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Thermal Comfort Satisfaction Analysis at The Natural Ventilated Non-Air Conditioner Gymnasium

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Abstract: In recent years, people's inclination to go to the gym has increased as people begin to care more about a healthy lifestyle. Thermal comfort at the gym affects employees in terms of health, productivity, and satisfaction. External environmental conditions also have a significant impact on non-air-conditioned buildings. This study was conducted to analyze the impact of outdoor environmental conditions from different times on the level of thermal comfort of the occupants and evaluate the best time to go to the gym based on the level of thermal comfort of the gym. The method used for this study was the thermal comfort assessment performed inside the gym. The environments examined were relative humidity (%), air velocity (m/s), air temperature, and radiant temperature (° C). Environmental factor data were collected using the portable anemometer. The thermal comfort of gym occupants was assessed using a thermal sensation scale using Prediction Mean Vote (PMV) and Prediction Percentage Dissatisfied (PPD) which was used to estimate the satisfaction and level of thermal comfort. Calculation of PMV and PPD values were done using the CBE thermal comfort tool. The results of the evaluation had shown that the value of PMV at noon and evening was higher than at night. This indicated that at night had a better level of thermal comfort. All PMV values calculated were positive values, an indication that the occupants were experiencing a hot environment in the gym. All PMV values did not fall in the comfort zone even though the environment was good. All the PPD value not in a good range which showed that most of the occupants were dissatisfied with the gym thermal condition. In conclusion, the results obtained in this naturally ventilated gym without air conditioning were not able to meet a good level of thermal comfort.

Keywords: Gym, Thermal Comfort, PMV and PPD Value

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1. Introduction

A gym is a sports facility that can be defined as space in the building used for indoor sport activity equipped with sports equipment. This room is highly used for physical activity or exercise that usually focuses on endurance and strength. Endurance training can be defined as an exercise to increase heart rate and respiration [1] while strength training makes your muscles stronger. High levels of physical activity from exercise increase the metabolic rate of the human body. The metabolic rate is the rate of change of chemical energy from the activity of the human body into thermal energy according to Turner et al. [2]. The amount of heat released from the human body in large quantities will affect the temperature of the indoor environment and critically affect the comfort level of the gym occupant. The most common method of reducing indoor temperatures is to consider the presence of openings in the design to maximize natural ventilation in the building.

Openings in buildings are an important component of a building designed to increase the efficiency of the building based on considerations of airflow and natural lighting in the building. These building components do not have a definite size or shape but are usually rectangular in design that allows light from outside to move into the building and cross ventilation.

Thermal comfort in a building is a subjective measure for different occupants. However, it can be defined as a situation when people in the building are satisfied with the thermal stress environment [3] This thermal comfort has no specific measurements for each individual and varies according to climate, lifestyle, and culture. Heating, ventilation, and air conditioning (HVAC) engineering design is important in achieving thermal comfort based on six basic factors that affect thermal comfort namely relative humidity, air temperature, radiant temperature, air velocity, metabolic rate, and clothing.

People who usually go to the gym can be called a gym-goer. This type of person is very concerned about their health and fitness. On a normal day, men are more likely to go to the gym than women. Most gym-goers are bodybuilders, athletes, and exercisers. Each type of gym-goer will have different training according to their target. There is an increasing trend of people living a healthy lifestyle recently [4], and this explains why the number of people going to the gym to exercise is increasing. Most of these people do moderate strength and cardiovascular training because they only go to the gym to improve their fitness and can be classified as a type of gym workout. This situation usually occurs in areas with a large number of office workers and students as they lack free time for working out due to work and study commitment.

1.1 Problem statement

In recent years, people's inclination to go to the gym has increased [4]. More people are interested in living a healthy life making people tend to engage in many sports activities. Previously, many people went to indoor sports such as badminton, futsal, squash, and others. However, the current trend is people tend to go to the gym to exercise due to time constraints and as an alternative place to exercise. This situation makes the gym more popular and as a result, its existence is also increasing in urban and rural areas. Urban residents in the hot and humid climates prefer to stay in air-conditioned indoor areas when they are doing their sports activities [5]. The air conditioner has helped many people to achieve more comfortable indoor living. Nevertheless, it cannot be denied that the usage of this life-saving-machine had greatly increased energy consumption at home as well as carbon dioxide emissions. On top of that, staying in the indoor-conditioned-area, reduced the adaptive ability of humans to the natural environment and limited physical health [6]. Thus, this clearly shows that a naturally ventilated indoor area with greater thermal including the gym is one of the important considerations to the people nowadays [7]. From several studies on indoor thermal comfort on how these thermal comfort can affect occupants in terms of health, performance, and productivity [8], the situation in this gym is particularly significant for indoor conditions where occupants performing high

physical work intensity face challenges in thermal conditions comfort. This is due to several thermal variables namely high metabolic rate, clothing, humidity, heat redemption, ambient temperature, and air velocity. Environmental conditions outside the building can also have a significant impact on buildings without air conditioning [9]. There are many thermal comfort studies for indoor games such as badminton and squash but studies are rarely done in the gym. If you take the average number of people in the gym at one time and compare it to the people in the badminton court, the number of people in the gym is even greater. Furthermore, gym sizes are often smaller and tighter than badminton courts. Therefore, it is important to know the level of thermal comfort in the gym in ensuring the comfort and efficiency of gym users while doing sports activities in the gym. In the context of a gymnasium, there is no standard size for the space that can satisfy the occupants. However, there are many studies on the improvement that can be made on the gymnasium to enhance its thermal comfort such as studies on the relationship between architectural form and thermal comfort by Okeil (2010) [10] had resulted in him to propose a holistic approach to energy-efficient building forms. A different approach proposed by Barbosa et al. (2010) [11] indicated that the application of shading devices within the cavity, the cavity width, and the tapered cavity with an inclined outer layer and a "bottom closed" and "window position" were the most influential factors on architectural thermal performance. Li et al. (2013) [12] performed a simulation of gymnasium ventilation with wind pressure to analyse the impact of interface form on natural ventilation which concluded that the asymmetric interface greatly improves ventilation capacity and then proposed interface design strategies.

1.2 Objective

The objective of the study is to measure the indoor gym condition for non-air-conditioned gymnasium, to determine the value of PMV and PPD value for non-air-conditioned gymnasium, and to evaluate the thermal comfort satisfaction for non-air-conditioned gymnasium.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Study area

This study was conducted in a non-air-conditioned gymnasium located nearby a residential area in Batu Pahat which the occupants were mostly the local working people and also students. People tend to go to this gym because it is closer and more economical. The gym is a two-story shop lot and is located on the first floor. The size of the gym is 20 meters x 12 meters with one washroom and prayer room. It is a non-air-conditioned and mechanically ventilated with four fans. This building is suitable for this case study because the indoor environment is mostly influenced by the surrounding environment (outdoor temperature and capacity of the gym). The gym can accommodate a capacity of 15 to 20 people at a time. The gym opening hours are from 1:00 to 10:00 pm from Saturday to Thursday.

2.2 Equipment

The device used for this case study was a portable anemometer that collected data on air temperature (°C), relative humidity (%), and air velocity (m/s). In ensuring that wind speeds can be compared from one location to another, consideration should be given to the field-effect, especially in terms of height and perpendicularness of the device towards the wind.

2.3 Method

2.3.1 Data collection

Thermal comfort is influenced by four environmental factors namely air temperature, radiant temperature (°C), relative humidity (%), and air velocity (m/s). Data were taken during gym operations hours for a few weeks at noon (1 pm - 2 pm), evening (5 pm-6 pm), and night (9 pm-10 pm). Data were collected every 15 minutes and the number of gym occupants for each data collection was recorded. Data would not be collected during rainy days to avoid inaccurate data for thermal comfort analysis and unable to achieve the objectives of the study.

2.3.2 Data analysis

A thermal comfort sensation for the gym occupant was predicted using predicted mean vote (PMV) which was proposed by Fanger in 1970. The data of air temperature, air humidity, mean radiant temperature, relative air velocity collected from the study would be substituted into the PMV equation. The PMV values gotten from the equation would then be compared to ASHRAE thermal sensation scale that ranges from -3 to 3 as follows: -3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, 1 = slightly warm, 2 = warm, 3 = hot.

The thermal comfort satisfaction of the gym occupant for these studies was estimated using the Predicted Percentage Dissatisfied (PPD) formula. The PPD is ranged between 5 to 100% where 20% and below is a good condition for the occupant.

The average data collected for the temperature, air velocity, and humidity during noon, evening, and night would be calculated using the CBE thermal comfort tool. The value of the metabolic rate and clothing insulation was referred to as the ASHRAE Standard [13]. The determination of this value was based on the observation of the gym occupant activity level and their clothes. The CBE thermal comfort tool was used to calculate the value of PMV and PPD based on the data collected.

2.3.3 Interview

An interview session was conducted with the gym taker to get more understanding and clarification about the gym conditions and activities. This session was able to help to support the data collected for the analysis. The gym taker had been working there for more than one year and much of experience in managing the gym. This person could help to provide the input through explaining, understanding, and investigating the thoughts, attitudes, perceptions, phenomena of the study subject.

The interview session was conducted as a one-to-one interview which the questions had been asked directly to the gym caretaker. This way of interview sessions would result in a high response rate. The interviewee's remarks or viewpoints that stand out from the asked question would be noted as supporting information for this study. The interview session was conducted via telephone call through the gymnasium’s main phone number.

The purpose of this interview session was to support further the information about this study based on the experience, knowledge, perceptions and opinions of gym takers. The information collected helps to strengthen the data collection and analysis of the results.

Interviews were done based on the main points of the study such as the state of the gym environment, the type of gym occupants, and their activities in the gym. The answers from the interviewed sessions would then be compared with the data collected. This helped in analyzing the data for a more accurate understanding of the state of the gym.

3. Results and Discussion

3.1 Relative humidity

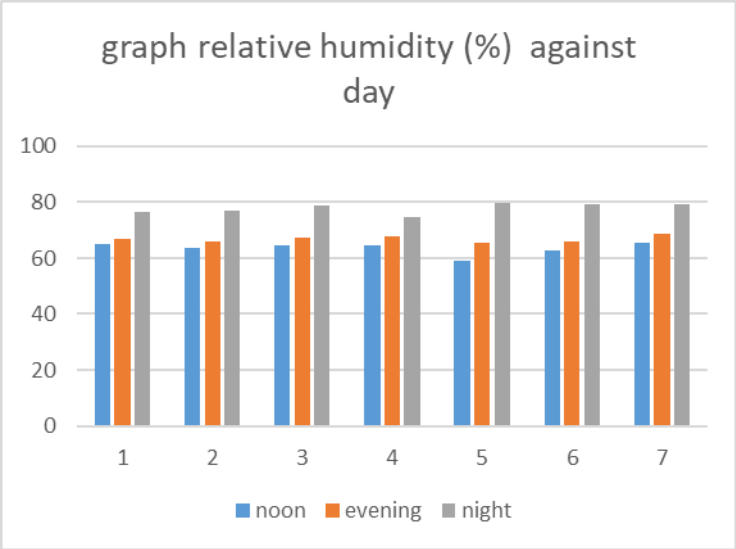

Figure 1: Graph relative humidity (%) against day

Based on the graph of relative humidity, the pattern of relative humidity in the gym was increasing all day from noon to night. The highest average of relative humidity at noon was 65.3% on day 7 while the lowest was 59.26% on day 5. The highest average of relative humidity in the evening was 67.36% on day 7 while the lowest was 65.6% on day 5. The highest average of relative humidity at night was 79.82% on day 5 while the lowest was 74.54% on day 4. For the relative humidity on day 5, it has shown the highest difference between noon and night.

Relative humidity between 40% to 70% did not have a significant effect on thermal comfort level. From the data collected, it was in between that range, thus the thermal comfort at the gym was not majorly affected by its relative humidity. High humidity would only cause more sweat for the occupant, and since the relative humidity was in that range, the gym occupants could produce sweat for all that time frame. From the table, noon has the lowest humidity followed by evening and night. So for the person that wants to burn many calories and produce more sweat, they are suggested to come at night.

3.2 Temperature

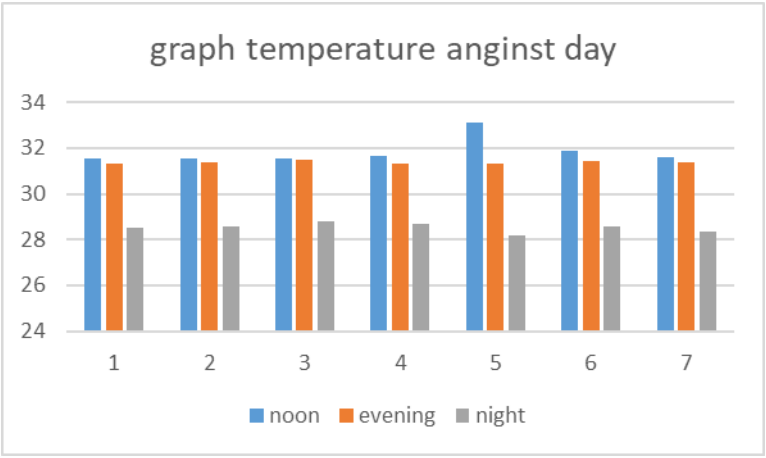

Figure 2: Graph of air temperature (°C) against day

Based on the graph of temperature, the pattern of temperature in the gym was decreasing all day from noon to night. The highest average of temperature at noon was 33.1 ℃ on day 5 while the lowest was 31.54 (℃) on day 2. The highest average of temperature in the evening was 31.48 (℃) on day 3 while the lowest was 31.3 (℃) on the first day. The highest average of temperature at night was 28.78 (℃) on day 3 while the lowest was 28.16 (℃) on day 5. For the temperature on day 5, it has shown the highest difference between noon and night.

From the data gathered, noon and evening had shown an average of high temperature in the gym. This high temperature can cause dehydration and increasing occupants' body temperature. For a person who wanted to go for a cardiovascular exercise that needed to focus on muscle endurance, it is suggested to come at night which has a low and more comfortable temperature. This is to prevent any unwanted muscle problem as increasing body temperature would decrease muscle endurance. When a person does high-intensity exercise, they could lose up to 2% to 8% of body weight. At the same time, if the rate of water absorption in the body were too high throughout the activity, this might lead to dehydration. This dehydration problem is more critical when they are in high temperature as dehydration causes inefficient utilization of oxygen by our body in order to provide energy. Therefore, it is suggested that night is the best time for people to come to this gym because with good temperatures they can do exercise more efficiently and able to prevent any unwanted injuries.

3.3 Air speed

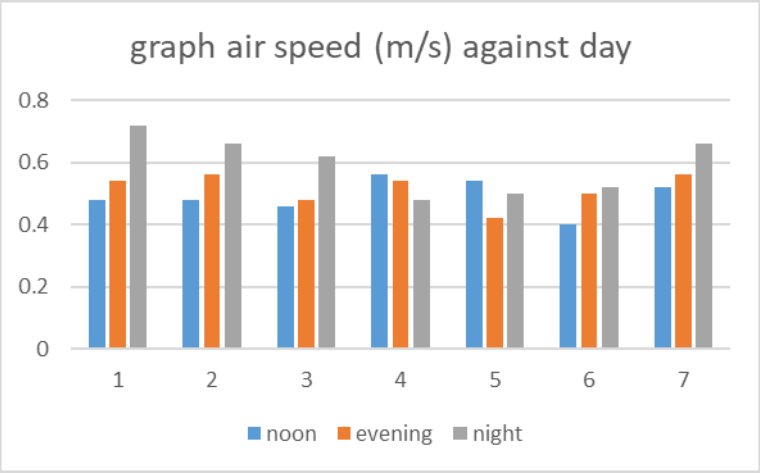

Figure 3: Graph of air speed (m/s) against day

Based on the graph of airspeed, there was no consistent pattern of airspeed in the gym from noon to night. It seemed like the airspeed was maximum at night for the first three days, changed to noon with maximum airspeed on the fourth and fifth day, and picked up back by night as the maximum airspeed on the sixth and seventh day. The highest average of airspeed at noon was 0.54 (m/s) on day 4 while the lowest was 0.4(m/s) on day 6. The highest average of temperature in the evening was 0.56 (m/s) on day 2 and day 7 while the lowest was 0.42 (m/s) on day 5. The highest average of temperature at night was 0.72 (m/s) on day 1 while the lowest was 0.48 (m/s) on day 4.

The windows of the gym were opened all the time for natural ventilation to allow the wind flow into the gym as it provided better airflow inside the gym. Improved airflow inside the building helps reduce indoor air pollution such as unpleasant odours especially from the sweat of the human body while doing their exercise activities. High concentrations of carbon dioxide occur due to high respiratory rate when exercising with large occupants in small spaces. Improved airflow will reduce the concentration of carbon dioxide for better ventilation and always provide fresh air to the occupants. For high airspeed, it helps to improve the cooling process so that people can cool down after completing their exercise routine. Therefore, for this non-air-conditioned gym, windows are a

good choice to maintain natural ventilation and thermal comfort in the room and help increase the comfort of the occupants when exercising especially during the day and night.

3.4 PMV value

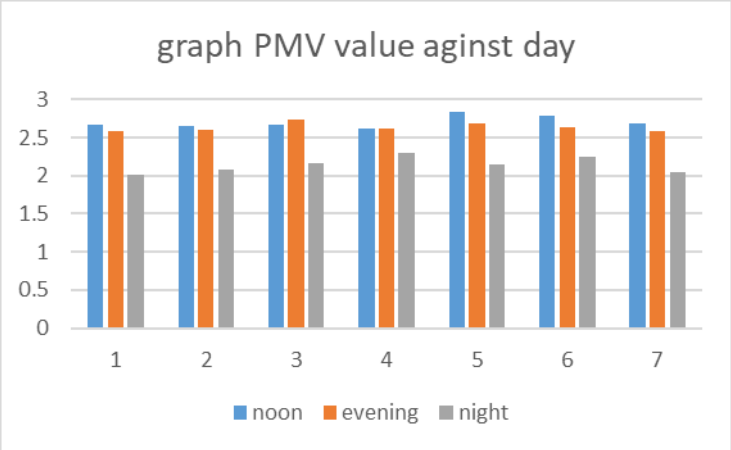

Figure 4: Graph of PMV value against day

PMV value was calculated using the CBE tool which is derived from the ASHRAE standard. The value of PMV was calculated using the collected data of airspeed, temperature, and relative humidity. The clothing insulation value and metabolic rate were gathered from the table provided by the ASHRAE standard. The occupant activities and their clothes were observed at the gym to determine the most suitable value from the table. Based on the PMV value calculated and its graph, it shows there was a pattern of decreasing of PMV value from noon to night for five days except day 3 and day 5. For the average PMV value for noon, the highest was 2.83 on day 5 while the lowest was 2.62 on day 4. The average PMV value for the evening, the highest was 2.73 on day 3 while the lowest was 2.59 on day 7. The average of PMV value for the night, the highest was 2.3 on day 4 while the lowest was 2.02 on day 1. For the overall value of the PMV value calculated, the result was all positive value. From the overall graph, it can be concluded that the PMV value of night was near to zero than evening and noon and this showed that evening and noon were warmer than at night. Therefore, all positive values with a range from 1 to 3 PMV values indicated that the occupants in this gym were not in the comfort zone hence it can be concluded that the occupants in the gym feel uncomfortable in this gym. This uncomfortable result was due to the large influence of the metabolic rate and environmental factors.

The data evaluated shows that the occupants in this gym feel a hot sensation for all periods with noon as the maximum, followed by evening and lastly at night. This hot sensation can cause stress to the occupants as it affects their psychology while in the gym. Human psychology influences human behaviour, where unstable psychology can cause people to be in a low mood. The occupants' stress makes them unable to focus on what they are doing where it will result in a lack of performance as they train inefficiently. Experiencing stress in this gym for a long time can make people less inclined to this gym.

3.5 PPD Value

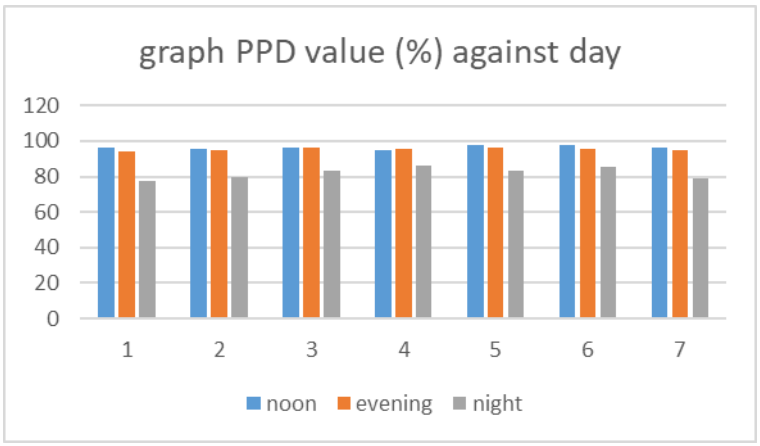

Figure 5: Graph of PPD value against day

For the PPD value, it was calculated using the CBE tool. Based on the PPD value calculated and its graph, it shows there was a pattern of decreasing of PMV value from noon to night for five days except day 3 and day 5. For the average PPD value for noon, the highest was 97.8 % on day 5 while the lowest was 95.2 % on day 4. For the average PPD value for the evening, the highest was 96.6% on day 3 while the lowest was 94.2 on day 2. For the average PPD value for the night, the highest was 86% on day 4 while the lowest is 77.2% on day 1. The higher the value shows that the thermal comfort level becomes lower. For the overall PPD value is in high value as the lowest is 77.2%, it showed the gym condition is not in good thermal comfort level. These results clearly show the ratio of dissatisfied people. From the data, most gym occupants were not satisfied with the state of the gym. This could affect the emotions of the occupants and would lower their motivation. Lack of motivation causes human performance to be lower hence the occupants of this gym would not exercise at maximum intensity. This condition could cause them to feel lazy and less eager to exercise and lead to less frequent to the gym.

3.6 Overall result

It can be concluded that for non-air-conditioned gyms, the surrounding conditions greatly affect the indoor gym environment as there are different conditions at different times during the day - afternoon, evening, and night. The environment in the afternoon and evening is hot but cold at night. This results in higher PMV and PPD values for afternoon and evening than at night, which says that the environment at night produces a better level of thermal comfort than the afternoon and evening. This situation occurs because the outdoor environment strongly influences the indoor environment of the gym and the indoor temperature of the gym resulted from the occupants' activities. This will greatly affect the thermal comfort of the occupants in the gym.

All PMVs evaluated were not in the comfort zone despite being in good environmental conditions due to metabolic rate factors. The high metabolic rate was due to the high-intensity activities at the gym which was why the value of PMV did not fall into the comfort zone. It could be said that it was difficult to stay comfortable while doing activities in this gym.

4. Conclusion

From the results of the PMV and PPD value calculated, this non-air-conditioned gym produced different levels of thermal comfort for each time frame of noon, evening, and night. PMV and PPD for noon and evening were higher than night as showed in the graph discussed earlier. This was due to hot surrounding daytime weather which led to a hot indoor gym condition. This was

because they cannot control the condition of the indoor gym because the gym was a non-air-conditioned so the surrounding weather would manipulate the condition of the indoor gym.

From the results and discussions, all PMVs evaluated were not in the comfort zone due to metabolic rate factors despite being in good environmental conditions. High metabolic rate due to high-intensity activities performed in the gym makes the value of PMV not in the comfort zone. However, the occupants still coming to the gym. It turned out that when they were working out in the gym, the focus was on getting more sweats while burning all the calories. And to achieve that, an indoor area which could provide extra 'non-thermal comfort' would become a more efficient work out area.

Some suggestions can be made to improve thermal comfort in the gym. For non-air-conditioned gyms, the users who prefer light work out should visit at night as it provides better thermal comfort than during noon and evening. For those who want to burn more calories, they can take advantage of the extra 'non-thermal comfort' during noon and evening. In addition, since the internal area of the gym is combining both activities and rehabilitation area under the same roof, the management can also install more standing fans to increase the airflow in the gym. Lastly, they may choose to install the air conditioning systems as a way to provide a much better thermal environment inside the gym.

To improve further this research, for future study, researchers may collect the data for a longer period which includes during rainy days too. The time period of this case study had to be cut short due to Movement Control Orders as the gymnasium had to stop its operation time for more than three months. Therefore, an online interview session had been conducted with the gym-taker to understand more about the gym condition and to support the findings for this research.

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