Thermal Comfort and Building-related Symptoms in Air-conditioned Office Buildings in a Hot-humid Climate: The Impact of Set-point Temperature

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Introduction

Indoor thermal environment is important for maintaining comfort and health. In a tropical region, it becomes more critical when the cool indoor environment consumes excessive energy for a whole year. After-built assessment is necessary to conduct to benefit occupants and building operation teams to produce suitable cooling indoor environment. However, there is a lack of scientific evidence on adjusting the cooling setpoint in the real situation. This study questions on whether thermal environments are adjustable to support comfort and health and what the comfort temperature range of occupants in open-plan offices should be. It aims to evaluate the actual thermal environment in air-conditioned offices and to clarify the optimum temperature by considering human comfort and building-related symptoms. This present study comprises of five chapters as following.

Chapter 1 is an introduction that briefly explains about the background and rational for this study. The background information includes the overview on thermal environmental theory, significance of cooling setpoints that affects energy saving, comfort, and building-related symptoms. The research structure covered an identification of thermal comfort factors from a review of existing assessments and standards which links to subjective responses effected by both existing thermal performance and set-up thermal performance. The main objectives are: 1) To clarify indoor thermal environments in air-conditioned offices in a hot-humid climate between an actual condition and a controlled condition; 2) To determine people responses and estimate comfort temperature ranges in each thermal condition.; 3) To find the relation between thermal environments and building-related symptoms in order to support an optimum indoor temperature.

Chapter 2 covers a systematically review of previous studies; including existing international and local standards & guidelines, thermal environmental effects on comfort and health, and a measurement for occupant comfort. Many previous studies declared the comfort temperature and thermal acceptability towards different indoor thermal environments. A knowledge related to the specific requirements on, particularly in a hot-humid context, is yet to be explored. Therefore, this research aims to fill this gap and rigorously verified the knowledge with an intensive field study.

Summary of set-point temperature.

Table 2-3. Summary of indoor setpoint temperatures.

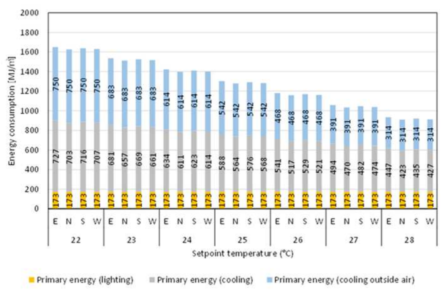
County	Authority or name of standard	Temperature (°C)	Types	Season
USA	ASHERAE 55	23-26	R	Summer
UK	British Council for Offices (BCO)	22-24	R	Summer
Japan	Cool Biz campaign	Up to 28	R	Summer
Singapore	SS 554: 2009	24-26	C	All
Indonesia	SNI 6390:2011	25.5	C	All
Malaysia	Malaysian government	24	R	All
Thailand	Thai government	25	R	All
Thailand	E.I.T.	24	R	All

Note: R, Recommendation; C, Code of practice

Chapter 3 explains about the research methodology which adopted a mixed-method approach to assess a complex integration of qualitative and quantitative findings. Six air-conditioned offices located in Bangkok metropolitan, Thailand, was selected as case studies (Office A–F). Indoor environmental quality (IEQ) measuring devices were installed in all open-plan office spaces to collect thermal variables. During working hours, the indoor setpoint temperature was increased from the actual value to +1 and +2 °C, respectively. The questionnaire was distributed to occupants to evaluate thermal sensation, thermal comfort, thermal preference, adaptive behaviors, and building-related symptoms. There were 323–348 persons (179 males and 260 females) participating the survey. This chapters also presents the potential of energy savings towards changing set-point temperature and relative humidity in the tropics by using the computer simulation program called "hLoad-L". The simulation showed the wide range of adaptable scenarios ranging between 22 and 28 °C. At 60% RH, the primary energy

Measuring devices.

Energy consumption by simulation.



consumption could be reduced at least 7% when the set-point temperature was changed to be one degree higher (from 22 to 23 °C). The simulation confirms a great potential on energy saving in air-conditioned office spaces in the tropics.

Chapter 4 the results of on-site measurement and questionnaire.

4.1 Thermal variables

Before intervention, the average room temperature of both zones ranged between 22.3 and 23.2 °C. The mean room temperature of all offices was lower than 25 °C and several points were out of the ASHRAE recommended values (23–26 °C). When the set-point temperature increased, the temperature continued to increase from the first day reaching 23.8–25.3 °C (interior) and 24.8–26.5 °C (perimeter), respectively. The values on the controlled days fitted to the recommendation more than those on the normal day. In the actual condition, the relative humidity was 51.2–68.3%. Most values belonged to the range of the ASHRAE standard (40– 60%). However, When the set-point temperature increased, the relative humidity became more varied as 41.0–65.7%, which the values were out of the standard in some cases. Thermal environments are plotted on a psychometric chart, those in the actual cooling set-point were generally in the 1.0 clo zone rather than the 0.5 clo zone. However, thermal environments on a controlled condition gradually shifted to the 0.5 clo zone or out of comfort zones owing to the absolute humidity that was higher than 0.012 g/g.

4.2 Questionnaire

4.2.1 Thermal sensation vote (TSV)

In the actual condition, all cases reported the colder-than-neutral votes (TSV-) with higher different ratio than the warmer-than-neutral votes (TSV+). The rate of warmer-than-neutral votes (TSV+) increased when temperature was changed, whereas the rate of colder-than-neutral votes (TSV-) significantly decreased. The acceptable rate at the actual setpoint was lower than the increased setpoint either +1 or +2 °C. The acceptable rate of TSV could meet up with the ASHRAE requirement when the temperature was set as 24–26 °C.

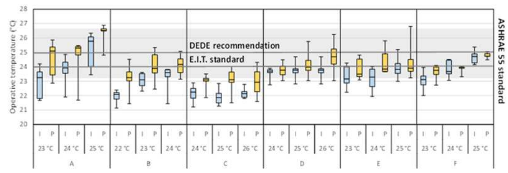
4.2.2 Thermal comfort vote (TCV)

On the first day, all cases generally reported the comfortable range (0, 1, and 2) higher than the uncomfortable range. There were a large number of occupants reporting the cold sensation while voting uncomfortable. People could handle to a warmer condition with small number of complaints. In terms of maintain comfortable rate, increasing setpoint + 1 °C is possible to set in all cases, while + 2 °C is applicable to three out of the six cases.

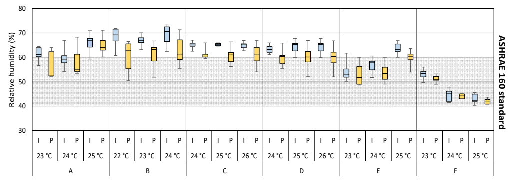
4.2.3 Thermal preference vote (TPV)

For the TPV, the colder-than-neutral votes (TPV-) with higher different ratio than the warmer-than-neutral votes (TPV+). The rate of TPV- became lower when the temperature increased. The TPV is generally related to TSV, when almost 80% of occupants who voted

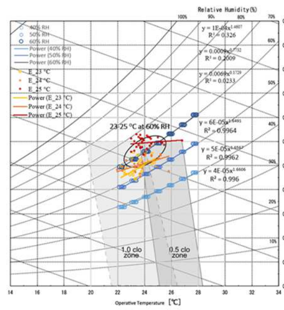
Distribution of room temperature.



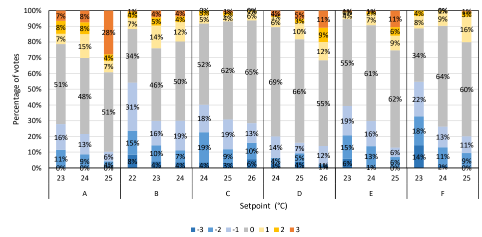
Distribution of relative humidity.



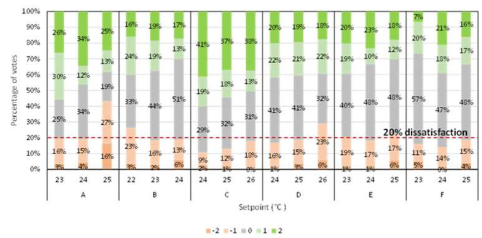
Psychometric chart.



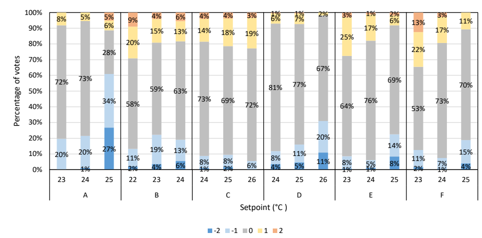
Thermal sensation votes.



Thermal comfort votes.



Thermal preference votes.



for TSV=0 chose to vote for TPV=0 at the same time.

The significant level of the change of temperature is calculated by using a statical Mann-Whitney (U) test. The results found that people noticed the change of temperature and they changed sensation and preference votes. However, the comfort votes were not significantly changed to be significantly different from the actual day. This confirmed that people could possibly adapted the change of thermal environment.

4.2.4 Predicted mean vote (PMV)

The estimation tended to be out of the recommendation zone (PMV= - 0.5 to 0.5) due to the low air temperature. Percentage of PMV fitted with ASHRAE standard 55 – 2017 gradually increased when the setpoint was increased. It could be concluded that in terms of the PMV, the best values belonged to the warmest set-point temperature.

4.2.5 Griffith's method

The mean of each office ranged 22.4–25.6 °C (average = 23.9 °C) (the interior zone) and 23.3–25.1 ° C (average = 24.1 °C) (the perimeter zone), which the median was higher than the actual average operative temperatures about +1.3° C (22.7 °C) (interior) and +0.4 ° C (23.7 ° C) (perimeter), respectively.

4.2.6 Comfort temperature range

The comfort temperature range evaluated by using data of thermal performance and subjective votes.

- **TSV and TCV**

Considering 20% of dissatisfaction of TSV, occupants accepted operative temperature between 23 and 25 °C, whereas the acceptable rate of TCV was 1 °C higher ranging between 24 and 26 °C. The overlapping acceptable range between TSV and TCV was found to be 24–25 °C.

- **Average values of selected votes**

The 0 scale of TSV and TPV, and the comfortable scale of TCV, were selected for finding the average operative temperature that could obtain those votes. The average comfort temperatures from the three types of votes were comparable to each other in the ranges of 22.9–23.0 °C (perimeter) and 24.1–24.5 °C (interior).

- **CIBSE guideline**

The comfort temperature using the CIBSE equation lied within the recommended zone ranging between 24.5 and 25.0 °C (average = 24.7 °C).

- **Probit regression**

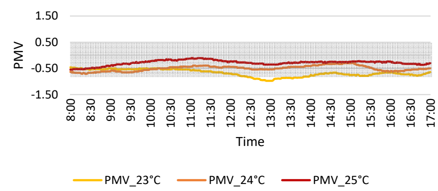
The comfort temperature ranges for a dissatisfaction of 20% were 22.7–25.1 °C (perimeter) and 22.7–26.0 °C (interior). The points of intersection between the colder-than-neutral votes and warmer than neutral votes were 24.8 °C (interior zone) and 24.0 °C (perimeter zone). The possibility of increasing temperature is found to be 0.9 to 2.2 K.

Significant level of TSV.

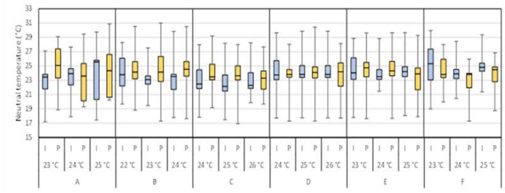
Case	Index	Setpoint °C Day 1 (±0 °C)	Day 2 (+1 °C)	Day 3 (+2 °C)	Sig. 1:2	Sig. 1:2
A	N	61	93	97	0.28014	0.00168
	Mean	0.03	0.23	0.85		
	SD	1.28	1.25	1.51		
B	N	144	167	163	< .00001	0.00008
	Mean	-0.69	-0.11	-0.14		
	SD	1.23	1.29	1.19		
C	N	194	159	144	.11184.	0.16758
	Mean	-0.55	-0.35	-0.43		
	SD	1.07	0.97	0.97		
D	N	170	175	165	0.14986	.00026
	Mean	-0.11	0.02	0.45		
	SD	0.97	1.15	1.24		
E	N	257	245	218	0.01352	< .00001
	Mean	-0.58	-0.32	0.32		
	SD	1.05	0.93	1.24		
F	N	168	175	149	< .00001	< .00001
	Mean	-0.87	-0.31	-0.05		
	SD	1.31	0.88	0.92		

Note: N, number of samples; SD, standard deviation; Sig.1:2, significant level of thermal sensation votes between the first day and the second day; Sig.1:3, significant level of thermal sensation votes between the first day and the third day. Statistical test: Mann-Whitney (U) test.

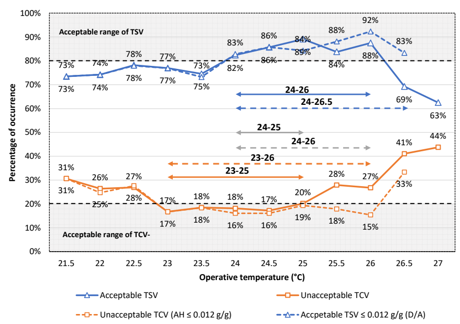
PMV (example of Office F).



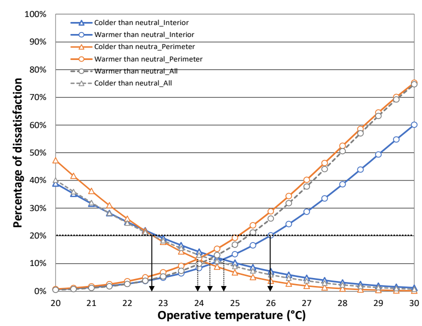
Neutral temperature by Griffiths' method.



Acceptable range of TSV
and Unacceptable range of TCV.



Probit percentage of dissatisfaction.



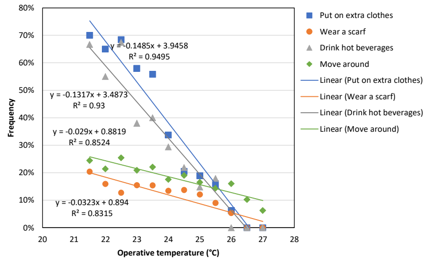
4.2.7 Thermal adaptive behaviors

In the cooling conditioning, the high tendency of adaptive behaviors easily occurred, while the warmer condition declared the lower rate of thermal adaptability. Particularly, the frequency of clothing change of people who felt colder-than-neutral was higher than 20% from 24.5 °C, while those who felt warmer-than-neutral started reported this behavior being larger than 20% at 25.5°C.

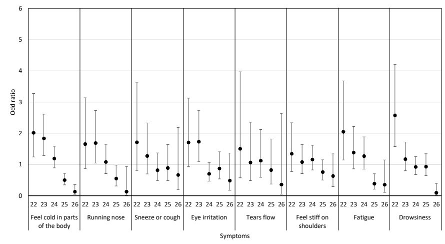
4.2.7 Building-related symptoms (BRS)

The last content of this section focuses on the relation between the thermal environment and the building-related symptoms. The prevalence of general, mucosal, skin symptoms which were associated with eyes, nose, and upper respiratory, and skin, were observed. It was found that among sixteen symptoms, the three highest report belonged to feeling in cold parts of the body (38%), drowsiness (28%), feeling stiff on shoulders (22%). The frequency of overall BRS reports was found to be gradually reduced by 15%, 13%, and 11% respectively. The symptom reports declared that a high frequency of symptoms is observed in the low temperature range. The Odds Ratios (OR) estimates that a low temperature of 22–23 °C results in the highest occurrence of most symptoms. In contrast, high temperatures between 25–26 °C are associated with a decrease in most symptoms, except for the sensation of heat in different parts of the body, sweating, and stuffy nose. Occupants in offices with colder thermal environments complained about the symptoms more frequently than those in warmer conditions. The TSV- side exhibited a higher frequency of ten symptoms, except for feeling hot in parts of the body, sweating, and swelling of legs. People who were sensitive to the cold complained more about their symptoms, as compared to those who felt warm (76:40). Considering thermal comfort votes, the ratio of the TCV- was slightly lower than that of TCV+ (38:19). The highest three different values between TCV+ and TCV+ were feeling hot in parts of the body (32%), swelling of legs (30%), and stuffy nose and headache (25%). When the ratio between the comfortable votes and the uncomfortable votes was not much different in serval symptoms, it could not be confirmed that the thermal environment featuring high comfort was supportive of the wellbeing of occupants.

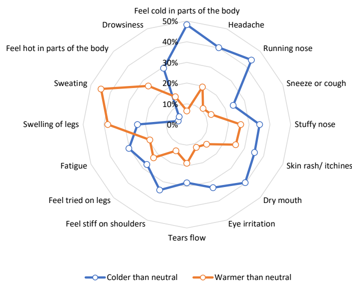
Adaptive thermal behaviors.



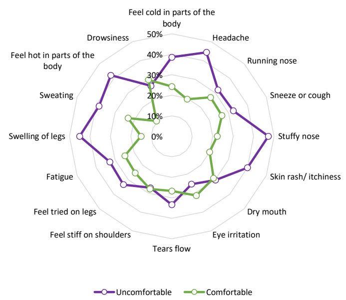
Odds ratio.



BRS with respect to the thermal sensation vote.



BRS with respect to the thermal comfort vote.



Chapter 5 finally concludes the major findings of this study. All comfort temperatures found from several methods could be a reference to rethink about setting the optimum temperature in shared office spaces in a hot-humid climate. In summary, apart from the reduction in energy consumption, a warmer environment satisfies human comfort and improves health in the long run. To reduce sensitivity to cold and similar symptoms, the indoor thermal environment should be maintained at a higher temperature; however, the humidity of this environment needs to be controlled to ensure optimum thermal performance. The intention of enhancing comfort and promoting better health conditions in the offices of these regions was discussed by considering warmer indoor temperatures. A possibility of increasing cooling set-point temperature to be 24–25 °C is applicable to air-conditioned offices in Thailand. The findings of this study support the implications for healthy building development in areas featuring hot and humid climates.