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Field Study on Thermal Performance of a Green Office in Bangkok, Thailand: A Possibility of Increasing Temperature Set-Points

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Abstract**—**In the tropics, indoor thermal environment is usually provided by a cooling mode to maintain comfort all year. Indoor thermal environment performance is sometimes different from the standard or from the first design process because of operation, maintenance, and utilization. The field study of thermal environment in the green building is still limited in this region, while the green building continues to increase. This study aims to clarify thermal performance and subjective perception in the green building by testing the temperature set-points. A Thai green office was investigated twice in October 2018 and in May 2019. Indoor environment variables (temperature, relative humidity, and wind velocity) were collected continuously. The temperature set-point was normally set as 23 °C, and it was changed into 24 °C and 25 °C. The study found that this gap of temperature set-point produced average room temperature from 22.7 to 24.6 °C and average relative humidity from 55% to 62%. Thermal environments slight shifted out of the ASHRAE comfort zone when the set-point was increased. Based on the thermal sensation vote, the feeling-colder vote decreased by 30% and 18% when changing +1 °C and +2 °C, respectively. Predicted mean vote (PMV) shows that most of the calculated median values were negative. The values went close to the optimal neutral value (0) when the set-point was set at 25 °C. The neutral temperature was slightly decreased when changing warmer temperature set-points. Building-related symptom reports were found in this study that the number of votes reduced continuously when the temperature was warmer. The symptoms that occurred by a cooler condition had the number of votes more than ones that occurred by a warmer condition. In sum, for this green office, there is a possibility to adjust a higher temperature set-point to +1 °C (24 °C) in terms of reducing cold sensitivity, discomfort, and symptoms. All results could support the policy of changing a warmer temperature of this office to become “a better green building”.

Keywords**—**Thermal environment, green office, temperature set-point, comfort.

I. INTRODUCTION

RECENTLY, green building continues to be developed rapidly in the tropics [1]. Indoor environment is one of the main criteria because it is important to people who live inside in the building. Indoor air quality (IAQ) and its effects on health and comfort have been studied in several parts for decades [2]. The green building is potential to reduce energy use and improve satisfaction [3]. The gap between the design performance was sometimes different from the actual performance when the use of energy consumption was exceeding [4]. The actual thermal environment in the tropics was often controlled as low as those in the temperate climate zone [5]. The comfort temperature of some countries in Southeast Asia (Indonesia, Malaysia, and Singapore) was between 25.6 and 26.4 °C which was lower than that of other regions [6]. To achieve the ideal indoor thermal environment quality, the office needs to deal with energy saving and satisfaction by adjusting several factors. For example, the study of [7] in the UK tried to adjust temperature set-points in the shared-space office from 22 to 24 °C in summer. This study declares that changing higher temperature in this range did not affect discomfort levels, but thermal environments were better fit to the summer comfort zone. It was also beneficial to energy consumption in the long term [8]. However, occupants in the green office may expect higher levels of IAQ [9]. The acceptable vote in the conventional cellular office can be changed rapidly when the set-point was colder than 23 °C and warmer than 26 °C [10]. It is questionable that how much the set-point can be adjusted in the green large-scale building. In order to support more evidence, this paper present one part of the ongoing study in the tropics which mainly focuses on a case study in Bangkok, Thailand. It aims to identify a current situation of indoor thermal environment and try to enhance satisfaction by following the previous study of changing temperature set-point. It would be advantage to the office to apply to air-conditioning management to support a better green building performance in the tropics.

II. METHODOLOGY

A. Indoor Environment Measurement

The surveyed office is located in a center of Bangkok, Thailand. The office has obtained LEED Gold certification with a well-operated building management. The air conditioning system of the office is central water chiller system. The building uses the fresh-air system for the ventilation. During the survey, outdoor temperature was most stable but sometimes it was cloudy. The average of outdoor temperature during the day was between 32 and 35 °C. The average humidity was ranging at 78%–84%. In fact, the owner was aiming to apply the concept of saving energy and wellbeing encouragement in the office. So, we had an opportunity to do the actual test which was on the 11th floor. Table I describes the information of the office.

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TABLE I
BUILDING INFORMATION

General Information	
Building type	Rental office
Opening year	2017
Location	Bangkok, TH
Number of floors	25 over grounds, 3 under grounds
Floor of measurement	11th floor
Accreditation	LEED Gold
Gross area (m^2)	56,000
Office area (m^2)	1,400
Floor to floor (m)	4.2
Floor to ceiling (m)	3.2
HVAC System	
System type	Central water chiller
Ventilation system	Fresh-air system
Cooling set point (°C)	23
A/C System operation hourly	7:00–18:00
Ventilation system hourly	7:00–18:00
Occupants Information	
Number of males	36
Number of females	74
Office working hour	8:30-17.30

Table II shows the list of indoor environmental quality measuring devices. Air temperature and relative humidity were measured by TR–74Uvi that collected automatically in 1–min intervals. We also used the RTR–52A 7” Globe attached to a partition nearby occupants’ working area that was 1.1 m high from the floor. To calculate thermal performance, air velocity was measured every 10 minutes by an anemometer that was attached on a tripod. All devices were installed at every orientation in the office.

TABLE II
AUTOMATICALLY-RECORDED DEVICES

Thermal variables	Equipment	Recorded Interval
Air Speed	Anemometer	60 min
Mean radiant temperature	RTR-52A 7” Globe	10 min
Air temperature/ Humidity	TR-74Uvi	10 min

TABLE III
TEMPERATURE SET-POINT SCHEDULE

Year	Month	Date	Set-point (°C)
2018	September	Mon 24th	23
		Tue 25th	
		Wed 26th	
2019	March	Tue 21st	23
		Wed 22nd	
		Thu 23rd	24
		Fri 24th	25

One of the main issues was about to adjust indoor environment fitted to people. The building manager allowed us to change temperature from Building Automation System (BAS) from 23 to 24 °C, and 25 °C, respectively. The actual set-point of this office was quite similar to that of other offices in Thailand [10]. This study is a blinded study in order to receive the perception vote without bias. In order to focus on one variable, the air flow of the air-conditioning system was operated continuously without adjustment. The set-up plan of the cooling set-point schedule during the survey was shown in Table III.

B. The Questionnaire

The questionnaire is used to evaluate the subjective perception towards thermal environments. It was generated from ASHRAE 55 [11] and ISO 9920 [12]. Occupants could check their feelings by the 7-scale sensation vote (cold to hot), the 5-scale comfort vote (uncomfortable to comfortable), the 2-scale acceptance vote (acceptable or unacceptable), and the 5-scale preference vote. The scales of votes were explained in Table IV. The questionnaire was answered both in the morning (11:00) and in the afternoon (15:00). The time of asking the questionnaire was the same time as measuring the wind velocity for calculating operative temperature. We could collect 1,733 samples in total.

TABLE IV
SCALES OF THE QUESTIONNAIRE

Scale	Sensation (TSV)	Comfort (TCV)	Acceptance (TAV)	Preference (TPV)
-3	Cold			
-2	Slightly cold	Uncomfortable		Colder
-1	Cool	Slightly uncomfortable		Slightly colder
0	Neutral	Neutral	Acceptable	No change
1	Warm	Slightly comfortable	Unacceptable	Slightly warmer
2	Slightly hot	Comfortable		Warmer
3	Hot			

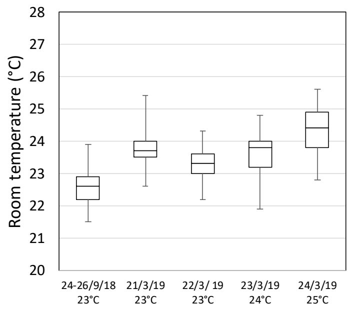

Fig. 1 Room temperature at the interior zone

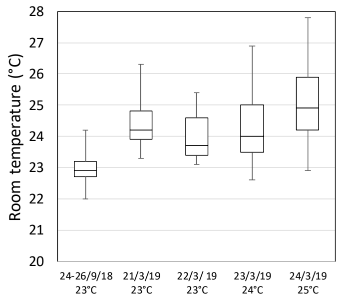

Fig. 2 Room temperature at the perimeter zone

III. RESULT AND DISCUSSION

The boxplots in Figs. 1 and 2 illustrate the values of thermal environments between the interior zone and the perimeter zone during working hours from 8:00 to 17:00. In the interior zone, median room temperature was reading as 22.2, 23.7, 23.3, 23.8, and 24.4 °C, respectively. The interquartile range of all points stayed within between 22.2 and 24.9 °C. In the perimeter zone, median room temperature was 22.9, 24.2, 23.7, 24, and 24.9 °C, correspondingly. The interquartile range of all points stayed within 22.7 and 25.9 °C. Average room temperature was ranging as 22.7, 23.5, 23.6, and 24.6 °C, respectively. Thermal environments in the perimeter zone were slightly warmer than that in the interior zone about 0.2 and 0.5 °C. Room temperature gradually extended different values when temperature set-points were changed. Especially, on 24th May 2019, it was obvious that room temperature in the perimeter zone was the widest range which differences of the maximum value and the minimum vale was 2.8 °C.

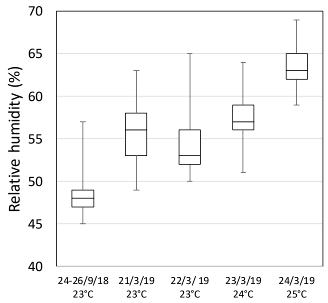

Fig. 3 Relative humidity at the interior zone

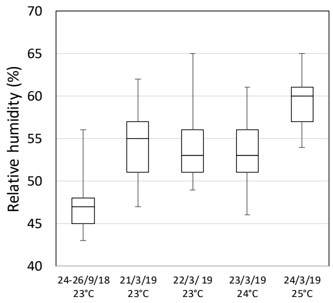

Fig. 4 Relative humidity at the perimeter zone

Relative humidity between the perimeter zone and the interior zone was drawn in Figs. 3 and 4. In the interior zone, median relative humidity was reading as 48%, 56%, 53%, 57%, and 63%, respectively. The interquartile range of all points fell within 47%–65%. In the perimeter zone, median relative was 47%, 55%, 53%, 53%, and 60%, correspondingly. The interquartile range of all points stayed within 47%–65%. Relative humidity in the perimeter zone was slightly higher than that in the interior zone about 45%–61%. There was not a significant difference between the perimeter zone and the interior zone. However, when changing the temperature on 23rd and 24th May, average relative humidity went from 54.94% to 55.8% and 61.5%, respectively. A different value between a 23 °C set-point and a 25 °C set-point was 13.8%.

Fig. 5 pictures thermal environments both operative temperature and absolute humidity drawn in the thermal comfort zone of ASHRAE [11]. Most of thermal environments fitted into the 1.0 clo comfort zone rather than the 0.5 clo comfort zone. Particularly, on 24th–26th September 2018, 90% of thermal environments were in the 1.0 clo comfort zone. When operative temperature dropped to 21.4 °C, absolute humidity was 0.008 g/g. When the set-point was changed to 24 °C on 23rd March 2019, 40% of thermal environments were in the 0.5 clo comfort zone. Operative temperature was ranging from 21.6 to 26.7 °C, while absolute humidity was controlled in the range of 0.008 and 0.011 g/g. When the set-point was changed to 25°C on 24th March 2019, 25% of thermal environments were in the 0.5 clo comfort zone and 51% of them fell outside both comfort zones. It is possible changing a higher set-point is that thermal environments could not meet the comfort range because of the excessive absolute humidity is out of control which its value was over 0.012 g/g. Difference of operative temperature and absolute humidity of each temperature set-point became more various.

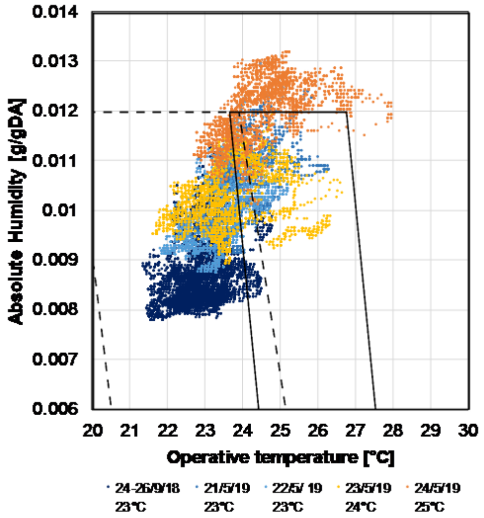

Fig. 5 A psychometric chart

Fig. 6 shows the percent vote of thermal sensation vote. Most of samples voted for neutral (51%, 54%, 56%, 60%, and 63%, respectively. Neutral votes slightly increased when colder-than-neutral votes decreased. The colder-than-neutral side refers to three scales of the vote which are slightly cool, cool, and cold. The warmer-than-neutral side refers to three scales of the vote which are slightly warm, warm, and hot. In total, percentage of the colder-than-neutral votes was different from that of the warmer-than-neutral votes by +42%, +28-, +33%, +20%, and -12%. Most of the day, occupants felt in the colder side. Considering the date of 25 °C, the thermal sensation vote declares a different trend from others. The warmer side had higher percent of vote than the colder side (27%:13%). Occupants might notice that the set-point was changed as high as +2 °C.

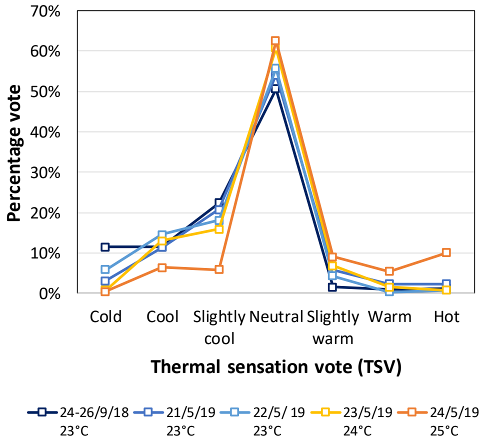

Fig. 6 Thermal sensation vote

According to the thermal comfort vote, Fig. 7 shows that percent vote of neutral was the highest rate compared with other scales. The neutral comfort rate on the set-up condition increase almost 10%. It seems that changing temperature could be mostly relative to the slightly-than-neutral scale. The slightly comfortable rate significantly became lower when changing into higher temperature from 28% to 12%. Regarding to 20% of discomfort, the votes of some days were a little over at 21% (24th–26th September 2019, 22nd and 24th May 2018. The 24 °C set-point day had the lowest rate (1%) in an uncomfortable scale and the highest in a comfortable scale (23%) at the same time.

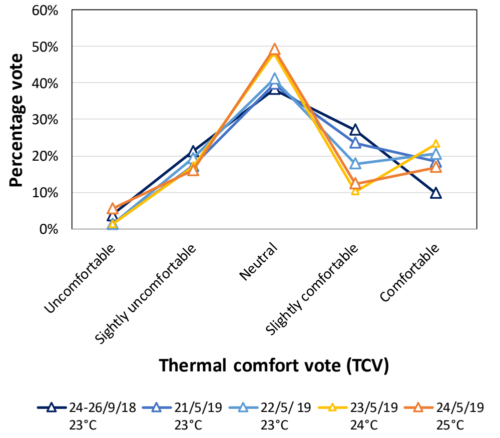

Fig. 7 Thermal sensation vote

Relation between thermal sensation and thermal comfort is illustrated in Fig. 8. Number of votes in a neutral group was the highest in neutral comfort. Occupants who voted for neutral answered comfortable at 25%, but they answered uncomfortable only at 1%. Considering a colder-than-neutral group, occupants voted for the uncomfortable side rather than the discomfort able side. Slightly discomfort votes were twice as high as slightly comfortable votes.

The thermal acceptance votes in Fig. 9 show that over 80% of samples accepted thermal environments. The highest rate was in a day of 24° C set-point which was 92%. Percentage of unacceptable votes of each day was reading as 18%, 11%, 14%, 8%, 19%. The unacceptable votes increased when thermal conditions had changed into cooler or higher points. If we consider the limit of unacceptable votes at 20%, all thermal environments still mitigate occupants' satisfaction. However, if we shorten the scope of unacceptable votes at 10%, there were only thermal environments at a 24 °C set-point being with this requirement.

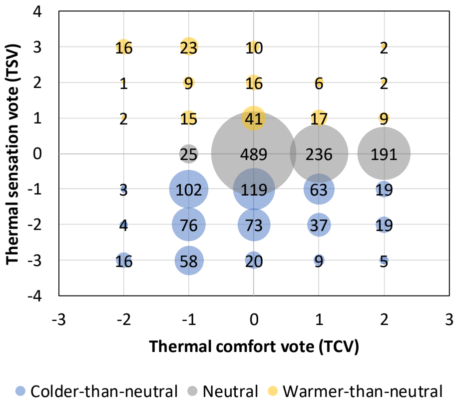

Fig. 8 Relation of comfort and sensation

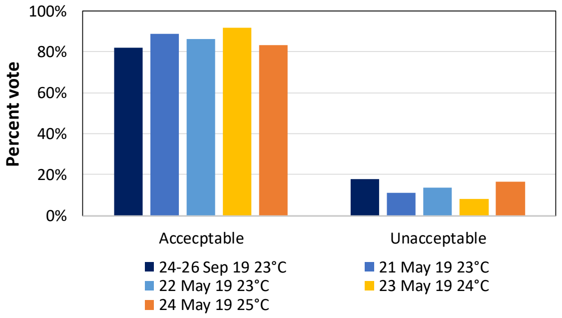

Fig. 9 Thermal acceptance vote

Despite that, the thermal preference was compared with the thermal sensation vote shown in Fig. 10. When changing higher set-points, percent vote of colder-than-neutral sensation slightly reduced while the percent of preferring warmer temperature decreased. In contrast, percent vote of warmer-than-neutral sensation and that of preferring colder temperature were almost stable, but they increased only when the set-point was at 25 °C. The highest percent of "No change" was at 24 °C which reached to 76%.

Fig. 11 shows the results of PMV calculated by using the equation from [13]. The median values were -0.45, -0.31, -0.35, 0.37, and 0.14, respectively. Data of all dates was in a range of the recommendation (-0.5–0.5). The nearest optimal value (PMV = 0) was in the last day of 25 °C. Fig. 12 expresses differences between thermal sensation vote and PMV that were 0.01, -0.1, 0.06, 0.23, 0.19. Both were not much different in this case study.

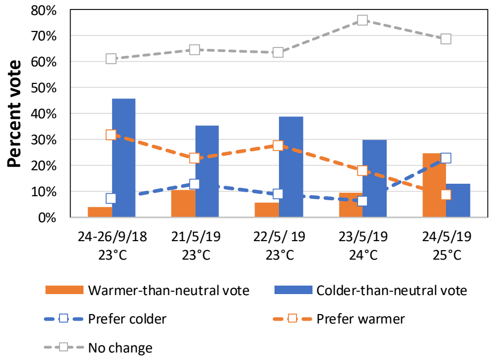

Fig. 10 Thermal sensation vote and thermal preference vote

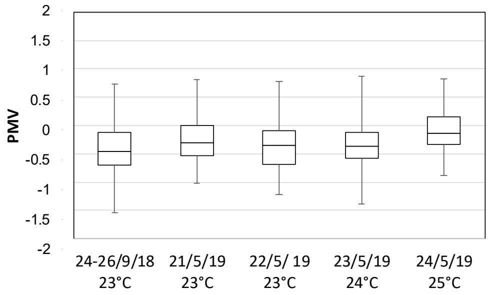

Fig. 11 PMV

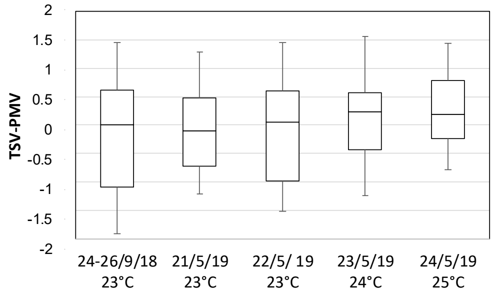

Fig. 12 Difference between the thermal sensation vote and the PMV

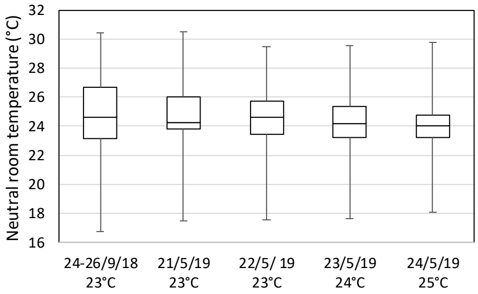

Fig. 13 Neutral room temperature

Based on the calculation of [14], Fig. 13 shows that the median values of neutral room temperature of each day were 24.6, 24.3, 24.6, 24.2, and 24.1, respectively. The interquartile range of in the 2018 survey was which was between 23.2 and 26 °C which were wider than those in the 2019 survey. Different values from 25% to 75% of this range were slightly shortened from 3.1 to 1.5 °C. The 25 °C set-point had the shortest interquartile ranging at between 23.2 and 24.8 °C. It is noticeable that the neutral temperature of each day was mostly close to thermal environments on 24th May 2019 when the set-point was set as 24 °C.

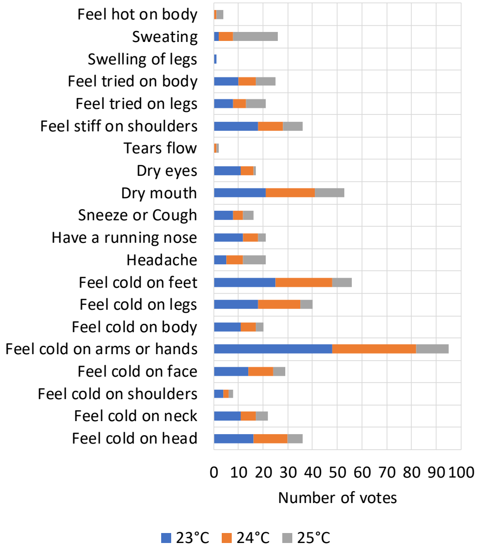

Fig. 14 Symptom reports

By means of a better living condition, Fig. 14 pictures the number of votes that occupants thought those symptoms were caused by indoor thermal environment. The votes of the day of 23 °C set-point were selected only on 22nd May 2019 due to the highest rate. In each group, the summed votes were 283, 184, and 122, respectively. It found that 23 °C group had the highest complaints of symptom reports which was 44%. The votes gradually reduced when the temperature was set higher. For example, the number of votes of feeling cold on arms or hands was 48, 34, 13, respectively. However, 25 °C group could bring about higher complaints of being sweating, being tired of body parts, and being headache. The symptoms that occurred by a cool condition had the number of votes more than those that occurred by a hot condition. The results could compare with [15] that there were similar symptoms affecting occupants when most thermal conditions were in the 1.0 clo comfort zone.

IV. CONCLUSION

The field study was conducted in a green office in Bangkok, Thailand to observe thermal environments in order to estimate a possibility of adjustment towards occupant's satisfaction. In general, thermal environments were in the 1.0 clo comfort zone rather than in the 0.5 clo comfort zone when the set-point in the office was controlled as 23 °C. Some thermal environments in measure referent points were not suitable to people in the tropics as the ASHRAE standard recommended. Adjustment of chiller performance at the same set-point temperature could reduce overcool conditions and dryness. It was possible to adjust the set-point temperature higher than 23 °C. However, this study found that the 25 °C set-point could provide excessive humidity in some reference points. In terms of sensation, the feeling-colder-than neutral was slightly decreased when changing temperature was warmer. Percent of discomfort vote of each day was stable, but the slightly comfortable rate significantly became lower when changing into higher temperature. The number of symptoms votes became smaller when temperature was warmer. The symptoms that occurred by a cooler temperature were higher than those of a warmer temperature. In sum, this office building can increase a higher temperature set-point at 24 °C for the higher acceptance. However, this study has a limitation of case studies. A future study should extend number of buildings and occupants.

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REFERENCES

[1] BCI ASIA, Green Building Market Report South East Asia 2014, (Online). Available: https://www.bciasia.com/wp-content/uploads/2015/03/Green.Building.Market.Report.2014.pdf (Accessed: 29 June 2019).

[2] K.W. Tham, Indoor air quality and its effects on humans—A review of challenges and developments in the last 30 years. Energy Build. 130 (2016) 637-650.

[3] B. Lin, Y. Liu, Z. Wang, Z. Pei, M. Davies, Measured energy use and indoor environment quality in green office buildings in China, Energy Build. 129 (2016) 9–18.

[4] C. Ionescu, T. Baracu, G.-B. Vlad, H. Necula, A. Badea, The historical evolutionof the energy efficient buildings, Renew. Sustain. Energy Rev. 49 (2015) 243–253.

[5] Eco-Business, Freezing in the tropics - Asean's air-con conundrum (Online). Available: https://www.iea.org/southeastasia/ (Accessed: 30 June 2019).

[6] S.A. Damiati, S.A. Zaki, H.B. Rijal, S. Wonorahardjo, Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot humid season, Build. Environ.109 (2016) 208-223.

[7] M.P. Deuble, R.J. de Dear, Green occupants for green buildings: the missing link, Build. Environ. 56 (2012) 21–27.

[8] BCO. 24_C Study: comfort, productivity and energy consumption: case study. British Council for Offices; 2010.

[9] M. Lakeridou, M.Ucci, A. Marmot, I. Ridley, The potential of increasing cooling set-points in air-conditioned offices in the UK, Applied Energy 94 (2012) 338–348.

[10] N. Yamtraipat, J. Khedari, J. Hirunlabh, J.Kunchornrat, Assessment of Thailand indoor set-point impact on energy consumption and environment, Energy Policy. 34 (2006) 765–770.

[11] ASHRAE, Thermal Environmental Conditions for Human Occupancy, ANSI/ASHRAE standard, 2013, 55—2013.

[12] ISO 9920, Ergonomics of the Thermal Environment: Estimation of Thermal Insulation and Water Vapour Resistance of a Clothing Ensemble International Standard, 2007.

[13] ČSN EN ISO 7730. Moderate thermal environment – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, Prague, 1997.

[14] F. Nicol, M.A. Humphreys, S. Roaf, Adaptive Thermal Comfort: Principles and Practice, Routledge, London, 2012.

[15] S. K. Jusuf, M. Ichinose, Y. Fukawa, S. Sattayakorn, Study on the thermal performance of office spaces in the tropics: A case study in Singapore, in: Proceedings of 34th International Passive and Low Energy Architecture.