

A case study of energy expenditure based on walking speed reduction during walking upstairs situation at a staircase in FKAAS, UTHM, Johor building

M S Abustan¹, M F M Ali¹, S H A Talib¹

¹ Department of Infrastructure and Geomatic Engineering, Faculty of Civil Engineering and Environmental, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor

E-mail: sallehb@uthm.edu.my

Abstract. Walking velocity is a vector quantity that can be determined by calculating the time taken and displacement of a moving objects. In Malaysia, there are very few researches that were done to determine the walking velocity of citizens to be compared with other countries such as the study about walking upstairs during evacuation process is important when emergency case happen, if there are people in underground garages, they have to walk upstairs for exits and look for shelter and the walking velocity of pedestrian in such cases are necessary to be analysed. Therefore, the objective of this study is to determine the walking speed of pedestrian during walking upstairs situation, finding the relationship between pedestrian walking speed and the characteristics of the pedestrian as well as analysing the energy reduction by comparing the walking speed of pedestrian at the beginning and at the end of staircase. In this case study, an experiment was done to determine the average walking speed of pedestrian. The pedestrian has been selected from different gender, physical character, and age. Based on the data collected, the average normal walking speed of male pedestrian was 1.03 m/s while female was 1.08 m/s. During walking upstairs, the walking speed of pedestrian decreased as the number of floor increased. The average speed for the first stairwell was 0.90 m/s and the number decreased to 0.73 m/s for the second stairwell. From the reduction of speed, the energy used has been calculated and the average kinetic energy used was 1.69 J. Hence, the data collected can be used for further research of staircase design and plan of evacuation process.

1. Introduction

Energy expenditure in human body is the amount of energy needed to do physical activities, respiration and food digestion. Walking is one of the activities that contributes to energy expenditure. The average of walking velocity may vary depending on the countries' cultural and environmental factors. The velocity might be affected by the peoples' age, sex, trip purposes and disabilities. The average walking speed of pedestrian in Malaysia is 1.16 m/s which is said to be lower compared to other Asian countries such as Singapore with 1.23 m/s and Thailand with 1.22 m/s [1]. During walking upstairs, factors such as human behaviour and physical activities will affect the walking speed. The effect from physical activities may differ for different personality based on how frequent they exercise, health status and also mental status. The energy reduction of human during walking upstairs sometimes might be affected by the design of staircase. Long distance staircase will cause physical exhaustion to people compare to short distance staircase and surely will affect the speed of walking.



This research is objectively to determine the walking speed of pedestrian during walking upstairs. It is done by collecting data of the speed of pedestrian and obtaining the relationship of the speed with the characteristic of human. In order to find the solution for the problem found in the problem statement, there are three objectives in order to achieve the aim of this research. The first objective is to determine the walking speed of pedestrian during walking upstairs. Next, finding the correlation of pedestrian walking speed and the characteristic of the pedestrian. Lastly is analysing the energy reduction by comparing the walking speed of pedestrian at beginning, middle and end of staircase.

This study focuses on the walking velocity of pedestrian during walking upstairs. The speed of the pedestrian was collected at two parts of the staircase in FKAAS, UTHM, Johor building by placing one camera at each part. The data collection was categorized in different gender which consists of 26 male and 32 female. A set of questionnaire about the pedestrians' characteristics and physical activities was prepared. The value of walking speed of pedestrian were finally obtained and it was categorized based on pedestrians' gender. The value of walking speed was then converted to the mechanical energy which consist of kinetic energy.

2. Literature Review

2.1. *Walking speed*

Physical activities and health of human are the factors that have to be considered in collecting the information of energy expenditure. This is because physical activities can contribute to mental health as well as for the physical health such as muscles, bones and joints. Data on energy expenditure also must consider psychological factor which can affect the perception of tiredness [2] as an example, physical exertion are associated with psychological aspects that can affect the movement speeds of pedestrian.

Based on the past research, the analysis on pedestrian walking velocity in Malaysia was done by considering the age and gender [1]. The average walking speed of children was 1.06 m/s, women senior adult has the least amount of velocity with 1.04 m/s while men had the highest amount of velocity with 1.38 m/s. Meanwhile, the average walking velocity of women adult pedestrian was 1.20 m/s and men senior adult was 1.14 m/s. These values have the approximate value of men and women walking speed on the reduction.

2.2. *Factors affecting walking speed*

In general, the average walking speed may be different depending on the difference of cultural and environmental backgrounds in all countries. From past research, the continent of Europe and North America have high measurement in average walking speed while Asia continent has the least value of average walking speed [7]. This may be due to the difference in the ways of the physical build as well as the activities of socio-economics. The average walking velocity in Malaysia is quite low to be compared with other country in Asia continent.

There is a research done in collecting distribution on walking upstairs. To obtain the data, there is a difficulty that happen due to the number of long stairs without elevator is only few. People will refuse to walk the stairs if there is an elevator as one of the easiest way to go upstairs. The type of person that are willing to use the stairs are assumed to be physically better than others. The data from the usage of long stairs might help for emergency cases when there is no elevator can be used unless a long stairs to exit [3].

2.3. *Ascending stair evacuation and physical exhaustion*

A study had been done on evacuation on high rise building, the authors stated that the average walking velocity will reduce in correlation to the building's height [4] in which the higher the building, the slower people will walk. The average walking velocity is reduced due to physical exhaustion. From the previous research that was done by Choi et al., 2013 [5], the type of exercise done by each individual will affect

the physical exhaustion as well as personal factors such as physical condition, health, and previous physical work during the experiment.

3. Methodology

The area used in conducting the study was located in Faculty of Civil and Environmental Engineering or shortly known as FKAAS of Universiti Tun Hussein Onn Malaysia (UTHM). The type of pedestrians that were chosen in this experiment were students, females and males in UTHM with the age range between 20-30 years. The experiment was carried out to determine the walking speed of the pedestrian but not to get the evacuation speed. The velocity in evacuation situation are comparatively higher than normal condition velocity. Questionnaire was given to each pedestrian before the experiment started. The questions consist of personal factor regarding age, sex, weight and exercise habits.

3.1. Experimental setup

The method to obtain the velocity information of pedestrian was taken using a video image analysis technique. A video of the movement of pedestrian through the staircase was recorded. This experiment was an individual experiment where all the participants walked individually without the distraction by other participants. Throughout the experiment, the participants were free to choose on walking with a pace they wanted. The participants were asked to walk upstairs to the second floor. After reaching at the top floor, the participants took a rest and prepared themselves to walk back downstairs. Figure 1 shows a part of the stairwell used in the experiment. The stairs consist of two flights with a half landing in between Stairwell 1 and Stairwell 2. The size of riser is 14.90 cm and the tread size is 29.00 cm. Stairwell 1 consists 24 stairs with a landing in between with a total length of 696.00 cm (6.96 m) while Stairwell 2 consists of 12 stairs with a total length of 348.00 cm (3.48 m).



Figure 1. Stairwell used in the experiment.

3.2. Data analysis

From the experiment of the walking participant at stairs, the video recorded was analysed by using Human Behaviour Simulator plug-in to the software of the Autodesk® MAYA®. The following are the steps in making the analysis.

1. Import images' sequence into the Autodesk® MAYA® software.
 - Firstly the new camera created by selecting create > cameras> camera (see Figure 2 (a)). Then camera1 was created.
 - To view through the new created camera (camera1), panels > perspective > camera1. The perspective view will be the viewpoint of camera1 (see Figure 2(b)). From the attribute of the camera1, the camerashape1 tab was selected. From the menu selection, in the section of environment, Create button is click and imagePlane1 will initiate directly.
 - Image Plane Attributes in imagePlane1 was selected and Image Name button is clicked to select the sequence image of the movement of participant. Then tick the box of Use Image Sequence (see Figure 2 (c)).

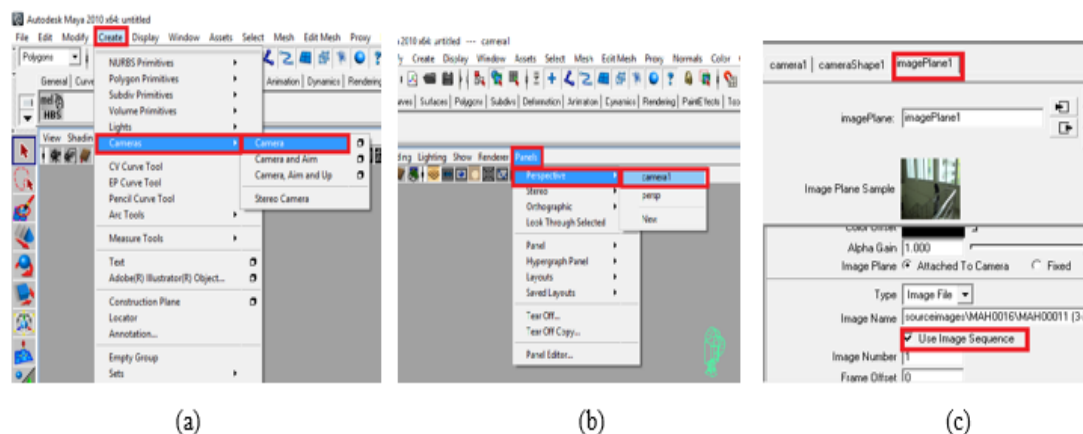


Figure 2 (a). Create new camera, **(b)** change the perspective view to look through camera 1, **(c)** import the sequence image.

2. Scale adjustment
 - Rectangular polygon was drawn according to the dimension of stairs form top view in the Autodesk® MAYA® with the ratio 1:1 scale between reality and the Autodesk® MAYA®.
 - The position of camera1 view is adjusted to be fitted with the rectangular polygon drawn in previous step above by returning to the camera1 view. The procedure is shown in Figure 3.
 - After the position of the rectangular polygon is satisfied, the position of camera1 will be locked by clicking the channel box and the coordinate of camera1 was selected and it was locked to maintain the position.



Figure 3. The rectangular polygon drawn in accordance to the ratio of actual dimension to fit with the sequence image in scale adjusted process.

3. Ascertain position of pedestrian

- The position of participants were determined using EP Curve tool. The head of participant was used as the reference to appoint the coordinate. The time slide was removed and the “mark” was executed.
- After the route of participant being tracked, the track line was selected. Then, the wall menu is selected from the Human Behaviour Simulator and the button of output cylinder is clicked. Within 1 second of time interval, the detail coordinate was recorded.

The changes of participant coordinate was recorded in the “.txt” file which allows the determination of walking speed. To calculate the energy used by participant, it was then being calculated using kinetic energy formula. Kinetic energy of moving objects are depending on the velocity and based on the walking speed of the pedestrian, the kinetic energy was calculated.

4. Results and Analysis

From the data presented in the table 1, the average walking speed for the female pedestrian has the value of 1.03 m/s and the male pedestrian has the value of 1.08 m/s. Male have higher walking speed and this is perhaps because male usually have longer length of stride. Therefore male pedestrian only need lower frequency to maintain the same walking speed.

Table 1. Average walking velocity for male and female.

Gender	N	Mean (m/s)	Standard deviation (m/s)	Range	
				High	Low
Female	32	1.03	0.14	1.31	0.78
Male	26	1.08	0.19	1.45	0.83
Average	-	1.06	0.17	1.45	0.78
Total	58	-	-	-	-

Table 2. Table of pedestrian walking speed corresponding to location.

Stairwell	N	Mean (m/s)	Standard deviation (m/s)	Range	
				High	Low
1	58	0.90	0.31	1.21	0.63
2	58	0.73	0.12	0.92	0.47
Both	116	0.82	0.22	1.21	0.47

Table 2 depicts the data of velocity collected during the pedestrian started to walk upstairs. The data presented in the table depicts the maximum, minimums and average speed for the stairwells. The average speed in table above is the average of all the speed from floor to floor that have been calculated along the stairwell and not the average velocity of pedestrian to walk the stair ascendingly. The walking speed of pedestrian at stairwell 2 was found to be slower than the walking speed at stairwell 1. This might be due to the reduction of energy took place. The average velocities reported in the table ranging from 0.82 m/s.

Table 3. Female pedestrian speed correspond to section of staircase

Section	N	Mean (m/s)	Standard deviation (m/s)	Range	
				High	Low
Stairwell1	32	0.90	0.13	1.19	0.63
Stairwell2	32	0.71	0.12	0.99	0.47
Both	64	0.81	0.12	1.09	0.55

Table 4. Male pedestrian speed correspond to section of staircase

Section	N	Mean (m/s)	Standard deviation (m/s)	Range	
				High	Low
Stairwell1	26	0.94	0.14	1.21	0.70
Stairwell 2	26	0.76	0.12	1.00	0.54
Both	52	0.85	0.13	1.10	0.62

The results in Table 3 and Table 4 represent the speed of pedestrians for movement of pedestrian starting from stairwell 1 to stairwell 2. Speed for both genders display that there are speed reduction took place. For stairwell 1, male pedestrian had higher walking speed with 0.94 m/s compare to female speed with 0.90 m/s while for stairwell 2, male pedestrian still had the higher mean of speed with 0.76 m/s while female pedestrian slightly lower with 0.71 m/s. However, speed variation for both categories were the same for stairwell 2.

These findings support the result of previous study [4] which stated that the average walking speed will decrease in correlation to height of a building. The changes in walking speed may be influenced by the physical exhaustion. This is because there are additional physical work that needed for forward movement.

The results from Table 5 are quite different to be compared with the data from previous study [6], in which the walking speeds of pedestrian walking upwards on the stairs were 0.75 m/s for men and 0.53 m/s for women. This difference might be due to the number of floor needed to be climbed by the pedestrian. In this case study, the pedestrian were asked to only move for two floors while the previous study required the pedestrian to climb up to 25 floors. The speed reduction can be used in order to calculate the energy decaying that took place during the movement of pedestrian as shown in Table 5.

The energy reduction was correlated to Body Mass Index (BMI) of pedestrian. The BMI range of < 18.5 is categorized under underweight, 18.5 - 24.9 are normal, 25-29.9 are overweight and > 30 are obesity.

Table 5. Energy reduction correspond to BMI range

BMI range	N	Mean (J)	Standard deviation (J)	Range	
				High	Low
< 18.5	11	1.09	1.01	3.00	0.04
18.5-24.9	37	1.51	2.01	4.78	0.00
25-29.9	5	1.11	1.53	0.57	0.00
>30	5	3.06	3.09	8.11	0.53
Total	58	1.69	1.60	8.11	0.00

Most of the pedestrian were in the category of normal weight. The highest mean of energy reduction was from the pedestrians who were obesity and the lowest mean of energy was from the pedestrian who were under weight. The obese pedestrian had gone through more energy decaying due to usage of more energy to move forward compared to underweight pedestrian. The pedestrian in obesity also had experienced higher physical exhaustion due to the weight in comparison with underweight pedestrian.

5. Conclusion and recommendation

The average speed of pedestrian in this case study are quite similar to the average walking speed of pedestrian in country of Saudi Arabia with speed of 1.08 m/s. Based on the data that had been analysed, the type of gender affect the walking speed of pedestrian. Male pedestrian undergo less speed reduction if compared to female pedestrian. The speed of pedestrian also might be affected in correlation to the number of floor needed to be climbed. The speed will be reduced when the number of floor increasing. Energy reduction in this case study was calculated by using the formula of kinetic energy. The energy of the pedestrian will be reduced as they start to climb up the stairs. Several recommendations can be made from this case study as follow:-

1. This study only focused on the person walking in one direction and restricted to staircase area only and various case of studies can be implemented in the future such as making an experiment about the energy reduction in going down the stairs.
2. The study of changes in movement can be conducted since some pedestrian may walk in the opposite direction of the main stream;
3. Due to the increase of skyscrapers, a study of a higher number of floors to be climbed should be implemented in order to obtain significant effects to the reduction of pedestrian walking speed.

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