Assessment Comfortability of Climbing Stairs and the Height of Building Stair

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Abstract

Climbing stair requires considerable work energy, many people avoid climbing stair because it need much energy and make them exhausted. However, based on regulation in Government Regulation of Republic Indonesia number 36 in 2005 article 58 about the Implementation of Law No. 28 of 2002 concerning on Buildings, the use of elevators is only required for office buildings with a height above 5 floors. This study aims to test whether climbing four floors of stairs is physically safe. The research was conducted on building stairs, that have a slope of 30^{o} and a bordest after 11 steps in a row of stairs. Convenient of the stairs height were assessed from the amount of physiological load based on heart rate (pulse/minute) and heart rate range (HRR) when climbing the stairs. A total of 14 participants climbed the stairs to the height of 17,6 m. Based on the heart rate, as many as 29% and 14% of the subjects had a heavy and very heavy energy when they climbed stairs 2 floors or a height of 8.8 meters, with 21% subjects expended energy at heart rate range (HRR) more than physiological load limit (33%). When they went to a height of 13.2 metres or 3 floors, 57% and 36% subjects expended energy at heavy and very heavy level, with 50% subjects expended energy at heart rate range (HRR) more than physiological load limit. Based on this data, daily activities for climbing stairs to 8 meters should be done carefully and with a tempo adjusted to the condition of the subject body. Daily activity of climbing stairs up more than 13 m is not recommended because more than 50% of subjects expend energy on heavy level and passing physiogical load limit.

Keywords
convenient stairs, physiological load, stair height.

1. Introduction
Climbing stairs requires considerable work energy, many people avoid climbing stairs because up stair need much energy. Complaints often came from building users because going stairs up makes them exhausted. Many people feel discomfort when climbing stairs because of need high physical demand meanwhile human have limited energy from metabolism. Physical exhausted is a decreasing of physical capacity in working. For reducing physical fatique risk when climbing stairs up, need to set a height of the stairs that are safe for office buildings and an elevated that are comfort for people.

Based on regulation in Government Regulation of Republic Indonesia number 36 in 2005 article 58 about the Implementation of Law No. 28 of 2002 concerning on Buildings, the use of elevators is only required for office buildings with an height above 5 floors. Safe energy is one of the reason why the building which have no more than 5 floors doesn't facilitated with a lift. But building users often complain because climbing stairs up to 4 floors make them exhausted. Assessment on working energy when climbing stairs up is need to do to generate a criterion of the ofice building stair height.

Templer (1994) in Kumar (1999) notes that the energy expended durings stair climbing exceeds that of any other routine daily physical activity and comparable to an heavy physical load. An experiment by Templer for a 70 kg person, the work energy of climbing stairs, dependent on stair geometry, with ranges from 0.548 to 1.12 kcallmetre for climbing up and 0.098 to 0.280 kcallmetre for stair descent. The optimum stair has an ooptrade of 16.6 cm and an antrede of 28.6 cm with a slope of approximately 30 degrees.

Study on university student by Mbachu and Okonkwo (2018) said student with smaller mass will perform better and have less strain. The studkuy got a very strong positive correlation between the work rate and the efficiency.

The relative aerobic strain (RAS) correlate on work rate where increasing of the work rate was in line with the increase of RAS, where the work rate responsible for 35.9% of the variations in the RAS.

Individual factors affect a person's ability to perform physical activity and the amount of energy expended. According to Tarwaka (2004) workload is influenced by two factors, namely external factors and internal factors. Internal factors are factors that come from within the individual body itself as a result of external workload reactions. Internal factors cover somatic factors (gender, age, body size, nutritional status, and health conditions) and psychical factors (motivation, perception, trust, desire and satisfaction).

Measurement of fatigue levels can be done by measuring heart beat, cardiovascular load, energy consumption and the amount of metabolic cost that calculated from the heart rate range (HRR) (Iridiastadi and Yassierli 2014). The energy expended for working is caused by metabolic processes that occur in the muscles supported by the cardiovascular system and respiratory system of the body. Cardiovascular load is an estimate of the individual workload using his working heart rate compared to his maximum heart rate. The different physical characteristics will impact on different in physical abilities. Maximal volume of oxygen intake on americans according to NIOSH in 1981 is 3.2 l/minute for male and 2.2 l/minute for female, while the results of the study the prediction of volume of oxigen intake for male industry workers in Indonesia is 2.78 ± 0.5 liters/minute and a multiple linear regression equation for maximum oxigen intake = 3,996 - 0.046*age (Wicaksono 2012).

The sensitivity of the herat rate to changes depend on the load received by the body. The heart beat will soon change in line with the changes of the load that derived from mechanical, physical, as well as chemical (Tarwaka et al. 2004). The energy consumption under certain working conditions is not enough for workload assessment. Physical workload is not only determined by the amount of energy consumed, but also determined by the amount of muscle involved to make a work and the static muscle load that the body receives as well as the presence of temperature pressure from the environment. Increasing of energy when climb the stair was depend on how method to climb stairs up. Research on climbing the stair using two methods of climb conducted by Gottschall et al. (2010). Double-step methods need difference amount of work energy from each step methods. After conducting each method of climbing stair in an experiment, study got that the double-step method need a greater metabolic energy than each step methods, equal to approximately 1.0-1.3 kcal/hour. Higher energy consumption because the double-step strategy required a greater muscle activity for the ankle and knee flexion and extension.

Study by Peacock et al. (2012) used a multiple regression model in determining subject movement speed when up and down the stairs. There were two variables that significant in determining subject speed, they were the stairwell that the occupant was in and the density. This study got the speeds of subjects movement was 0.48 m/s ± 0.16 m/s.

Research on ergonomic building stair height needs to be done for safety and health of building users. Previous research on the use of stairs has calculated and analyzed the amount of energy expended when climbing stairs based methods of climbing stairs and based on subject age. Other themes that have been studied related to the effect of climbing stairs on physiology both at young and old age, as well as variables that affect the speed of a person going up and down stairs. The maximum height limit for climbing building stairs has not yet been researched.

This study measured and analyzed people's fatique when climbing stairs. The experiment conducted on a type and size of stairs commonly found in office buildings, an optimal stairs geometry using in the experiment with a slope of 30^{o} and bordest after 11 steps. Convenient of the stairs height were assessed from the amount of physiological load based on heart rate (pulse/minute) and heart rate range (HRR) when climbing the stairs.

2. Methods

2.1 Research location

The stairs used as the location of the experiment are the stairs in the X building at the Faculty of Engineering, Sultan Ageng Tirtayasa University. The building has 4 floors (from ground floor until 4th floor) with a total of 83 stairs. Between floors has 21 steps with a height of 4.4 meters. There is a bordest every goes up one floor, the bordest position is after the 11th step. The antrede of the stair is 30 cm and the optrede is 21 cm, and the slope of stairs is 30^{o}. Subject climbed the stairs from ground floor until the 4th floor with height of 17.4 meters.

2.2 Subjects

There were 14 subjects participating in the study, subjects were students with aged between 20 to 23 years with a Body Mass Index (BMI) in the normal range between 18 to 25. Subjects were 7 male and 7 female.

2.3 Experiment Design

The experiment was conducted around 09.00 to 12.00 am with normal temperature levels in the Indonesian climate ranging from 28 – 30 ºC. The subject climbs the stair from ground floor up to 4 floors or as high as 17.4 meters. For each subject, heart rate measurements were taken before going up the stairs (on the ground floor), after climber 2 floors, after climbed 3 floors and after climbed 4 floors. When reached the first floor (climbed 1 floor) was not taken measurements with assumption the energy expended to reach the first floor is not large enough.

The subjects were ensured had a light working energy level with pulse rate between from 65-85 beats per minute before climbing the stairs. In actual condition before a person climbing the stairs the precedence activity is walking to the stairs that need an energy on light level. In this experiment, the speed of climbing stairs for each subject follows a metronome with 100 beats per minute

2.4 Flowchart

Energy when climbs the stairs were calculated from the subject's heart rate. Heart rate measured by oximeter. Heart rate is a manifestation of muscle movement so that it can be used to assess working energy. Workload assessments are also performed based on each individual's ability by calculating the physiological load value. Physiological load is assessed from Heart Rate Range (HRR) using next formula:

$$HRR(\%) = \frac{100(HR_{work} - HR_{rest})}{HR_{max} - HR_{rest}}$$
$$HR_{max} = 220 - age$$

where

$HRR(\%)$ = Heart rate range (%);
HR_{work} = Heart rate when individu work *(pulse/minute)*;
HR_{rest} = Heart rate after individu rest 20 minutes *(pulse/minute)*;
HR_{max} = Maximum heart rate *(pulse/minute)*

Next in the Figure 1 is the flowchart of the research.

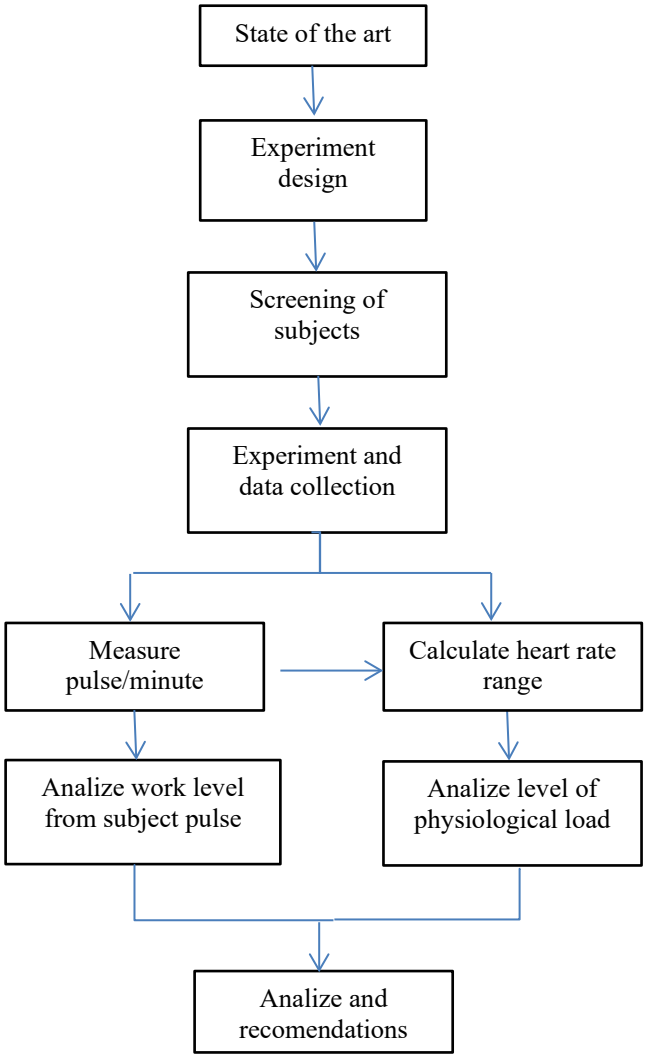

Figure 1. Research flowchart

3. Data Collection

Measurement of workload when climbing stairs is carried out in X building at the Faculty of Engineering, Sultan Ageng Tirtayasa University which has 4 floors.

The subjects involved in this study were university students aged between 20 and 23 years. The following table 1 presents data about students who are the subjects of this study.

Table 1. Subjects in research

Subject	Weight	Age	Height	BMI
1	54,0	21	1,70	18,69
2	57,0	21	1,69	19,96
3	70,0	21	1,73	23,39
4	68,0	21	1,73	22,72
5	46,5	20	1,60	18,16
6	58,0	20	1,60	22,66
7	60,0	20	1,54	25,30
8	50,0	20	1,55	20,81
9	65,0	20	1,66	23,59
10	65,0	21	1,63	24,46
11	68,0	21	1,68	24,09
12	45,0	21	1,50	20,00
13	60,0	23	1,67	21,51
14	56,0	23	1,57	22,72

This study measures physical load when climbing the stairs of a building by referring to common activities performed in campus or office areas. Increased work energy occurs in the form of linear patterns depending on the elevation.

The subject physical load when climbing stairs is measured by a pulse rate per-minute. Pulse indicates heart rate, a variable used to calculate energy up the stairs. The subject heart rate during experimentation and the physical load assessment in Heart Rate Range (HRR) is presented in Table 2 below.

4. Results and Discussions

4.1 Climbing Up Energy

The following table 2 is the result of measuring the physical load when climbing the stairs from the ground floor to the 4th floor. Criteria of physical load can be grouped based on pulse rate. For male and female, criteria of light work level if pulse is 90 pulse/minute, moderate level work if pulse between 90 to 100 pulse/minute, heavy level work if pulse between 100 to 120 pulse/minute, very heavy work if pulse between 120 to 140 pulse/minute and extreme work if pulse between 140 to 160 litre/minute (Kroemer et al. 2001).

Table 2 shows the result of the experiment. When the subject climbed the stairs up 2nd floors or a height of 8.8 metres as many as 57% of respondents expended energy at a moderate work level, 29% expended energy at the heavy work level and 14% expended energy at the very heavy work level. When they climbed up 3rd floors, 7% of respondents expended energy at a moderate work level, 57% expended energy at the heavy work level and 36% expended energy at the very heavy work level. When they climbed up 4th floors, the number of subjects expended energy at the level of heavy and very heavy were 43% and 36%, and 21% of subjects at the level of extreem heavy energy. This research is in line with Templer's research (1994) in Kumar (1999) that the energy expended durings stair climbing comparable to heavy physical labour.

The workload approach is based on the Heart Rate Range (HRR) which is a comparison of the pulse when doing activities to the maximum pulse of the individual observed. This approach is more objective because the assessment is based on the percentage increase in the individual's heart rate compared to the individual's maximum heart rate. The maximum recommended HRR value for physical loads is 33%. The value of 33% refers to a person's load of working for 8 hours (Chengalur et al. 2004). However, in exercising, physical load at HRR up to 70% is normal. Ideal level for warm ups is in zone 1 (60-70% HRR), keeping the heart rate in zone 1 helps individu get blood flowing which can pump out lactic acid post-workout (Parkinson 2016).

Table 2. Physical demand when climbing stairs

Subject	Gender	HR Rest	Pulse/minute after climbed			Heart Rate Range (%) after climbed			
		(pulse/mt)	2 floors	3 floors	4 floors	HRmax	2 floors	3 floors	4 floors
1	M	69	92	110	115	199	17,69	31,52	35,44
2	M	65	85	105	109	199	14,93	29,69	32,96
3	M	74	106	120	127	199	25,60	37,06	42,31
4	M	71	98	114	120	199	21,09	33,91	38,39
5	F	84	108	120	132	200	20,69	31,03	41,38
6	F	84	120	132	144	200	31,03	41,38	51,72
7	F	72	132	138	150	200	46,88	51,56	60,94
8	F	84	126	138	144	200	36,21	46,55	51,72
9	M	78	120	126	132	200	34,43	39,34	44,26
10	F	80	91	125	127	199	9,24	37,82	39,50
11	F	80	90	113	121	199	8,40	27,73	34,45
12	F	78	89	106	110	199	9,09	23,14	26,45
13	M	72	90	96	102	197	14,40	19,20	24,00
14	M	66	90	102	102	197	18,32	27,48	27,48
	light								
	moderate		57%	7%					
	heavy		29%	57%	43%				
	very heavy		14%	36%	36%	HRR>33%	21%	50%	71%
	extreme				21%				

Assessment of energy consumption based on the ability of each individual is calculated based on the percentage of energy use when doing activities to the maximum energy capacity of the subject. Table 2 shows while subjects climbed stairs 2 floors (8.8 metres), 21% of respondent expended energy at heart rate range (HRR) more than 33% or more than physiological load limit. Climbing stairs 3 floors (13.2 metres) caused 50% of respondents expended energy at heart rate range (HRR) more than 33% and climbing stairs 4 floors caused 71% of respondents expended energy at heart rate range (HRR) more than 33%.

Based on above result, it's not recommended to climb stairs more than 13 m because half of subjects expended energy on Heart Rate Range (HRR) more than 33%. In heavy physiological load subjects use more than 33% of their aerobic capacity to do the job. Based on HRR in experiment, daily activities for climbing stairs up to 8 meters should be done carefully and with a tempo adjust to the condition of the subject body.

Using HRR criteria there were four subjects that expended energy at safe criteria when climbing the stairs up to the 4th floor, three of them were male. Frequent physical activity or exercise helps subjects use energy more efficiently. Based on the interviews to the subjects, they stated that they often have physical activity or exercise such as playing football. In general, men do more physical activity than females in daily activity.

The pattern of increased physiological load in the form of pulse/minute when climbing stairs is a linear pattern. The pulse will continue increase with the increasing height of the stairs. The following graph in Figure 2 shows an increase in pulse/minute at 14 subjects during the climb the stairs.

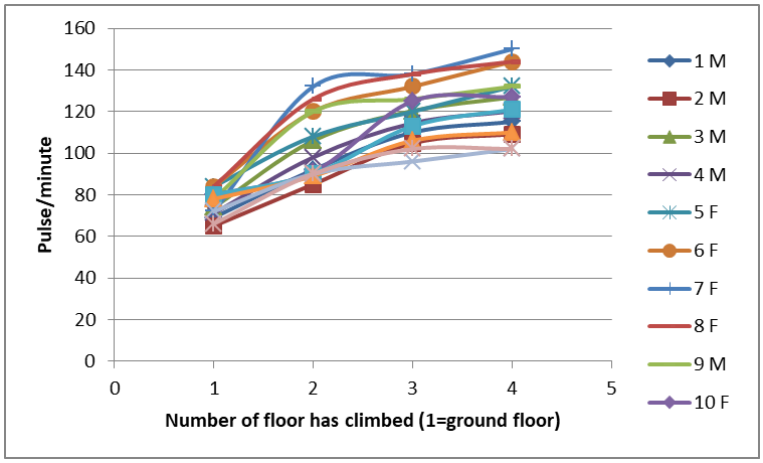

Figure 2. Level of physical demand when climb the stair

4.2 The Energy of Climbing Stairs Based on Age

Human on 20 to 35 year olds have the highest level of physical ability and strength (Kroemer 2001). Subjects in the optimal physical ability (20-23 years age) with ideal body mass index will produce maximum ability when climbing stairs. The condition going up the stairs will make the physical load more heavy for people over the age of 40 years. Physical ability will decrease up to 10% for people with age about 50 years old. In studies of special populations by Benn et al. (1996) in Kumar (1999) found that the older men (age above 60 years) that climbed stair have side effect, its include of producing greater systolic blood pressure, heart rate, and rate pressure product than did treadmill walking or dynamic weight lifting, so it have caused the increasing of heart rate and mean arterial pressure, and mean pressure product were extremely rapid and reached very high levels. The rate pressure product was more than twice that recorded in normal walking.

Although the physiological load of climbing stair in the elderly group was greater than in the younger group, the up and down speed of the building in both groups was not different. Climbing the stair requires more energy than the activity of descending stairs. The speed of up and down the stair has been studied by several researchers, Fujiyama and Tyler (2004) states age has no effect on the speed of up and down the stairs, the old age group has the same speed as the young age group when descending the stairs. In the study of activity down the stairs found the variable of body mass index or body size has no effect on the speed of people descending the stairs. Gender variables affect the speed of descending stairs, according to Hoskins and Milke (2013) gender factors influenced the speed of descending stairs, male groups down stairs faster than the female group.

5. Conclussion

Climb stair need height energy. When the subject climbed the stairs two floors or a height of 8.8 metres as many as 29% and 14% subject expended energy on heavy and very heavy level, and 21% of subjects had heart rate range (HRR) passing the save limit 33%, so this activity can be done with carefully and with tempo adjusted to the condition of subject body. When climb to a height of 13.2 metres or climbed the stairs three floors as many as 50% of the subject expended energy at HRR passing the save limit. Climbing stair more than 13 metres or climb the stair 3 floors or more is not recommended because more than 50% of subject expended energy at heavy and very heavy level, and Hear Rate Range (HRR) more than 33%.

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