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Field Study on Nationality Differences in Adaptive Thermal Comfort of University Students in Dormitories during Summer in Japan

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Abstract: A summer field study was conducted in two university dormitories in the Tokai region of Central Japan. The study aimed at understanding the correlation between subjective thermal responses as well as whether nationality was affecting the responses. It was observed that nationality significantly affected thermal sensitivity and preference. The occupants' acceptance for thermal stress was invariably above 90%. Despite the high levels of humidity observed, the multiple regression model showed that only the indoor air temperature was significant for explaining the variability of thermal sensation for both Japanese and non-Japanese students. The highest probability of voting neutral for university students in dormitory buildings in the Tokai region of Japan was estimated within 24~26.5 °C (by probit analysis). Japanese students were more sensitive to their indoor environment as opposed to the international students. The adjusted linear regression coefficient yielded from the room-wise day-wise averages were 0.48/K and 0.35/K for Japanese sensitivity and international sensitivity, respectively. In our study, the Griffiths' model of estimating comfort temperature (or thermal neutrality) showed weak predictability and notable differences from the actually voted comfort. The neutral and comfort temperature observed and estimated in the study remained invariably below the recommended temperature threshold for Japan in summer leading to believe that that threshold is worth reevaluating.

Keywords: dormitory buildings; field survey; summer season; subjective thermal responses; neutrality; comfort

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1. Introduction

Research about indoor thermal comfort—its physical, psychological and physiological aspects, as well as its influence on architectural design—has been continuously conducted since the 1970s [1,2]. The development of Fanger's Predicted Mean Vote (PMV) thermal comfort model [3] shaped the scientific thinking and legislation making for an extended period during which the occupant has been considered mostly as passive towards the indoor environment. However, with the development of the "adaptive thermal comfort" model, the focus shifted back to the human occupants and their active interaction with the indoor environment. The adaptive approach is grounded on the notion that "comfort temperatures . . . are changeable, rather than fixed" [2] and given the possibility people will make themselves comfortable using numerous measures. Structured studies on adaptive thermal comfort stem from the pioneering work of Dr. Bedford in the 1930s [2], who laid the basic foundations of the field research, developing his seven-point scale to evaluate subjective votes and integrated statistical analysis in comfort research. In the following

~90 years (especially the last 20 [4]) the research in the field of thermal comfort has compiled vast amounts of worldwide data [5] and scientific insights.

Thermal comfort research in Japan is extensive in office [6–12] and residential [13–15] buildings and mainly targets Japanese subjects [8–10,12,14], occasionally including foreigners in Japan [7,11]. The comfort temperature in summer for Japanese office workers was determined as 25 °C [10,11] 26 °C [6,9] or 27 °C [7,8] as compared to other Asian nationals from Malaysia, Indonesia and Singapore [6] (28 °C) living in their native countries. When subjected to the same climatic conditions in Japan, the observed difference in neutral temperature between Japanese and non-Japanese office workers (In that study mainly native to Northern America and Europe) was 3 °C where foreigners preferred the lower temperature [11]. In residential buildings comfort was again reported at 26 °C [14], 27 °C [13] in summer, however with much bigger seasonal differences [13,14] as compared to offices. Researchers warn that the recommended summer minimum temperature of 28 °C in Japan might be too high to ensure comfort [6,7,10]. The level of acceptability, despite the poorer indoor environment quality, was observed as high when people were aware of the reasons for energy saving and are given certain adaptive opportunity in offices. However, with the undesirable follow-up result of lower productivity and high level of dissatisfaction [9]. Researchers appeal for further analyses on thermal comfort and occupant behavior for the effective implementation of energy saving programs [8,9] and developing a Japanese adaptive model for offices [7,10] and dwellings [13].

Adaptive comfort has been investigated in offices in Qatar [16,17], Iran [18], Pakistan [19], in traditional houses in Nepal [20], in contemporary houses in UK [21], Singapore [22], Indonesia [23], Malaysia [24], India [25], China [26–28] and all over the world in various building types since developing the adaptive concept. The necessity to rethink comfort has been widely agreed on. Subjective comfort was proven to be achieved in much wider range of conditions than previously believed and, even though this challenges the design of built environment, it holds great potential for energy conservation. Building type and occupancy are factors influencing subjective comfort. Being previously under-investigated, dormitory buildings have spiked the research interest in the recent years in China, leading to field studies in all seasons [29–33]. The less restricted personal control in dormitories stimulated a wide range of adaptive behaviors and subsequently wide comfort ranges. In hot summer conditions and indoor temperatures within 28–33 °C, comfort was observed within 25–29 °C [29] and was mainly predetermined by the local body sensation at head and chest, rather than extremities [32].

Adaptive thermal comfort research in dormitory buildings have been somewhat neglected in Japan, while they can be considered a unique combination of residence and office. Still, Schweiker and Shukuya focused their research interest on dormitories in Japan investigating on changing occupant's behavioral patterns. They found that in moderate climates it can lead to significant decrease in building's energy use. If combined with building's envelope improvements, the overall energy consumption might drop by 76–95% [34]. They experimented further to find which methods could most effectively stimulate behavioral change towards the use of low energy measures to achieve comfort. Their studies showed that personally disseminating information in the form of a workshop can lead to effective behavioral change and subsequently to up to 16% reduction in the use of cooling devices [35] as well as to changing occupant-window interaction [36] both leading to potential energy conservation.

The concept of adaptive comfort implies that in a dormitory with single-occupant rooms it is likely to observe the true subjective sensation and evaluation of indoor environment. In a private dormitory room (1) a maximum "adaptive opportunity" exists, (2) there are limited financially induced energy consumption restraints and (3) the social etiquette or the office dress code has hardly any impact. Moreover, Japan aims at increasing the number of international students as a response to the country's pressing demographic and economic problems [37], and dormitories accommodate occupants from diverse nationalities. Most international students are accommodated in dormitories mainly built in the 1970s. It can be expected that in Japan, the process of refurbishing or rebuilding the university dormitories has just started. However, the new buildings must perform at an elevated level for an unprecedented combination of factors–accommodating multinational occupants, providing healthy and emotionally stimulating environment for effective and creative studies, for the optimum rest and socialization, as well as limiting the energy consumption without compromising comfort.

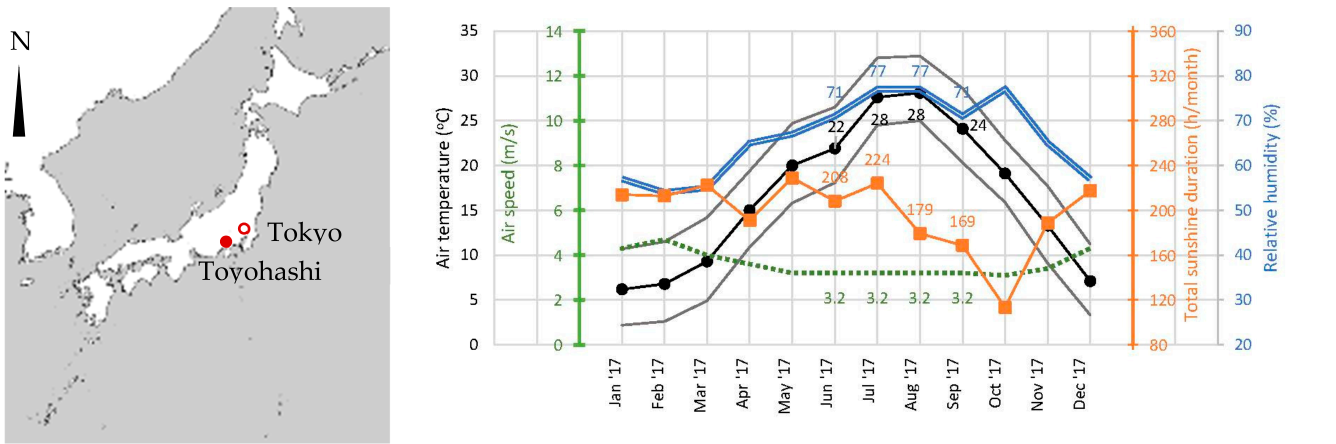
This reasoning led to planning and conducting a field survey in the summer of 2017 in two university dormitory buildings. The aim was:

- To snapshot the subjective thermal comfort of the Japanese and non-Japanese students relative to temperature, humidity, and other factors;
- To understand what the difference is, if any, between the temperature defined as neutral or comfortable; and
- To get an insight of how tolerant the students are to their indoor environment.

2. Methodology

2.1. Location and Climate

Toyohashi (34°46′9″ N 137°23′29.5″ E) is located in the southeastern part of Aichi Prefecture (central part of the main Honshu island, on the Pacific Ocean side). The climate is classified as Cfa by the Köppen–Geiger climate classification system [38,39]. It is mild, generally warm, and temperate. It has four seasons with a hot, humid summer (June, July, and August) and a distinct rainy season. The data for 2017 was provided by Japan Meteorological Data Agency (JMA) from WMO ID:47654 (weather meteorological observation point) [40]. This WMO point is located 35 km to the northeast of Toyohashi at similar distance from the Pacific coastline. The mean monthly outside temperature reached its maximum in August ($T_{avg.}$ = 28.1 °C; $T_{min.}$ = 25.0 °C; $T_{max.}$ = 32.2 °C). The mean relative humidity reached its maximum of 77% in July, August and October as shown in Figure 1.



(**a**) (**b**)

Figure 1. Toyohashi, Japan: (**a**) location (Note: the map is not to scale – to be used for general location only); (**b**) climate. Data from JMA WMO ID: 47654—min, max and mean air temperature, and relative humidity for 2017.

2.2. Measuring Period

The summer stage of the field survey was conducted in 2017 (from 26 June–29 September). The targeted period was the hot-humid summer. The period was divided in three sub periods. Each sub period consisted of two weeks of measurements (sub-period 1: 6/26~7/07; sub-period 2: 7/17~7/28; sub-period 3: 8/14~9/29). The weeks of the survey were not sequential to better adjust to the academic calendar and students' lifestyle. Within each week, the measurements were taken during the normal working days, from Monday to Friday (see Section 2.5).

2.3. Dormitory Buildings Information

The survey was conducted in two dormitory buildings (Figure 2): International dormitory (Kaikan) and in the newly built dormitory for Japanese and foreign students (GSD–Global students' dormitory) in Toyohashi University of Technology, Japan (TUT). Kaikan was built in 1970s and the load bearing structure and building envelope are predominantly reinforced concrete while GSD buildings were built in 2016. GSD has a steel load bearing structure. The structure and building envelopes of both dormitories are completely different. However, the feeling of comfort is considered to be irrespective of the building envelope even though the final energy consumption is highly dependent on it. As previously stated, "achieving high energy performance results from a dynamic system of four main key factors–thermal comfort range, heating/cooling source, building envelope and climatic conditions. A change in any single one of them can affect the final energy performance" [41]. In this study, the focus was on the thermal comfort range.

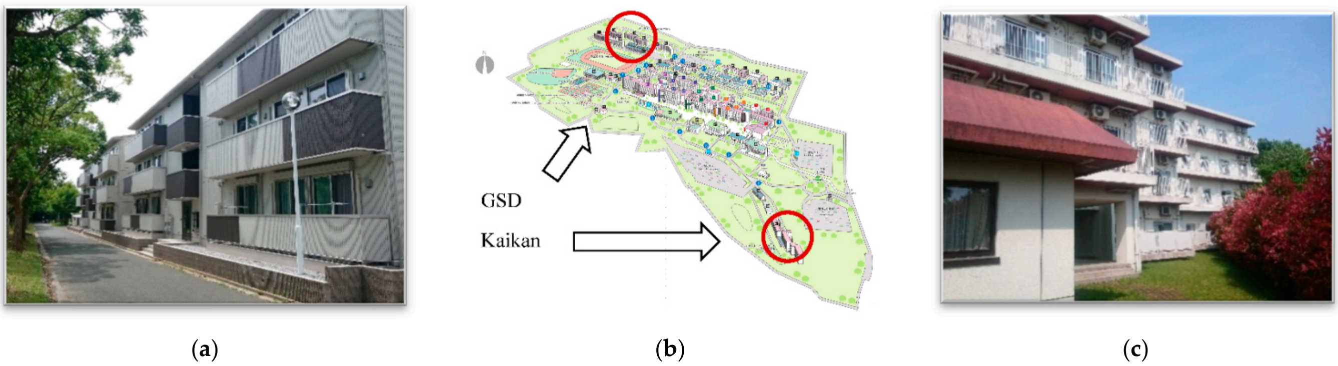


Figure 2. Dormitory buildings in TUT: (**a**) GSD; (**b**) TUT campus and dormitory locations; (**c**) Kaikan.

In both buildings, there are air conditioners installed, so the buildings can be considered as mixed mode. The rooms from Kaikan which were part of the study, were for a single occupant. They are either with a shared kitchen and a shared bathroom on the same floor, or with a small private kitchen and a private bathroom (Figure 3b,c). The GSD building is organized as shared apartments where five students live in the same apartment in private rooms but share a living space and a bathroom (Figure 3a,b). Air conditioning for both dormitory buildings is local for each single room and students have full adaptive opportunity of control over the indoor environment in their private rooms.

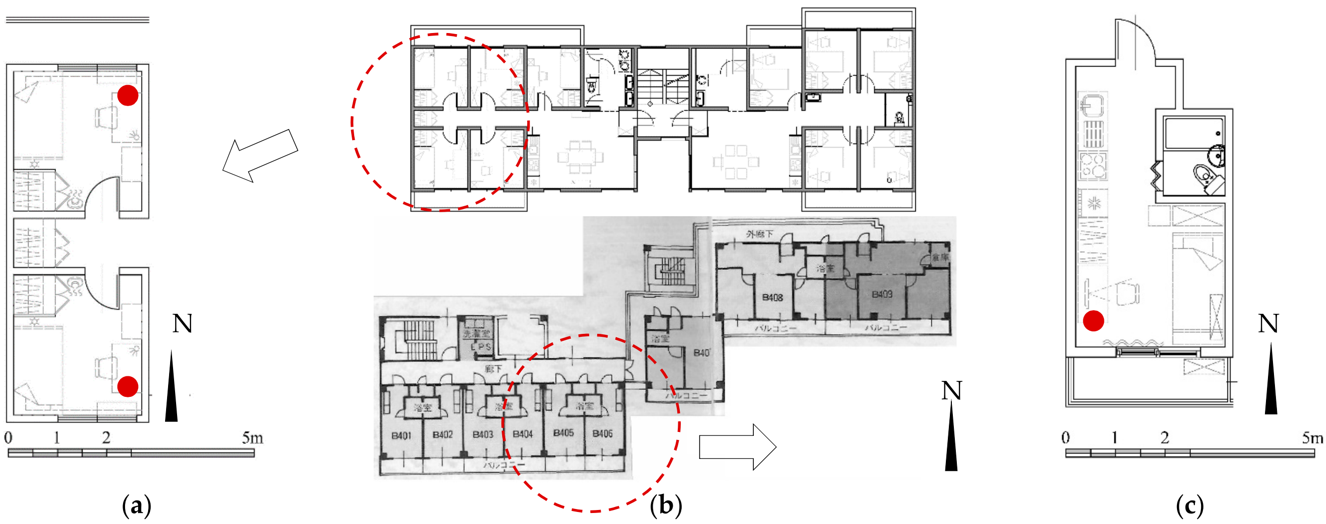


Figure 3. Floor plans of dormitory buildings in TUT: (**a**) GSD; (**b**) TUT campus and dormitory locations; (**c**) Kaikan.

2.4. Sample Selection

The population of interest was represented by a sample from the international students currently residing in Kaikan and in GSD. The sample was stratified by residence, convenient within each stratum and within a quota of a maximum of ten subjects per dormitory which was the limitation of our survey. Because of the small size of the study, the sample was treated as random [42].

2.5. Field Survey, Data Collection and Analysis

The field survey was designed as longitudinal (repeated sampling of limited number of subjects). The time difference between each answer of a subject was usually more than 3–4 h, and even 6–10 h. Because of this sizeable time-difference between answers, the data was analyzed as from a cross-sectional research (singular sampling of many subjects). This approach has been used before in previous studies [43].

At the beginning of each measuring week, a set of paper questionnaires was provided to each volunteer in their preferred language—Japanese or English. The general questionnaire (2 in Figure 4) collected information about country of origin, sex, age, and past climate history. It was to be completed at the beginning of the first measuring week. Description of the information from the general questionnaire is presented in Figure 5. The questionnaire about subjective sleep quality (4 in Figure 4) was to be completed after waking up. The subjects were asked to fill in the indoor environment questionnaire several times per day–mandatory at waking up and at bedtime (3 in Figure 4); and optional at breakfast, at noon and at dinnertime (3 * in Figure 4). The English and Japanese version of the questionnaires about indoor environment are in Appendix A and Appendix B.

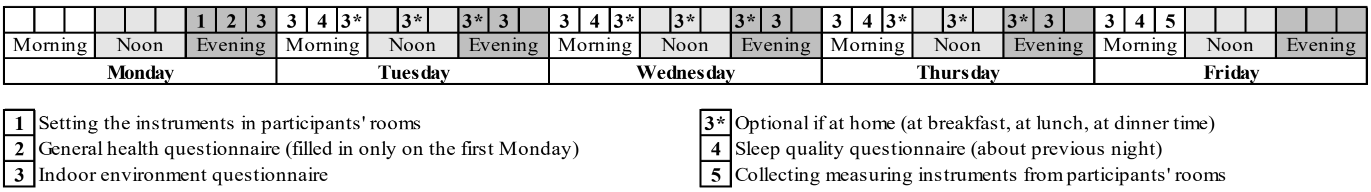
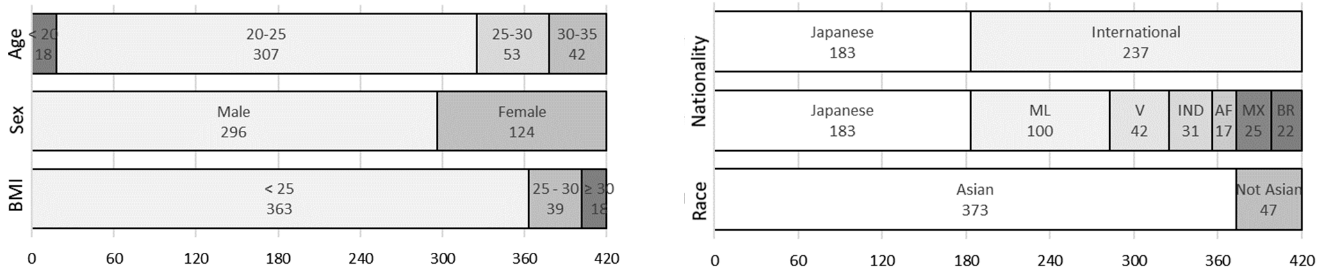


Figure 4. Week 1—Events schedule (Note: each volunteer participated for three non-sequential weeks).



(**a**) (**b**)

Figure 5. Number of observations (N = 420 votes)—Distribution of the votes relative to (**a**) age, sex and BMI, and (**b**) relative to nationality and ethnicity. Note: ML (Malaysian); V (Vietnamese); IND (Indonesian); AF (Afghani); BR (Brazilian); MX (Mexican).

The subjective thermal votes were collected using the recommended scales and wording of the questions in ISO 10551: 1995 I for assessment of thermal environment using subjective judgmental scales [44] and in ASHRAE 2013 handbook [45]. The associated questions were:

TSV (thermal sensation vote): “How do you feel about thermal environment at this precise moment in your room?”

TC (thermal comfort/evaluation vote): “How do you find the thermal environment in your room?”

TP (thermal preference vote): "Please, state how would you prefer to be now?"

TA (thermal acceptability vote): "How do you judge the thermal environment?"

The wording for each point on the scale of the thermal responses is presented in Section 3.3.

The subjects were asked to state their metabolic activity and clothing at the time of each vote. A list of reference clothing and physical activity was provided to facilitate the description (see Appendix A and Appendix B). The participants were advised to fill in the indoor environmental questionnaire after spending at least thirty minutes indoors for proper acclimatization. Our study highly depended on the subjects' personal responsibility as they were to complete the questionnaires unattended at their own convenient time. However, test markers were included to ensure quality of the votes—for example, some typical outdoor activities. This way the small percentage of votes stating less than twenty minutes spent indoors prior to voting were excluded. Occupant behavior was marked by the participants on a list provided and recorded in binary form.

Measurements of the indoor and outdoor air temperature and relative humidity were continuous at one-minute intervals from Monday to Friday. The measuring devices used are in Table 1. They were placed in each individual room at the desk at height assuming sedentary activity. Air speed was measured close to the bed. However, almost all of air speed measurements observed at the time of the valid votes were close to 0.0 m/s—suggesting still air. A value of 0.1 m/s for the air speed was used to conduct the calculation of the thermal indices. However, conducting a field survey focused on the effect of air speed is necessary in the future.

Table 1. Measuring devices.

Name	Type	Parameter	Range and Accuracy			Image	Notes
Thermo-hygrometer	TR-74Ui ISA-3151 sensor THA-3151 sensor by "T and D corporation" www.tandd.co.jp, acceseed on 20 April 2021	Air temperature Relative humidity Illuminance	0–55 10–95 0–130	°C %RH kLUX	(±0.5 °C) (±5%) (±5%)		Continuous measurement (1-min interval)
Air Flow Transducer	6332D (probe by KANOMAX www.kanomax.co.jp, acceseed on 20 April 2021) (VR-71 data logger by "T and D corporation")	Air Speed	0.01~30.0m/s (±2%)				Continuous measurement (1-min interval)

The collected data was analyzed using Microsoft Excel and its add-in tool Data Analysis, as well as the add-in application Xlstat, developed by Addinsoft (https://www.xlstat.com/en/company/about-us) (accessed on 1 October 2017) [46]. The algorithm for analysis and calculations followed the explanation by Humphreys et al. [2].

2.6. Analysis Flow

The structure of the analysis conducted, was as follows: first, outdoor conditions were analyzed in relation to the indoor conditions. The set of four subjective thermal responses (TSV, TC, TP, and TA) was listed, distributed, and correlated to one another as well as to indoor conditions. Logistic regression of sensation vote and indoor air temperature was conducted to obtain a range of temperature within which the expected probability of voting neutral was the highest. Linear regression of sensation vote and indoor air temperature was conducted to obtain a single value for neutral temperature. The influence of other factors such as humidity, clothing, and activity on TSV was checked using multiple regression. Finally, Griffiths' method was used to calculate the comfort temperature which was then compared to the actually voted comfort temperature. The results from our study were corelated to international standards and previous research in the field.

3. Results and Discussion

3.1. Participants

In the summer stage of the survey, 18 healthy, Japanese, and International students from 19 to 31 years of age volunteered to participate (males: Median = 21, Standard Deviation (SD) = 4; females: median = 21, SD = 1). The participants' body mass index (BMI) was in the normal zone (median = 22.8, SD = 3.4). The distribution of votes relative to sex, age, nationality, ethnicity, and BMI is presented in Figure 5.

The summer climates in the subjects' countries of origin differ notably from the summer climate they are subjected to in Central Japan (Figure 1 in Appendix B). The summer mean monthly temperature is lowest in Mexico and highest in Vietnam. However, in Central Japan (JMA WMO ID: 47654–Hamamatsu city, see Section 2.1), the relative humidity is the highest. The temperatures in Afghanistan and Central Japan are comparable, however the difference in humidity is almost 50%. Non-Japanese subjects certainly have different prior climate experience and, the current study aims at understanding whether it affects their subjective thermal sensation while in Japan.

3.2. Indoor and Outdoor Environment

The subjects were asked to mark the time of their vote. This time was then set to the closest fifteen minutes. The physical data about indoor and outdoor temperature (T_i, T_o) and relative humidity (RH_i, RH_o) was recorded every minute. To match both the subjective and objective data, the physical data was divided into fifteen-minute periods and the average values of each period were calculated. The subjective votes were then linked to the 15 min averages of the physical measurements. During the summer study, a total of 280 questionnaires in Kaikan and 234 questionnaires in GSD were collected. We considered these votes as valid, at which there was a physical record of temperature and humidity indoors and out, as well as the set of four votes (sensation, comfort, preference, and acceptability). In addition, the votes that were stated less than twenty minutes before the adjustment period prior to voting were excluded. Considering all of the above, 420 valid votes were collected in summer.

The daily mean outdoor temperature (T_{od}) was provided online by JMA [40]. Exponentially weighed running mean of the daily outdoor temperature ($T_{rm\ (t)}$) was calculated using the approximate formula as given in the BS EN 16798-1:2019 [47].

$$T_{rm\ (t)} = (T_{t-1} + 0.8T_{t-2} + 0.6T_{t-3} + 0.5T_{t-4} + 0.4T_{t-5} + 0.3T_{t-6} + 0.2T_{t-7})/3.8 \quad (1)$$

The indoor and outdoor absolute humidity during voting (AH_i, AH_o) were calculated for the respective air T_i/T_o and RH_i/RH_o (Chapter 1 in [45]).

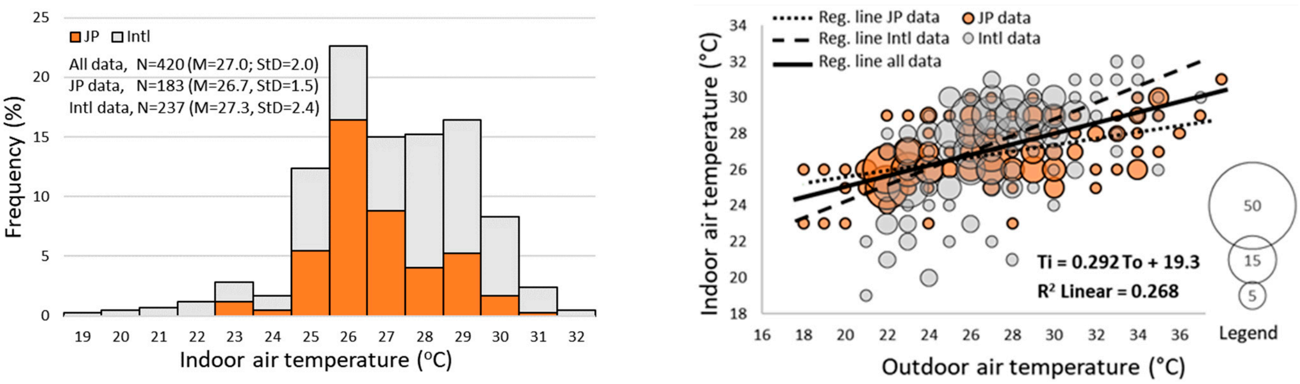
The questionnaires that were distributed to the subjects contained a short list of clothing and activities, and the subjects were asked to mark all the items they were wearing at the time of vote and the percentage of each activity carried out within the last thirty minutes prior to voting. The clothing insulation and activity rate values were assigned according to Chapter 9 of the ASHRAE handbook: Fundamentals [45], and presented in Appendix B (Tables 2 and A1). The numerical results at the times of vote are presented in Table 2.

Variations in outdoor conditions were high while indoors the parameters were more stable. Indoor temperature was well correlated to the outdoor temperature ($r = 0.52$, $p < 0.001$) (Figure 6a,b). However, it was not the case for indoor relative humidity ($r = 0.31$, $p < 0.001$). Indoor absolute humidity indoors was better correlated to the outdoors. As seen in Figures 7 and 8, indoor humidity was constantly high at about RH_i of 70% (IQR from 66%–77%) and AH_i of 0.016 kg/kg_{DA} (IQR from 0.015–0.018 kg/kg_{DA}). As mentioned in Section 2.5, the measured air speed was very-low, suggesting still air. In the case of the Qatar offices, Indraganti and Bousaa also observed such low values [45]. A standard value of 0.10 m/s air speed was selected for any necessary further calculations.

Table 2. Descriptive statistics of the collected data at times of vote.

	All Data Points (N = 420)				**Japanese (N = 183)**				**International (N = 237)**			
	min	max	mean	StD	min	max	mean	StD	min	max	mean	StD
T_i	18.6	31.6	27.0	2.0	23.2	30.7	26.7	1.5	18.6	31.6	27.3	2.4
T_o	18.3	37.9	26.6	3.6	18.3	37.9	26.3	4.3	21.2	36.9	26.8	3.1
T_{od}	20.7	30.1	25.8	2.4	20.7	30.1	25.2	2.6	22.4	30.1	26.3	2.2
T_{rm}	22.3	28.2	25.7	2.3	22.4	28.2	25.1	2.5	22.3	28.2	26.1	2.0
RH_i	40	89	71	8	41	85	71	8	40	89	70	9
RH_o	36	100	80	15	36	100	78	16	37	100	81	13
AH_i	0.007	0.022	0.016	0.003	0.008	0.020	0.016	0.002	0.007	0.022	0.016	0.003
AH_o	0.007	0.023	0.017	0.002	0.007	0.022	0.017	0.003	0.012	0.023	0.018	0.002
I_{cl}	0.19	0.64	0.33	0.07	0.19	0.49	0.34	0.005	0.19	0.64	0.31	0.009
M	1.0	2.7	1.3	0.4	1.0	2.5	1.4	0.5	1.0	2.7	1.2	0.3

NOTE: Number of observations N = 420; Ti: Indoor temperature (°C); T_o: Outdoor daily mean temperature (°C); T_{od}: Outdoor daily mean temperature (°C); T_{rm}: Outdoor daily running mean temperature (°C); RH_i: Indoor relative humidity (%); RH_o: Outdoor relative humidity (%); AH_i: Indoor absolute humidity (kg/kg_{DA}); AH_o: Outdoor absolute humidity (kg/kg_{DA}); I_{cl}: clothing insulation (clo), where 1clo = 0.155 m^2 K/W; M: metabolic activity (met), where 1 met = 58.2 W/m^2.



(**a**) (**b**)

Figure 6. Indoor and outdoor temperature: (**a**) frequency percentage distribution of indoor air temperature; (**b**) correlation between indoor and outdoor air temperature at vote.

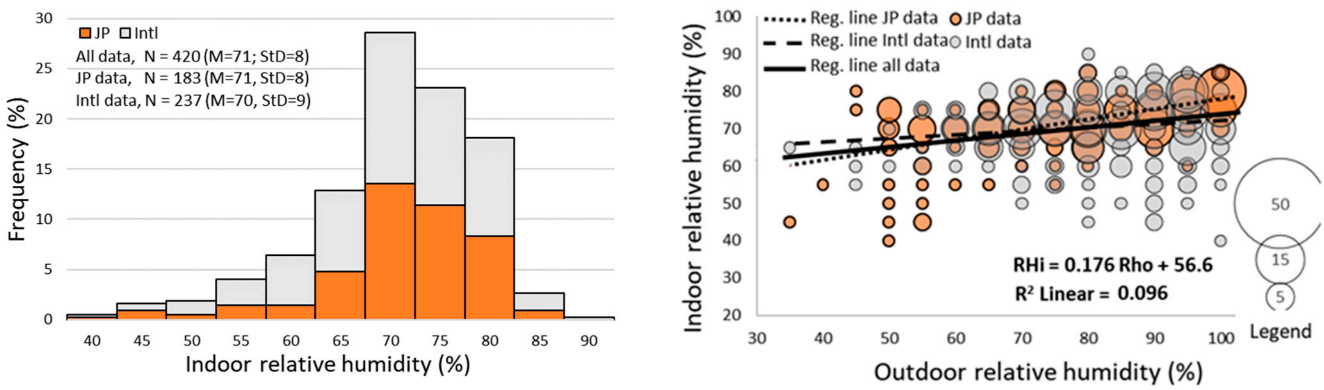


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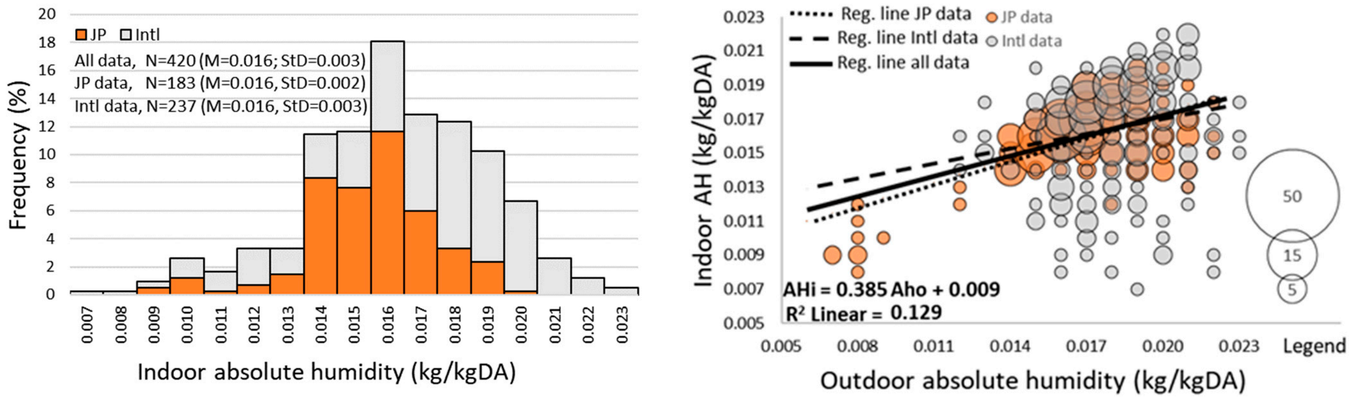
Figure 7. Indoor and outdoor relative humidity: (**a**) frequency percentage distribution of indoor relative humidity; (**b**) correlation between indoor and outdoor relative humidity at vote.



(**a**) (**b**)

Figure 8. Indoor and outdoor absolute humidity: (**a**) frequency percentage distribution of indoor absolute humidity; (**b**) correlation between indoor and outdoor absolute humidity at vote.

The correlation between indoor and outdoor environment was examined for all the data points and relative to nationality (Japanese or international data sets). The results are presented in Table 3. The correlation coefficient between the measured T_i and measured T_o, the daily mean T_{od} and the running daily mean T_{rm} progressively increased when focusing on all the data as well as on the international part of it. However, the Japanese data set showed the opposite trend. The change in outdoor temperature conditions seems to influence the indoor environment of the international students more than the one of the Japanese. The Japanese indoor thermal environment seems to relate better with the immediate outdoor temperature measurement.

Table 3. Correlation coefficients.

	All Data Points (*N* = 420)					**Japanese (*N* = 183)**					**International (*N* = 237)**				
	r	***a***	**β**	**R^2**	***p***	**r**	***a***	**β**	**R^2**	***p***	**r**	***a***	**β**	**R^2**	***p***
T_i: T_o	0.52	0.292	19.3	0.268	<0.001	0.52	0.181	21.9	0.267	<0.001	0.58	0.448	15.3	0.336	<0.001
T_i: T_{od}	0.52	0.437	15.8	0.269	<0.001	0.40	0.226	21.0	0.159	<0.001	0.61	0.664	9.8	0.368	<0.001
T_i: T_{rm}	0.55	0.488	14.5	0.298	<0.001	0.41	0.250	20.4	0.172	<0.001	0.64	0.746	7.8	0.414	<0.001
RH_i: RH_o	0.31	0.176	56.6	0.096	<0.001	0.55	0.266	50.7	0.306	<0.001	0.12	0.083	63.3	0.016	fail
AH_i: AH_o	0.36	0.385	0.01	0.129	<0.001	0.62	0.458	0.008	0.378	<0.001	0.20	0.289	0.011	0.039	<0.05

NOTE: N: number of observations; r: coefficient of correlation (Pierson's r); a: slope of regression line; β: intercept of regression line; R^2: regression coefficient of determination; p: confidence interval 95%; T_i: indoor temperature (°C); T_o: outdoor temperature (°C); T_{od}: outdoor daily mean temperature (°C); T_{rm}: outdoor daily running mean temperature (°C); RH_i: indoor relative humidity (%); RH_o: outdoor relative humidity (%); AH_i: indoor absolute humidity (kg/kg_{DA}); AH_o: outdoor absolute humidity (kg/kg_{DA}).

The indoor–outdoor correlations regarding humidity were generally weaker and, when comparing relative and absolute humidity the indoor relative humidity was invariably more weakly correlated to its outdoor counterpart as opposed to the absolute humidity. Interestingly, when dividing the data points by nationality, there was considerably stronger correlations in the Japanese datasets as opposed to the international ones. So much so that the correlation between indoor and outdoor relative humidity in the international dataset was statistically insignificant, that is—the indoor relative humidity was not reflecting in as meaningful a way as the outdoor relative humidity for international people.

3.3. Thermal Sensation, Comfort, Preference and Acceptability

The distribution of TSV, TC, TP and TA relative to nationality is presented in Table 4. The neutral TSV was less than one third in the international dataset (30%), and even less in the Japanese one (21%). More than half of the international votes were on the warm side of the scale (52%), which was 10% more than the Japanese votes (42%). On the cold side of the scale the difference was almost double: 38% of the Japanese TSV was "slightly cool" and "cool" as opposed to only about 19% of the international dataset (19% difference).

Furthermore, observing 2% of international votes on the point “cold” in summer, leads to assume overuse of air conditioning. As for the voted thermal comfort, irrespective of nationality, more than 70% of the votes were on the comfortable side of the scale (71% of Japanese votes and 79% of the international). The Japanese votes “prefer no change” were more than 60% (63%) as opposed to only 38% of the international. More than half of the international votes were “prefer cooler” (52%). Irrespective of nationality, the acceptance of the indoor environment was very high—equal to or more than 95% (96% for Japanese and 95% for the international).

Table 4. Percentage of thermal responses for each scale relative to nationality (Japanese: N = 183; international: N = 237).

Scale	Thermal Sensation (TSV) %			Thermal Comfort (TC) %			Thermal Preference (TP) %			Thermal Acceptability (TA)%		
		JP	Intl		JP	Intl		JP	Intl		JP	Intl
3	Hot	7.7	6.8	Very comfortable	2.2	3.0						
2	Warm	12.6	13.1	Comfortable	38.8	40.1						
1	Sl. warm	21.3	31.6	Slightly comfortable	30.1	35.9	Warmer	1.1	9.3	Unacceptable	4.4	5.5
0	Neutral	20.8	30.0				No change	63.4	38.4	Acceptable	95.6	94.5
−1	Slightly cool	28.4	11.4	Slightly uncomfortable	23.5	13.1	Cooler	35.5	52.3			
−2	Cool	9.3	5.1	Uncomfortable	5.5	7.2						
−3	Cold	-	2.1	Very uncomfortable	-	0.8						

Thermal sensation had strong negative correlation with thermal comfort ($r = -0.70$, $p < 0.001$) and thermal preference ($r = -0.57$, $p < 0.001$) as presented in Table 5. The hotter the subjects sensed their environment, the less comfortable they felt (Figure 9b) and their preference inclined towards “prefer cooler” (Figure 9d). The correlation between comfort and preference was also strong, but positive ($r = 0.55$, $p < 0.001$). The more comfortable the subjects evaluated their indoor environment, the closer their preference vote was to “no change” (Figure 9f). Interestingly, in both Japanese and international data, there were votes “prefer warmer” despite being summer season leading once again to the assumption of overuse of air conditioning. The correlation between TA and other thermal responses was either weak or even insignificant. It seems the subjects could bear very well diverse indoor conditions.

Table 5. Correlation between thermal responses.

	All Data Points (N = 420)					Japanese (N = 183)					International (N = 237)				
	r	*a*	β	R^2	*p*	r	*a*	β	R^2	*p*	r	*a*	β	R^2	*p*
TC:TSV	−0.70	−0.660	1.1	0.438	<0.001	−0.70	−0.673	0.9	0.488	<0.001	−0.65	−0.672	1.3	0.422	<0.001
TP:TSV	−0.57	−0.248	−0.3	0.323	<0.001	−0.72	−0.253	−0.3	0.518	<0.001	−0.48	−0.242	−0.3	0.232	<0.001
TP:TC	0.55	0.238	−0.6	0.297	<0.001	0.72	0.261	−0.6	0.515	<0.001	0.46	0.224	−0.6	0.213	<0.001

NOTE: N: number of observations; r: coefficient of correlation (Pierson’s r); a: slope of regression line; β: intercept of regression line; R^2: regression coefficient of determination; p: confidence interval; T_i: indoor temperature (°C); T_o: outdoor daily mean temperature (°C); T_{od}: outdoor daily mean temperature (°C); T_{rm}: outdoor daily running mean temperature (°C); RH_i: indoor relative humidity (%); RH_o: outdoor relative humidity (%); AH_i: indoor absolute humidity (kg/kg$_{DA}$); AH_o: outdoor absolute humidity (kg/kg$_{DA}$).

The regression lines derived from all the data, the Japanese and the international datasets were either very close (Figure 9b), or overlapping (Figure 9d,f) revealing the same relationship between thermal responses irrespective of nationality.

It is a typical assumption that nationality affects the subjective thermal responses. To investigate which factors indeed significantly affected the thermal responses in our survey, the votes TSV, TC, TP and TA were divided by time of the day, use of air-conditioning, dormitory building, sex, and nationality, and tested for dependency on each of these factors through a chi-square test. The percentage of the “acceptable” votes was very high in all the conditions, but it was not dependent on any one of them. Only one of the factors significantly affected all the three remaining thermal responses and it was the use of air conditioning. Nationality affected thermal sensation and preference. The statistically significant results are presented in Table 6.

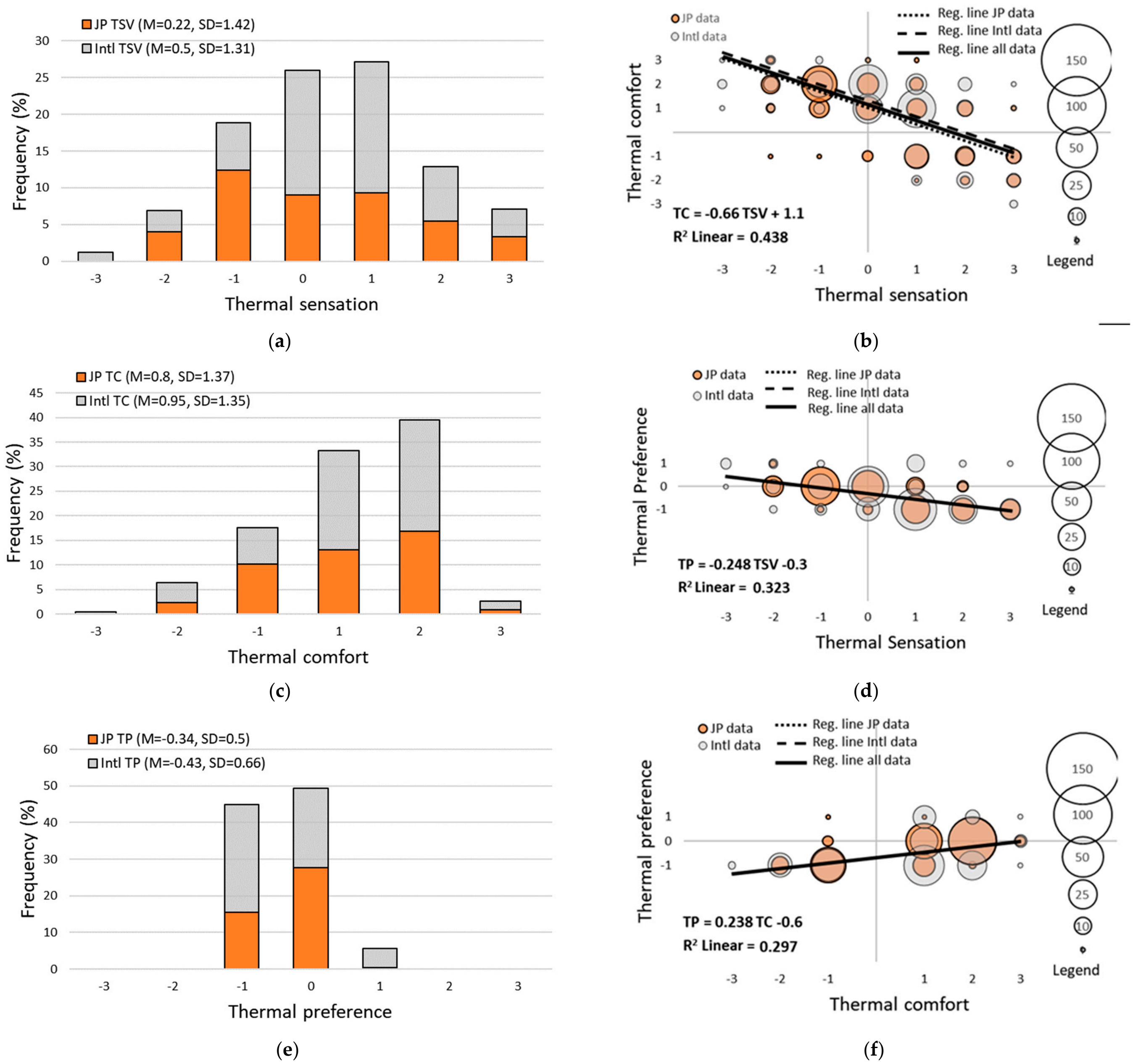


Figure 9. Graphical display of the frequency distributions and correlation between thermal responses; (**a**) frequency distribution of TSV; (**b**) correlation TC: TSV; (**c**) frequency distribution of TC; (**d**) correlation TP: TC; (**e**) frequency distribution of TP; (**f**) correlation TP: TSV.

The test confirmed the initial assumption. In the following analysis of the current paper the focus was placed on the nationality factor and its effect on thermal sensation. The analysis of air conditioning use will be presented separately.

The linear regression conducted between the subjective votes and the measured air temperature estimated the neutral, comfortable and "prefer no change" temperature for Japanese and international subjects (Table 6). Interestingly, even though the thermal sensation vote varies significantly depending on nationality, the neutral temperature is expected to be achieved at value of 25–26 °C (equations in Section 3.4.2.). Towards either end of the scale, the difference in sensation response and the temperature difference increased. The comfort vote itself was independent of nationality, however the linear regression displayed that Japanese subjects are expected to start feeling comfortable at about 2 °C lower temperature as compared to the international subjects (at 25.4 °C and

27.0 °C respectively). Similarly, the Japanese "prefer no change" vote is expected at almost 2 °C lower temperature than the international vote (at 21.3 °C and 22.9 °C respectively).

Table 6. Summary of Chi-square results: dependence of TSV, TC, TP, and TA on sub-divisions.

	Sub-Division	*n*	df	χ^2 Critical	χ^2	*p*	Estimated by Regression (°C)		δT (°C)
TSV	Day:Night	234:186	6	12.59	12.96	<0.05			
	AC on:AC off	145:275			47.33	<0.001			
	GSD:Kaikan	212:208			32.30	<0.001			
	Male:Female	296:124			18.29	<0.05			
	Japanese:International	183:237			30.00	<0.001	$T_{n\ JP} = 25.9$	$T_{n\ Intl} = 25.4$	+0.5
TC	Day:Night	234:186	5	11.07	18.02	<0.05			
	AC on:AC off	145:275			23.71	<0.001			
	GSD:Kaikan	212:208			5.07	0.407			
	Male:Female	296:124			11.69	<0.05			
	Japanese:International	183:237			9.69	0.084	$T_{c\ JP} < 25.4$	$T_{c\ Intl} < 27.0$	−1.6
TP	Day:Night	234:186	2	5.99	0.04	0.982			
	AC on:AC off	145:275			6.89	<0.05			
	GSD:Kaikan	212:208			38.09	<0.001			
	Male:Female	296:124			3.17	0.205			
	Japanese:International	183:237			31.68	<0.001	$T_{p\ JP} = 21.3$	$T_{p\ Intl} = 22.9$	−1.6
TA	Day:Night	234:186	1	3.84	0.34	0.558			
	AC on:AC off	145:275			1.12	0.289			
	GSD:Kaikan	212:208			0.03	0.858			
	Male:Female	296:124			0.01	0.922			
	Japanese:International	183:237			0.27	0.604			

Note: T_n, calculated temperature at TSV = 0 (neutral); T_c, calculated values for temperature at TC = 1 (slightly comfortable). As values TC 2 and TC 3 are on the comfortable side of the scale, the results are given as an inequality; T_p, calculated temperature at TP = 0 (no change).

3.4. Neutral Temperature

3.4.1. Logit Regression Analysis for Neutral Zone

Estimating the proportion of Japanese and international occupants that would vote neutral at a certain temperature, requires conducting a probability analysis of TSV with the indoor temperature. Using the Xlstat add-in application for Microsoft Excel, an ordinal logistic regression analysis (probit model) was conducted. The resulting equations for six probit lines derived from our dataset are shown in Table 7.

The equations $P(\leq \text{TSV})$ represent the probability of voting the respective TSV vote or less–for example $P(\leq -1)$ represents the probability of voting −1 or less than −1 (that is: from "slightly cool" down on the scale to "cold") [2,10,16]. The probit regression coefficient for Japanese university students is calculated to be 0.204/K and for international ones: 0.232/K. Mean temperature of the probit line is the absolute value of the result from dividing the y-intercept with the constant–for example $|+4.1/-0.204| = |-20.1| = 20.1$ °C. The SD is the absolute value of the inverse of the constant (SD = $|1/-0.204| = |-4.89| = 4.89$). Each equation was calculated for temperatures from 18 °C–32 °C which was the range of all the observed temperature records (separately, the JP records were in a narrower range). For each result obtained, the cumulative normal distribution was calculated in MS Excel (function NORM.S. DIST (z, cumulative). The six sigmoid curves of the probabilities were then plotted and presented in Figure 10.

The curves help to estimate the probability of voting at a specific scale point or lower at all temperatures within the observed temperature range. As shown on Figure 10a, the probability of Japanese students voting neutral or less (dotted black line of $p \leq 0$)) at lower temperatures is high, while with the rise of temperatures, this probability decreases. And, at ~23.5 °C there is 80% probability of voting neutral or less. The explanation for all curves follows the same pattern.

Table 7. Probit analysis of thermal sensation and indoor temperature.

JP/Intl	TSV	Probit Regression Line	Mean Temperature (°C)	SD	N	R^2	SE	*p*
Japanese TSV	-	-	-	4.89	183	0.47	0.05	<0.001
	≤−2	$P_{(\leq -2)} = -0.204\ T_i + 4.1$	20.1					
	≤−1	$P_{(\leq -1)} = -0.204\ T_i + 5.1$	24.9					
	≤0	$P_{(\leq 0)} = -0.204\ T_i + 5.7$	27.9					
	≤1	$P_{(\leq 1)} = -0.204\ T_i + 6.3$	30.8					
	≤2	$P_{(\leq 2)} = -0.204\ T_i + 7.0$	34.2					
International TSV	≤−3	$P_{(\leq -3)} = -0.232\ T_i + 3.9$	16.8	4.31	237	0.62	0.03	<0.001
	≤−2	$P_{(\leq -2)} = -0.232\ T_i + 4.6$	19.8					
	≤−1	$P_{(\leq -1)} = -0.232\ T_i + 5.3$	22.8					
	≤0	$P_{(\leq 0)} = -0.232\ T_i + 6.3$	27.2					
	≤1	$P_{(\leq 1)} = -0.232\ T_i + 7.3$	31.5					
	≤2	$P_{(\leq 2)} = -0.232\ T_i + 8.0$	34.5					

Note: $P(\leq 1)$ is the probability of voting 1 and less; $P(\leq 2)$ is the probability of voting 2 and less and so on; SD: standard deviation; *N*: number of samples; R2 (Cox and Snell): coefficient of determination; SE: standard error; significance $p < 0.001$).

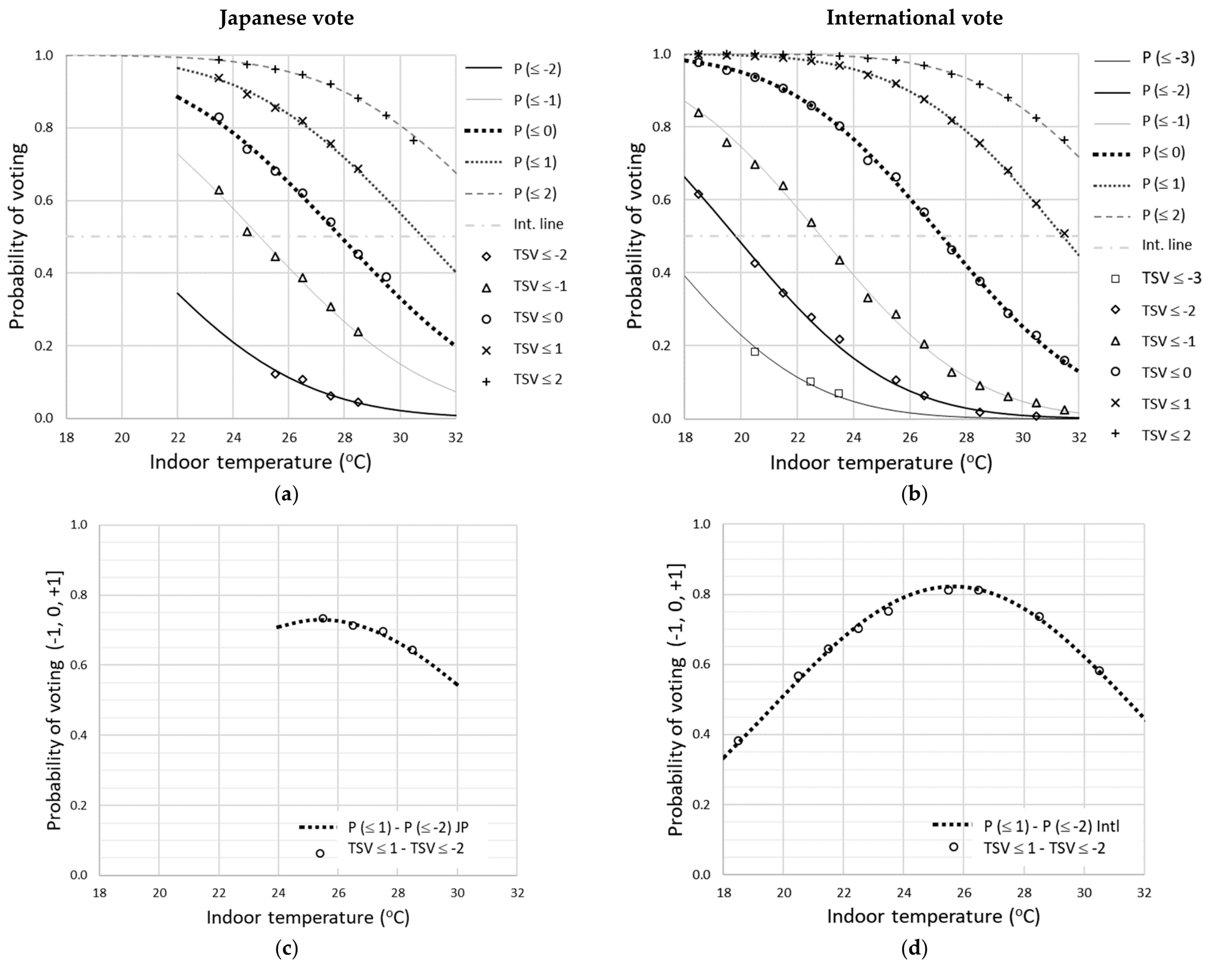


Figure 10. Graphical representation of probit analysis: (**a**) probability of voting a certain TSV for Japanese subjects; (**b**) probability of voting a certain TSV for international subjects; (**c**) proportion voting within the "extended neutral range" of TSV scale–from −1 to +1 for Japanese subjects; (**d**) proportion voting within the "extended neutral range" of TSV scale–from −1 to +1 for international subjects. Note: marker points represent the actual proportion voting.

When subtracting the probability of voting −2 from the probability of voting 1, the probability of voting within the extended neutral range (−1, 0 and 1) can be obtained.

It was observed that within the range of 24 and 26.5 °C indoor temperature, the probability of Japanese students voting extended neutral is the highest. However, it is between 70% and 75% (Figure 10c). The peak of the graph for international subjects was within the same interval (from 24 °C–26.5 °C). However, the expected percentage is above 80%. Japanese students appear to be more critical to their indoor environment.

3.4.2. Linear Regression Method

Neutral is the temperature at TSV = 0, where the subjects felt neither cold nor warm. Using linear regression is a common method to derive the expected neutral temperature out of observed survey responses despite some downsides as observed by researchers previously. During summer stage more than 70% of the Japanese TSV (N = 183, M = 0.22, SD = 1.42) were within the −1 to +1 segment of the scale and, the neutral votes were 20% (Table 8). As for the International TSVs (N = 237, M = 0.50, SD = 1.31), the respective percentages were 73% and 30%. When regressing the TSV and the measured indoor temperature, a strong positive correlation was observed and, based on the data collected, the neutral temperature relative to nationality could be estimated using the equations below:

$$TSV_{JP} = 0.285T_i - 7.4, \text{ where } (N = 183;\ p < 0.001;\ R2 = 0.09;\ S.E. = 1.36;\ F \text{ statistic} = 17.7) \quad (2)$$

$$TSV_{Intl} = 0.262T_i - 6.6, \text{ where } (N = 237;\ p < 0.001;\ R2 = 0.22;\ S.E. = 1.15;\ F \text{ statistic} = 67.4) \quad (3)$$

Table 8. Statistics of the multiple regression analysis.

Variable		Japanese (N = 183)				International (N = 237)			
n	Name	p	S.E.	$R^2_{adj.}$	F Statistics	p	St. Error	$R^2_{adj.}$	F Statistics
1	T_i	$p_1 < 0.001$	$S.E._1 = 0.069$	0.08	4.8	$p_1 < 0.001$	$S.E._1 = 0.032$	0.22	17.6
2	RH_i	$p_2 = 0.506$	$S.E._2 = 0.009$			$p_2 = 0.722$	$S.E._2 = 0.009$		
3	I_{cl}	$p_3 = 0.517$	$S.E._3 = 2.017$			$p_3 = 0.529$	$S.E._3 = 0.878$		
4	M	$p_4 = 0.320$	$S.E._4 = 0.226$			$p_4 = 0.126$	$S.E._4 = 0.219$		

NOTE: n: number of observations; p_n: significance of the effect on variable n; $S.E._n$: standard error for variable n; $R^2_{adj.}$: adjusted regression coefficient of determination; T_i: indoor temperature (°C); RH_i: indoor relative humidity (%); I_{cl}: clothing; M: metabolic activity.

The calculated neutral temperature for Japanese subjects ($_{JP}T_n$) using the Equation (2) is $_{JP}T_n$ = 25.9 °C. This is only 0.6 °C lower than voted $_{JP}T_n$ = 26.5 °C–the mean indoor air temperature when the Japanese subjects voted “extended neutral”. The calculated neutral temperature for international subjects (IntlTn) using the Equation (3) is $_{Intl}T_n$ = 25.4 °C. This is 2.0 °C lower than voted $_{Intl}T_n$ = 27.4 °C, which was the mean indoor air temperature when the international subjects voted “extended neutral”. The difference in slopes leads to the conclusion that Japanese subjects are more sensitive to their indoor environment, even though the difference in sensitivity is small. It would take 3.5 °C change in the indoor temperature for the Japanese vote to change by one unit, while the same change in the International vote would require 3.8 °C change in the indoor temperature. This supports the outcome of the probit analysis. Additionally, the slopes of the regression equations are comparable with the slopes derived from similar research: Indraganti and Bousaa estimated 0.216/K [16] and 0.283/K [17] in office buildings in Doha, Qatar; Katsuno et al. [48] estimated 0.273/K in CL mode in residential houses in Kanto region, Japan; Ning et al. [30] found 0.248/K in dormitory buildings in spring in Harbin, China; He et al. [33] found 0.225/K, 0.269/K and 0.282/K for Chinese students of different origin in dormitories during summer in Changsha, China. However, there are instances when the sensitivity to the indoor temperature was observed to be higher (0.403/K in FR in Kanto, Japan [48]) or quite lower (0.187/K in FR and 0.106/K in CL in Kanto, Japan [49]).

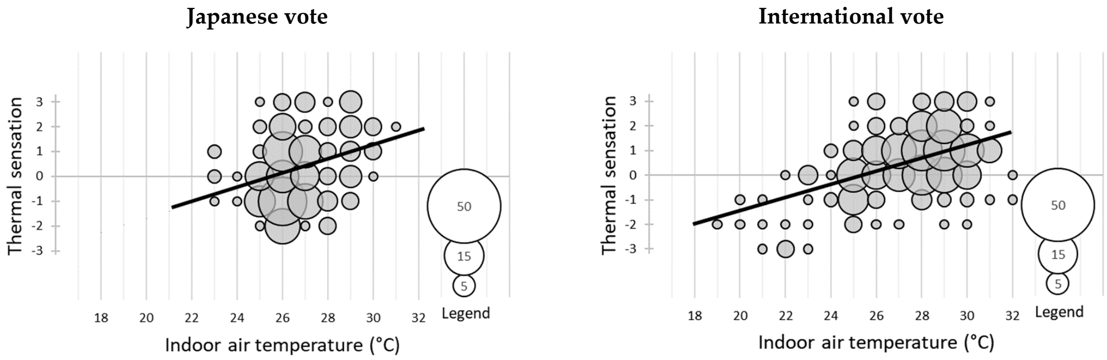
The linear regression defines a single value for the expected T_n. However, if using the assumptions in the PMV/PPD model and calculating for TSV = ±0.85 and for TSV = ±0.5, it is possible to derive the range of T_i corresponding to 80% and 90% acceptable thermal sensation respectively [43]. In our survey 80% falls within 23 and 29 °C for Japanese subjects and within 22 and 29 °C for non-Japanese. The 90% fall within 24–28 °C for Japanese and within 23 and 27 °C for non-Japanese. The overlapping range is between 24 and 27 °C irrespective of nationality. A similar range was already observed in Section 3.4.1, however the percentages associated with nationality there differed by ~10%.

To investigate which other variables affected the TSV together with T_i, a multiple regression analysis was conducted including T_i, RH_i, I_{cl} and M values. As AH_i was strongly correlated with T_i (${}_{JP}AH_i{:}_{JP}T_i$, $r = 0.60$, $p < 0.001$; ${}_{Intl}AH_i{:}_{Intl}T_i$, $r = 0.79$), this variable was excluded from regressing in combination with Ti. The expectation was that relative humidity, clothing and metabolic activity would significantly affect TSV for both Japanese and international students. However, this was not the case neither for Japanese votes, nor for the international (see the equation below). Based on the Type III sum of squares only the Ti brings significant information to explain the variability of TSV. The following analysis focused only on the temperature.

$$TSV_{JP} = 0.287T_i + 0.009RH_i - 1.310\ I_{cl} + 0.225\ M - 7.9 \quad (4)$$

$$TSV_{Intl} = 0.259T_i + 0.003RH_i + 0.553\ I_{cl} + 0.337\ M - 7.7 \quad (5)$$

Linear regression is believed to have some major drawbacks when used for estimating the neutral temperature: (1) the majority of votes are clustered around the central point of the thermal sensation scale (Figure 11) as well as (2) the constant behavioral adaptation from the subjects that cannot be accounted for by this analysis as the vote remains constant especially because of the adaptive measures implemented [16]. The precision of the linear regression coefficient was improved following the usual analytical approach. Then, the comfort temperature was estimated using the Griffiths' method.



(**a**) (**b**)

Figure 11. Thermal sensation votes: (**a**) correlation between TSV and indoor air temperature at vote for Japanese subjects; (**b**) correlation between TSV and indoor air temperature at vote for international subjects.

3.4.3. Improving the Precision of Linear Regression Coefficient

When considering the downsides of the regression method as mentioned above, it is necessary to improve its precision. The widely accepted method to do that is to analyze the within-day and within-room averages. That is to use the variability of the thermal sensation vote from its mean and, to correlate it to the variability of the indoor temperature from its mean [2,16].

In order to apply this method to our data set, the mean thermal feeling (T_{fm}) and mean indoor temperature (T_{im}) were calculated for all the sets of data collected within a day in each of the 18 dormitory rooms for all the survey days within summer. These values were the room-wise day-survey averages. The variability in thermal sensation is defined as $\delta T_f = T_f - T_{fm}$ (the mean of the thermal sensation/feeling vote within the day in a single room is subtracted from the actual thermal sensation/feeling vote). Similarly, the variability in indoor temperature is defined as $\delta T_i = T_i - T_{im}$ (the mean of the indoor temperature within the day from a single room is subtracted from the actual measured temperature at vote). The data was then split relative to nationality. More than 50% of the variability in international subjective sensation was zero, while a little over 40% was the zero variability in the Japanese sensation. That means that within a single day a subject's mean vote was mostly equal to their actual vote of that day. If their average vote of the day was "neutral" the actual vote "neutral" frequented too.

The regression $\delta T_f{:}\delta T_i$ from both Japanese and international votes demonstrated that when there was low to no variability in the temperature, there was low to no variability in the sensation vote too (Figure 12). However, the relation was positive in both cases, that is, when the variability in temperature increases (bigger fluctuations from the mean), the sensation vote variability is expected to also increase. The linear regression equation is given below:

$$_{JP}(T_f - T_{fm}) = 0.441_{JP}(T_i - T_{im}) + 0.0, \text{ where } (N = 183;\ p < 0.001;\ R^2 = 0.12;\ S.E. = 0.94;\ F \text{ statistic} = 23.5) \quad (6)$$

$$_{Intl}(T_f - T_{fm}) = 0.322_{Intl}(T_i - T_{im}) - 0.0, \text{ where } (N = 237;\ p < 0.001;\ R^2 = 0.15;\ S.E. = 0.74;\ F \text{ statistic} = 41.8) \quad (7)$$

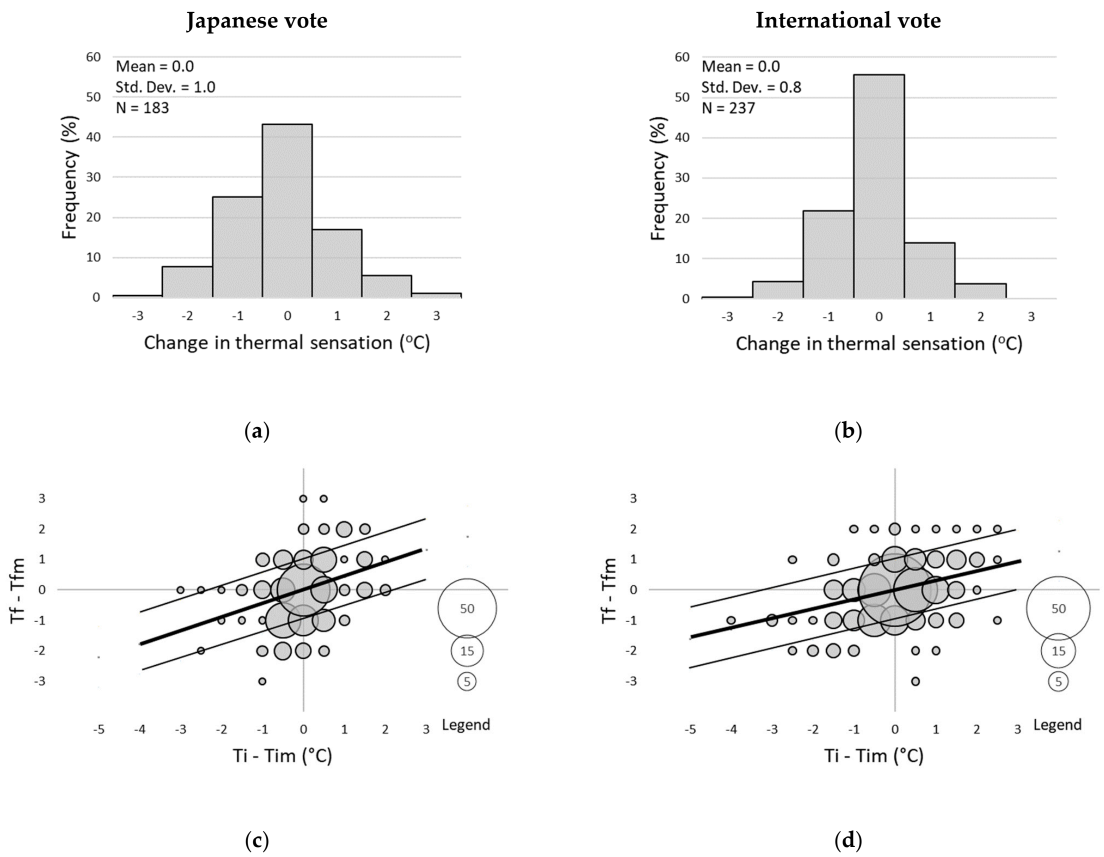


Figure 12. Room-wise day-survey averages: (**a**) frequency distribution of Japanese vote; (**b**) frequency distribution of international vote; (**c**) regression of the day surveys from Japanese vote; (**d**) regression of the day surveys from international vote. Note: outer lines indicate the residual standard deviation.

From the linear regression $\delta T_f{:}\delta T_i$ the corrected value of the regression gradient was derived. It was 0.44/K for Japanese and 0.32/K for international vote. It needs further adjustment as this value does not account for the possibility of measurement errors. The adjusted coefficient is calculated using the formula following below:

$$b_{adj.} = \frac{b\left(\sigma^2_{\delta T_i}\right)}{\sigma^2_{\delta T_i} - \sigma^2_{err}} \quad (8)$$

where b is the coefficient from δT_f:δT_i linear regression (0.441 for Japanese and 0.322 for international vote); $\sigma^2_{\delta T_i}$ is the variance of δT_i; and σ^2_{err} is the error variance of δT_i taken as the $\sigma^2_{\delta T_i}/\sqrt{N}$—the variance of δT_i divided by the square root of the number of data points. Solving the equation provided us with an adjusted regression coefficient of $_{JP}b_{adj.}$ = 0.48/K and $_{Intl}b_{adj}$.= 0.34/K. Similar values were derived from SCATs and ASHRAE databases [50]. The adjusted coefficient for Japanese data got closer to 0.5/K value that has been used in previous studies. The difference between b and $b_{adj.}$ is explained with the effect of the adaptive behavior people undertake in order to maintain their neutral sensation [2,10,16].

Lee et al. [51] investigated the difference in thermoregulatory responses between Japanese and non-Japanese subjects (indigenous to tropical climates) in resting conditions. They observed higher core temperature and lower temperature in the extremities in their non-Japanese subjects as compared to the Japanese ones. Lee et al. attributed the observation to a "pre-conditioned state to reduce thermal and cardiovascular strains when working in heat" and this may also be the explanation of the observed difference in subjective sensitivity in the current study.

3.4.4. Griffiths' Method

Griffiths' method estimates a temperature that is assumed comfortable based on the actual vote of neutral sensation and a regression coefficient. It is calculated by the equation following below:

$$_{G}T_c = T_i + \frac{0 - TSV}{a} \tag{9}$$

where $_{G}T_c$ is Griffiths' comfort temperature (°C); Ti is indoor temperature (°C); 0 is numeric code for "neutral" sensation vote based on the seven–point sensation scale used in this study; TSV is actual sensation vote using the same scale; a is Griffiths' regression coefficient.

Griffiths' coefficient accounts for the sensitivity to indoor temperature change and the value used predominantly is a = 0.5 [2,16]. However, previous research explores $_{G}T_c$ at two more values: a = 0.25, and a = 0.33 [14,49], as well as the value of the adjusted coefficient $b_{adj.}$ derived from room-wise day-survey analysis if conducted [16]. $_{G}T_c$ was estimated using four values for the Griffiths' coefficient and the results are presented below:

The current field survey directly asked about the comfort. It made it possible to compare the calculated $_{G}T_c$ (Table 9) and the observed $_{voted}T_c$ (Table 10). For the Japanese data, the calculated comfort temperature at 0.48/K was close to the voted at the median and mean, but the estimated range by the calculation was much wider than the observed (difference of 6.5 °C), respectively the estimated by calculation standard deviation was double the observed. At 0.48/K 80% of the $_{JP\ G}T_c$ fall within 22 and 30 °C, while the actual voted 80% of the $_{JP\ voted}T_c$ fall within 25 and 29 °C (narrower range by 4 °C).

As for the international data, the calculated comfort temperature at 0.34/K was close to the voted at the inter quartile range (IQR) but differed at the median and mean by more than 1 °C. The estimated range by the calculation was again much wider than the observed (difference of 6.9 °C). Respectively, the estimated by calculation standard deviation was bigger than the observed. At 0.34/K 80% of the $_{Intl\ G}T_c$ fall within 22 and 30 °C, while the actual voted 80% of the $_{Intl\ voted}T_c$ fall within 24 °C and 30 °C (narrower range by 2 °C).

Graphing the calculated and the voted mean comfort temperature for each survey month (Figure 13) relative to nationality visually displayed the above, the Japanese voted comfort temperature is relatively close to the calculated value and usually a bit higher. The international voted comfort temperature however notably differed from its calculated counterpart. However, it almost coincided with the mean indoor temperature.

Table 9. Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients.

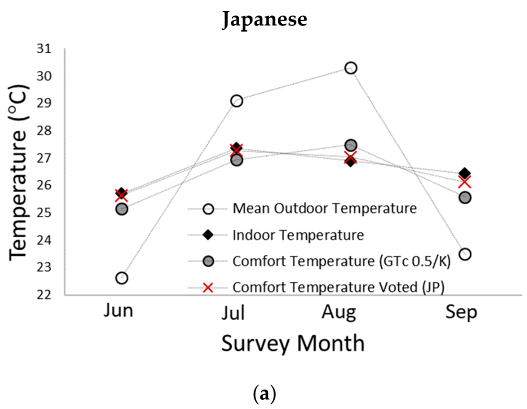
			Calculated Comfort Temperature $_{G}T_{c}$ (°C)						
	Regression Coefficient (/K)	**N**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
JP	0.50	183	18.8	24.4	26.5	28.3	32.4	26.2	2.8
	0.48 (see Section 3.4.3.)		18.5	24.2	26.2	28.3	32.6	26.2	2.9
	0.33		15.7	23.2	26.4	29.1	34.5	26.0	4.1
	0.25		12.8	22.0	26.2	29.9	36.4	25.8	5.4
Intl.	0.50	237	18.6	24.5	26.2	27.7	34.2	26.2	2.6
	0.34 (see Section 3.4.3.)		16.0	23.4	26.1	27.9	35.9	25.9	3.3
	0.33		15.5	23.2	26.0	28.1	36.3	25.8	3.5
	0.25		12.6	22.2	25.4	28.4	38.2	25.3	4.6

Note: Q1: first quartile marks 25% of the data points; Median: marks 50% of the data points; Q3: marks 75% of the data points; (Q3–Q1): marks the interquartile range–central 50% of the data points; Mean: arithmetic average; SD: standard deviation.

Table 10. Descriptive statistics of the actual temperature at TC +1, +2 and +3 (comfortable side of the scale).

	Observed Comfort Temperature T_c (°C)							
	N	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
JP TC votes "comfortable"	130	23.2	25.6	26.2	27.2	30.7	26.5	1.4
Intl TC votes "comfortable"	187	18.6	25.4	27.6	29.0	31.6	27.1	2.5

Note: Q1: first quartile marks 25% of the data points; Median: marks 50% of the data points; Q3: marks 75% of the data points; (Q3-Q1): marks the interquartile range–central 50% of the data points; Mean: arithmetic average; SD: standard deviation.



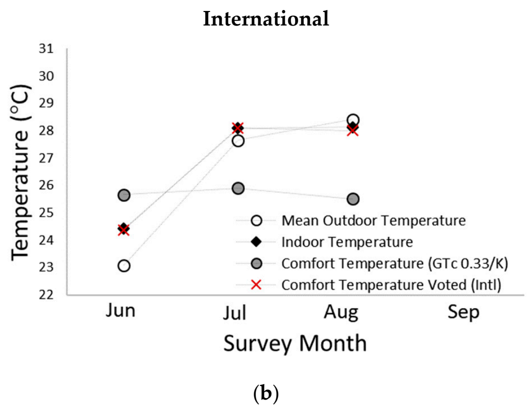


Figure 13. Comparing mean temperatures in each survey month (**a**) Japanese data; (**b**) international data.

To compare with the existing research and, to investigate whether the Griffiths model holds statistical significance with respect to our dataset, the analysis was continued. The $_{G}T_{c}$ at 0.5/K was used for the Japanese data and $_{G}T_{c}$ at 0.33/K for the international data.

The calculated comfort temperature for all nationalities in our survey proved to be very weakly correlated to the indoor air temperature, directly measured outdoor temperature T_o, as well as the T_{rm} and T_{od} (Figures 14 and 15). For the international students, the relation between calculated comfort temperature and the outdoor temperature was even statistically insignificant.

$$_{JP\,G}T_c = 0.429T_i + 14.8, \text{ where } (N = 183;\ p < 0.05;\ R^2 = 0.05;\ \text{S.E.} = 2.72;\ \text{F statistic} = 10.0) \quad (10)$$

$$_{INtl\,G}T_c = 0.207T_i + 20.1, \text{ where } (N = 237;\ p < 0.05;\ R^2 = 0.02;\ \text{S.E.} = 3.50;\ \text{F statistic} = 4.6) \quad (11)$$

$${}_{JP\,G}T_c = 0.105T_o + 23.5, \text{ where } (N = 183;\ p < 0.05;\ R^2 = 0.03;\ \text{S.E.} = 2.76;\ \text{F statistic} = 4.8) \quad (12)$$

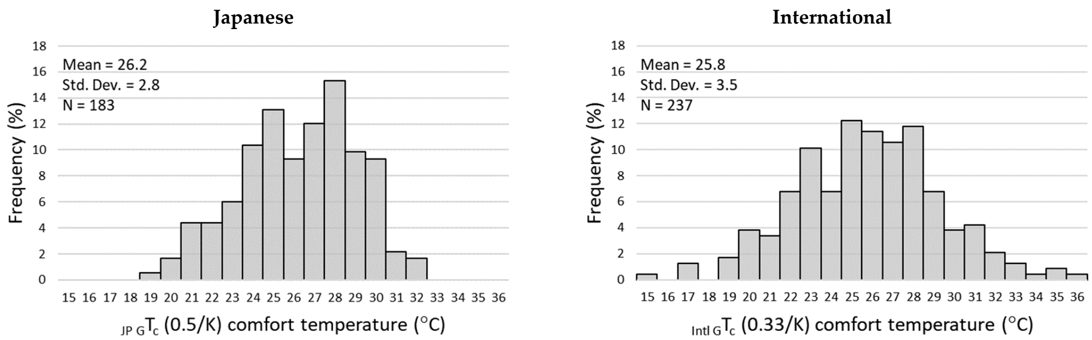
$${}_{INtl\,G}T_c = -0.048T_o + 27.1, \text{ where } (N = 237;\ p = 0.523;\ R^2 = 0.00;\ \text{S.E.} = 3.53;\ \text{F statistic} = 0.4) \quad (13)$$

$${}_{JP\,G}T_c = 0.356T_{rm} + 17.3, \text{ where } (N = 183;\ p < 0.001;\ R^2 = 0.01;\ \text{S.E.} = 2.65;\ \text{F statistic} = 19.9) \quad (14)$$

$${}_{INtl\,G}T_c = 0.166T_{rm} + 21.5, \text{ where } (N = 237;\ p = 0.142;\ R^2 = 0.00;\ \text{S.E.} = 3.52;\ \text{F statistic} = 2.2) \quad (15)$$

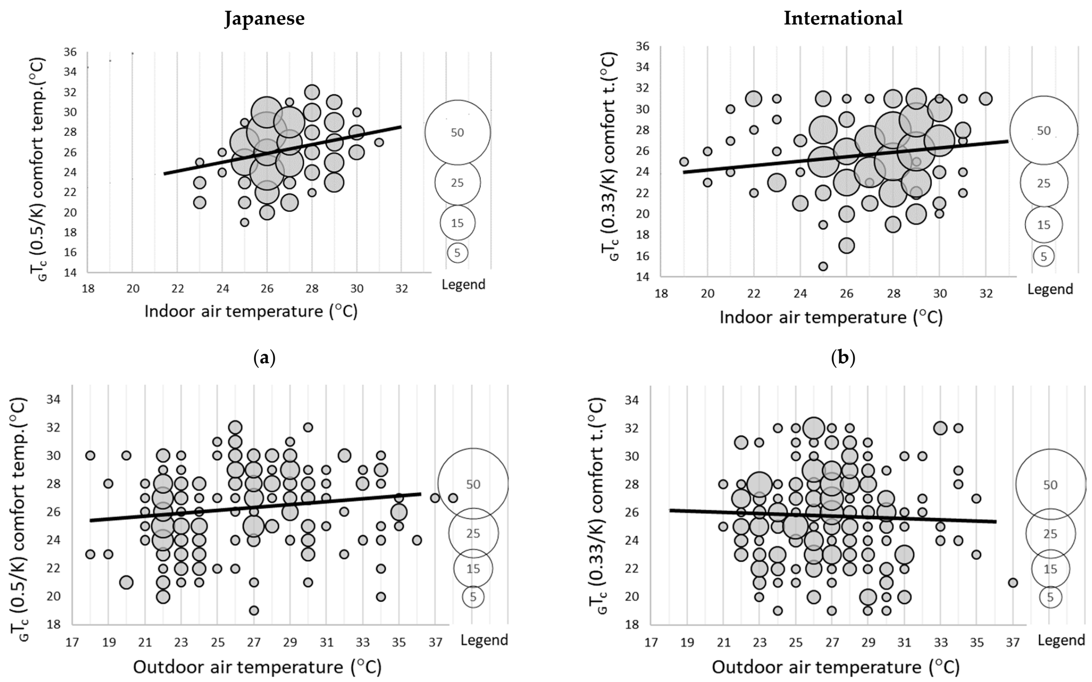
$${}_{JP\,G}T_c = 0.299T_{od} + 18.7, \text{ where } (N = 183;\ p < 0.001;\ R^2 = 0.08;\ \text{S.E.} = 2.68;\ \text{F statistic} = 15.6) \quad (16)$$

$${}_{INtl\,G}T_c = 0.028T_{od} + 25.1, \text{ where } (N = 237;\ p = 0.794;\ R^2 = 0.00;\ \text{S.E.} = 3.53;\ \text{F statistic} = 0.1) \quad (17)$$



(**a**) (**b**)

Figure 14. Griffiths' comfort temperature: (**a**) frequency distribution of the calculated Japanese comfort temperature; (**b**) frequency distribution of the calculated international comfort temperature.



(**a**) (**b**)

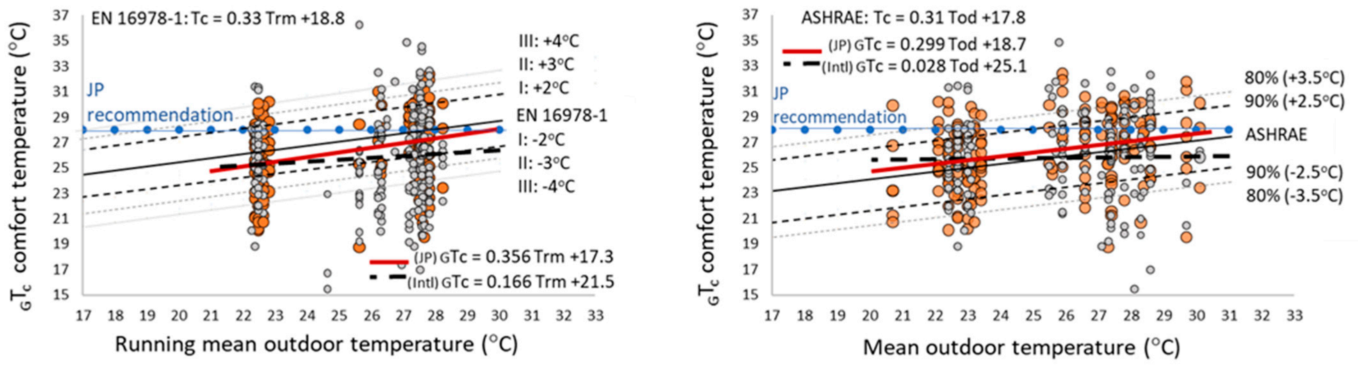
(**c**) (**d**)

Figure 15. Griffiths' comfort temperature at 0.5/K: (**a**) regression with indoor air temperature for Japanese; (**b**) regression with indoor air temperature for international; (**c**) regression with outdoor air temperature for Japanese; (**d**) regression with outdoor air temperature for international.

3.5. Comparison with Related Standards

A number of international standards regulate the indoor environment [1]. They have established thermal comfort models to predict the indoor comfort temperature based on the running mean outdoor temperature. The comfort temperature derived for Japanese and international students was correlated to running mean outdoor air temperature as calculated in Section 3.2 and to mean daily outdoor temperature to compare the results to EN 16978-1 [52] and ASHRAE [53] respectively.

Relating the Japanese comfort temperature to both Trm and Tod resulted in statistically significant positive correlation (Equations (14) and (16)). And the sensitivity to both is almost equal. Relating the international comfort temperature to both Trm and Tod resulted in statistically insignificant positive correlation to both Trm and Tod (Equations (15) and (17), Figure 16). Comparing to the adaptive model in EN 16978-1, it can be observed that almost all data points are within the range of group III and that our model for Japanese students is parallel to it, though consistently at ~1 °C below. The observed Japanese sensitivity was similar to the standard's model (regression coefficient of 0.356). The regression line estimated by our data set remains within the boundaries of the EN 16978-1 Class I comfort zone.



(**a**) (**b**)

Figure 16. Comparison of comfort temperature with standards: (**a**) EN 16978-1 and (**b**) ASHRAE.

The closest to a university dormitory building type included in the ASHRAE Global Thermal Comfort Database II is the "multifamily housing building" or a "classroom" [5]. However, dormitories resemble but also differ from either one. In addition, dormitories accommodate multinational students at the beginning of their stay in Japan, thus being the first indoor environment, they experience under different climatic conditions. It seems reasonable that field survey datasets from dormitories should aim at becoming part of that global database. As the correlation $_{Intl\,G}T_c$:T_{od} was statistically insignificant, only the Japanese comfort model could be compared. Its slope was parallel to the standard's, but it predicts ~0.5 °C higher comfort temperatures than the standard.

The summer energy conservation measures in Japan, issued by METI (Ministry of Economy, Trade and Industry) recommend indoor temperature in summer no less than 28 °C (blue dotted line in Figure 16) in order to limit the energy consumption and thus address the issues of energy dependency of the country [54]. However, this study shows that for all nationalities comfort is to be expected at a lower temperature and the difference can get up to 2~3 °C.

The neutral and comfort temperature observed and estimated in the study, remained invariably below the recommended temperature threshold for Japan in summer leading to believe that that threshold is worth reevaluating.

Comparison with existing research.

The sensitivity to indoor conditions observed in Section 3.4.2 is comparable with the sensitivity in similar research: 0.216/K [16] and 0.283/K [17] in Doha, Qatar; 0.273/K [48] in residential houses in Kanto region, Japan; 0.248/K in dormitory buildings in spring in

Harbin, China [30]; 0.225/K, 0.269/K and 0.282/K for Chinese students of different origin in dormitories during summer in Changsha, China [33]. However, there are instances when the sensitivity to the indoor temperature was observed to be almost twice lower (0.106/K in CL in Kanto, Japan [49]).

In the field survey conducted by Nakano et al. [11] in an office building in Japan, the "neutral" votes recorded were ~26%-a number between the percentages observed in the current study for Japanese and non-Japanese neutral votes (Table 4). However, in Nakano's study, the votes "comfortable" were also 26%, showing strong non-linear correlation between the two. In our survey more than 70% of the votes were "comfortable" irrespective of nationality and a strong negative linear correlation to the sensation (Figure 9b). The difference in linearity might be because our survey reports only summer data while the other research team reported a year-round data.

In both surveys, a significant difference in TSV was found relative to nationality. Nakano et al. [11] observed 3.1 °C difference in neutral temperature between Japanese females (25.2 °C) and non-Japanese males (22.1 °C), and 2.2 °C difference between Japanese males (24.3 °C) and non-Japanese males (22.1 °C). In both cases, the non-Japanese vote was at lower temperatures. Interestingly, even though the thermal sensation vote varies significantly depending on nationality, the neutrality for all in our study is expected to be achieved at the same temperature (~26 °C) (Table 6) and within the same range of 24–28 °C (Section 3.4.1). The difference in results might be influenced by the actual nationalities in the international sample (61% of the international subjects in Nakano's study were from North America and Europe, and only 22% Asian); or it might be due to the different period of conducting the studies (summer season vs. entire year).

Indraganti and Boussaa [16] also observed strong correlation between TSV and TP in their yearlong office survey in Qatar. The difference in the coding of the votes gives a positive value for the correlation they observed, however, practically the subjective attitude observed was the same—the hotter the people felt, the colder they would prefer it to be. However, the mean TSV they observed was on the cooler side of neutrality, while in our study it is on the warmer side for both Japanese and non-Japanese students (see Section 3.2, Figure 9a). This can be explained either by the different length of the study or by the higher percentage of air conditioner use in Qatar survey as compared to our current survey. Similar to our study, in Qatar the observed percentage of "comfortable" was high (just slightly less than 80%); as well as the acceptability was very high (over 80%).

Comparing with the previous research, it can be observed that other researchers also report values of comfort close to 26 °C in Japan irrespective of the variable they use for the calculation or the type of building where they conduct the research. The comfort temperatures in southern countries demonstrated higher values, while in countries located more to the north researchers report lower comfort temperatures. The data observed in our study complies with previous comfort research in Japan and other Asian countries as shown in Table 11.

Table 11. Comparison of comfort temperature in summer with existing research.

Area of the Research	Reference	Temperature for Calculation	Comfort Temperature (°C)
Nepal	[20]	T_g	21.1–30.0
UK	[21]	T_i	22.9
Japan (Tokai)	This study (see Section 3.4.2.)	T_i	26.0 (24.0–27.0) *
Japan (Tokai)	This study (see Section 3.4.1.)	T_i	24.0–26.5 **
Japan (Gifu)	[14]	T_i	26.1
Pakistan	[19]	T_g	26.7–29.9
Iran	[18]	T_i	28.4
Singapore	[22]	T_{op}	28.5
China	[26]	T_{op}	28.6
India	[25]	T_g	29.2
Indonesia	[23]	T_{op}	29.2
Malaysia	[24]	T_i	30.1

Table 11. *Cont.*

Area of the Research	Reference	Temperature for Calculation	Comfort Temperature (°C)
Japan (Kanto)	[6]	T_{rm}	25.8 (FR, CL)
Malaysia	[6]	T_{rm}	25.6 (CL)
Indonesia	[6]	T_{rm}	24.7, 26.3, 27.5 (FR, CL, MM)
Singapore	[6]	T_{rm}	26.4 (CL)
Japan (Kanto)	[10]	T_g	25.0 (FR), 25.4 (CL)
Japan (Kanto)	[13]	T_i	23.6 (FR), 27.0 (CL)
China	[29]	T_{op}	25–29 (FR)

Note: T_g: globe temperature (°C); T_i: indoor air temperature (°C); T_{op}: operative temperature (°C); * estimation by regression; ** estimation by probit analysis; FR: free-running mode; CL: cooling mode; MM: mixed mode.

4. Conclusions

The current study aimed to reveal if there was any difference in subjective thermal comfort of Japanese and international students living in Japan and experiencing Japanese summer climate. We were interested to know the magnitude of that difference in subjective perception and evaluation of the indoor environment and, whether the students were willing to tolerate unfavorable conditions. The data was collected through a field survey in dormitory buildings in the summer of 2017. For the subjective votes we used a traditional paper questionnaire which were later linked to the physical measurements of indoor environment. We ran the analysis focusing on the differences in the two groups we defined—the Japanese and non-Japanese group. We found that:

- Nationality significantly affected thermal sensitivity and preference.
- Voted thermal acceptability was invariably above 90%.
- The study investigated the combined influence of the measured temperature, humidity, clothing, and activity on the thermal sensation with respect to nationality. Interestingly, despite the high levels of humidity observed, the multiple regression model showed that only the indoor temperature was significant for explaining the variability of thermal sensation for both Japanese and non-Japanese students.
- Probit analysis showed that the highest probability of voting neutral for university students in dormitory buildings can be estimated within 24–26.5 °C indoor temperature. However, within that range, the probability for Japanese students was estimates only as high as 70–75%, while for the international students it was above 80%.
- The adjusted linear regression coefficient yielded from the room-wise day-wise averages were 0.48/K and 0.34/K for Japanese sensitivity and international sensitivity respectively, showing that Japanese students are notably more sensitive to their indoor environment as compared to non-Japanese ones.
- The Griffiths model of estimating comfort temperature showed little predictability in our study and notable differences from the actually voted comfort, especially for non-Japanese students.

The neutral and comfort temperature observed and estimated in the study remained invariably below the recommended temperature threshold for Japan in summer, leading us to believe that that threshold is worth re-evaluating.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Toyohashi University of Technology H29-17/2017.2.1.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Part 2: Questionnaire about subjective perception of indoor environment (Please, fill it in 3 times per day–just after waking up; at noon; just before going to bed)

Date and Time:	**Year**	**Month**	**Day**	**Hour (am/pm)**	**min**
☐ Wake up		☐ Noon		☐ Going to bed	

Environmental Conditions RIGHT NOW (perception, evaluation, preference, acceptability).

1-① How do you feel about the thermal environment at this precise moment in your room? I feel: ☐ hot ☐ warm ☐ slightly warm ☐ neutral ☐ slightly cool ☐ cool ☐ cold	1-② How do you find the thermal environment of your room? ☐ very comfortable ☐ comfortable ☐ slightly comfortable ☐ slightly uncomfortable ☐ uncomfortable 1. very uncomfortable	1-③ Please state how would you prefer to be now: ☐ warmer ☐ no change ☐ cooler 1-④How do you judge the thermal environment? ☐ Acceptable ☐ Unacceptable
2-① How do you feel about the humidity in your room? I feel: ☐ very humid ☐ humid ☐ slightly humid ☐ neutral ☐ slightly dry ☐ dry ☐ very dry	2-② How do you find the humidity of your room? ☐ very comfortable ☐ comfortable ☐ slightly comfortable ☐ slightly uncomfortable ☐ uncomfortable ☐ very uncomfortable	2-③ Please state how would you prefer to be now: ☐ more humid ☐ no change ☐ dryer 2-④How do you judge the humidity in your room? ☐ Acceptable ☐ Unacceptable
3-① How do you feel about the air movement within your room? I feel: ☐ very strong movement ☐ strong movement ☐ slight movement ☐ neutral ☐ slightly still ☐ still ☐ very still	3-② How do you find the air movement of your room? ☐ very comfortable ☐ comfortable 1. slightly comfortable ☐ slightly uncomfortable ☐ uncomfortable ☐ very uncomfortable	3-③ Please state how would you prefer to be now: ☐ stronger air movement ☐ no change ☐ weaker air movement 3-④How do you judge the air movement in your room? ☐ Acceptable ☐ Unacceptable

4-① How do you feel about the air quality in your room? I feel:

- ☐ very stuffy air
- ☐ stuffy air
- ☐ slightly stuffy
- ☐ neutral
- ☐ slightly fresh air
- ☐ fresh air
- ☐ very fresh air

4-② How do you find the air quality of your room?

- ☐ very comfortable
- ☐ comfortable
- ☐ slightly comfortable
- ☐ slightly uncomfortable
- ☐ uncomfortable
- ☐ very uncomfortable

4-③ Please state how would you prefer to be now:

- ☐ more stuffy
- ☐ no change
- ☐ more fresh

4-④How do you judge the air quality in your room?

- ☐ Acceptable
- ☐ Unacceptable

5-① How do you feel about the odours in your room? I feel:

- ☐ very strong odours
- ☐ noticeable
- ☐ slightly noticeable
- ☐ neutral
- ☐ slightly unnoticeable
- ☐ unnoticeable
- ☐ no odours at all

5-② How do you find the odours in your room?

- ☐ very comfortable
- ☐ comfortable
- ☐ slightly comfortable
- ☐ slightly uncomfortable
- ☐ uncomfortable
- ☐ very uncomfortable

5-③ Please state how would you prefer to be now:

- ☐ more noticeable odours
- ☐ no change
- ☐ less noticeable odours

5-④How do you judge the odours in your room?

- ☐ Acceptable
- ☐ Unacceptable

6-① How do you feel about the brightness level of your room? I feel:

- ☐ very bright
- ☐ bright
- ☐ slightly bright
- ☐ neutral
- ☐ slightly dim
- ☐ dim
- ☐ very dim

6-② How do you find the brightness of your room?

- ☐ very comfortable
- ☐ comfortable
- ☐ slightly comfortable
- ☐ slightly uncomfortable
- ☐ uncomfortable
- ☐ very uncomfortable

6-③ Please state how would you prefer to be now:

- ☐ brighter
- ☐ no change
- ☐ dimmer

6-④How do you judge the brightness in your room?

- ☐ Acceptable
- ☐ Unacceptable

7-① How do you feel about the noise level in your room? I feel:

- ☐ very disturbing
- ☐ disturbing
- ☐ slightly disturbing
- ☐ neutral
- ☐ slightly unnoticeable
- ☐ unnoticeable
- ☐ not at all noticeable

7-② How do you find the noise level in your room?

- ☐ very comfortable
- ☐ comfortable
- ☐ slightly comfortable
- ☐ slightly uncomfortable
- ☐ uncomfortable
- ☐ very uncomfortable

7-③ Please state how would you prefer to be now:

- ☐ higher noise levels
- ☐ no change
- ☐ lower noise levels

7-④ How do you judge the noise level in your room?

- ☐ Acceptable
- ☐ Unacceptable

Please, mark the closest to your clothing, activity and personal control over the room environment:

CLOTHING (Circle the Appropriate)		**ACTIVITY (in the Last 30 min)**	%	**CONTROLS (Circle the Appropriate)**	
Shirt, short/long sleeves		Sitting (passive work)		Door opened/closed	
Trousers/ long skirt		Sitting (active work)		Window slightly open	
Dress		Standing relaxed		Window wide open	
Pullover		Standing working		Lights on/off	
Jacket		Walking outdoors		Air-condition on (heat)	
Long/short socks		Walking indoors		Air-condition on (cool)	
Shoes		Riding a bicycle outdoors		Air-condition off	
Sneakers		Other (specify)		Fan on/off	
Slippers				Local heater on/off	
Other (specify)				Blinds open/closed	
		Total	100%	Other (specify)	

8-① During THE LAST 30 min have you experienced any of the following symptoms? (*please, check ALL that apply*)

- ☐ dry, itching or irritated eyes
- ☐ headache
- ☐ sore or dry throat
- ☐ unusual tiredness, fatigue or drowsiness
- ☐ stuffy or runny nose, or sinus congestion
- ☐ cough or difficulty breathing
- ☐ tired or strained eyes
- ☐ tension, irritability or nervousness
- ☐ pain or stiffness in back, shoulders or neck
- ☐ sneezing
- ☐ dizziness or lightheadedness
- ☐ nausea or upset stomack
- ☐ dry or itchy skin
- ☐ others (please specify)

8-② Within THE LAST 30 min did you eat a snack or meal?

- ☐ YES
- ☐ NO

8-③ Within THE LAST 30 min did you have a drink that was: YES/NO

- ☐ HOT
- ☐ COLD
- ☐ Caffeinated

8-④ Within THE LAST 30 min did you smoke a cigarette?

- ☐ YES
- ☐ NO

8-⑤ Within THE LAST 30 min did you adjust your clothing? (*if YES, please describe briefly*)

- ☐ YES
- ☐ NO

Thank You for Participating in Thermal Comfort Survey.

Appendix B

Table A1. List of garments used in the questionnaire and the clo values assigned.

Garment	Clo	Garment	Clo	Garment	Clo
Shirt (short sleeves)	0.19	Pullover	0.36	Shoes	0.07
Shirt (long sleeves)	0.25	Jacket	0.36	Sneakers	0.07
Trousers/long skirt	0.15	Long socks	0.03	Slippers	0.03
Dress	0.33	Short socks	0.02	Other	0.57

Table 2. List of activities used in the questionnaire and the Met values assigned.

Activity	Met	Wording in ASHRAE Handbook (Chapter 9, Table 4)
Sitting (passive work)	1.0	Office activities–reading seated; writing
Sitting (active work)	1.2	Office activities–filing seated
Standing (relaxed)	1.2	Resting–standing, relaxed
Standing (working)	2.7	Miscellaneous occupational Activities: housecleaning
Walking outdoors	2.6	Walking (on level surface) 4.3 km/h
Walking indoors	1.7	Office activities: walking about
Riding a bicycle	4.0	Bicycling <16 km/h. general, leisure to work or for pleasure [1]
Other activity indoors	1.0	Resting–seated, quiet

[1] The value for "riding a bicycle" from: https://community.plu.edu/~chasega/met.html (accessed on 14 October 2017).

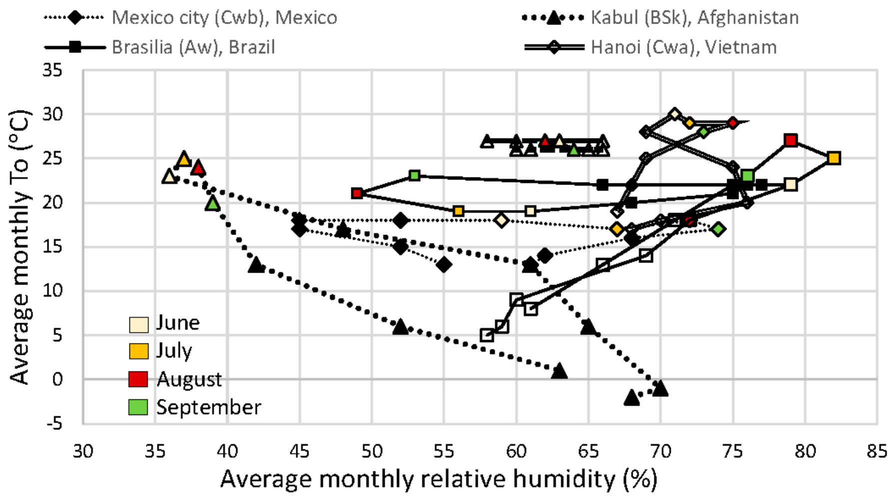

Figure 1. Climate in the countries of origin of the subjects in the summer field survey. Cwb: Dry-winter subtropical highland climate, BSk: Cold semi-arid climate, Aw: Tropical savanna climate with non-seasonal or dry winter characteristics; Cwa: Dry-winter humid subtropical climate, Af: Tropical rainforest climate, Cfa: Humid subtropical climate. Note: Each marker represents monthly mean value. The markers for June, July, August and September are color coded.

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