Appropriate indoor environment for southeast asian people; physiological and psychological responses to humidity

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Abstract. The purpose of this research is to verify the necessity to control indoor humidity in Southeast Asia, while the setting temperature of indoor air is increased for energy-saving. Therefore, physiological and psychological responses to ambient humidity were studied using subject experiments in a climate chamber where indoor air condition can be controlled at discretion. For easily finding the characteristics of Southeast Asians, two subject groups, hot humid and temperate natives, participated in the test. As a result, this study revealed an existence of the variation in the physiological and the psychological reactions to a change in ambient humidity, regarding hot humid natives. In particular, a surrounding with high humidity tend to reduce heat flux on forehead and humidity acceptability. These circumstances could not be found in the temperate natives. The conclusion drawn from our experiments is that it is necessary to control not only indoor temperature but also humidity in the case of a building where there are occupants coming from hot humid locations. However, it remains a challenge for future researches to investigate the amount of sweating, physiological and psychological responses of the whole body and the influence of long-term acclimatization for artificial environment upon physical and mental well-being.

1. Introduction

1.1. Background and previous research

Nowadays, in Southeast Asia, economic development and population growth are causing an increase in energy demand on air conditioning [1, 2]. Then, there is a way to raise the indoor temperature setting as an energy-saving measure in building management. There are some reports that the average value of actual air temperature in Southeast Asian office buildings is operated at the range of 23°C to 26°C [3, 4, 5, 6]. These values are following each local regulation [7, 8, 9], and then this air temperature bands probably fall within a range of thermal comfort suggested by ANSI/ASHRAE standard 55 [10]. As a result, hot humid countries need more heat loads for fresh air than the others in mild climate zone, to make the temperature and humidity as the same degree as the supply air. In summary, regarding air conditioning in Southeast Asia, to raise setting temperature is efficient for reduction in the energy.

However, based on previous researches, it is insisted that tropical natives tend to prefer "cool" environment in spite of great physical function to tolerate heat exposure. For example, Wijayanto [11] has proved that a performance of cognitive test does not lose, even if with their feet were warmed up. Furthermore, physiologists such as Kuno [12] and Hori [13, 14] have also described that bodies of
tropical natives are excellent at keeping the amount of heat dissipation without transpiration. In contrast, several studies have also proved that Southeast Asians have the tendency to prefer lower temperature environments with survey data [4, 5, 6, 15]. In summary, earlier studies have indicated that energy conservation may sacrifice physical and mental health of occupants.

On the other hand, there are fewer researches and development intended for the control of indoor humidity in hot humid area than ones of temperature. Concretely, according to field survey of earlier research [5, 16], indoor humidity is damp heavily in some offices in Southeast Asia during one third of working hours. As described above, hot humid areas with large quantities of moisture probably have the risk of rising damp inside and require the dehumidifier technology. Simple air handling unit spread globally has cooling process with incidental removal of the moisture in supply air, but the value of humidity will be uncontrollable. That is to say, in spite of hard climate, there is also little forceful argument about the indoor humidity situations in Southeast Asia compared with temperature.

1.2. Purpose of this research

A major goal of this research is to verify the necessity to control indoor humidity in Southeast Asia. In addition, recently, there is tendency to assess whether building designs and managements contribute not only to the energy-saving but also to the well-being of occupants. Consequently in this research, human subjects experiment was chosen as the way to record physiological and psychological responses. In summary, the purpose of this study is to obtain more detailed knowledge about the physiological and psychological responses of people living in the hot humid zone. The information on relation between environment and human probably aid in a future building management.

2. Methodology

Human experiments have been performed in a climate chamber, and then physiological and psychological responses to an ambient condition were measured by testing young subjects. All of subjects were paid volunteers, and they were divided into two groups. One consists of people from a hot humid area (Southeast Asia), and the other is from a temperate area (Japan). The survey on two kinds of people has supported to find easily characteristics of Southeast Asians. All response data from subjects were left on record thought or after body acclimation to the predetermined air temperature and humidity conditions. Data on physiology and psychology responses to the environment had obtained from two subject groups participated in human experiments, and compared. Further information on this test is as follows.

2.1. Climate chamber and experiment term

An experimental room and outdoor conditions are displayed in figure 1 and table 1. Our experiments were conducted in a climate chamber (an artificial climate room). The temperature and humidity in this room can be adjusted to appointed air conditions and kept constantly. Furthermore, the outside space of climate chamber can also be controlled at discretion with air conditioning. A schematic drawing of the room plan is shown in figure 1. The room was measured at 4 m wide, 6 m deep and 2.8 m high. It is sufficiently large for maximum 4 participants at the same time. In addition, the air conditioning system in this room can be changed freely, for example, a convention system, a replacement system and a radiation system. In this study, the convention system was adopted with supply air from the ceiling, and the air velocity around subjects was always kept at less than 0.26 m/s.

| Term  | Average of outdoor aira Temperature | Humidity | Climate of birth area for subjects |
|-------|-------------------------------------|----------|-----------------------------------|
| 1st   | Sep.2017 22.7°C 75%RH (13.0g/kg DA) | Hot-humid area |
| 2nd   | Jul.-Aug.2018 28.1°C 76%RH (18.2g/kg DA) | Temperate area |

a Average values are calculated from AMeDAS [29] data (location: Tokyo)
The experiment was conducted twice in Tokyo in summer. Table 1 reveals the average value of outdoor environment in 2017 were slightly below compared to the following year. That is to say, the subject experiment was conducted during two terms in the climate chamber where indoor environment can be controlled and maintained.

2.2. Air temperature and humidity in climate chamber
The combinations of air temperature and humidity ratio in the experimental room are shown in table 2. There are two levels of temperature settings, "the high" and "the low". "The high" temperature setting is 28°C which is recommended as indoor air temperature for energy-saving in Japan during summer. On the other hand, "the low" is 23°C near to an actual indoor environment in Southeast Asia. Secondly, we established three levels of the absolute humidity setting, "the high", "the middle" and "the low". "The middle" humidity is identical with upper limit of thermal comfort defined by ASHRAE [10]. Unfortunately, since it is hard to produce and maintain constantly the combination of "the low" temperature and "the high" humidity, the result of this pairing is excluded from this report. Further to the above, the radiant temperature is same as air temperature in climate chamber by the air control in outer space. In addition, all subjects were not told any information about an indoor condition and an air-conditioning system at all. In other words, five combinations of ambient temperature and humidity were reproduced in the climate chamber as the stage for the subjects’ experiments.

2.3. Procedure for experiment and data collection
The procedure for conducting tests is shown in figure 2. Subjects were placed in the climate chamber under certain conditions and sedentary on the chair for more than 60 minutes. A long time as 60 minutes is helpful not only in acclimating human bodies but also in excluding the influence of the outside weather from physiological and psychological responses of subjects [17].

The three physiological responses shown in table 3 were recorded. As a physiological response to the environment, the heat flux and the skin surface temperature were measured with a sensor attached to forehead (photo 1). There are two reasons why we chose the forehead as the measurement part of the body. The first is that there is little effect by clothes and hair as thermal buffer. The other reason is that head is the most important part showing the state of health, because it is necessary to maintain heat balance between thermolysis and thermogenesis good for brain to work normally. In addition, the amount of body weight losses was measured too as one of the physiological responses. The body weight was measured twice, before and after acclimation time. The difference was defined as the amount of weight losses and was indirectly used as a substitute for an amount of perspiration.

Many questions as psychological response were investigated after the acclimation, however the five psychological responses shown in table 4 were excerpted from them and presented. We assigned a
Table 2. Combinations of setting air temperature and humidity in climate chamber for experiments.

| Humidity ratio (Absolute humidity) | The low | The middle | The high |
|-----------------------------------|---------|------------|----------|
| Air temperature                   | The low | 23°C and 9g/kg DA | 23°C and 12g/kg DA | 23°C and 15g/kg DA |
| Temperature                       | The high| 28°C and 9g/kg DA | 28°C and 12g/kg DA | 28°C and 15g/kg DA |

Figure 2. Procedure for subject experiments.

Photo 1. Heat flux sensor on forehead.

Table 3. Details of instruments for physiological responses measured in subject experiments.

| Parameter measured | Unit | Device (Product No.) | Manufacturer (Country) |
|--------------------|------|----------------------|------------------------|
| Skin temperature   | ºC   |                      |                        |
| Heat flux          | W/m² | Heat flux sensor (S11A) | Eto Denki Ltd. (Japan) |
| Body weight loss   | kg   | Weight scale (WB-150) | TANITA corporation (Japan) |

Table 4. Scale for psychological responses measured with questionnaire in subject experiments.

| Scale | Thermal sensation | Thermal comfort | Thermal preference | Humidity acceptability |
|-------|-------------------|-----------------|--------------------|------------------------|
| 3     | Very hot          | Very comfortable| Much warmer        | Acceptable             |
| 2     | Hot               | Comfortable     | Slightly warmer    | Slightly acceptable    |
| 1     | Slightly hot      | Slightly comfortable| Slightly warmer | Slightly acceptable    |
| 0     | Neutral           | Neither comfortable| No change          | (good as it)           |
| -1    | (neither hot or cold) | or uncomfortable| Slightly cooler    | Slightly unacceptable  |
| -2    | Slightly cold     | Slightly uncomfortable| Much cooler      | unacceptable            |
| -3    | Cold              | Uncomfortable   | Very uncomfortable |                        |

score to each answer as shown in table 4 and analyzed the result statistically. In this experiment, human subjects were sufficiently acclimated to the ambient preset to an appointed temperature and humidity.

In summary, three physiological data and five psychological data were acquired after going through the acclimation phase.

2.4. Property of subjects

A summary of subjects is shown in table 5. They were divided into two groups according to their hometown climate. In this study, the hometown is defined as the place where subjects lived continuously from their birth to 12 years old. Furthermore, the subjects from hot humid zone were required that their duration of residence in the temperate area has to be within 5 years by the reason of avoiding the constitutional change [18]. The average age of the subjects is 25 years old for both groups which are consisting of 17 persons. Moreover, the sex bias is regarded as none in our analysis, because bilateral proportion of male to female is half and half as shown in table 5. The average value of body weight is about 60kg for both groups, there is no significant difference. It differs from previous research which had experiment with Thai and Japanese subjects [19, 20]. At former studies, Thai people were lighter and thinner than Japanese. All subjects were required to wear clothing generally
being seen as office workers. Then, there was no one who wears outfit too casual. However, the clothing weight of subjects from the hot humid area was 170g heavier than one from the temperate area. The gap of the clothing weight may be due to the difference in outdoor temperature and humidity between 2 periods as shown in table 1. Seeking the cause aside, the gap is regarded as none and not considered in this report, since 170g is as small as 0.1clo when converted to the heat resistance value with Hanada formula [21]. In addition, this experiment plan in this research is approved by the Ethics Review Committee, and all subjects participated voluntarily. In summary, all data of physiological and psychological responses were recorded and collected with helps of young subjects from the hot humid or the temperate area.

3. Results

In the group from the hot humid area, there was a variation in both physiological and psychological responses to an environmental humidity. In particular, the heat flux at forehead tends to decrease while raising ambient humidity. In the psychological responses, their thermal sensation shifted to the "feel hot" side and humidity acceptability decreased in accordance with the raise in humidity only at high temperature conditions. This study revealed an existence of the variation in the physiological and the psychological responses to a change in ambient humidity, regarding hot humid natives.

3.1. Physiological responses

Figure 3 to 5 show test results of physiological responses. According to figure 3, it can be seen in both groups that skin surface temperatures at forehead tend to rise while air temperature increases. Similarly, figure 4 reveals that the heat flux at forehead was also apt to decrease while the ambient temperature rises. In the case of "the high" air temperature, both the skin surface temperature and the heat flux of hot humid natives were high, compared with temperate natives. A matter of common knowledge is that the rise in skin surface temperature is helpful to radiate body heat constantly. Therefore, this result means that people from hot humid areas have better heat adaptability than people from temperate zones.

It is found out from figure 4 that the heat flux of subjects from hot humid areas decreased with raising humidity, even though the difference is not significant. In contrast, it cannot be seen in the group consisting of subjects from temperate areas. The same result as above is also shown for the partial regression coefficient and significance level at multiple regression analysis between heat flux as objective variable and ambient air factors as explanatory variables (Table 6). Figure 4 and these analysis results suggest that the humidity goes up, heat radiation amount becomes smaller. Therefore, ambient high humidity may prevent efficient evaporation of sweat for hot humid natives.

On the other hand, as indicated in figure 5, there was no significant difference in body weight losses both among five ambient conditions and among two subject groups. However, these values of body weight loss are insufficient to argue whether or not there were meaningful variations in amount of sweating, because a range of these variations is about the same as the minimum resolution of weight scale (0.05kg: accuracy class 3).

In summary of the result of physiological responses, it is observed that the subjects from hot humid

| Table 5. Profiles of two subject groups participating in human subject experiments. |
|-----------------------------------------------|-----------------------------------------------|
| Subjects group 1 from hot humid area | Subjects group 2 from temperate area |
| Number | 17 persons | 17 persons |
| Gender | Male 8 persons: Female 9 persons | Male 9 persons: Female 8 persons |
| Birth place (City) | Penang, Bangkok, Manila, Davao, Jakarta, Bekasi | Kagawa, Kochi, Kanagawa, Chiba, Hyogo, Oita |
| Age (years) | Average: 25.7 (min:20-max:32) | Average: 24.6 (min:20-max:30) |
| Body weight | Average: 61.61 kg | Average: 60.38 kg |
| Clothing weight (insulation) | Average: 0.78 kg (0.50clo) | Average: 0.61 kg (0.41clo) |
Thermal Sensation
Humidity unacceptability
Skin Temperature
Heat Flux
Body Weight Loss
percentage of thermal comfort

: p<0.01; : p<0.05; +: p<0.1 (Figure 3-9)
areas tend to decrease the amount of heat radiation in accordance with the rise in ambient humidity. However, it could not be corroborated by perspiration measured.

3.2. Psychological responses
Figure 6 to 9 show the measurement results of psychological responses. Subjects from temperate areas nearly did not vary their psychological responses, especially thermal comfort. In contrast, regarding hot humid natives, there is a slight difference in a few psychological responses to environment among ambient humidity levels.

Firstly, multiple regressions were performed regarding thermal sensation and thermal comfort as objective variable on ambient air factors as explanatory variable (Table 6). All of coefficients of determination are lower than ones of heat flux on above. Nevertheless, significant regression coefficient was found between absolute humidity and thermal sensation only for hot humid natives. This is presumably attributed to the highest score at "the high" temperature and humidity (Figure 6). On the other side, in thermal comfort, even at the combination of "the high" temperatures and "the middle" humidity, the proportion of "uncomfortable" is already 40% in thermal comfort vote, as shown in figure 7. Secondly, figure 8 gives results of humidity unacceptability of both groups. From this figure, it is understood that humidity unacceptability of hot humid group is the highest ratio, about 33%, at "the high" temperature and humidity. At last, refer to figure 9 for thermal preference. It is clear that temperate natives have preferred "much warmer" environment at "the low" temperature, 23°C. In contrast, hot humid natives tend to evaluate "the low" temperature environment as "comfortable" and "no change (good as it)" or "slightly cooler".

In summary, the experimental results indicate that subjects from hot humid areas have the variation of some psychological responses in accordance with the change of surrounding humidity at 28°C. To be concrete, "the high" temperature tends to be evaluated as uncomfortable and unacceptable.

4. Discussion
The aim of this study was to obtain more detailed information on relation between environmental humidity and well-being of the Southeast Asians. As a result, it is cleared that hot humid natives who participated in our experiment as subjects have a variation in both physiological and psychological responses to an ambient humidity. In particular, the heat flux on forehead and humidity acceptability tends to decrease while raising ambient humidity.

Some experimental results on physiological and psychological responses to ambient temperature do not contradict the earlier studies. Former researchers reported as follows. For the people living in hot humid or dry climate, the temperature felt as "neutral (neither hot nor cold)" on thermal sensation is over 24°C and higher than Europeans [4, 22, 23]. On the other hand, note that there are two levels of temperature bands felt as "comfortable", which may mean positive "pleasantness" and negative "comfort". However anyway, our observation indicates that subjects from hot humid areas have judged

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**Table 6. Multiple regression analysis between human responses and ambient air factors.**

| Subject group       | Objective variable | Air temperature | Absolute humidity | n<sup>d</sup> | R²  |
|---------------------|--------------------|-----------------|-------------------|------------|-----|
|                     |                    | a<sup>a</sup>   | S.E.<sup>b</sup> | p<sub>i</sub><sup>c</sup> | b<sup>b</sup> | S.E.<sup>b</sup> | p<sub>i</sub><sup>c</sup> |
| Hot humid natives   | Heat flux          | -8.86           | 0.71              | <0.001     | -1.26         | 0.62         | <0.05     | 58 | 0.75 |
|                     | Thermal sensation  | 0.16            | 0.05              | <0.01      | 0.10          | 0.05         | <0.05     | 57 | 0.21 |
|                     | Thermal comfort    | -0.32           | 0.09              | <0.001     | -0.01         | 0.08         | >0.1      | 57 | 0.17 |
| Temperate natives   | Heat flux          | -8.31           | 0.77              | <0.001     | 0.60          | 0.67         | >0.1      | 61 | 0.66 |
|                     | Thermal sensation  | 0.27            | 0.05              | <0.001     | -0.002       | 0.01         | >0.1      | 61 | 0.37 |
|                     | Thermal comfort    | 0.02            | 0.09              | >0.1       | 0.09          | 0.08         | >0.1      | 61 | 0.01 |

<sup>a</sup> Partial regression coefficients
<sup>b</sup> Standard Error of regression coefficients for first and second terms
<sup>c</sup> Significance level of the regression coefficients for first and second terms
<sup>d</sup> Number in sample
the lower ambient temperature as cool, comfortable and preferable, only without air movement and behavior for adaptation.

Next, our observation of psychological reaction to ambient humidity has expanded the existing results from other researchers. The experimental evidence that Japanese thermal comfort does not depend on humidity agrees with previous study [24]. However, humidity acceptability of hot humid natives in "the high" temperature and humidity (28°C and 15g/ kg DA) is about 70%, whereas the percent satisfied predicted by acceptability in the earlier study [25] is over 90%. Preceding ratio was predicted with the situation of 20°C to 26°C ET* and less than 15g / kg DA, and it is described that there is no difference in humidity acceptability under non-sedentary activities. Furthermore, another research [23] indicates the water vapor pressure do not effect thermal comfort. However, these past studies are different in ambient temperature, air movement, race and activity during experiments, from this study. Thus, the relationship between psychological responses and ambient humidity provides ample scope for us to examine.

On the physiology, the outline may contradict previous observations [20, 26] which suggest that people living in tropic areas require a stronger stimulus for provoking a sweat reflex than Japanese. Incidentally, in these existing studies, subjects had immersed own leg into hot water (43 to 45.5 °C), their procedure therefore differ from ours. For hot humid natives in our research, the observation of variable heat flux along with a change in humidity has implied that the proportion of latent heat to heat flux is large. Then, this inference leads the argument that people born at hot humid areas are easy to sweat, and it does not agree with earlier data. Unfortunately, the sweating data suitable to verify this hypothesis was not obtained. However, there is congruity between heat flux and psychological reaction to humidity regarding hot humid natives in this study.

Therefore, in order to further verify our experimental results, it is necessary to obtain exact numerical data on sweating. In addition, it would be better to verify the change of other body parts except head, because perspiration function is scattered throughout the whole body. However, the decision drawn from these experimental results is that an upper limit on indoor humidity should be noticed for well-being of Southeast Asians.

5. Conclusion
Human subject experiments have been practiced in climate chamber, and then physiological and psychological responses to an ambient temperature and humidity were measured. All data of human reactions were recorded and collected with helps of young subjects from the hot humid or the temperate area. As a result, this experiment revealed an entity of the variation in the physiological and the psychological responses to a change in ambient humidity, regarding hot humid natives.

The brief conclusion is that it is necessary to control not only indoor temperature but also its humidity in the case of a building where there are occupants coming from hot humid locations. A surrounding with high humidity may reduce the efficiency of sweat transpiration. Furthermore, not only physiological responses but also psychological responses vary along with a change in humidity. There is a possibility that high humidity environment damages physical and mental health, that is the well-being of people from hot humid areas. In summary, a point to remember is an upper limit on indoor humidity for well-being when the prescribed temperature setting is raised for energy-saving.

From the numerical results in this study, we have reached two conclusions. Firstly, both subject groups have reacted primarily to ambient temperature. A change in ambient temperature has the tendency to involve psychological and physiological responses. Furthermore, skin surface temperature has showed that participants from hot humid regions have great physical function to tolerate heat exposure. Secondly, hot humid natives have reacted physiologically and psychologically also to a change in ambient humidity. To be concrete, the indoor air environment including much moisture may prevent sweat from efficient evaporating. In addition, dampness will make subjects feel uncomfortable and unacceptable to environment. The results lead to the recommendation that the upper limit of humidity should be determined when a setting value of temperature is raised for decreasing energy...
consumption in Southeast Asian buildings. Otherwise, many occupants would probably increase their internal heat and regard such an environment as inappropriate for working or living.

6. Next problem

To further verify our experimental results, three future works should be performed as follows. The first is to obtain exact numerical data on sweating, and the second is to understand the human reaction on the whole of the body to ambient environment. The last is to observe the long-term influence on well-being by ambient condition. Firstly, the data of body weight losses as perspiration have lacked precision in this experimental research. Numerical data should be obtained to support discussion about heat flux on sweat with transpiration. Secondly, to grasp the adequate value of humidity for physical well-being, only forehead on behalf of the whole body has been measured in this subject experiment. However, since the head is only a part of a human body, it is necessary to verify whether it is appropriate to regard the head as its representative. Lastly, this report explains the results through an acclimatization time for only one hour. There are some questions as to whether the same results can be obtained in longer acclimatization periods like as daily life. It has been known that people spend 90% of their life inside a building. Then, the fact leads the possibility that physiological and psychological characteristics may be affected by indoor climate rather than the outside. As similar opinion, the earlier researcher has been also worried that long-term exposure to the Air-Conditioned environment cause the fall in temperature felt as "comfortable" [27, 28]. It remains a challenge for future researches to investigate the actual sweating and to clear influences of physiological and psychological responses in a long term for the whole body.

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