34,35,36	25	470
C	188	49,50,51	25	599.3
C	188	74,75,76	25	805
C	188	99,100,101	25	1010
D	188	4,5,6	25	129.8
D	188	9,10,11	25	193.3

D	188	14,15,16	25	251.5
D	188	24,25,26	25	365.8
D	188	34,35,36	25	473.8
D	188	49,50,51	25	599.8
D	188	74,75,76	25	809.5
D	188	99,100,101	25	1018.3
E	188	4,5,6	25	133.8
E	188	9,10,11	25	195.8
E	188	14,15,16	25	256.5
E	188	24,25,26	25	368.5
E	188	34,35,36	25	476.3
E	188	49,50,51	25	602.8
E	188	74,75,76	25	812.3
E	188	99,100,101	25	1022.5
F	188	4,5,6	25	140.3
F	188	9,10,11	25	201.5
F	188	14,15,16	25	262.5
F	188	24,25,26	25	377.3
F	188	34,35,36	25	477.5
F	188	49,50,51	25	606.5
F	188	74,75,76	25	820.3
F	188	99,100,101	25	1034.8
A	152	4,5,6	50	218
A	152	9,10,11	50	286.5
A	152	14,15,16	50	352.3
A	152	24,25,26	50	480
A	152	34,35,36	50	601.3
A	152	49,50,51	50	771
A	152	74,75,76	50	990.5
A	152	99,100,101	50	1196.3
B	152	4,5,6	50	231.3
B	152	9,10,11	50	298.8
B	152	14,15,16	50	367.5
B	152	24,25,26	50	494.3
B	152	34,35,36	50	615.8
B	152	49,50,51	50	778.5
B	152	74,75,76	50	991.5
B	152	99,100,101	50	1198.5
C	152	4,5,6	50	248

C	152	9,10,11	50	320.5
C	152	14,15,16	50	386.8
C	152	24,25,26	50	517.3
C	152	34,35,36	50	633
C	152	49,50,51	50	780
C	152	74,75,76	50	993.3
C	152	99,100,101	50	1201.5
D	152	4,5,6	50	279.3
D	152	9,10,11	50	351.3
D	152	14,15,16	50	415.3
D	152	24,25,26	50	544.3
D	152	34,35,36	50	647.3
D	152	49,50,51	50	782.5
D	152	74,75,76	50	997
D	152	99,100,101	50	1207.8
E	152	4,5,6	50	306
E	152	9,10,11	50	374
E	152	14,15,16	50	438.5
E	152	24,25,26	50	553.8
E	152	34,35,36	50	647.5
E	152	49,50,51	50	784.3
E	152	74,75,76	50	999.8
E	152	99,100,101	50	1212.3
F	152	4,5,6	50	334.8
F	152	9,10,11	50	403.3
F	152	14,15,16	50	460.8
F	152	24,25,26	50	558
F	152	34,35,36	50	650
F	152	49,50,51	50	787
F	152	74,75,76	50	1004.5
F	152	99,100,101	50	1220.8
A	188	4,5,6	50	198.5
A	188	9,10,11	50	268
A	188	14,15,16	50	333.3
A	188	24,25,26	50	454
A	188	34,35,36	50	571.8
A	188	49,50,51	50	737.8
A	188	74,75,76	50	995
A	188	99,100,101	50	1202.3

B	188	4,5,6	50	201.5
B	188	9,10,11	50	268.3
B	188	14,15,16	50	335.3
B	188	24,25,26	50	456.8
B	188	34,35,36	50	573.8
B	188	49,50,51	50	739.5
B	188	74,75,76	50	999.8
B	188	99,100,101	50	1202.5
C	188	4,5,6	50	206.8
C	188	9,10,11	50	273
C	188	14,15,16	50	337.5
C	188	24,25,26	50	458.8
C	188	34,35,36	50	575.8
C	188	49,50,51	50	744.5
C	188	74,75,76	50	999.3
C	188	99,100,101	50	1206
D	188	4,5,6	50	213.3
D	188	9,10,11	50	279.8
D	188	14,15,16	50	343.3
D	188	24,25,26	50	467.5
D	188	34,35,36	50	581.3
D	188	49,50,51	50	753
D	188	74,75,76	50	1003.8
D	188	99,100,101	50	1213.8
E	188	4,5,6	50	226
E	188	9,10,11	50	290
E	188	14,15,16	50	353.8
E	188	24,25,26	50	479.5
E	188	34,35,36	50	594.8
E	188	49,50,51	50	757.8
E	188	74,75,76	50	1005.3
E	188	99,100,101	50	1215.5
F	188	4,5,6	50	238.8
F	188	9,10,11	50	308.8
F	188	14,15,16	50	369.3
F	188	24,25,26	50	487.3
F	188	34,35,36	50	606.3
F	188	49,50,51	50	771
F	188	74,75,76	50	1009.8

F	188	99,100,101	50	1225.5
A	152	4,5,6	75	400.8
A	152	9,10,11	75	468.3
A	152	14,15,16	75	534
A	152	24,25,26	75	666.3
A	152	34,35,36	75	797.5
A	152	49,50,51	75	985.8
A	152	74,75,76	75	1289
A	152	99,100,101	75	1568
B	152	4,5,6	75	438
B	152	9,10,11	75	508.3
B	152	14,15,16	75	570.3
B	152	24,25,26	75	702.3
B	152	34,35,36	75	837.5
B	152	49,50,51	75	1022.5
B	152	74,75,76	75	1319.5
B	152	99,100,101	75	1571.5
C	152	4,5,6	75	500.5
C	152	9,10,11	75	547.3
C	152	14,15,16	75	615.5
C	152	24,25,26	75	752.5
C	152	34,35,36	75	885.3
C	152	49,50,51	75	1077
C	152	74,75,76	75	1349.3
C	152	99,100,101	75	1574
D	152	4,5,6	75	548
D	152	9,10,11	75	604.5
D	152	14,15,16	75	674.8
D	152	24,25,26	75	804.3
D	152	34,35,36	75	943
D	152	49,50,51	75	1117
D	152	74,75,76	75	1353.3
D	152	99,100,101	75	1577.5
E	152	4,5,6	75	597.3
E	152	9,10,11	75	665.3
E	152	14,15,16	75	732.3
E	152	24,25,26	75	866
E	152	34,35,36	75	977.3
E	152	49,50,51	75	1124

E	152	74,75,76	75	1358
E	152	99,100,101	75	1582
F	152	4,5,6	75	652.3
F	152	9,10,11	75	714.3
F	152	14,15,16	75	784.3
F	152	24,25,26	75	887.3
F	152	34,35,36	75	984.8
F	152	49,50,51	75	1129.8
F	152	74,75,76	75	1360.3
F	152	99,100,101	75	1588.8
A	188	4,5,6	75	346.8
A	188	9,10,11	75	419.8
A	188	14,15,16	75	490
A	188	24,25,26	75	619.5
A	188	34,35,36	75	749.3
A	188	49,50,51	75	928.3
A	188	74,75,76	75	1218
A	188	99,100,101	75	1494.8
B	188	4,5,6	75	354
B	188	9,10,11	75	425.5
B	188	14,15,16	75	494.3
B	188	24,25,26	75	624.5
B	188	34,35,36	75	754
B	188	49,50,51	75	933.8
B	188	74,75,76	75	1225.5
B	188	99,100,101	75	1499.5
C	188	4,5,6	75	368.8
C	188	9,10,11	75	436.3
C	188	14,15,16	75	500.8
C	188	24,25,26	75	631.3
C	188	34,35,36	75	759.3
C	188	49,50,51	75	938.8
C	188	74,75,76	75	1229.3
C	188	99,100,101	75	1507.3
D	188	4,5,6	75	388
D	188	9,10,11	75	450.5
D	188	14,15,16	75	516.8
D	188	24,25,26	75	648
D	188	34,35,36	75	771.5

D	188	49,50,51	75	946.3
D	188	74,75,76	75	1238.8
D	188	99,100,101	75	1512.3
E	188	4,5,6	75	422.8
E	188	9,10,11	75	484.3
E	188	14,15,16	75	543.3
E	188	24,25,26	75	668.8
E	188	34,35,36	75	787.3
E	188	49,50,51	75	967.3
E	188	74,75,76	75	1252
E	188	99,100,101	75	1531.8
F	188	4,5,6	75	482.8
F	188	9,10,11	75	519.3
F	188	14,15,16	75	574.8
F	188	24,25,26	75	704
F	188	34,35,36	75	825
F	188	49,50,51	75	1003.3
F	188	74,75,76	75	1285.3
F	188	99,100,101	75	1560.3
A	152	4,5,6	100	400.8
A	152	9,10,11	100	468.3
A	152	14,15,16	100	534
A	152	24,25,26	100	666.3
A	152	34,35,36	100	797.5
A	152	49,50,51	100	985.8
A	152	74,75,76	100	1289
A	152	99,100,101	100	1568
B	152	4,5,6	100	438
B	152	9,10,11	100	508.3
B	152	14,15,16	100	570.3
B	152	24,25,26	100	702.3
B	152	34,35,36	100	837.5
B	152	49,50,51	100	1022.5
B	152	74,75,76	100	1319.5
B	152	99,100,101	100	1571.5
C	152	4,5,6	100	500.5
C	152	9,10,11	100	547.3
C	152	14,15,16	100	615.5
C	152	24,25,26	100	752.5

C	152	34,35,36	100	885.3
C	152	49,50,51	100	1077
C	152	74,75,76	100	1349.3
C	152	99,100,101	100	1574
D	152	4,5,6	100	548
D	152	9,10,11	100	604.5
D	152	14,15,16	100	674.8
D	152	24,25,26	100	804.3
D	152	34,35,36	100	943
D	152	49,50,51	100	1117
D	152	74,75,76	100	1353.3
D	152	99,100,101	100	1577.5
E	152	4,5,6	100	597.3
E	152	9,10,11	100	665.3
E	152	14,15,16	100	732.3
E	152	24,25,26	100	866
E	152	34,35,36	100	977.3
E	152	49,50,51	100	1124
E	152	74,75,76	100	1358
E	152	99,100,101	100	1582
F	152	4,5,6	100	652.3
F	152	9,10,11	100	714.3
F	152	14,15,16	100	784.3
F	152	24,25,26	100	887.3
F	152	34,35,36	100	984.8
F	152	49,50,51	100	1129.8
F	152	74,75,76	100	1360.3
F	152	99,100,101	100	1588.8
A	188	4,5,6	100	346.8
A	188	9,10,11	100	419.8
A	188	14,15,16	100	490
A	188	24,25,26	100	619.5
A	188	34,35,36	100	749.3
A	188	49,50,51	100	928.3
A	188	74,75,76	100	1218
A	188	99,100,101	100	1494.8
B	188	4,5,6	100	354
B	188	9,10,11	100	425.5
B	188	14,15,16	100	494.3

B	188	24,25,26	100	624.5
B	188	34,35,36	100	754
B	188	49,50,51	100	933.8
B	188	74,75,76	100	1225.5
B	188	99,100,101	100	1499.5
C	188	4,5,6	100	368.8
C	188	9,10,11	100	436.3
C	188	14,15,16	100	500.8
C	188	24,25,26	100	631.3
C	188	34,35,36	100	759.3
C	188	49,50,51	100	938.8
C	188	74,75,76	100	1229.3
C	188	99,100,101	100	1507.3
D	188	4,5,6	100	388
D	188	9,10,11	100	450.5
D	188	14,15,16	100	516.8
D	188	24,25,26	100	648
D	188	34,35,36	100	771.5
D	188	49,50,51	100	946.3
D	188	74,75,76	100	1238.8
D	188	99,100,101	100	1512.3
E	188	4,5,6	100	422.8
E	188	9,10,11	100	484.3
E	188	14,15,16	100	543.3
E	188	24,25,26	100	668.8
E	188	34,35,36	100	787.3
E	188	49,50,51	100	967.3
E	188	74,75,76	100	1252
E	188	99,100,101	100	1531.8
F	188	4,5,6	100	482.8
F	188	9,10,11	100	519.3
F	188	14,15,16	100	574.8
F	188	24,25,26	100	704
F	188	34,35,36	100	825
F	188	49,50,51	100	1003.3
F	188	74,75,76	100	1285.3
F	188	99,100,101	100	1560.3
A	152	5	25	99.5
A	152	10	25	150.5

A	152	15	25	192
A	152	25	25	273.8
A	152	35	25	353.8
A	152	50	25	474.8
A	152	75	25	676.3
A	152	100	25	876.8
B	152	5	25	102
B	152	10	25	150.5
B	152	15	25	192.8
B	152	25	25	274
B	152	35	25	356.5
B	152	50	25	478.5
B	152	75	25	682.5
B	152	100	25	889.8
C	152	5	25	105.8
C	152	10	25	151.5
C	152	15	25	193.3
C	152	25	25	276
C	152	35	25	357.8
C	152	50	25	481.3
C	152	75	25	686.3
C	152	100	25	890.8
D	152	5	25	104.5
D	152	10	25	152.3
D	152	15	25	194.3
D	152	25	25	277.3
D	152	35	25	359.8
D	152	50	25	483.3
D	152	75	25	689.8
D	152	100	25	895.3
E	152	5	25	107.8
E	152	10	25	153
E	152	15	25	195.3
E	152	25	25	279.3
E	152	35	25	363.5
E	152	50	25	489.5
E	152	75	25	699.5
E	152	100	25	909.8
F	152	5	25	108

F	152	10	25	153.3
F	152	15	25	196
F	152	25	25	280.8
F	152	35	25	364.8
F	152	50	25	491
F	152	75	25	701.3
F	152	100	25	910.5
A	188	5	25	95.3
A	188	10	25	148.3
A	188	15	25	193.8
A	188	25	25	276.5
A	188	35	25	356.5
A	188	50	25	478.3
A	188	75	25	680.8
A	188	100	25	883.8
B	188	5	25	94.8
B	188	10	25	150.3
B	188	15	25	193.5
B	188	25	25	275.8
B	188	35	25	358
B	188	50	25	481.5
B	188	75	25	685.8
B	188	100	25	889.8
C	188	5	25	97.5
C	188	10	25	150.8
C	188	15	25	194.3
C	188	25	25	276.5
C	188	35	25	358.8
C	188	50	25	481.8
C	188	75	25	687.3
C	188	100	25	892.3
D	188	5	25	97.8
D	188	10	25	151.5
D	188	15	25	195
D	188	25	25	278.5
D	188	35	25	361
D	188	50	25	485.5
D	188	75	25	692.3
D	188	100	25	899.5

E	188	5	25	100
E	188	10	25	153.3
E	188	15	25	197.3
E	188	25	25	280
E	188	35	25	364.8
E	188	50	25	491.5
E	188	75	25	701.8
E	188	100	25	910
F	188	5	25	103.3
F	188	10	25	154.3
F	188	15	25	196.8
F	188	25	25	281.5
F	188	35	25	365.3
F	188	50	25	491.3
F	188	75	25	701.8
F	188	100	25	912.3
A	152	5	50	132.3
A	152	10	50	195.3
A	152	15	50	250
A	152	25	50	338.8
A	152	35	50	420.8
A	152	50	50	542.3
A	152	75	50	745.3
A	152	100	50	948.5
B	152	5	50	140
B	152	10	50	197.8
B	152	15	50	253.3
B	152	25	50	340
B	152	35	50	422.3
B	152	50	50	545.8
B	152	75	50	751
B	152	100	50	955.8
C	152	5	50	145.8
C	152	10	50	204.3
C	152	15	50	255
C	152	25	50	340.8
C	152	35	50	423.8
C	152	50	50	547.5
C	152	75	50	752.8

C	152	100	50	957.5
D	152	5	50	153.3
D	152	10	50	210.5
D	152	15	50	256.5
D	152	25	50	342.5
D	152	35	50	426.3
D	152	50	50	550.5
D	152	75	50	757.3
D	152	100	50	962.5
E	152	5	50	162.3
E	152	10	50	211.8
E	152	15	50	257.3
E	152	25	50	344.3
E	152	35	50	428.5
E	152	50	50	554.5
E	152	75	50	764.8
E	152	100	50	975
F	152	5	50	166.3
F	152	10	50	214
F	152	15	50	259
F	152	25	50	345.5
F	152	35	50	430.8
F	152	50	50	558.5
F	152	75	50	770
F	152	100	50	983.8
A	188	5	50	124.8
A	188	10	50	182.3
A	188	15	50	240.8
A	188	25	50	340.3
A	188	35	50	422
A	188	50	50	544
A	188	75	50	746.8
A	188	100	50	949.3
B	188	5	50	127
B	188	10	50	184
B	188	15	50	243.5
B	188	25	50	343
B	188	35	50	424
B	188	50	50	547

B	188	75	50	752.3
B	188	100	50	959.5
C	188	5	50	126.3
C	188	10	50	183.8
C	188	15	50	239.5
C	188	25	50	343.8
C	188	35	50	424.8
C	188	50	50	548
C	188	75	50	753.8
C	188	100	50	959.3
D	188	5	50	133.8
D	188	10	50	188.3
D	188	15	50	244.8
D	188	25	50	343.3
D	188	35	50	426
D	188	50	50	550.5
D	188	75	50	758.3
D	188	100	50	966.5
E	188	5	50	134.3
E	188	10	50	191.3
E	188	15	50	249.3
E	188	25	50	345.3
E	188	35	50	429.8
E	188	50	50	554.5
E	188	75	50	764.5
E	188	100	50	974.3
F	188	5	50	140.3
F	188	10	50	195.8
F	188	15	50	250.5
F	188	25	50	345.3
F	188	35	50	429.5
F	188	50	50	556.3
F	188	75	50	766
F	188	100	50	976.5
A	152	5	75	156.8
A	152	10	75	221.3
A	152	15	75	280
A	152	25	75	396.8
A	152	35	75	484.8

A	152	50	75	608
A	152	75	75	810.8
A	152	100	75	1013.5
B	152	5	75	166.3
B	152	10	75	228.5
B	152	15	75	289.8
B	152	25	75	399.8
B	152	35	75	485.3
B	152	50	75	608.8
B	152	75	75	813.8
B	152	100	75	1018.8
C	152	5	75	178.5
C	152	10	75	238
C	152	15	75	301.8
C	152	25	75	400.3
C	152	35	75	485
C	152	50	75	610
C	152	75	75	817
C	152	100	75	1024.8
D	152	5	75	183.5
D	152	10	75	246.8
D	152	15	75	305.8
D	152	25	75	401
D	152	35	75	485.3
D	152	50	75	612
D	152	75	75	819.8
D	152	100	75	1029.3
E	152	5	75	202.3
E	152	10	75	261.3
E	152	15	75	311
E	152	25	75	402
E	152	35	75	488.8
E	152	50	75	615
E	152	75	75	825.3
E	152	100	75	1034.8
F	152	5	75	212.3
F	152	10	75	265.5
F	152	15	75	312.3
F	152	25	75	403.3

F	152	35	75	490
F	152	50	75	619.8
F	152	75	75	833.8
F	152	100	75	1048.8
A	188	5	75	153.8
A	188	10	75	212.8
A	188	15	75	272
A	188	25	75	383.3
A	188	35	75	488.3
A	188	50	75	612.5
A	188	75	75	816.3
A	188	100	75	1019.3
B	188	5	75	162
B	188	10	75	220
B	188	15	75	277
B	188	25	75	385.5
B	188	35	75	487.3
B	188	50	75	611.3
B	188	75	75	816.3
B	188	100	75	1021.3
C	188	5	75	158.8
C	188	10	75	218.5
C	188	15	75	277.3
C	188	25	75	386.8
C	188	35	75	489.3
C	188	50	75	612.8
C	188	75	75	819.3
C	188	100	75	1025.8
D	188	5	75	165.5
D	188	10	75	225.5
D	188	15	75	281.3
D	188	25	75	388.8
D	188	35	75	492
D	188	50	75	616.8
D	188	75	75	825.5
D	188	100	75	1033.3
E	188	5	75	179.3
E	188	10	75	232.3
E	188	15	75	285

E	188	25	75	397.8
E	188	35	75	491.5
E	188	50	75	618.3
E	188	75	75	828.3
E	188	100	75	1038
F	188	5	75	186.3
F	188	10	75	244.3
F	188	15	75	300.5
F	188	25	75	407.3
F	188	35	75	494
F	188	50	75	623.3
F	188	75	75	835.3
F	188	100	75	1042.3
A	152	5	100	197.5
A	152	10	100	261
A	152	15	100	321.8
A	152	25	100	438.8
A	152	35	100	545.5
A	152	50	100	672.8
A	152	75	100	877.5
A	152	100	100	1081.8
B	152	5	100	203
B	152	10	100	265.8
B	152	15	100	327
B	152	25	100	449
B	152	35	100	547.3
B	152	50	100	673
B	152	75	100	879
B	152	100	100	1084.3
C	152	5	100	221.8
C	152	10	100	280
C	152	15	100	342.3
C	152	25	100	457
C	152	35	100	547
C	152	50	100	673.8
C	152	75	100	881.5
C	152	100	100	1088.3
D	152	5	100	241.3
D	152	10	100	306.3

D	152	15	100	362.5
D	152	25	100	459.5
D	152	35	100	548.8
D	152	50	100	676.3
D	152	75	100	886.3
D	152	100	100	1097
E	152	5	100	261
E	152	10	100	318.3
E	152	15	100	367.5
E	152	25	100	460.8
E	152	35	100	550.8
E	152	50	100	679.3
E	152	75	100	890
E	152	100	100	1100.8
F	152	5	100	279.8
F	152	10	100	324.5
F	152	15	100	372
F	152	25	100	464.8
F	152	35	100	553.3
F	152	50	100	682.8
F	152	75	100	897.8
F	152	100	100	1113.8
A	188	5	100	179.8
A	188	10	100	242.8
A	188	15	100	302.3
A	188	25	100	418
A	188	35	100	528.8
A	188	50	100	675.3
A	188	75	100	883.3
A	188	100	100	1084.5
B	188	5	100	182
B	188	10	100	245
B	188	15	100	304.3
B	188	25	100	418.8
B	188	35	100	528.8
B	188	50	100	676.8
B	188	75	100	882.8
B	188	100	100	1087.8
C	188	5	100	185.5

C	188	10	100	247.3
C	188	15	100	310
C	188	25	100	422
C	188	35	100	530.3
C	188	50	100	681.8
C	188	75	100	884.5
C	188	100	100	1091.3
D	188	5	100	195.8
D	188	10	100	262.5
D	188	15	100	317.8
D	188	25	100	426.3
D	188	35	100	536.5
D	188	50	100	679.5
D	188	75	100	888.3
D	188	100	100	1097.3
E	188	5	100	210.3
E	188	10	100	270.3
E	188	15	100	326.8
E	188	25	100	442.8
E	188	35	100	552
E	188	50	100	683.3
E	188	75	100	893.3
E	188	100	100	1103.3
F	188	5	100	217.8
F	188	10	100	280.8
F	188	15	100	339.8
F	188	25	100	455.3
F	188	35	100	557.5
F	188	50	100	686.8
F	188	75	100	900.3
F	188	100	100	1113.3

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