A Study on Adaptive Thermal Comfort in University Dormitories. Effect of Nationality

(大学寮における適応型温熱快適性に関する研究：国籍の影響)

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Abstract（Doctor）

Title of Thesis	**A Study on Adaptive Thermal Comfort in University Dormitories. Effect of Nationality**

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Our contemporary world faces unprecedented global problems – environmental, geopolitical, societal, economic and technological. Excessive and insensible energy use on a global scale is one of the major contributors to the complex environmental issues. Any local effective measure for energy conservation and its efficient use can contribute to the solution. One way to limit energy use is through implementing adaptive thermal comfort. Allowing building occupants to control and connect back to their immediate thermal environment and, to adapt to it, eventually affects the energy consumption of the building itself. Providing comfort is complicated and it is the outcome of a flexible system including 1) the occupant; 2) the building; 3) the indoor microclimate and 4) the outdoor climate.

The current thesis is focused on investigating the behavior and subjective preferences for their indoor environment of Japanese and non-Japanese students living in university dormitory buildings under Japanese climatic conditions. The major initial objective is to determine what does comfort mean in terms of temperature range for Japanese and non-Japanese people; to compare the differences and, to understand how tolerant the occupants are to their environment. We expected to observe 1) difference in comfort temperatures between Japanese and non-Japanese students in summer as well as in winter; 2) that Japanese comfort vote will fall within the current recommendations for summer and winter in Japan; and 3) that Japanese students will be more tolerant to their environment in both seasons as it is native to them.

Dormitory buildings were selected for conducting the research as 1) they are a unique combination of a residence and office; 2) they are under-investigated in Japan in terms of adaptive thermal comfort; 3) they are for temporary multinational occupancy and, can reveal the differences between Japanese and non-Japanese students; 4) they are expected to need major refurbishment in the recent years.

We planned and conducted a field survey in the summer and winter of 2017 – 2018 in two university dormitory buildings in Toyohashi University of Technology – the international dormitory (Kaikan) and the Global Students Dormitory (GSD).

Subjective votes were collected through a traditional paper questionnaire. Simultaneously, measurements of physical parameters of the indoor and outdoor environment were conducted and the two data-sets were linked. The correlation of the subjective neutrality and comfort were investigated in relation to nationality

The study revealed that for both observed groups, in summer, the subjective neutrality and comfort was related to outdoor climate conditions, but in winter it was strongly disconnected from the outdoors.

For both Japanese and non-Japanese students, thermal responses were strongly correlated to one another, where feeling warmer resulted in increase of subjective comfort in winter and decrease in summer. In winter, feeling warmer led to decrease in the desire to warm up the indoor environment, while in summer it led to the desire to cool it down. Nevertheless, voted thermal acceptability in both seasons was invariably above 85% which can be explained with the high level of personal control.

During summer, the recorded indoor humidity was very high (71%), while in winter it was very low (47%). However, in both seasons it did not affect the thermal sensation vote. For both Japanese and non-Japanese students, thermal sensation was significantly determined only by the indoor temperature. The effects of clothing and activity were also negligible both in summer and in winter.

The summer neutral indoor temperature could be estimated as 26°C for Japanese students and as 25°C for non-Japanese. However, the highest probability of voting neutral for Japanese students was only 70-75% and it was estimated within 24~28°C indoor temperature. For non-Japanese students it's above 80% within the same temperature range.

The winter neutral indoor temperature could be estimated as 21°C for Japanese students and as 22°C for non-Japanese. However, the highest probability of voting neutral for Japanese students was only 65% and it was estimated within 19~22°C indoor temperature. For non-Japanese students it's 75% within 19~24°C indoors.

Japanese students were notably more sensitive to their indoor environment as compared to non-Japanese ones in both seasons. The summer comfort temperature for both groups could be estimated as 26°C and, in winter it is 20°C for Japanese and 22°C for non-Japanese.

For both Japanese and non-Japanese students, the yielded predicting models from the survey deviated from the models in the current international standards. In addition, the voted and the estimated neutrality and comfort in the study were mostly below the recommended minimum indoor temperature in summer and, above the recommended maximum indoor temperature in winter in Japan. As the recommendation is set considering the energy conservation, it is reasonable to further investigate how to make it possible to adjust the subjective neutral and comfort temperatures without compromising personal comfort.

Contents

List of Appendices

List of Figures

List of Figures in Appendices

List of Tables

List of Tables in Appendices

List of Equations

CHAPTER I

Adaptive Thermal Comfort. Overview and Research Problem

1. Introduction

Our contemporary world faces unprecedented global problems – environmental, geopolitical, societal, economic and technological [1]. None of the others will matter however, if the environmental ones remain unsolved. A potential solution demands no less than a collective geopolitical, societal, economic and technological will and urgent actions; a solution that stems from a "biosensitive society"[2]. It has been widely accepted that the environmental problems are a result of the cumulative global human activity [2], [3] and have especially intensified after the first industrial revolution of the 19th century [4]. However, there are still skeptics that assume the catastrophic climatic phenomena we observe today are just a part of the planet's life cycle and have nothing to do with human activity. With the extensive evidence for the former however, it is close to undeniable that human activity is the reason for the current climatic turmoil. Luckily, there is still hope we can do something about it – slow it down, stop it or if we dear to dream – even reverse it.

Environmental issues of today are complex and energy use is a major contributor to the problems, but still just a fragment of it. Energy use itself is a multi-faceted problem that can be addressed differently – one way being through adaptive thermal comfort. Allowing to connect back to our immediate thermal environment, to adapt to it, eventually affects the energy consumption of the buildings. Currently, in Japan buildings consume 29% of the total energy the country uses (89:312Mtoe as for FY2017) [5]. Narrowing down the environmental problems from the global scale to the scale of national security, it must be noted that Japan hit its lowest energy self-sufficiency ratio of only 6% [6], [7] in 2014 and, implementing all measures for energy efficient use and conservation matter nationally, as well as globally. Despite its singularity, however, adaptive thermal comfort is a complex conundrum in itself as there is not a single recipe for comfort – it is different for every single person – very much so as the subjective understanding of happiness, success, balance and fulfilment. The current thesis is focused on investigating further about adaptive thermal comfort.

1.1. Current Global Environmental Problems. Overview

Everyone is familiar more or less with the words "climate change". But, why does it matter? After all, the planet Earth has faced periods of climatic changes before. Who can claim that exactly now it is because of us – one single species in an entire planet? And, what does it really mean? What was it before and how is it different now? Why all the fuss?

In his "Short history of climate change on planet Earth" [8] James Potzick examines extensive climate data from multiple sources to answer to exactly these questions. A realistic climate change model is expected to be complex and to include thermodynamics; changes in water, air and soil chemistry mix; ocean and air currents; insolation and more. Because of such complexity it hasn't been yet fully developed. Much more simplistic model of climate change would focus mainly on the trapped solar radiation due to the anthropogenic carbon dioxide (CO_2) – the "greenhouse" effect and, the subsequent increase of the global average surface temperature (GAST). This is only the "tip of the iceberg", however, the recent and dramatic rise in CO_2 levels of ~ 200ppm (parts per million) is impossible to ignore (Figure 1). Human overpopulation, rapid and extensive deforestation, agriculture and animal husbandry, urbanization, industry and over consumption of fossil fuels; increased transportation; ocean surface pollution with insoluble plastics – the majority of human activities disbalance the carbon-oxygen cycle releasing more and more CO_2 in the atmosphere while limiting both the CO_2 sinks and the O_2 sources. Data reveals the correlation of increased CO_2 levels to the evident increase in GAST (Figure 1); as well as to the world population growth (Figure 2). The climatic consequences are already undeniably affecting people, ecosystems and livelihoods on a global scale – rise in global terrestrial and ocean temperatures, ice-caps meltdown, accelerating sea-level rise, floods and landslides, devastating storms, severe draughts, land degradation and desertification, rapid rate of species extinction and loss of biodiversity and more, many more. [9], [10], [11], [12].

In Paris in 2015, an agreement has been reached to mitigate the global temperature rise to less than 2^{o}C higher than the pre-industrial age, or even lower [12] by significantly cutting down the global

CO_2 emissions. Failing to achieve that is expected to trigger practically unknown environmental effects. Even the best predictions are speculative as there has never been a precedent before to ground upon. An attempt to classify the environmental risks and describe the anticipated outcome has been made at the World Economic Forum 2019 (Table 1)

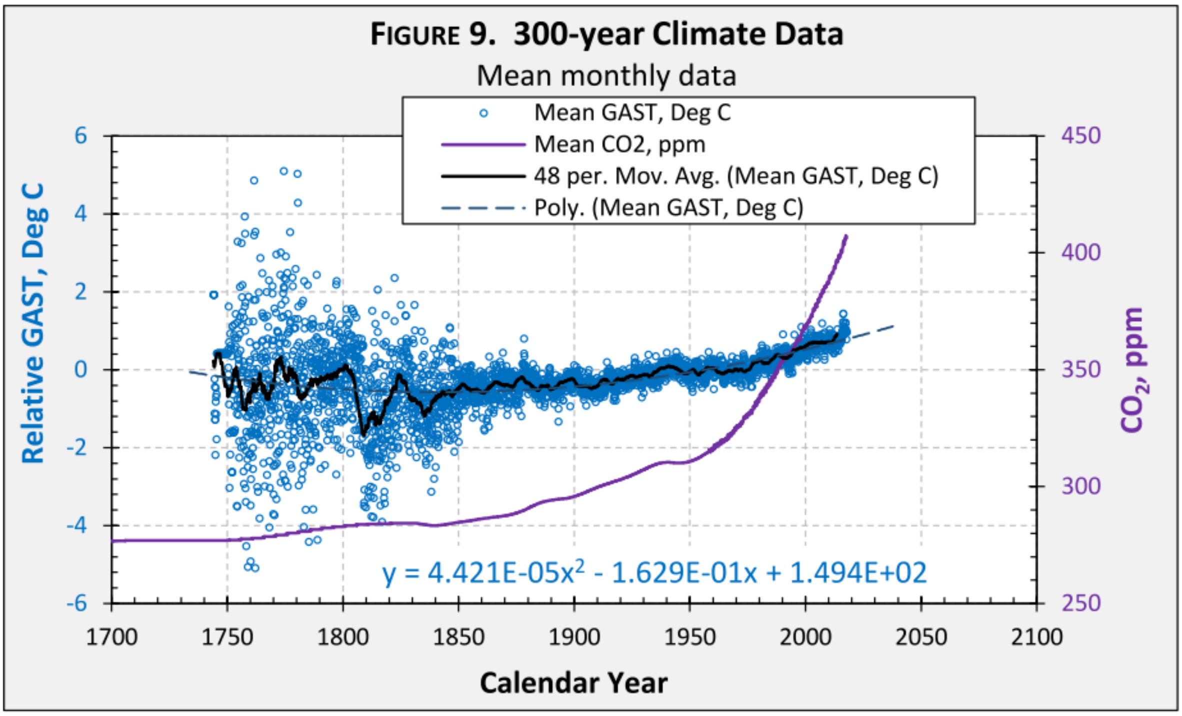


Figure 1. Main monthly GAST and CO_2 data in the last 300 years. Figure from J. Potzick [8]

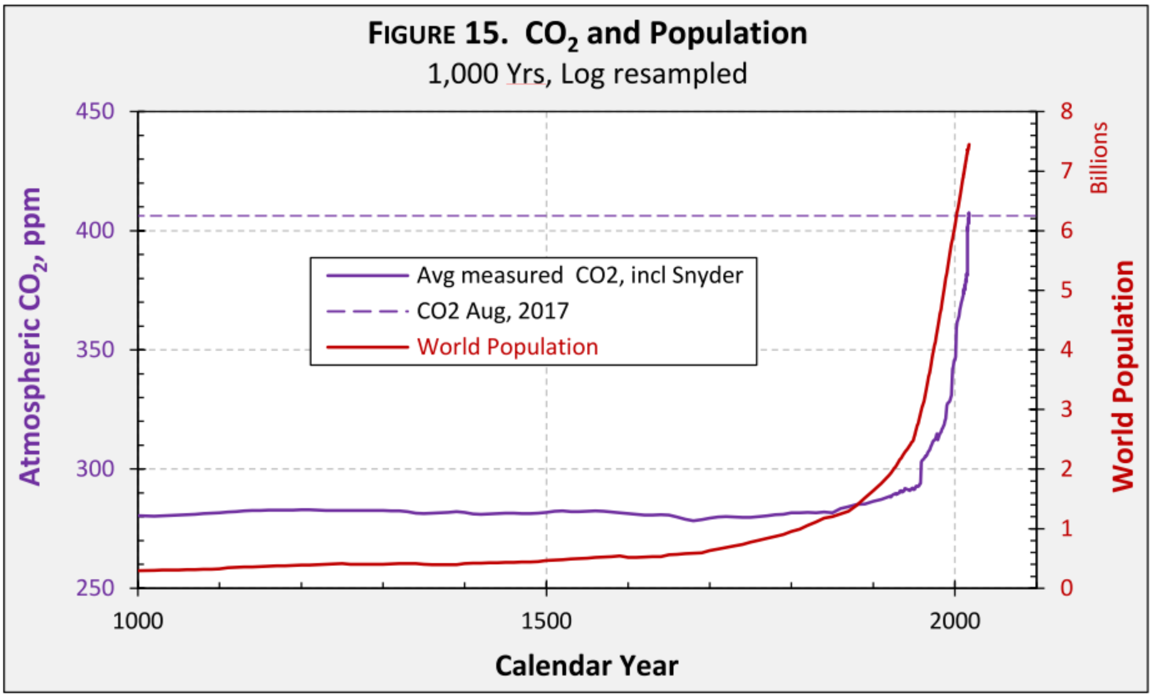


Figure 2 World population growth in the last 14,000 years. Figure from J. Potzick [8]

Table 1 Environmental global risks as defined in World Economic Forum 2019 [p.102 [1]]

Global Risk	Description
Extreme weather events (e.g. floods, storms, etc.)	Major property, infrastructure, and/or environmental damage as well as loss of human life caused by extreme weather events.
Failure of climate-change mitigation and adaptation	The failure of governments and businesses to enforce or enact effective measures to mitigate climate change, protect populations and help businesses impacted by climate change to adapt.
Major biodiversity loss and ecosystem collapse (terrestrial or marine)	Irreversible consequences for the environment, resulting in severely depleted resources for humankind as well as industries.
Major natural disasters (e.g. earthquakes, tsunamis, volcanic eruptions, geomagnetic storms)	Major property, infrastructure, and/or environmental damage as well as loss of human life caused by geophysical disasters such as earthquakes, volcanic activity, landslides, tsunamis, or geomagnetic storms.
Man-made environmental damage and disasters (e.g. oil spills, radioactive contamination, etc.)	Failure to prevent major man-made damage and disasters, including environmental crime, causing harm to human lives and health, infrastructure, property, economic activity and the environment.

But, nothing to worry about. Putting aside the potential global economic disruption and imminent conflicts triggered by food and resources scarcity, “climate change” simply means that in order to survive the human species must evolve to breathe toxic air, to eat insects or plastic or better even – to not eat at all, to drink polluted water and enjoy acid rains; to consider a tornado a mild breeze and temperatures of about 40ºC pleasantly warm; to be a supreme swimmer as to still inhabit the flooded areas, or to move to the limited higher grounds with all the other 10~12 billion humans (as estimated by United Nations about the year 2100[1]). Mild changes like that. ASAP. And, if the evolution cannot happen fast enough (because one cannot rush evolution – it tends to take its time), well, there are still some options left – to genetically modify the entire species to fit the new conditions, to abandon the planet, to get extinct, or to hit reverse.

1.2. Energy and Climate

1.2.1. Energy Consumption and Environmental Impact

The World Meteorological Organization (WHO) has reported data showing that the past twenty years have included eighteen of the twenty warmest years since the beginning of climate data

[1] https://population.un.org/wpp/Graphs/Probabilistic/POP/TOT/900

recording in 1850. The energy consumption and CO_2 emissions by the G-20 countries hit a historically high levels – as observed last year (2018) by Enerdata [2,3] – a leading statistical analyst in the field of energy and climate monitoring and forecasting. The G-20 countries account for 80% of the world's energy consumption and CO_2 emissions. In 2018, Enerdata recorded an increase of +2.2% in the G-20 countries' energy consumption. Worldwide, the increase is +2.9% (Figure 3) as reported in the BP plc Statistical Review on World Energy in 2018 [13] (** BP plc – a British multinational oil and gas company. Formerly - The British Petroleum Company plc and BP Amoco plc). Carbon emissions have also grown by +1.7% in the G-20 and by 2.0% worldwide.

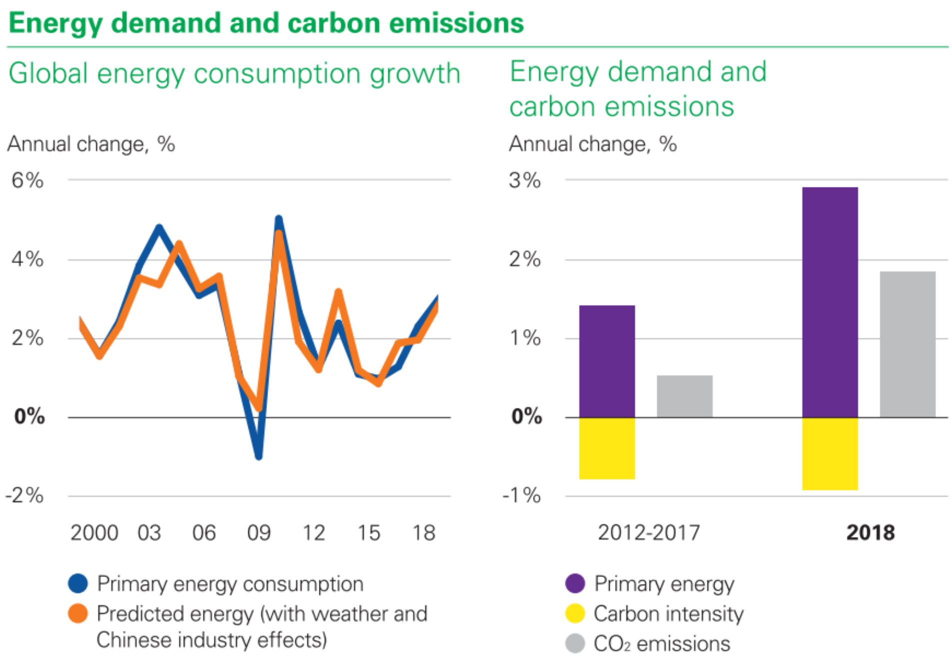


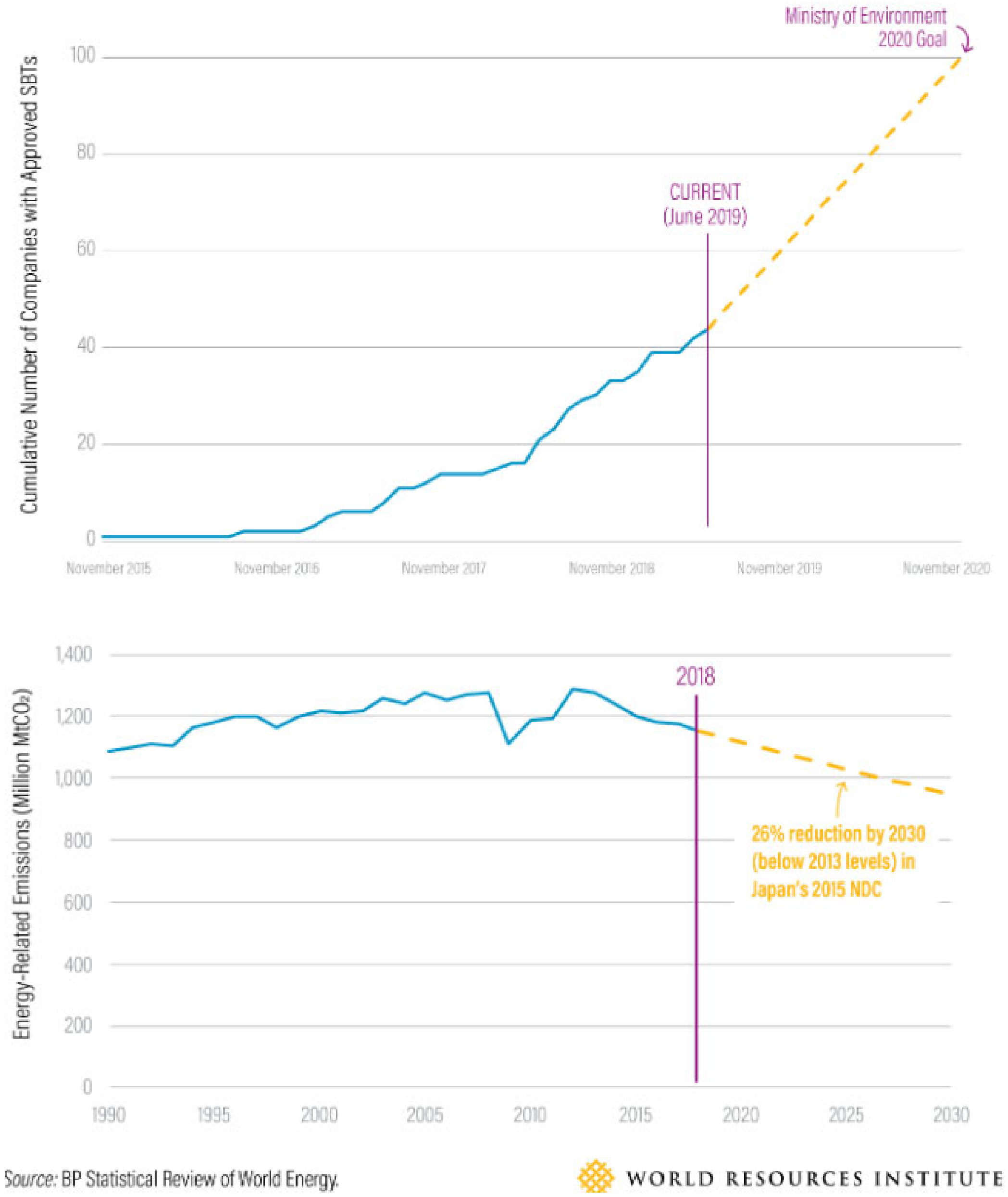
Figure 3 Global total energy consumption and carbon emissions growth in 2018 [13]

As the world's economic development remains highly energy-intensive, it is doubtful whether the 2015 Paris Agreement resolutions could be met and, consequently – whether the environmental impact could be mitigated.

1.2.2. History Overview. Current State and Future Strategies in Japan

Human energy needs worldwide were limited prior to the 1st industrial revolution [4]. For heating people used to utilize the sun, or to burn easily accessible wood or straw; transportation was provided by animals on land and by wind at sea; work was done by humans themselves or with the use of animal power. The machines were simple and limited in number and accessibility.

[2] https://d1owejb4br3l12.cloudfront.net/about-us/press-release/2019-press-release-world_energy-news.pdf
[3] https://www.enerdata.net



a)

b)

Figure 4 Goals from Japan's long-term strategy[4] about: a) growth in Japanese companies setting science-based targets (SBTs); b) reduction in energy-related CO_2 emissions. [14]

Inventing the modern steam engine in the 1700s marked the beginning of ever so accelerating technological advances and the subsequent constant increase in energy demand[5]. In 1880 the first electric generator was powered by a steam engine on coal. Hydroelectric plants followed soon after. By the end of the century, petroleum and its products became indispensable fuel and, paved the way for the combustion engines and the spur of transportation. The higher lifestyle standards, the decreasing energy prices, the accessibility and spread of the new technologies predetermined

[4] https://www.wri.org/blog/2019/06/japan-leading-business-climate-engagement-will-ambitious-policies-follow
[5] https://www.ucsusa.org/clean_energy/our-energy-choices/a-short-history-of-energy.html

the boosting energy demand globally. In the 1950s nuclear power used in electricity production contributed to lowering the consumption costs even further and, until the Great Energy Crash of 1973, the concern about efficient energy use practically did not exist. Certain geopolitical decisions led to the energy crisis of 1973 and the following one in 1979. The rise in prices and demand, eventually raised the issue of energy conservation. The multiple accidents in nuclear power plants added the issue of the effect on environment and human health.

The 2015 Paris Agreement marked a milestone in geopolitical will to tackle the climate-change related issues. Following the agreement, Japan committed to reduce its greenhouse emissions by 26% by 2030 (relative to 2013 levels) and by 80% by 2050 (Figure 4). The targeted goal is to achieve net zero emissions "as early as possible in the second half of this century"[6] and, to build a "decarbonized society" by balancing the anthropogenic emissions and the amount removed by greenhouse gas sinks. The country's long-term strategy and related policies were finalized prior to the summit of G-20 environment and energy ministers in June 2019 [14].

To realize the goal, Japan has focused its efforts in three main directions: energy security, economic efficiency and environmental suitability while providing safety (3E+S approach). Japan strongly promotes the efforts of companies to set science based targets (SBTs) for mitigating environmental impact (Figure 4) and, it is proceeding with research and development of non-conventional energy resources such as methane hydrate and hydrogen energy. It aims also at increasing the renewable energy ratio in electricity generation. As of 2016 it has reached 14.5% and the trend is upwards, especially so in the increase of solar energy use [7]

1.2.3. Energy Consumption in Japan. Total and in Residential Buildings

In 2018, Japan consumed 424Mtoe total energy and ranked 5th within G-20 countries after China, the US, India and Russia (3,164; 2,258; 929 and 800Mtoe respectively)[7]. Relative to the CO_2 emissions the country was again 5th with 1,123MtCO_2 (Figure 5).

The total energy consumption trend in Japan is currently decreasing. It reached a peak of 524Mtoe in 2004 and in 2018 is at its minimum in the last three decades (424Mtoe). During the same period CO_2 emissions remain within 1,000-1,200MtCO_2 closely distributed between oil, coal and gas-originating (38%, 39%, 23% respectively).

[6] https://thediplomat.com/2019/04/does-japans-new-climate-change-strategy-go-far-enough/

[7] https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

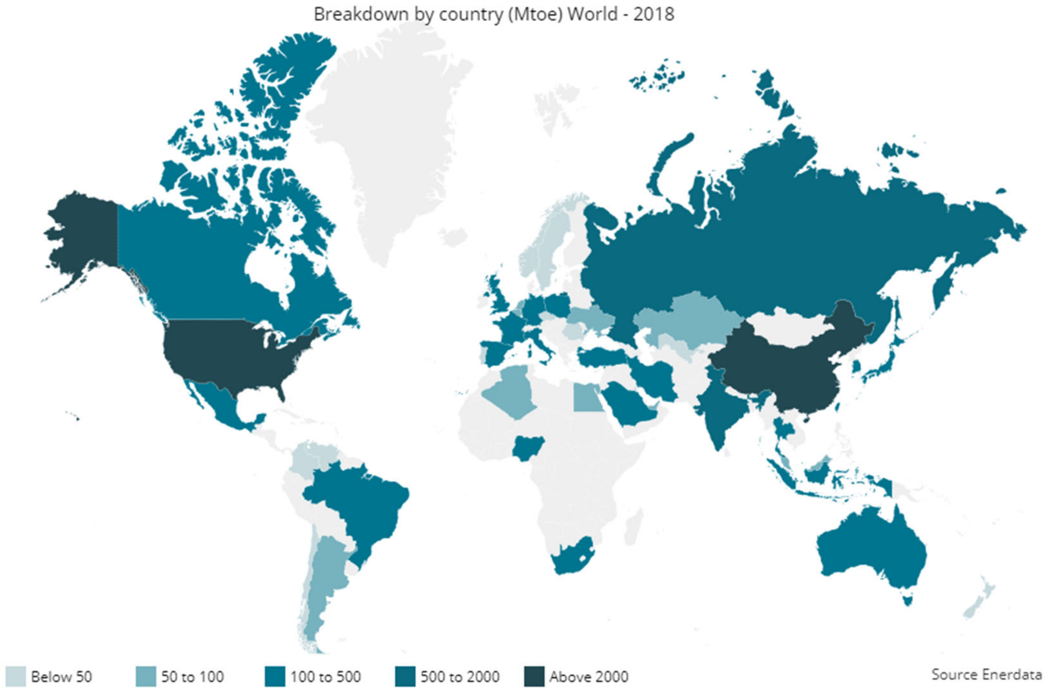


Figure 5 Energy consumption in G-20 countries in 2018 (data: https://yearbook.enerdata.net)

Since FY2014 the carbon emissions in Japan keep decreasing as well. The renewable-energy use for electricity production in Japan has noticeably increased from 9% in 2007 to 18% in 2018. Prior to Fukushima Daiichi nuclear plant accident in 2011, Japan was the third largest producer of nuclear power after the US and France and, nuclear power accounted for 27% of the country's energy demand. Following the accident, for almost two years between 2013 and 2015 Japan suspended nuclear power generation which led the country to its lowest energy self-sufficiency ratio of 6% in 2014[6], [7]. From 2015, a few reactors were restarted and the current government's intention is to resume using nuclear energy to ensure energy security, lower the electricity cost and suppress CO_2 emissions. New regulatory safety and security standards were issued in 2013. The self-sufficiency ratio bounced back up to 8.3% in 2016 [7]. (see also Appendix A and Appendix B).

In Japan, buildings currently consume 29% of the total energy the country uses (89:312Mtoe as for FY2017) [5]. As compared to the energy consumption in 1973 – the first oil crisis, residential buildings consume 1.9 times more, the total energy consumption increase of the country being 1.2 times [7].

Energy efficiency and conservation tackles both the local issue of Japan's energy security as well as the global warming in general. There is not one measure that can single-handedly solve the problem. It demands a cumulative solution where every single contribution, no matter how big or small, is indispensable. Even by a small rate, occupants' behavior and adaptation can limit building energy consumption and in result the carbon footprint, eventually limiting the environmental human impact.

1.2.4. Climate Classification System

The first quantitative classification of Earth's climate was developed by Wladimir Köppen in 1900[15]. Despite being created more than a hundred years ago the use of Köppen-Geiger climate classification system is still widespread[16]. It is highly used both for research purposes, and for teaching in general. It has been modified several times after its first publication (1923, 1931, 1936), but some scientists argued that it is about time to generate new classification system [17], [18] based on much more precise data available today than more of a century ago.

Table 2 Köppen-Trewartha Classification [8] Definition of types and subtypes as defined by the Köppen-Trewartha climate classification. T denotes mean annual temperature (°C), P_{mean} is the mean annual rainfall (cm), R is Patton's precipitation threshold. T_{cold} (T_{warm}) stands for monthly mean air temperature of the coldest (warmest) month.

Type	Criteria	Sub-type	Rainfall Regime
A	T_{cold}>18°C	A_r	10 to 12 months wet; 0 to 2 months dry
	P_{mean} above value given in B	A_w	winter (low-sun period) dry; more than 2 months dry
		A_s	summer (high-sun period) dry; rare in A climates
B	P_{mean} < R	BS	R/2 < P_{mean} < R
	(R = 2.3T - 0.64 P_w +41)	BW	P_{mean} < R/2
C	8-12 months with T>10°C	C_s	summer dry; at least three times as much rain in winter half year as in summer half year; driest summer month less than 3 cm of precipitation; annual precipitation total under 89 cm
		C_w	winter dry; at least ten times as much rain in summer half year as in winter half year
		C_f	no dry season; difference between driest and wettest month less than required for s and w; driest month of summer more than 3 cm
D	4-7 months with T>10°C	D_o	T_{cold} > 0°C (to 2°C in some locations inland). In present study the limit is 0°C
		D_c	T_{cold} < 0°C (to 2°C). In present study the limit is 0°C
E	1-3 months with T>10°C	-	
F	T_{warm}<10°C	F_t	T_{warm} > 0°C
		F_i	T_{warm} < 0°C

There have been further attempts for modification aiming at greater precision especially in Asian area. One has been presented in 1968 as the Trewartha [15] climate classification system. Also,

[8] http://kfa.mff.cuni.cz/projects/trewartha/koppen-trewartha.html

several revisions of the Köppen-Geiger map itself have been done with different resolutions and depicting climate at different time limits.

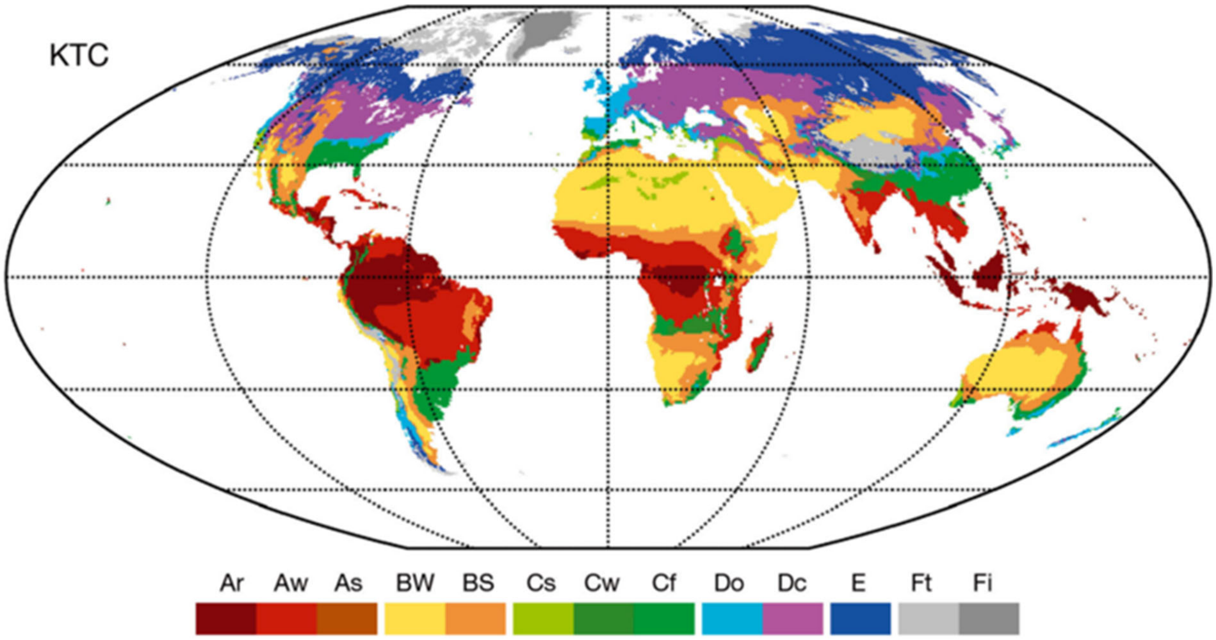


Figure 6 World maps of Köppen climate classification KCC and Köppen-Trewartha climate classification KTC, based on CRU TS 3.10 data for the period of 1961−1990 on a regular 0.5° latitude/longitude grid [15]

In the current study, the updated world map of the Köppen-Geiger classification was used (Figure 6). This map has been presented by M.C.Peel at al. [16] and is freely available electronically.

2. Adaptive Model for Thermal Comfort. Literature Review

2.1. Static and Adaptive Model of Comfort

Buildings' energy consumption increases in contemporary society with the increasing demand for comfort and the affordability of air-conditioning. With people spending over 80% of their time indoors, providing quality indoor environment becomes essential for maintaining health and productivity. The interest in comfort dates back to antiquity [19]. However, structured studies on thermal comfort stem from the pioneering work of Bedford in the 30s [20]. In the following ~ 90 years (especially the last 20 [21]) the research in the field of thermal comfort has compiled vast amount of data [22] and scientific insights.

The concept of providing thermal comfort has been approached differently by scientists leading to the establishment of the two main models – the static and the adaptive. Initially considered irreconcilable, they have been proven to complement each other in understanding human comfort. While static model focuses on physics and physiology and is founded on the theory of thermal balance between a body and its environment, the adaptive model accounts for the psychological and behavioral aspects as well.

The static model (or otherwise Fanger's Predicted Mean Vote (PMV) model [23], [24]) was defined in the 70s and it assumes the occupant is mostly passive to the indoor environment; that the comfortable conditions are the same irrespective of building type, climate or location; that they are fixed within a narrow band of temperature and they should be provided to the occupant by all technological means available for environmental control. Thus, the static model might recommend unnecessarily excessive energy consumption and ignore personal preferences and more energy-conserving building solutions. Developing of Fanger's model shaped the scientific thinking and legislation making for an extended period and was the base for developing international standards like ISO 7730 [25] and ASHRAE [26].

The need for energy conservation and efficient energy use however, has become unquestionable as well as the certainty that it should not be achieved at the expense of progress or quality of living. Japan's energy demand depends more than 80% on import. Under the concept of adaptive model more diverse energy-conserving building solutions can be implemented as the model acknowledges that comfort can be achieved under variable conditions, in much wider range of temperature; that it depends on cultural, climatic and social factors and it allows for personal control. Structured studies on adaptive thermal comfort stem from the pioneering work of Dr. Bedford in the 30s [20], [27], who then laid the basic foundations of the field research, developed his seven-point scale to evaluate subjective votes and integrated statistical analysis in the comfort research. Prior to the first oil crisis, the adaptive comfort studies were temporarily very limited, however they were restarted in the 70s when the formal definition was finally coined [20], [27]. "**The adaptive approach** [to thermal comfort] **notices that people use numerous strategies to achieve thermal comfort. They are not inert recipients of the environment, but interact with it to optimize their conditions**" [p.6 [20]] and adapt - either behaviorally, physiologically or psychologically [28] [29]. In case people have the provided possibilities to change their environment, they will do so and, the "comfort" temperature will vary from person to person, rather than remain fixed.

2.2. Current State of the Research in the Field. Overview

Adaptive comfort has been investigated in offices in Qatar [30], [31], Iran [32], Pakistan [33], in traditional houses in Nepal [34], in contemporary houses in UK [35], Singapore [36], Indonesia [37], Malaysia [38], India [39], China [40], [41], [42] 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.

Thermal comfort research in Japan is extensive in office [43], [44], [45], [46], [47], [48], [49] and residential [50], [51], [52] buildings and is mainly targeting Japanese subjects [45], [46], [47], [49], [51], however occasionally including foreigners in Japan [44], [48]. The targeted season is usually summer as Japanese hot and humid summer is challenging for achieving thermal comfort [43], [44], [45], [46]. More limited is the research throughout several seasons [47], [48], [49], [50], [51], [52].

The comfort temperature in summer for Japanese office workers was determined as 25ºC [47], [48] 26ºC [43], [46] or 27ºC [44], [45] as compared to other Asian nationals from Malaysia, Indonesia and Singapore [43] (28ºC) 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 was 3ºC where foreigners preferred the lower temperature [48]. In residential buildings comfort was again reported at 26ºC [51], 27ºC [50] in summer, however with much bigger seasonal differences [50], [51] as compared to offices. In winter, the comfort temperatures observed varied within a wide range of 20-26ºC [47], [52], [53], [54]. Researchers alarm that the recommended summer minimum temperature of 28ºC and, the recommended winter maximum of 20ºC in Japan might be too high (or too low respectively) to ensure comfort [43], [44], [47]. The level of acceptability, despite the poorer indoor environment quality, was observed 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 [46]. Researchers appeal for further analyses on thermal comfort and occupant behavior for the effective implementation of energy saving programs [45], [46] and developing a Japanese adaptive model for offices [44], [47] and dwellings [50].

Being previously under-investigated, dormitory buildings has spiked the research interest in the recent years in China, leading to field studies in all seasons [53], [54], [55], [56], [57]. The less restricted personal control in dormitories stimulated a wide range of adaptive behaviors and subsequently wide comfort ranges. 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% [58]. They experimented further 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 [59] as well as to changing occupant-window interaction [60] both leading to potential energy conservation.

3. Defining a Research Problem

3.1. Idea. Purpose. Method

The main purpose of any built environment is to provide shelter. However, built environment is much more than that. Enveloping human life, built environment should address all the human needs as described almost a hundred years ago by Maslow in his hierarchy of needs [61]. And, as Maslow's theory states, the higher need can only emerge when the lower, more basic need has been at least partially met. Comfort is at the top of the pyramid of what a built environment should provide. It is probably analogous the self-actualization level – level 5, the highest level of human needs (Figure 7). The comfort solution is a whole system including 1) the occupant behavior; 2) the buildings themselves and 3) the indoor microclimate, as Humphreys (one of the pioneering researchers in the adaptive comfort field) said in his book [p.7. [20]] on foundations and analysis of adaptive thermal comfort.

Dealing with the flexibility that the adaptive approach entails, is the main challenge triggering the research in the field. How can a designer design a building that can address the needs of any inhabitant if the inhabitants' needs are unique for every single one? How can an engineer provide all the necessary equipment? Which equipment is necessary for that matter?

These questions become even more relevant in buildings where the inhabitants often change, that is – buildings for temporary occupation, like dormitories which cannot be precisely tailored to particular occupants. In the globalized world it becomes common for people to live outside of their native countries during their studies and to be subjected to new cultural and climatic conditions while still having their native expectations and habits. The phenomenon can be broadly observed in Japan. It is challenging the existing and the newly designed buildings for multi-national occupancy which now must provide for a diverse subjective understanding of comfort and still maintain low energy consumption. To tackle the issue, it is necessary to determine what does comfort mean in terms of temperature range for non-Japanese people and what are the differences.

While in offices people may not have the freedom to make their indoor environment to their liking (shared offices, formal clothing, central heating/cooling, etc.), buildings for temporary occupancy as dormitories in Japan are likely to demonstrate the actual preference of their occupants. There, 1) students live in private rooms where immediate social restraints are practically non-existent with the exception for the habitual or culturally predetermined ones; 2) the rooms are relatively small so no matter the energy consumption, the final financial burden cannot get excessive; 3) the occupants are young and assumingly still developing their finance managing attitude, so their indoor environment setting is expected to represent more genuinely their subjective preference.

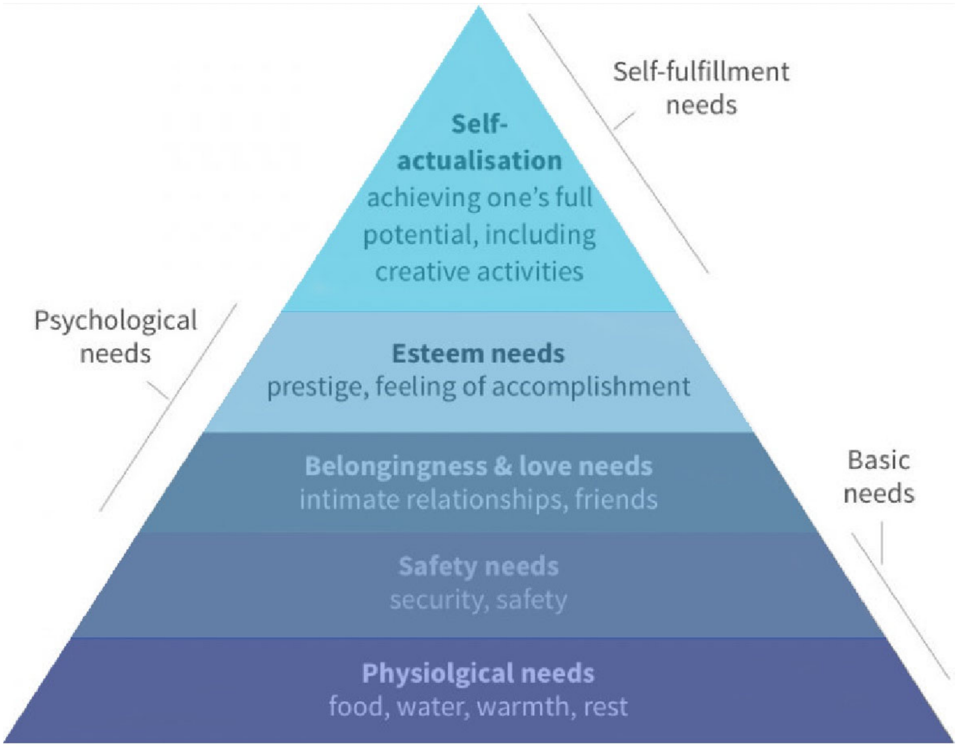


Figure 7 Expanded Maslow's hierarchy of needs[9]

We planned and conducted a field survey in the summer of 2017 in two university dormitory buildings. We aimed to snapshot the thermal comfort of the students as related to temperature and humidity as well as to factors like the time of day, the use or not of air-conditioning (CL – cooling mode and FR – free running mode respectively), the occupied building, sex and most importantly – nationality. We wanted to understand what do the occupants prefer at a certain sensation and how tolerant are they to their indoor environment.

[9] https://commons.wikimedia.org/wiki/File:Maslow%27s_Hierarchy_of_Needs.jpg#/media/File:Maslow's_Hierarchy_of_Needs.jpg

3.2. Hypothesis

Non-Japanese students come from various countries and nationalities and they have diverse prior climate history. We expected to observe differences in comfort between Japanese and non-Japanese students and, that the Japanese will be more accepting of their environment in any season.

We expected to see similar difference in the comfort temperatures between Japanese and non-Japanese students in summer as compared to winter. Furthermore, we expected that Japanese comfort vote will fall within the current recommendations for summer and winter in Japan.

Research have shown that when people can control their environment, the comfort temperatures vary so dormitories were a perfect place to observe what do people mainly use to control their environment.

3.3. Significance. Contribution. Applicability

Dormitories in Japan will keep increasing the number of their non-Japanese occupants relative to Japan's aim of internationalization of the universities [62]. However, dormitories can never be as flexible as necessary to accommodate the ever-changing residents.

In dormitories in Japan, non-Japanese students live less than a year, sometimes even only several months and their prior climate history is from all around the world. Air-conditioning can provide a solution, however at the cost of high energy consumption and subsequently CO_2 emissions. Japan's strong resolution towards energy efficiency and conservation, as well as its determination to increase the number of foreign students poses the question of how to simultaneously address both issues. As a result, a study on neutral and comfortable indoor conditions for Japanese and non-Japanese students in dormitories seems relevant and timely.

CHAPTER II

Summer Survey. Data Summary and Statistical Analysis

The first stage of the field survey was planned and conducted in the summer of 2017 in two university dormitory buildings. The aim was 1) to snapshot the subjective summer thermal comfort of the Japanese and non-Japanese students relative to temperature, humidity and other factors, 2) to understand what is the difference, if any, between the temperature defined as neutral or comfortable and 3) to get an insight how tolerant are the students to their indoor environment.

1. Methodology

1.1. Location and Summer 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 [15], [63]. It is mild, generally warm and temperate. It has four seasons with a hot, humid summer (Jun, Jul, and Aug) 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) [64]. This WMO 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 (Tavg.= 28.1°C; Tmin.= 25.0°C; Tmax.= 32.2°C). The mean relative humidity reached its maximum of 77% in July, August and October.

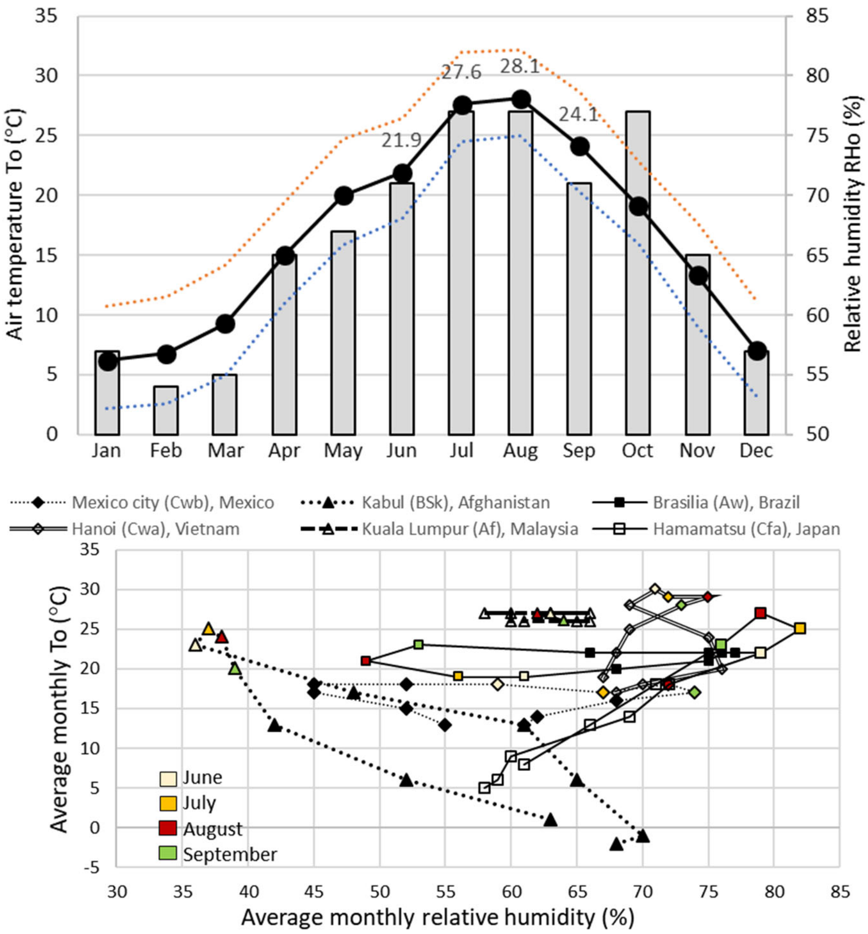


Figure 8 Toyohashi. Japan. a) Climate. Data from JMA WMO ID: 47654 – min, max and mean air temperature and relative humidity for 2017; b) Climate in the countries of origin of the subjects in the summer field survey. Cwb: Dry-winter subtropical highland climate, BSk: Cold semi-arid climate, Aw: Tropical 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 colour coded.

1.2. Summer Measuring Period

The summer stage of the field survey was conducted from June 26th to September 29th 2017. 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 sub-section 1.5 on p.20).

1.3. Dormitory Buildings Information

The survey was conducted in two dormitory buildings (Figure 9): 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 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" [65]. In this study, the focus was on the thermal comfort range.

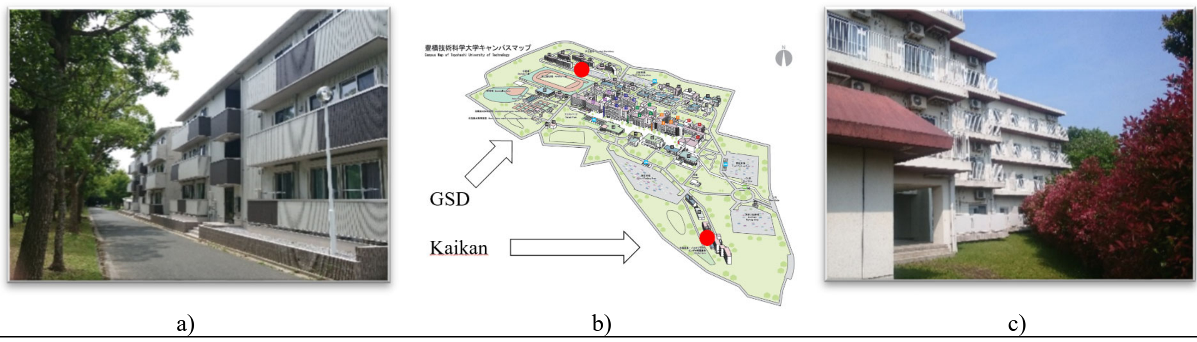


Figure 9 Dormitory buildings in TUT: a) GSD; b) TUT campus and dormitory locations; c) Kaikan

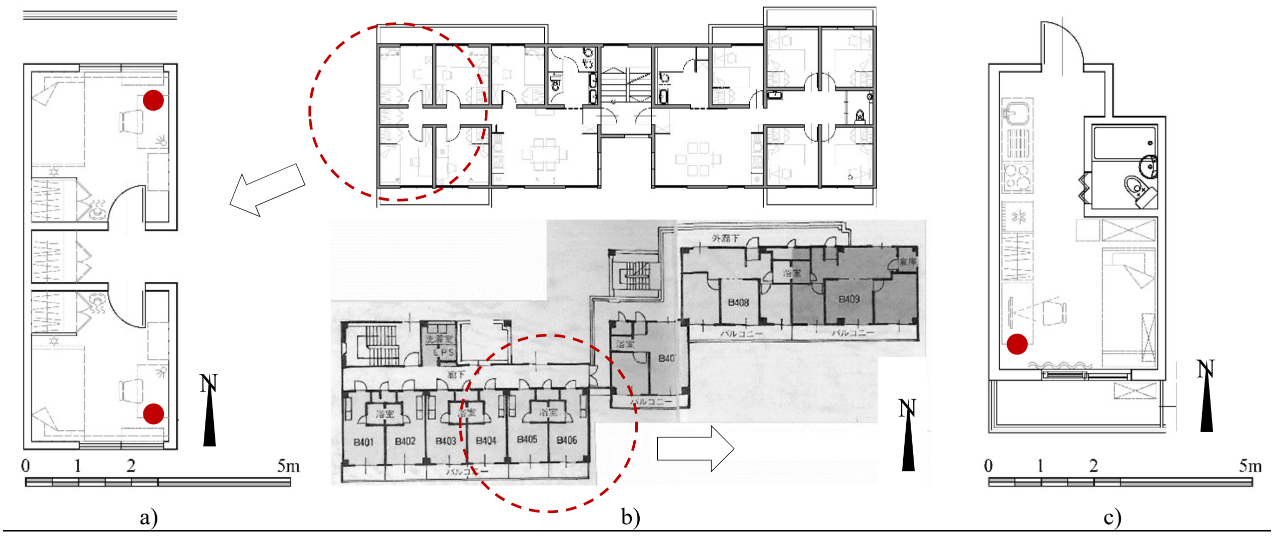


Figure 10 Dormitory rooms: a) Typical south and north facing room from GSD; b) Floor plans of GSD (up) and Kaikan (down); c) Typical room from Kaikan

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 10b, 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 10a, 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.

1.4. Sample Selection

The subjects sample consisted of Japanese and non-Japanese students currently residing in the two dormitories. We targeted same number of participants from both buildings (sample stratified by residence). However, within each building we worked with volunteering students (convenient sample) [66]. As a limitation to the study should be noted that there was a quota of maximum ten participants from a dormitory.

1.5. Field Survey – Summer Stage. 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 hours, and even 6-10 hours. 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 [29].

	Morning	Noon	Evening
Monday			1 2 3
Tuesday	3 4 3*	3*	3* 3
Wednesday	3 4 3*	3*	3* 3
Thursday	3 4 3*	3*	3* 3
Friday	3 4 5		

1	Setting the instruments in participants' rooms
2	General health questionnaire (filled in only on the first Monday)
3	Indoor environment questionnaire
3*	Optional if at home (at breakfast, at lunch, at dinner time)
4	Sleep quality questionnaire (about previous night)
5	Collecting measuring instruments from participants' rooms

Figure 11 Week 1 – Events schedule (**Each volunteer participated three non-sequential weeks)

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 11) 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 12. The questionnaire about subjective sleep quality (4 in Figure 11) was to be completed after waking up. Results are not presented in this paper. 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 11); and optional at breakfast, at noon and at dinnertime (3* in Figure 11). The English and Japanese version of the questionnaires about indoor environment are in Appendix C and Appendix D.

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 [67] and in ASHRAE 2013 handbook [68]. 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 Table 6.

The questionnaires distributed to the subjects contained a short list of clothing and the subjects were asked to mark all the items they were wearing at the time of vote. The list and the values of clothing insulation used are in Appendix E, Appendix Table E-1 . The value for “other” clothing was used whenever the subjects did not fill in anything in the clothing section. The value is typical for garment ensemble “trousers, short-sleeved shirt” as in Table 7, Chapter 9 of ASHRAE handbook: Fundamentals [69]. For the cases when the subjects did mark some items but there was obvious omission of garments, a minimum value of 0.19clo (short-sleeved, dress shirt) was assigned.

The questionnaires distributed to the subjects contained a short list of activities and the subjects were asked to mark the percentage of each activity within the last thirty minutes prior to the vote. The percentages should add up to 100. The list of the Met values used are in Appendix E, Appendix Table E-3 . The participants were advised to fill in the indoor environmental questionnaire after spending at least thirty minutes indoors for proper acclimating. 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.

Table 3 Measuring devices

Name	Type	Parameter	Range and accuracy	Image	Notes
Thermo-hygrometer	TR-74Ui ISA-3151 sensor THA-3151 sensor	Air temperature Relative humidity Illuminance	0-55 °C (±0.5°C) 10-95 %RH (±5%) 0-130klx (±5%)		Continuous measurement (1-minute interval)
Air Flow Transducer	6332D (KANOMAX probe) (VR-71 data logger)	Air Speed	0.01~30.0m/s (±2%)		Continuous measurement (1-minute interval)

Measurements of the indoor and outdoor air temperature and relative humidity were continuous at one-minute intervals from Monday to Friday. The measuring devices were placed in each individual room at the desk at height assuming sedentary activity. The height of the data loggers was within the acceptable range of 0.6~1.1 m above the floor in the living room [70]. 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 0.0m/s – suggesting still air. A value of 0.1m/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.

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). The algorithm for analysis and calculations followed the explanation by Humphreys et al. [20].

1.6. Sequence of Analysis. Summer Data

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 actually voted comfort temperature. The results from our study were corelated to international standards and previous research in the field.

2. Results and Discussion

2.1. Participants in Summer Stage

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, 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 in Figure 12.

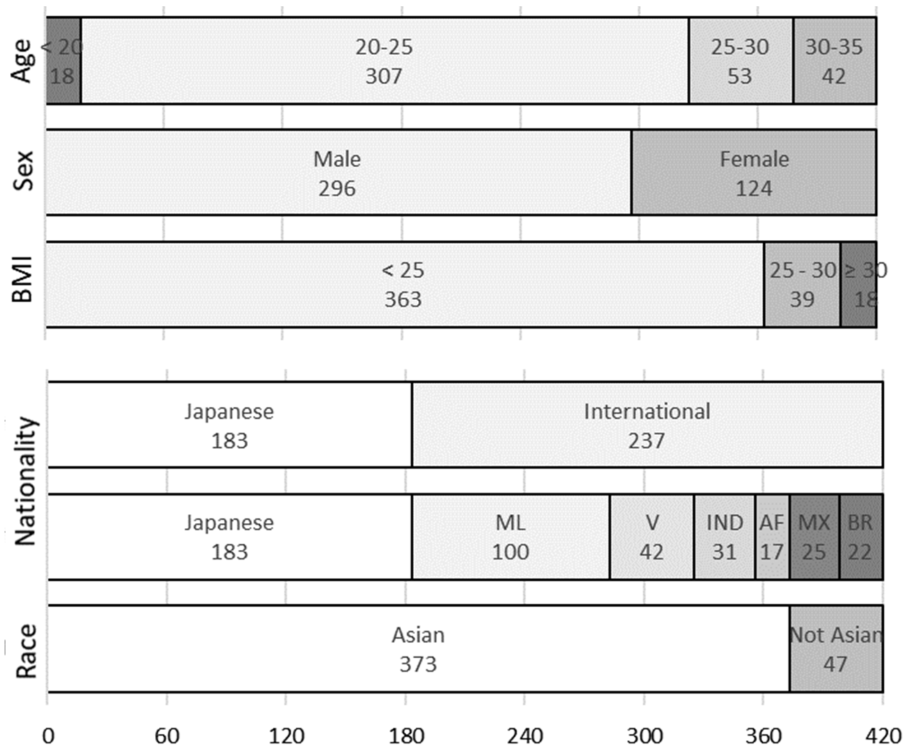


Figure 12 Population sample in summer (N=420 votes) – Distribution of the votes relative to age, sex, nationality, ethnicity and BMI. ** ML (Malaysian); V (Vietnamese); IND (Indonesian); BR (Brazilian); MX (Mexican); AF (Afghani)

Summer climate in the subjects' countries of origin differ notably from the summer climate they are subjected to in Central Japan (Figure 8). 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 1.1, page 17), 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.

2.2. Summer Indoor and Outdoor Environment at Vote

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-minute averages of the physical measurements. During the summer time study, a total of 280 questionnaires in Kaikan and 234 questionnaires in GSD were collected. As valid are considered these votes, 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 stated less than twenty minutes adjustment period prior to voting were excluded. Considering all of the above, 443 valid votes were collected in summer.

The daily mean outdoor temperature (T_{od}) was provided online by JMA [64]. Exponentially weighed running mean of the daily outdoor temperature (T_{rm}) was calculated using the formula given by Humphreys and Nicol [71] and the EN 15521 [72].

Eq. 1 Calculating exponentially weighed running mean of the daily outdoor temperature

$$T_{rm\,(t)} = (1 - \alpha)\,(T_{t-1} + \alpha T_{t-2} + \alpha^2 T_{t-3} + \ldots + \alpha^{n-1} T_{t-n})$$

$T_{rm\,(t)}$ is the running mean temperature at a certain time-period, currently a day (°C); α is 0.8 constant estimating the effect of past temperatures; T_{t-i} is the temperature i periods before the calculated one (°C); n is number of the periods back.

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 [68]]. The numerical results at the times of vote are in Table 4.

Variations in outdoor conditions were high while indoors the parameters were more stable. Indoor temperature was well correlated to the outdoor temperature ($r = 0.52$, $p < 0.001$) (Table 5 and Figure 14). However, it was not the case for indoor relative humidity ($r = 0.27$, $p < 0.001$). Indoor absolute humidity indoors was better correlated to the outdoors. As seen in Figure 13 and Figure 14, indoor humidity was constantly high at about RH_i of 70% (IQR from 66% to 77%) and AH_i of 0.016 kg/kg$_{DA}$ (IQR from 0.015 to 0.018 kg/kg$_{DA}$). As mentioned in sub-section 1.5 (page 22), 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 [68]. A standard value of 0.10m/s air speed was selected for any necessary further calculations.

Table 4 Descriptive statistics of the collected data at times of vote. Stage 1 (summer)

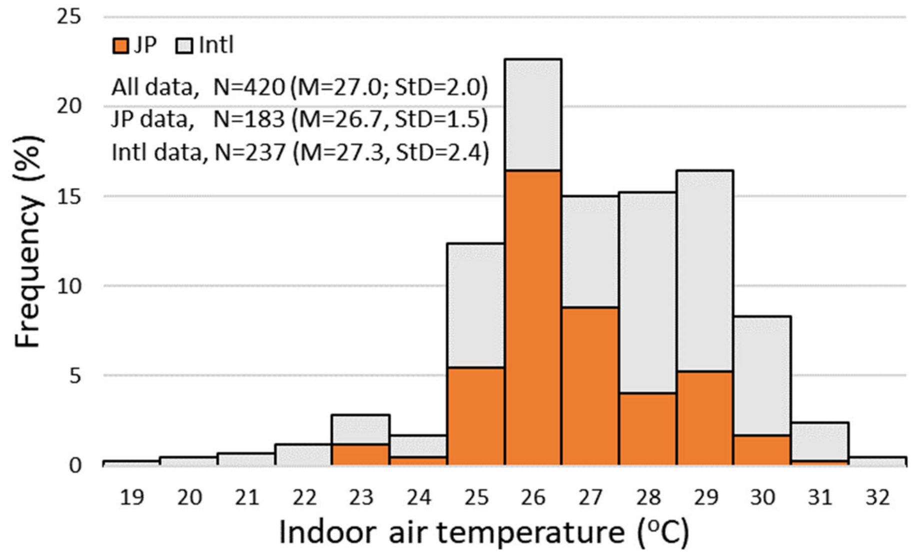
	All data points (N=420)				**Japanese (N=183)**				**International (N=237)**			
	min	**max**	**mean**	**StD**	**min**	**max**	**mean**	**StD**	**min**	**max**	**mean**	**StD**
T_i	18.6	31.6	27.0	2.0	23.2	30.7	26.7	1.5	18.6	31.6	27.3	2.4
T_o	18.3	37.9	26.6	3.6	18.3	37.9	26.3	4.3	21.2	36.9	26.8	3.1
T_{od}	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}	17.6	22.3	20.3	1.8	17.7	22.3	19.8	1.9	17.6	22.3	20.6	1.6
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 in summer N=443; 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}); I_{cl}: clothing insulation (clo) where 1clo = 0.155 m^2K/W; M: metabolic activity (met) 1met = 58.2 W/m^2

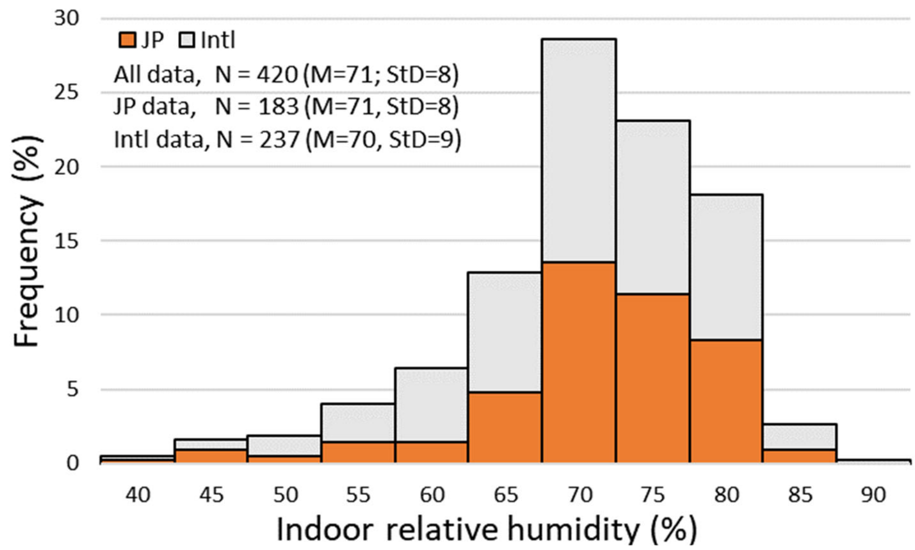
Table 5 Correlation coefficients. Stage 1 (summer)

	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	0.618	14.5	0.298	<0.001	0.42	0.317	20.4	0.173	<0.001	0.64	0.943	7.9	0.413	<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; 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})



a)



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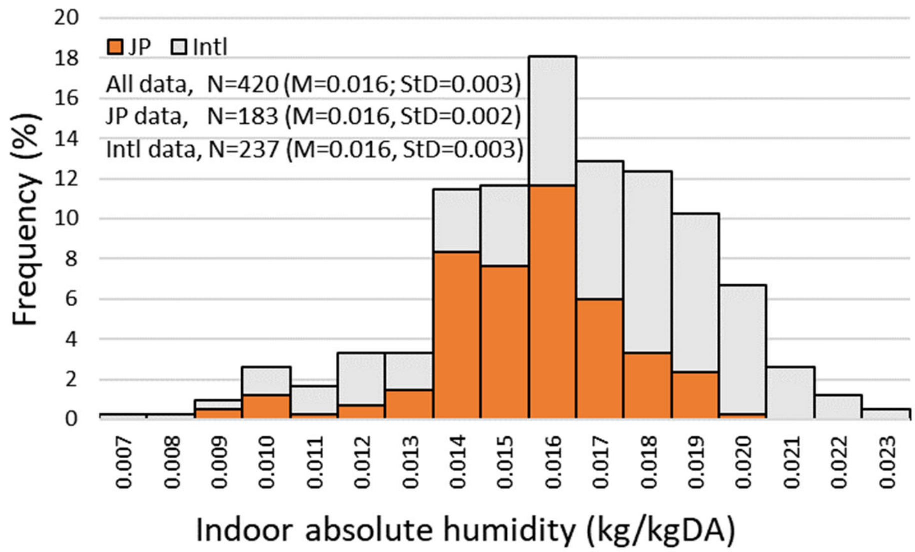


c)

Figure 13 Frequency percentage distribution at vote in summer: a) T_i (°C); b) RH_i (%); c) AH_i (kg/kg_{DA}).

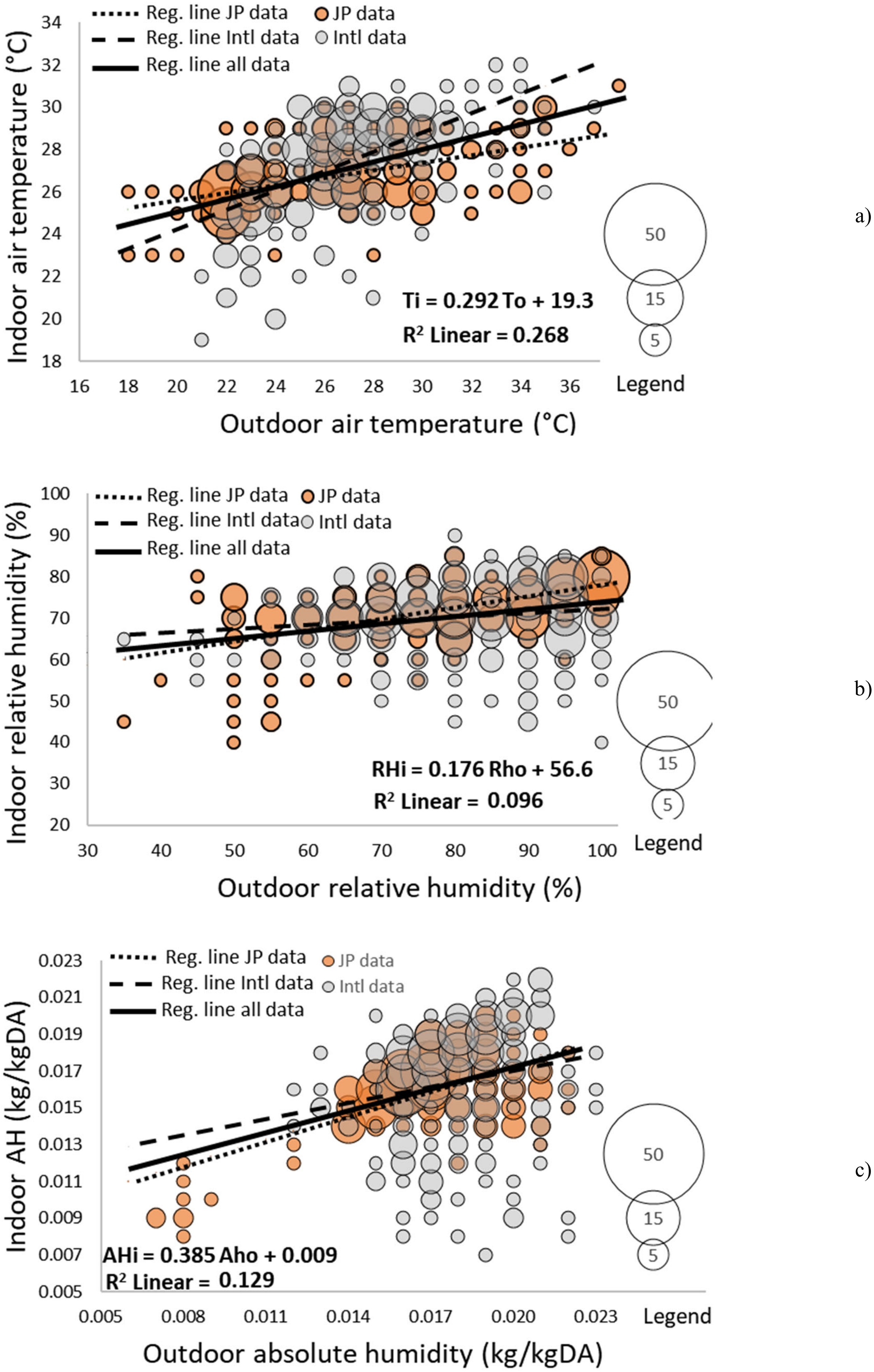


Figure 14 Correlation between indoor and outdoor parameters at vote in summer: a) T_i: T_o; b) RH_i: RH_o; c) AH_i: AH_o.

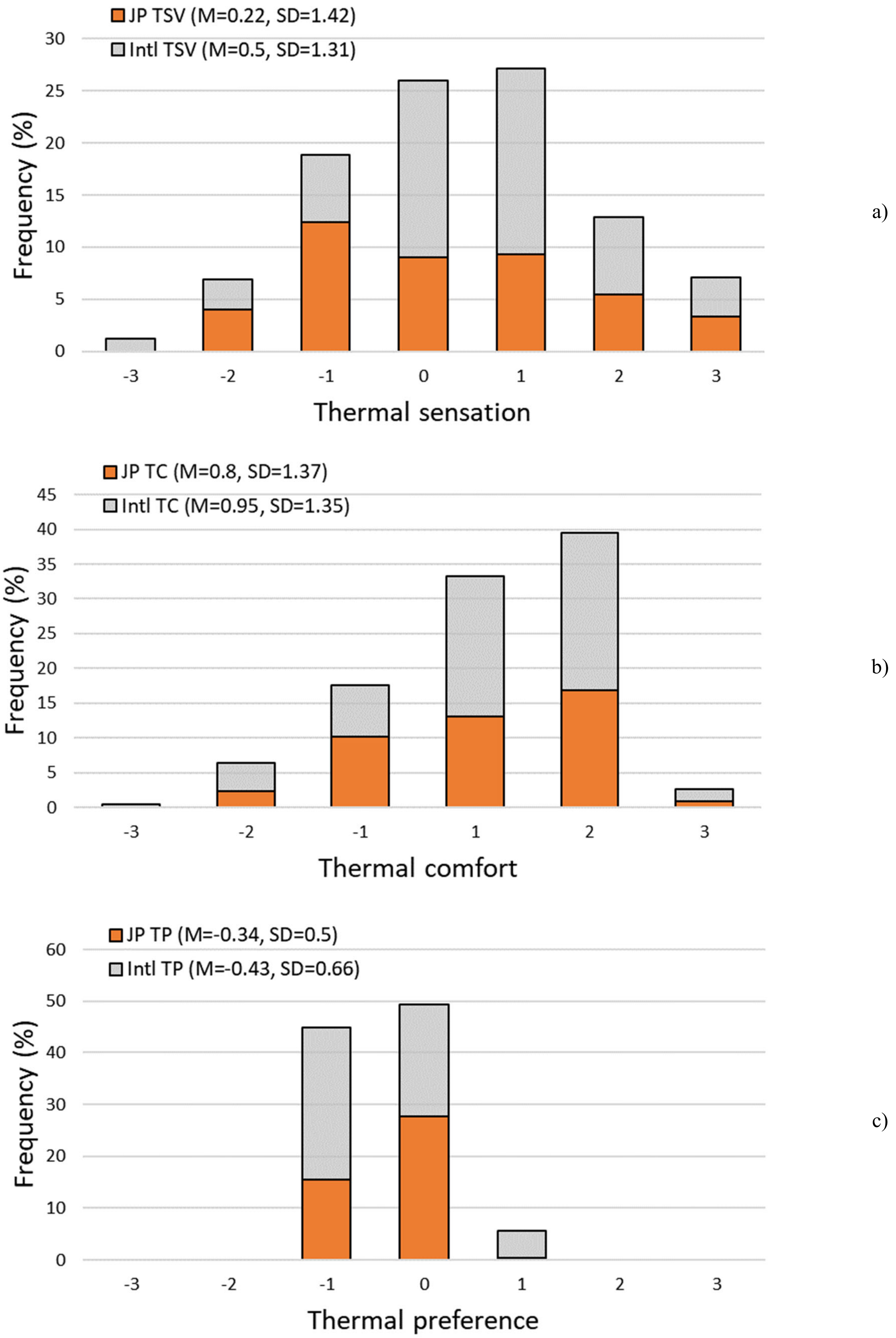
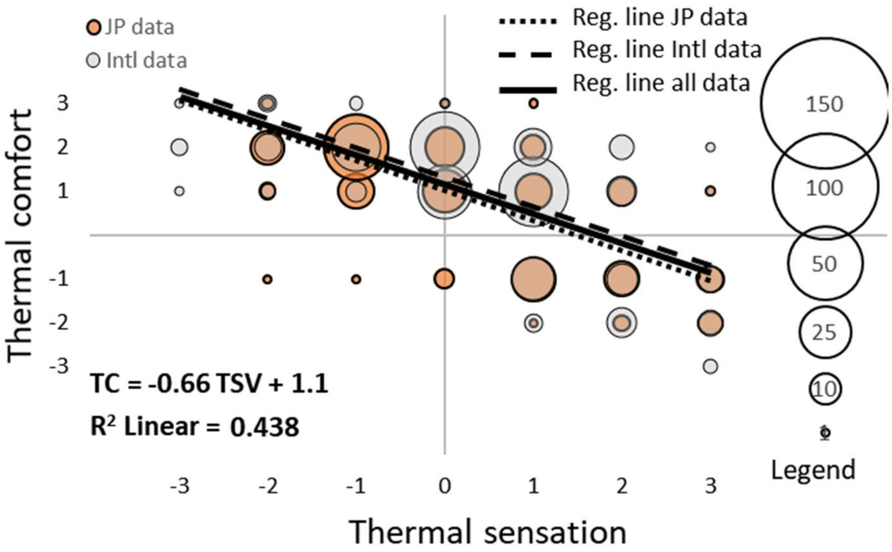
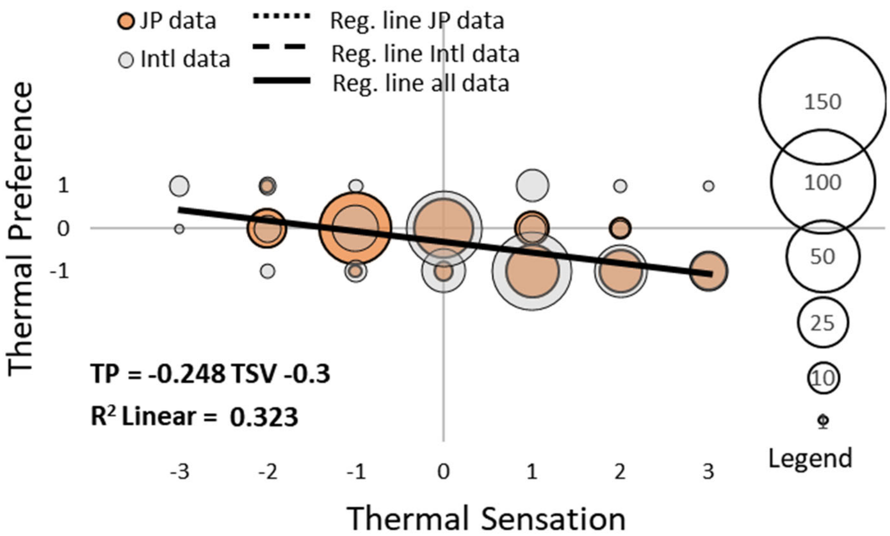


Figure 15. Frequency percentage distributions of thermal responses in summer; a) TSV; b) TC; c) TP



a)



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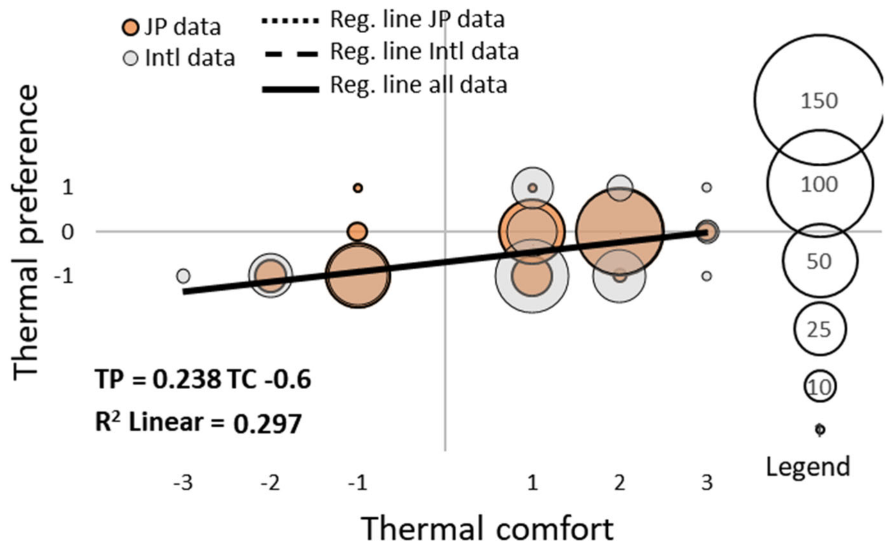


c)

Figure 16 Correlation between thermal responses in summer: a) TC: TSV; b) TP: TSV; c) TP: TC

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 5. 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.

The indoor-outdoor correlations regarding humidity were generally weaker and, when comparing relative and absolute humidity – 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 a meaningful way the outdoor relative humidity for international people.

2.3. Thermal Sensation, Comfort, Preference and Acceptability in Summer

The distribution of TSV, TC, TP and TA relative to nationality is presented in Table 6 and Figure 15. The neutral TSV was only a third in the international dataset, and even less in the Japanese one (21%). On the warm side of the scale the percentage distribution was almost identical, however, on the cold side of the scale there were notable differences. Close to 40% of the Japanese TSV was "slightly cool" and "cool" as opposed to only 20% of the international dataset. 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. The Japanese votes "prefer no change" were more than 60%, while almost half of the international votes were "prefer cooler". Irrespective of nationality, the acceptance of the indoor environment was very high –equal or more than 95%.

Thermal sensation had strong negative correlation with thermal comfort ($r = -0.70$, $p < 0.001$) and thermal preference ($r = -0.57$, $p < 0.001$) (Table 7 and Figure 16). The hotter the subjects sensed their environment, the less comfortable they felt and, their preference inclined towards "prefer cooler". 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". 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 6 Percentage of thermal responses for each scale relative to nationality (Japanese: N=183; international: N=237). Stage 1 (summer)

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	Sl. 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	Sl. cool	28.4	11.4	Sl. 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						

Note: Sl.: Slightly ~

Table 7 Correlation between thermal responses. Stage 1 (summer)

	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 16a), or overlapping (Figure 16b, c) 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 votes "acceptable" was very high in all the conditions but it was not dependent on any one of them. Only two of the factors significantly affected all the three remaining thermal responses: nationality and the use of air conditioning. The statistically significant results are presented in Table 8.

Table 8 Summary of Chi-square results: Dependence of TSV, TC, TP and TA on sub-divisions. Stage 1 (summer)

	Sub-division	n	df	χ^2 critical	χ^2	p	Estimated by Regression* (°C)		δT(°C)
TSV	Day: Night	234: 186			12.96	< 0.05			
	AC on: AC off	145: 275			47.33	< 0.001			
	GSD: Kaikan	212: 208	6	12.59	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			18.02	< 0.05			
	AC on: AC off	145: 275	5	11.07	23.71	< 0.001			
	Male: Female	296: 124			11.69	< 0.05			
	Japanese: International	183: 237			9.69	0.922	$T_{c\ JP} < 25.4$	$T_{c\ Intl} < 27.0$	-1.6
TP	AC on: AC off	145: 275			6.89	< 0.05			
	GSD: Kaikan	212: 208	2	5.99	38.09	< 0.001			
	Japanese: International	183: 237			31.68	< 0.001	$T_{p\ JP} = 21.3$	$T_{p\ Intl} = 22.9$	-1.6

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).

The test confirmed the initial assumption. In the following analysis of the current paper the focus was placed on the nationality factor. 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 8). 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 2.4.2, page 35). 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, Japanese vote "prefer no change" is expected at almost 2°C lower temperature than the international vote (at 21.3°C and 22.9°C respectively).

2.4. Summer Neutral and Comfortable Temperature

2.4.1. Logit Regression Analysis for Neutrality Range in Summer

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 9. The equations $P_{(\leq TSV)}$ 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") [20], [30], [47], The probit regression coefficient for Japanese university students is calculated to be 0.204/K and for international ones: 0.232/K.

Table 9 Probit analysis of thermal sensation and indoor temperature. Stage 1 (summer)

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 sample; R^2: Coefficient of determination; SE: Standard error; significance $p < 0.001$)

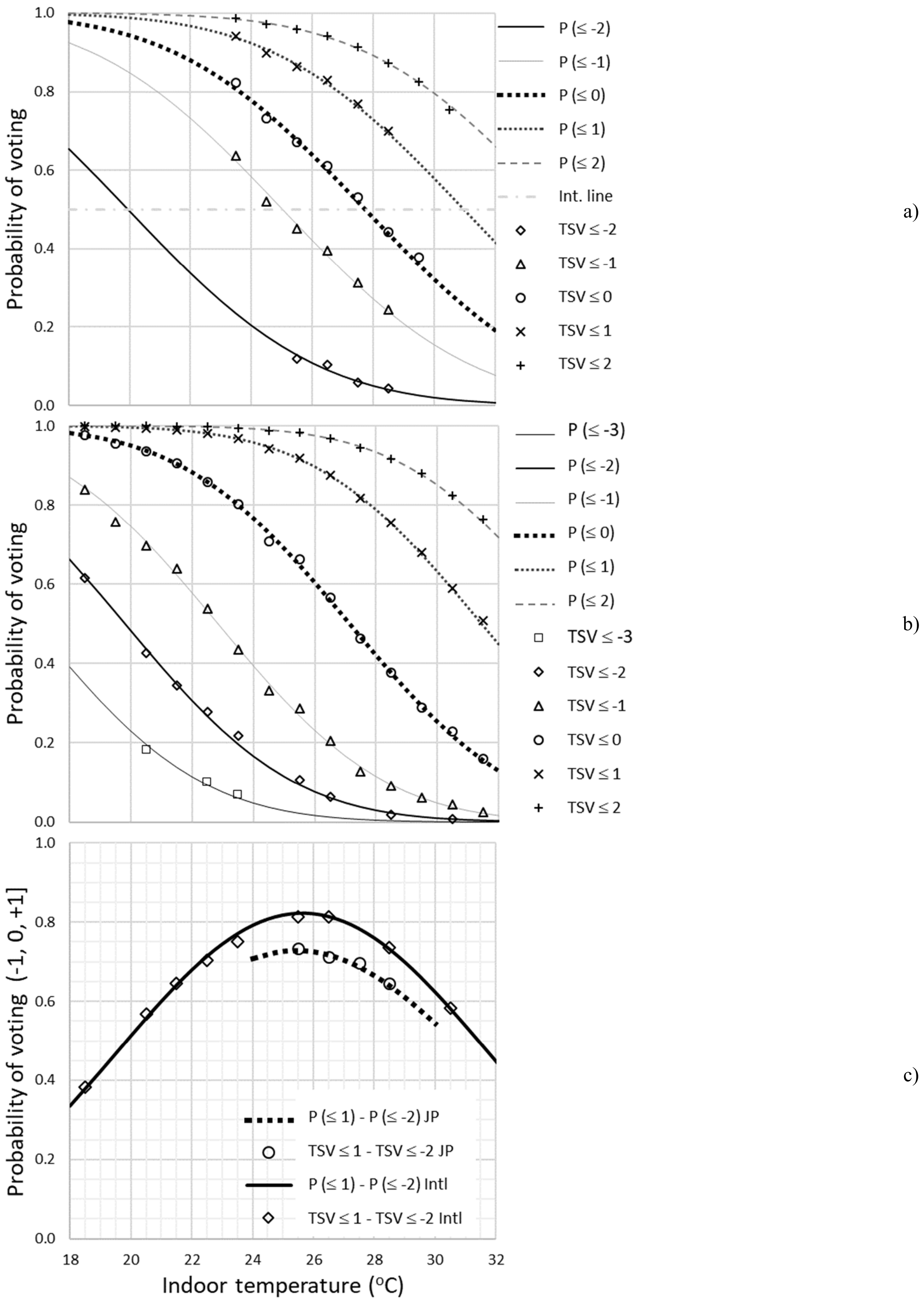


Figure 17 Graphical representation of probit analysis: a) Probability of $_{JP}$TSV; b) Probability of $_{Intl}$TSV; c) Probability of "extended neutral range" (-1,0,+1) Note: Marker points represent the actual proportion voting.

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 ºC. 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 18ºC to 32ºC 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 MSExcel (function NORM.S.DIST(z, cumulative). The six sigmoid curves of the probabilities were then plotted and presented in Figure 17.

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 17a, the probability of Japanese students voting neutral or less (dotted black line of P≤ 0)) at lower temperatures is high, while with the rise of temperatures, this probability decreases. And, at ~23.5ºC there is 80% probability of voting neutral or less. The explanation for all curves follows the same pattern. 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 24ºC and 27.5ºC indoor temperature, the probability of Japanese students voting extended neutral is the highest. However, it is between 70% and 75% (Figure 17c).

The peak of the graph for international subjects was within the same interval (from 24ºC to 27.5ºC). However, the expected percentage is above 80%. Japanese students appear to be more critical to their indoor environment.

2.4.2. Linear Regression Method for Summer Neutral Temperature

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 6). 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:

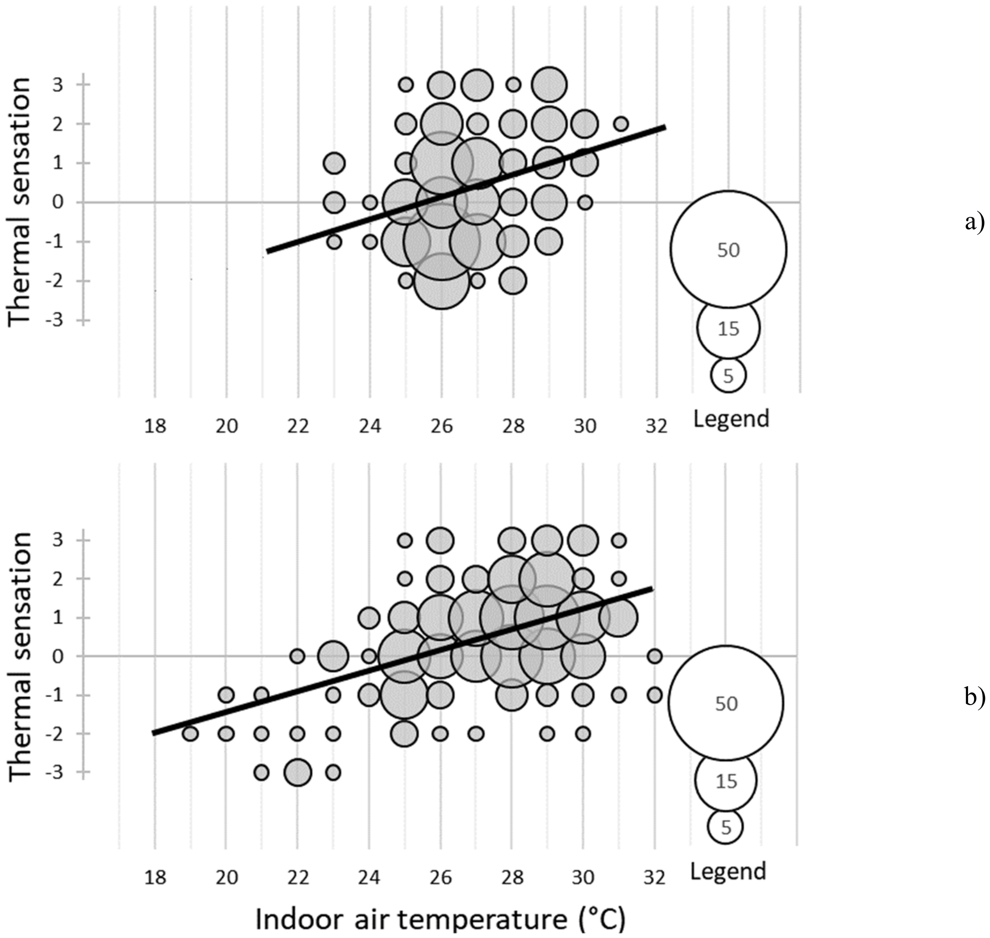


Figure 18 Thermal sensation votes (summer): a) Correlation between TSV and indoor air temperature at vote for Japanese subjects; b) Correlation between TSV and indoor air temperature at vote for international subjects.

Eq. 2 Linear regression model TSV_{JP}: T_i (summer)

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

Eq. 3 Linear regression model TSV_{Intl}: T_i (summer)

$TSV_{Intl} = 0.262\ T_i – 6.6$, where ($N = 237$; $p < 0.001$; $R^2 = 0.22$; S.E.=1.15; F statistic = 67.4)

The calculated neutral temperature for Japanese subjects (${}_{JP}T_n$) using Eq. 2 is ${}_{JP}T_n$ = 25.9ºC. This is only 0.6ºC lower than ${}_{voted\ JP}T_n$=26.5ºC – the mean indoor air temperature when the Japanese subjects voted "neutral". The calculated neutral temperature for international subjects (${}_{Intl}T_n$) using Eq. 3 is ${}_{Intl}T_n$ = 25.4ºC. This is 1.8ºC lower than ${}_{voted\ Intl}T_n$=27.2ºC – the mean indoor air temperature when the international subjects voted "neutral". The difference in slopes leads to thinking Japanese subjects are more sensitive to their indoor environment, even though the difference in sensitivity is small. This supports the outcome of the probit analysis. Also, the slopes of the regression equations are comparable with the slopes derived from similar research: Indraganti and Bousaa estimated 0.216/K [30] and 0.283/K [31] in office buildings in Doha, Qatar; Katsuno et al. [70] estimated 0.273/K in CL mode in residential houses in Kanto region, Japan; Ning et al. [53]

found 0.248/K in dormitory buildings in spring in Harbin, China; He et al. [57] 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 [70]) or lower (0.187/K in FR and 0.106/K in CL in Kanto, Japan [73]).

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 [29]. In our survey 80% falls within 23ºC and 29ºC for Japanese subjects and within 22ºC and 29ºC for non-Japanese. The 90% fall within 24ºC to 28ºC for Japanese and within 23ºC and 27ºC for non-Japanese. Similar range was already observed in subsection 2.4.1, 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, clo and Met 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 T_i. The expectation was that relative humidity, clothing and metabolic activity would significantly affect TSV for both Japanese and international students. However, this was the case neither for Japanese votes, nor for the international (see Eq. 4 and Eq. 5). 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.

Eq. 4 Multiple regression model TSV_{JP}: T_i, RH_i, I_{cl}, M

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

Eq. 5 Multiple regression model TSV_{Intl}: T_i, RH_i, I_{cl}, M

$$TSV_{Intl} = 0.259\ T_i + 0.003\ RH_i + 0.553\ clo + 0.337\ Met - 7.7$$

Linear regression is believed to have some major drawbacks when used for estimating the neutral temperature: 1) majority of votes are clustered around the central point of the thermal sensation scale (Figure 18) 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 [30]. The precision of the linear regression coefficient was improved following the usual analytical approach. Then, the comfort temperature was estimated using the Griffiths' method.

Table 10 Statistics of the multiple regression analysis. Stage 1 (summer)

Variable		**Japanese (N=183)**				**International (N=237)**			
n	**name**	**p**	**S.E.**	**$R^2_{adj.}$**	**F stats**	**p**	**St. error**	**$R^2_{adj.}$**	**F stats**
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	clo	$p_3 = 0.517$	$S.E._3$=2.017			$p_3 = 0.529$	$S.E._3$=0.878		
4	Met	$p_4 = 0.320$	$S.E._4$=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 insulation (clo) where 1clo = 0.155 m^2K/W; M: Metabolic activity (met) where 1met = 58.2 W/m^2

2.4.3. 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 [20], [30].

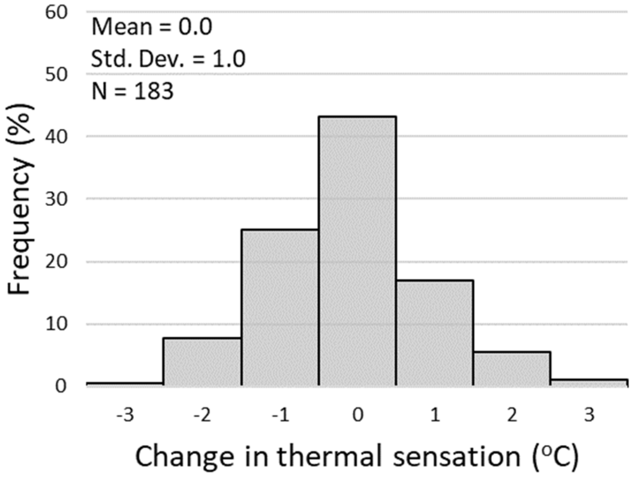
In order to apply this method to our data set, the mean thermal feeling (T_{fm}) and mean indoor temperature (T_{im}) were calculated for all the sets of data collected within a day in each of the 18 dormitory rooms for all the survey days within summer. These values were the room-wise day-survey averages. 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 19 and Figure 20). 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 equations are:

Eq. 6 Room-wise day-wise linear regression model for Japanese subjects (summer)

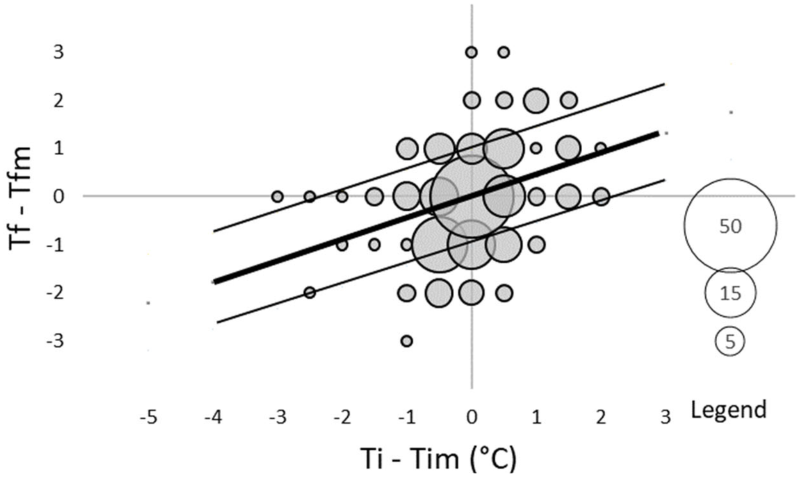
$$_{JP}(T_f - T_{fm}) = 0.441\ _{JP}(T_i - T_{im}) + 0.0, \quad (N = 183;\ p < 0.001;\ R^2 = 0.12;\ S.E.=0.94;\ F\ stat. = 23.5)$$

Eq. 7 Room-wise day-wise linear regression model for non - Japanese subjects (summer)

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



a)



b)

Figure 19 Room-wise day-survey averages – Japanese vote (summer) a) Frequency distribution; b) Linear regression. 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:

Eq. 8 Formula for calculating adjusted linear regression coefficient

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

Where b is the coefficient from $\delta T_f : \delta T_i$ 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 [74]. 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 [20], [47], [30].

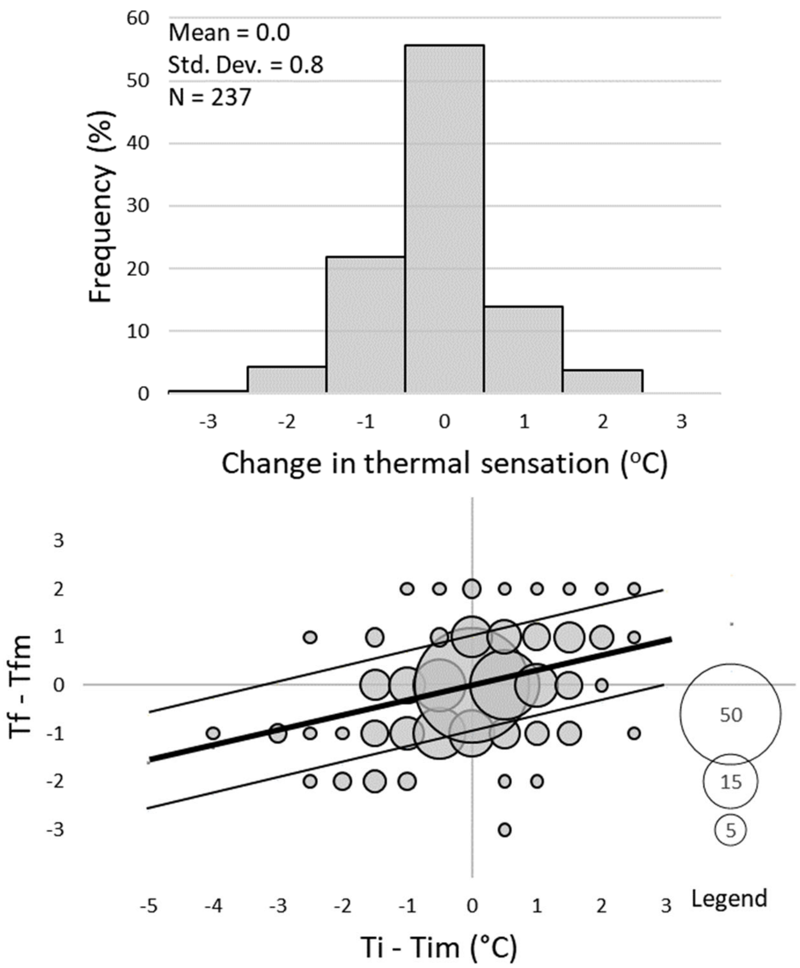


Figure 20 Room-wise day-survey averages – International vote (summer) a) Frequency distribution; b) Linear regression. Note: Outer lines indicate the residual standard deviation

Lee et al. [75] 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.

2.4.4. Griffiths' Method for Calculating Summer Comfortable Temperature

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 Eq. 9:

Eq. 9 Griffiths' model - formula for calculating comfort temperature using indoor temperature and sensation vote

$$_{G}T_{c} = T_{i} + \frac{0 - \mathrm{TSV}}{a}$$

Where $_{G}T_{c}$ is Griffiths' comfort temperature (ºC); T_i is indoor temperature (ºC); 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 [20], [30]. However, previous research explores $_{G}T_{c}$ at two more values: a=0.25, and a=0.33 [51], [74], as well as the value of the adjusted coefficient $b_{adj.}$ derived from room-wise day-survey analysis if conducted [30]. $_{G}T_{c}$ was estimated using four values for the Griffiths' coefficient and the results are presented in Table 11.

The current field survey directly asked about the comfort. It made it possible to compare the calculated $_{G}T_{c}$ (Table 11) and the observed $_{voted}T_{c}$ (Table 12). 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 6.1ºC), respectively the estimated by calculation standard deviation was double the observed. At 0.48/K 80% of the $_{JP\ G}T_{c}$ fall within 22ºC and 30ºC, while the actual voted 80% of the $_{JP\ voted}T_{c}$ fall within 25ºC and 29ºC (narrower range by 4ºC).

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 ~1ºC. The estimated range by the calculation was again much wider than the observed (difference of 6.9ºC). 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 22ºC and 30ºC, while the actual voted 80% of the $_{Intl\ voted}T_{c}$ fall within 24ºC and 30ºC (narrower range by 2ºC). Graphing the calculated and the voted mean comfort temperature for each survey month (Figure 21) 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 11 Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients. Stage 1 (summer)

	Regression coefficient (/K)	N	Min	Q1	Median	Q3	Max	Mean	SD
		Calculated comfort temperature ${}_{G}T_c$ (°C)							
Japanese	0.50	183	18.8	24.4	26.5	28.3	32.4	26.2	2.8
	0.48 (see Section 2.4.3)		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
International	0.50	237	18.6	24.5	26.2	27.7	34.2	26.2	2.6
	0.34 (see Section 2.4.3)		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 12 Descriptive statistics of the actual temperature at TC +1,+2 and +3 (Comfortable side of the scale) in summer

	Observed comfort temperature T_c (°C)							
	N	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
JP votes "comfortable"	130	23.2	25.6	26.2	27.2	30.7	26.5	1.4
Intl 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.

Eq. 10 Linear regression model ${}_{JP\,G}T_C$: T_i (summer)

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

Eq. 11 Linear regression model ${}_{Intl\,G}T_C$: T_i (summer)

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

Eq. 12 Linear regression model ${}_{JP\,G}T_C$: T_o (summer)

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

Eq. 13 Linear regression model ${}_{Intl\,G}T_C$: T_o (summer)

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

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 (Figure 22,). The calculated comfort temperature for all nationalities in our survey proved to be very weakly correlated to the indoor air temperature or outdoor temperature (Figure 23, Figure 24, Eq. 10~Eq. 13). For the international students the relation between calculated comfort temperature and the outdoor temperature was even statistically insignificant (Eq. 13).

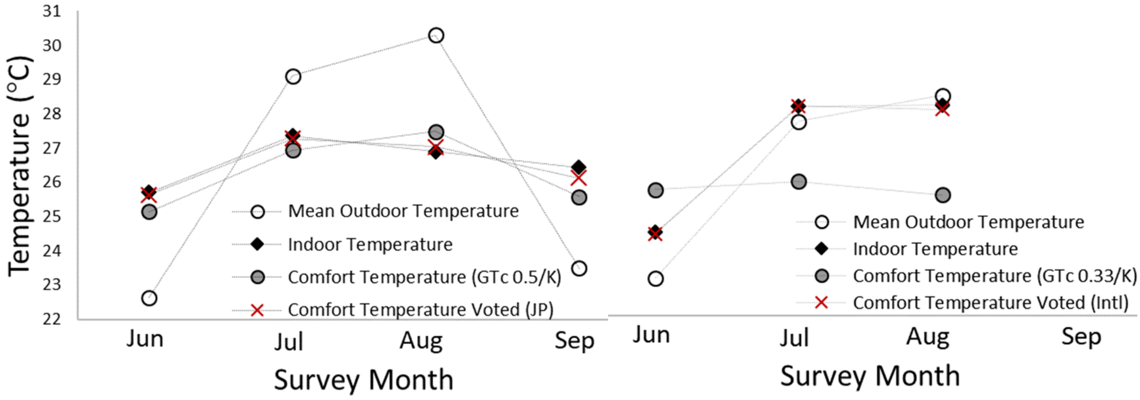
a)  b)

Figure 21 Comparing mean temperatures in each survey month a) Japanese data; b) International data

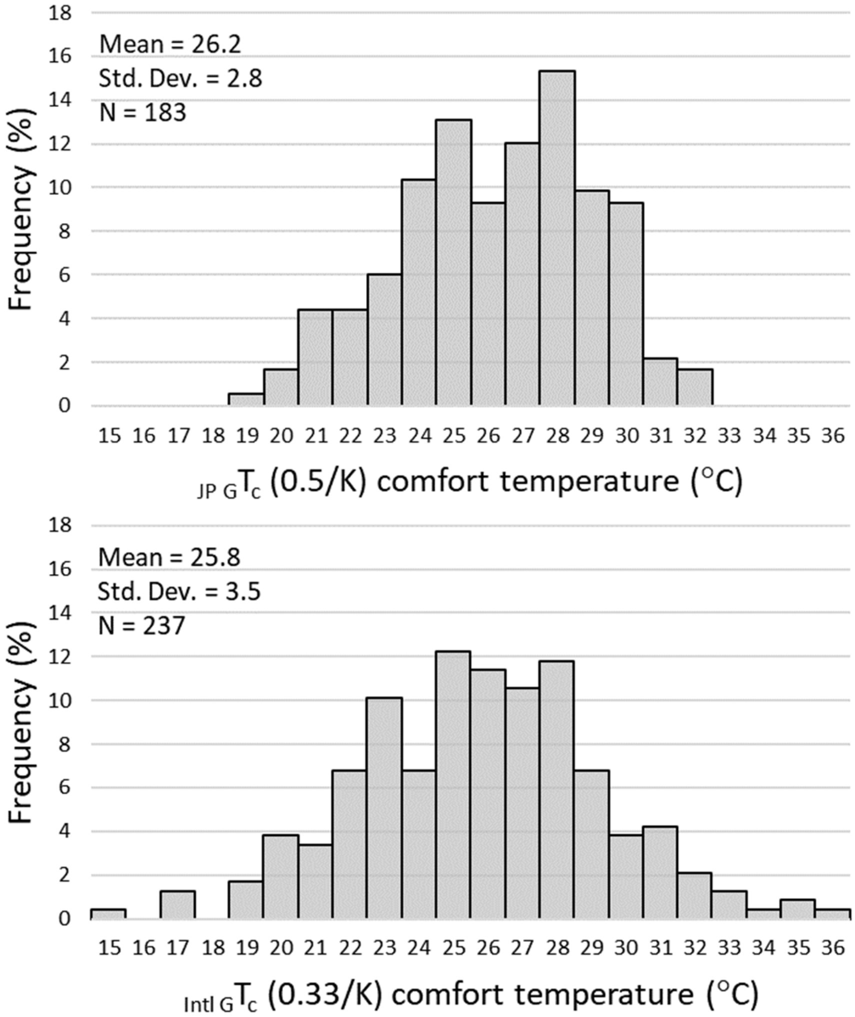


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Figure 22 Griffiths comfort temperature: a) Frequency distribution of the calculated Japanese comfort temperature; b) Frequency distribution of the calculated international comfort temperature

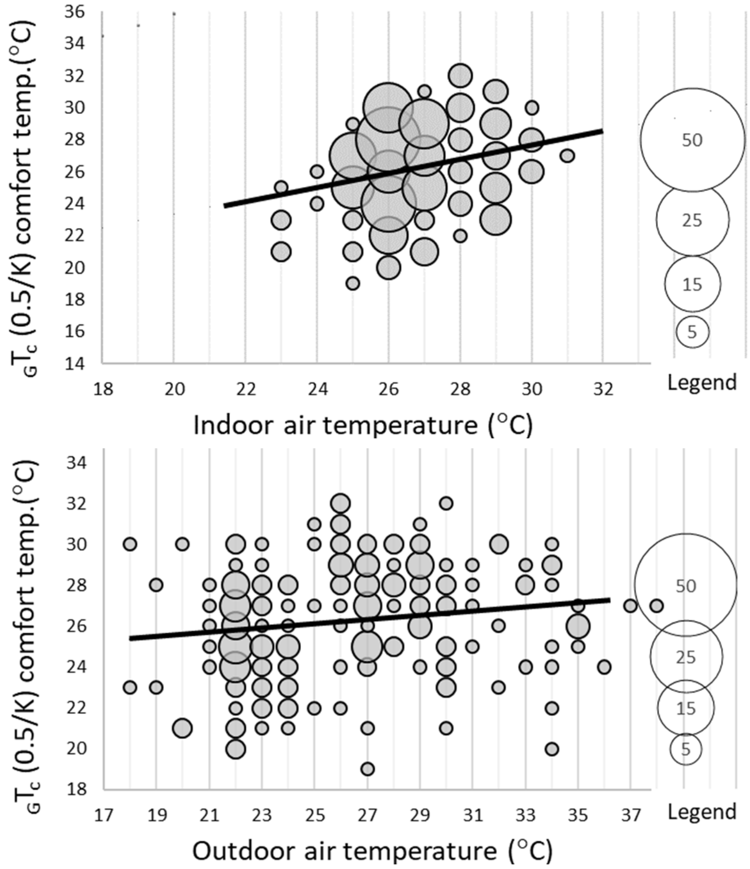

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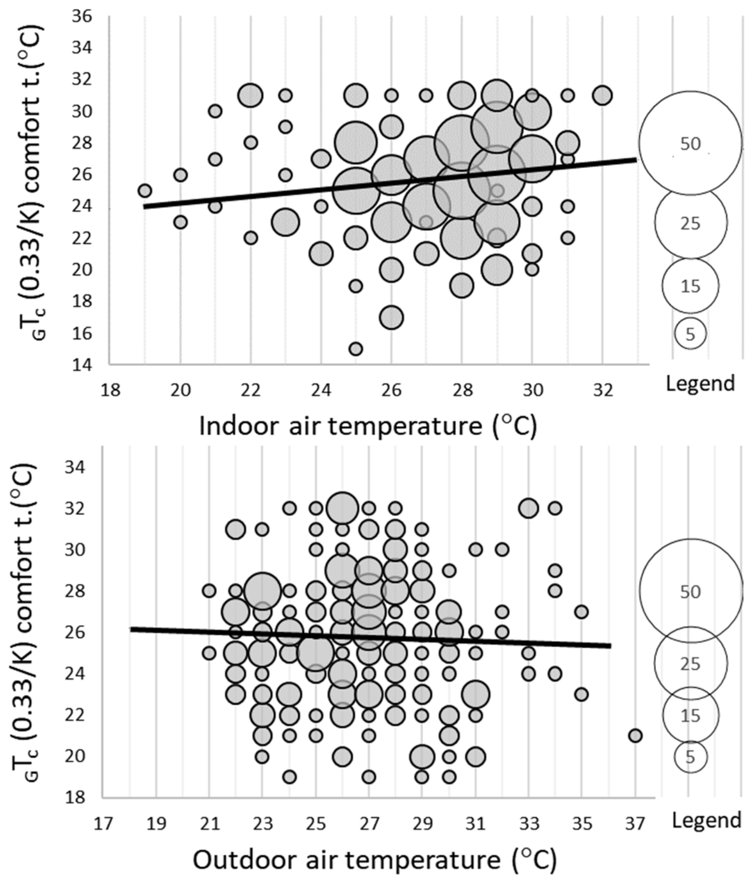
Figure 23 Griffiths comfort temperature at 0.5/K – Japanese data (summer) a) Correlation $_{JP\,G}T_c$: T_i; b) Correlation $_{JP\,G}T_c$: T_o



a)

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Figure 24 Griffiths comfort temperature at 0.33/K – International data (summer) a) Correlation $_{Intl\,G}T_c$: T_i; b) $_{Intl\,G}T_c$: T_o

2.5. Summer Results. Comparison with Related Standards

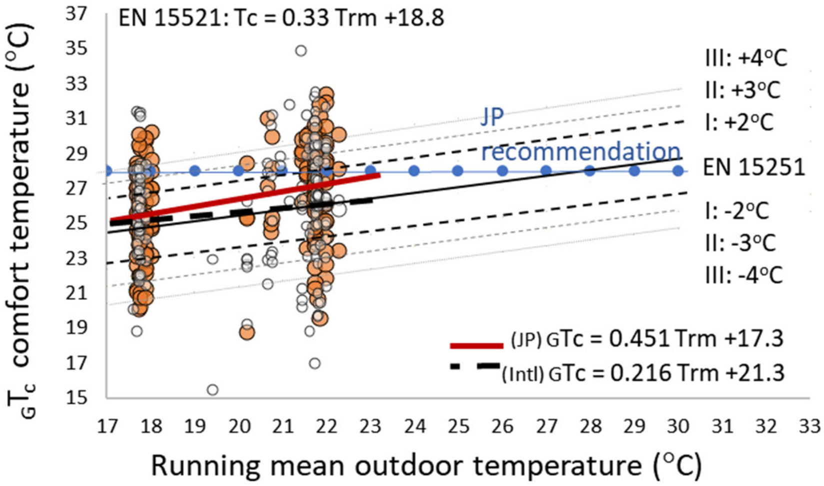
A number of international standards regulate the indoor environment [19]. They have established thermal comfort models to predict the indoor comfort temperature based on the running mean outdoor temperature. The comfort temperature derived for Japanese and international students was correlated to running mean outdoor air temperature as calculated in subsection 2.2 and to mean daily outdoor temperature to compare the results to EN 15521 [72] and ASHRAE [76] respectively.

Relating the Japanese comfort temperature to both T_{rm} and T_{od} resulted in statistically significant positive correlation ($p < 0.001$). However, the sensitivity to T_{rm} is almost two times higher than to the T_{od}. Relating the international comfort temperature to both T_{rm} and T_{od} resulted in statistically insignificant positive correlation to both T_{rm} and T_{od} (Figure 25). Comparing to the adaptive model in EN 15521, it can be observed that almost all data points are within the range of group III and that our model for international students almost coincided with it. However, the Japanese sensitivity was stronger than in the standard's model (regression coefficient of 0.451). Still, the regression line estimated by our data set remains within the boundaries of the EN 15521 Class I comfort zone.

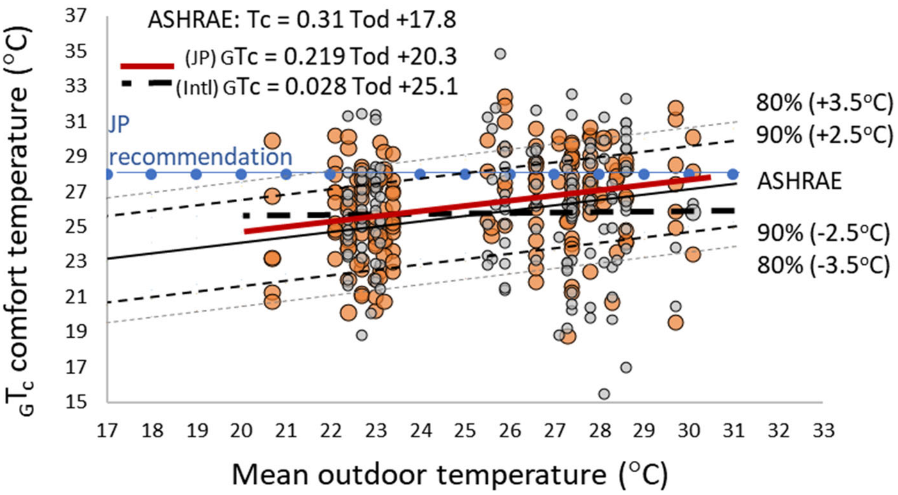
The closest to a university dormitory building type included in the ASHRAE Global Thermal Comfort Database II is the "multifamily housing building" or a "classroom" [22]. However, dormitories resemble but also differ from either one. In addition, dormitories accommodate multinational students at the 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 very close 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 25) in order to limit the energy consumption and thus address the issues of energy dependency of the country [77]. 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.



a)



b)

Figure 25 Comparison of comfort temperature with standards: a) EN 15521 (updated to EN 16978-1) and b) ASHRAE

2.6. Summer Results. Comparison with Existing Research

The sensitivity to indoor conditions observed in subsection 2.4.2 is comparable with the sensitivity in similar research: 0.216/K [30] and 0.283/K [31] in Doha, Qatar; 0.273/K [70] in residential houses in Kanto region, Japan; 0.248/K in dormitory buildings in spring in Harbin, China [53]; 0.225/K, 0.269/K and 0.282/K for Chinese students of different origin in dormitories during summer in Changsha, China [57]. 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 [73]).

In the field survey conducted by Nakano et al. [48] 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 6). 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 16). 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. [48] 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 8) and within the same range of 24-28°C (subsection 2.4.1). 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).

Table 13 Comparison of comfort temperature in summer with existing research

Area of the research	Reference	Temperature for calculation	Comfort temperature (°C)
Japan (Tokai)	This study (see section 2.4.2, p.35)	T_i	26.0 (24.0-28.0) *
Japan (Tokai)	This study (see section 2.4.1, p.33)	T_i	24.0-28.0 **
Iran	[32]	T_i	28.4
Pakistan	[33]	T_g	26.7-29.9
Nepal	[34]	T_g	21.1-30.0
UK	[35]	T_i	22.9
Singapore	[36]	T_{op}	28.5
Indonesia	[37]	T_{op}	29.2
Malaysia	[38]	T_i	30.1
India	[39]	T_g	29.2
China	[40]	T_{op}	28.6
Japan (Kanto)	[43]	T_{rm}	25.8 (FR, CL)
Malaysia	[43]	T_{rm}	25.6 (CL)
Indonesia	[43]	T_{rm}	24.7, 26.3, 27.5 (FR, CL, MM)
Singapore	[43]	T_{rm}	26.4 (CL)
Japan (Kanto)	[47]	T_g	25.0 (FR), 25.4 (CL)
Japan (Kanto)	[50]	T_i	23.6 (FR), 27.0 (CL)
Japan (Gifu)	[51]	T_i	26.1
China	[55]	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

Indraganti and Boussaa [30] also observed strong correlation between TSV and TP in their year-long office survey in Qatar. Difference in 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 2.2, Figure 15a). 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 26ºC 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 demonstrate 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 13.

3. Conclusions for Summer Neutrality and Comfort

Currently presented results were obtained from a field survey about environmental comfort in typical university dormitory buildings in Japan during the summer period of 2017. The aim of the study was 1) to snapshot the subjective thermal comfort of the Japanese and non-Japanese students relative to temperature, humidity and other factors, 2) to understand what is the difference, if any, between the temperature defined as neutral or comfortable and 3) to get an insight how tolerant are the students to their indoor environment.

Subjective votes were collected through a traditional paper questionnaire. Simultaneously, measurements of physical parameters of the indoor and outdoor environment were conducted and the two data-sets were linked. The correlation of the subjective neutrality and comfort were investigated in relation to nationality; as well as the effect of sensation to occupants' preference and tolerance to their indoor environment.

Nationality significantly affected thermal sensitivity, comfort 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 24~28ºC 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.

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.

CHAPTER III

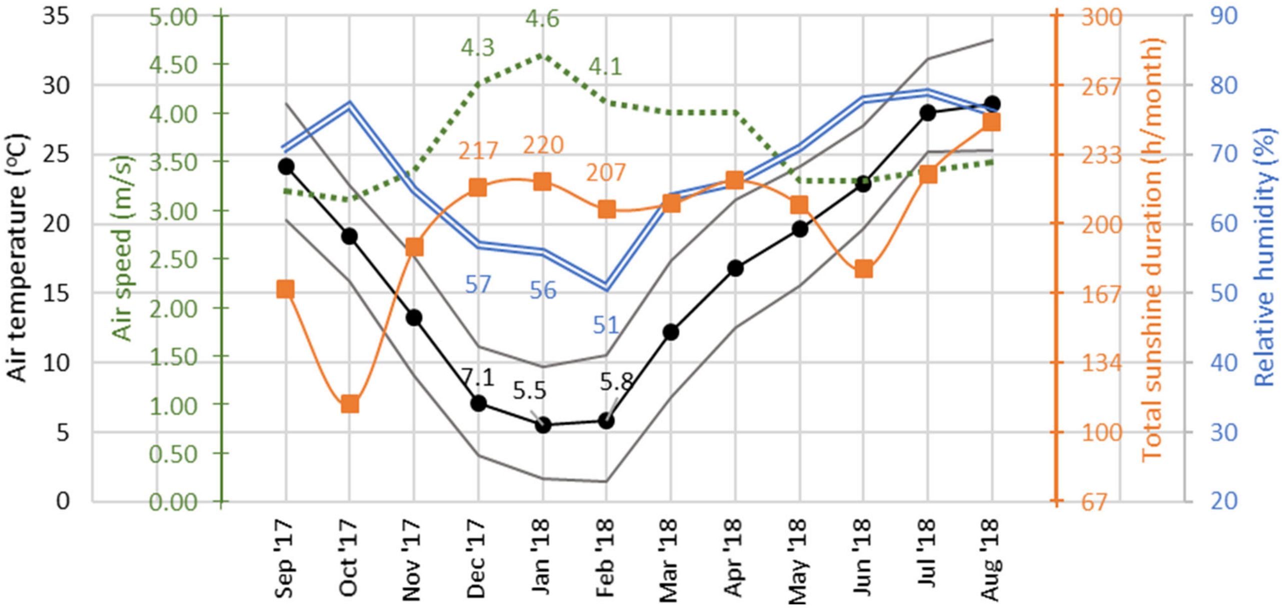
Winter Survey. Data Summary and Statistical Analysis

The second stage of the field survey was planned and conducted in the winter of 2017-2018 in the same two university dormitory buildings. The aim was again 1) to snapshot the subjective thermal comfort of the Japanese and non-Japanese students relative to temperature, humidity and other factors, however – this time about winter season, 2) to understand what is the difference, if any, between the temperature defined as neutral or comfortable and 3) to get an insight how tolerant are the students to their indoor environment.

1. Methodology

1.1. Location and Winter Climate

The climate data for winter 2017-2018 in Toyohashi (Figure 26; see also Chapter I, sub section 1.1, page 17) was provided by Japan Meteorological Data Agency (JMA) from WMO ID:47654 (weather meteorological observation point) [64]. The mean monthly outside temperature reached its minimum in January ($T_{avg.}$ = 5.5°C; $T_{min.}$ = 1.7°C; $T_{max.}$ = 9.7°C). The mean relative humidity reached its minimum of 51% in February.



a) b)

Figure 26 Toyohashi. Japan. a) Location; b) Climate. Data from JMA WMO ID: 47654 – min, max and mean air temperature and relative humidity for winter season 2017 - 2018

1.2. Winter Measuring Period

In Toyohashi the residents experience two opposing climate conditions within a year - peak humidity and temperature in summer and their lowest values in winter. The survey was conducted in both periods and the current paper presents the winter findings. The winter stage of the field survey was conducted in 2017 and 2018 (from December 5, 2017 to February 2, 2018). The targeted period was the winter. The period was divided in three sub periods. Each sub period consisted of two weeks of measurements (sub-period 1: 12/5~12/15; sub-period 2: 12/18~1/19; sub-period 3: 1/22~2/2). 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 (sub-section 1.4).

1.3. Dormitory Buildings and Sample Selection

The winter survey was conducted in the same two dormitory buildings as in summer: International dormitory (Kaikan) and the newly built dormitory for Japanese and foreign students (GSD – Global students' dormitory) in Toyohashi University of Technology, Japan (TUT) (see also Chapter I, sub-section 1.3, page 18). The population of interest was represented by a sample from the international students currently residing in Kaikan and in GSD. In both dormitories the students were living in private rooms. The heating source was a separate for each room air conditioner, split system, with heating, cooling and dehumidifying operation modes. The inner body was installed at 2.0-2.2m from the floor.

1.4. Field Survey – Winter Stage. Data Collection and Analysis

The design of Stage 2 (winter) of the field survey study was the same as Stage 1 (summer) - longitudinal with repeated sampling of limited number of subjects (see also Chapter I, sub-section 1.4,page 20). At the beginning of each measuring week, a set of paper questionnaires was provided to each volunteer in their preferred language – Japanese or English (Appendix C and Appendix D). The subjective thermal votes were collected using the recommended scales and wording of the questions in ISO 10551: 2003 (E) for assessment of thermal environment using subjective judgmental scales [67] and in ANSI/ASHRAE 55 [26]. The wording for each point on the scale of the thermal responses and the percentage distribution of votes in winter is presented in Table 16.

The subjects were asked to state their activity and clothing at the time of each vote. A list of reference clothing and physical activity was provided with the questionnaire. The values assigned for calculation of the winter clothing and activity are in Appendix E, Appendix Table E-1 , Appendix Table E-2 and Appendix Table E-3 . The same approach as in summer was used to ensure quality of votes (see also Chapter I, sub section 1.5, page 20). Measurements of the indoor and outdoor air temperature and relative humidity were continuous at one-minute intervals from Monday to Friday. Globe temperature was not measured and, it is considered as a limitation to the study. However, the correlation between the indoor air temperature and globe temperature is invariably very strong, as reported by other researchers in various buildings [45], [47], [51]. Furthermore, it has been stated that simple air temperature can be used in long term measurements provided that there are no large hot/ cold surfaces [78]. In winter stage of the survey CO_2 indoors was also measured. Placement of devices and air velocity assumptions were the same as in summer (Chapter I, sub section 1.5, page 20)

1.5. Analysis Sequence

The winter analysis followed same sequence as in summer (Chapter I, sub section 1.6, page 22):

- indoor conditions defined as “neutral” were analyzed in relation to the outdoor conditions.
- the set of four subjective thermal responses (TSV, TC, TP and TA) was listed, distributed and correlated to outdoor conditions, 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 on TSV of other factors such as humidity, clothing and activity was checked using multiple regression.
— Finally, Griffiths method was used to calculate the comfort temperature which was then compared to actually voted comfort temperature.
— The results were corelated to international standards and previous research in the field.

2. Results and Discussion

2.1. Participants in Winter Stage

In the winter stage of the survey, 19 healthy, Japanese and International students from 20 to 30 years of age volunteered to participate (males: M = 24.6, SD = 3.5; females: M = 22.2, SD = 1.5). More than 90% of the participants' body mass index (BMI) was in the normal zone (M = 22.2, SD = 2.0). The total number of volunteers, sex, age, nationality, ethnicity and BMI distribution is presented in Figure 27.

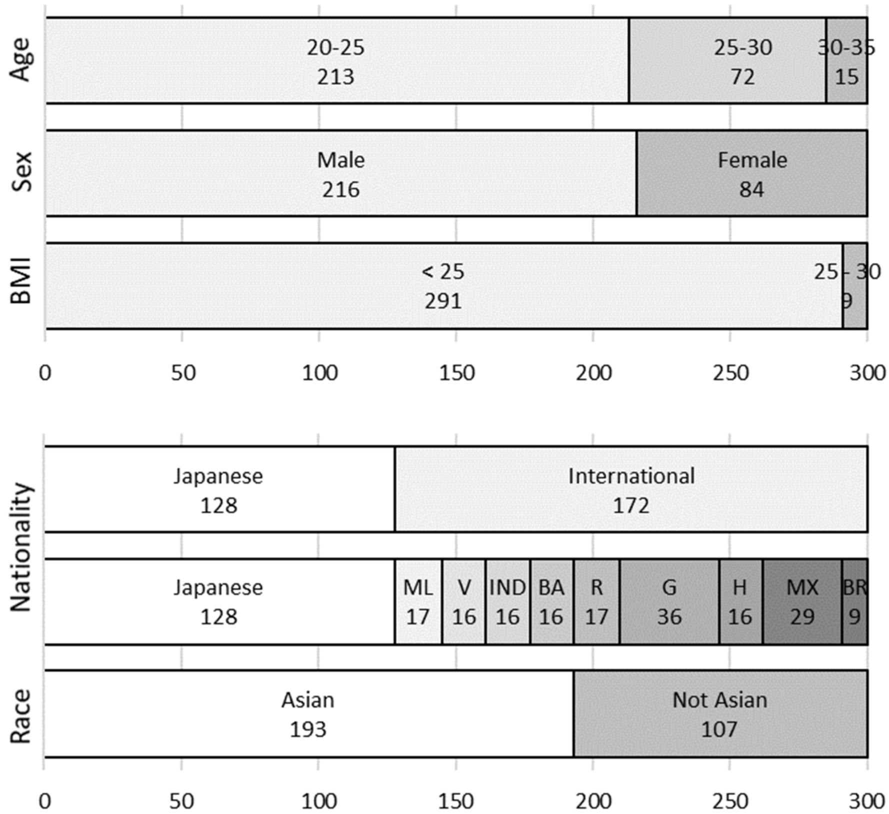


Figure 27 Population sample in winter (N=300 votes) – Number of votes: distribution relative to age, sex, nationality, ethnicity and BMI. ** ML (Malaysian); V (Vietnamese); IND (Indonesian); BA (Bangladeshi); MX (Mexican); G (German); BR (Brazilian); H (Hungarian); R (Russian)

2.2. Winter Indoor and Outdoor Environment at Vote

The subjects were asked to mark the time of their vote. This time was then set to the closest fifteen minutes. The subjective and objective data was coded, organized and matched to one another the same way as in summer (Chapter I, sub-section 2.2, page 24). During the winter time study, a total of 172 questionnaires in Kaikan and 152 questionnaires in GSD were collected. As valid are considered these votes, at which 1) 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); and 2) there was no outdoor activity stated, or it was less than ten minutes within the last thirty minutes prior to voting. Considering the above, 300 valid votes were collected in winter.

The daily mean outdoor temperature (T_{od}) was provided by JMA [64]. Exponentially weighed running mean of the daily outdoor temperature for winter (T_{rm}) was calculated using Eq. 1.

The numerical results at the times of vote are presented in Table 14. Variations in indoor temperature and absolute humidity were higher than outdoors, while for the relative humidity it was the opposite.

Table 14 Descriptive statistics of the collected data at times of vote. Stage 2 (winter)

	T_i (°C)	T_{out} (°C)	T_{od} (°C)	T_{rm} (°C)	RH_i (%)	RH_o (%)	V_a (m/s) **	AH_i (kg/kg$_{DA}$)	AH_o (kg/kg$_{DA}$)	I_{cl} (clo)	M (met)	BMI (kg/m²)
Min	9.8	-2.9	-0.3	1.2	21	25	0.001	0.003	0.001	0.36	1.0	19.4
Max	33.7	14.8	10.8	7.9	98	100	0.425	0.011	0.009	2.11	2.7	27.8
Mean	19.6	4.2	4.7	4.4	47	66	0.032	0.007	0.003	0.63	1.3	22.2
St. D	4.7	3.7	2.6	1.5	14	18	0.063	0.002	0.001	0.23	0.4	2.0

NOTE: Number of observations in winter N=300; T_i: Indoor temperature (°C); Tout: 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$_{DA}$); V_a: air velocity (m/s); I_{cl}: clothing insulation (clo) where 1clo = 0.155 m^2K/W; M: activity level (met) where 1met = 58.2 W/m^2; BMI: Body mass index (kg/m^2)** The observed values of air velocity were outside of the measurement range, that is why they were all set to 0.1m/s

Extended "neutral" is the parameter when the subjects voted TSV = -1, 0, +1 (Figure 28). There was no significant correlation between the indoor neutral temperature (T_n) and the outdoor temperature (Table 15, Figure 29), irrespective of whether it was the measured outdoor value, the daily mean or the daily running mean. It was surprising to observe such disconnection from the local climate. It is foundational assumption in the adaptive model theory and, extensive studies have supported it. For example, in residential buildings in China, Li et. al [41] reported very strong sensitivity to climate in the zones with severe cold and cold winter (0.471/K, 0.660/K) and even stronger in the zones with hot summer and cold winter (0.748/K, 0.739/K). Similar are the results by Yan et. al [42].

In our study there was no correlation to relative humidity (RH_n) either irrespective of nationality. Only extended neutral absolute humidity indoors showed significant correlation to its outdoor counterpart (Table 15). As seen in Figure 28 and Figure 29, indoor humidity at extended "neutral" vote was low with mean RH_n of 47% (IQR from 38% to 58%) and AH_n of 0.007 kg/kg_{DA} (IQR from 0.006 to 0.008 kg/kg_{DA}). The measured air speed in winter was again very low suggesting still air. Such low values were observed by Indraganti and Bousaa offices in Qatar in summer [30], as well as by Ning et al. in Chinese dormitories in winter [53]. In the current study, a standard value of 0.10m/s air speed was selected for any necessary further calculations.

Table 15 Correlation coefficients. Stage 2 (winter)

	All data points (N=189)					**Japanese (N=75)**					**International (N=114)**				
	r	***a***	**β**	**R^2**	**p**	**r**	***a***	**β**	**R^2**	**p**	**r**	***a***	**β**	**R^2**	**p**
T_n: T_{out}	-0.04	-0.040	20.3	0.001	0.619	-0.02	-0.022	19.2	0.001	0.843	-0.09	-0.102	21.2	0.007	0.360
T_n: T_{od}	-0.07	-0.106	20.6	0.005	0.351	-0.14	-0.208	20.0	0.020	0.222	-0.12	-0.192	21.8	0.013	0.225
T_n: T_{rm}	0.07	0.189	19.2	0.004	0.370	0.40	1.169	14.4	0.163	**<.001**	-0.13	-0.379	22.5	0.017	0.172
RH_n: RH_o	0.13	0.106	40.1	0.016	0.082	0.20	0.149	35.4	0.041	0.082	0.09	0.077	43.2	0.008	0.352
AH_n: AH_o	0.51	0.562	0.005	0.261	**<.001**	0.37	0.414	<.05	0.139	**<.001**	0.54	0.556	<.05	0.288	**<.001**

NOTE: N: Number of observations at TSV (-1,0,+1); r: Coefficient of correlation (Pierson's r); a: Slope of regression line; β: Intercept of regression line; R2: Regression coefficient of determination; p: Confidence interval; T_n: Neutral indoor temperature (°C); T_{out}: Outdoor temperature (°C); T_{od}: Outdoor daily mean temperature (°C); T_{rm}: Outdoor daily running mean temperature (°C); RH_n: Neutral indoor relative humidity (%); RH_o: Outdoor relative humidity (%); AH_n: Neutral indoor absolute humidity (kg/kg_{DA}); AH_o: Outdoor absolute humidity (kg/kg_{DA})

2.3. Thermal Sensation, Comfort, Preference and Acceptability in Winter

The distribution of TSV, TC, TP and TA relative to nationality is presented in Table 16. Less than one in every five Japanese students were feeling neutral (17%), while the percentage for the non-Japanese ones was slightly higher (22%). Although there were notable differences in percentage of votes, at almost every point of the TSV scale the differences both in mean and in variance of the T_i of Japanese and non-Japanese data were insignificant . On the cold side of the scale were

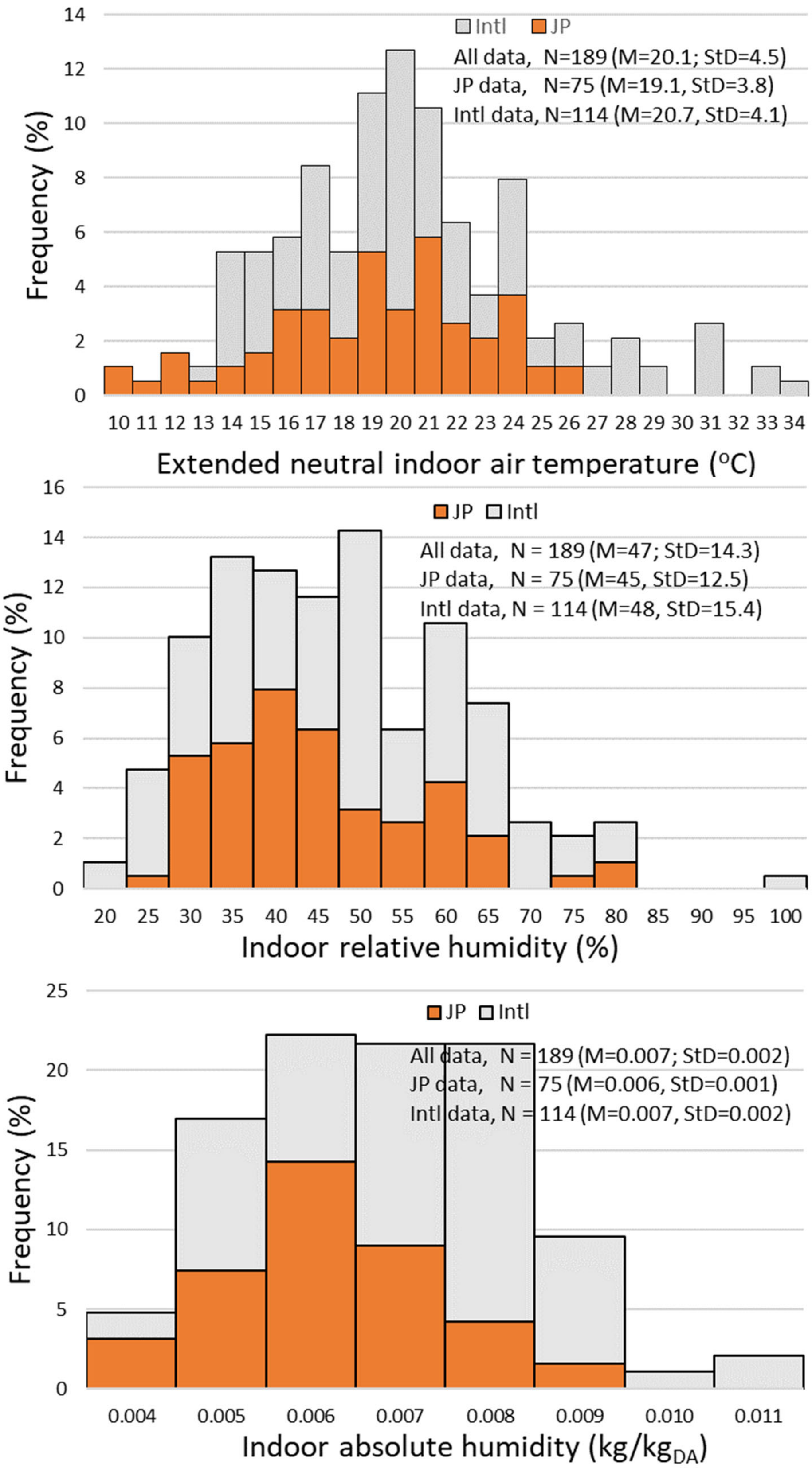
44% of the non-Japanese votes and 46% of the Japanese. On the warm side of the scale – 34% and 38% respectively. As for the voted thermal comfort, 72% of the non-Japanese votes were on the comfortable side of the scale as compared to 66% of the Japanese votes. Only in the non-Japanese dataset there were votes "very uncomfortable". However, the percentage was low (2%). The Japanese votes "prefer no change" were more than 50%, while more than half of the international votes were "prefer warmer". The acceptability for both was high - hovering slightly below and slightly above 90% (for non-Japanese and Japanese subjects respectively).

Table 16 Percentage of thermal responses for each scale relative to nationality (Japanese: N=128; international: N=172). Stage 2 (winter)

Scale	Thermal sensation (TSV) %			Thermal comfort (TC) %			Thermal preference (TP) %			Thermal acceptability (TA)%		
		JP	**Intl**		**JP**	**Intl**		**JP**	**Intl**		**JP**	**Intl**
3	Hot	-	-	Very comfortable	-	5.2						
2	Warm	16.4	13.4	Comfortable	38.3	41.9						
1	Sl. warm	21.1	20.9	Sl. comfortable	27.3	24.4	Warmer	42.2	51.7	Unacceptable	8.6	11.6
0	Neutral	17.2	22.1				No change	53.9	47.7	Acceptable	91.4	88.4
-1	Sl. cool	20.3	23.3	Sl. uncomfortable	29.7	16.3	Cooler	3.9	0.6			
-2	Cool	9.4	9.9	Uncomfortable	4.7	9.9						
-3	Cold	15.6	10.5	Very uncomfortable	-	2.3						

Note: Sl.: Slightly

The outdoor temperature measurements were grouped in 1ºC bins. Frequency distribution of Japanese and non-Japanese responses within each bin was graphed in Figure 30 and Figure 31. The percentage of votes at heating mode (HT) and without the use of air conditioning (FR) were graphed and overlaid onto thermal responses. It is noticeable that bigger percentage of Japanese students vote "very cold" at temperatures of 1~7ºC as compared to the non-Japanese ones. Overall the pattern of air conditioning use is similar in both groups – predominantly heating at temperatures below zero, balancing FR/ HT in the central area and increased percent of not using air conditioning with the increase of outdoor temperatures. The subjective evaluation of comfort seems to closely follow the use of heating and, the vote "prefer to be warmer" is almost uniformly distributed throughout the observed range of outdoor temperatures. Correlating the mean values of the thermal sensation votes within each bin to the outdoor temperatures showed there was no significant linear correlation (Table 17). However, strong quadratic correlation could be observed for the subjective sensation and evaluation votes (Figure 34). Much weaker is the curve for preference and acceptability. Below zero, both TSV and TC decrease to about 4-5ºC outdoor temperature, after which the trends were upward.

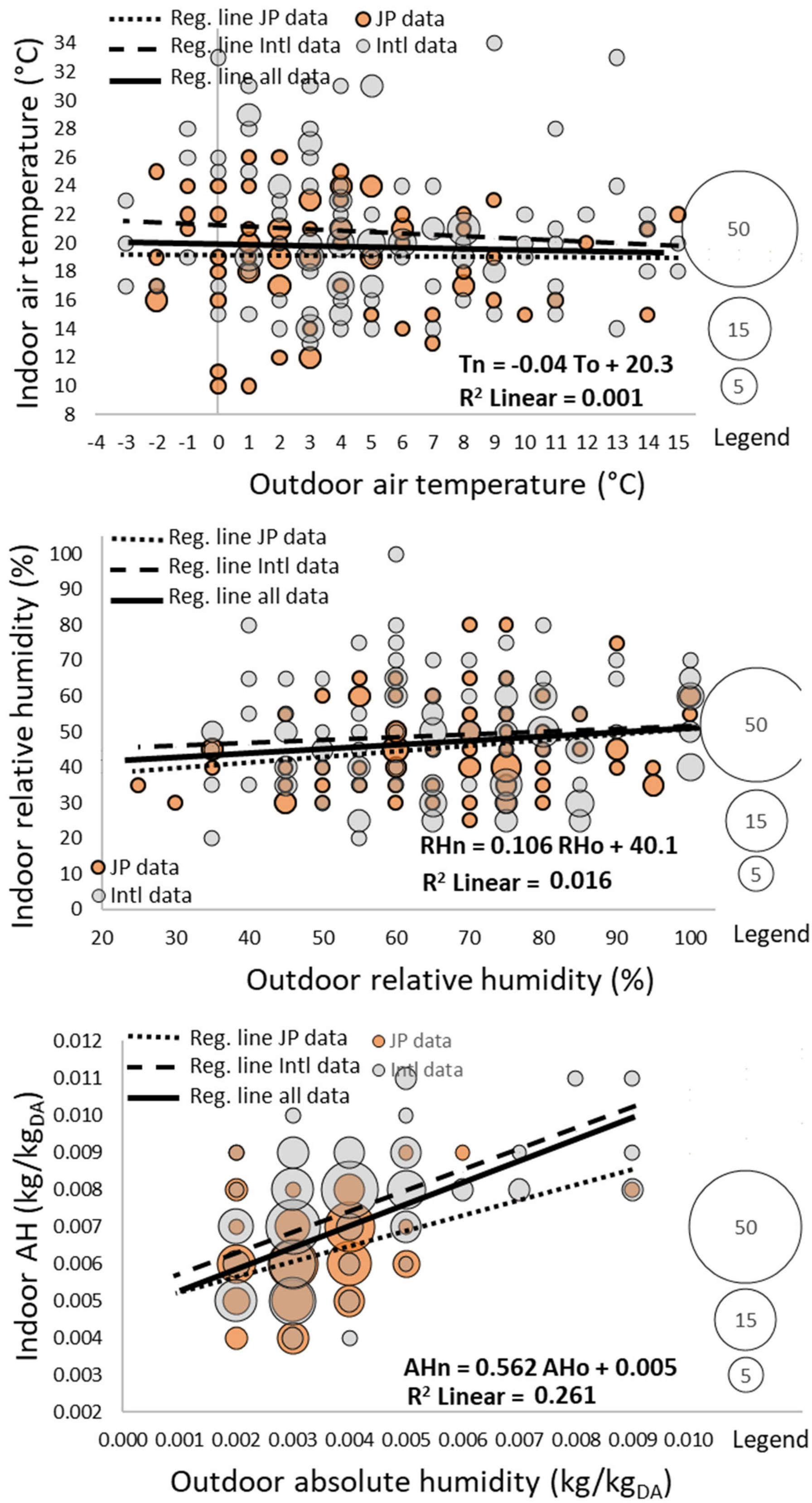


a)

b)

c)

Figure 28 Frequency percentage distribution of indoor parameters in winter at TSV (-1, 0, +1) at vote: a) T_n; b) RH_n; c) AH_n

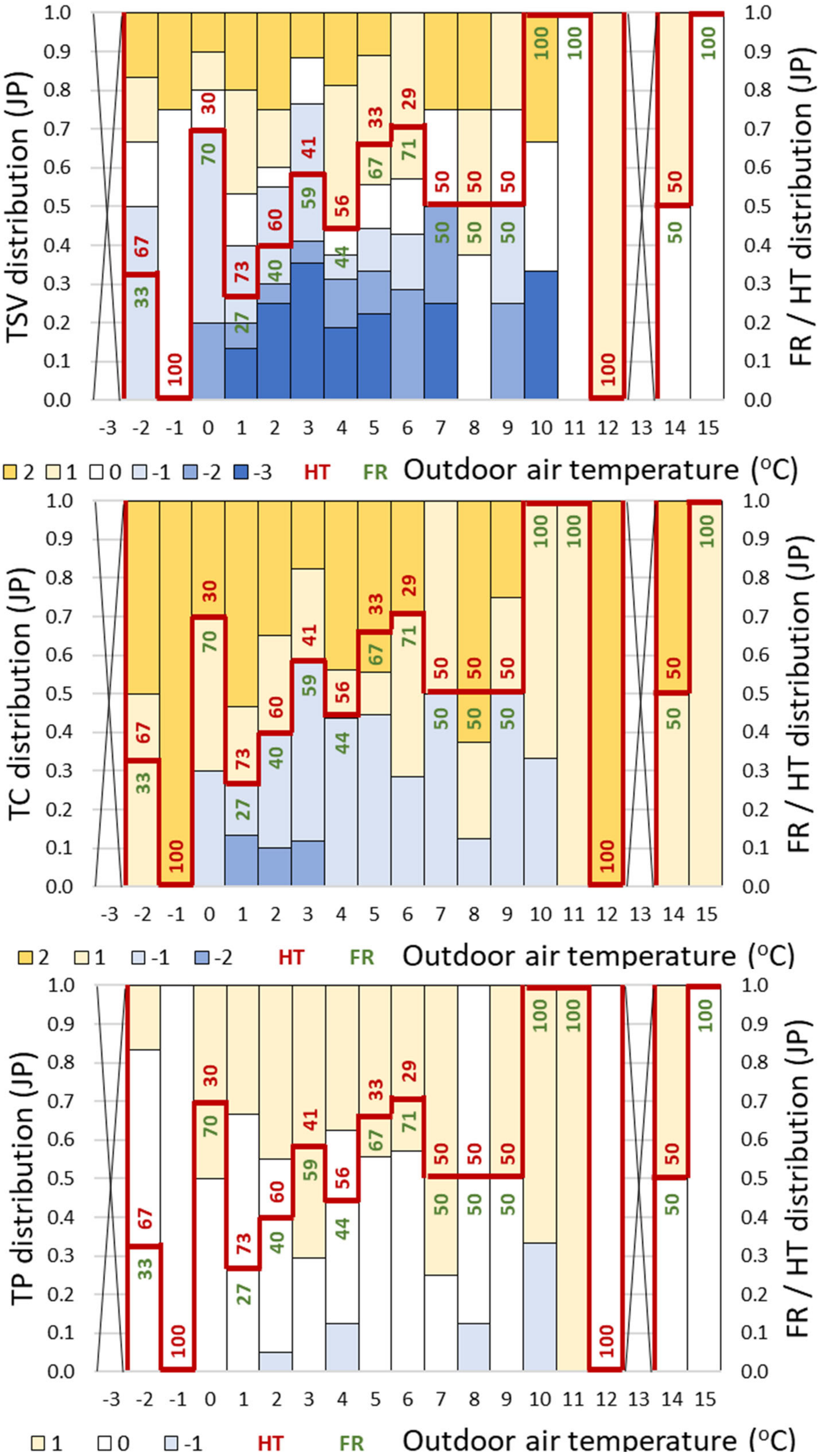


a)

b)

c)

Figure 29 Correlation between indoor and outdoor parameters in winter at TSV (-1, 0, +1): a) T_n: T_o; b) RH_n: RH_o; c) AH_n: AH_o.

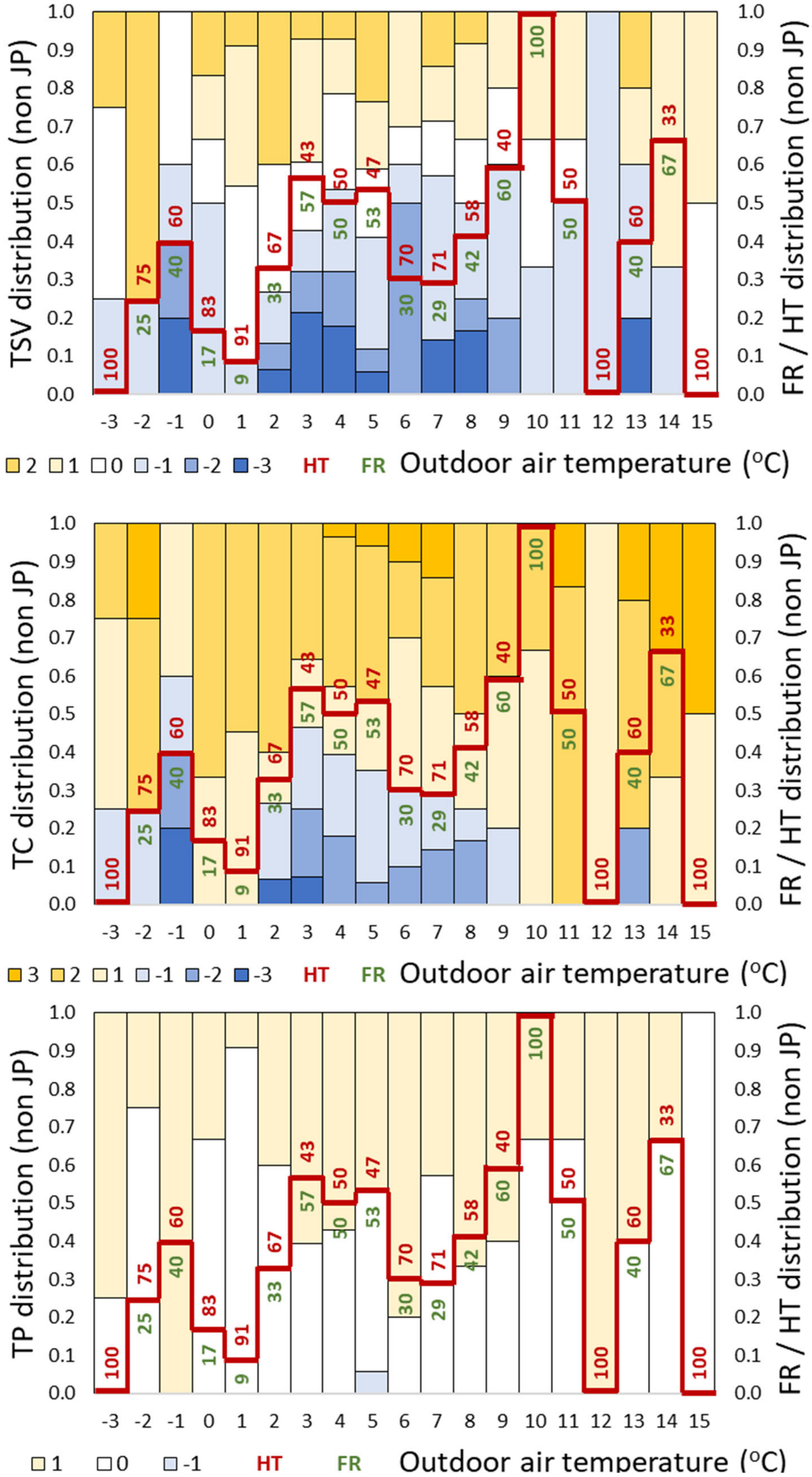


a)

b)

c)

Figure 30 Frequency distributions of Japanese thermal responses in winter relative to outdoor temperature and the use of air-conditioning; a) $_{JP}TSV:T_{out}$; b) $_{JP}TC:T_{out}$; c) $_{JP}TP:T_{out.}$ NOTE: The percentage of FR:HT was added in each 1°C temperature bin. Percentage of FR (without the use of air conditioning) is presented in green; Percentage of HT (air conditioning for heating) is presented in red.



a)

b)

c)

Figure 31 Frequency distributions of International thermal responses in winter relative to outdoor temperature and the use of air-conditioning; a) ${}_{Intl}TSV:T_{out}$; b) ${}_{Intl}TC:T_{out}$; c) ${}_{Intl}TP:T_{out}$. NOTE: The percentage of FR:HT was added in each 1°C temperature bin. Percentage of FR (without the use of air conditioning) is presented in green; Percentage of HT (air conditioning for heating) is presented in red.

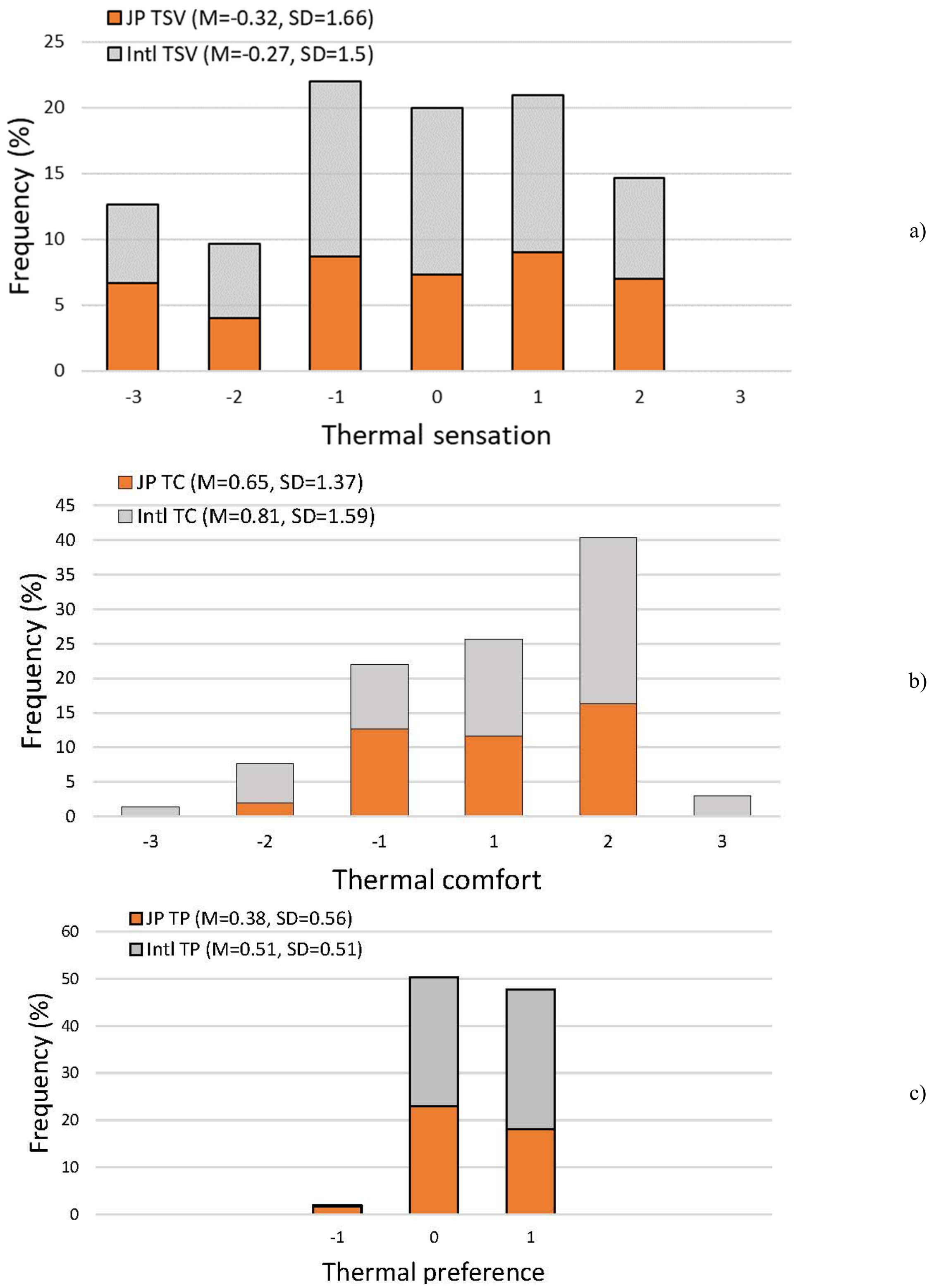
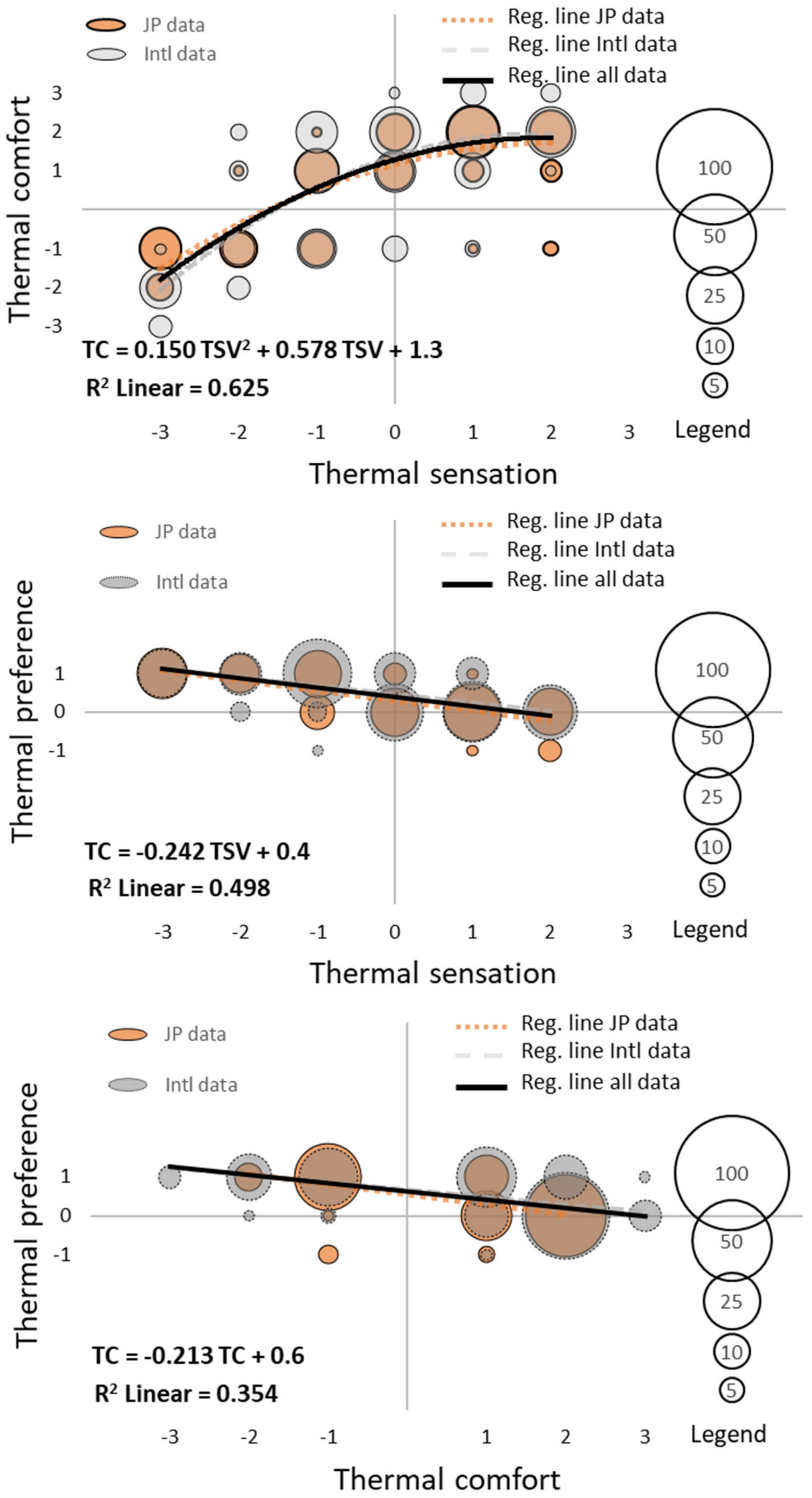


Figure 32 Frequency percentage distribution of thermal responses in winter; a) TSV; b) TC; c) TP



a)

b)

c)

a)

Figure 33 Correlation between thermal responses in winter; a) TC: TSV; b) TP: TSV; c) TP: TC

Table 17 Correlation between mean thermal responses and outdoor temperature in winter

Relation to T_{out}	All data points				Japanese				International			
	TSV_{all}	TC_{all}	TP_{all}	TA_{all}	TSV_{JP}	TC_{JP}	TP_{JP}	TA_{JP}	TSV_{Intl}	TC_{Intl}	TP_{Intl}	TA_{Intl}
r	0.06	0.52	-0.23	-0.23	0.31	0.07	0.04	-0.35	-0.17	0.48	-0.14	-0.19
$p_{correlation}$	-0.406	0.087	-0.618	-0.618	-0.201	-0.429	-0.451	-0.712	-0.577	< 0.05	-0.556	-0.592
$_{quadratic}R^2$	0.45	0.55	0.11	0.17	0.22	0.37	0.13	0.21	0.24	0.33	0.05	0.10

NOTE: T_{out}: Outdoor air temperature (°C); r: Coefficient of linear correlation (Pierson's r); p: Confidence interval for linear correlation; R^2: Regression coefficient of determination for the quadratic expression of the correlation; TSV: Mean thermal sensation vote; TC: Mean thermal comfort vote; TP: Mean thermal preference vote; TA: Mean thermal acceptability vote

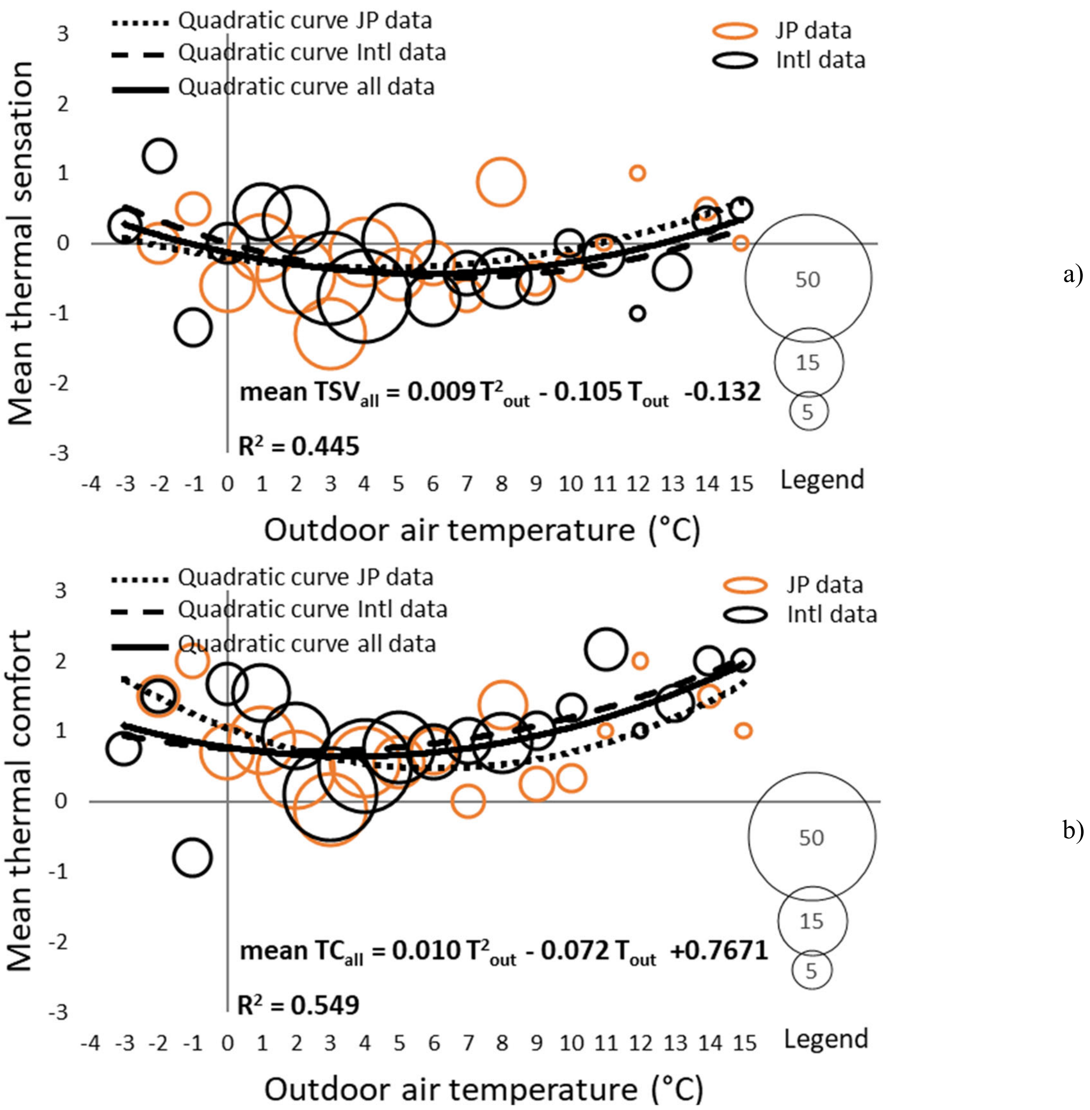


Figure 34 Relationship of mean thermal responses to outdoor temperature. a) mean TSV : T_{out}; b) mean TC : T_{out}

Thermal sensation had strong positive correlation with thermal comfort ($r = 0.75$, $p < 0.001$) and strong negative correlation with thermal preference ($r = -0.71$, $p < 0.001$) (Table 18). The hotter the subjects sensed their environment, the more comfortable they felt (Figure 33a) and, their preference inclined from "prefer warmer" towards "prefer no change" without passing over the neutral line (Figure 33b). The correlation between comfort and preference was also strong and negative (r = -0.60, p < 0.001). The more comfortable the subjects evaluated their indoor environment, the closer their preference vote was to "no change" (Figure 33c). There was significant correlation between TA and the other thermal responses, however the coefficient of determination was relatively low ($R^2_{TSV:\ TA}$ = 0.253; $R^2_{TC:\ TA}$ = 0.342 and $R^2_{TP:\ TA}$ = 0.092).

The regression lines derived from all the data, from only the Japanese and only the international datasets were either very close or overlapping (Figure 33) revealing the same relationship between thermal responses irrespective of nationality.

Table 18 Correlation between thermal responses. Stage 2 (winter)

	All data points (N=300)					**Japanese (N=128)**					**International (N=172)**				
	r	***a***	**β**	**R²**	**p**	**r**	***a***	**β**	**R²**	**p**	**r**	***a***	**β**	**R²**	**p**
TC: TSV	0.75	0.718	0.9	0.565	<.001	0.79	0.650	0.9	0.621	<.001	0.74	0.778	1.0	0.542	<.001
TP: TSV	-0.71	-0.242	0.4	0.498	<.001	-0.78	-0.265	0.3	0.615	<.001	-0.65	-0.222	0.5	0.421	<.001
TA: TSV	-0.50	-0.098	0.1	0.253	<.001	-0.36	-0.061	0.1	0.130	<.001	-0.61	-0.131	0.1	0.376	<.001
TP: TC	-0.60	-0.213	0.6	0.354	<.001	-0.64	-0.262	0.6	0.409	<.001	-0.59	-0.191	0.7	0.348	<.001
TA:TC	-0.59	-0.119	0.2	0.342	<.001	-0.45	-0.093	0.1	0.204	<.001	-0.67	-0.135	0.2	0.444	<.001
TA:TP	0.30	0.172	0.0	0.092	<.001	0.23	0.119	0.0	0.057	<.05	0.35	0.217	0.0	0.120	<.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

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 use of air conditioning affected three thermal responses (TSV, TC and TP). Dormitory building, sex and nationality affected two responses while time of day affected only one – only the thermal acceptability. The statistically significant results are presented in Table 19.

The test only partially confirmed the initial assumption. It was surprising that the nationality did not affect the thermal sensation vote. However, it affected the subjective comfort and the preference vote. Current paper explores the nationality factor. It was evident that a certain adaptation has taken place so to equalize the subjective thermal sensation votes of Japanese and non-Japanese subjects. Similar observations have marked the necessity of an adaptive approach to comfort from its very beginning [p. 27, [20]]. Investigating further what might have caused such equality in neutral vote, the mean values and the variance for clothing insulation, activity level and BMI at each TSV scale point were compared. It seems that non-Japanese students voting on the warm side were predominantly larger by one point of BMI, non-Japanese students tended to adjust their clothing when feeling cold and, when Japanese students voted on the warm side, they did more varying activities inside their dormitory rooms. In Chinese dormitories during winter, Ning et al. also observed that clothing adjustment is a main behavioral response [53].

Table 19 Summary of Chi-square results: Dependence of TSV, TC, TP and TA on sub-divisions. Stage 2 (winter)

	Sub-division	n	df	χ^2 critical	χ^2	p	Estimated by Regression* (°C)		δT(°C)
TSV	AC on: AC off	165: 135	5	11.07	43.34	< 0.001			
	Male: Female	216: 84			12.93	< 0.05			
TC	AC on: AC off	165: 135	5	11.07	29.79	< 0.001			
	GSD: Kaikan	147: 153			15.25	< 0.001			
	Male: Female	216: 84			25.52	< 0.001			
	Japanese: International	128: 172			18.73	< 0.05	$T_{c\ JP} > 22.0$	$T_{c\ Intl} > 21.9$	0.1
TP	AC on: AC off	165: 135	2	5.99	15.75	< 0.001			
	GSD: Kaikan	147: 153			8.41	< 0.05			
	Japanese: International	128: 172			6.03	< 0.05	$T_{p\ JP} = 27.0$	$T_{p\ Intl} = 33.2$	-6.2
TA	Day: Night	163: 137	1	3.84	7.43	< 0.05			

Note: 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).

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 19). As the chi-square test showed that TSV was independent from nationality, the regression was run for all the data points together and estimated the neutral temperature T_n=21.5°C irrespective of nationality. Japanese subjects are expected to start feeling comfortable at slightly higher temperature as compared to the international subjects (at 22.0°C and 21.9°C respectively). However, the estimated comfort temperature by regression is extremely close. Only in the preference vote, the estimated difference was notably sizable. Japanese vote "prefer no change" is expected at about 6ºC lower temperature than the international vote (at 27.0ºC and 33.2ºC respectively).

2.4. Winter Neutral and Comfort Temperature

2.4.1. Logit Regression Analysis for Neutrality Range in Winter

Estimating the probability of getting a neutral Japanese and non-Japanese vote 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 winter dataset are shown in Table 20.

Table 20 Probit analysis of thermal sensation and indoor temperature. Stage 2 (winter)

JP Intl	TSV	Probit regression line	Mean Temperature (ºC)	SD	N	R^2	SE	p
Japanese TSV	≤ -3	$P_{(\leq -3)} = -0.135\ T_i + 1.4$	10.4	7.42	128	0.46	0.03	< 0.001
	≤ -2	$P_{(\leq -2)} = -0.135\ T_i + 1.8$	13.4					
	≤ -1	$P_{(\leq -1)} = -0.135\ T_i + 2.4$	17.8					
	≤ 0	$P_{(\leq 0)} = -0.135\ T_i + 2.9$	21.5					
	≤ 1	$P_{(\leq 1)} = -0.135\ T_i + 3.7$	27.4					
	-	-	-					
International TSV	≤ -3	$P_{(\leq -3)} = -0.114\ T_i + 0.8$	7.0	8.80	172	0.53	0.02	< 0.001
	≤ -2	$P_{(\leq -2)} = -0.114\ T_i + 1.3$	11.4					
	≤ -1	$P_{(\leq -1)} = -0.114\ T_i + 2.1$	18.5					
	≤ 0	$P_{(\leq 0)} = -0.114\ T_i + 2.8$	24.6					
	≤ 1	$P_{(\leq 1)} = -0.114\ T_i + 3.6$	31.7					
	-	-	-					

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; R^2 (Cox and Snell): Coefficient of determination; SE: Standard error; significance $p < 0.001$)

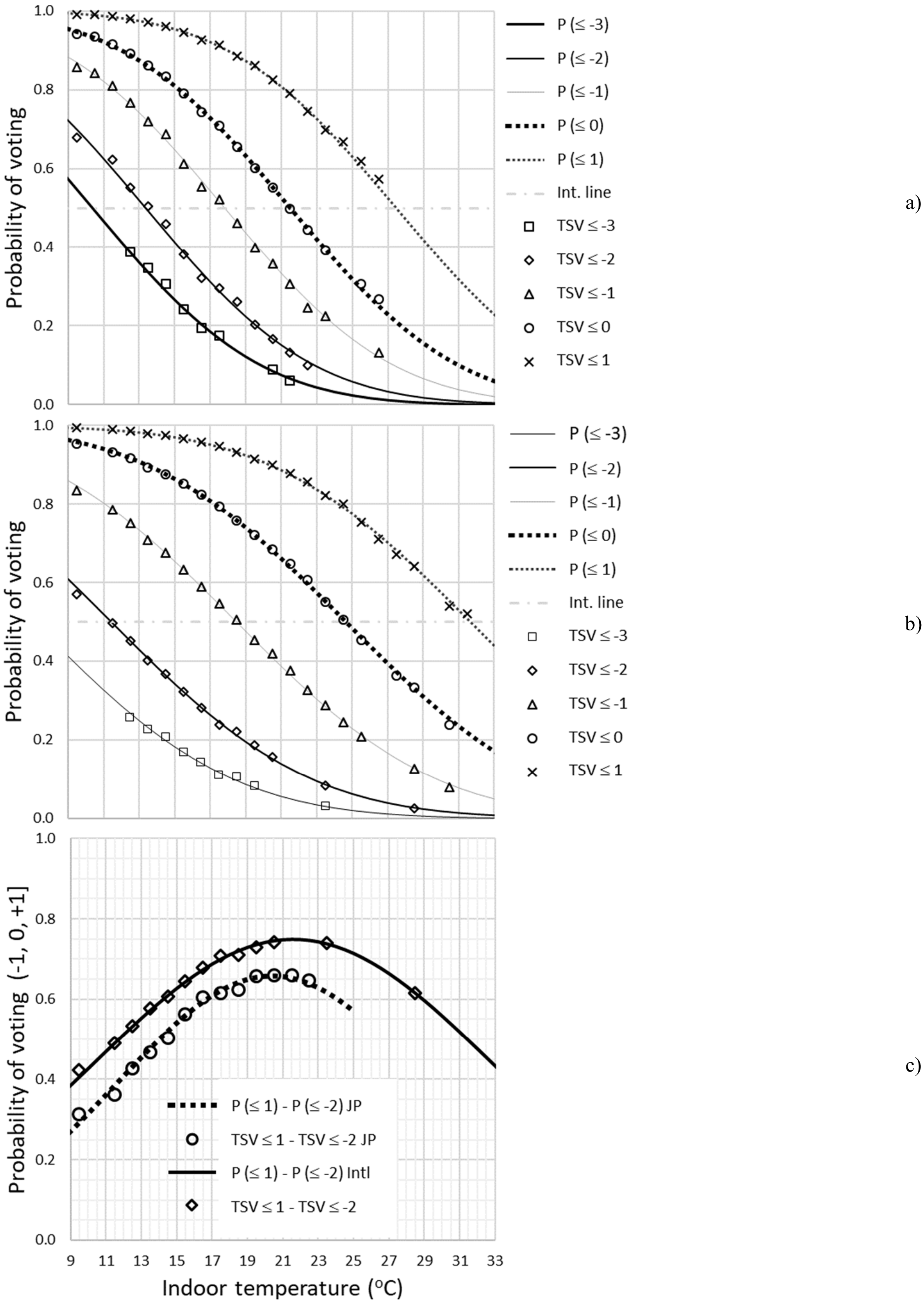


Figure 35 Graphical representation of probit analysis in winter: a) Probability of $_{JP}$TSV; b) Probability of $_{Intl}$TSV; c) Probability of voting within the "extended neutral range" of TSV (-1, 0, +1) Note: Marker points represent the actual proportion voting

The equations $P_{(\leq TSV)}$ 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”) [20], [30], [47]. The probit regression coefficient for Japanese university students is calculated to be -0.135/K and for international ones: - 0.114/K. Mean temperature of the probit line is the absolute value of the result from dividing the y-intercept with the constant – for example | +1.4/-0.135 | = | -10.4 | = 10.4 ºC The SD is the absolute value of the inverse of the constant (SD = |1/-0.135| = | - 7.42 | = 7.42). Each equation was calculated for temperatures from 9ºC to 33ºC which was the range of all the observed indoor 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 35.

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 35a, 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 ~15.0ºC there is 80% probability of voting neutral or less. The explanation for all curves follows the same pattern.

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 19ºC and 22ºC indoor temperature, the probability of Japanese students voting extended neutral is the highest. However, it is just slightly above 65% (Figure 35c). The peak of the graph for international subjects was within the interval from 19ºC to 24ºC). However, the expected percentage is higher – reaching 75%. Japanese students appear to be more critical to their indoor environment.

2.4.2. Linear Regression Method for Winter Neutral Temperature

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 winter stage 59% of the Japanese TSV (N=128, M= -0.32, SD=1.66) were within the -1 to +1 segment of the scale and, the neutral votes were 17% (Table 16). As for the International TSVs (N=172, M=-0.27, SD=1.50), the respective percentages were 66% and 22%.

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:

Eq. 14 Linear regression model TSV_{JP}: Ti (winter)

$TSV_{JP} = 0.195\ T_i - 4.0$, ($N = 128$; $p < 0.001$; $R^2 = 0.21$; S.E.=1.48; F statistic = 33.8)

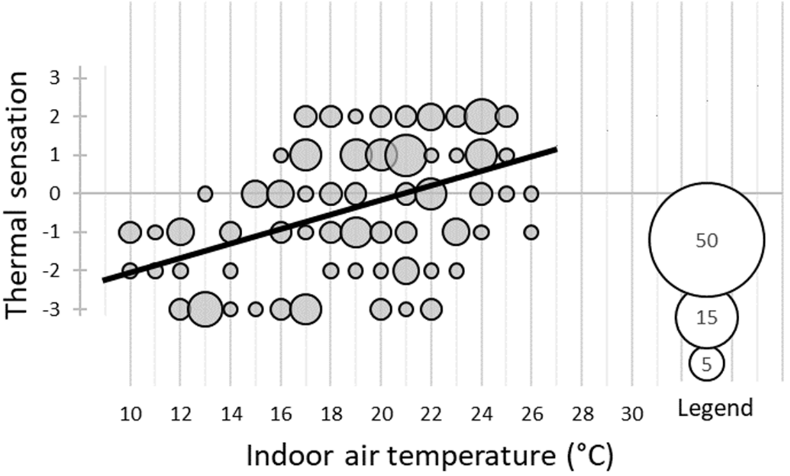
Eq. 15 Linear regression model TSV_{Intl}: Ti (winter)

$TSV_{Intl} = 0.146\ T_i - 3.2$, ($N = 172$; $p < 0.001$; $R^2 = 0.24$; S.E.=1.31; F statistic = 54.7)

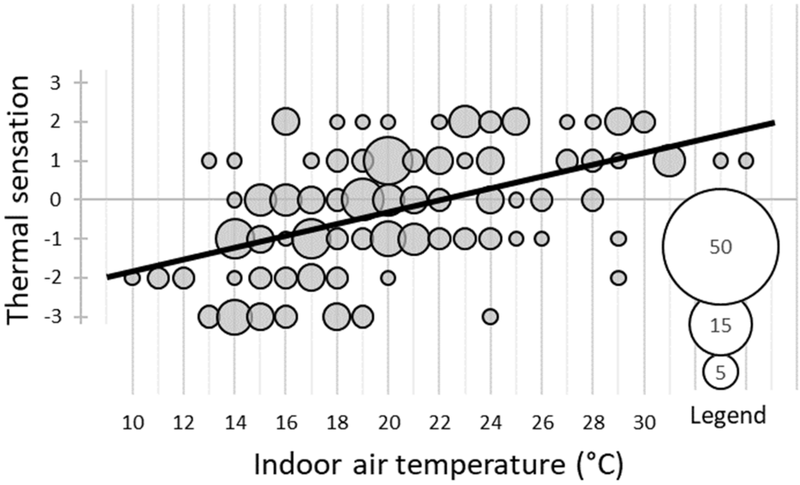
The calculated neutral temperature for Japanese subjects ($_{JP}T_n$) using Eq. 14 is $_{JP}T_n$ = 20.6ºC. This is 1.3ºC higher than $_{voted\ JP}T_n$=19.3ºC - the mean indoor air temperature when the Japanese subjects voted "neutral". The calculated neutral temperature for international subjects ($_{Intl}T_n$) using the Eq. 15 is $_{Intl}T_n$ = 22.0ºC. This is 2.3ºC higher than $_{voted\ Intl}T_n$=19.7ºC - the mean indoor air temperature when the international subjects voted "neutral". The difference in slopes leads to thinking Japanese subjects are more sensitive to their indoor environment, even though the difference in sensitivity appears to be small. This supports the outcome of the probit analysis. Also, the slopes of the regression equations are comparable with the slopes derived from similar research: Rijal et al. estimated 0.183/K and 0.168/K for Japanese subjects in offices in FR mode throughout a year and in winter HT mode respectively [47];

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 [29]. In our survey these ranges are from 16ºC to 25ºC (80%) and from 18ºC to 23ºC (90%) for the Japanese subjects and, from 16ºC to 29ºC (80%) and from 19ºC to 25ºC (90%) for the International subjects. The ranges are wider, but invariably include the range of 19ºC to 22ºC (and 19ºC to 24ºC respectively) which was already observed in subsection 2.4.1. However, the expected probability of voting neutral differed. Probit analysis showed that probability of voting neutral never reaches 80% no matter how wide the temperature range.

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 both RH_i and AH_i were strongly correlated with T_i ($_{JP}RH_i$: $_{JP}T_i$ r = -0.60, p<0.001; $_{JP}AH_i$: $_{JP}T_i$ r =0.40, p<0.001; $_{Intl}RH_i$: $_{Intl}T_i$ r = -0.27, p<0.001; $_{Intl}AH_i$: $_{Intl}T_i$ r =0.27, p<0.001), these variables should be excluded from regressing in combination with T_i. The expectation was that clothing and activity level would significantly affect TSV for both Japanese and international students. However, this was not the case (see the equation above). Based on the Type III sum of squares, only the T_i brings significant information to explain the variability of TSV irrespective of nationality. The following analysis focused only on the temperature.



a)



b)

Figure 36 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.

Eq. 16 Multiple regression model TSV_{JP}: Ti, RHi, Icl, M (winter)

$$TSV_{JP} = 0.196\ T_i + 0.000\ RH_i + 0.331\ I_{cl} - 0.011\ M - 4.2$$

(N = 128; significance of the effect of T_i: $p_1 < 0.001$; sign. of the effect of RH_i: $p_2 = 0.979$; significance of the effect of I_{cl}: $p_3 = 0.727$; significance of the effect of M: $p_4 = 0.972$; $R^2_{adj.} = 0.19$; standard error for T_i: $S.E._1$=0.045; standard error for RH_i: $S.E._2$=0.015; standard error for I_{cl}: $S.E._3$=0.946; standard error for M: $S.E._4$=0.314; F stat = 8.3)

Eq. 17 Multiple regression model TSV_{Intl}: T_i, RH_i, I_{cl}, M (winter)

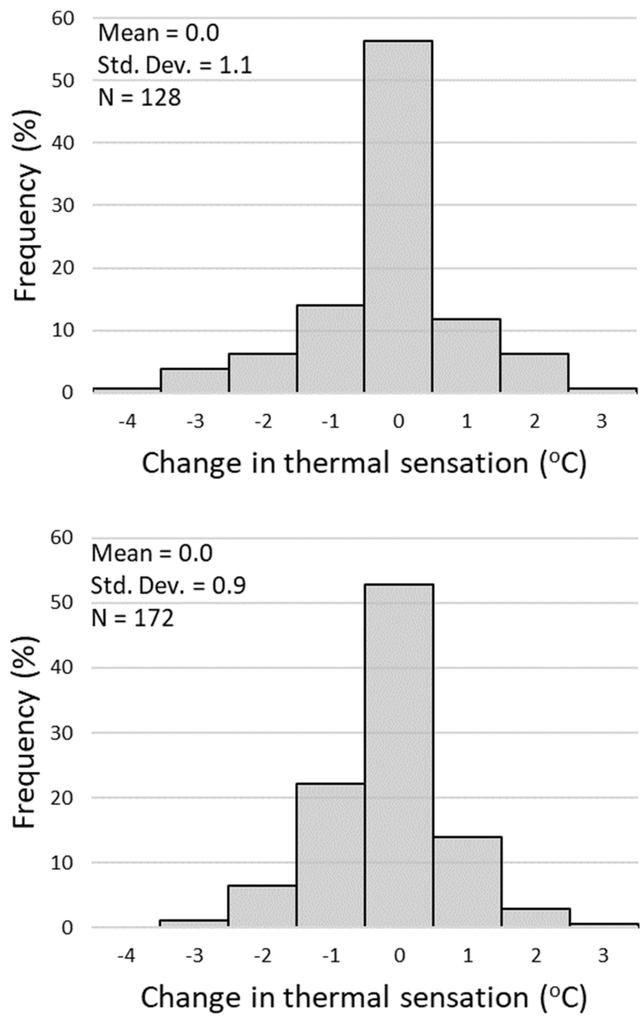
$$TSV_{Intl} = 0.160\ T_i + 0.008\ RH_i + 0.191\ I_{cl} - 0.268\ M - 3.7$$

(N = 172; significance of the effect of Ti: p1 < 0.001; sign. of the effect of RHi: p2 = 0.368; sign. of the effect of Icl: p3 = 0.613; significance of the effect of M: p4 = 0.312; R2adj. = 0.24; standard error for Ti: S.E.1=0.027; standard error for RHi: S.E.2=0.009; standard error for Icl: S.E.3=0.378; standard error for M: S.E.4=0.264; F stat = 14.2)

Linear regression is believed to have some major drawbacks when used for estimating the neutral temperature: 1) majority of votes are clustered around the central point of the thermal sensation scale (Figure 36) 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 [30]. In our analysis, the precision of the linear regression coefficient was improved following the usual analytical approach. Then, the comfort temperature was estimated using the Griffiths' method.

2.4.3. Improving the Precision of Linear Regression Coefficient

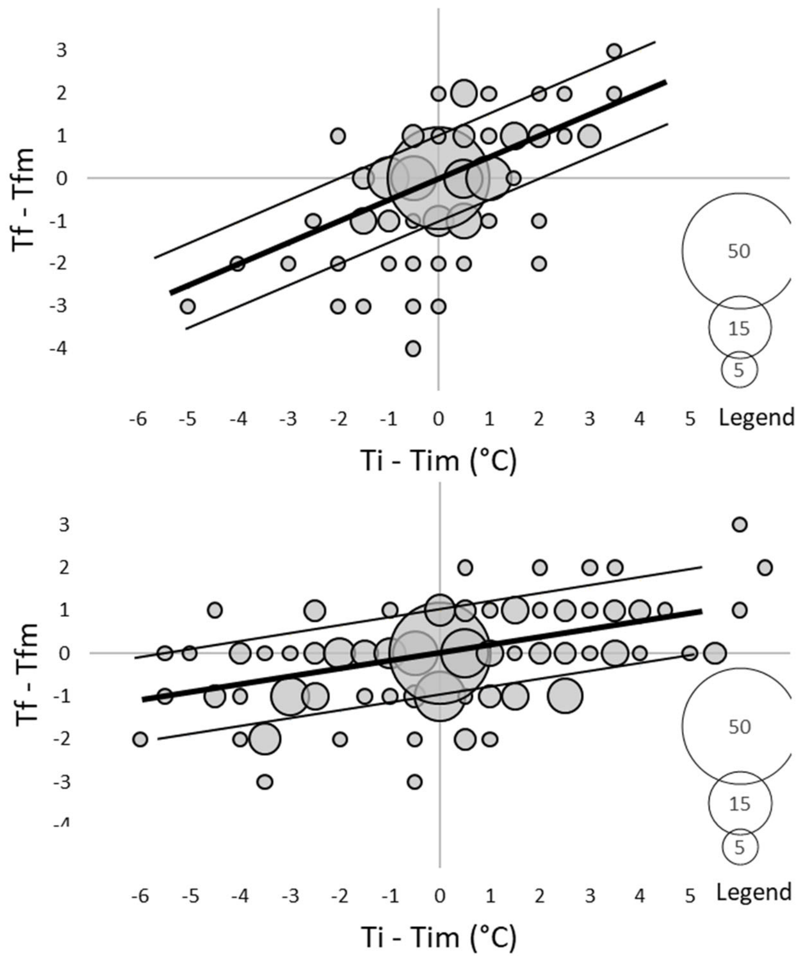
When considering the downsides of the regression method as mentioned above, it is necessary to improve its precision. The widely accepted method to do that is to analyze the within-day and within-room averages. That is to use the variability of the thermal sensation vote from its mean and, to correlate it to the variability of the indoor temperature from its mean [20], [30], [47].



a)

b)

Figure 37 Room-wise day-survey averages. Frequency percentage distribution: a) Japanese vote; b) International vote



a)

b)

Figure 38 Room-wise day-survey averages. Correlation between change of sensation and change of indoor temperature: a) Japanese vote; b) International vote. Note: Outer lines indicate the residual standard deviation

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 19 dormitory rooms for all the survey days within winter. 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. Irrespective of nationality, more than 50% of the variability in subjective sensation was zero (Figure 37). Zero variability 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 δT_f: δT_i from both Japanese and non-Japanese votes demonstrated that when there was low to no variability in the temperature, there was low to no variability in the sensation vote too. The relation was positive in both cases; however, it was much stronger for the Japanese data

(Figure 38). That is, when the variability in temperature increases (bigger fluctuations from the mean), the sensation vote variability is expected to also increase and, Japanese vote changes quicker than the non-Japanese. The linear regression equations are:

Eq. 18 Room-wise day-wise linear regression model for Japanese subjects (winter)

$_{JP}(T_f - T_{fm}) = 0.506\ _{JP}(T_i\text{-}T_{im})$ - 0.0, (N = 128; $p < 0.001$; $R^2 = 0.32$; S.E.=0.92; F stat. = 58.2)

Eq. 19 Room-wise day-wise linear regression model for non - Japanese subjects (winter)

$_{Intl}(T_f - T_{fm}) = 0.181\ _{Intl}(T_i\text{-}T_{im})$ – 0.0, (N = 172; $p < 0.001$; $R^2 = 0.22$; S.E.=0.79; F stat. = 49.0)

From the linear regression δT_f: δT_i the corrected value of the regression gradient was derived. It was 0.51/ K for Japanese and 0.18/ 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 Eq. 8 (see Chapter II, sub-section 2.4.3, page 39).

2.4.4. Griffiths' Method for Calculating Winter Comfortable Temperature

Griffiths method estimates a temperature that is assumed comfortable based on the actual vote of neutral sensation and a regression coefficient. It is calculated using Eq. 9 (see Chapter II, sub-section 2.4.4, page 41)

Table 21 Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients. Stage 2 (winter)

			Calculated comfort temperature $_GT_c$ (ºC)						
	Regression coefficient (/K)	**N**	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
JP	0.55 (see Section 2.4.3)	128	11.6	17.0	19.3	22.1	27.9	19.5	3.7
	0.50		11.8	16.9	19.3	22.1	28.1	19.6	3.8
	0.33		10.9	16.3	18.9	23.3	31.0	19.9	4.8
	0.25		9.0	15.5	19.2	24.7	33.9	20.2	6.0
Intl.	0.50	172	11.2	17.8	20.0	23.5	35.1	20.7	4.5
	0.33		9.6	17.3	20.7	23.9	36.2	21.0	4.9
	0.25		7.6	16.9	20.9	25.4	37.1	21.2	5.6
	0.20 (see Section 2.4.3)		5.6	16.4	21.1	26.2	38.6	21.5	6.7

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.

Griffiths' coefficient accounts for the sensitivity to indoor temperature change and the value used predominantly is a=0.5 [20], [30]. However, previous research explores $_GT_c$ at two more values: a=0.25, and a=0.33 [51], [74], as well as the value of the adjusted coefficient $b_{adj.}$ derived from room-wise day-survey analysis if conducted [30]. In the current study, $_{G}T_c$ was estimated using four values for the Griffiths' coefficient and the results are presented above.

Table 22 Descriptive statistics of the actual temperature at TC +1, +2 and +3 (Comfortable side of the scale) in winter

	Observed comfort temperature T_c (ºC)							
	N	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
JP TC votes "comfortable"	84	9.8	17.3	20.4	22.5	26.1	19.7	3.7
Intl TC votes "comfortable"	123	11.2	17.5	20.5	24.5	33.7	21.3	5.2

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.

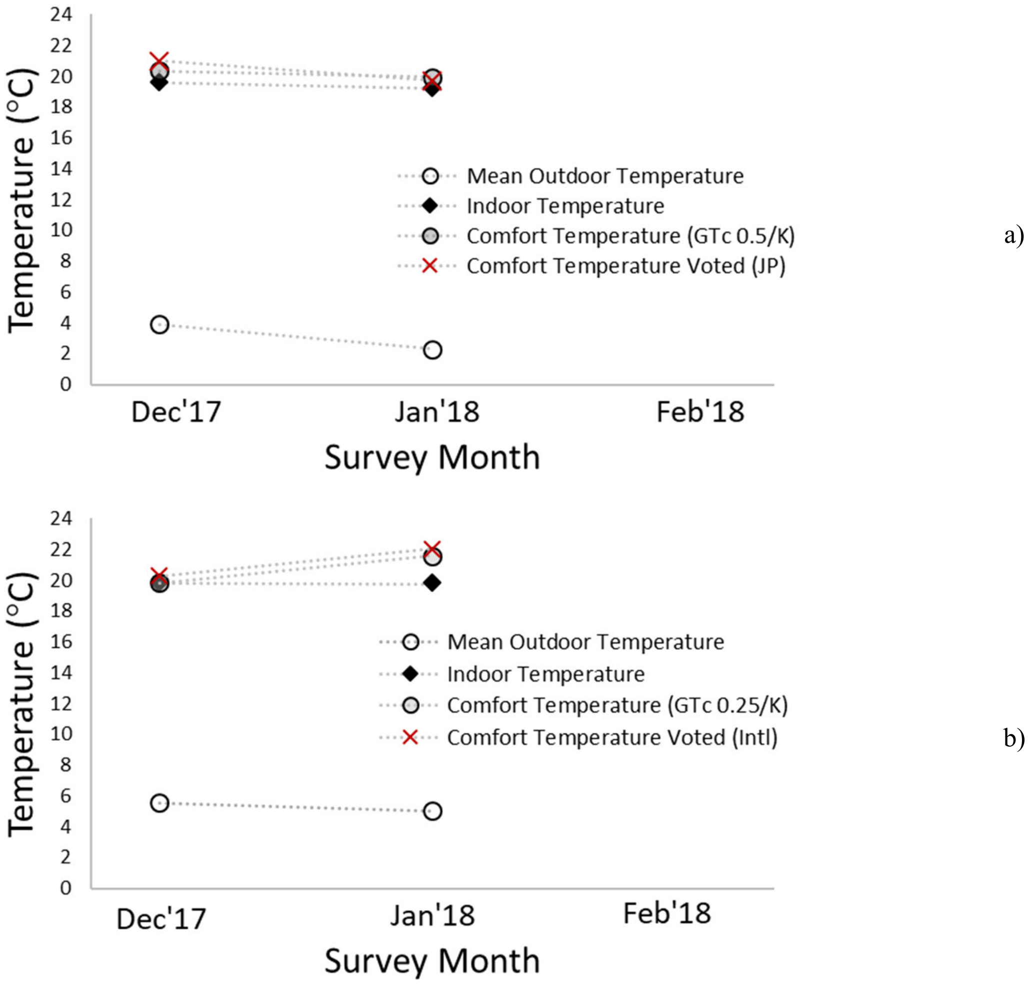


Figure 39 Comparing mean temperatures in each survey month a) Japanese data; b) International data Note: There was only Japanese data for February (and only two days), that is why the February data was added to January data and analysed together.

The current field survey directly asked about the comfort. It made it possible to compare the calculated $_{G}T_c$ (Table 21) and the observed $_{voted}T_c$ (Table 22). For the Japanese data, there was no significant difference in means and in variance of the calculated comfort temperature at 0.55/K and its voted counterpart. At 0.55/K 80% of the ${}_{JP\,G}T_c$ fall within 15ºC and 25ºC. As for the international data, the calculated comfort temperature at 0.20/K showed no significant difference in means, but a significant difference in variance. At 0.20/K 80% of the ${}_{Intl\,G}T_c$ fall within 14ºC and 30ºC, while the actual voted 80% of the ${}_{Intl\,voted}T_c$ fall within 15ºC and 29ºC (narrower range by 2ºC).

Graphing the calculated and the voted mean comfort temperature for each survey month (Figure 39) relative to nationality visually displayed the above – the non-Japanese voted comfort temperature was close and kept the same relation to the calculated value - the voted comfortable temperature remained at about half degree higher. The Japanese voted comfort temperature changed the relation to its calculated counterpart – its mean value was higher than the calculated comfort in December and lower in January (Figure 39).

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 0.25/K for the international data. Frequency distributions of calculated comfort temperature demonstrated a significant shift in mean by 1.6ºC to the right in the non-Japanese data ($t\,(295) = -3.0$, $p < 0.05$). The range of comfort temperatures for non-Japanese students was also significantly wider ($F\,(127,171) = 0.455$, $p < 0.001$) with 80% of the ${}_{G}T_c$ within 15-26ºC and 15-28ºC range for Japanese and non-Japanese respectively (Figure 40).

The calculated comfort temperature in our survey was significantly correlated to the indoor air temperature, however the relation was much stronger in the Japanese data (Figure 41, Figure 42, Table 23). One of the fundamental assumptions of the adaptive model is that the comfort indoor temperature would be in relation with the seasonal outdoor temperature provided that the outdoor conditions are not unpleasantly hot or unpleasantly cold [p.60, [20]]. For both Japanese and non-Japanese data, there was significant correlation between the calculated comfort temperature and the running mean outdoor temperature (Figure 41, Figure 43, Table 23). However, while ${}_{calc\,JP\,G}T_c$ varied in sympathy with the T_{rm}, the correlation ${}_{calc\,Intl\,G}T_c$: T_{rm} was inverse. Other researchers [20] have noted similar effect and have attributed it to unpleasantly cold outdoor conditions in which case the subjects tend to use mechanical means to assure comfort. The percentage of non-Japanese subjects using heating in winter did indeed differ from Japanese (64% to 53% respectively) and, the TSV when using or not air-conditioning was indeed dependent on nationality ($\chi^2(5, N = 300) = 43.34$, $p < 0.001$). Further analysis about how using or not using air-conditioning affects the comfort temperature in winter in dormitories will be the focus of a following paper.

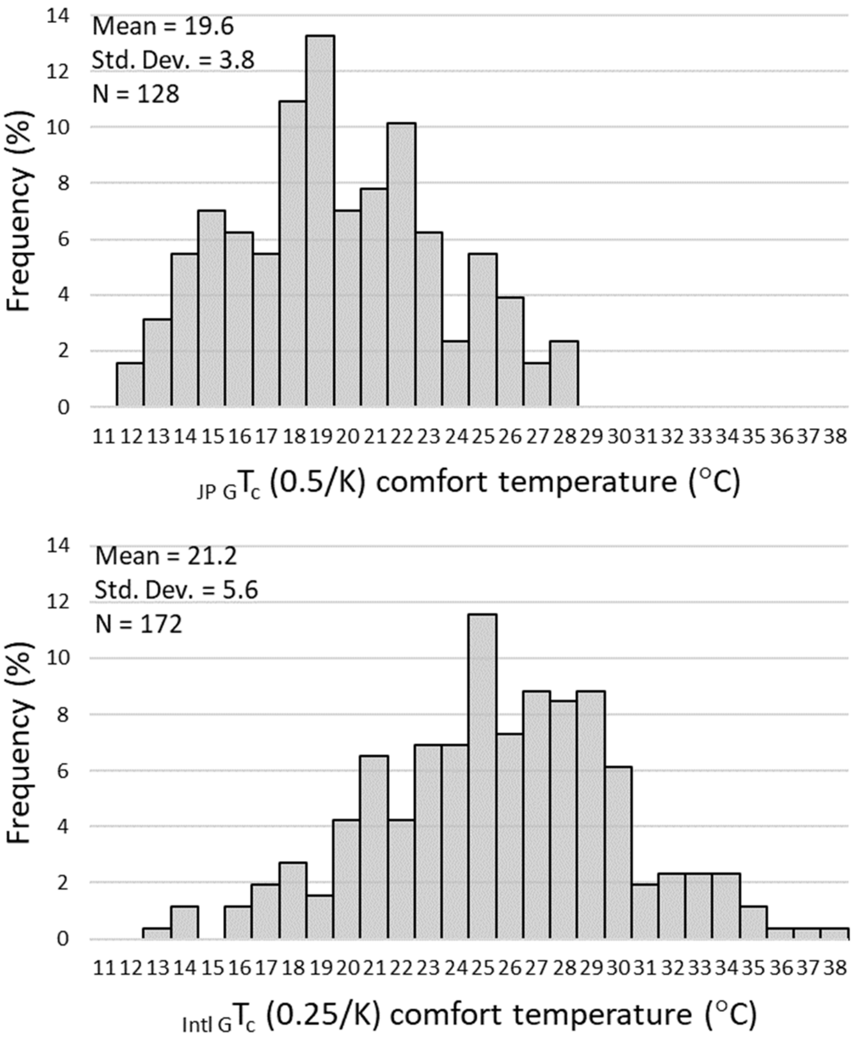


Figure 40 Griffiths comfort temperature. Frequency percentage distribution: a) Japanese calculated comfort temperature; b) International calculated comfort temperature

Eq. 20 Linear regression model ${}_{JP\ G}T_C$: T_i (winter)

$${}_{JP\ G}T_c = 0.610\ T_i + 8.0, (N = 128;\ p < 0.001;\ R^2 = 0.40;\ S.E.=2.97;\ F\ statistic = 82.9)$$

Eq. 21 Linear regression model ${}_{Intl\ G}T_C$: T_i (winter)

$${}_{Intl\ G}T_c = 0.418\ T_i + 12.8, (N = 172;\ p < 0.001;\ R2 = 0.14;\ S.E.=5.24;\ F\ statistic = 28.1)$$

Eq. 22 Linear regression model ${}_{JP\ G}T_C$: T_o (winter)

$${}_{JP\ G}T_c = -0.062\ T_o + 19.8, (N = 128;\ p > 0.05\ -\ fail;\ R^2 = 0.00;\ S.E.=3.81;\ F\ statistic = 0.4)$$

Eq. 23 Linear regression model ${}_{JP\ G}T_C$: T_{rm} (winter)

$${}_{JP\ G}T_c = 1.275\ T_{rm} + 14.3, (N = 128;\ p < 0.001;\ R^2 = 0.17;\ S.E.=3.48;\ F\ statistic = 26.2)$$

Eq. 24 Linear regression model ${}_{Intl\,G}T_C$: T_o (winter)

$${}_{Intl\,G}T_c = 0.013\ T_o + 21.2,\ (N = 172;\ p > 0.05 \text{ - fail};\ R^2 = 0.00;\ S.E.=5.66;\ F \text{ statistic} = 0.0)$$

Eq. 25 Linear regression model ${}_{Intl\,G}T_C$: T_{rm} (winter)

$${}_{Intl\,G}T_c = -0.650\ T_{rm} + 24.3,\ (N = 172;\ p < 0.05;\ R^2 = 0.03;\ S.E.=5.56;\ F \text{ statistic} = 5.86)$$

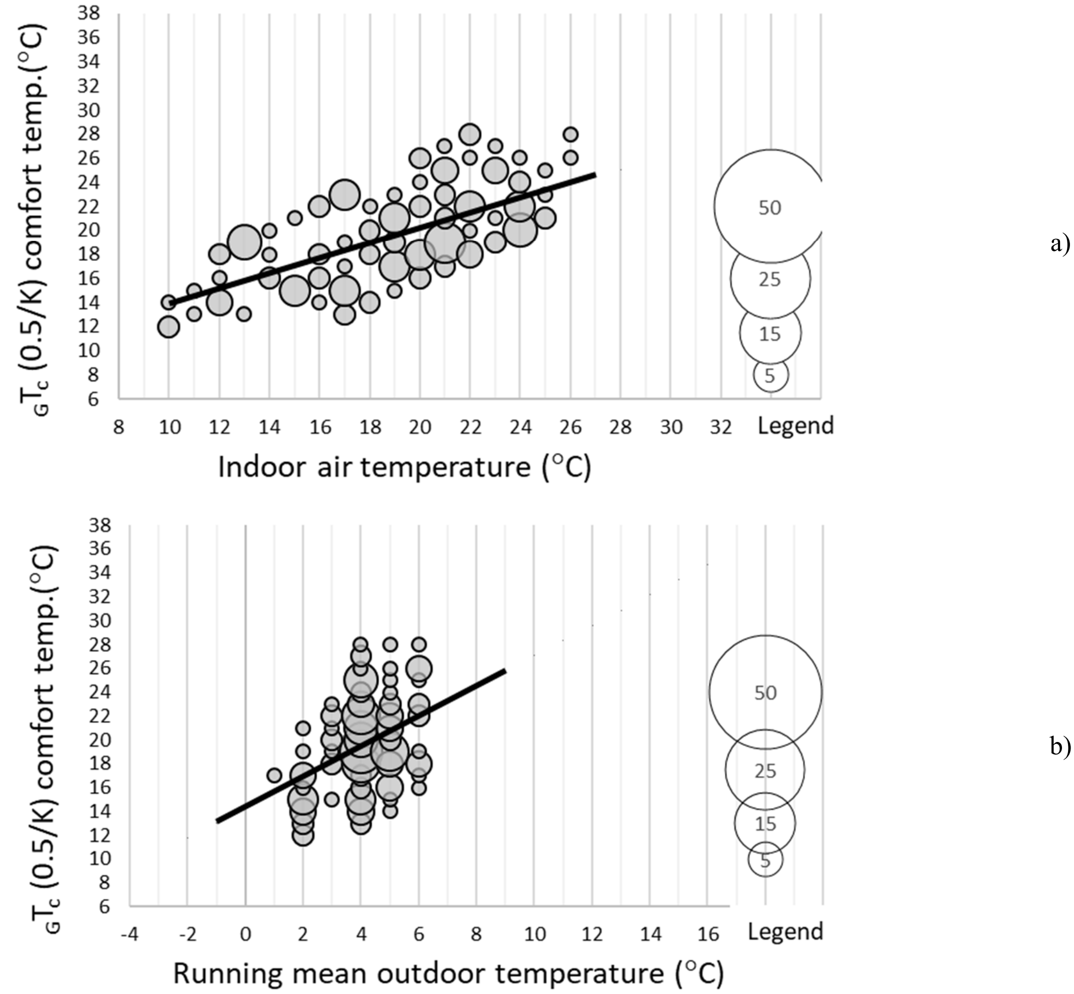


Figure 41 Griffiths comfort temperature at 0.5/K – Japanese data (winter) a) ${}_{JP\,G}T_c$: T_i; b) ${}_{JP\,G}T_c$: T_{rm}

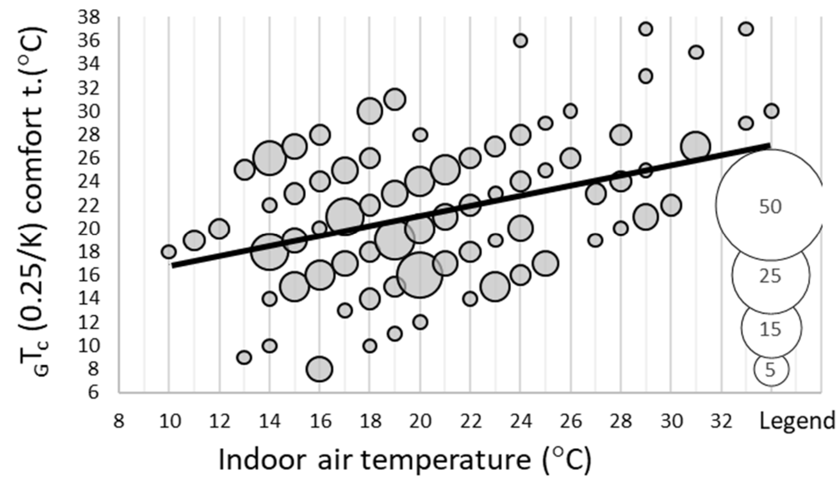


Figure 42 Griffiths comfort temperature at 0.25/K – International data (winter): ${}_{Intl\,G}T_c$: T_i

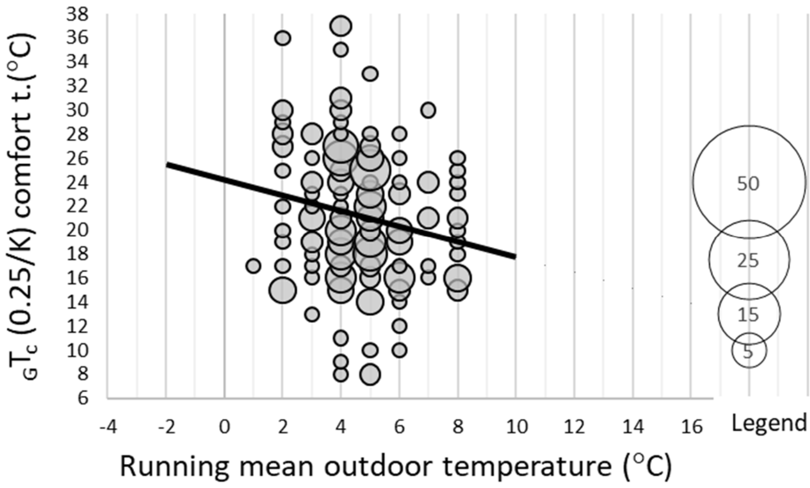


Figure 43 Griffiths comfort temperature at 0.25/K – International data (winter): $_{Intl\,G}T_c$: T_{rm}

2.5. Winter Results. Comparison with Related Standards

A number of international standards regulate the indoor environment [19]. They have established thermal comfort models to predict the indoor comfort temperature based on the mean/ running mean outdoor temperature. The comfort temperature derived for Japanese and international students was correlated to running mean outdoor air temperature as calculated in subsection 2.4.4 of the current chapter as well as to mean daily outdoor temperature. This calculation is needed in order to compare the results to EN 16978-1 [78] and ASHRAE [26] respectively.

The calculated comfort temperature in winter had no significant correlation to the outdoor daily mean temperature irrespective of nationality. However, the neutral and comfortable temperatures estimated in the current study fall within the range of 20-24 C as recommended for winter by ASHRAE [26].

Japanese and non-Japanese comfort temperature had significant correlation ($p < 0.001$ and $p<0.05$ respectively) to the outdoor daily running mean temperature. However, it was positive for the Japanese and negative for the non-Japanese data. In addition, the Japanese sensitivity to T_{rm} is almost two times higher than the non-Japanese sensitivity (Figure 41, Table 23). Comparing to EN 16978-1, it was observed that sizeable amount of data points are within the range of group III – "an acceptable, moderate level of expectation and may be used for existing buildings" [78] but, sizable amount is outside as well. For new buildings and renovations, level II should be targeted and while the regression lines mainly remain within these limits, a bulk of datapoints are above and below. Furthermore, the model from the current study demonstrated much higher sensitivity for both Japanese and non-Japanese subjects than the standard suggests and, for the non-Japanese the correlation is even reversed as compared to the standard.

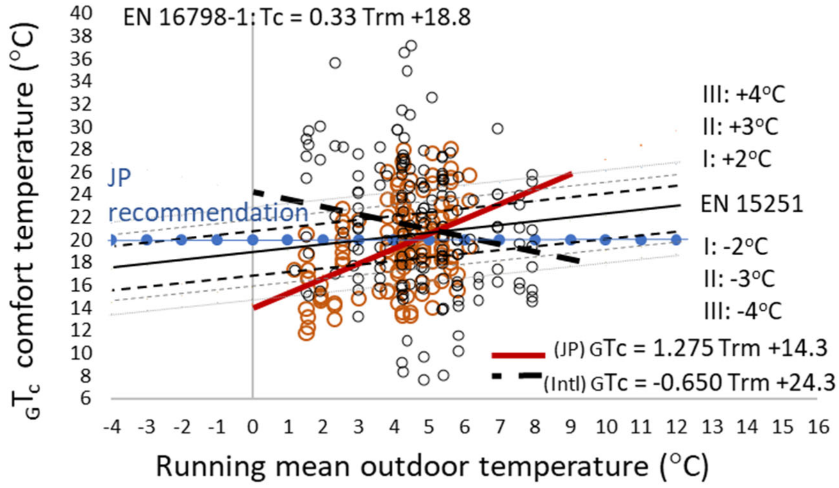


Figure 44 Comparison of calculated winter comfort temperature with the standard EN 16978-1

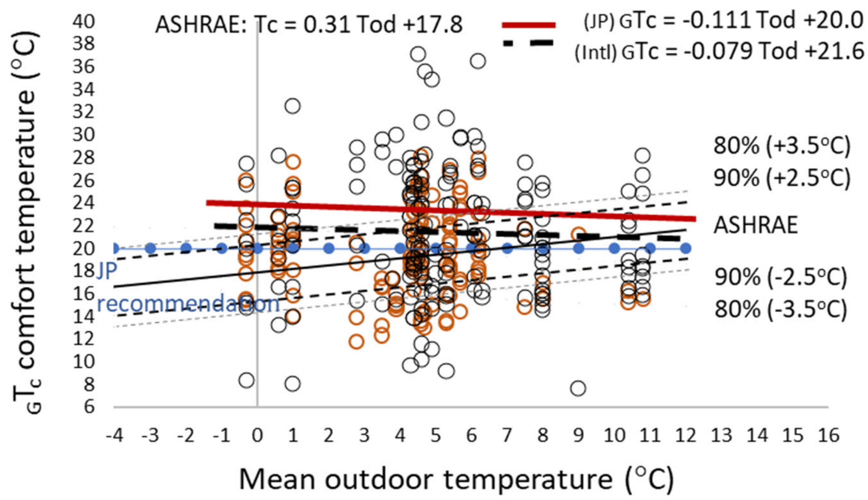


Figure 45 Comparison of calculated winter comfort temperature with the recommendation in ASHRAE

Table 23 Correlation coefficients

	All data points (N=300)					Japanese (N=128)					International (N=172)				
	r	*a*	β	R^2	p	r	*a*	β	R^2	p	r	*a*	β	R^2	p
$_{G}T_{C}$: T_{rm}	0.00	0.009	20.6	0.000	0.969	0.41	1.275	14.3	0.172	**<0.001**	-0.18	-0.650	24.3	0.033	**<0.05**
$_{G}T_{C}$: T_{od}	0.00	-0.002	20.6	0.000	0.987	-0.07	-0.111	20.0	0.005	0.448	-0.04	-0.079	21.6	0.002	0.609

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_{od}: Outdoor daily mean temperature (°C); T_{rm}: Outdoor daily running mean temperature (°C); $_{G}T_{C}$: Comfort temperature as calculated using the Griffiths' method (°C)

The winter energy conservation measures in Japan, issued by METI (Ministry of Economy, Trade and Industry) recommend indoor temperature in winter no higher than 20°C (blue dotted line in (Figure 44, Figure 45) in order to limit the energy consumption and thus address the issues of energy dependency of the country [79]. The same is the winter threshold suggested for residential buildings in EN 16978-1 too, however there it is the recommended minimum – temperature should be no less than 20ºC in winter [78]. The threshold line cuts through the middle of the dataset of comfort temperatures estimated by the current study and it makes it difficult to suggest which recommendation is more suitable for the targeted study group. In their field survey Indraganti et al. [44] already questioned the rational basis for the METI requirements.

2.6. Winter Results. Comparison with existing research

From the data collected during the winter stage of the current survey, it was observed that the thermal acceptability was over 85% irrespective of nationality. The winter comfort temperature for both Japanese and non-Japanese subjects was higher than 22ºC as derived from linear regression (see subsection 2.3) and, the Griffith's model estimated a comfort temperature of 20ºC for Japanese and 22ºC for non-Japanese students (see subsection 2.4.4). The comfort temperature for non-Japanese subjects is at a 2ºC wider range and at a 2ºC higher average than the comfort temperature for the Japanese subjects. As for the sensitivity to indoor changes – Japanese subjects were two times more sensitive and, for either Japanese or non-Japanese the comfort temperature increased with the increase of the indoor temperature. However, the changing outdoor conditions affected comfort temperature differently – for the Japanese the correlation was again positive, but for the non-Japanese it was reversed. With the increase of the running mean outdoor temperature, the indoor comfort temperature for Japanese students increased too but, decreased for the non-Japanese.

At the dawn of adaptive research, Humphreys [p.60 [20]] and Goromosov [80] attributed such a reverse relation to unpleasantly hot or cold conditions when people tend to use cooling or heating respectively. Applying that logic, it appears that in winter non-Japanese students in dormitories tend to use heating more. It was assumed at the beginning of the current study that the absence of economic restraint might reveal the genuine comfort temperature, however Humphreys assumes it might as well lead to the complete opposite results - to conceal it – "people might run buildings warmer or cooler than normal" if money is not an issue and "become adapted to different temperatures"[20]. There might be a liable possibility that the observed wider comfort temperature range in non-Japanese vote is because non-Japanese students feel less financially restrained as the period of dormitory stay is partially financially supported. On the other hand, it is possible that well-known Japanese thrifty mentality is affecting the results of the survey. In any case, subjective financial evaluation is a factor worth exploring further as in such young individuals it displays an attitude that will affect their energy consumption for a long period ahead.

Table 24 Comparison with existing research in winter

Area	Reference	Building type	Season	Temperature (variable) ºC	Temperature (ºC) in Mode			
					FR	CL	HT	ns
Japan (Tokai)	This study (2.4.2)	dormitory	winter	Neutral temp. (T_i)				$_{JP}$21; $_{Intl}$22
Japan (Tokai)	This study (2.4.4)	dormitory	winter	Comfort temp. (T_i)				$_{JP}$20; $_{Intl}$22
Japan (Chubu)	[51]	residential	4 seasons	Comfort temp. (T_i)	$_{JP}$22.7	$_{JP}$27.1	$_{JP}$18.9	
Japan (Kanto)	[52]	residential	4 seasons	Comfort temp. (T_i)	$_{JP}$24.1	$_{JP}$27.0	$_{JP}$20.2	
Japan (Kanto)	[47]	office	4 seasons	Neutral temp. (T_g)	$_{JP}$25.1	$_{JP}$25.0	$_{JP}$25.6	
Japan (Kanto)	[47]	office	4 seasons	Comfort temp. (T_g)	$_{JP}$25.0±1.7	$_{JP}$25.4±1.5	$_{JP}$24.3±1.6	
Japan (Kanto)	[48]	office	4 seasons	Neutral temp. (T_{op})				$_{JP}$24.8; $_{Intl}$22.7
Japan	[49]	office	4 seasons	Comfort t. (SET*)				$_{JP}$26
Japan (Fuku-shima)	[81]	temporary houses	winter, spring, sum-mer	Neutral temp. (T_i)		$_{JP}$22.8-24.8	$_{JP}$13-17	
China (Harbin)	[53]	dormitory	autumn, win-ter, spring	Neutral temp. (T_i)			$_{Intl}$20.9-22.6	
China (Beijing)	[54]	dormitory	winter	Neutral temp. (T_i)			$_{Intl}$23	

Note: T_g: Globe temperature (ºC); T_i: Indoor air temperature (ºC); SET*: Standard Effective Temperature (ºC); FR: Free-running mode – without the use of mechanical heating/ cooling; CL: Cooling mode – mechanical cooling was used; HT: Heating mode – mechanical cooling was used; ns: The heating/ cooling mode was not specified.

In the year-long study in Japanese offices, Rijal et al. [47] also observed high rate of thermal acceptability of the indoor environment, however the winter comfort temperature was 24.3 (4.3ºC higher than the recommended 20ºC by METI [79] and 2.3-4.3ºC higher than the current study). Nakano et al. [48] and Goto et al. [49] also observed high neutral and comfort temperatures in Japanese offices. The Japanese sensitivity in the survey of Rijal et al. [47] yielded from the day-wise datasets was lower than the sensitivity observed in the current study (0.45/K and 0.55/K respectively) probably because of the differences in the data division (HT mode vs. non-specified mode).

The results of the current study coincided with the results of Ning et al. [53] from their 3-season-long dormitory study that covered the entire winter heating period in Harbin, China. They also observed neutral temperatures within 21-23ºC range as well as clothing adjustment as the main adaptive behavior. However, in the temporary houses in Fukushima, North Japan investigated by Shinohara et al. [81], Japanese neutral thermal sensation in winter was at notably lower temperatures (13-17ºC). This shift from higher observed values, through equal ones and eventually lower, may be attributed to the economic and psychological factors. As for the office environment in Kanto, the subjects are not the direct responsible party for the consumption payments, in Harbin they are, and in Fukushima after the earthquake the occupants must have been under major financial stress and trying to limit their expenses to their minimum.

3. Conclusions for Winter Neutrality and Comfort

A field survey about environmental comfort in typical university dormitory buildings in Japan was conducted during the winter of 2017-2018. The aim of the study was 1) to snapshot the subjective thermal comfort of the Japanese and non-Japanese students relative to temperature, humidity and other factors, 2) to understand the difference, if any, between the temperature defined as neutral or comfortable and 3) to get an insight how tolerant are the students to their indoor environment.

Subjective votes were collected using traditional paper questionnaire. Simultaneously, measurements of physical parameters of the indoor and outdoor environment were conducted and the two data-sets were linked. The correlation of the subjective neutrality and comfort were investigated in relation to nationality; as well as the effect of thermal sensation to occupants' preference and tolerance to their indoor environment.

The study revealed that the voted subjective neutrality is strongly disconnected from the outdoor climate for both observed groups. There still could be observed a mild downward trend in the averaged TSV and TC at outdoor temperatures below zero, reversing upward again at about 4-5ºC outdoors. In the lowest area, bigger percentage of non-Japanese students were using air conditioning for heating.

For both Japanese and non-Japanese students, thermal responses were strongly correlated to one another, where feeling warmer resulted in increase of subjective comfort, and decrease in the desire to warm up the indoor environment. Voted thermal acceptability was invariably above 85%.

During winter, the recorder indoor humidity was very low, however it did not affect the thermal sensation vote. For both Japanese and non-Japanese students, thermal sensation was significantly determined only by the indoor temperature. The effects of clothing and activity were also negligible.

The neutral indoor temperature could be estimated as 21ºC for Japanese students and as 22ºC for non-Japanese (by linear regression analysis). However, the highest probability of voting neutral for Japanese students was only 65% and it was estimated within 19~22ºC indoor temperature. For non-Japanese students it's 75% within 19~24ºC indoors.

Japanese students were notably more sensitive to their indoor environment as compared to non-Japanese ones (sensitivity of 0.55/ K and 0.20/ K respectively) and, the comfort temperature for Japanese subjects could be estimated as 20ºC and as 22ºC for non-Japanese. The calculated indoor comfort for both groups was correlated to the changing outdoor climate (T_{rm}) that could have been reassuring about estimating indoor comfort based on outdoor climate. However, there was significant difference in the comfort we calculated and, the comfort voted by the participating subjects.

For both Japanese and non-Japanese students, the yielded predicting models from the survey deviated from the models in the current international standards. In addition, the voted and the estimated neutrality and comfort in the study were mostly above the recommended maximum winter indoor temperature in Japan. As the recommendation is set considering the energy conservation, it is reasonable to further investigate how to make it possible to lower down the subjective neutral and comfort temperatures without compromising personal comfort.

CHAPTER IV

Effect of Air Conditioning on Comfort in Summer/ Winter

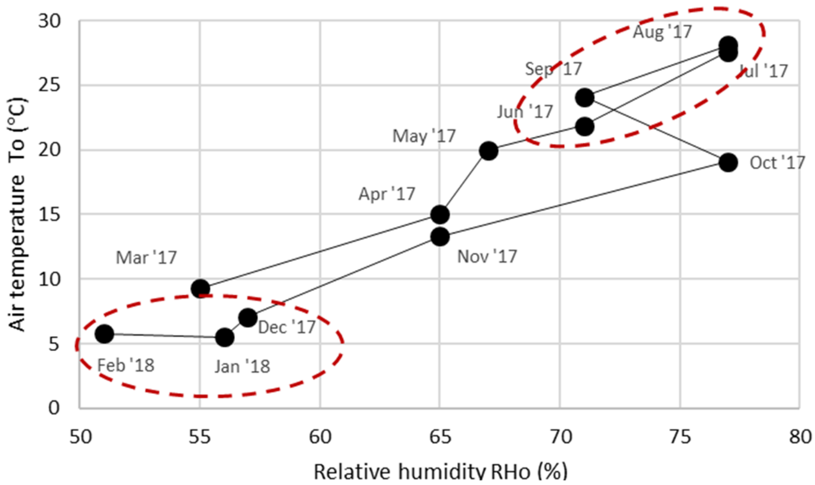
Together, the collected data from both stages of the survey covered the two opposing climatic conditions that dormitory students experience in Japan – the cold dry winter and the hot humid summer. Investigating about the effect of air conditioning in these two periods of the year aimed to 1) to discover when the subjective thermal comfort was achieved relative to the season and the use of air conditioning and, 2) to understand the magnitude of the difference, if any, between the temperature defined as neutral or comfortable and) to get an insight of students' tolerance their indoor environment.

1. Methodology

1.1. Location and Climate

During summer, the mean monthly outside temperature in Toyohashi reached its maximum in August ($T_{avg.}$= 28.1°C; $T_{min.}$= 25.0°C; $T_{max.}$= 32.2°C) and the relative humidity outdoors was above 70-75%. In winter, the mean monthly outside temperature reached its minimum in January ($T_{avg.}$= 5.5°C; $T_{min.}$= 1.7°C; $T_{max.}$= 9.7°C) and the mean relative humidity was around 50-55%.

a)



b)

Figure 46 Toyohashi. Japan. a) Location; b) Climate. **Data from JMA WMO ID: 47654 – min, max and mean air temperature and relative humidity for summer/winter season 2017 - 2018

1.2. Measuring Period

The summer stage of the field survey was conducted from June 26 to September 29, 2017 and the winter stage was from December 5, 2017 to February 2, 2018. We targeted the periods with highest and lowest temperature-relative humidity combination (Figure 46). The survey was conducted in three weeks in summer and three weeks in winter. The weeks 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 (sub-section 1.4).

1.3. Dormitory Buildings. Sample Selection. Field Survey

The information about dormitory buildings, the sample selection and the settings of the survey in summer and winter stages are described in Chapter II (on page 18) and Chapter III (on page 52) respectively. The analysis of the collected data followed the previously established sequence. The number of valid votes from summer stage were 420 and, from winter stage – 300. (Table 25).

Table 25 Description of the survey in summer and winter stage.

Survey	Measured variables	Number of rooms	Number of subjects			Number of valid votes
			Male	Female	Total	
Summer	T_i, RH_i	18	12	6	18	420
Winter	T_i, RH_i	19	14	5	19	300
Total	–	37	26	11	37	720

2. Results and Discussion

2.1. Participants

In the summer and winter stage combined, a total number of 37 healthy, Japanese and International students from 19 to 31 years of age volunteered to participate (males: Median = 24, SD = 4; females: Median = 21, SD = 1). The participants' body mass index (BMI) was in the normal zone (Median = 22.5, SD = 2.8). The distribution of votes relative to sex, age, BMI, nationality and race is presented in Figure 47.

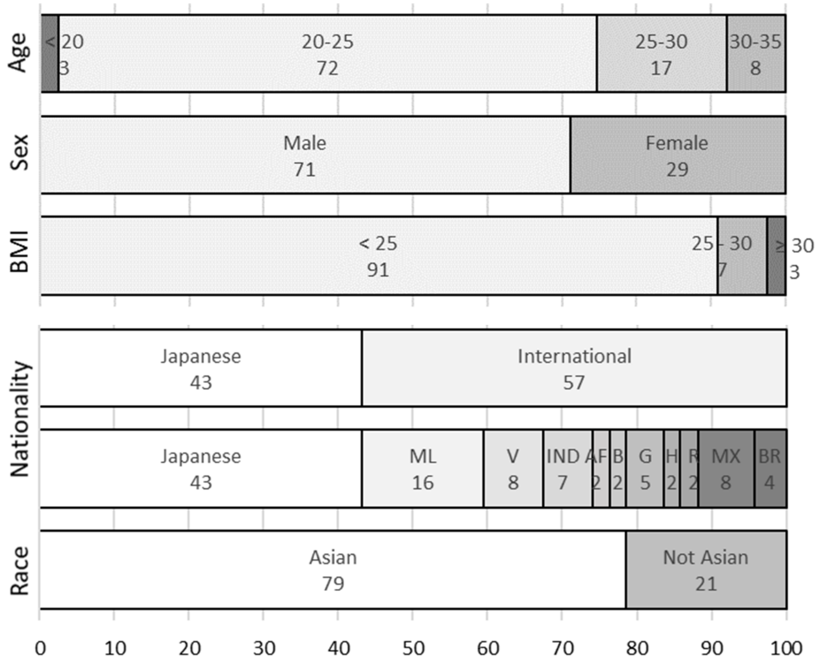


Figure 47 Percentage distribution (in %) of the votes relative to age, sex, BMI, nationality and race. Where: ML (Malaysian); V (Vietnamese); IND (Indonesian); AF (Afghani); B (Bangladeshi); G (German); H (Hungarian); R (Russian); MX (Mexican); BR (Brazilian). NOTE: Population sample: N=720 valid votes

2.2. Indoor and Outdoor Environment During the Voting

In summer indoor temperature varied less than the outdoor temperature and on average indoors was ~27ºC irrespective of the use of air conditioning (Table 26). In winter, it was the opposite – indoor temperature varied more than the outdoors, especially at heating mode. On average in winter, indoors was 17ºC in FR mode and 22ºC in HT mode. Relative humidity in summer was high with an average of 68% and 72% in CL and FR mode respectively (Figure 48 and Appendix F). The winter values were about 20% lower at 42% and 53% in HT and FR mode respectively. Activity indoors appears the same in all seasons and modes, while the average clothing doubled in winter season (0.32-0.33clo in summer to 0.61-0.65clo in winter). In summer and winter, T_n was significantly correlated to the outdoor temperature irrespective of what representation of outdoor temperature is used (T_o, T_{od} or T_{rm}) (Figure 49, Table 27). When analyzing the combined summer and winter data, this correlation was even stronger.

Table 26 Descriptive statistics of the collected data at times of vote

		All data points				**FR mode**				**CL / HT mode**			
		min	**max**	**mean**	**StD**	**min**	**max**	**mean**	**StD**	**min**	**max**	**mean**	**StD**
Summer and Winter Stage (Nall=720; NFR=410; NCL/HT=310)	Ti	9.8	33.7	23.9	5.0	9.8	31.6	24.0	5.5	13.2	33.7	23.9	4.2
	To	-2.9	37.9	17.3	11.6	-1.9	37.9	19.3	10.8	-2.9	36.9	14.6	12.1
	Tod	-0.3	30.1	17.0	10.7	-0.3	30.1	18.8	9.8	-0.3	30.1	14.7	11.4
	Trm	1.2	22.3	13.7	8.0	1.5	22.3	14.9	7.5	1.2	22.3	12.1	8.3
	RHi	21	98	61	16	26	98	66	13	21	81	54	17
	RHo	25	100	74	17	32	100	74	17	25	100	74	18
	AHi	0.003	0.022	0.012	0.005	0.003	0.022	0.013	0.005	0.004	0.020	0.011	0.005
	AHo	0.001	0.023	0.016	0.007	0.002	0.023	0.013	0.007	0.001	0.023	0.010	0.008
	Icl	0.19	2.11	0.45	0.22	0.19	2.11	0.43	0.22	0.19	1.39	0.48	0.21
	M	1.0	2.7	1.3	0.4	1.0	2.7	1.3	0.4	1.0	2.7	1.3	0.4
	BMI	19.3	33.6	22.2	2.7	19.3	33.6	22.1	2.2	19.3	33.6	22.3	3.2
Summer Stage (Nall=420; NFR=275; NCL=145)	Ti	18.6	31.6	27.0	2.0	19.8	31.6	27.3	1.9	18.6	30.2	26.5	2.2
	To	18.3	37.9	26.7	3.6	18.3	37.9	26.4	3.7	19.6	36.9	26.9	3.4
	Tod	20.7	30.1	25.8	2.4	20.7	30.1	25.5	2.4	22.1	30.1	26.6	2.3
	Trm	17.6	22.3	25.8	2.4	17.6	22.3	20.0	1.8	17.7	22.3	20.8	1.6
	RHi	40	89	71	8	41	89	72	8	40	81	68	8
	RHo	36	100	80	15	36	100	79	15	45	100	81	13
	AHi	0.007	0.022	0.016	0.003	0.008	0.022	0.017	0.002	0.007	0.020	0.015	0.003
	AHo	0.007	0.023	0.017	0.002	0.007	0.023	0.017	0.003	0.012	0.023	0.018	0.002
	Icl	0.19	0.64	0.33	0.07	0.19	0.57	0.32	0.08	0.19	0.64	0.33	0.06
	M	1.0	2.7	1.3	0.4	1.0	2.7	1.3	0.4	1.0	2.7	1.3	0.4
	BMI	19.3	33.6	22.4	3.2	19.3	33.6	22.3	2.5	19.3	33.6	22.7	4.1
Winter Stage (Nall=300; NFR=135; NHT=165)	Ti	9.8	33.7	19.6	4.7	9.8	26.8	17.2	3.9	13.2	33.7	21.6	4.3
	To	-2.9	14.8	4.2	3.7	-1.9	14.8	4.8	3.5	-2.9	14.7	3.7	3.8
	Tod	-0.3	10.8	4.7	2.6	-0.3	10.8	5.3	2.5	-0.3	10.8	4.3	2.7
	Trm	1.2	7.9	4.4	1.5	1.5	7.9	4.4	1.5	1.2	7.9	4.5	1.5
	RHi	21	98	47	14	26	98	53	13	21	78	42	12
	RHo	25	100	66	18	32	100	66	17	25	100	67	18
	AHi	0.003	0.011	0.007	0.002	0.003	0.011	0.007	0.002	0.004	0.011	0.007	0.001
	AHo	0.001	0.009	0.003	0.001	0.002	0.009	0.004	0.001	0.001	0.009	0.003	0.001
	Icl	0.36	2.11	0.63	0.23	0.36	2.11	0.65	0.26	0.36	1.39	0.61	0.21
	M	1.0	2.7	1.3	0.4	1.0	2.7	1.4	0.5	1.0	2.7	1.3	0.4
	BMI	19.4	27.8	21.9	1.7	19.4	24.7	21.8	1.5	19.4	27.8	21.9	1.9

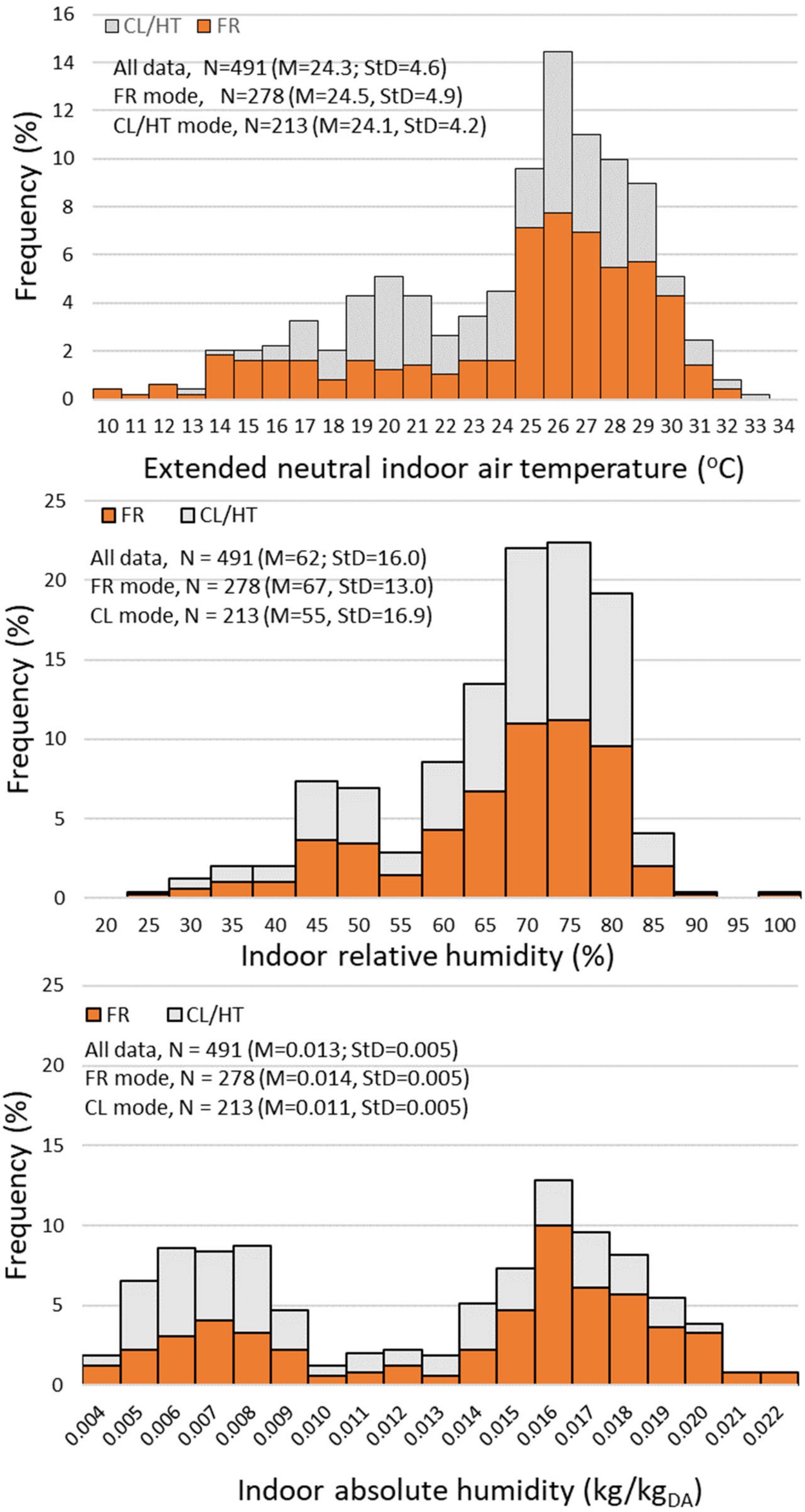
NOTE: FR mode: Free running mode – without air conditioning; CL mode: Cooling mode – air conditioning for cooling; HT mode: Heating mode – air conditioning for heating; Ti: Indoor temperature (ºC); T_o: Outdoor daily mean temperature (ºC); T_{od}: Outdoor daily mean temperature (ºC); T_{rm}: Outdoor daily running mean temperature (ºC); 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 1 clo = 0.155 m^2K/W; M: activity level (met) where 1 met = 58.2 W/m^2; BMI: Body mass index (kg/m^2). ** The observed values of air velocity were outside of the measurement range, that is why they were all set to 0.1m/s

Table 27 Correlation coefficients

		All data points					FR mode					CL / HT mode				
		r	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**
Both seasons	T_n: T_{out}	0.73	0.298	19.0	0.528	<.001	0.87	0.430	15.8	0.762	<.001	0.59	0.204	21.1	0.348	<.001
	T_n: T_{od}	0.73	0.324	18.6	0.540	<.001	0.88	0.470	15.2	0.773	<.001	0.60	0.223	20.8	0.365	<.001
	T_n: T_{rm}	0.75	0.443	18.1	0.568	<.001	0.88	0.606	15.1	0.783	<.001	0.61	0.310	20.3	0.380	<.001
	RH_n: RH_o	0.40	0.387	32.8	0.160	<.001	0.45	0.359	39.9	0.199	<.001	0.40	0.401	25.2	0.162	<.001
	AH_n: AH_o	0.91	0.660	0.005	0.824	<.001	0.92	0.718	0.004	0.853	<.001	090	0.575	0.005	0.805	<.001
Summer	T_n: T_{out}	0.54	0.303	19.0	0.294	<.001	0.62	0.356	17.8	0.388	<.001	0.40	0.213	21.0	0.160	<.001
	T_n: T_{od}	0.59	0.460	15.1	0.353	<.001	0.70	0.563	12.9	0.496	<.001	0.46	0.351	17.4	0.209	<.001
	T_n: T_{rm}	0.63	0.656	13.7	0.394	<.001	0.71	0.764	11.9	0.508	<.001	0.55	0.576	14.8	0.304	<.001
	RH_n: RH_o	0.34	0.195	55.4	0.113	<.001	0.50	0.271	50.7	0.250	<.001	0.04	0.027	66.8	0.002	0.681
	AH_n: AH_o	0.36	0.378	0.010	0.131	<.001	0.60	0.588	0.007	0.363	<.001	0.00	-0.001	0.016	0.000	0.994
Winter	T_n: T_{out}	-0.04	-0.040	20.3	0.001	0.619	0.24	0.230	16.6	0.058	<0.05	-0.08	-0.081	22.0	0.006	0.428
	T_n: T_{od}	-0.07	-0.106	20.6	0.005	0.351	0.16	0.226	16.6	0.027	0.150	-0.06	-0.097	22.1	0.004	0.501
	T_n: T_{rm}	0.07	0.189	19.2	0.004	0.370	0.24	0.566	15.4	0.056	<0.05	-0.05	-0.141	22.3	0.003	0.598
	RH_n: RH_o	0.13	0.106	40.1	0.016	0.082	0.05	0.046	51.0	0.003	0.441	0.26	0.175	30.5	0.066	<0.05
	AH_n: AH_o	0.51	0.562	0.005	0.261	<.001	0.50	0.618	0.005	0.254	<.001	0.52	0.527	0.005	0.270	<.001

NOTE: FR mode: Free running mode – when air conditioning was not used; CL mode: Cooling mode – air conditioning was used for cooling; HT mode: Heating mode – air conditioning was used for heating; 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_n: Neutral indoor temperature (ºC); T_{out}: Outdoor temperature (ºC); T_{od}: Outdoor daily mean temperature (ºC); T_{rm}: Outdoor daily running mean temperature (ºC); RH_n: Neutral indoor relative humidity (%); RH_o: Outdoor relative humidity (%); AH_n: Neutral indoor absolute humidity (kg/kg_{DA}); AH_o: Outdoor absolute humidity (kg/kg_{DA}) ** N: Number of observations at TSV (-1,0,+1); Summer and Winter Stage (${}_nN_{all}$=491; ${}_nN_{FR}$=278; ${}_nN_{CL/HT}$=213) – for separated graphs – see Appendix F; Summer Stage (${}_nN_{all}$=302; ${}_nN_{FR}$=200; ${}_nN_{CL}$=102); Winter Stage (${}_nN_{all}$=189; ${}_nN_{FR}$=78; ${}_nN_{HT}$=111)

Adaptive model assumes that when no mechanical means are used, indoor environment is strongly related to the outdoors. In that respect, invariably, we observed that the correlation between indoor and outdoor temperature at FR mode was stronger as compared to the correlation when mechanical cooling/heating was used. As result from the dehumidifying function of the air conditioners installed in the surveyed rooms, when air conditioning was used for cooling in summer, there was no correlation between indoor and outdoor relative or absolute humidity. In winter however, indoor absolute humidity remained significantly correlated to outdoors irrespective of the operation mode. Regretfully, the measured air speed was very low suggesting still air (Section 1.4) and it became impossible to investigate the effect of air speed on the neutral temperature. It is not uncommon to observe still air. Other researchers also reported still air indoors (the case of Qatar offices investigated by Indraganti and Bousaa [45]).

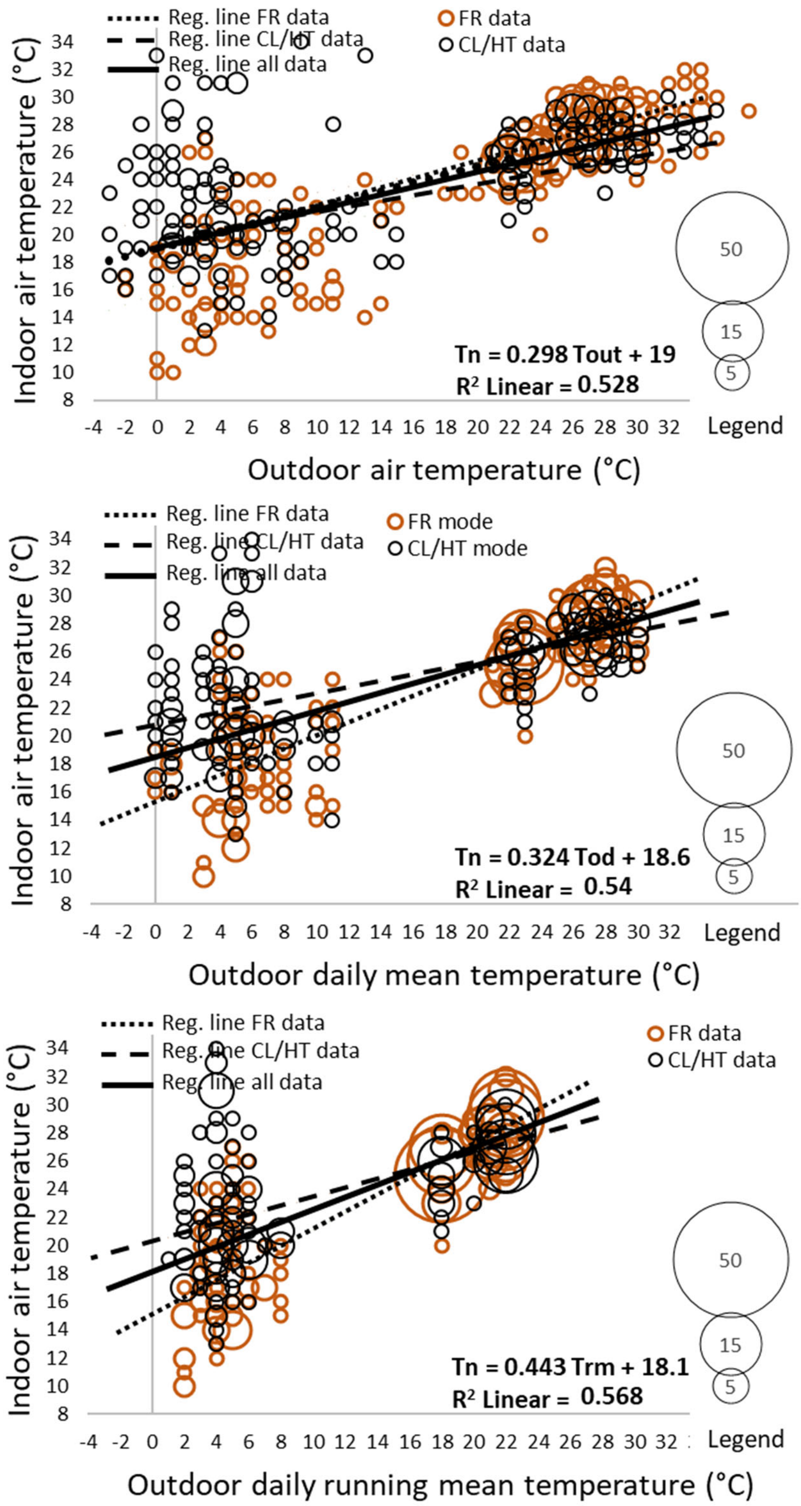


a)

b)

c)

Figure 48 Frequency percentage distribution of indoor parameters in summer and winter at TSV (-1, 0, +1): a) T_i; b) RH_i; c) AH_i

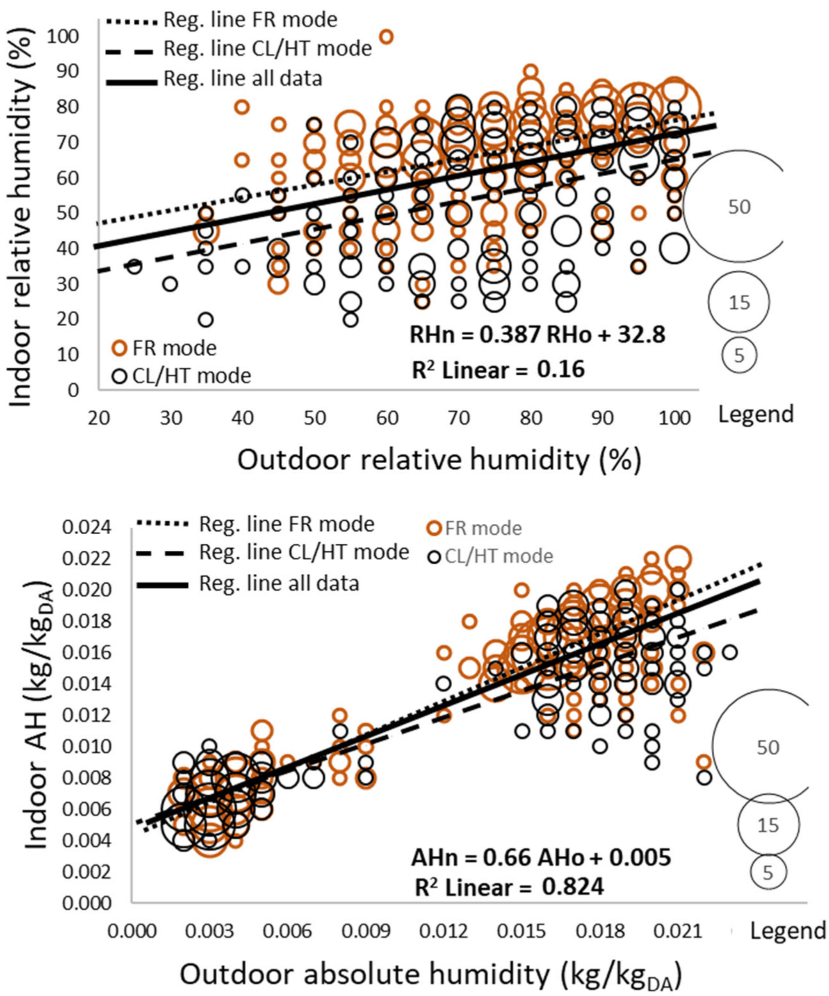


a)

b)

c)

Figure 49 Correlation between indoor air temperature at TSV (-1, 0, +1) and outdoor temperature: a) T_n: T_o; b) T_n: T_{od}; c) T_n: T_{rm}



a)

b)

Figure 50 Correlation between indoor humidity at TSV (-1, 0, +1) and outdoor humidity: a) RH_n: RH_o; b) AH_n: AH_o

2.3. Thermal Sensation, Comfort, Preference and Acceptability

Summer and winter percentage distribution of thermal responses was surprisingly similar. Irrespective of the season, about 60% of the TSV votes were within the extended neutral area of the scale; more than 70% of TC votes were "comfortable"; almost half of the preference votes stated "no need to change" the environment and, acceptability level was invariably high at 90% and above. The most noticeable differences were at the opposite ends of the scales. For instance, on the TSV scale there were no votes at point 3 (hot) in winter and, only 1% of the votes were at point -3 (cold) in summer while in winter this percentage "cold" is 13%. The "preference" responses in summer were almost equally split between "prefer no change" and "prefer cooler", while in winter, identical division was between "prefer no change" and "prefer warmer". (Table 28)

When dividing the data into with or without the use of air conditioning, it can be observed that in summer the extended neutral TSV is above 70% in both cases (70% in AC and 73% in no AC); the percentage of votes on the "comfortable" scale are about 10% more in AC than in no AC (81%

and 73% respectively); the votes "prefer no change" in AC are almost 60% as compared to 45% in no AC; however, the acceptability rate is invariably high (more than 90% in both cases).

Table 28 Percentage of thermal responses for each scale in summer and winter

Scale	Thermal sensation (TSV) %				Thermal comfort (TC) %				Thermal preference (TP) %				Thermal acceptability (TA)%			
		All	**S**	**W**		**All**	**S**	**W**		**All**	**S**	**W**		**All**	**S**	**W**
3	Hot	4	7		Very comf.	3	3	3								
2	Warm	14	13	15	Comfortable	40	40	40								
1	Sl. warm	25	27	21	Slightly comf.	30	33	26	Warmer	23	6	48	Unaccept.	7	5	10
0	Neutral	23	26	20					As it is	50	49	50	Acceptable	93	95	90
-1	Slightly cool	20	19	22	Slightly uncomf.	19	18	22	Cooler	27	45	2				
-2	Cool	8	7	10	Uncomfortable	7	6	8								
-3	Cold	6	1	13	Very uncomf.	1	0	1								

		S and W			**S and W**			**S and W**			**S and W**	
		AC	**no AC**		**AC**	**no AC**		**AC**	**no AC**		**AC**	**no AC**
3	Hot	2	6	Very comf.	4	2						
2	Warm	15	13	Comfortable	52	31						
1	Sl. warm	27	23	Slightly comf.	24	35	Warmer	23	23	Unaccept.	6	8
0	Neutral	20	26				As it is	59	42	Acceptable	94	92
-1	Slightly cool	22	19	Slightly uncomf.	16	22	Cooler	18	34			
-2	Cool	10	6	Uncomfortable	4	9						
-3	Cold	5	7	Very uncomf.	0	1						

		Summer			**Summer**			**Summer**			**Summer**	
		AC	**no AC**		**AC**	**no AC**		**AC**	**no AC**		**AC**	**no AC**
3	Hot	3	9	Very comf.	6	1						
2	Warm	8	15	Comfortable	50	34						
1	Sl. warm	22	30	Slightly comf.	25	38	Warmer	6	6	Unaccepta-	3	6
0	Neutral	21	28				As it is	58	45	ble	97	94
-1	Slightly cool	27	15	Slightly uncomf.	16	19	Cooler	37	49	Acceptable		
-2	Cool	14	3	Uncomfortable	3	8						
-3	Cold	3		Very uncomf.	1	0						

		Winter			**Winter**			**Winter**			**Winter**	
		AC	**no AC**		**AC**	**no AC**		**AC**	**no AC**		**AC**	**no AC**
3	Hot			Very comf.	2	4						
2	Warm	20	8	Comfortable	53	24						
1	Sl. warm	31	9	Slightly comf.	22	30	Warmer	38	59	Unaccepta-	8	13
0	Neutral	18	22				As it is	61	38	ble	92	87
-1	Slightly cool	18	27	Slightly uncomf.	16	29	Cooler	1	3	Acceptable		
-2	Cool	7	13	Uncomfortable	5	10						
-3	Cold	6	21	Very uncomf.		3						

Note: Number of votes: ${}_{all}N=720$, ${}_{S}N=420$; ${}_{W}N=300$; ${}_{all}N_{AC}=310$; ${}_{all}N_{noAC}=410$; ${}_{S}N_{AC}=145$; ${}_{S}N_{noAC}=275$; ${}_{W}N_{AC}=165$; ${}_{A}N_{noAC}=135$)
**"AC": Air conditioning used for heating or cooling; "no AC": without use of air conditioning

In winter, the extended neutral TSV is lower than in summer (67% in AC and 58% in no AC) and, the votes on the cold side of the scale noticeably increased; the percentage of votes on the "uncomfortable" side of the scale have increased and, the ones on the "comfortable" side are this time about 20% more in AC than in no AC (77% and 58% respectively); the votes "prefer no change" in AC have increased to above 60% as compared to the decreased counterpart in no AC (38%); the acceptability rate in winter dropped but is still very high (92% in AC and 87% in no AC).

The outdoor temperature measurements for both seasons were grouped in 1ºC bins. The percentage of votes when using air conditioning (AC) and without the use of air conditioning (no AC) were graphed and overlaid onto thermal responses. It is noticeable that bigger percentage of air conditioning use is during winter at temperatures below and around zero. The distribution of subjective thermal responses in both seasons are in Figure 51. The distribution of subjective thermal responses each season separately and separated by using or not using air conditioning are presented in the appendices (from Appendix G to Appendix O).

Correlating the mean values of the thermal sensation votes weighed by their number and, within each bin of the outdoor temperature showed there was significant linear correlation predominantly in summer (Table 29). However, strong polynomial correlation of second order could be observed for the subjective sensation and evaluation votes when analyzing summer and winter data together (Figure 52 and Figure 53). Whenever significant, the correlation is linear for the preference and acceptability (Figure 54, Figure 55 and Appendix P). In summer, all subjective responses and in all modes of operation were significantly correlated to the outdoor temperature, while in winter this was true only when not using air conditioning (Table 29). Thermal sensation was almost linearly related to outdoor temperature when not using air conditioning in both seasons – that is when outside temperature increased the sensation vote changed towards the warm side of the scale (Figure 52). When using air conditioning, the non-linearity of the correlation became more prominent – in winter, at outdoor temperatures below and around zero, the subjective sensation gradually dropped to the colder side of the scale. At outdoor temperatures around 20ºC and above, the subjective sensation trend reversed to an upward one. The non-linearity in the correlation between subjective evaluation (comfort vote) and the outdoor temperature is again very prominent. However, the curve is reversed as compared to thermal sensation (Figure 53). Below and around zero outdoor temperatures, the subjective comfort improved with the increase of the temperature, but at outdoor temperatures above 20ºC with the rise of the temperatures, the comfort feeling deteriorated. The preference vote has practically linear negative correlation to outdoor temperature – with the increase of the temperatures outdoors, people started to vote “prefer cooler” indoor environment. Even though the calculations proved the acceptability was significantly correlated to the outdoor temperature, the correlation remained weak in all seasons and operation modes. We observe almost horizontal line at zero (“acceptable” vote) irrespective of the change in the outdoor temperature (Figure 55).

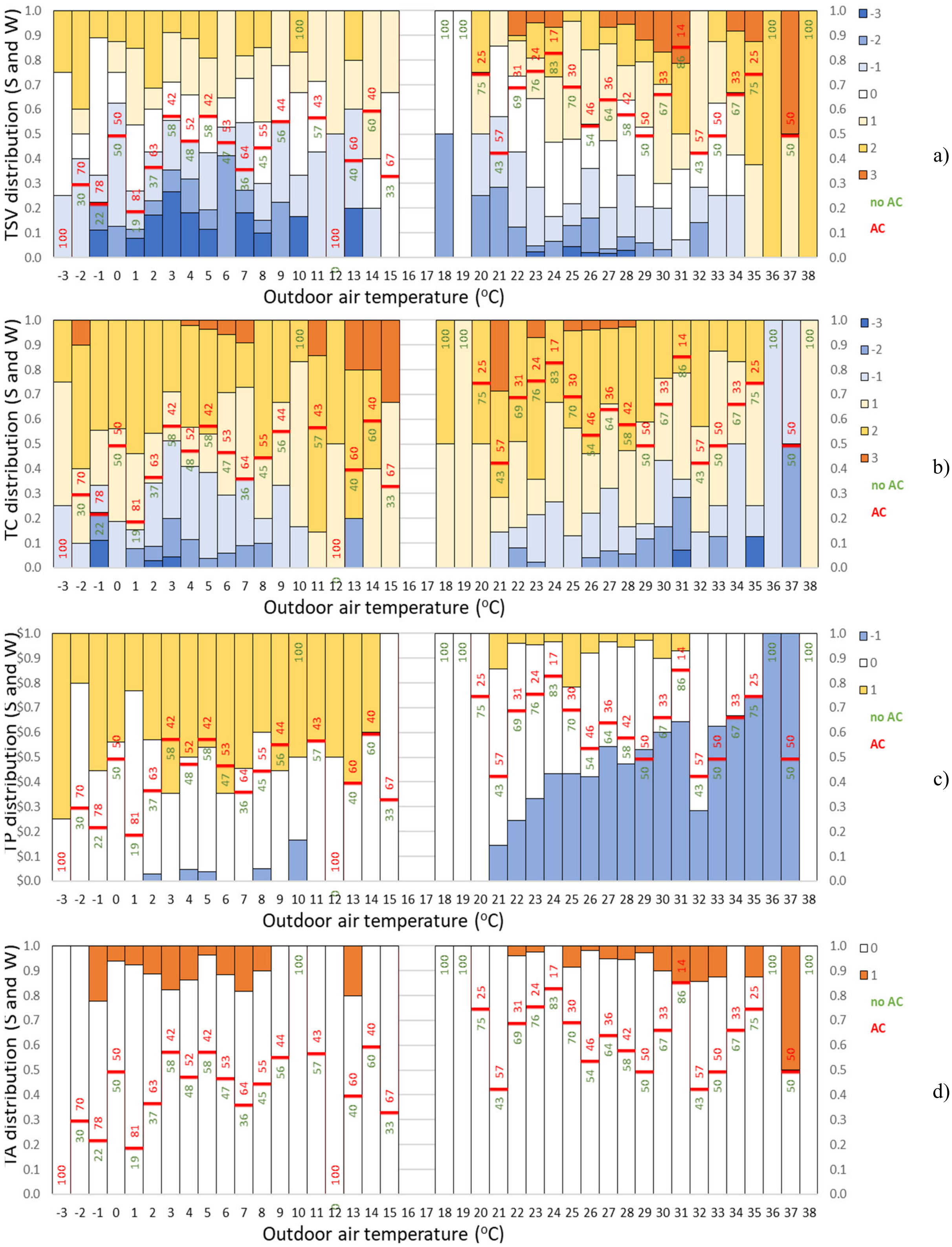


Figure 51 Frequency distributions of thermal responses in summer and winter relative to outdoor temperature; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) TA:T_{out}; NOTE: The percentage of AC: no-AC was added in each 1°C temperature bin. Percentage of no-AC (without the use of air conditioning) is presented in green; Percentage of AC (air conditioning used for heating or cooling) is presented in red. All numerical values of the graph are in Appendix Table O-1 in the appendices.

Table 29 Correlation between weighted mean thermal responses and outdoor temperature

Relation to T_{out}		All data points				Using air conditioning				Not using air conditioning			
		TSV_{all}	TC_{all}	TP_{all}	TA_{all}	TSV_{AC}	TC_{AC}	TP_{AC}	TA_{AC}	TSV_{noAC}	TC_{noAC}	TP_{noAC}	TA_{noAC}
Summer and winter	r	0.71	0.08	-0.95	-0.36	-0.35	0.02	-0.85	-0.25	0.91	0.29	-0.96	-0.29
	p correl.	**<0.001**	0.044	**<0.001**	**<0.001**	**<0.001**	0.710	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	linear R^2	0.502	0.006	**0.893**	0.127	0.121	0.000	0.722	0.060	0.826	0.086	0.921	0.083
	polynom. R^2	**0.707**	**0.406**	**0.812**	0.123	0.408	0.313	0.751	0.009	0.749	0.304	0.809	0.191
Summer	r	0.73	-0.70	-0.84	0.53	**0.86**	**-0.90**	**-0.82**	0.35	**0.74**	**-0.62**	**-0.82**	0.34
	p correl.	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	linear R^2	0.534	0.490	0.704	0.279	**0.740**	**0.810**	**0.675**	0.120	**0.552**	**0.384**	**0.671**	0.116
	polynom. R^2	0.744	0.504	0.562	0.223	**0.859**	**0.927**	**0.845**	0.128	**0.627**	**0.432**	**0.590**	0.180
Winter	r	-0.02	0.30	0.03	-0.20	-0.36	-0.01	0.13	0.13	0.56	0.59	-0.33	-0.36
	p correl.	0.778	**<0.001**	0.587	**<0.05**	**<0.001**	0.862	0.101	0.085	**<0.001**	**<0.001**	**<0.05**	**<0.001**
	linear R^2	0.000	0.093	0.001	0.039	0.131	0.000	0.017	0.018	0.312	0.348	0.107	0.126
	polynom. R^2	0.445	0.549	0.109	0.168	0.270	0.286	0.036	0.100	0.331	0.356	0.120	0.198

NOTE: T_{out}: Outdoor air temperature (°C); r: Coefficient of linear correlation (Pierson's r); p: Confidence interval for linear correlation; R^2: Regression coefficient of determination for the linear / quadratic expression of the correlation; TSV: Mean thermal sensation vote; TC: Mean thermal comfort vote; TP: Mean thermal preference vote; TA: Mean thermal acceptability vote

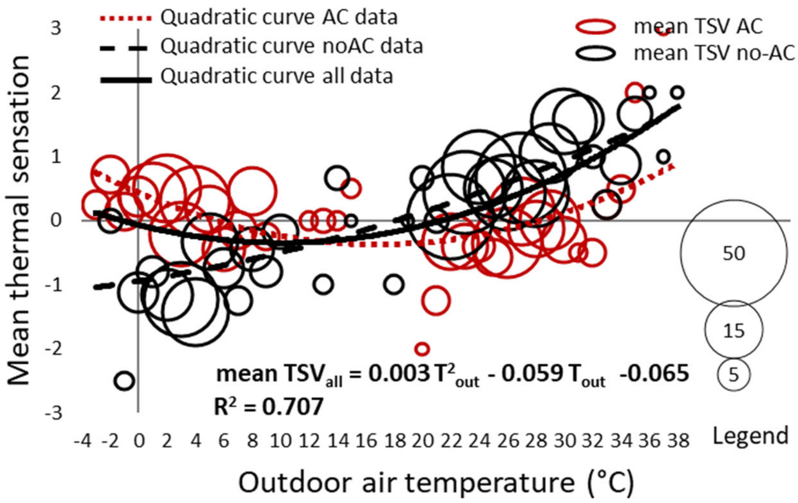


Figure 52 Correlation between mean values of thermal sensation to outdoor temperature in summer and winter

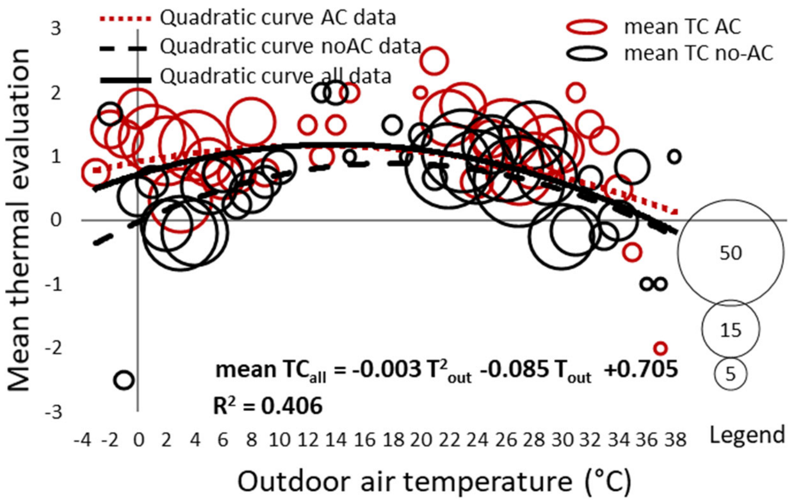


Figure 53 Correlation between mean values of thermal evaluation to outdoor temperature in summer and winter

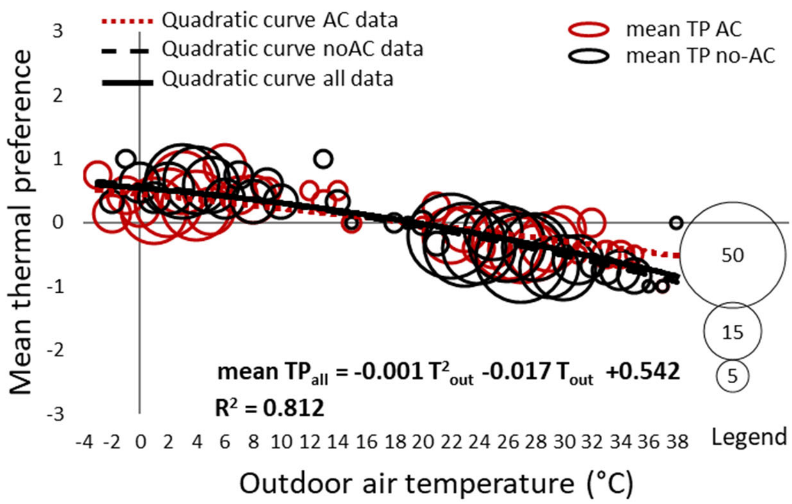


Figure 54 Correlation between mean values of thermal preference to outdoor temperature in summer and winter

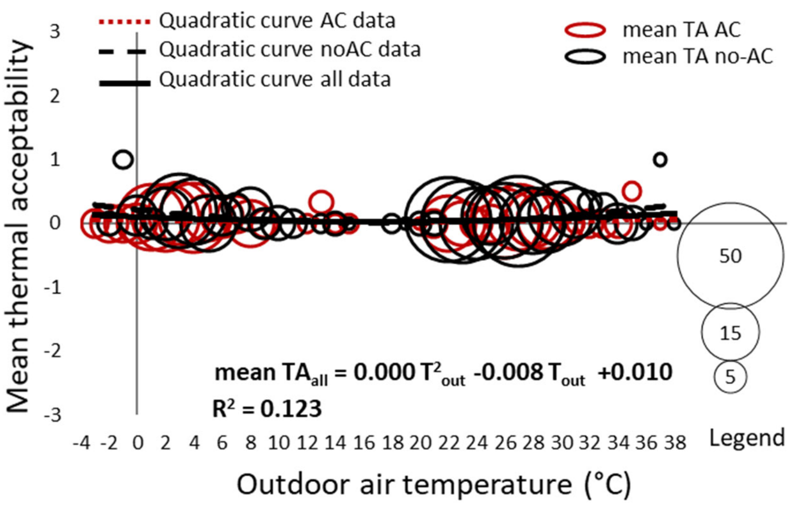


Figure 55 Correlation between mean values of thermal acceptability to outdoor temperature in summer and winter

Following the correlation to the outdoor temperatures, the thermal votes of both seasons were distributed (Figure 56, Figure 57, Figure 58, Figure 59) and correlated to one another in bulk and relative to the use of air conditioning (Figure 60, Figure 61 and Table 30). The graphical representation in each season separately is in Appendix R.

In summer, thermal sensation had strong negative correlation with thermal comfort ($r = -0.65$, $p < 0.001$) and thermal preference ($r = -0.68$, $p < 0.001$). The hotter the subjects sensed their environment, the less comfortable they felt and, their preference inclined towards "prefer cooler". In winter, the correlation comfort: sensation (TC: TSV) reversed, however the correlation preference: sensation (TP: TSV) kept the downward trend. In winter, the hotter the subjects sensed their environment, the more comfortable they felt but, their preference still inclined towards "prefer cooler" (Appendix R).

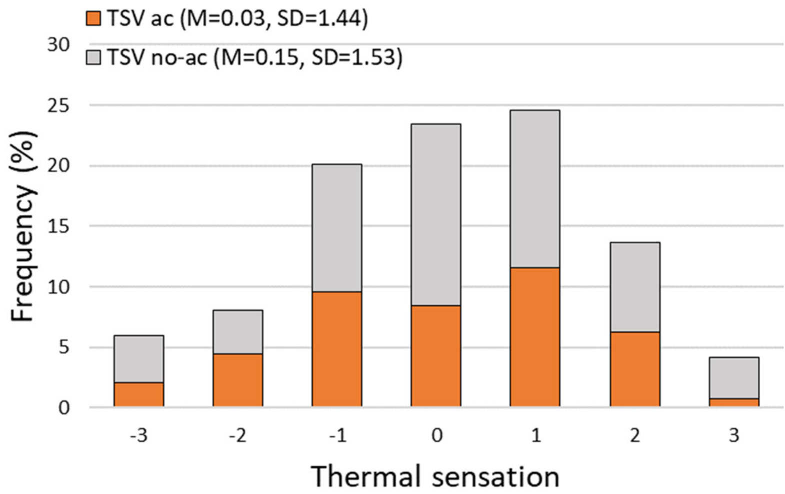


Figure 56 Frequency distributions of TSV in summer and winter. ** Number of observations ($_{n}N_{all}$=720; $_{n}N_{FR}$=410; $_{n}N_{CL/HT}$=310)

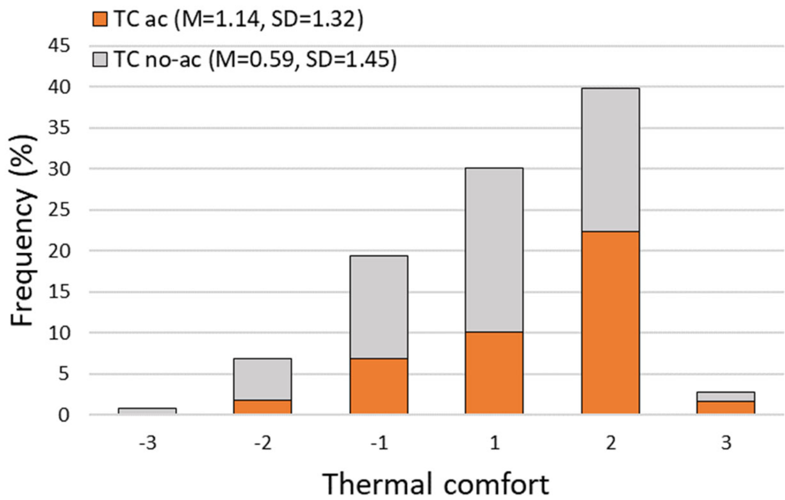


Figure 57 Frequency distributions of TC in summer and winter. ** Number of observations ($_{n}N_{all}$=720; $_{n}N_{FR}$=410; $_{n}N_{CL/HT}$=310)

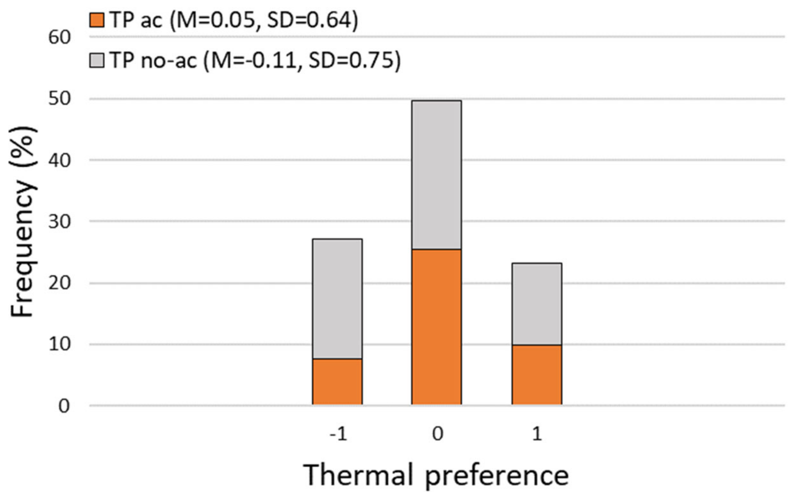


Figure 58 Frequency distributions of TP in summer and winter. ** Number of observations ($_nN_{all}$=720; $_nN_{FR}$=410; $_nN_{CL/HT}$=310)

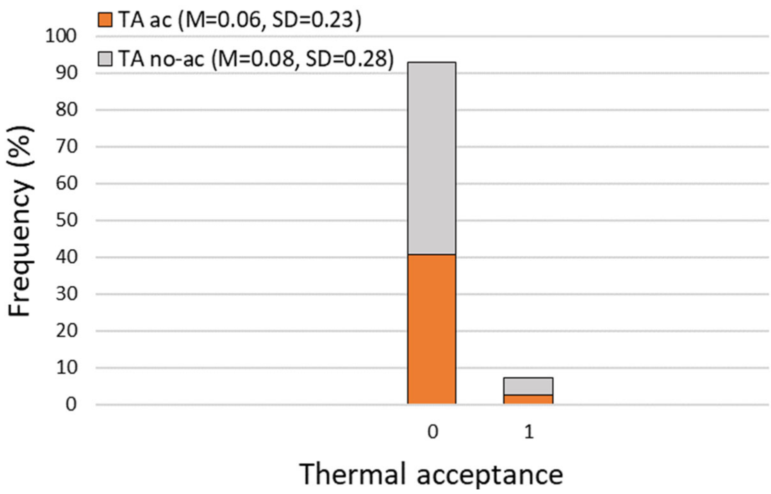


Figure 59 Frequency distributions of TA in summer and winter. ** Number of observations ($_nN_{all}$=720; $_nN_{FR}$=410; $_nN_{CL/HT}$=310)

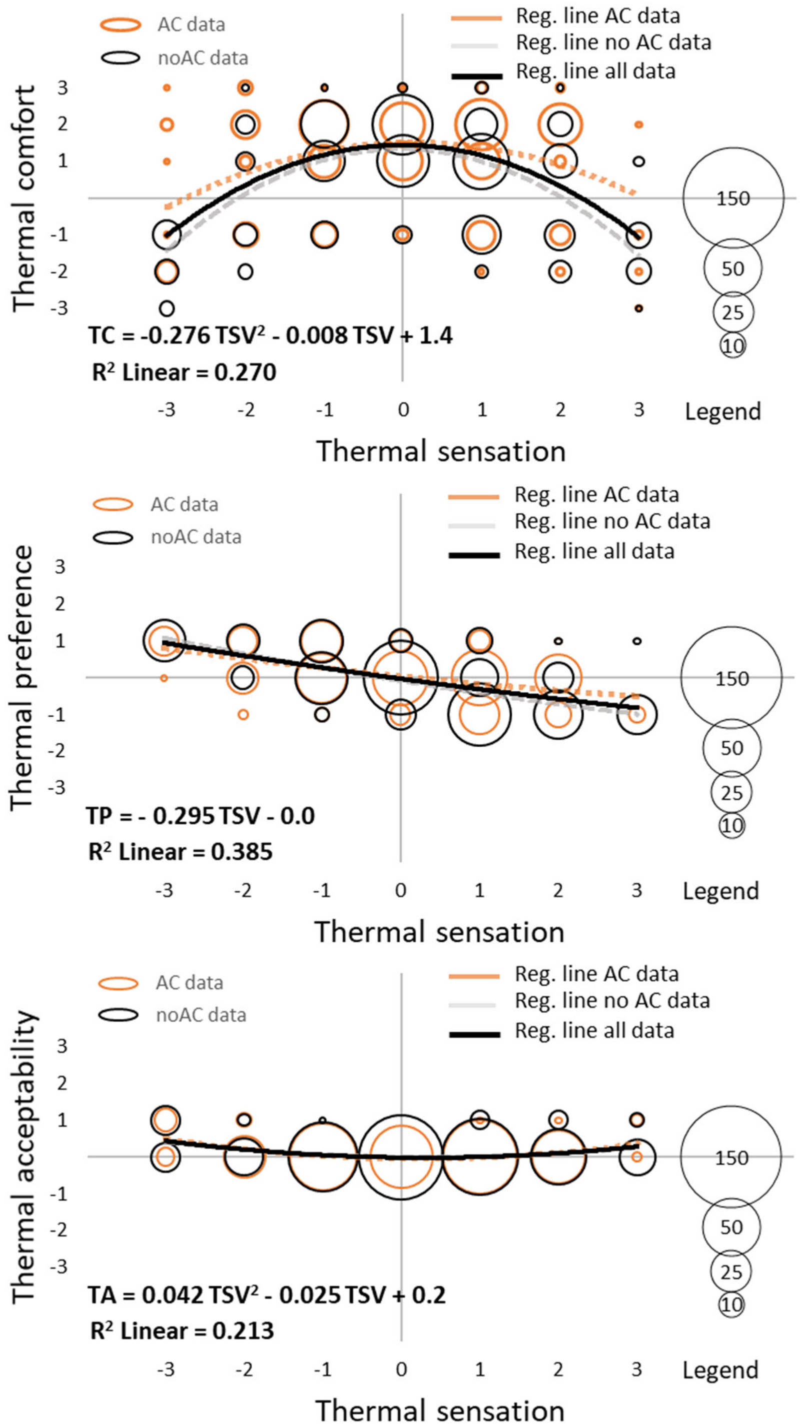
The correlation between comfort and preference was also strong, but positive in summer ($r = 0.55$, $p < 0.001$) and negative in winter ($r = -0.67$, $p < 0.001$) which produced almost flat line when analyzing the data together for both seasons (Figure 60, Figure 61; see Appendix R).

In summer, the more comfortable the subjects evaluated their indoor environment, the closer their preference vote increased from “prefer cooler” to “no change”, while in winter, the more comfortable the subjects evaluated their indoor environment, the closer their preference vote decreased from “prefer warmer” to “no change”. The correlation between TA and other thermal responses was either weak or even insignificant. The subjects could accept diverse indoor conditions. The correlation lines (or curves) were very close or overlapping irrespective of the season and the operational mode which leads to believe that the relationship between subjective thermal responses remains constant and unaffected by the air conditioning mode. It is important to note however that the relationships comfort: sensation (TC: TSV) and preference: comfort (TP: TC) have opposite trends relative to the season.

Table 30 Correlation between thermal responses in summer and winter relative to air conditioning mode

		All data points					Using air conditioning (HT/CL)					Not using air conditioning (FR)				
		r	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**
Summer and Winter	TC: TSV	0.02	0.020	0.8	0.000	0.575	0.11	0.101	1.1	0.012	0.052	-0.02	-0.02	0.6	.001	0.639
	TP: TSV	-0.62	-0.295	-0.0	0.385	**<.001**	-0.50	-0.221	0.1	0.250	**<.001**	-0.70	-0.342	-0.1	0.483	**<.001**
	TA: TSV	-0.17	-0.030	0.1	0.029	**<.001**	-0.23	-0.037	0.1	0.051	**<.001**	-0.14	-0.025	0.1	0.020	**<0.05**
	TP: TC	0.03	0.014	-0.1	.001	0.458	-0.08	-0.039	0.1	0.007	0.151	0.06	0.030	-0.1	0.003	0.242
	TA: TC	-0.46	-0.083	0.1	0.209	**<.001**	-0.54	-0.096	0.2	0.291	**<.001**	-0.41	-0.078	0.1	0.167	**<.001**
	TA:TP	0.14	0.053	0.1	0.021	**<0.05**	0.153	0.056	0.1	0.024	**<0.05**	0.15	0.055	0.1	0.022	**<0.05**
Summer	TC: TSV	-0.66	-0.660	1.1	0.438	**<.001**	-0.65	-0.600	1.1	0.427	**<.001**	-0.65	-0.719	1.2	0.428	**<.001**
	TP: TSV	-0.57	-0.248	-0.3	0.323	**<.001**	-0.68	-0.273	-0.4	0.457	**<.001**	-0.51	-0.247	-0.3	0.258	**<.001**
	TA: TSV	0.25	0.040	0.0	0.062	**<.001**	0.35	0.045	0.0	0.119	**<.001**	0.20	0.038	0.0	0.041	**<0.05**
	TP: TC	0.55	0.238	-0.6	0.297	**<.001**	0.55	0.239	-0.6	0.297	**<.001**	0.54	0.236	-0.6	0.287	**<.001**
	TA: TC	-0.32	-0.051	0.1	0.101	**<.001**	-0.44	-0.061	0.1	0.189	**<.001**	-0.27	-0.046	0.1	0.072	**<.001**
	TA:TP	-0.07	-0.025	0.0	0.005	0.158	-0.229	-0.073	0.0	0.052	**<0.05**	0.00	0.000	0.1	0.000	0.994
Winter	TC: TSV	0.75	0.718	0.9	0.565	**<.001**	0.77	0.709	0.9	0.586	**<.001**	0.70	0.732	1.0	0.490	**<.001**
	TP: TSV	-0.71	-0.242	0.4	0.498	**<.001**	-0.69	-0.244	0.4	0.477	**<.001**	-0.71	-0.259	0.329	0.499	**<.001**
	TA: TSV	-0.50	-0.098	0.1	0.253	**<.001**	-0.59	-0.111	0.1	0.351	**<.001**	-0.43	-0.097	0.0	0.185	**<.001**
	TP: TC	-0.60	-0.213	0.6	0.354	**<.001**	-0.67	-0.256	0.6	0.449	**<.001**	-0.49	-0.172	0.6	0.241	**<.001**
	TA: TC	-0.59	-0.119	0.2	0.342	**<.001**	-0.61	-0.124	0.2	0.375	**<.001**	-0.56	-0.121	0.2	0.315	**<.001**
	TA:TP	0.30	0.172	0.0	0.092	**<.001**	0.36	0.193	0.0	0.132	**<.001**	0.23	0.142	0.1	0.054	**<0.05**

NOTE: FR mode: Free running mode – when air conditioning was not used; CL mode: Cooling mode – air conditioning was used for cooling; HT mode: Heating mode – air conditioning was used for heating; 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; TSV: Thermal sensation vote; TC: Thermal comfort / evaluation vote; TP: Thermal preference vote; TA: Thermal acceptability vote; ** The calculations in the table uses raw data – N: Number of observations; Summer and Winter Stage (${}_{n}N_{all}$=720; ${}_{n}N_{FR}$=410; ${}_{n}N_{CL/HT}$=310); Summer Stage (${}_{n}N_{all}$=420; ${}_{n}N_{FR}$=275; ${}_{n}N_{CL}$=145); Winter Stage (${}_{n}N_{all}$=300; ${}_{n}N_{FR}$=135; ${}_{n}N_{HT}$=165)

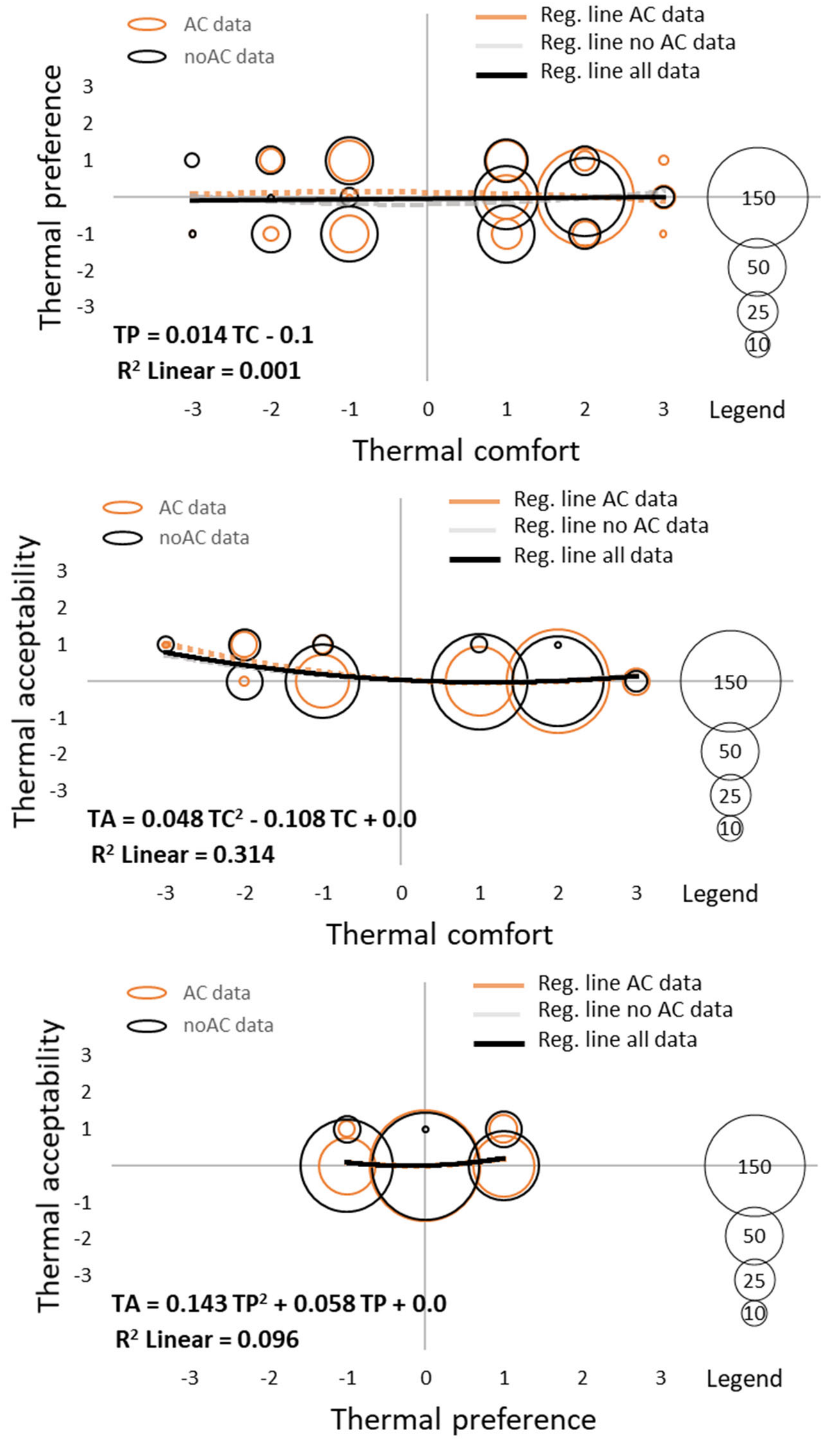


a)

b)

c)

Figure 60 Correlations between thermal responses in summer and winter: a) TC: TSV; b) TP: TSV; c) TA: TSV ** N: Number of observations (N_{all}=720; N_{FR}=410; $N_{CL/HT}$=310)



a)

b)

c)

Figure 61 Correlations between thermal responses in summer and winter: a) TP: TC; b) TA: TC; c) TA: TP ** N: Number of observations (N_{all}=720; N_{FR}=410; $N_{CL/HT}$=310)

The TSV, TC, TP and TA votes together and for each season 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 (full list of results in Appendix T) Depending on the use of air-conditioning, there were three modes of operation: FR – free running mode (or no AC), when the subjects did not report using air conditioning; CL – cooling mode and HT – heating mode. CL and HT modes were observed only in summer and winter respectively. When analyzing the dataset for both seasons together, this mode is marked as AC (with the use of air conditioning for either heating or cooling). Only the factor of air conditioning mode affected all three thermal responses (TSV, TC and TP) in both seasons together and separately (Table 31). The percentage of the votes "acceptable" was very high in all the conditions and seasons but, it was hardly ever dependent on any one of them. Table 32 presents the results of the chi-square test for the thermal responses in both seasons and separately depending on air-conditioning mode.

Table 31 Summary of Chi-square Results: Dependence of TSV, TC, TP and TA on Sub-Divisions

	Time of Day (day/night)			**Use of AC (AC/ no AC)**			**Dormitory (GSD/Kaikan)**			**Sex (M/F)**			**Nationality (JP/Intl)**		
TSV	○			○	●	x	○		x	○	●	x	○		x
TC	○		x	○	●	x		●	x	○	●	x		●	x
TP				○	●	x	○	●	x				○	●	x
TA		●	x												

Note: ○ – Summer; ● – Winter x – Both seasons together

Table 32 Summary of Chi-square results: Dependence of TSV, TC and TP on air-conditioning modes in summer and winter

		Division	**n**	**df**	**χ^2 critical**	**χ^2**	**p**	**Estimated by Regression* (ºC)**		**δT(ºC)**
TSV	All	AC: no AC	310: 410	6	12.59	19.11	<0.05	$T_{n\ AC\ on} = 23.4$	$T_{n\ AC\ off} = 23.1$	0.3
	Summer	CL: no AC	145: 275	6	12.59	47.33	< 0.001	$T_{n\ AC\ on} = 27.1$	$T_{n\ AC\ off} = 24.2$	2.9
	Winter	HT: no AC	165: 135	5	11.07	43.34	< 0.001	$T_{n\ AC\ on} = 19.5$	$T_{n\ AC\ off} = 22.4$	-2.9
TC	All	AC: no AC	310:410	5	11.07	40.81	<0.001	$T_{c\ AC\ on} > 20.4$	$T_{c\ AC\ off} > 35.1$	-14.7
	Summer	CL: no AC	145: 275	5	11.07	23.71	< 0.001	$T_{c\ AC\ on} < 27.9$	$T_{c\ AC\ off} < 25.2$	2.7
	Winter	HT: no AC	165: 135	5	11.07	29.79	< 0.001	$T_{c\ AC\ on} > 20.6$	$T_{c\ AC\ off} > 24.0$	-3.5
TP	All	AC: no AC	310: 410	2	5.99	27.72	<0.001	$T_{p\ AC\ on} = 24.6$	$T_{p\ AC\ off} = 22.8$	1.8
	Summer	CL: no AC	145: 275	2	5.99	6.89	< 0.001	$T_{p\ AC\ on} = 21.9$	$T_{p\ AC\ off} = 23.1$	-1.2
	Winter	HT: no AC	165: 135		5.99	15.75	<0.001	$T_{p\ AC\ on} = 32.6$	$T_{p\ AC\ off} = 30.0$	2.6
TA	All	AC: no AC	310:410	1	3.84	1.63	0.202	$T_{a\ AC\ on} = 24.6$	$T_{a\ AC\ off} = 39.4$	-14.8
	Summer	CL: no AC	145: 275	1	3.84	1.12	0.289	insignificant	insignificant	-
	Winter	HT: no AC	165: 135	1	3.84	2.38	0.123	insensible result	insignificant	-

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). ** The full list of linear regression equations are provided as an Appendix S (for the seasons together and separately)

The linear regression between the subjective votes and the measured air temperature in the different air-conditioning modes estimated the neutral, comfortable and "prefer no change" temperature in both seasons combined and, in winter and summer separately. The observed difference between the estimates is presented in Table 8. Some of the calculated values challenge the sensibility – for example, it is hardly possible that 39.4°C would be acceptable temperature in free running mode. The results should be considered together with the observed temperature ranges and the results from the following analysis.

Simple linear regression estimates that in summer, the difference between the neutral temperature in CL and FR is about 3°C; with higher neutral temperature at cooling mode. The threshold in CL below which the comfort vote is expected to be on the "comfortable" side of the scale, is ~3°C degrees higher than in FR. The "prefer no change" vote can be expected at about 1°C lower temperature in CL than in FR.

In winter however, the difference between the neutral temperature in CL and FR is estimated again about 3°C, but with the opposite relation comparing to summer - the higher neutral temperature is at free-running mode. The threshold in CL above which the comfort vote is expected to be on the "comfortable" side of the scale, is 3.5°C degrees lower than in FR. The "prefer no change" vote can be expected at 2.6°C higher temperature in CL than in FR.

It is interesting to observe that in CL the neutral sensation during summer is at higher temperature than the FR, while in winter, the neutral sensation in HT is at a lower temperature than in FR. It might lead to the assumption that the fact of using air-conditioning causes a psychological effect over the neutral vote and people define as neutral higher temperatures when cooling and lower temperatures when heating as compared to their respective counterparts in free running mode. On the other hand, the estimated neutral temperature at FR in both seasons is surprisingly close with a difference of less than 2°C.

Similarly, in summer people are expected to start voting comfortable at a higher temperature in CL than in FR; while in winter they are expected to start voting comfortable at a lower temperature in HT than in FR. The threshold temperature in FR when the vote enters the comfortable side of the scale in winter and in summer is very close with only about 1°C difference. The observation of TC is similar to the observation of TSV, however the preference vote shows the opposite relation. The vote "prefer no change" in CL in summer is expected at a lower temperature than in FR, while in winter the vote "prefer no change" in HT is expected at a higher temperature than in FR. At TP we also observed greater seasonal difference of almost 7°C in the estimated "prefer no change" temperature in FR.

The observed differences in mean temperature (Appendix S) however, vary from the differences estimated by regression (Table 8) and sometimes are even contradictory. This may be attributed to the drawbacks of the linear regression analysis as previously stated by other researchers [2, 10].

2.4. Neutral and Comfort temperature

2.4.1. Distribution of Thermal Sensation Depending on Season and Mode

Table 33 Percentage of thermal responses for each scale in summer and winter

Mode	Items	Thermal sensation in both seasons							
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**Total**
ALL	N	43	58	145	169	177	98	30	720
	(%)	6.0	8.1	20.1	23.5	24.6	13.6	4.2	100
FR	N	28	26	76	108	94	53	25	410
	(%)	6.8	6.3	18.5	26.3	22.9	12.9	6.1	100
CL/HT	N	15	32	69	61	83	45	5	310
	(%)	4.8	10.3	22.3	19.7	26.8	14.5	1.6	100
Mode	**Items**	**Thermal sensation in summer**							
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**Total**
ALL	N	5	29	79	109	114	54	30	420
	(%)	1.2	6.9	18.8	26.0	27.1	12.9	7.1	100
FR	N	–	8	40	78	82	42	25	275
	(%)	–	2.9	14.5	28.4	29.8	15.3	9.1	100
CL	N	5	21	39	31	32	12	5	145
	(%)	3.4	14.5	26.9	21.4	22.1	8.3	3.4	100
Mode	**Items**	**Thermal sensation in winter**							
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**Total**
ALL	N	38	29	66	60	63	44	–	300
	(%)	12.7	9.7	22.0	20.0	21.0	14.7	–	100
FR	N	28	18	36	30	12	11	–	135
	(%)	20.7	13.3	26.7	22.2	8.9	8.1	–	100
HT	N	10	11	30	30	51	33	–	165
	(%)	6.1	6.7	18.2	18.2	30.9	20.0	–	100

Note: FR: Free running mode (or "no AC" - without the use of air conditioning); CL: Air conditioning for cooling; HT: Air conditioning for heating

2.4.2. Logit Regression Analysis for Neutrality Range Relative to Season and Mode.

Estimating the proportion of occupants that would vote comfortable at a certain temperature, requires conducting a probability analysis of TSV with the indoor temperature. We conducted an ordinal logistic regression analysis for both seasons and all modes of air conditioning using the probit model.

The equations $P_{(\leq TSV)}$ in Table 34 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, 31]. The summer-and-winter combined probit regression coefficient for Toyohashi is calculated to be 0.102/K. Mean temperature of the probit line is the absolute value of the result from dividing the y-intercept with the constant – for example | +0.600/-0.102 | = | -5.9 | = 5.9ºC. The SD is the absolute value of the inverse of the constant (SD = |1/-0.102| = | -9.84 | = 9.84). Each equation was calculated for temperatures from 9ºC to 33ºC (the range of the observed temperature records in both seasons combined). For each result obtained, the cumulative normal distribution was calculated in MSExcel (function NORM.S.DIST(z, cumulative). The sigmoid curves of the probabilities for both seasons and all the modes were then plotted and presented in Figure 62. In Figure 63 and Figure 64 the data is divided by season and air conditioning modes. (see also Appendix U)

Table 34 Probit analysis of thermal sensation and indoor temperature in summer and winter

Mode		Probit regression line	Mean	SD	N	R^2	SE	p
Summer and winter	AC and no AC	$P_{(\leq -3)} = -0.102\ T_i + 0.6$	5.9	9.84	720	0.600	0.008	< 0.001
		$P_{(\leq -2)} = -0.102\ T_i + 1.2$	11.8					
		$P_{(\leq -0)} = -0.102\ T_i + 2.0$	19.7					
		$P_{(\leq \pm 0)} = -0.102\ T_i + 2.7$	26.6					
		$P_{(\leq +1)} = -0.102\ T_i + 3.5$	24.5					
		$P_{(\leq +2)} = -0.102\ T_i + 4.3$	42.3					
	AC (CL/HT)	$P_{(\leq -3)} = -0.048\ T_i - 0.6$	12.5	20.89	310	0.523	0.014	< 0.001
		$P_{(\leq -2)} = -0.048\ T_i + 0.1$	2.1					
		$P_{(\leq -0)} = -0.048\ T_i + 0.8$	16.7					
		$P_{(\leq \pm 0)} = -0.048\ T_i + 1.3$	27.2					
		$P_{(\leq +1)} = -0.048\ T_i + 2.1$	43.9					
		$P_{(\leq +2)} = -0.048\ T_i + 3.3$	68.9					
	No AC (FR)	$P_{(\leq -3)} = -0.136\ T_i +1.3$	9.6	7.35	410	0.663	0.011	< 0.001
		$P_{(\leq -2)} = -0.136\ T_i + 1.8$	13.2					
		$P_{(\leq -0)} = -0.136\ T_i + 2.7$	19.8					
		$P_{(\leq \pm 0)} = -0.136\ T_i + 3.6$	26.5					
		$P_{(\leq +1)} = -0.136\ T_i + 4.4$	32.3					
		$P_{(\leq +2)} = -0.136\ T_i + 5.1$	37.5					

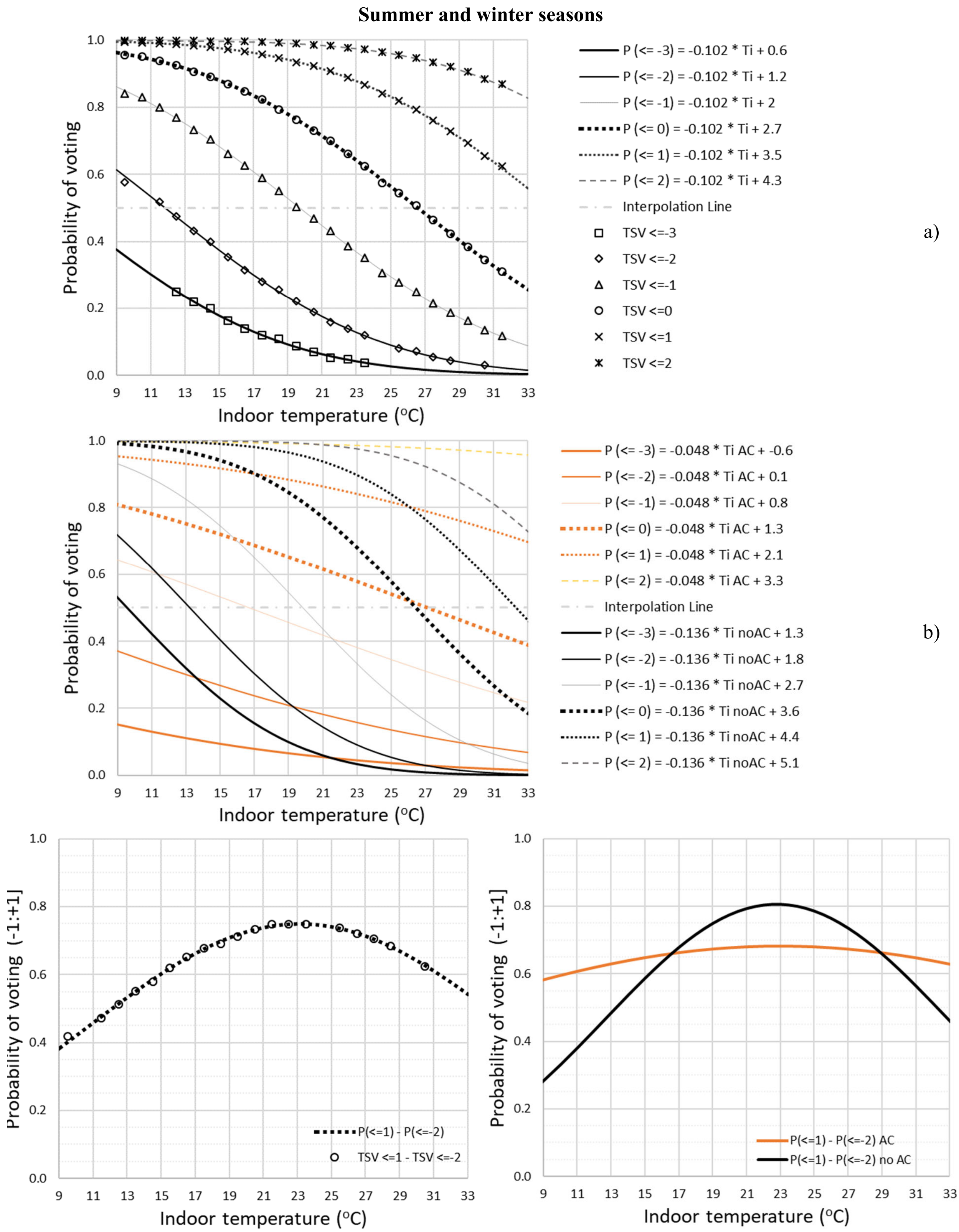
Note: $P_{(\leq 1)}$ is the probability of voting 1 and less; $P_{(\leq 2)}$ is the probability of voting 2 and less and so on; SD = standard deviation; N = number of samples; R^2 (Nagelkerke) - coefficient of determination ; SE = standard error; significance $p < 0.001$)

Table 35 Probit analysis of thermal sensation and indoor temperature in summer

Mode		Probit regression line	Mean	SD	N	R^2	SE	p
Summer	AC and no AC	$P_{(\leq -3)} = -0.229\ T_i + 3.6$	15.7	4.37	420	0.597	0.026	< 0.001
		$P_{(\leq -2)} = -0.229\ T_i + 4.6$	20.1					
		$P_{(\leq -0)} = -0.229\ T_i + 5.5$	24.0					
		$P_{(\leq \pm 0)} = -0.229\ T_i + 6.3$	27.5					
		$P_{(\leq +1)} = -0.229\ T_i + 7.1$	31.0					
		$P_{(\leq +2)} = -0.229\ T_i + 7.8$	34.1					
	AC (CL)	$P_{(\leq -3)} = -0.246\ T_i + 4.3$	17.5	4.07	145	0.620	0.043	< 0.001
		$P_{(\leq -2)} = -0.246\ T_i + 5.5$	22.4					
		$P_{(\leq -0)} = -0.246\ T_i + 6.4$	26.1					
		$P_{(\leq \pm 0)} = -0.246\ T_i + 7.0$	28.5					
		$P_{(\leq +1)} = -0.246\ T_i + 7.8$	31.8					
		$P_{(\leq +2)} = -0.246\ T_i + 8.5$	34.6					
	No AC (FR)	-	-	5.26	275	0.535	0.034	< 0.001
		$P_{(\leq -2)} = -0.190\ T_i + 3.2$	16.8					
		$P_{(\leq -0)} = -0.190\ T_i + 4.2$	22.1					
		$P_{(\leq \pm 0)} = -0.190\ T_i + 5.1$	26.8					
		$P_{(\leq +1)} = -0.190\ T_i + 5.9$	31.0					
		$P_{(\leq +2)} = -0.190\ T_i + 6.6$	34.7					

Table 36 Probit analysis of thermal sensation and indoor temperature in winter

Mode		Probit regression line	Mean	SD	N	R^2	SE	p
Winter	AC and no AC	$P_{(\leq -3)} = -0.116\ T_i + 1.0$	8.6	8.59	300	0.506	0.014	< 0.001
		$P_{(\leq -2)} = -0.116\ T_i + 1.4$	12.0					
		$P_{(\leq -0)} = -0.116\ T_i + 2.1$	18.0					
		$P_{(\leq \pm 0)} = -0.116\ T_i + 2.7$	23.2					
		$P_{(\leq +1)} = -0.116\ T_i + 3.5$	30.0					
		-	-					
	AC (HT)	$P_{(\leq -3)} = -0.076\ T_i + 0.0$	0.0	13.18	165	0.451	0.020	< 0.001
		$P_{(\leq -2)} = -0.076\ T_i + 0.4$	0.4					
		$P_{(\leq -0)} = -0.076\ T_i + 1.1$	1.1					
		$P_{(\leq \pm 0)} = -0.076\ T_i + 1.6$	1.6					
		$P_{(\leq +1)} = -0.076\ T_i + 2.5$	2.5					
		-	-					
	No AC (FR)	$P_{(\leq -3)} = -0.133\ T_i + 1.4$	10.6	7.54	135	0.451	0.024	< 0.001
		$P_{(\leq -2)} = -0.133\ T_i + 1.8$	13.6					
		$P_{(\leq -0)} = -0.133\ T_i + 2.6$	19.6					
		$P_{(\leq \pm 0)} = -0.133\ T_i + 3.4$	25.6					
		$P_{(\leq +1)} = -0.133\ T_i + 3.9$	29.4					
		-	-					



c) d)

Figure 62 Graphical representation of probit analysis for summer and winter season: a) Probability of voting; b) Probability of voting relative to air conditioning; c) Total probability of voting within the "extended neutral range" of TSV scale – from -1 to +1; d) Probability of voting within the "extended neutral range" of TSV scale relative to using or not using air conditioning. **Marker points represent the actual probability of voting.

Summer season

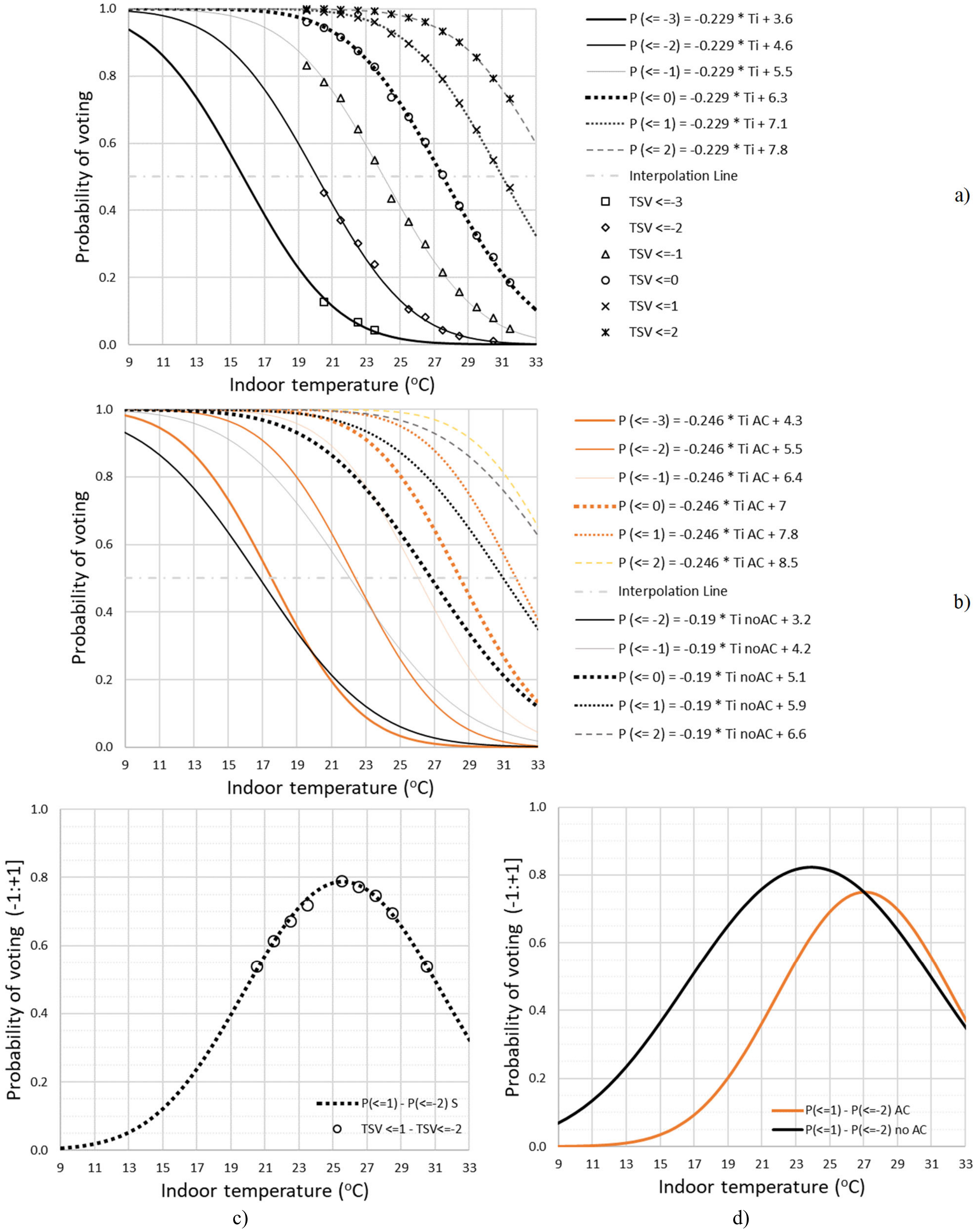


Figure 63 Graphical representation of probit analysis for summer season: a) Probability of voting; b) Probability of voting relative to air conditioning; c) Total probability of voting within the "extended neutral range" of TSV scale – from -1 to +1; d) Probability of voting within the "extended neutral range" of TSV scale relative to using or not using air conditioning. **Marker points represent the actual probability of voting.

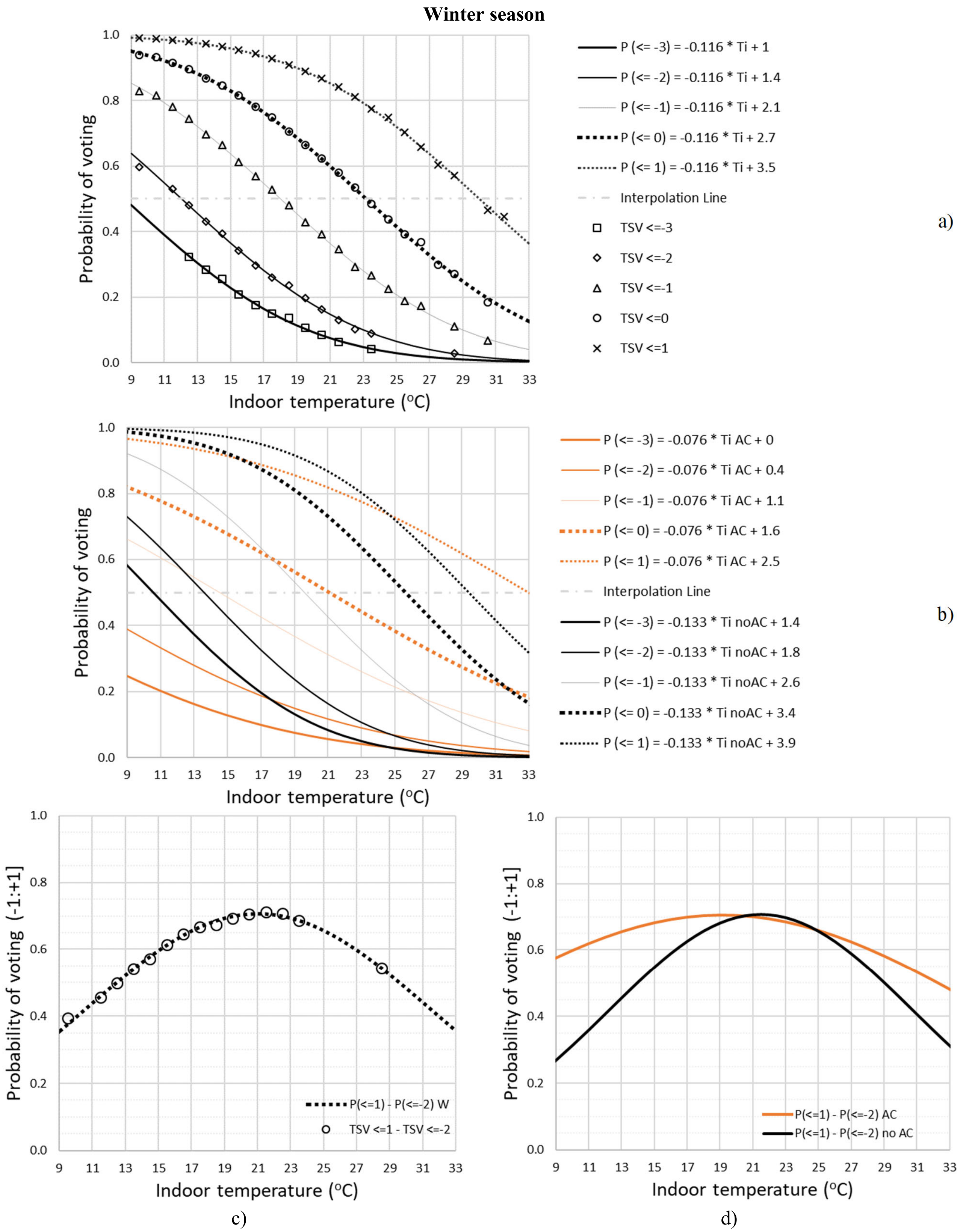


Figure 64 Graphical representation of probit analysis for winter season: a) Probability of voting; b) Probability of voting relative to air conditioning; c) Total probability of voting within the "extended neutral range" of TSV scale – from -1 to +1; d) Probability of voting within the "extended neutral range" of TSV scale relative to using or not using air conditioning. **Marker points represent the actual probability of voting.

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 62Figure 63a), the probability of people voting neutral (dotted black line of P≤ 0)) or less at lower temperatures is high, while with the rise of temperatures, this probability decreases. And, at 18ºC there is 80% probability of voting neutral or less. The explanation for all curves follows the same pattern.

When subtracting the probability of voting -2 from the probability of voting 1, we can obtain the probability of voting within the extended neutral range (-1, 0 and 1).

In both seasons, in AC mode, we can observe that within the range of 22ºC and 25ºC indoor temperature, the probability of voting extended neutral is at its peak, however this peak is far below the recommended 80% (Figure 62d). However, in no-AC mode, the probability of voting extended neutral at least reaches 80% within the same range of 21ºC to 25ºC. In summer the respective ranges are 25-29ºC in AC mode and 22-26ºC in no-AC mode (Figure 63d) while in winter the ranges are overlapping at ~20-24ºC (Figure 64d). The peak probability of voting extended neutral is about 80% only when not using air conditioning in summer season (or in no-AC when analyzing the data from both seasons in bulk).

2.4.3. Linear Regression Method for Determining Neutral Temperature

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 both seasons 68% of the TSV (N=720, M=0.10, SD=1.49) were within the -1 to +1 segment of the scale and, the neutral votes were 23% (Table 33 and Appendix S, Appendix Table S-1). The extended neutral votes remained 68% from either AC and no-AC votes, while the neutral votes were higher percentage (26%) in AC as compared as 20% in no AC mode.

In summer these respective percentages were 72% (extended neutral TSV) and 26% (neutral TSV), while in winter they were 63% and 20% respectively. In summer, the extended neutral percentage is similar in AC and no-AC mode (73% to 70% respectively), while in winter there is a bigger difference (58% to 67% respectively). It should be noted that despite the observed differences relative to season and air conditioning mode, the percentage of extended neutral thermal sensation votes remained high (Appendix S).

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:

Eq. 26 Linear regression model TSV_{AC}: T_i (summer and winter)

$$_{s\&w}TSV_{AC} = 0.063\ T_i - 1.5, (N = 310; p < 0.05; R^2 = 0.04; S.E.=0.06; F\ statistic = 11.0)$$

Eq. 27 Linear regression model $TSV_{no\ AC}$: T_i (summer and winter)

$$_{s\&w}TSV_{no\ AC} = 0.164\ T_i - 3.8, (N = 410; p < 0.001; R^2 = 0.35; S.E.=0.04; F\ statistic = 218.3)$$

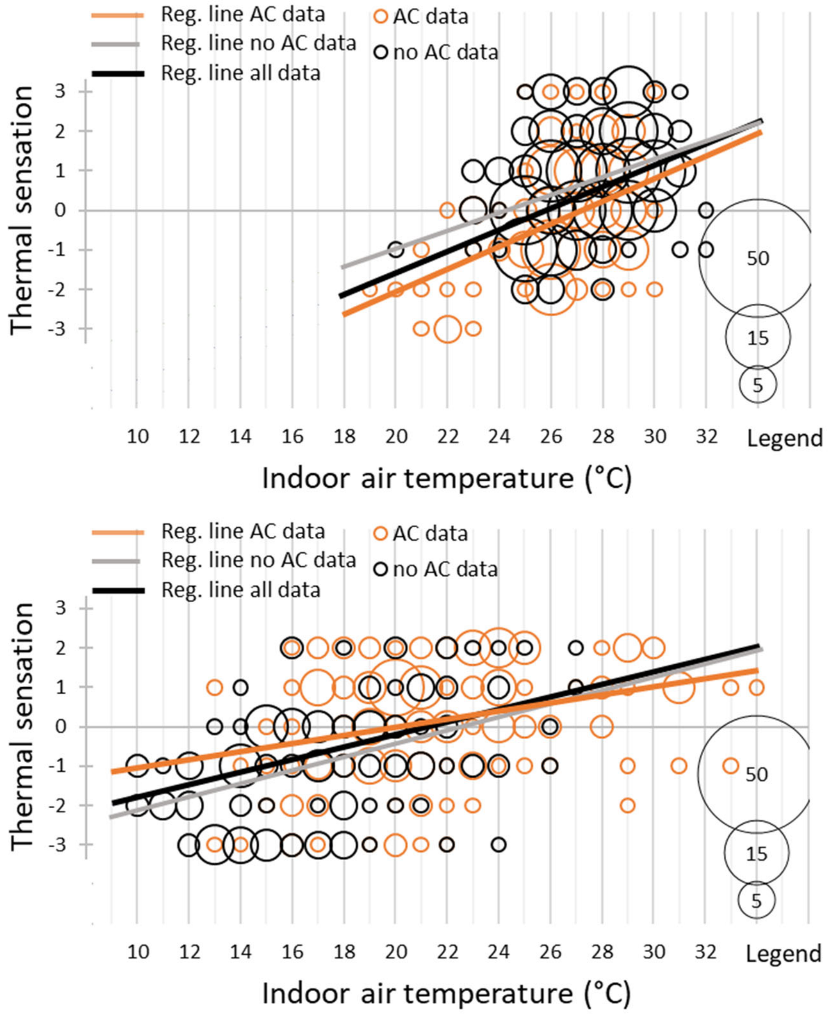


Figure 65 Correlation between thermal sensation vote and indoor temperature relative to air conditioning mode: a) summer data TSV: T_i; b) winter data TSV: T_i

Eq. 28 Linear regression model TSV_{AC}: T_i (summer)

$$_{s}TSV_{AC} = 0.284\ T_i - 7.7, (N = 145; p < 0.001; R^2 = 0.19; S.E.=0.08; F\ statistic = 33.1)$$

Eq. 29 Linear regression model $TSV_{no\ AC}$: T_i (summer)

$$_{s}TSV_{no\ AC} = 0.213\ T_i - 5.2, (N = 275; p < 0.001; R^2 = 0.11; S.E.=0.06; F\ statistic = 33.5)$$

Eq. 30 Linear regression model TSV_{AC}: T_i (winter)

$$_{w}TSV_{AC} = 0.101\ T_i - 2.0, (N = 165; p < 0.001; R^2 = 0.09; S.E.=0.08; F\ statistic = 16.2)$$

Eq. 31 Linear regression model $TSV_{no\ AC}$: T_i (winter)

$_{W}TSV_{no\ AC} = 0.176\ T_i - 3.9$, (N = 135; $p < 0.001$; $R^2 = 0.21$; S.E.=0.08; F statistic = 35.6)

The calculated neutral temperature for both seasons when using air conditioning ($_{S\&W}T_{n\ AC}$) using the equation (Eq. 26) is $_{S\&W}T_{n\ AC}$ = 23.4ºC. This is 0.8ºC lower than $_{voted\ S\&W}T_{n\ AC}$ =24.2ºC - the mean indoor air temperature when the subjects voted "neutral" in both seasons (Appendix S). The calculated neutral temperature for both seasons when not using air conditioning ($_{S\&W}T_{n\ no\ AC}$) using the equation (Eq. 27) is very similar: $_{S\&W}T_{n\ no\ AC}$ = 23.1ºC. This is 1.3ºC lower than $_{voted\ S\&W}T_{n\ no\ AC}$ =24.4ºC - the mean indoor air temperature when the subjects voted "neutral" while not using air conditioning.

The respective calculated neutral temperatures for summer are $_{S}T_{n\ AC}$ = 27.1ºC and $_{S}T_{n\ no\ AC}$ = 24.2ºC (Eq. 28 and Eq. 29), while for winter they are $_{W}T_{n\ AC}$ = 19.5ºC and $_{W}T_{n\ no\ AC}$ = 22.4ºC (Eq. 30 and Eq. 31). Analyzing the data from both seasons together masks the difference relative to air conditioning mode we observed in each season separately. Even though the model might explain a higher percentage of the variability of the TSV (35% in no AC mode in summer and winter combined), the result might be misleading and, it seems more sensible to analyze the data for each season separately. The difference in slopes leads to thinking that in summer, students are more sensitive to their indoor environment when air conditioning is on, while in winter it is the opposite – they appear almost twice more sensitive to the indoor environment when they do not use air conditioning. The slopes of the regression equations are comparable with the slopes derived from similar research: Rijal et al. estimated 0.183/K for Japanese subjects in offices in FR mode throughout a year. However, their winter slope in HT mode was 0.168/K – stronger positive relation than observed in the current survey [47].

Table 37. Ranges of T_i (ºC) for acceptability of thermal sensation. Estimated from linear regression

	Summer and winter			**Summer**			**Winter**		
	All	**AC**	**No AC**	**All**	**AC**	**No AC**	**All**	**AC**	**No AC**
T_n	23	23	23	26	27	24	21	19	22
80%	17~30	10~37	18~28	22~29	24~30	20~28	16~27	11~28	18~27
δ80%	δ13	δ27	δ10	δ7	δ6	δ8	δ11	δ17	δ9
90%	19~27	15~31	20~26	24~27	25~29	22~27	18~25	15~24	20~25
δ90%	δ8	δ16	δ6	δ3	δ4	δ5	δ7	δ9	δ5

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 [29]. In our survey these ranges are in the table above.

The ranges in AC mode are wider in winter, and narrower in summer as compared to their counterpart in no AC mode. The probit analysis in subsection 2.4.2 (page 105) suggested similar temperature ranges for the peak probability of people voting extended neutral. However, the expected probability of voting neutral differed between the two methods. Probit analysis showed that probability of voting neutral barely reaching 80% in no AC mode summer (and in summer and winter combined) in a very narrow temperature range of 22~25ºC.

Table 38. Voted ranges of T_n (ºC) for acceptability of thermal sensation. From the collected direct votes

	Summer and winter			Summer			Winter		
	All	**AC**	**No AC**	**All**	**AC**	**No AC**	**All**	**AC**	**No AC**
T_n	24	24	24	27	27	27	20	22	18
80%	17~29	19~29	16~30	25~30	25~29	25~30	15~26	17~28	14~23
δ80%	δ12	δ10	δ14	δ5	δ4	δ5	δ11	δ11	δ9
90%	15~30	17~30	14~30	24~30	23~29	24~30	14~28	16~31	12~24
δ90%	δ15	δ13	δ16	δ6	δ6	δ6	δ14	δ15	δ12

The collected data provided the values on indoor temperature when the students voted "extended neutral". From the datasets it was possible to extract the range of indoor temperature when 80% of the students (or 90% respectively) voted extended neutral, as well as the average temperature of the neutral vote. The results are presented in Table 38. There were notable differences between the calculated and the observed values. Generally, the calculated range of 80% is usually wider than the observed, while it's the opposite with the 90% range.

Table 39 Correlation between clothing insulation and observed neutral temperature (at TSV -1, 0, +1)

		All data points					Using air conditioning (HT/CL)					Not using air conditioning (FR)				
		r	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**
S&W	I_{cl}: T_n	-0.63	-0.029	1.2	0.392	**<0.001**	-0.58	-0.029	1.2	0.332	**<0.001**	-0.66	-0.029	1.1	0.435	**<0.001**
S	I_{cl}: T_n	-0.20	-0.008	0.5	0.040	**<0.001**	-0.05	-0.002	0.4	0.003	0.598	-0.25	-0.010	0.6	0.060	**<0.001**
W	I_{cl}: T_n	-0.27	-0.014	0.9	0.072	**<0.001**	-0.33	-0.016	1.0	0.109	**<0.001**	-0.14	-0.010	0.8	0.020	0.223

NOTE: I_{cl}: Clothing insulation (clo) where 1 clo=0.155m²K/W; T_n: Voted neutral temperature (ºC) – the recorded indoor temperature when TSV vote is -1, 0 or +1 (slightly cool, neutral, slightly warm). ** Number of observations; Summer and Winter Stage ($T_{n\,ALL}$=491; $T_{n\,AC}$=213; $T_{n\,noAC}$=278); Summer Stage ($T_{n\,ALL}$=302; $T_{n\,AC}$=102; $T_{n\,noAC}$=200); Winter Stage ($T_{n\,ALL}$=189; $T_{n\,AC}$=111; $T_{n\,noAC}$=78). ** See also Appendix X for graphical representations of regressions

Adjusting the clothing is a typical adaptive comfort measure. Within the voted neutral temperature range, we observed that the average clothing insulation in summer was two times less than in winter – 0.32clo as compared to 0.63clo (Appendix X). The correlation was invariably negative – with the rising of the indoor neutral temperature, the subjects reduced their clothing. The strength of the correlation was higher when analyzing the data from both seasons together, while when analyzing it separately by season and mode, it can be observed that there is no correlation between clothing and neutral indoor temperature in two cases – in summer, when using air conditioning, and in winter, when not using air conditioning. It appears that using air conditioning in summer, breaks the connection and practically this adaptive measure is not utilized. Interestingly, this is not the case in winter. In winter however, there is no link between clothing and indoor temperature when not using air conditioning. This can be explained with the different approach subjects had about adjusting their clothing, probably because of their different tolerance to indoor conditions.

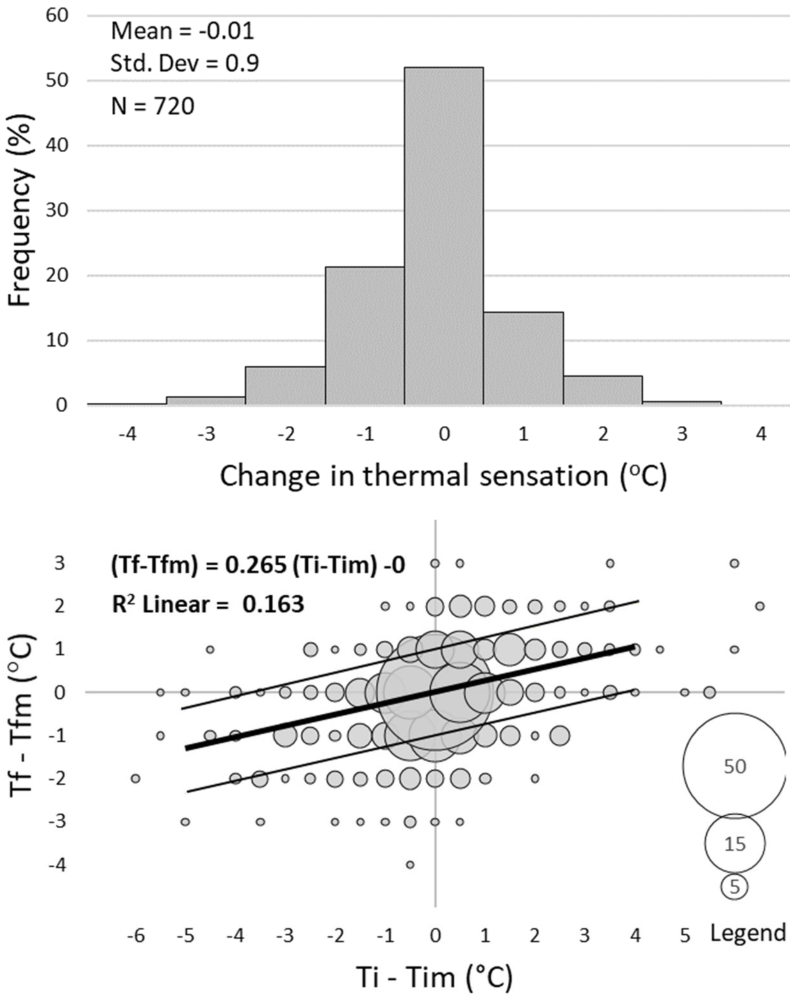
Japanese Act for Maintenance and Sanitation in Buildings recommends the range of 17~28ºC indoor temperature. From the current study and the linear regression model (Table 39 and Appendix X), we can calculate the respective clothing range as 0.33~0.66clo. In terms of real clothing ensembles, it means for example, wearing walking shorts and short sleeved shirt in summer, and trousers and long sleeved shirt in winter [Chapter 9, Table 7 in [68]]. It is well known that energy consumption in buildings is strongly dependent on the temperatures levels the occupants create with the use of air conditioning. With that respect, it is reasonable to suggest using clothing adjustment more intensively – levels lower than 0.33clo in summer in order to still feel comfortable at temperatures higher than 28ºC and, levels higher than 0.66clo in winter in order to still feel comfortable at temperatures lower than 17ºC.

When trying to establish the model for estimating the neutral temperature indoors, linear regression is believed to have some major drawbacks: 1) majority of votes are clustered around the central point of the thermal sensation scale (Figure 65) 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 [30]. In our analysis, the precision of the linear regression coefficient was improved following the usual analytical approach. Then, the comfort temperature was estimated using the Griffiths' method.

2.4.4. 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 [20], [30], [47].

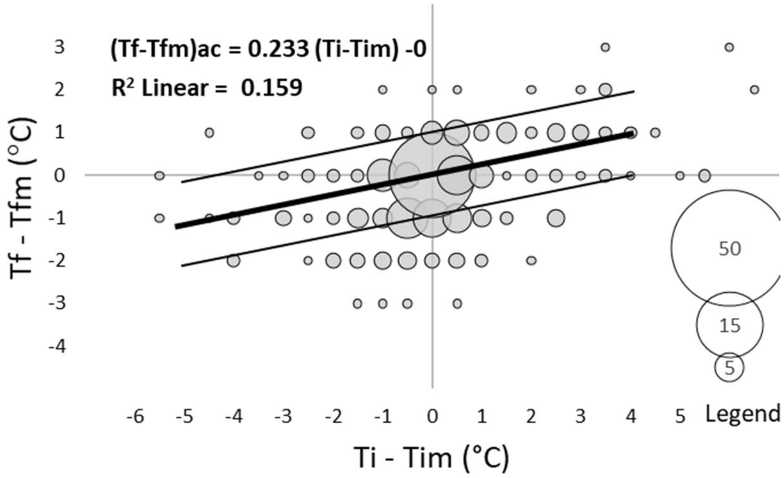
In order to apply this method to our data set, the mean thermal feeling (T_{fm}) and mean indoor temperature (T_{im}) were calculated for all the sets of data collected within a day in each of the 37 dormitory rooms for all the survey days within summer and winter. These values were the room-wise day-survey 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).



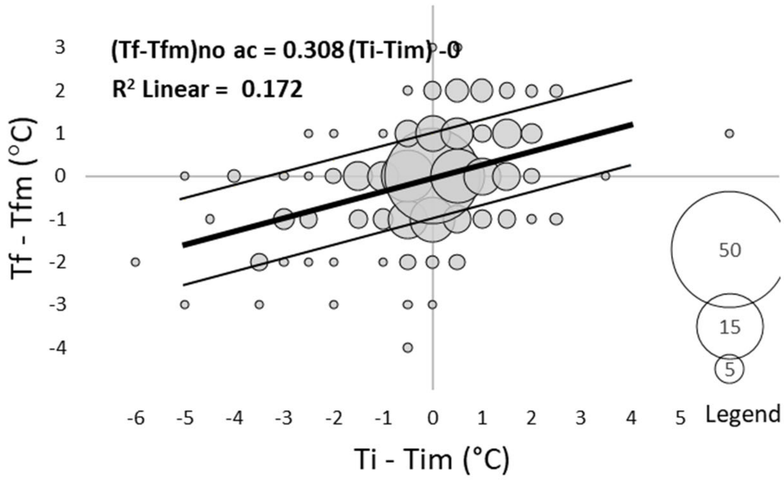
a)

b)

Figure 66 Room-wise day-survey averages in summer and winter a) Frequency distribution; b) Regression of all day surveys
** Note: Outer lines indicate the residual standard deviation.



a)



b)

Figure 67 Room-wise day-survey averages in summer and winter a) Regression of the day surveys in AC mode; d) Regression of the day surveys in no-AC mode; ** Note: Outer lines indicate the residual standard deviation.

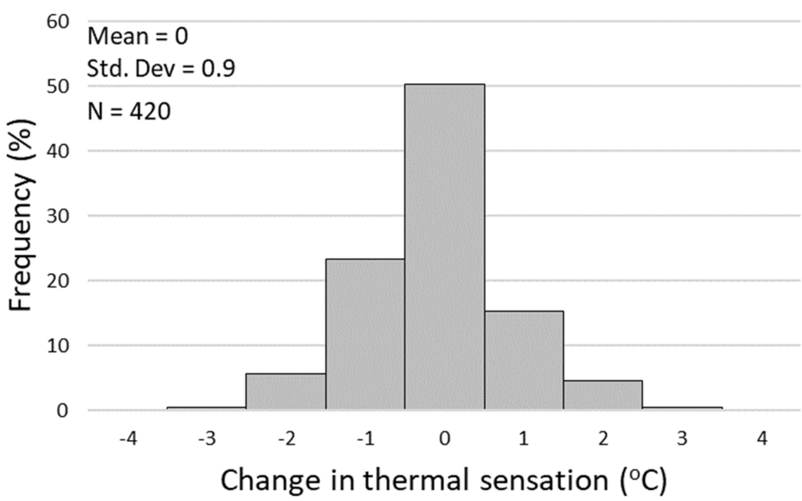
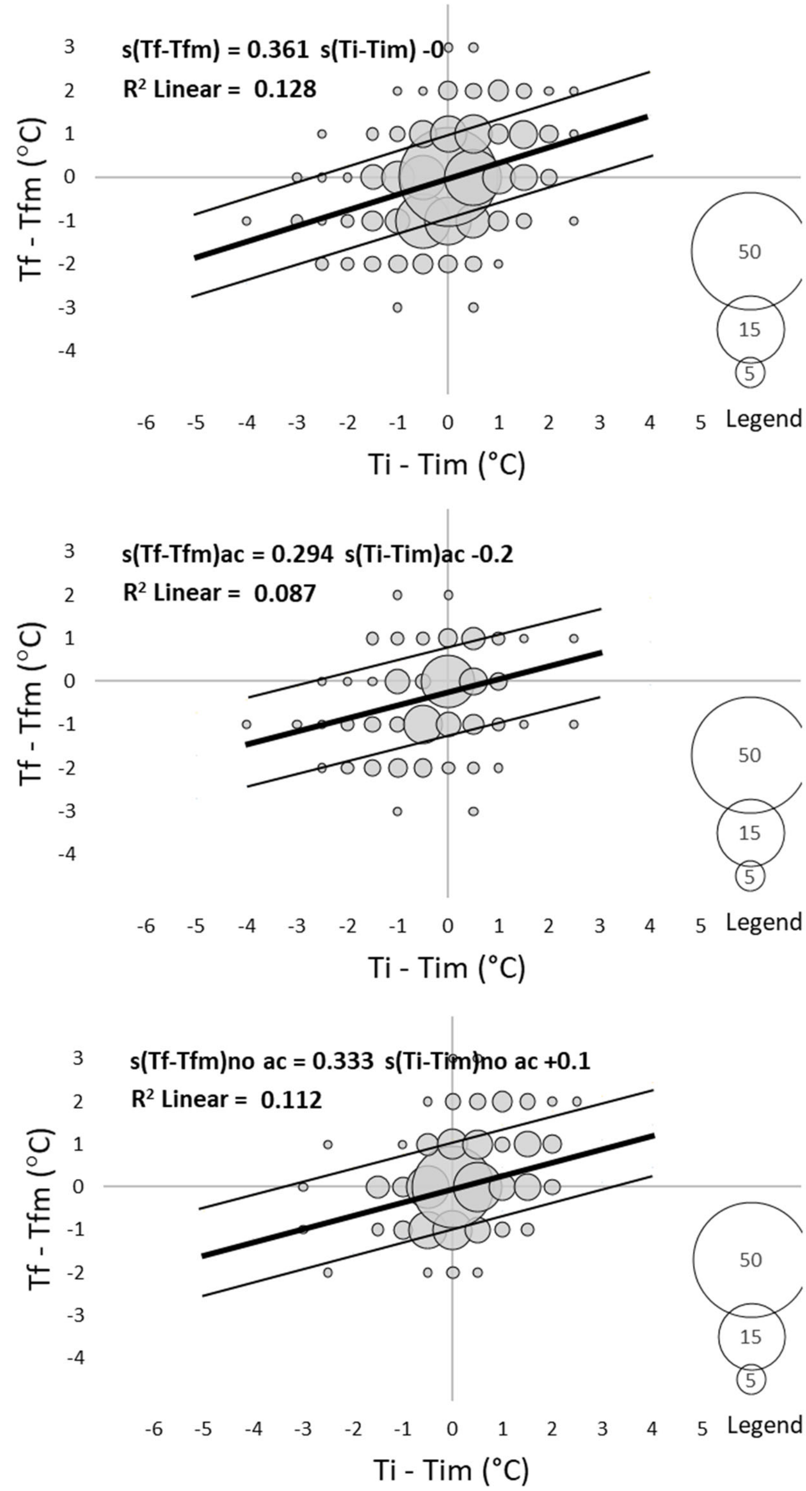


Figure 68 Room-wise day-survey averages in summer. Frequency distribution

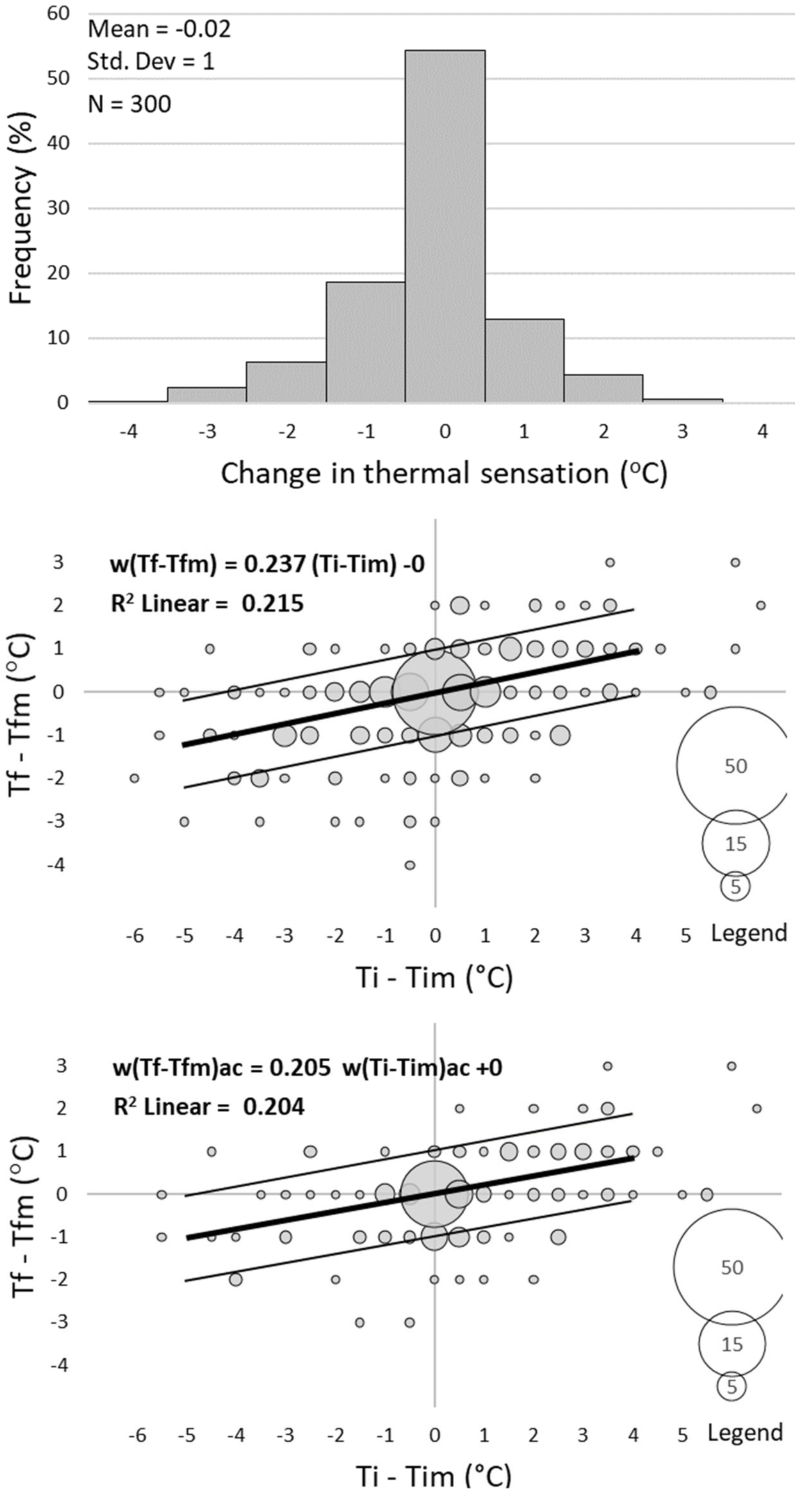


a)

b)

c)

Figure 69 Room-wise day-survey averages in summer a) Regression of all day surveys; b) Regression of the day surveys in AC mode; c) Regression of the day surveys in no-AC mode; ** Note: Outer lines indicate the residual standard deviation.



a)

b)

c)

Figure 70 Room-wise day-survey averages in winter a) Frequency distribution; b) Regression of all day surveys; c) Regression of the day surveys in AC mode; ** Note: Outer lines indicate the residual standard deviation.

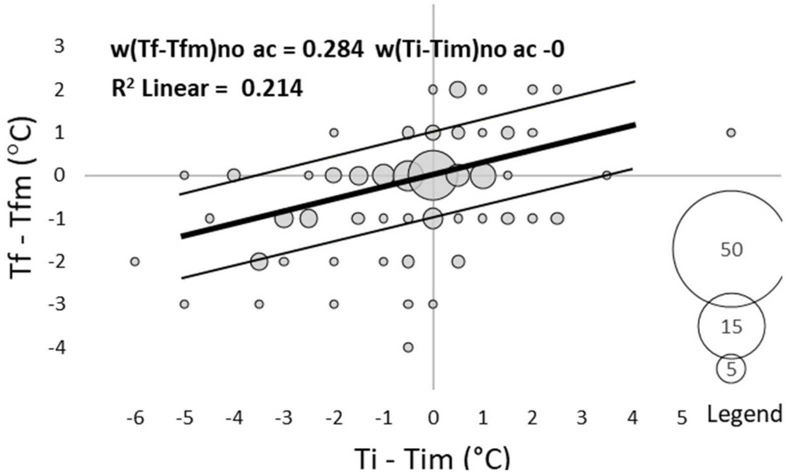


Figure 71 Room-wise day-survey averages in winter. Regression of the day surveys in no-AC mode; ** Note: Outer lines indicate the residual standard deviation.

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 season and air conditioning mode. Irrespective of season or mode, about 50% of the variability in subjective sensation was zero. Zero variability 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 δT_f: δT_i from both summer and winter votes demonstrated that when there was low to no variability in the temperature, there was low to no variability in the sensation vote too (from Figure 66 to Figure 71). The relation δT_f: δT_i was positive; however, it was stronger in free running mode. That means: when the variability in temperature increases (bigger fluctuations from the mean), the sensation vote variability is expected to also increase and, the sensation when there is no air conditioning changes quicker than when air conditioning is used. The sensitivity separately in summer and in winter kept the same trend only to be slightly stronger in summer (Figure 69) and, slightly weaker in winter (Figure 70, Figure 71). The linear regression equations are:

Eq. 32 Room-wise day-wise linear regression model (summer and winter)

$(T_f - T_{fm}) = 0.265\ (T_i - T_{im}) - 0.0$, ($N = 720$; $p < 0.001$; $R^2 = 0.16$; S.E.=0.86; F stat. = 139.8)

Eq. 33 Room-wise day-wise linear regression model in AC mode (summer and winter)

$(T_f - T_{fm})_{AC} = 0.233\ (T_i - T_{im})_{AC} - 0.0$, ($N = 310$, $p < 0.001$; $R^2 = 0.16$; S.E.=0.88; F stat. = 58.5)

Eq. 34 Room-wise day-wise linear regression model in no-AC mode (summer and winter)

$(T_f - T_{fm})_{no\ AC} = 0.308\ (T_i - T_{im})_{no\ AC} - 0.0$, ($N = 410$, $p < 0.001$; $R^2 = 0.17$; S.E.=0.83; F stat. = 84.9)

Eq. 35 Room-wise day-wise linear regression model (summer)

$s(T_f - T_{fm}) = 0.361\ s(T_i - T_{im}) - 0.0$, ($N = 420$, $p < 0.001$; $R^2 = 0.13$; S.E.=0.83; F stat. = 61.4)

Eq. 36 Room-wise day-wise linear regression model in AC mode (summer)

$s(T_f - T_{fm})_{AC} = 0.294\ s(T_i - T_{im})_{AC} - 0.2$, ($N = 145$, $p < 0.001$; $R^2 = 0.09$; S.E.=0.91; F stat. = 13.6)

Eq. 37 Room-wise day-wise linear regression model in no-AC mode (summer)

$s(T_f - T_{fm})_{no\ AC} = 0.333\ s(T_i - T_{im})_{no\ AC} + 0.1$, ($N= 275$, $p < 0.001$; $R^2= 0.11$; S.E.=0.76; F stat= 34.3)

Eq. 38 Room-wise day-wise linear regression model (winter)

$w(T_f - T_{fm}) = 0.237\ w(T_i - T_{im}) - 0.0$, ($N= 300$, $p< 0.001$; $R^2= 0.22$; S.E.=0.88; F stat.= 81.8)

Eq. 39 Room-wise day-wise linear regression model in AC mode (winter)

$w(T_f - T_{fm})_{AC} = 0.205\ w(T_i - T_{im})_{AC} - 0.0$, ($N= 165$, $p< 0.001$; $R^2= 0.20$; S.E.=0.83; F stat= 41.7)

Eq. 40 Room-wise day-wise linear regression model in no AC mode (winter)

$w(T_f - T_{fm})_{no\ AC} = 0.284\ w(T_i - T_{im})_{no\ AC} - 0.0$, ($N= 135$, $p< 0.001$; $R^2= 0.21$; S.E.=0.94; F stat= 58.5)

The constant in the linear regressions above (the regression gradient) defines the slope of the regression line – the steeper the slope, the more sensitive are the subjects to the change of indoor environment. The regression gradient however, needs further adjustment as this value does not account for the possibility of measurement errors. The adjusted coefficient is calculated using the Eq. 8 (see Chapter II, sub-section 2.4.3, page 39)

Table 40. Adjusted regression coefficients relative to season and air conditioning mode.

	Summer and winter			**Summer**			**Winter**		
	All	AC	No AC	All	AC	No AC	All	AC	No AC
b	0.26/K	0.23/K	0.31/K	0.36/K	0.29/K	0.33/K	0.24/K	0.20/K	0.28/K
$b_{adj.}$	0.27/K	0.25/K	0.32/K	0.38/K	0.32/K	0.35/K	0.25/K	0.22/K	0.31/K

Note: b is the regression coefficient from $\delta T_f : \delta T_i$ linear regressions (Eq. 32 to Eq. 40); $b_{adj.}$ Is the adjusted regression coefficient calculated using Eq. 8.

2.4.5. Griffiths' Method for Calculating Comfortable Temperature

Griffiths method estimates a temperature that is assumed comfortable based on the actual vote of neutral sensation and a regression coefficient. It is calculated using Eq. 9 (see Chapter II, sub-section 2.4.4, page 41)

Table 41 Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients relative to air conditioning mode (summer and winter)

		Regression coefficient (/K)	Calculated comfort temperature $_GT_c$ (°C)							
			N	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
Summer and Winter	**All data**	0.50	720	11.2	20.5	24.5	27.1	35.1	23.7	4.5
		0.33		9.6	20.2	23.9	27.5	36.3	23.6	5.0
		0.27 (see Table 40)		8.2	19.4	23.9	27.7	37.6	23.6	5.5
		0.25		7.6	19.2	23.9	27.8	38.2	23.5	5.8
		Voted (TC +1, +2, +3)	524	9.8	21.5	25.6	27.8	33.7	24.4	4.5
	AC mode	0.50	310	11.2	20.3	24.5	27.4	35.1	23.8	4.6
		0.33		10.0	19.5	23.8	28.2	36.3	23.8	5.5
		0.25 (see Table 40)		8.1	18.7	23.9	28.8	38.2	23.7	6.5
		Voted (TC +1, +2, +3)	246	13.2	21.0	25.1	27.3	33.7	24.2	4.1
	No AC mode	0.50	410	11.6	20.8	24.6	27.0	33.5	23.6	4.4
		0.33		9.6	20.2	23.9	26.9	34.6	23.5	4.6
		0.32 (see Table 40)		9.4	20.2	23.9	27.0	34.7	23.5	4.7
		0.25		7.6	19.4	24.1	27.3	36.4	23.4	5.3
		Voted (TC +1, +2, +3)	278	9.8	23.2	26.0	28.2	31.6	24.6	4.9

Table 42 Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients relative to air conditioning mode (summer)

		Regression coefficient (/K)	Calculated comfort temperature $_GT_c$ (°C)							
			N	**Min**	**Q1**	**Median**	**Q3**	**Max**	**Mean**	**SD**
Summer	**All data**	0.50	420	18.6	24.4	26.4	28.0	34.2	26.2	2.7
		0.38 (see Table 40)		16.7	23.7	26.2	28.4	35.5	**26.0**	3.3
		0.33		15.5	23.2	26.1	28.6	36.3	25.9	3.8
		0.25		12.6	22.1	25.5	29.3	38.2	25.5	5.0
		Voted (TC +1, +2, +3)	317	18.6	25.6	26.8	28.5	31.6	**26.9**	2.1
	AC mode	0.50	145	18.6	24.9	27.2	28.6	34.2	26.8	2.7
		0.33		15.5	24.1	27.2	29.6	36.3	27.0	3.9
		0.32 (see Table 40)		15.2	24.0	27.2	29.7	36.5	**27.0**	4.0
		0.25		12.6	23.2	27.6	30.6	38.2	27.2	5.1
		Voted (TC +1, +2, +3)	117	18.6	25.6	26.5	27.9	30.2	**26.4**	2.2
	No AC mode	0.50	275	18.8	24.2	26.0	27.6	33.5	25.9	2.6
		0.35 (see Table 40)		16.2	23.2	25.5	27.8	34.4	**25.4**	3.4
		0.33		15.7	22.9	25.5	27.9	34.6	25.3	3.6
		0.25		12.8	21.5	25.1	28.4	36.4	24.6	4.7
		Voted (TC +1, +2, +3)	200	19.8	25.5	27.1	28.9	31.6	**27.2**	2.0

Table 43 Descriptive statistics of comfort temperature calculated by Griffiths' method using different regression coefficients relative to air conditioning mode (winter)

		Regression coefficient (/K)	Calculated comfort temperature $_{G}T_{c}$ (°C) N	Min	Q1	Median	Q3	Max	Mean	SD
Winter	All data	0.50	300	11.2	17.5	19.7	22.8	35.1	20.2	4.2
		0.33		9.6	17.0	20.3	23.8	36.2	20.5	4.8
		0.25 (see Table 40)		7.6	16.2	20.2	25.1	37.1	**20.8**	5.8
		Voted (TC +1, +2, +3)	207	9.8	17.3	20.5	23.7	33.7	**20.7**	4.7
	AC mode	0.50	165	11.2	18.3	20.5	23.9	35.1	21.2	4.4
		0.33		10.0	17.1	20.8	24.2	36.2	20.9	5.1
		0.25		8.1	16.0	20.6	24.8	37.1	20.7	6.0
		0.22 (see Table 40)		7.0	15.3	20.1	25.4	37.7	**20.6**	6.6
		Voted (TC +1, +2, +3)	129	13.2	19.3	21.5	24.4	33.7	**22.2**	4.3
	No AC mode	0.50	135	11.6	16.1	18.8	21.7	29.6	19.0	3.7
		0.33		9.6	16.8	19.4	23.3	32.7	20.0	4.4
		0.31 (see Table 40)		9.2	16.8	19.4	23.8	33.3	**20.1**	4.6
		0.25		7.6	16.6	19.9	25.4	35.6	20.8	5.5
		Voted (TC +1, +2, +3)	78	9.8	15.1	17.5	21.0	26.8	**18.1**	4.1

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.

Griffiths' coefficient accounts for the sensitivity to indoor temperature change and the value used predominantly is a=0.5 [20], [30]. However, previous research explores $_{G}T_{c}$ at two more values: a=0.25, and a=0.33 [51], [74], as well as the value of the adjusted coefficient $b_{adj.}$ derived from room-wise day-survey analysis if conducted [30]. In the current study, $_{G}T_{c}$ was estimated using the values for the Griffiths' coefficient previously established as well as the adjusted value from the current study. The results are presented in Table 41, Table 42 and Table 43. The current field survey directly asked about the comfort. It made it possible to compare the calculated $_{G}T_{c}$ and the observed $_{voted}T_{c}$ (Table 41, Table 42 and Table 43).

There were notable differences in calculated comfort temperature and the actual voted comfort temperature – from 0.5°C to ~ 2°C in mean values as well as in the calculated ranges of comfort. In no-AC mode, the calculation overestimated the mean comfort for winter by 2°C and, underestimated it by the same difference in summer. In AC mode, the calculation again overestimated the mean comfort for winter but, the value overlapped with the voted mean in summer. As for the calculated ranges of comfort temperature – they were invariably expected to be much wider than the observed actually votes ranges.

Table 44 Correlation between Griffiths' comfort temperature and indoor temperature

		All data points					Using air conditioning (HT/CL)					Not using air conditioning (FR)				
		r	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**
S&W	${}_{G}T_c$: T_i	0.45	0.507	11.4	0.208	**<0.001**	0.49	0.747	5.9	0.237	**<0.001**	0.57	0.488	11.8	0.326	**<0.001**
S	${}_{G}T_c$: T_i	0.18	0.286	18.3	0.031	**<0.001**	0.06	0.112	24.0	0.004	0.467	0.22	0.390	14.8	0.048	**<0.001**
W	${}_{G}T_c$: T_i	0.29	0.365	13.6	0.086	**<0.001**	0.35	0.540	9.0	0.120	**<0.001**	0.38	0.433	12.7	0.135	**<0.001**

NOTE: ${}_{G}T_c$: Calculated comfort temperature using Griffiths' method (°C); T_i: Indoor temperature (°C). ** See also Appendix VAppendix X for graphical representations of regressions

Table 45 Correlation between comfort temperature (calculated and voted) to outdoor temperature

		All data points					Using air conditioning (HT/CL)					Not using air conditioning (FR)				
		r	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**	**r**	**a**	**β**	**R^2**	**p**
Summer and Winter	${}_{G}T_c$: T_{rm}	0.44	0.308	19.4	0.197	**<0.001**	0.49	0.383	19.1	0.241	**<0.001**	0.53	0.329	18.6	0.278	**<0.001**
	${}_{G}T_c$: T_{od}	0.43	0.223	19.8	0.185	**<0.001**	0.48	0.274	19.7	0.234	**<0.001**	0.51	0.245	18.9	0.261	**<0.001**
	${}_{V}T_c$: T_{rm}	0.70	0.402	18.8	0.488	**<0.001**	0.53	0.260	21.0	0.282	**<0.001**	0.87	0.599	15.3	0.758	**<0.001**
	${}_{V}T_c$: T_{od}	0.67	0.290	19.4	0.449	**<0.001**	0.51	0.181	21.5	0.256	**<0.001**	0.86	0.466	15.4	0.743	**<0.001**
Summer	${}_{G}T_c$: T_{rm}	0.21	0.381	18.3	0.043	**<0.001**	0.09	0.214	22.6	0.008	0.290	0.16	0.300	19.4	0.026	**<0.05**
	${}_{G}T_c$: T_{od}	0.15	0.207	20.7	0.023	**<0.05**	0.04	0.073	25.1	0.002	0.623	0.10	0.138	21.9	0.010	0.106
	${}_{V}T_c$: T_{rm}	0.57	0.658	13.6	0.325	**<0.001**	0.52	0.671	12.5	0.269	**<0.001**	0.71	0.774	11.8	0.510	**<0.001**
	${}_{V}T_c$: T_{od}	0.56	0.474	14.7	0.313	**<0.001**	0.49	0.464	14.1	0.236	**<0.001**	0.71	0.563	12.9	0.506	**<0.001**
Winter	${}_{G}T_c$: T_{rm}	0.03	0.126	20.2	0.001	0.580	0.03	0.123	20.1	0.001	0.727	0.07	0.221	19.2	0.005	0.424
	${}_{G}T_c$: T_{od}	-0.02	-0.034	20.9	0.000	0.789	0.01	0.029	20.5	0.000	0.882	-0.02	-0.033	20.3	0.000	0.838
	${}_{V}T_c$: T_{rm}	0.11	0.361	19.1	0.013	0.108	0.02	0.069	21.9	0.001	0.791	0.30	0.856	14.3	0.088	**<0.05**
	${}_{V}T_c$: T_{od}	-0.13	-0.211	21.7	0.016	0.065	-0.12	-0.193	23.1	0.016	0.159	0.15	0.226	16.8	0.022	0.193

NOTE: ${}_{G}T_c$: Comfort temperature calculated using Griffiths' method (°C); ${}_{V}T_c$: Voted comfort temperature – the recorded indoor temperature when TC vote is 1, 2 or 3 (slightly comfortable, comfortable, very comfortable). * Calculated ${}_{G}T_c$ (°C) uses the adjusted regression coefficients as in Table 40. ** Number of observations; Summer and Winter Stage (${}_{G}T_{c\ ALL}$=720; ${}_{G}T_{c\ AC}$=310; ${}_{G}T_{c\ noAC}$=410; ${}_{V}T_{c\ ALL}$=524; ${}_{V}T_{c\ AC}$=246; ${}_{V}T_{c\ noAC}$=278); Summer Stage (${}_{G}T_{c\ ALL}$=420; ${}_{G}T_{c\ AC}$=145; ${}_{G}T_{c\ noAC}$=275; ${}_{V}T_{c\ ALL}$=317; ${}_{V}T_{c\ AC}$=117; ${}_{V}T_{c\ noAC}$=200); Winter Stage (${}_{G}T_{c\ ALL}$=300; ${}_{G}T_{c\ AC}$=165; ${}_{G}T_{c\ noAC}$=135; ${}_{V}T_{c\ ALL}$=207; ${}_{V}T_{c\ AC}$=129; ${}_{V}T_{c\ noAC}$=78). ** See also Appendix W for graphical representations of regressions

The calculated comfort temperature using the Griffith's method had strong correlation to the measured indoor temperature especially when considering both seasons together. In winter the correlation was weaker, while in summer in AC mode there was even no correlation. We can assume that using air conditioning causes the indoor environment to vary extensively thus lowering the predictability of the method for calculating comfort temperature.

For the year, the mean comfort temperature can be estimated as 24ºC. The ranges of 80% comfort differ significantly relative to mode and, in AC mode the range is by 6ºC wider (15~33ºC in AC mode and, 17~29ºC in no-AC mode).

In summer, there is a significant difference of 2ºC in mean comfort temperature (27ºC in AC mode and, 25ºC in no-AC mode). The ranges of 80% comfort again differ significantly relative to mode and, in AC mode the range is by 1ºC wider (22~32ºC in AC mode and, 20~29ºC in no-AC mode).

In winter, the mean comfort temperature can be estimated as 20ºC. The ranges of 80% comfort again differ significantly relative to mode and, in AC mode the range is by 4ºC wider (13~29ºC in AC mode and, 15~27ºC in no-AC mode).

2.5. Comparison with Related Standards

One of the fundamental assumptions of the adaptive model is that the comfort indoor temperature would be in relation with the seasonal outdoor temperature provided that the outdoor conditions are not unpleasantly hot or unpleasantly cold [p.60, [20]]. The outdoor temperature can be represented by the daily mean as provided by the local meteorological station or by the running mean as calculated using Eq. 1.

A number of international standards regulate the indoor environment [19]. They have established thermal comfort models to predict the indoor comfort temperature based on the mean/ running mean outdoor temperature. The comfort temperature relative to use of air conditioning as correlated to outdoor air temperature subsection 2.4.5 (page 124) was compared to EN 16978-1 [78] and ASHRAE [26] (Figure 72 and Appendix Y).

For the year, we observed significant correlation of the calculated comfort temperature to both irrespective of air conditioning mode (Table 45 and Appendix W). However, in summer and winter separately and, relative to AC mode, there was hardly any correlation. The voted comfort voted however, remained strongly correlated to outdoors in summer too. In winter neither the calculated, nor the voted comfort temperature had any correlation to outdoors.

EN 16798-1 [78] recommends temperature range of 20-25ºC for heating season and, 23-26ºC for the cooling season. ASHRAE [26] recommends temperature range of 20-23ºC for heating season and, 23-27ºC for the cooling season (at still air). The Japanese Act for Maintenance of Sanitation in Buildings recommends temperature range of 17-28ºC throughout the year. As part of the energy conservation measures of Japan, METI (Ministry of Economy, Trade and Industry of Japan) recommends indoor temperatures lower than 20ºC in winter and, higher than 28ºC in summer.

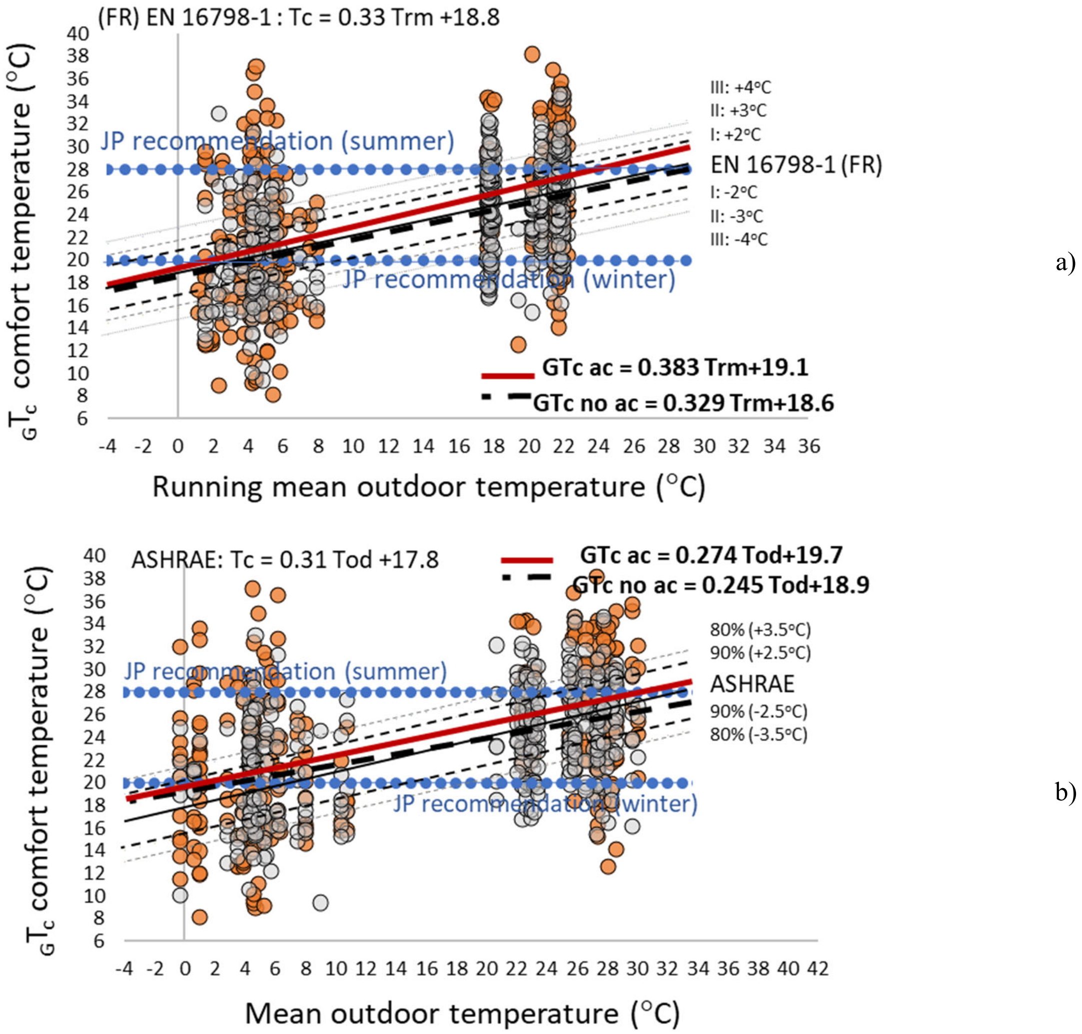


Figure 72 Comparison of comfort temperature with standards: a) EN 16978-1 and b) ASHRAE

Comparing to EN 16978-1, the model for comfort temperature derived from the current study, almost overlaps with the model of the standard in FR mode. In AC mode, the model is very close and, remains within the boundaries of buildings in Category I (the highest). Comparing to ASHRAE, the slope of our model is a little less steep but, remains invariably within the 90% comfortable band. Most of the data points and the model itself fit within 17-28ºC band. However, METI recommendation is challenging to meet. Our model fits within the recommended threshold summer and winter temperatures (28ºC and 20ºC respectively), however METI recommends above 28ºC and below 20ºC – the complete opposite. The summer and winter datasets are split in half by the recommended threshold lines, giving the reason to believe that about half of the occupants will feel comfortable within the METI recommended ranges, However, about half would not. In their field survey Indraganti et al. [44] already questioned the rational basis for the METI requirements and the current study supports the idea that re-evaluation of these requirements is needed.

3. Conclusions for neutrality and comfort relative to season and air conditioning

A field survey about environmental comfort in typical university dormitory buildings in Japan was conducted during the summer and winter of 2017-2018. The aim of the study was 1) to snapshot the subjective thermal comfort of students living in university dormitories relative to temperature 2) to understand the difference, if any, between the temperature defined as neutral or comfortable and 3) to get an insight how tolerant are the students to their indoor environment.

Subjective votes were collected using traditional paper questionnaire. Simultaneously, measurements of physical parameters of the indoor and outdoor environment were conducted and the two data-sets were linked. The correlation of the subjective neutrality and comfort were investigated in relation to season and the use of air conditioning; as well as the effect of thermal sensation to occupants' preference and tolerance to their indoor environment.

The study revealed that the average indoor temperature in dormitory rooms in summer gravitates around 27ºC irrespective of air conditioning mode, while in winter it is 17ºC in FR and 22ºC in HT. The humidity in summer were very high, while in winter were very low. Indoor activity does not change throughout the year, while the clothing gets double in winter.

Throughout the year and, in summer separately, indoor and outdoor environmental parameters changed in respect, while in winter, the indoor environment had low to no relation to outdoors.

Mean subjective thermal responses were well related to outdoor conditions, except for the thermal acceptability. Irrespective of season and air conditioning mode, more than 87% of the students voted that the indoor environment was "acceptable". The subjective thermal votes were well correlated within each another in both investigated seasons and modes.

The use of air conditioning significantly affected the subjective votes of sensation, evaluation and preference.

In AC mode, within the range of 22~ 25ºC indoor temperature, the probability of occupants voting extended neutral is the highest, however it's below the recommended 80%. In no-AC mode, the probability of voting extended neutral barely reaches 80% within the same temperature range. In summer the respective ranges are 25-29ºC in AC mode and 22-26ºC in no-AC mode while in winter the ranges are overlapping at ~20-24ºC.

Much wider neutral temperature ranges were derived from linear regression analysis within the boundaries of the actual neutral votes. Neutral temperature can be estimates as 23ºC throughout the year (26ºC in summer and, 21ºC in winter). And, the ranges of 80% neutrality are 19-29ºC throughout the year (25-29ºC in summer and, 17-28ºC in winter). There was 3ºC difference in the mean neutral temperature in each season relative to the use of air conditioning.

The sensitivity to indoor environment did not vary much relative to the season and air conditioning. However, in summer, students seem to be a bit more sensitive to their indoor environment when air conditioning is on, while in winter it is the opposite – they appear almost twice more sensitive to the indoor environment when they do not use air conditioning. With the rising of the indoor neutral temperature, the subjects reduced their clothing and, the summer clothing was two times lighter than the winter one.

The mean comfort temperature for the year calculated using Griffiths' method, can be estimated as 24ºC (25-27ºC in summer and 20ºC in winter). The ranges of 80% comfort differed significantly relative to mode and, in AC mode the ranges were wider.

Comparing to the standards and recommendations regulating the adaptive comfort field, it was observed that the model for comfort temperature derived from the current study, is very close to the existing models in EN 16798-1 and in ASHRAE. However, METI recommendations are practically the opposite of the current study data and meeting them poses a real challenge. It appears that re-evaluation of these requirements is needed.

CHAPTER V

Conclusions. Initial Hypothesis in the Light of Results

Often, self-contradictory, the conundrum of providing comfortable, yet energy efficient built environment in a globalized world where occupants in buildings often change, is challenging the scientific field. We were interested in the concept of adaptive comfort and its flexibility, together with the great potential it holds for energy conservation. We expect that in Japan the necessity for new and renovated buildings for more or less temporary multi-national occupancy will gradually increase. In order to provide it, we first need to know what comfort is in said buildings. The purpose of the study therefore, was to determine what does comfort mean for multi-national occupants in Japan. The selected buildings were dormitories because of the short-term occupancy there, as well as the multi-nationality of their residents. Studies in offices and pure residences in Japan have been conducted by a plethora of researchers, however such research has neglected dormitory buildings so far. Dormitories are a unique combination of office and residence and we strongly believe they have higher potential to reveal the actual preferences of their occupants because 1) students live in private rooms where immediate social restraints are practically non-existent with the exception for the habitual or culturally predetermined ones; 2) the rooms are relatively small so no matter the energy consumption, the final financial burden cannot get excessive; 3) the occupants are young and assumingly still developing their finance managing attitude, so their indoor environment setting is expected to represent more genuinely their subjective preference.

The current study presents results obtained from a field survey about environmental comfort in typical university dormitory buildings in Japan conducted in the summer and winter of 2017-2018. Subjective votes were collected through a traditional paper questionnaire. Simultaneously, measurements of physical parameters of the indoor and outdoor environment were conducted and the two data-sets were linked. The correlation of the subjective neutrality and comfort were investigated in relation to nationality, season and air conditioning mode; as well as the effect of sensation to occupants' preference and tolerance to their indoor environment.

1. Hypothesis - Revised

The initial hypothesis was that, there will be differences in comfort and comfort temperature between Japanese and non-Japanese students and, that that the Japanese will be more accepting of their environment in any season. We expected such difference to be relative to season too, as well as to the use of air conditioning.

We expected that the current Japanese recommendations for summer and winter will reflect the actual Japanese vote better than the non-Japanese one and, that the Japanese subjects will be more accepting of their environment in any season. We did observe differences, where:

- The summer neutral indoor temperature was estimated as 26ºC for Japanese students and as 25ºC for non-Japanese. However, the highest probability of voting neutral for Japanese students was only 70-75% and it was estimated within 24~28ºC indoor temperature. For non-Japanese students it's above 80% within the same temperature range.
- The winter neutral indoor temperature could be estimated as 21ºC for Japanese students and as 22ºC for non-Japanese. However, the highest probability of voting neutral for Japanese students was only 65% and it was estimated within 19~22ºC indoor temperature. For non-Japanese students it's 75% within 19~24ºC indoors.
- Relative to air conditioning, neutral temperature can be estimates as 23ºC throughout the year (26ºC in summer and, 21ºC in winter). And, the ranges of 80% neutrality are 19-29ºC throughout the year (25-29ºC in summer and, 17-28ºC in winter). There was 3ºC difference in the mean neutral temperature in each season relative to the use of air conditioning.
- Japanese students were notably more sensitive to their indoor environment as compared to non-Japanese ones in both seasons
- The sensitivity to indoor environment did not vary much relative to the season and air conditioning. However, in summer, students seem to be a bit more sensitive to their indoor environment when air conditioning is on, while in winter it is the opposite – they appear

almost twice more sensitive to the indoor environment when they do not use air conditioning.

- With the rising of the indoor neutral temperature, the subjects reduced their clothing and, the summer clothing was two times lighter than the winter one. Obviously, the adaptive measure of clothing adjustment was put to practice. The energy consumption in buildings is strongly dependent on the temperatures levels the occupants create with the use of air conditioning. In that respect, it is reasonable to suggest using clothing adjustment more intensively – levels lower than 0.33clo in summer in order to still feel comfortable at temperatures higher than 28ºC and, levels higher than 0.66clo in winter in order to still feel comfortable at temperatures lower than 17ºC.
- The summer Griffiths' comfort temperature for both Japanese and non-Japanese subjects could be estimated as 26ºC. In winter it is 20ºC for Japanese and 22ºC for non-Japanese.
- The mean comfort temperature for the entire year, can be estimated as 24ºC (25-27ºC in summer and 20ºC in winter). The ranges of 80% comfort differed significantly relative to air conditioning mode and, in AC mode the ranges were wider.
- Voted thermal acceptability was invariably above 85% irrespective of nationality, season or air conditioning mode, which can be explained with the high level of personal control.

We expected that Japanese comfort vote will fall within the current recommendations for summer and winter in Japan. We observed that, for both Japanese and non-Japanese students, the yielded predicting models from the survey deviated from the models in the current international standards. In addition, the voted and the estimated neutrality and comfort in the study were mostly below the recommended minimum indoor temperature in summer (28ºC) and, above the recommended maximum indoor temperature in winter (20ºC) in Japan.

Similar was the case relative to air conditioning: the model for comfort temperature in the current study, was very close to the existing models in Europe and United States. However, Japanese recommendations are practically the opposite of the current study data and meeting them poses a real challenge. As Japanese recommendation is set considering the energy conservation, it is reasonable to further investigate how to make it possible to adjust the subjective neutral and comfort temperatures without compromising personal comfort. It appears that re-evaluation of these requirements is needed.

2. Significance. Contribution. Applicability - Revised

The number of foreign people moving to Japan for temporary or long term work/study will continue to increase together with the demand for decreasing energy consumption. Not only university dormitories, or dormitories for company employees, but more buildings are expected to fall under the category – multinational occupancy – temporary housing, evacuation shelters, office buildings. Depending on air conditioning to ensure comfortable living environment is undesirable solution.

Currently, Japan has demonstrated decrease of several percent in its energy consumption in respect to the Paris agreement. However, it is far from the long-term targeted decrease of almost 1.2 **times** less the current energy use.

The target can get closer with disseminating extensively the adaptive model by 1) more effective spread of knowledge that small personal behavioral changes can have a real and noticeable impact on the global energy consumption; with 2) providing better personal control over the indoor environment and with 3) widening the available and acceptable measured to adapt to the living/working conditions.

3. Limitations to the Study

There are certain limitations to the study as follows:

1) Because of Japanese lifestyle, some typical daily activities are conducted at a different height than usual – closer to or directly on the floor. This can include studying, sleeping, resting. The measuring instruments were placed in relation to the working plane in each particular room causing deviation from the standard established heights. In our survey, the devices were placed within 0.6m - 1.1m as opposed to the standard heights for measurements (0.1m, 0.6m, 1.1m for sedentary activity);

2) The measured air velocity suggested still air. This prevented any chance for analyzing further the effect of air velocity to the subjective thermal responses. In the future, it is necessary to conduct a field survey focused especially on air velocity, its correlation to behavioral adaptation and the effect on subjective thermal responses.

3) Operative indoor temperature is calculated from the radiant and the air temperature in the room. In a room for residential occupancy without large hot or cold surfaces, air temperature alone can

be used as an estimate of the operative temperature. However, we do acknowledge that not measuring the radiant temperature leaves room for unwanted assumptions and we do consider it a limitation to the study

4. Future work

The current research defined certain comfort temperature ranges for students living in dormitories in Japan relative to nationality and to air conditioning mode. The study was limited in several aspects one of which was the number of participants. The first step of the work in the future should be to collect more data so that the conclusions are grounded better.

As a next step, the investigated buildings should be modeled in a software for energy use analysis and the effect of the really observed subjective comfort ranges can be computed and evaluated. Following that, a set of refurbishment measures could be proposed. As one of the investigated buildings in TUT needs renovating soon (Kaikan), this set of measures can be applied and further investigated. A post-renovation field survey can prove or disprove the quality and effectiveness of the measures to the energy consumption of the building, as well as their effect on the subjective thermal responses about quality of indoor environment.

In addition, there are research laboratories in TUT which work is on improving the efficiency of photovoltaic solar cells; on improving air-conditioning systems; on investigating effects of clothing insulation or indoor foliage plants on subjective perception of indoor environment; on promoting natural ventilation in contemporary buildings; on human-robot interaction and more. All this knowledge can be utilized and implemented during the renovation. Comfort is flexible, variable, adaptive. Wide interdisciplinary collaboration can help not only to test the efficiency of every single measure applied, but also to investigate different combination of measures and discover the ones that ensure the optimum balance between comfort and energy consumption suitable for Japanese climatic condition and lifestyle.

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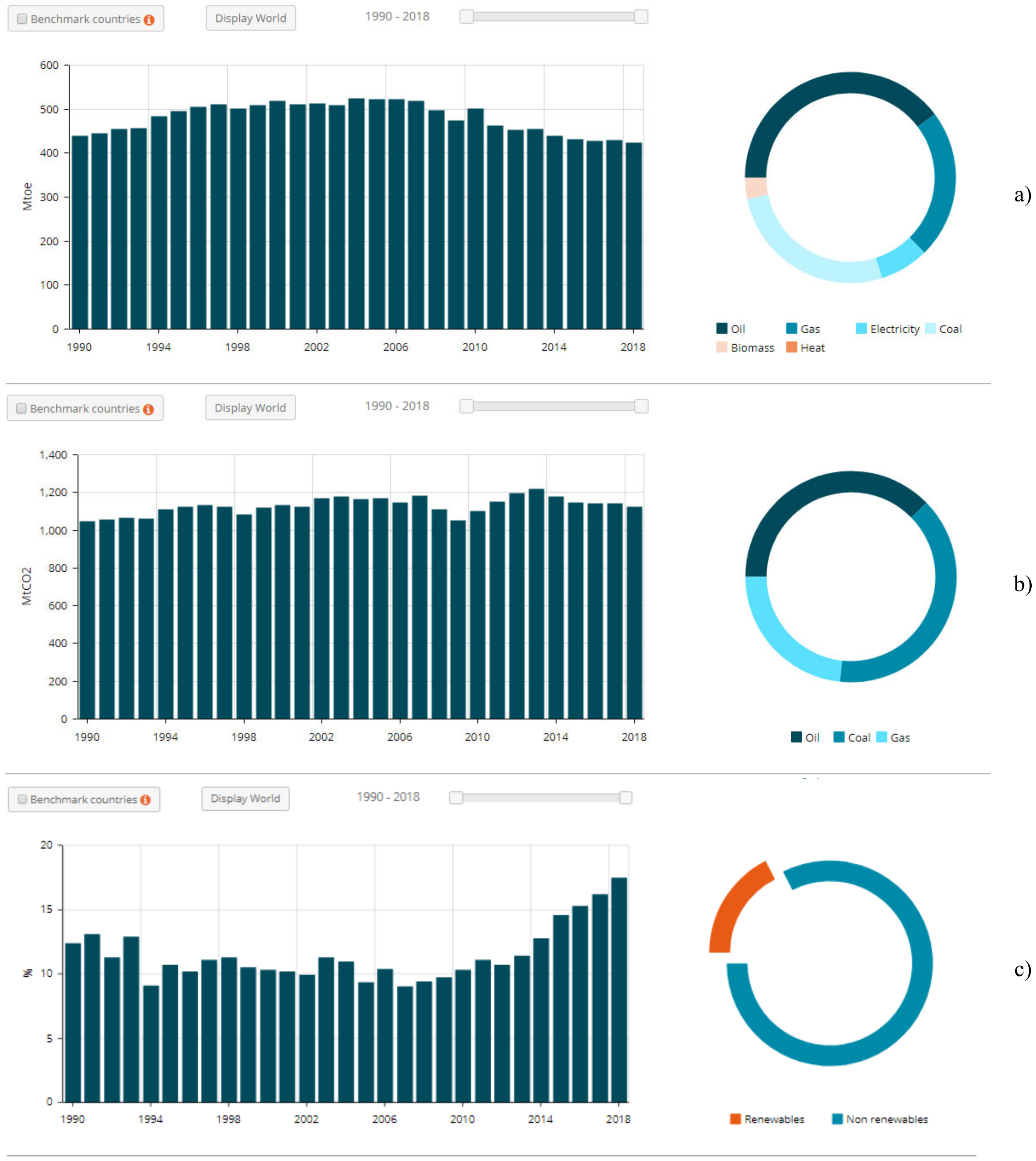
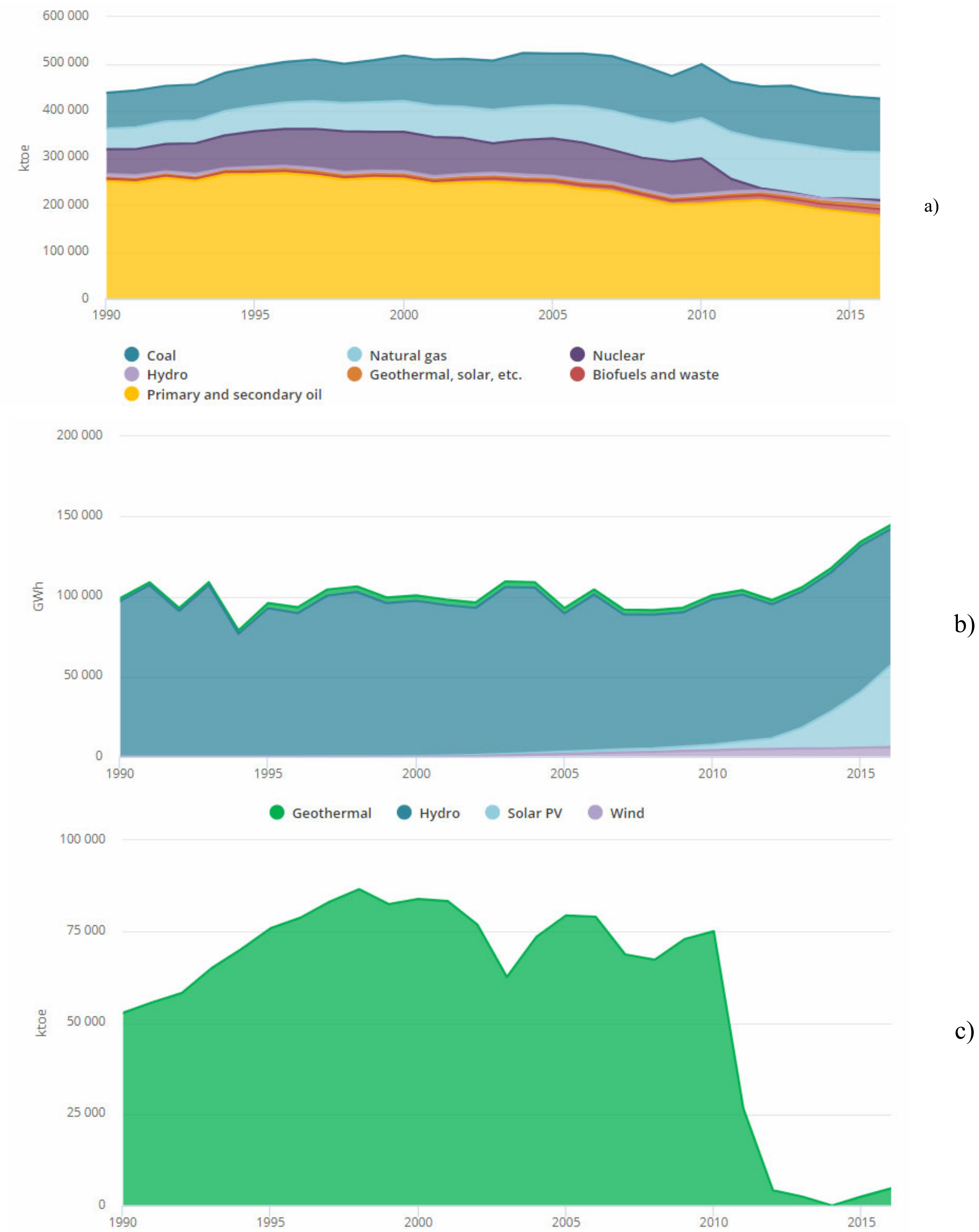
Appendix A. Japan. Trends in energy consumption over 1990-2018



Appendix Figure A-1. Japan. Trends over 1990-2018. a) Total energy consumption (in Mtoe). b) Total CO_2 emissions (in $MtCO_2$). c) Renewable energy use (% in electricity production). Source Enerdata [10]

[10] https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

Appendix B. Japan. Trends in energy supply over 1990-2016



Appendix Figure B-1. Japan. Trends over 1990-2016: a) Total primary energy supply by source, b) Renewable electricity generation by source, c) Nuclear energy production. Source IEA (International Energy Agency)[11]

[11] https://www.iea.org/statistics/?country=JAPAN&year=2016&category=Energy%20supply&indicator=TPESbySource&mode=chart&dataTable=BALANCES

Appendix C. Set of questionnaires in English

Toyohashi University of Technology
Building Environmental Engineering Laboratory

International Student Dormitory (Kaikan) Environmental Survey Questionnaire

This environment survey questionnaire consists of the following 3 parts.

Part 1: Questionnaire about health condition – Part 1(1): general health (to be filled in **once at the beginning of survey**) and Part 1(2): health condition at the day (to be filled in **each day just after waking up**)

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

Part 3: Sketch of the room layout including the places of the measurement devices and memo field (to be filled it in **at the beginning of survey** – we help with doing the sketch)

[Before answering the questionnaire, please pay attention to the following] ※ Please, read before answering:

- Please answer the questionnaire after staying AT LEAST 30 MINUTES inside the room for acclimatization.
- Please, ALWAYS note the date and time, because IT IS THE LINK between the objective and subjective data.
- Please, answer the questionnaire, based on the actual feeling AT THE MOMENT you fill it in.
- The information gathered from this questionnaire will be used for research purposes only and will not be provided to third parties.
- In the Part 1 - questionnaire about "health condition" please, answer about your normal life, health condition, sleep, etc.
- In the Part 2 - questionnaire about "subjective perception of indoor environment" please, answer while SITTING ON YOUR CHAIR IN YOUR PERSONAL ROOM.
- In Part 3 please draw a simple sketch of the layout of your room, the position and height of the measuring devices (**we can do this for you**). Please, write in the memo field only if the measuring equipment falls, stops working or breaks down. In such case, please write down the discovery time and explain the situation briefly.
- IN CASE THE MEASURING DEVICE STOPS RECORDING OR GETS DAMAGED IN ANY WAY, UNPLUG THE POWER SUPPLY AND NOTIFY THE INVESTIGATORS AS SOON AS POSSIBLE (Yokose or Vanya).

[Investigators: Building Environmental Engineering Laboratory (Laboratory of professor Tsuzuki)]

Hiroki Yokose (D2 - 609): e - mail: h153550@edu.tut.ac.jp; tel: 080 - 1100 – 7799 (in Japanese)

Vanya (D2 - 610): e - mail: vaniadraganova@abv.bg; tel: 090 – 4259 - 8855 (in English)

Professor Kazuyo Tsuzuki: email: ktsuzuki@ace.tut.ac.jp

Toyohashi University of Technology
Building Environmental Engineering Laboratory

Global Student Dormitory
Environmental Survey Questionnaire

This environment survey questionnaire consists of the following 3 parts.

Part 1: Questionnaire about health condition – Part 1(1): general health (to be filled in **once at the beginning of survey**) and Part 1(2): health condition at the day (to be filled in **each day just after waking up**)

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

Part 3: Sketch of the room layout including the places of the measurement devices and memo field (to be filled it in **at the beginning of survey** – we help with doing the sketch)

[Before answering the questionnaire, please pay attention to the following] ※ Please, read before answering:

- Please answer the questionnaire after staying AT LEAST 30 MINUTES inside the room for acclimatization.
- Please, ALWAYS note the date and time, because IT IS THE LINK between the objective and subjective data.
- Please, answer the questionnaire, based on the actual feeling AT THE MOMENT you fill it in.
- The information gathered from this questionnaire will be used for research purposes only and will not be provided to third parties.
- In the Part 1 - questionnaire about "health condition" please, answer about your normal life, health condition, sleep, etc.
- In the Part 2 - questionnaire about "subjective perception of indoor environment" please, answer while SITTING ON YOUR CHAIR IN YOUR PERSONAL ROOM.
- In Part 3 please draw a simple sketch of the layout of your room, the position and height of the measuring devices (**we can do this for you**). Please, write in the memo field only if the measuring equipment falls, stops working or breaks down. In such case, please write down the discovery time and explain the situation briefly.
- IN CASE THE MEASURING DEVICE STOPS RECORDING OR GETS DAMAGED IN ANY WAY, UNPLUG THE POWER SUPPLY AND NOTIFY THE INVESTIGATORS AS SOON AS POSSIBLE (Yokose or Vanya).

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Professor Kazuyo Tsuzuki: email: ktsuzuki@ace.tut.ac.jp

4. **General Lifestyle Questions:**

4.1. Do you smoke?

1 – I have never smoked **2** - I quit one or more years ago **3** – I quit within the last year

4 – I smoke less than 20 cigarettes a day **5** - I smoke around 20 to 40 cigarettes a day **6** – I smoke more than 40 cigarettes a day

4.2. How often do you drink alcohol within a week (how many days of a week)?

1 – I don't drink **2** – 2 days of a week **3** – 3 to 5 days of a week **4** – 6 or more days of a week

4.3. In case you drink, how much do you drink per day? (________________________)

4.4. Do you walk or do you do any exercise during the day?

1 – Almost no activity **2** – Moderately active **3** – Very active

4.5. How often do you walk or do any other exercise within a week? (________________________)

4.6. How intensive/hard exercises you do?

1 – Very hard **2** – Hard **3** – Normal **4** – Moderately easy **5** – Very easy

5. **General Questions About Your Body and Illness Predisposition?**

5.1. Can you easily endure hot environment?

1 – It is easy to endure heat **2** – It's moderately easy to endure heat **3** – I cannot say **4** – It's moderately hard to endure heat **5** – It's very hard to endure heat

5.2. Can you easily endure cold environment?

1 – It is easy to endure cold **2** – It's moderately easy to endure cold **3** – I cannot say **4** – It's moderately hard to endure cold **5** – It's very hard to endure cold

5.3. Do you sweat a lot?

1 – I sweat very intensively **2** – I sweat moderately intensive **3** – I cannot say **4** – I sweat a little **5** – I almost don't sweat

5.4. Are you sensitive to cold?

1 – I don't think so **2** – Slightly sensitive **3** – I cannot say **4** – Very sensitive **5** – Extremely sensitive

5.5. If the temperature in the room drops, do you notice immediately?________ Yes No

5.6. Do you feel cold even during summer?________ Yes No

5.7. Are you often barefoot in summer?________ Yes No

5.8. In summer, in a room with air conditioner on, when other people don't feel cold, do you feel cold? Yes No

6. **General Questions About Sleeping?**

6.1. Do you go to sleep at almost same time every day?________ Yes (at____pm) No

6.2. Do you get up at almost same time every day?________ Yes (at____am) No

6.3. Is your sleeping time almost the same every day?________ Yes (____hours) No

6.4. How good is the quality of your sleep?

1 – Good **2** – Moderately good **3** – I cannot say **4** – Somewhat bad **5** – Bad

6.5. How long does it take you to fall asleep?________around (   ) minutes

6.6. Do you usually wake up during the night to go to the toilet?________ Yes, around (   ) times No

6.7. Do you usually wake up during the night (other than to go the toilet)?____ Yes, around (   ) times No

6.8. Do you snore?

1 – I snore a lot **2** – Moderately **3** – I cannot say **4** – I hardly ever snore **5** – I don't snore **6** - I don't know

Part 1 (1): Questionnaire about general health condition (Please, fill it in only once at the beginning of Week 1)							
Date and time:	year	month		day	hour (am/pm)		min
Room number:				Name:			
Age:	Gender:	M / F		Height:	cm	Weight:	kg

Please, circle/tick the appropriate number/answer of fill in (the brackets)

What is your nationality?

- ☐ Japanese
- ☐ Indonesian
- ☐ Malaysian
- ☐ South Korean
- ☐ Vietnamese
- ☐ Thai
- ☐ Chinese
- ☐ Indian
- ☐ German
- ☐ Other (*please specify*)

What is your ethnicity?

- ☐ Asian
- ☐ White
- ☐ Black
- ☐ Hispanic / Latin
- ☐ Indian
- ☐ Middle Eastern
- ☐ Passific Islander
- ☐ Other (*please specify*)

What is your religion?

- ☐ Shintoism
- ☐ Buddhism
- ☐ Confucianism
- ☐ Christianity (*branch, please specify*)………
- ☐ Islam (*branch, please specify*)…………………
- ☐ Hinduism
- ☐ Atheist
- ☐ Other (*please specify*)

Until this moment, how long have you been living in Japan? (______________________________)

Is your daily life influenced by your religion?

- ☐ Yes, very much
- ☐ Yes, not that much
- ☐ Not at all

1. General Health Condition Questions:

1.1. Have you ever had any severe illness in the past? Yes No
In case your answer is "Yes" please specify what illness: (______________________________)

1.2. Are you suffering from some illness at the moment? Yes No
In case your answer is "Yes" please specify what illness: (______________________________)

1.3. Do you suffer from arrhythmia (irregular heart/pulse rhythm)? Yes No

2. In case you regularly practiced (in the past) any kind of sports, please describe your sports history:

Time Interval:	Type of Sports	Frequency of Practice
(Example: from age 20 to age 22)	(Example: Kendo)	(Example: once a week)
(____________)	(____________)	(____________)
(____________)	(____________)	(____________)
(____________)	(____________)	(____________)

3. In case you regularly practice (now) any kind of sports, please describe:

Time Interval:	Type of Sports	Frequency of Practice
(____________)	(____________)	(____________)
(____________)	(____________)	(____________)
(____________)	(____________)	(____________)

Part 1 (2): Questionnaire about health condition during the day (Please, fill it in **every day when you wake up**)

Date and time: year month day hour (am/pm) min

Please, answer about your health condition TODAY. Circle the appropriate number/answer of fill in (the brackets)

1. Was your day yesterday as usual (nothing extraordinary happened)?............Yes No
2. Did you have dinner last night?............Yes, around ( ) pm No
3. Did you drink last night?............Yes No
4. Did you have a bath (shower) last night / this morning?............Yes, (shower / bath) at ( ) am/pm No
5. At what time did you go to bed last night?............At around ( ) am/pm
6. At what time did you fall asleep last night?............At around ( ) am/pm
7. Did you fall asleep easily or it was hard to fall asleep?

   1 – I fell asleep almost immediately **2** – It took me a while to fall asleep **3** – It took me long time to fall asleep **4** – I could not sleep at all
8. Approximately how long did it take to fall asleep?(............)
9. How good was the quality of your sleep last night?
   In case your answer is (1, 2 or 3) was there a specific reason in your opinion?(............)

   1 – Very bad **2** – Bad **3** – Somewhat bad **4** – Somewhat good **5** – Good **6** – Very good
10. Are you satisfied with the sleep last night?

    1 – Very dissatisfied **2** – Dissatisfied **3** – Slightly dissatisfied **4** – Slightly satisfied **5** – Satisfied **6** – Very satisfied
11. Was your sleep deep or light last night?

    1 – Very deep **2** – Deep **3** – Slightly deep **4** – Slightly light **5** – Light **6** – Very light
12. Approximately how many times did you wake up last light?(............)
13. At what time did you wake up this morning?............At around ( ) am/pm
14. After waking up, did you feel your head clear or you were still sleepy?

    1 – Very sleepy **2** – Sleepy **3** – Slightly sleepy **4** – Slightly clear **5** – Clear **6** – Very clear
15. Did it cause you trouble to wake up early and not have the chance to sleep more?(............)
16. Did you have breakfast this morning?............Yes, at ( ) am No
17. Did you have some medicine this morning?............Yes, (what medicine?) No
18. Did you defecate this morning?............Yes No
19. How do you feel NOW?

    1 – I'm feeling good **2** – I am a bit tired **6** – I am very tired
20. Now, do you have symptoms of any of the following? (please, circle the appropriate answer)

    Cold Diarrhea Stomachache Headache Nausea Soar throat Anemia Dizziness None of these

THANK YOU FOR PARTICIPATING IN THE SURVEY

6.9. Do you have good quality of sleep (i.e. when you wake up you feel refreshed)?

1 – Very good | **2** – Moderately good | **3** – I cannot say | **4** – Moderately bad | **5** – Very bad

6.10. Do you have deep sleep?

1 – Very deep | **2** – Moderately deep | **3** – I cannot say | **4** – Moderately light sleep | **5** – Very light sleep

6.11. Do you wake up earlier than you wanted?

1 – Very often | **2** – Sometimes | **3** – I cannot say | **4** – Hardly ever | **5** – Never

6.12. How do you feel after waking up

1 – Refreshed | **2** – Somewhat refreshed | **3** – I cannot say | **4** – Not bad, but not refreshed | **5** – My body and head are heavy, it is hard to wake up

6.13. How do you usually wake up?

1 – I wake up naturally | **2** – I am using alarm clock | **3** – Someone calls me and I wake up | **4** – I wake up because I must go to the toilet | **5** – Sunlight or Room brightness | **4** – Because of the heat or coldness of the room | **5** – Other (______________)

7. General Lifestyle Questions

7.1. How do you cool your room in summer?

1 – I quickly turn on the air conditioner | **2** – I use air conditioner or electric fan | **3** – I rarely need cooling

7.2. What do you use for cooling?(____)

7.3. How do you heat your room in winter?

1 – I quickly turn on the heater | **2** – I wear as thick clothing as possible | **3** – I rarely need heating

7.4. What do you use for heating?(____)

THANK YOU FOR PARTICIPATING IN THE SURVEY

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 blightness 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- ④ How 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 minutes 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 minutes did you eat a snack or meal? ☐ YES ☐ NO	**8-④ Within THE LAST 30 minutes** did you smoke a cigarette? ☐ YES ☐ NO
8-③ Within THE LAST 30 minutes did you have a drink that was: YES / NO ☐ ☐ HOT ☐ ☐ COLD ☐ ☐ Caffeinated	**8-⑤ Within THE LAST 30 minutes** did you adjust your clothing? (*if YES, please describe briefly*) ☐ YES ☐ NO

THANK YOU FOR PARTICIPATING IN THERMAL COMFORT SURVEY

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 ☐ very uncomfortable	1-③ Please state how would you prefer to be now: ☐ warmer ☐ no change ☐ cooler 1- ④ How 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- ④ How 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 ☐ 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- ④ How do you judge the odours in your room? ☐ Acceptable ☐ Unacceptable

Measuring Instruments Status (memo field)

In case the measuring device stops recording or gets damaged in any way, please unplug the power supply and notify the investigators AS SOON AS POSSIBLE. Take a brief note explaining the situation.

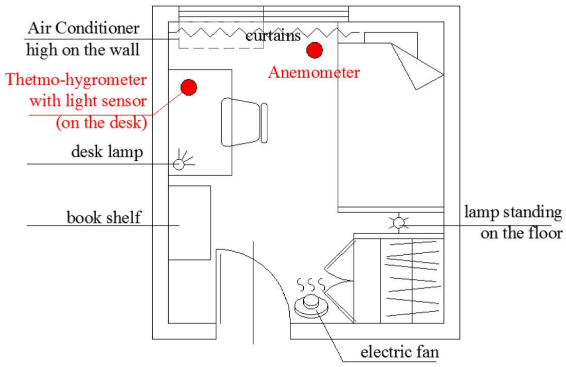
THANK YOU FOR PARTICIPATING IN THE SURVEY

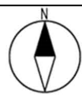
Part 3: Sketch of the Room Layout and Place of Devices (Please, fill it in only once.)

1. In the box, provided below, please draw a simple sketch of your room, showing the places of furniture, door and window. Use the example sketch.
   (If you find any difficulty doing that, contact the survey team and we will do it for you)
2. Please, refer to the example when positioning the measuring equipment. Some differences may occur depending on the room layout. Please, place thermo-hygrometer at 1.0m height close to your desk and the anemometer (air velocity sensor) close to your bed (the zone of the head). It is advisable the devices to be 20-30 cm away from adjacent walls to avoid influence from the wall.

Thermo-hygrometer (Temperature/Humidity/Light)

Anemometer (Air Velocity)





Appendix D.　Set of questionnaires in Japanese

豊橋技術科学大学　建築環境工学研究室

留学生寮
環境調査アンケート

本環境調査のアンケートは下記の３つのアンケートで構成されています。

その 1(1):日常の健康に関するアンケート(調査期間中 1 回のみ回答:いつでも可)

その 1(2):今日の健康に関するアンケート(毎朝、起床後に回答)

その 2:室内環境の主観申告に関するアンケート

(毎日、起床後・自室で昼・就寝前に回答)

※起床後、就寝前以外の回答は、可能な限り回答してください。

その 3:居室内配置図および測定機器状況メモ欄

【アンケートに回答する前の注意事項】※回答する前にお読みください。

- アンケートの回答は、調査期間 1 週間の実際の経験に基づき、適切にお答えください。
- 順応のため、アンケートの回答は出来る限り 30 分間以上、自分の居室で滞在した後にお答えください。
- 本アンケートにて知り得た事項については、この研究の範囲外での使用、第三者への提供、漏洩はいたしません。
- 『その 1：日常（今日）の健康に関するアンケート』では、あなたの普段の生活や健康状態、体質、睡眠に関する質問に回答して頂きます。
- 『その 2：室内環境の主観申告に関するアンケート』では、あなたの居室環境に対する認識について質問します。普段、居室でイスに座っている状態を考慮しつつ、質問にお答えください。
- 『その 3：居室内配置図および測定機器状況メモ欄』では、あなたの居室の間取り、測定機器の位置や高さについて簡単に描いてください。測定機器状況メモ欄では、測定機器が転倒、故障や破損した場合のみ、お手数ですが、その発見時刻や状況などを簡単に記入してください。
- 測定機器が故障や破損した場合は電源（コンセント）を抜き、調査担当の横瀬までメールにてお知らせください。

【調査担当：建築環境工学研究室（都築研究室）】

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グローバル学生宿舎
環境調査アンケート

本環境調査のアンケートは下記の3つのアンケートで構成されています。

その1(1):日常の健康に関するアンケート(調査期間中1回のみ回答:いつでも可)

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- 『その3:居室内配置図および測定機器状況メモ欄』では、あなたの居室の間取り、測定機器の位置や高さについて簡単に描いてください。測定機器状況メモ欄では、測定機器が転倒、故障や破損した場合のみ、お手数ですが、その発見時刻や状況などを簡単に記入してください。
- 測定機器が故障や破損した場合は電源(コンセント)を抜き、調査担当の横瀬までメールにてお知らせください。

【調査担当:建築環境工学研究室(都築研究室)】

横瀬裕紀(D2-609): E-mail: h153550@edu.tut.ac.jp　Tel: 080-1100-7799

Vanya(D2-610): E-mail: vaniadraganova@abv.bg

都築和代 教授 E-mail: ktsuzuki@ace.tut.ac.jp

3.　現在、定期的に運動やスポーツをしていれば、その頻度をお書き下さい。

時期　　　　　　運動の種類　　　　　　頻度

（　　　　　　　）（　　　　　　　）（　　　　　　　）

4.　普段の生活についてお尋ねします。

①たばこは、どのくらい吸いますか。

1－吸ったことがない　2－１年以上前にやめた　3－ここ１年以内にやめた

4－１日 20 本未満　5－１日 20～40 本　6－１日 40 本以上

②お酒は平均して１週間に何日位飲みますか。

1－全く飲まない　2－週に２日以内　3－週に３～５日　4－週に６日以上

③飲酒する方は、一日の飲む量を教えてください。(　　　　　　　　)

④日常生活で体を動かしたり、歩き回ったりすることが多いですか。

１．少ない　２．中程度　３．多い

⑤1 週間どれくらいの頻度で運動しますか？　(　　　　　　　　)

⑥1 週間の運動の負荷は自分にとってどれくらいだと感じていますか？

1.キツめ　2.ややキツめ　3.普通　4.やや軽め　5.軽め

5.　体質についてお尋ねします。

①あなたは暑さに強いですか。

1.強い　2.やや強い　3.どちらともいえない　4.やや弱い　5.弱い

②あなたは寒さに強いですか。

1.強い　2.やや強い　3.どちらともいえない　4.やや弱い　5.弱い

③あなたは汗をよくかく方ですか。

1.よくかく　2.ややかく　3.どちらともいえない　4.あまりかかない　5.かかない

④あなたは冷え性ですか。

１．そうは思わない　２．どちらかと言えば冷え性　３．やや冷え性

４．冷え性　５．かなり重症な冷え性（その症状：　　　　　　　　）

⑤部屋の温度が下がるとすぐに気がつく、あるいは気になりますか。

1.はい　2.いいえ

⑥夏でも寒さを感じることがありますか。　1.はい　2.いいえ

⑦夏は裸足で過ごすことが多いですか。　1.はい　2.いいえ

⑧夏、冷房のきいた部屋で、他の人は寒くないのに、

自分だけ寒さを感じていることはありますか。　1.はい　2.いいえ

その１（1）：日常の健康に関するアンケート（調査期間中１回のみ回答：いつでも可）

記入：平成　　年　　月　　日　　時　　分

部屋番号＿＿＿＿＿＿　氏名＿＿＿＿＿＿＿＿＿＿＿＿＿

年齢：＿＿＿歳　性別：＿男・女＿　身長：＿＿＿＿＿cm　体重：＿＿＿＿＿kg

はじめに、あなたの国籍、民族、宗教についてお尋ねします（あてはまるものに○）。

１.あなたの国籍は何ですか？　（　　　　　　）

２.あなたの民族は何ですか？

１.アジア人　２.白人　３.黒人　４.ヒスパニック／ラテン　５.インド人
６.中東　７.太平洋諸島　８.その他（　　　　　　）

３.あなたの宗教は何ですか？

１.神道　２.仏教　３.儒教　４.キリスト教（宗派：　　　　　　）
５.イスラム教（宗派：　　　　　）　６.ヒンドゥー教　７.無神論者
8.その他（　　　　　　）

４.これまで、あなたは日本にどれだけ長く住んでいますか？（　　　　　　　　）

５.あなたの日常生活は、あなたの宗教によって影響を受けていますか？

１.とても受けている　２.少し受けている　３.全くない

あてはまる番号に○印を付け、（　）内に記入して下さい。

1.　健康状態についてお尋ねします。

①これまでに大きな病気をしたことはありますか。　1.はい　　2.いいえ
　「はい」の場合、病名を記入してください。　1.はい　　2.いいえ
②現在、からだの悪いところはありますか。　1.はい　　2.いいえ
　「はい」の場合、治療している病名を記入してください。（　　　　　　　）
③脈やリズムがおかしくなったこと（不整脈）がありますか。1.はい　　2.いいえ

2.　今まで、定期的に運動やスポーツをしたことがあれば、その運動歴をお書き下さい。

時期	運動の種類	頻度
（例：　20～22 歳　　）	（例：　　剣道　　　）	（例：　週１回　　　）
（　　　　　　　）	（　　　　　　　）	（　　　　　　　）
（　　　　　　　）	（　　　　　　　）	（　　　　　　　）
（　　　　　　　）	（　　　　　　　）	（　　　　　　　）

その１（２）：今日の健康に関するアンケート（毎朝、起床後に回答）

記入日時：　　月　　日　　時　　分

今日の健康状態についてお答えください。

① 昨日は普段通りの生活でしたか？　1.はい　2.いいえ

② 昨夜は何時頃、夕食を食べましたか？（　　）時（　　）分頃

③ 昨夜はお酒を飲みましたか？　1.はい　2.いいえ

④ 昨夜または今朝、入浴（シャワー）しましたか？

1. はい（昨夜・今朝）（　　）時（　　）分頃　　2. いいえ

⑤昨夜は何時頃、就寝のために横になりましたか？　（　　）時（　　）分頃

⑥昨夜は何時頃、眠りに落ちましたか？（　　）時（　　）分頃

⑦昨夜はすぐ眠れましたか？それとも眠りにくかったですか？

1.すぐ眠れた　2.少し時間がかかった　3.たくさん時間がかかった　4.眠れなかった

⑧寝付くのにどれくらい時間がかかりましたか？（　　　　　）

⑨昨夜の睡眠の質はどうでしたか？

1.とても悪い　2.悪い　3.少し悪い　4.少し良い　5.良い　6.とても良い

※悪いほう（1と2と3）と答えた場合、何か原因がありましたか？

（　　　　　　　　　　　　　　　　　　）

⑩昨夜の睡眠には満足していますか？

1.とても不満　2.不満　3.少し不満　4.少し満足　5.満足　6.とても満足

⑪眠りは深い方でしたか？浅い方でしたか？

1.とても浅い　2.浅い　3.少し浅い　4.少し深い　5.深い　6.とても深い

⑫就寝中、何回起きましたか？　（　　）回

⑬今朝は、何時頃目覚めましたか？　（　　）時（　　）分頃

⑭起きた後、頭は冴えていましたか？

1.とても眠かった　2.眠かった　3.少し眠かった　4.少し冴えていた

5.冴えていた　6.とても冴えていた

⑮早く起きたことで、もう一度寝られずに困りましたか？　1.はい　2.いいえ

⑯朝食は食べましたか？　1.はい（　　）時（　　）分頃　　2.いいえ

⑰今朝、何か薬を飲みましたか？

1.はい（どのような薬ですか？：　　　　　　）　　2.いいえ

⑱今朝、排便はしましたか？　1.はい　2.いいえ

⑲現在の健康状態はどうですか？

1.良好　　2.やや疲れている　　3.非常に疲れている

⑳現在の健康状態について、下記の症状はありますか？（あてはまるものを○囲み）

（風邪気味・下痢・腹痛・頭痛・吐き気・喉の腫れ・貧血・めまい）

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6.　睡眠についてお尋ねします。

①寝る時刻は、毎日ほぼ一定ですか。　1.はい（　　　）時頃　　2.いいえ

②起きる時刻は、毎日ほぼ一定ですか。1.はい（　　　）時頃　　2.いいえ

③睡眠時間は、毎日ほぼ一定ですか。　1.はい（　　　）時間くらい　2.いいえ

④寝付きはよい方ですか。

1.よい　　2.ややよい　　3.どちらともいえない　　4.やや悪い　　5.悪い

⑤寝付くのにだいたい何分くらいかかりますか。　（　　　）分くらい

⑥普段、眠ってからトイレに行きますか。　1.はい（　　）回くらい　2.いいえ

⑦眠ってからトイレ以外に目覚めることはありますか。

1.はい（　　）回くらい　　2.いいえ

⑧いびきはかきますか。

1.よくかく　2.ややかく　3.どちらともいえない　4.あまりかかない

5.かかない　6.わからない

⑨普段、よく眠れますか。

1.よく眠れる　2.眠れる　3.どちらともいえない　4.あまり眠れない　5.眠れない

⑩眠りは深い方ですか。

1.深い　2.やや深い　3.どちらともいえない　4.やや浅い　5.浅い

⑪朝、起きようと思っていた時間よりも早く目が覚めることがありますか。

1.よくある　2.時々ある　3.どちらともいえない　4.あまりない　5.ない

⑫朝の目覚め感はどうですか。

1.爽快　2.やや爽快　3.どちらともいえない　4.悪くないがすっきりしない

5.体がだるい、または頭が重く、なかなか起きられない

⑬普段はどのようにして目を覚ましますか。

1.自然に　2.目覚まし時計　3.人の呼び声　4.尿意　5.日光・部屋の明るさ

6.部屋の寒さや暑さ　7.その他（　　　　　　　）

7.　生活についてお尋ねします。

①夏の冷房状況はどうですか。

1.すぐにエアコン冷房　2.エアコン冷房よりは扇風機などで対応

3.ほとんど冷房しない

②冷房には何を使用していますか？（　　　　　　　　　　）

③冬の暖房状況はどうですか。

1.すぐに暖房　2.なるべく暖房せず厚着で対応　3.ほとんど暖房しない

④暖房には何を使用していますか？（　　　　　　　　　　）

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7-①あなたは今、自分の居室でどの程度騒音が気になりますか?	7-②居室の騒音についてどう感じていますか?	7-③今の騒音はどちらに変えたいですか?:
□ とても気になる □ 気になる □ やや気になる □ どちらでもない □ あまり気にならない □ 気にならない □ 全く気にならない	□ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	□ 大きくしたい □ そのまま □ 小さくしたい 7-④今の騒音は許容できますか? □ 許容できる □ 許容できない

下記のあてはまる項目にチェック(あなたの今の服装,・日常活動 ・個人的に行っている居室の空調方法)

今の服装 **(当てはまるものに○)**		**日常の活動** **(直前の 30 分間について)**	**%**	**今の居室の空調方法** **(当てはまるものに○)**	
半袖シャツ		座る (安静的)		ドアを開ける／閉める	
長袖シャツ		座る (活動的)		わずかに窓を開ける	
ズボン/ロングスカート		立っている		大きく窓を開ける	
ドレス		立って作業している		照明を点ける／消す	
パーカー類（セーター)		屋外を歩いている		エアコン(暖房)を点ける	
ジャケット		室内を歩いている		エアコン(冷房)を点ける	
長い靴下		屋外で自動車などに乗る		エアコンを消す	
短い靴下		その他 ( )		扇風機を点ける／消す	
靴				暖房器具を点ける／消す	
スニーカー				暖房器具を消す	
スリッパ				カーテンを開ける／閉める	
その他（)				その他（)	
		Total	**100%**		

8-①：直前の 30 分間において、下記の症状のいずれかを経験しましたか? (該当するもの全てに○)

□ 目の乾燥、かゆみ、刺激
□ 頭痛
□ 喉の痛み、乾き
□ とても疲れている、眠たい
□ 鼻づまり、鼻水が出る
□ 咳が出る、呼吸が苦しい
□ 目が疲れている
□ 緊張またはイライラする
□ 首、肩、背中などの痛みまたはこり
□ くしゃみをする
□ めまい、ふらふらする
□ 吐き気がする
□ 肌の乾燥、かゆみ
□ その他 ( )

8-②：直前の 30 分間に、お菓子や食事を摂りましたか?
□ はい
□ いいえ

8-④：直前の 30 分間に、たばこを吸いましたか?
□ はい
□ いいえ

8-③：直前の 30 分間に、飲み物を飲みましたか？それは次のどれですか？
はい/いいえ
□ □ 温かい
□ □ 冷たい
□ □ カフェイン飲料

8-⑤：直前の 30 分間に、服を着替えましたか? (はいの場合、簡単に説明してください)
□ はい（)
□ いいえ

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その2：室内環境の主観申告に関するアンケート（毎日、起床後・昼・就寝前 に回答）

記入日時：＿＿月＿＿日＿＿時＿＿分

（ 起床後 ・ 自室で昼 ・ 就寝前 ）

↑どれかを〇で囲んでください。

あてはまる項目にチェックを記入してください。

今、自分の居室で感じている環境について質問にお答えください。		
1-①あなたは今、自分の居室にどのような温熱感覚を感じていますか? □ 暑い □ 暖かい □ やや暖かい □ どちらでもない □ やや涼しい □ 涼しい □ 寒い	1-②居室の温熱環境についてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	1-③今の温熱環境はどちらに変えたいと思いますか？: □ 暖かくしたい □ そのままでよい □ 涼しくしたい 1-④今の温熱環境は許容できますか？ □ 許容できる □ 許容できない
2-①あなたは今、自分の居室にどの程度の湿度を感じていますか? □ とても湿っている □ 湿っている □ やや湿っている □ どちらでもない □ やや乾燥している □ 乾燥している □ とても乾燥している	2-②居室の湿度についてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	2-③今の湿度はどちらに変えたいと思いますか？: □ 加湿したい □ そのままでよい □ 除湿したい 2-④今の湿度は許容できますか？ □ 許容できる □ 許容できない
3-①あなたは今、自分の居室の風の強さはどれくらいだと感じていますか? □ とても強い □ 強い □ 少し強い □ どちらでもない □ 少し弱い □ 弱い □ とても弱い	3-②居室の気流についてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	3-③今の気流はどちらに変えたいと思いますか？: □ 強くしたい □ そのままでよい □ 弱くしたい 3-④今の気流は許容できますか？ □ 許容できる □ 許容できない
4-①あなたは今、自分の居室にどの程度の空気の鮮度を感じていますか? □ とても息苦しい □ 息苦しい □ やや息苦しい □ どちらでもない □ やや快適 □ 快適 □ とても快適	4-②居室の空気の鮮度についてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	4-③今の空気の鮮度はどの程度変えたいですか？: □ むっとした空気にしたい □ そのままでよい □ 新鮮な空気にしたい 4-④今の空気の鮮度は許容できますか？ □ 許容できる □ 許容できない
5-①あなたは今、自分の居室にどの程度の臭いを感じていますか? □ とても気になる（とても臭う） □ 気になる □ やや気になる □ どちらでもない □ あまり気にならない □ 気にならない □ 全く気にならない(全く臭わない)	5-②居室の空気の臭いについてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	5-③今の臭いはどちらに変えたいですか？: □ においを発したい □ そのままでよい □ 無臭にしたい 5-④今の臭いは許容できますか？ □ 許容できる □ 許容できない
6-①あなたは今、自分の居室の明るさをどれくらいだと感じていますか? □ とても明るい □ 明るい □ やや明るい □ どちらでもない □ やや暗い □ 暗い □ とても暗い	6-②居室の明るさについてどう感じていますか? □ とても快適 □ 快適 □ やや快適 □ やや不快 □ 不快 □ とても不快	6-③今の明るさはどちらに変えたいと思いますか？: □ 明るくしたい □ そのままでよい □ 暗くしたい 6-④今の明るさは許容できますか？ □ 許容できる □ 許容できない

測定機器状況メモ欄

測定機器が転倒、もしくは故障や破損した場合のみ、その発見時刻と状況を簡単に記入してください。

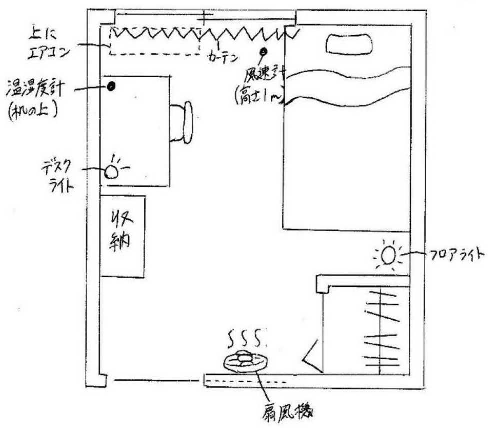
その3：居室内配置図

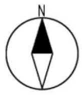
1. あなたの居室内の家具の配置などを、例を参考に枠内に描いてください。
2. 測定機器の位置と高さについても例を参考に記入してください。

温湿度計

風速計

記入例：





Appendix E. Lists of garments and activities used

Appendix Table E-1 List of garments used in the questionnaire and the clo values assigned (summer stage)

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

Appendix Table E-2 List of garments used in the questionnaire and the clo values assigned (winter stage)

Garment	clo	Garment	clo	Garment	clo
Shirt (short sleeves)	0.19	Pullover	0.36	Shoes	0.07
Shirt (long sleeves)	0.25	Jacket	0.44	Sneakers	0.07
Trousers / long skirt	0.24	Long socks	0.03	Slippers	0.03
Dress	0.47	Short socks	0.02	Other	0.72

Appendix Table E-3 List of activities used in the questionnaire and the Met values assigned (summer and winter stage)

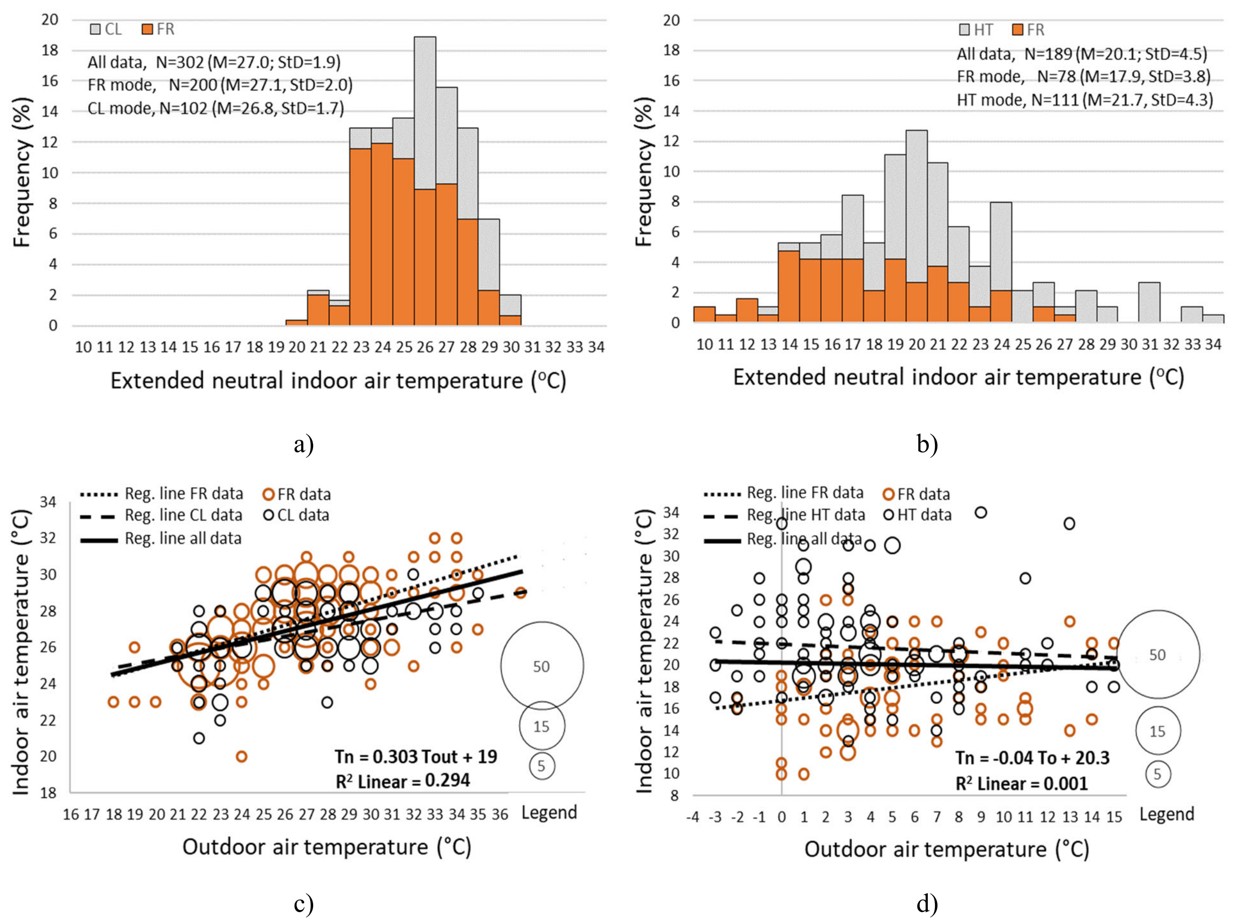
Activity	Met	Wording in ASHRAE handbook (Chapter 9, Table 4)
Sitting (passive work)	1.0	Office activities – reading seated; writing
Sitting (active work)	1.2	Office activities – filing seated
Standing (relaxed)	1.2	Resting – standing, relaxed
Standing (working)	2.7	Miscellaneous Occupational Activities: 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[12]
Other activity indoors	1.0	Resting – seated, quiet

NOTE: The questionnaires distributed to the subjects contained a short list of activities and the subjects were asked to mark the percentage of each activity within the last 30 minutes prior to the vote. The percentages should add up to 100. Whenever the subjects did not fill in anything in the activity section, 100% of the activity was assigned as “other activity indoors”. The outdoor activities in the list were with the purpose to determine whether the subjects had spent the required 30-minute period inside their rooms prior to the vote. The votes with more than 10 minutes outdoor activity were excluded from the following calculations as they suggest that the subjects stayed in their rooms prior to the vote less than 20 minutes. This time is considered insufficient for adjustment to the indoor environment conditions and cannot guarantee providing a reliable answer.

[12] https://community.plu.edu/~chasega/met.html

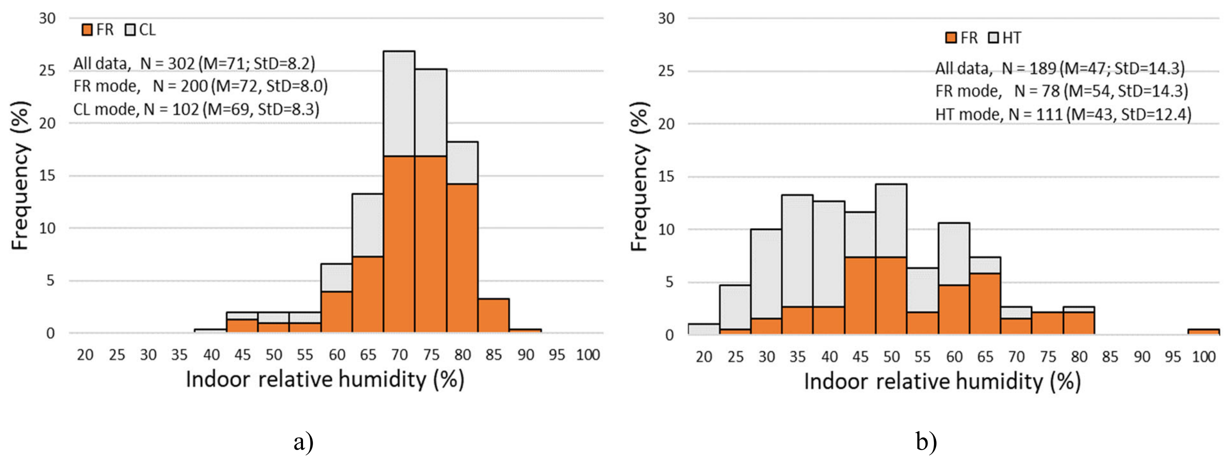
Appendix F. Indoor vs. outdoor at extended neutral sensation in summer and winter

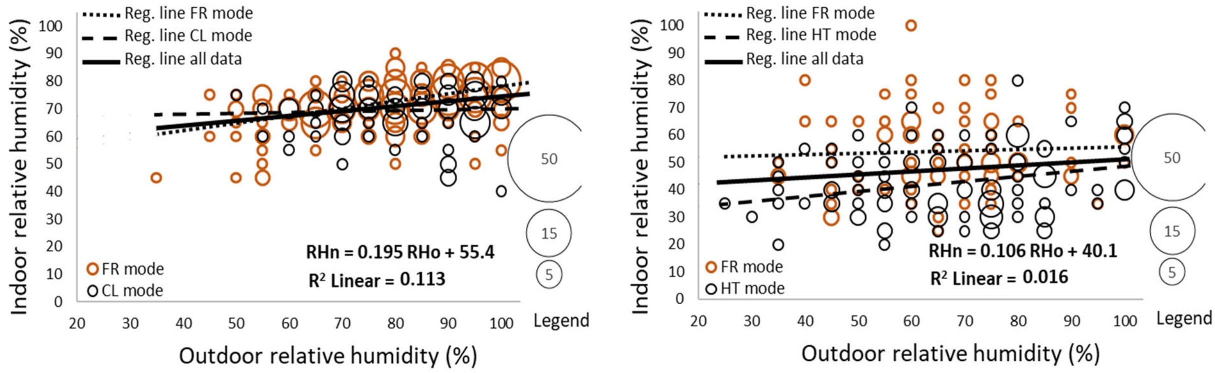
Summer Winter



Appendix Figure F-1 Indoor and outdoor temperature at TSV (-1, 0, +1): a) Percentage distribution of T_n in summer; b) Percentage distribution of T_n in winter; c) Correlation T_n : T_{out} at vote in summer; d) Correlation T_n : T_{out} at vote in winter.

Summer Winter

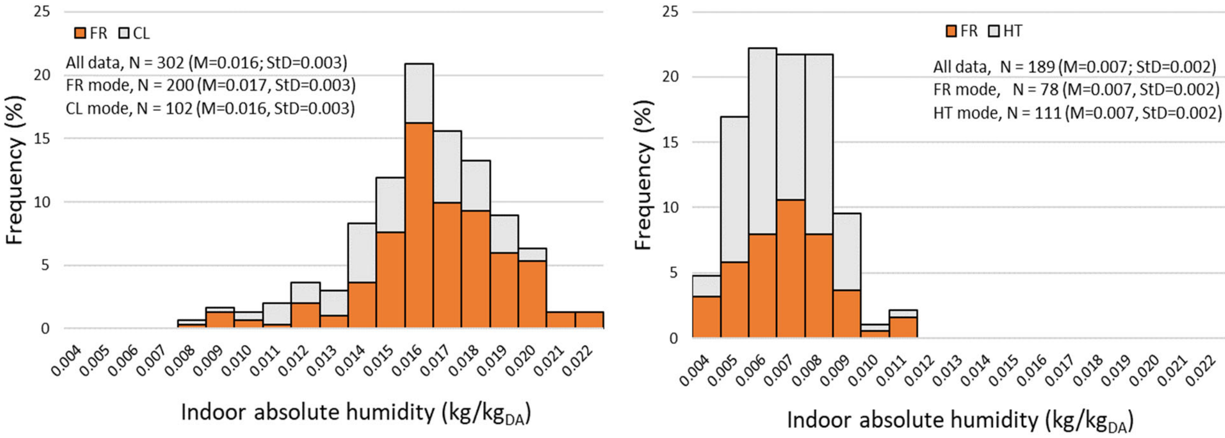




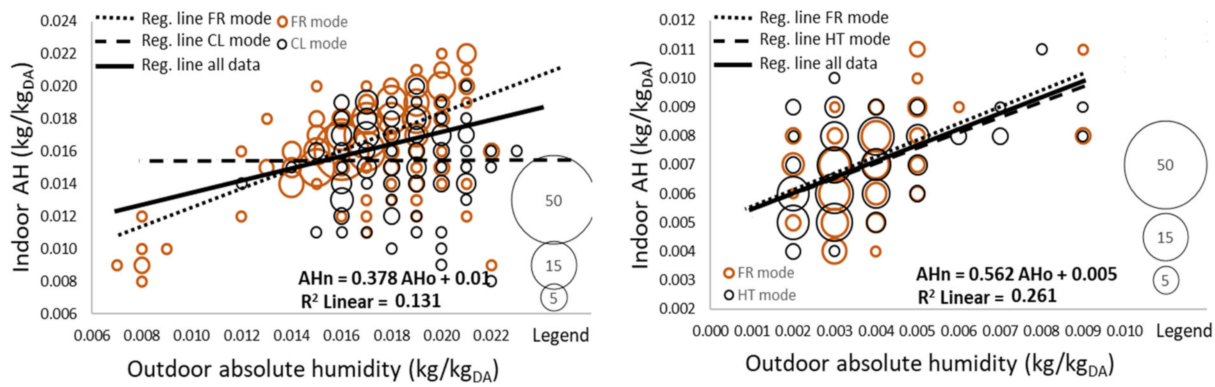
c) d)

Appendix Figure F-2 Indoor and outdoor relative humidity at TSV (-1, 0, +1): a) Percentage distribution of RH_n in summer; b) Percentage distribution of RH_n in winter; c) Correlation RH_n : RH_o at vote in summer; d) Correlation RH_n : RH_o at vote in winter.

Summer Winter



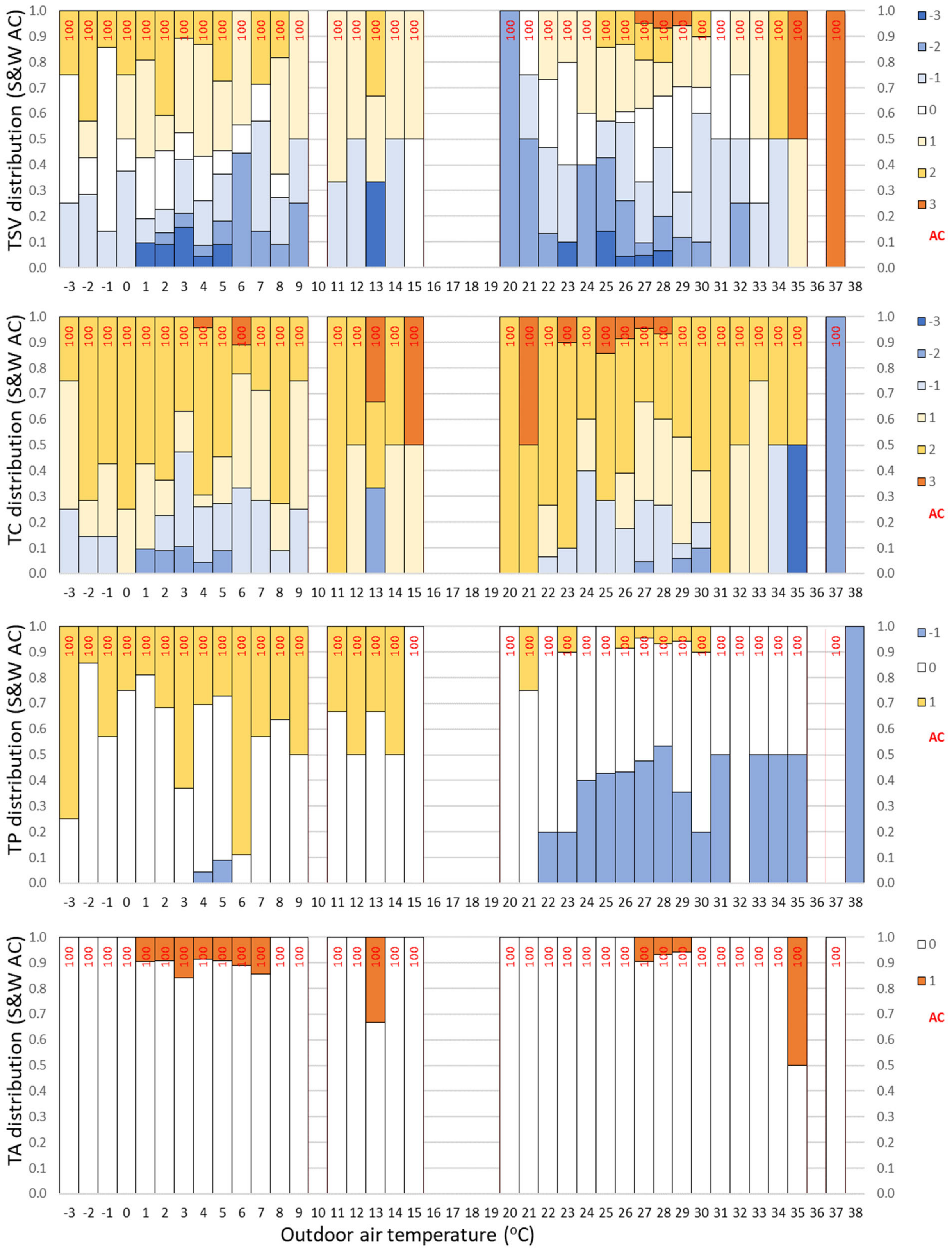
a) b)



c) d)

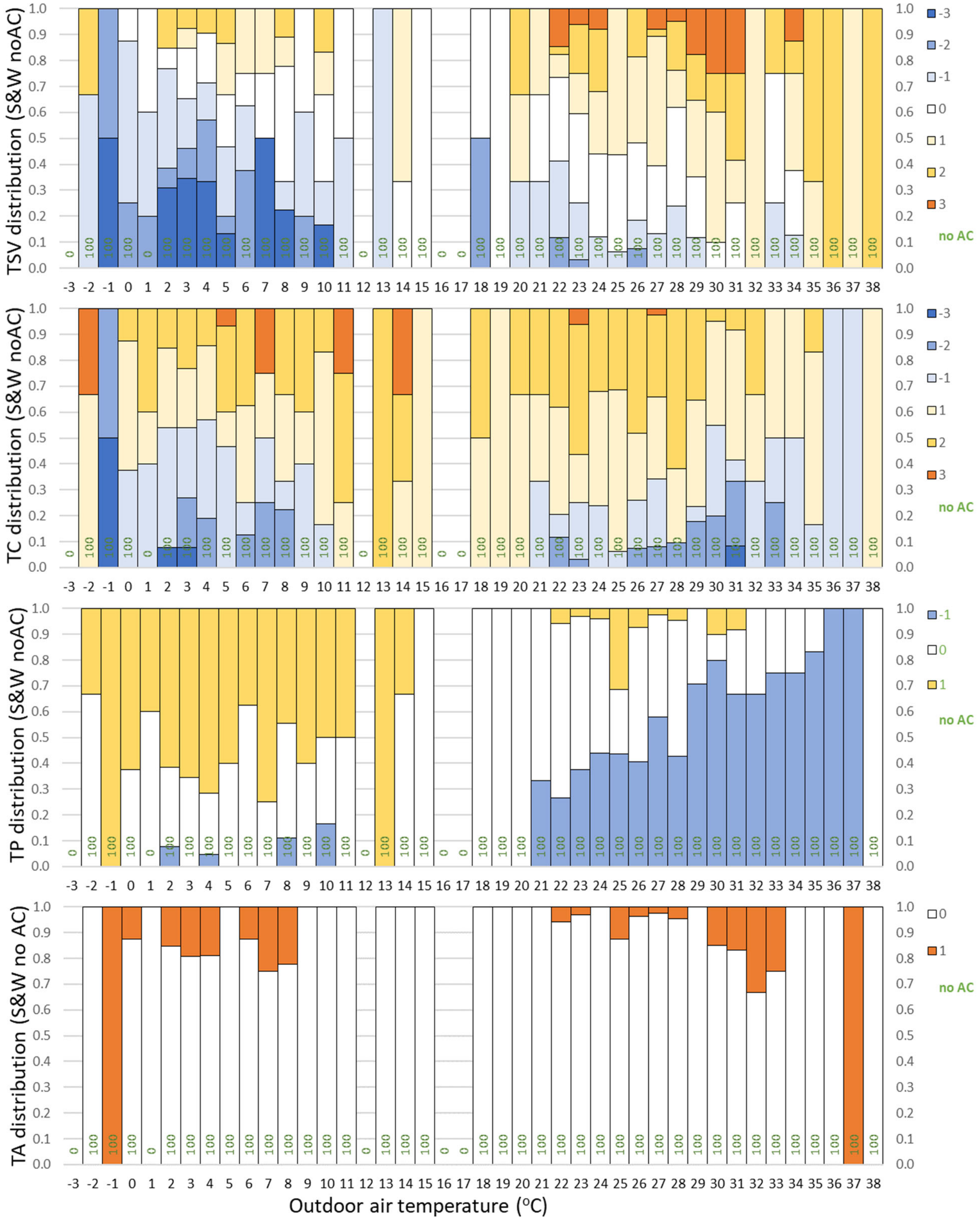
Appendix Figure F-3 Indoor and outdoor absolute humidity at TSV (-1, 0, +1): a) Percentage distribution of AH_n in summer; b) Percentage distribution of AH_n in winter; c) Correlation AH_n : AH_o at vote in summer; d) Correlation AH_n : AH_o at vote in winter.

Appendix G. Summer and winter distribution of thermal responses in AC mode



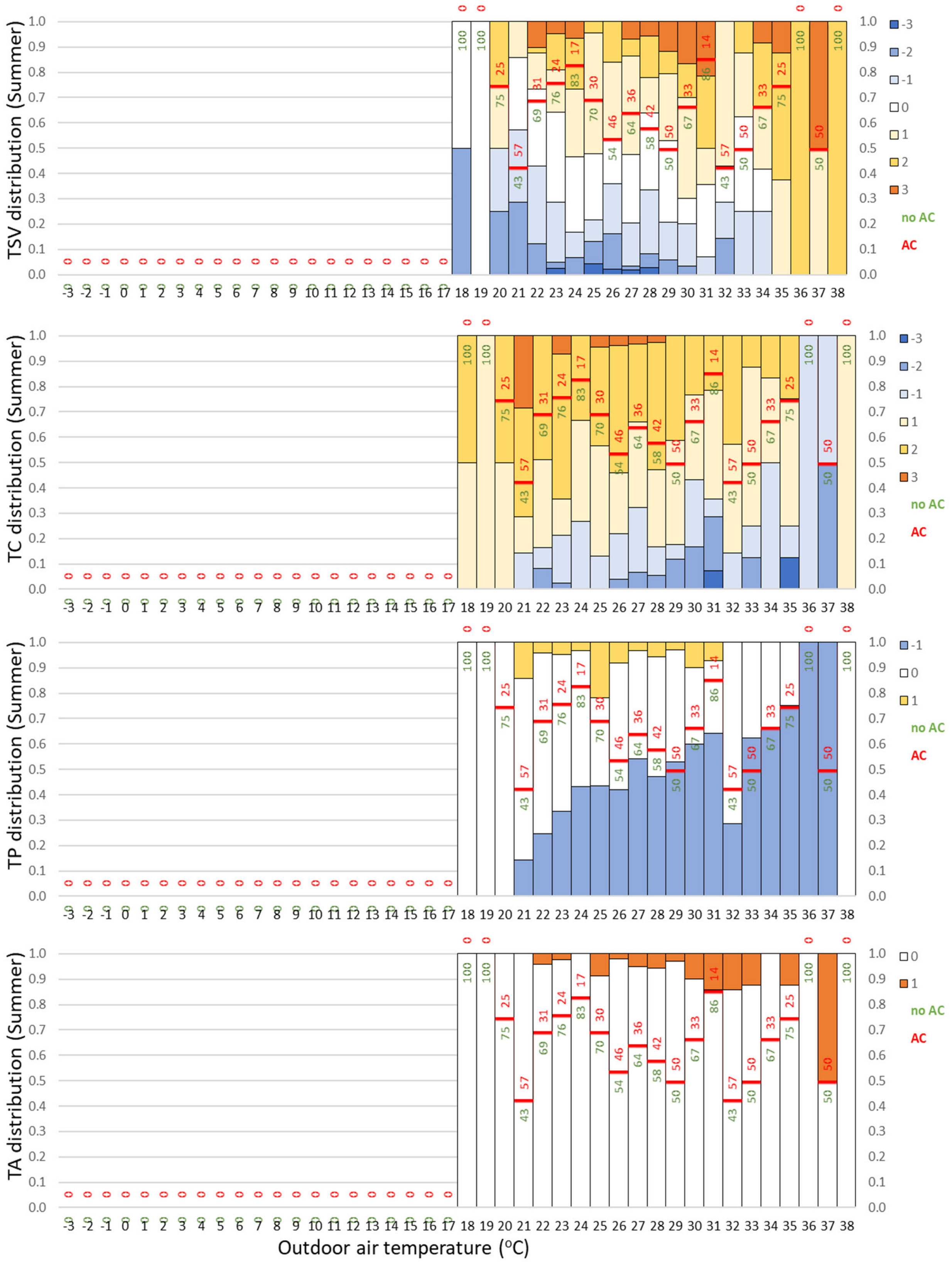
Appendix Figure G-1 Frequency distributions of thermal responses in summer and winter when using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values the figure, are in Appendix O.

Appendix H. Summer and winter distribution of thermal responses in no AC mode



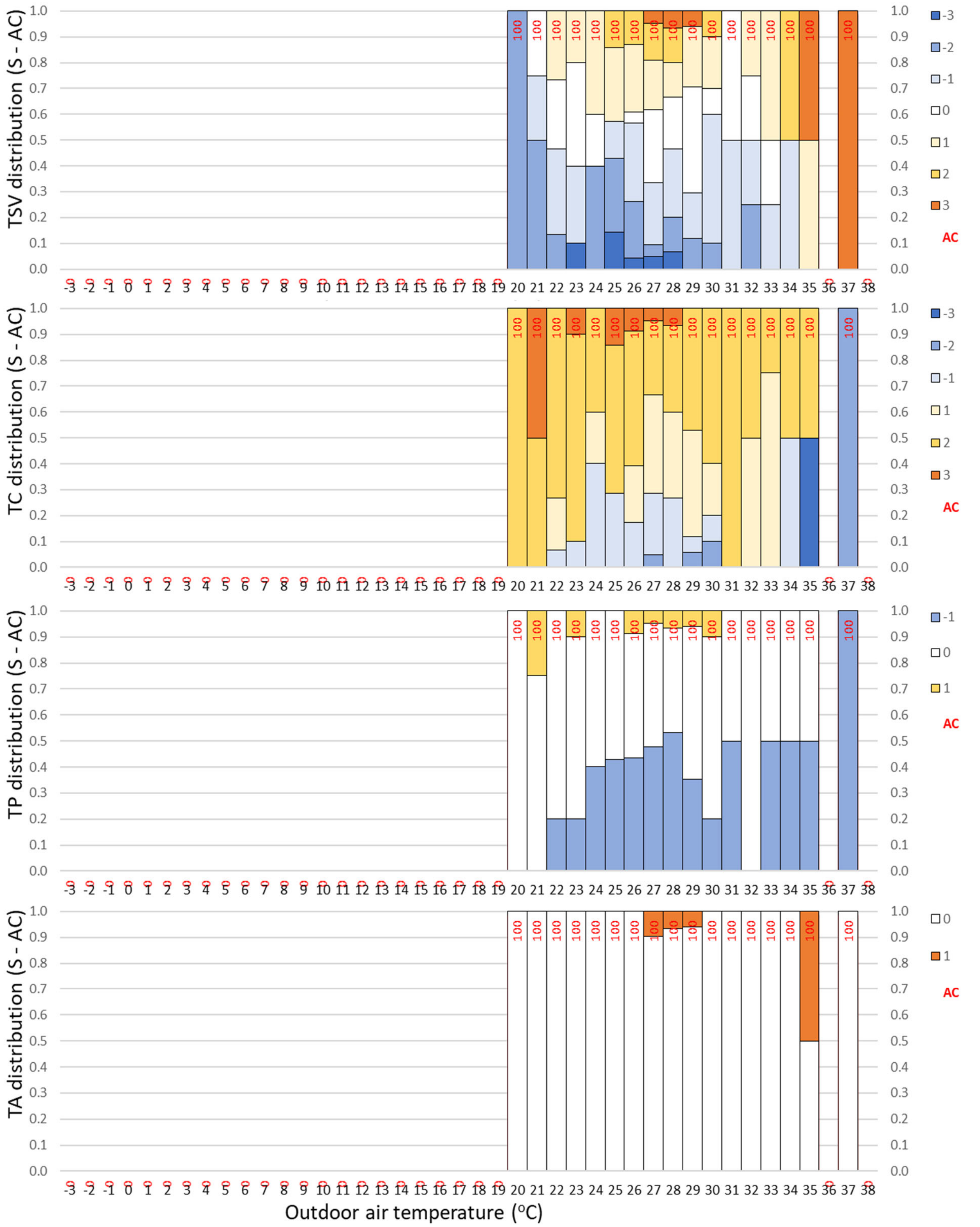
Appendix Figure H-1 Frequency distributions of thermal responses in summer and winter when not using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out};All numerical values in the figure, are in Appendix O.

Appendix I. Summer distribution of thermal responses in AC and no AC mode



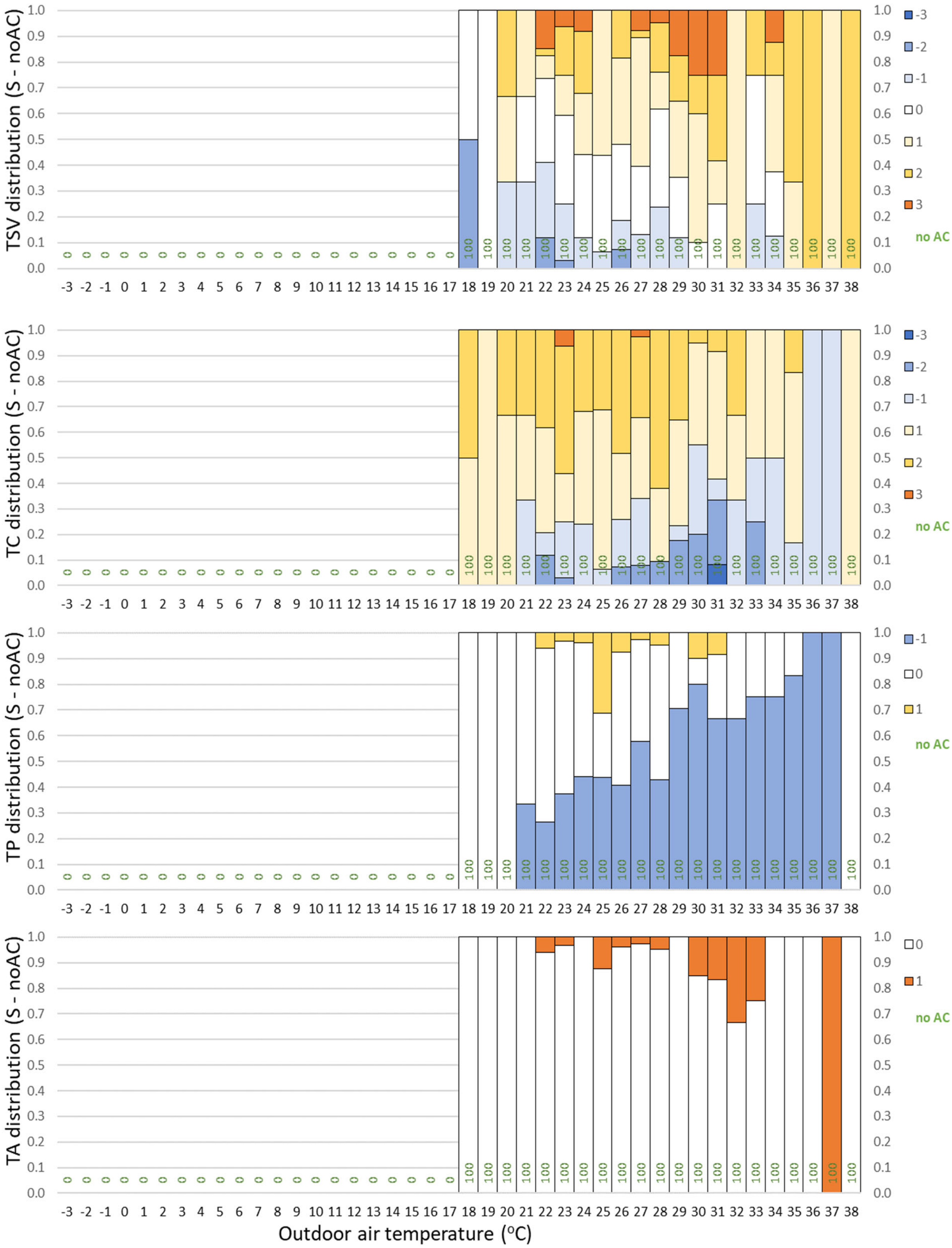
Appendix Figure I-1 Frequency distributions of thermal responses in summer; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values displayed in the figure, are in Appendix O

Appendix J. Summer distribution of thermal responses in AC mode



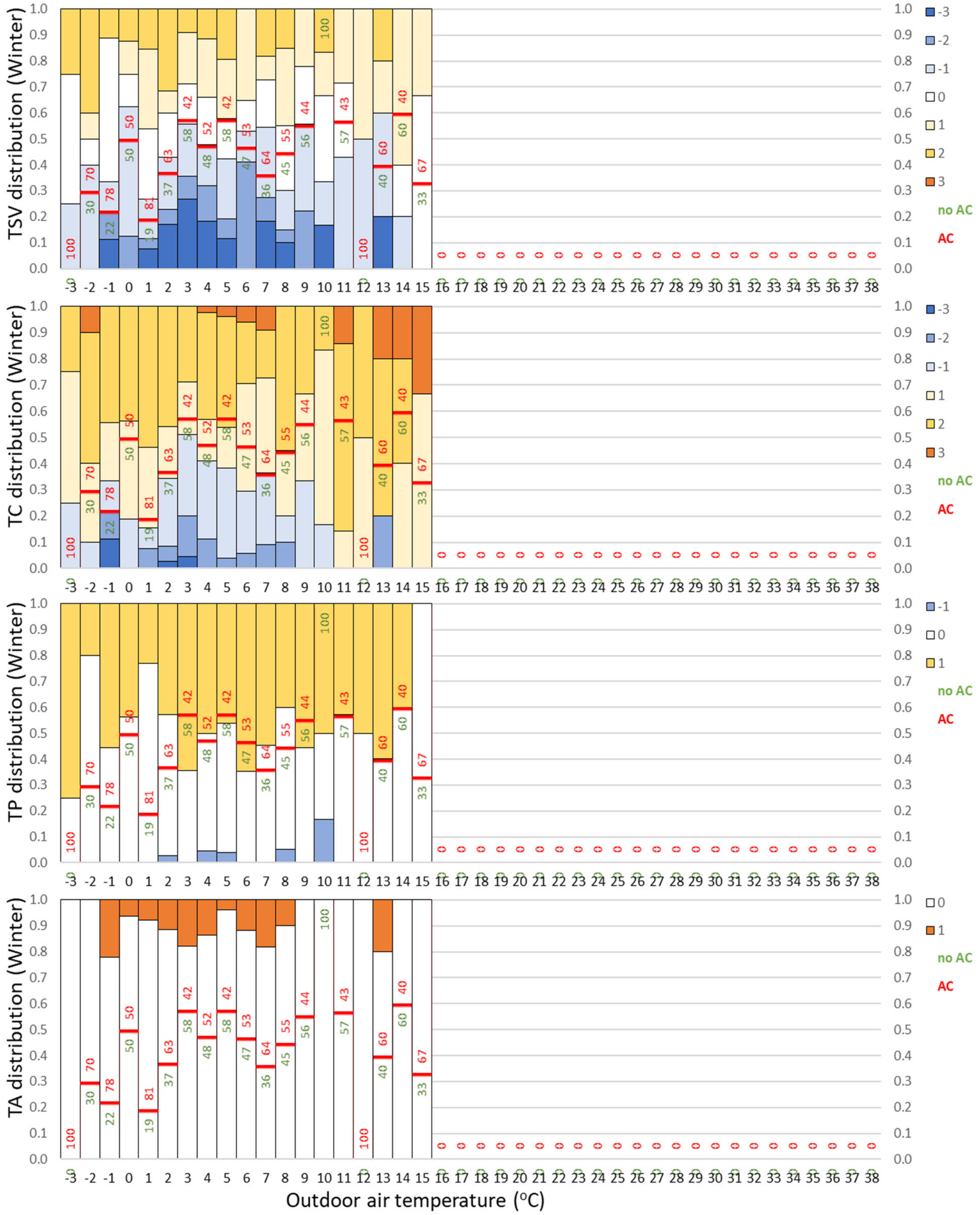
Appendix Figure J-1 Frequency distributions of thermal responses in summer when using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values displayed in the figure, are in Appendix O.

Appendix K. Summer distribution of thermal responses in no AC mode



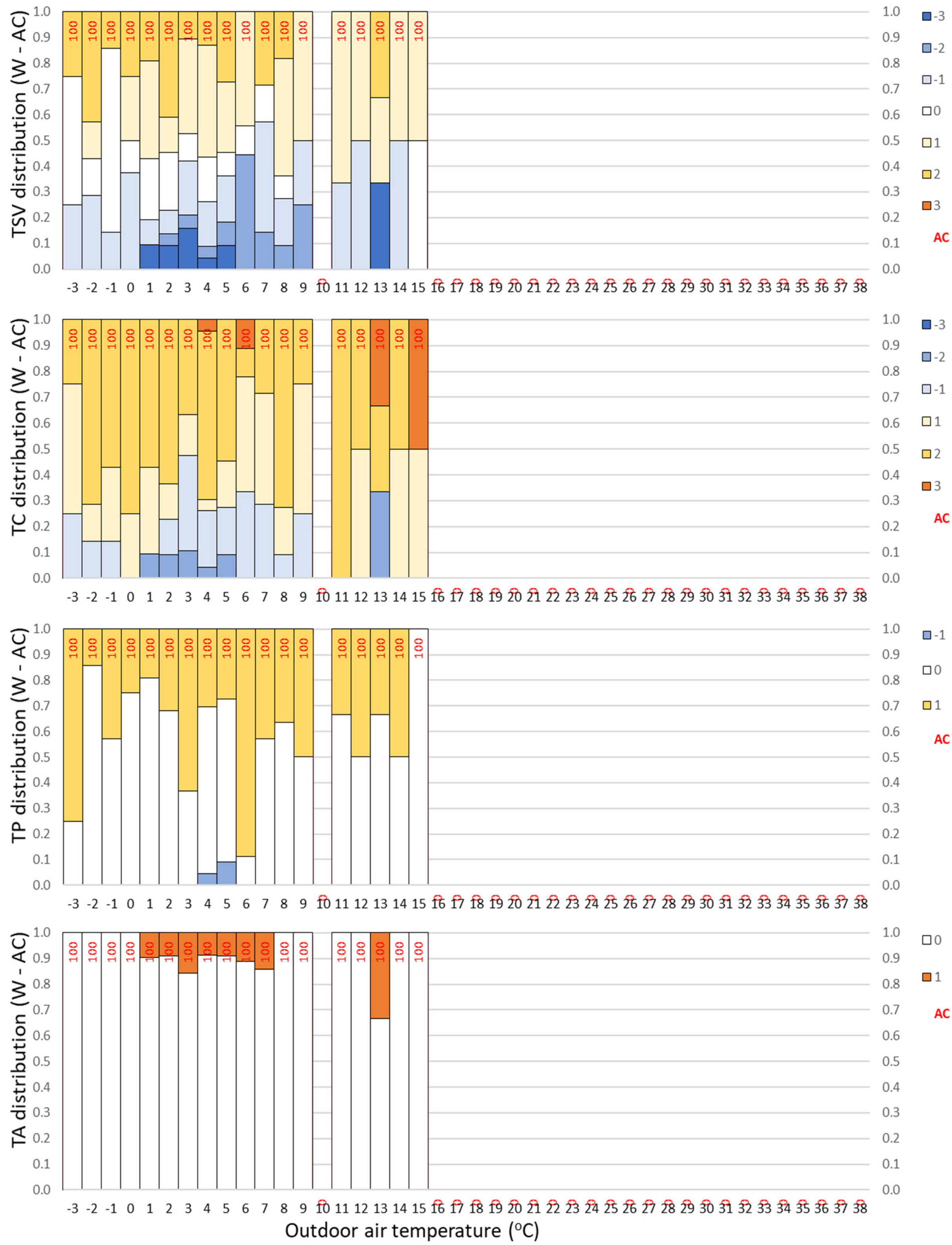
Appendix Figure K-1 Frequency distributions of thermal responses in summer when not using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values displayed in the figure are in Appendix O.

Appendix L. Winter distribution of thermal responses in AC and no AC mode



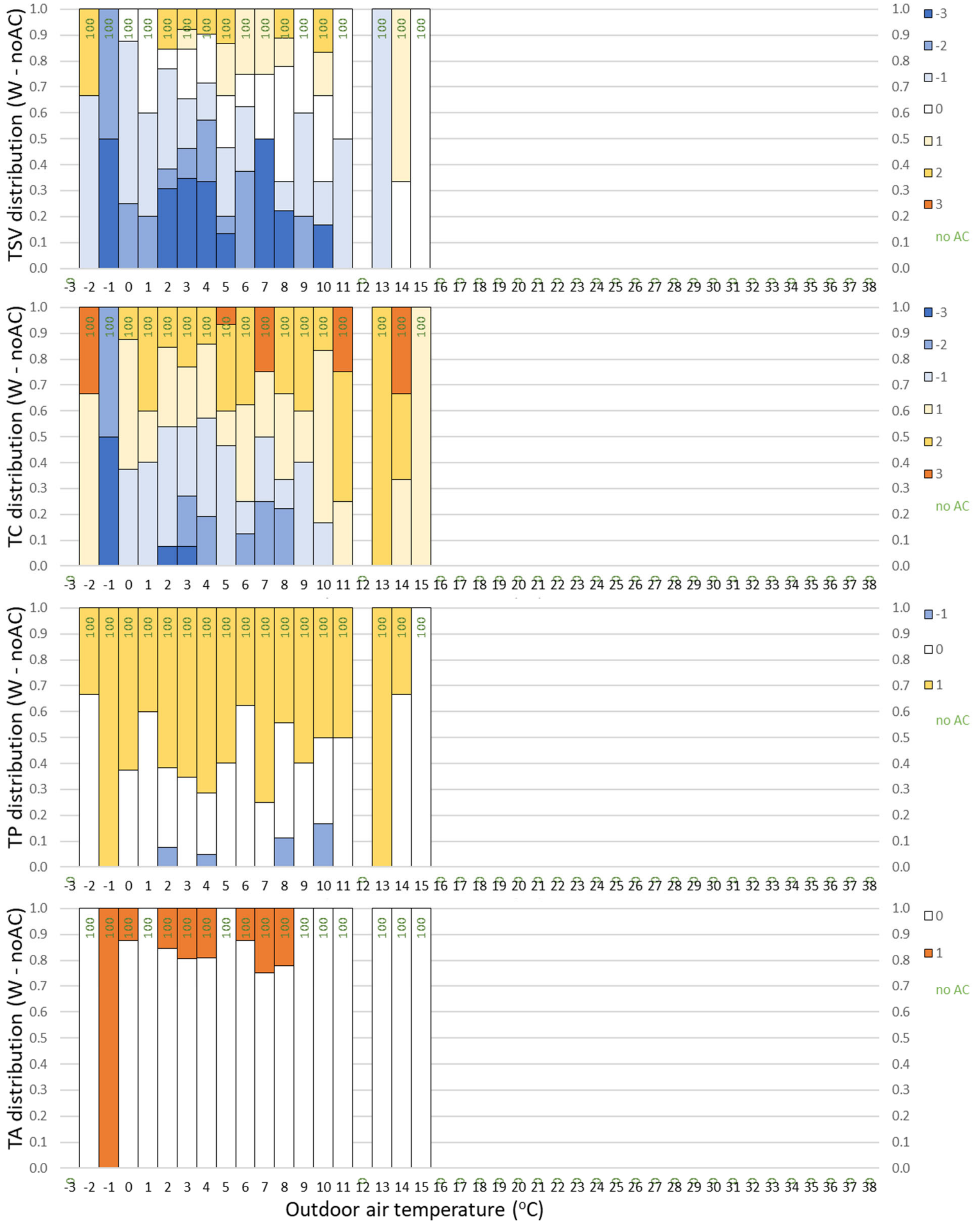
Appendix Figure L-1 Frequency distributions of thermal responses in winter when using and not using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values in the figure, are in Appendix O.

Appendix M. Winter distribution of thermal responses in AC mode



Appendix Figure M-1 Frequency distributions of thermal responses in winter when using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values displayed in the figure, are in Appendix O.

Appendix N. Winter distribution of thermal responses in no AC mode



Appendix Figure N-1 Frequency distributions of thermal responses in winter when not using air-conditioning; a) TSV:T_{out}; b) TC:T_{out}; c) TP:T_{out}; d) No-AC mode TA:T_{out}; All numerical values displayed in the figure, are in Appendix O.

Appendix O. Percentage distribution of thermal responses to Tout

Appendix Table O-1 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer and winter)

T_o	TSV (N=720)							TC (N=720)						TP (N=720)			TA (N=720)		AC mode (N=720)	
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**-1**	**0**	**1**	**0**	**1**	**AC**	**FR**
-3	0	0	25	50	0	25	0	0	0	25	50	25	0	0	25	75	100	0	0	100
-2	0	0	40	10	10	40	0	0	0	10	30	50	10	0	80	20	100	0	30	70
-1	11	11	11	56	0	11	0	11	11	11	22	44	0	0	44	56	78	22	22	78
0	0	13	50	13	13	13	0	0	0	19	38	44	0	0	56	44	94	6	50	50
1	8	4	15	27	31	15	0	0	8	8	31	54	0	0	77	23	92	8	19	81
2	17	6	20	17	9	31	0	3	6	26	20	46	0	3	54	43	89	11	37	63
3	27	9	20	16	20	9	0	4	16	31	20	29	0	0	36	64	82	18	58	42
4	18	14	16	18	23	11	0	0	11	30	16	41	2	5	45	50	86	14	48	52
5	12	8	23	15	23	19	0	0	4	35	15	42	4	4	50	46	96	4	58	42
6	0	41	12	12	35	0	0	0	6	24	41	24	6	0	35	65	88	12	47	53
7	18	9	27	18	9	18	0	0	9	27	36	18	9	0	45	55	82	18	36	64
8	10	5	15	25	30	15	0	0	10	10	25	55	0	5	55	40	90	10	45	55
9	0	22	33	22	22	0	0	0	0	33	33	33	0	0	44	56	100	0	56	44
10	17	0	17	33	17	17	0	0	0	17	67	17	0	17	33	50	100	0	100	0
11	0	0	43	29	29	0	0	0	0	0	14	71	14	0	57	43	100	0	57	43
12	0	0	50	0	50	0	0	0	0	0	50	50	0	0	50	50	100	0	0	100
13	20	0	40	0	20	20	0	0	20	0	0	60	20	0	40	60	80	20	40	60
14	0	0	20	20	60	0	0	0	0	0	40	40	20	0	60	40	100	0	60	40
15	0	0	0	67	33	0	0	0	0	0	67	0	33	0	100	0	100	0	33	67
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	50	0	50	0	0	0	0	0	0	50	50	0	0	100	0	100	0	100	0
19	0	0	0	100	0	0	0	0	0	0	100	0	0	0	100	0	100	0	100	0
20	0	25	25	0	25	25	0	0	0	0	50	50	0	0	100	0	100	0	75	25
21	0	29	29	29	14	0	0	0	0	14	14	43	29	14	71	14	100	0	43	57
22	0	12	31	31	14	2	10	0	8	8	35	49	0	24	71	4	96	4	69	31
23	2	2	24	36	17	14	5	0	2	19	14	57	7	33	62	5	98	2	76	24
24	0	7	10	30	27	20	7	0	0	27	40	33	0	43	53	3	100	0	83	17
25	4	9	9	26	48	4	0	0	0	13	43	39	4	43	35	22	91	9	70	30
26	2	14	20	18	30	16	0	0	4	18	24	50	4	42	50	8	98	2	54	46
27	2	2	17	27	39	7	7	0	7	25	34	31	3	54	42	3	95	5	64	36
28	3	6	25	31	14	17	6	0	6	11	31	50	3	47	47	6	94	6	58	42
29	0	6	15	32	26	9	12	0	12	6	41	41	0	53	44	3	97	3	50	50
30	0	3	17	10	40	13	17	0	17	27	33	23	0	60	30	10	90	10	67	33
31	0	0	7	29	14	29	21	7	21	7	43	21	0	64	29	7	86	14	86	14
32	0	14	14	14	57	0	0	0	0	14	43	43	0	29	71	0	86	14	43	57
33	0	0	25	38	25	13	0	0	13	13	63	13	0	63	38	0	88	13	50	50
34	0	0	25	17	25	25	8	0	0	50	33	17	0	67	33	0	100	0	67	33
35	0	0	0	0	38	50	13	13	0	13	50	25	0	75	25	0	88	13	75	25
36	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	100	0	100	0
37	0	0	0	0	50	0	50	0	50	50	0	0	0	100	0	0	50	50	50	50
38	0	0	0	0	0	100	0	0	0	0	100	0	0	0	100	0	100	0	100	0
	6	**8**	**20**	**23**	**25**	**14**	**4**	**1**	**7**	**19**	**30**	**40**	**3**	**27**	**50**	**23**	**93**	**7**	**57**	**43**

Note: The table presents the distribution of summer and winter data points in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning

Appendix Table O-2 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer and winter) AC mode

T_o	TSV (N=310)							TC (N=310)						TP (N=310)			TA (N=310)		AC mode (N=310)	
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**-1**	**0**	**1**	**0**	**1**	**AC**	**FR**
-3	0	0	25	50	0	25	0	0	0	25	50	25	0	0	25	75	100	0	100	0
-2	0	0	29	14	14	43	0	0	0	14	14	71	0	0	86	14	100	0	100	0
-1	0	0	14	71	0	14	0	0	0	14	29	57	0	0	57	43	100	0	100	0
0	0	0	38	13	25	25	0	0	0	0	25	75	0	0	75	25	100	0	100	0
1	10	0	10	24	38	19	0	0	10	0	33	57	0	0	81	19	90	10	100	0
2	9	5	9	23	14	41	0	0	9	14	14	64	0	0	68	32	91	9	100	0
3	16	5	21	11	37	11	0	0	11	37	16	37	0	0	37	63	84	16	100	0
4	4	4	17	17	43	13	0	0	4	22	4	65	4	4	65	30	91	9	100	0
5	9	9	18	9	27	27	0	0	9	18	18	55	0	9	64	27	91	9	100	0
6	0	44	0	11	44	0	0	0	0	33	44	11	11	0	11	89	89	11	100	0
7	0	14	43	14	0	29	0	0	0	29	43	29	0	0	57	43	86	14	100	0
8	0	9	18	9	45	18	0	0	0	9	18	73	0	0	64	36	100	0	100	0
9	0	25	25	0	50	0	0	0	0	25	50	25	0	0	50	50	100	0	100	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
11	0	0	33	0	67	0	0	0	0	0	0	100	0	0	67	33	100	0	100	0
12	0	0	50	0	50	0	0	0	0	0	50	50	0	0	50	50	100	0	100	0
13	33	0	0	0	33	33	0	0	33	0	0	33	33	0	67	33	67	33	100	0
14	0	0	50	0	50	0	0	0	0	0	50	50	0	0	50	50	100	0	100	0
15	0	0	0	50	50	0	0	0	0	0	50	0	50	0	100	0	100	0	100	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
20	0	100	0	0	0	0	0	0	0	0	0	100	0	0	100	0	100	0	100	0
21	0	50	25	25	0	0	0	0	0	0	0	50	50	0	75	25	100	0	100	0
22	0	13	33	27	27	0	0	0	0	7	20	73	0	20	80	0	100	0	100	0
23	10	0	30	40	20	0	0	0	0	10	0	80	10	20	70	10	100	0	100	0
24	0	40	0	20	40	0	0	0	0	40	20	40	0	40	60	0	100	0	100	0
25	14	29	14	0	29	14	0	0	0	29	0	57	14	43	57	0	100	0	100	0
26	4	22	30	4	26	13	0	0	0	17	22	52	9	43	48	9	100	0	100	0
27	5	5	24	29	19	14	5	0	5	24	38	29	5	48	48	5	90	10	100	0
28	7	13	27	20	13	13	7	0	0	27	33	33	7	53	40	7	93	7	100	0
29	0	12	18	41	24	0	6	0	6	6	41	47	0	35	59	6	94	6	100	0
30	0	10	50	10	20	10	0	0	10	10	20	60	0	20	70	10	100	0	100	0
31	0	0	50	50	0	0	0	0	0	0	0	100	0	50	50	0	100	0	100	0
32	0	25	25	25	25	0	0	0	0	0	50	50	0	0	100	0	100	0	100	0
33	0	0	25	25	50	0	0	0	0	0	75	25	0	50	50	0	100	0	100	0
34	0	0	50	0	0	50	0	0	0	50	0	50	0	50	50	0	100	0	100	0
35	0	0	0	0	50	0	50	50	0	0	0	50	0	50	50	0	50	50	100	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
37	0	0	0	0	0	0	100	0	100	0	0	0	0	100	0	0	100	0	100	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
	5	**10**	**22**	**20**	**27**	**15**	**2**	**0**	**4**	**16**	**24**	**52**	**4**	**18**	**59**	**23**	**94**	**6**	**100**	**0**

Note: Distribution of data points in AC mode (summer and winter) in percent (%) of raw total, where T_o: Outdoor air temperature (ºC), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning

Appendix Table O-3 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer and winter) no-AC mode

T_o	TSV (N=410)							TC (N=410)						TP (N=410)			TA (N=410)		AC mode (N=410)	
	-3	-2	-1	0	1	2	3	-3	-2	-1	1	2	3	-1	0	1	0	1	AC	FR
-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
-2	0	0	67	0	0	33	0	0	0	0	67	0	33	0	67	33	100	0	0	100
-1	50	50	0	0	0	0	0	50	50	0	0	0	0	0	0	100	0	100	0	100
0	0	25	63	13	0	0	0	0	0	38	50	13	0	0	38	63	88	13	0	100
1	0	20	40	40	0	0	0	0	0	40	20	40	0	0	60	40	100	0	0	100
2	31	8	38	8	0	15	0	8	0	46	31	15	0	8	31	62	85	15	0	100
3	35	12	19	19	8	8	0	8	19	27	23	23	0	0	35	65	81	19	0	100
4	33	24	14	19	0	10	0	0	19	38	29	14	0	5	24	71	81	19	0	100
5	13	7	27	20	20	13	0	0	0	47	13	33	7	0	40	60	100	0	0	100
6	0	38	25	13	25	0	0	0	13	13	38	38	0	0	63	38	88	13	0	100
7	50	0	0	25	25	0	0	0	25	25	25	0	25	0	25	75	75	25	0	100
8	22	0	11	44	11	11	0	0	22	11	33	33	0	11	44	44	78	22	0	100
9	0	20	40	40	0	0	0	0	0	40	20	40	0	0	40	60	100	0	0	100
10	17	0	17	33	17	17	0	0	0	17	67	17	0	17	33	50	100	0	0	100
11	0	0	50	50	0	0	0	0	0	0	25	50	25	0	50	50	100	0	0	100
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
13	0	0	100	0	0	0	0	0	0	0	0	100	0	0	0	100	100	0	0	100
14	0	0	0	33	67	0	0	0	0	0	33	33	33	0	67	33	100	0	0	100
15	0	0	0	100	0	0	0	0	0	0	100	0	0	0	100	0	100	0	0	100
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
18	0	50	0	50	0	0	0	0	0	0	50	50	0	0	100	0	100	0	0	100
19	0	0	0	100	0	0	0	0	0	0	100	0	0	0	100	0	100	0	0	100
20	0	0	33	0	33	33	0	0	0	0	67	33	0	0	100	0	100	0	0	100
21	0	0	33	33	33	0	0	0	0	33	33	33	0	33	67	0	100	0	0	100
22	0	12	29	32	9	3	15	0	12	9	41	38	0	26	68	6	94	6	0	100
23	0	3	22	34	16	19	6	0	3	22	19	50	6	38	59	3	97	3	0	100
24	0	0	12	32	24	24	8	0	0	24	44	32	0	44	52	4	100	0	0	100
25	0	0	6	38	56	0	0	0	0	6	63	31	0	44	25	31	88	13	0	100
26	0	7	11	30	33	19	0	0	7	19	26	48	0	41	52	7	96	4	0	100
27	0	0	13	26	50	3	8	0	8	26	32	32	3	58	39	3	97	3	0	100
28	0	0	24	38	14	19	5	0	10	0	29	62	0	43	52	5	95	5	0	100
29	0	0	12	24	29	18	18	0	18	6	41	35	0	71	29	0	100	0	0	100
30	0	0	0	10	50	15	25	0	20	35	40	5	0	80	10	10	85	15	0	100
31	0	0	0	25	17	33	25	8	25	8	50	8	0	67	25	8	83	17	0	100
32	0	0	0	0	100	0	0	0	0	33	33	33	0	67	33	0	67	33	0	100
33	0	0	25	50	0	25	0	0	25	25	50	0	0	75	25	0	75	25	0	100
34	0	0	13	25	38	13	13	0	0	50	50	0	0	75	25	0	100	0	0	100
35	0	0	0	0	33	67	0	0	0	17	67	17	0	83	17	0	100	0	0	100
36	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	100	0	0	100
37	0	0	0	0	100	0	0	0	0	100	0	0	0	100	0	0	0	100	0	100
38	0	0	0	0	0	100	0	0	0	0	100	0	0	0	100	0	100	0	0	100
	7	**6**	**19**	**26**	**23**	**13**	**6**	**1**	**9**	**22**	**35**	**31**	**2**	**0**	**38**	**63**	**92**	**8**	**0**	**100**

Note: Distribution of data points in no-AC mode (summer and winter) in percent (%) of raw total, where T_{out}: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-4 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer)

T_o	TSV (N=420))							TC (N=420)						TP (N=420)			TA (N=420)		AC mode (N=420)	
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**-1**	**0**	**1**	**0**	**1**	**AC**	**FR**
-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	0	50	0	50	0	0	0	0	0	0	50	50	0	0	100	0	100	0	100	0
19	0	0	0	100	0	0	0	0	0	0	100	0	0	0	100	0	100	0	100	0
20	0	25	25	0	25	25	0	0	0	0	50	50	0	0	100	0	100	0	75	25
21	0	29	29	29	14	0	0	0	0	14	14	43	29	14	71	14	100	0	43	57
22	0	12	31	31	14	2	10	0	8	8	35	49	0	24	71	4	96	4	69	31
23	2	2	24	36	17	14	5	0	2	19	14	57	7	33	62	5	98	2	76	24
24	0	7	10	30	27	20	7	0	0	27	40	33	0	43	53	3	100	0	83	17
25	4	9	9	26	48	4	0	0	0	13	43	39	4	43	35	22	91	9	70	30
26	2	14	20	18	30	16	0	0	4	18	24	50	4	42	50	8	98	2	54	46
27	2	2	17	27	39	7	7	0	7	25	34	31	3	54	42	3	95	5	64	36
28	3	6	25	31	14	17	6	0	6	11	31	50	3	47	47	6	94	6	58	42
29	0	6	15	32	26	9	12	0	12	6	41	41	0	53	44	3	97	3	50	50
30	0	3	17	10	40	13	17	0	17	27	33	23	0	60	30	10	90	10	67	33
31	0	0	7	29	14	29	21	7	21	7	43	21	0	64	29	7	86	14	86	14
32	0	14	14	14	57	0	0	0	0	14	43	43	0	29	71	0	86	14	43	57
33	0	0	25	38	25	13	0	0	13	13	63	13	0	63	38	0	88	13	50	50
34	0	0	25	17	25	25	8	0	0	50	33	17	0	67	33	0	100	0	67	33
35	0	0	0	0	38	50	13	13	0	13	50	25	0	75	25	0	88	13	75	25
36	0	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	100	0	100	0
37	0	0	0	0	50	0	50	0	50	50	0	0	0	100	0	0	50	50	50	50
38	0	0	0	0	0	100	0	0	0	0	100	0	0	0	100	0	100	0	100	0
	1	**7**	**19**	**26**	**27**	**13**	**7**	**0**	**6**	**18**	**33**	**40**	**3**	**45**	**49**	**6**	**95**	**5**	**65**	**35**

Note: Distribution of summer data points when using and not using air conditioning in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-5 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer) AC mode

T_o	TSV (N=145))							TC (N=145)						TP (N=145)			TA (N=145)		AC mode (N=145)	
	-3	-2	-1	0	1	2	3	-3	-2	-1	1	2	3	-1	0	1	0	1	AC	FR
-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	0	100	0	0	0	0	0	0	0	0	0	100	0	0	100	0	100	0	100	0
21	0	50	25	25	0	0	0	0	0	0	0	50	50	0	75	25	100	0	100	0
22	0	13	33	27	27	0	0	0	0	7	20	73	0	20	80	0	100	0	100	0
23	10	0	30	40	20	0	0	0	0	10	0	80	10	20	70	10	100	0	100	0
24	0	40	0	20	40	0	0	0	0	40	20	40	0	40	60	0	100	0	100	0
25	14	29	14	0	29	14	0	0	0	29	0	57	14	43	57	0	100	0	100	0
26	4	22	30	4	26	13	0	0	0	17	22	52	9	43	48	9	100	0	100	0
27	5	5	24	29	19	14	5	0	5	24	38	29	5	48	48	5	90	10	100	0
28	7	13	27	20	13	13	7	0	0	27	33	33	7	53	40	7	93	7	100	0
29	0	12	18	41	24	0	6	0	6	6	41	47	0	35	59	6	94	6	100	0
30	0	10	50	10	20	10	0	0	10	10	20	60	0	20	70	10	100	0	100	0
31	0	0	50	50	0	0	0	0	0	0	0	100	0	50	50	0	100	0	100	0
32	0	25	25	25	25	0	0	0	0	0	50	50	0	0	100	0	100	0	100	0
33	0	0	25	25	50	0	0	0	0	0	75	25	0	50	50	0	100	0	100	0
34	0	0	50	0	0	50	0	0	0	50	0	50	0	50	50	0	100	0	100	0
35	0	0	0	0	50	0	50	50	0	0	0	50	0	50	50	0	50	50	100	0
36																			100	0
37	0	0	0	0	0	0	100	0	100	0	0	0	0	100	0	0	100	0	100	0
38																			100	0
	3	**14**	**27**	**21**	**22**	**8**	**3**	**1**	**3**	**16**	**25**	**50**	**6**	**37**	**58**	**6**	**97**	**3**	**100**	**0**

Note: Distribution of summer data points when using air conditioning for cooling in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-6 Descriptive statistic: Thermal responses in relation to outdoor temperature (summer) no AC mode

T_o	TSV (N=275))							TC (N=275)						TP (N=275)			TA (N=275)		AC mode (N=275)	
	-3	-2	-1	0	1	2	3	-3	-2	-1	1	2	3	-1	0	1	0	1	AC	FR
-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	50	0	50	0	0	0	0	0	0	50	50	0	0	100	0	100	0	0	100
19	-	0	0	100	0	0	0	0	0	0	100	0	0	0	100	0	100	0	0	100
20	-	0	33	0	33	33	0	0	0	0	67	33	0	0	100	0	100	0	0	100
21	-	0	33	33	33	0	0	0	0	33	33	33	0	33	67	0	100	0	0	100
22	-	12	29	32	9	3	15	0	12	9	41	38	0	26	68	6	94	6	0	100
23	-	3	22	34	16	19	6	0	3	22	19	50	6	38	59	3	97	3	0	100
24	-	0	12	32	24	24	8	0	0	24	44	32	0	44	52	4	100	0	0	100
25	-	0	6	38	56	0	0	0	0	6	63	31	0	44	25	31	88	13	0	100
26	-	7	11	30	33	19	0	0	7	19	26	48	0	41	52	7	96	4	0	100
27	-	0	13	26	50	3	8	0	8	26	32	32	3	58	39	3	97	3	0	100
28	-	0	24	38	14	19	5	0	10	0	29	62	0	43	52	5	95	5	0	100
29	-	0	12	24	29	18	18	0	18	6	41	35	0	71	29	0	100	0	0	100
30	-	0	0	10	50	15	25	0	20	35	40	5	0	80	10	10	85	15	0	100
31	-	0	0	25	17	33	25	8	25	8	50	8	0	67	25	8	83	17	0	100
32	-	0	0	0	100	0	0	0	0	33	33	33	0	67	33	0	67	33	0	100
33	-	0	25	50	0	25	0	0	25	25	50	0	0	75	25	0	75	25	0	100
34	-	0	13	25	38	13	13	0	0	50	50	0	0	75	25	0	100	0	0	100
35	-	0	0	0	33	67	0	0	0	17	67	17	0	83	17	0	100	0	0	100
36	-	0	0	0	0	100	0	0	0	100	0	0	0	100	0	0	100	0	0	100
37	-	0	0	0	100	0	0	0	0	100	0	0	0	100	0	0	0	100	0	100
38	-	0	0	0	0	100	0	0	0	0	100	0	0	0	100	0	100	0	0	100
	-	**3**	**15**	**28**	**30**	**15**	**9**	**0**	**8**	**19**	**38**	**34**	**1**	**49**	**45**	**6**	**94**	**6**	**0**	**100**

Note: Distribution of summer data points when not using air conditioning in percent (%) of raw total, where T_o: Outdoor air temperature (ºC), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-7 Descriptive statistic: Thermal responses in relation to outdoor temperature (winter)

T_o	TSV (N=300))							TC (N=300)						TP (N=300)			TA (N=300)		AC mode (N=300)	
	-3	-2	-1	0	1	2	3	-3	-2	-1	1	2	3	-1	0	1	0	1	AC	FR
-3	0	0	25	50	0	25	-	0	0	25	50	25	0	0	25	75	100	0	0	100
-2	0	0	40	10	10	40	-	0	0	10	30	50	10	0	80	20	100	0	30	70
-1	11	11	11	56	0	11	-	11	11	11	22	44	0	0	44	56	78	22	22	78
0	0	13	50	13	13	13	-	0	0	19	38	44	0	0	56	44	94	6	50	50
1	8	4	15	27	31	15	-	0	8	8	31	54	0	0	77	23	92	8	19	81
2	17	6	20	17	9	31	-	3	6	26	20	46	0	3	54	43	89	11	37	63
3	27	9	20	16	20	9	-	4	16	31	20	29	0	0	36	64	82	18	58	42
4	18	14	16	18	23	11	-	0	11	30	16	41	2	5	45	50	86	14	48	52
5	12	8	23	15	23	19	-	0	4	35	15	42	4	4	50	46	96	4	58	42
6	0	41	12	12	35	0	-	0	6	24	41	24	6	0	35	65	88	12	47	53
7	18	9	27	18	9	18	-	0	9	27	36	18	9	0	45	55	82	18	36	64
8	10	5	15	25	30	15	-	0	10	10	25	55	0	5	55	40	90	10	45	55
9	0	22	33	22	22	0	-	0	0	33	33	33	0	0	44	56	100	0	56	44
10	17	0	17	33	17	17	-	0	0	17	67	17	0	17	33	50	100	0	100	0
11	0	0	43	29	29	0	-	0	0	0	14	71	14	0	57	43	100	0	57	43
12	0	0	50	0	50	0	-	0	0	0	50	50	0	0	50	50	100	0	0	100
13	20	0	40	0	20	20	-	0	20	0	0	60	20	0	40	60	80	20	40	60
14	0	0	20	20	60	0	-	0	0	0	40	40	20	0	60	40	100	0	60	40
15	0	0	0	67	33	0	-	0	0	0	67	0	33	0	100	0	100	0	33	67
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13	**10**	**22**	**20**	**21**	**15**		**1**	**8**	**22**	**26**	**40**	**3**	**2**	**50**	**48**	**90**	**10**	**45**	**55**

Note: Distribution of all winter data points when using and not using air conditioning in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-8 Descriptive statistic: Thermal responses in relation to outdoor temperature (winter) AC mode

T_o	TSV (N=165))							TC (N=165)						TP (N=165)			TA (N=165)		AC mode (N=165)	
	-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**1**	**2**	**3**	**-1**	**0**	**1**	**0**	**1**	**AC**	**FR**
-3	0	0	25	50	0	25	-	-	0	25	50	25	0	0	25	75	100	0	100	0
-2	0	0	29	14	14	43	-	-	0	14	14	71	0	0	86	14	100	0	100	0
-1	0	0	14	71	0	14	-	-	0	14	29	57	0	0	57	43	100	0	100	0
0	0	0	38	13	25	25	-	-	0	0	25	75	0	0	75	25	100	0	100	0
1	10	0	10	24	38	19	-	-	10	0	33	57	0	0	81	19	90	10	100	0
2	9	5	9	23	14	41	-	-	9	14	14	64	0	0	68	32	91	9	100	0
3	16	5	21	11	37	11	-	-	11	37	16	37	0	0	37	63	84	16	100	0
4	4	4	17	17	43	13	-	-	4	22	4	65	4	4	65	30	91	9	100	0
5	9	9	18	9	27	27	-	-	9	18	18	55	0	9	64	27	91	9	100	0
6	0	44	0	11	44	0	-	-	0	33	44	11	11	0	11	89	89	11	100	0
7	0	14	43	14	0	29	-	-	0	29	43	29	0	0	57	43	86	14	100	0
8	0	9	18	9	45	18	-	-	0	9	18	73	0	0	64	36	100	0	100	0
9	0	25	25	0	50	0	-	-	0	25	50	25	0	0	50	50	100	0	100	0
10							-	-											100	0
11	0	0	33	0	67	0	-	-	0	0	0	100	0	0	67	33	100	0	100	0
12	0	0	50	0	50	0	-	-	0	0	50	50	0	0	50	50	100	0	100	0
13	33	0	0	0	33	33	-	-	33	0	0	33	33	0	67	33	67	33	100	0
14	0	0	50	0	50	0	-	-	0	0	50	50	0	0	50	50	100	0	100	0
15	0	0	0	50	50	0	-	-	0	0	50	0	50	0	100	0	100	0	100	0
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	7	18	18	31	20	-	-	5	16	22	53	2	1	61	38	92	8	100	0

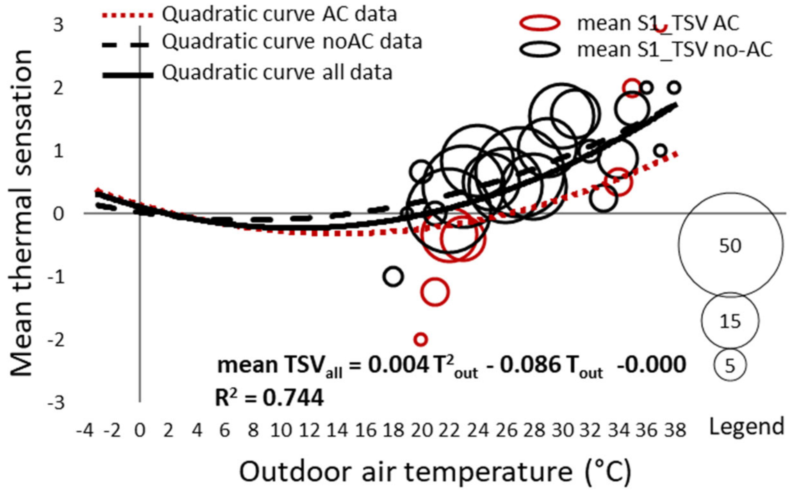
Note: Distribution of all winter data points when using air conditioning for heating in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

Appendix Table O-9 Descriptive statistic: Thermal responses in relation to outdoor temperature (winter) no AC mode

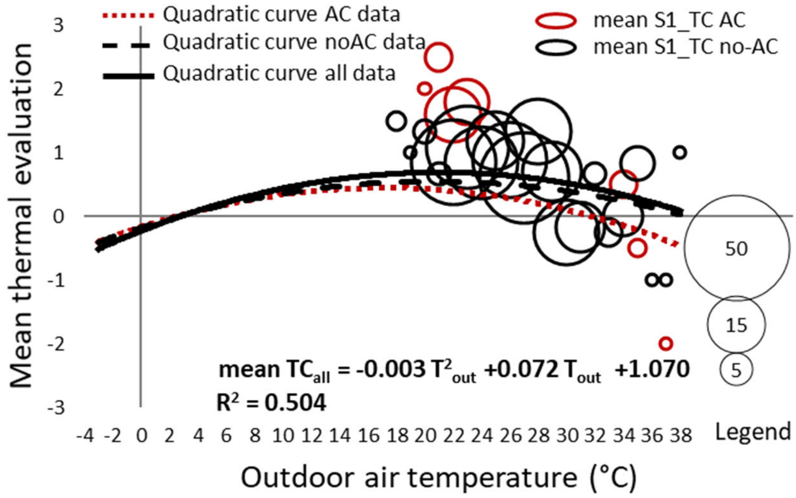
T_o	TSV (N=135))							TC (N=135)						TP (N=135)			TA (N=135)		AC mode (N=135)	
	-3	-2	-1	0	1	2	3	-3	-2	-1	1	2	3	-1	0	1	0	1	AC	FR
-3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-2	0	0	67	0	0	33	-	0	0	0	67	0	33	0	67	33	100	0	0	100
-1	50	50	0	0	0	0	-	50	50	0	0	0	0	0	0	100	0	100	0	100
0	0	25	63	13	0	0	-	0	0	38	50	13	0	0	38	63	88	13	0	100
1	0	20	40	40	0	0	-	0	0	40	20	40	0	0	60	40	100	0	0	100
2	31	8	38	8	0	15	-	8	0	46	31	15	0	8	31	62	85	15	0	100
3	35	12	19	19	8	8	-	8	19	27	23	23	0	0	35	65	81	19	0	100
4	33	24	14	19	0	10	-	0	19	38	29	14	0	5	24	71	81	19	0	100
5	13	7	27	20	20	13	-	0	0	47	13	33	7	0	40	60	100	0	0	100
6	0	38	25	13	25	0	-	0	13	13	38	38	0	0	63	38	88	13	0	100
7	50	0	0	25	25	0	-	0	25	25	25	0	25	0	25	75	75	25	0	100
8	22	0	11	44	11	11	-	0	22	11	33	33	0	11	44	44	78	22	0	100
9	0	20	40	40	0	0	-	0	0	40	20	40	0	0	40	60	100	0	0	100
10	17	0	17	33	17	17	-	0	0	17	67	17	0	17	33	50	100	0	0	100
11	0	0	50	50	0	0	-	0	0	0	25	50	25	0	50	50	100	0	0	100
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	0	0	100	0	0	0	-	0	0	0	0	100	0	0	0	100	100	0	0	100
14	0	0	0	33	67	0	-	0	0	0	33	33	33	0	67	33	100	0	0	100
15	0	0	0	100	0	0	-	0	0	0	100	0	0	0	100	0	100	0	0	100
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
l	**21**	**13**	**27**	**22**	**9**	**8**	**-**	**3**	**10**	**29**	**30**	**24**	**4**	**3**	**38**	**59**	**87**	**13**	**0**	**100**

Note: Distribution of winter data points when not using air conditioning for heating in percent (%) of raw total, where T_o: Outdoor air temperature (°C), TSV: Thermal sensation vote, TC: Thermal comfort vote; TP: Thermal preference vote, TA: Thermal acceptability vote, AC mode: Air conditioning mode, FR: Free running mode (without using air conditioning)

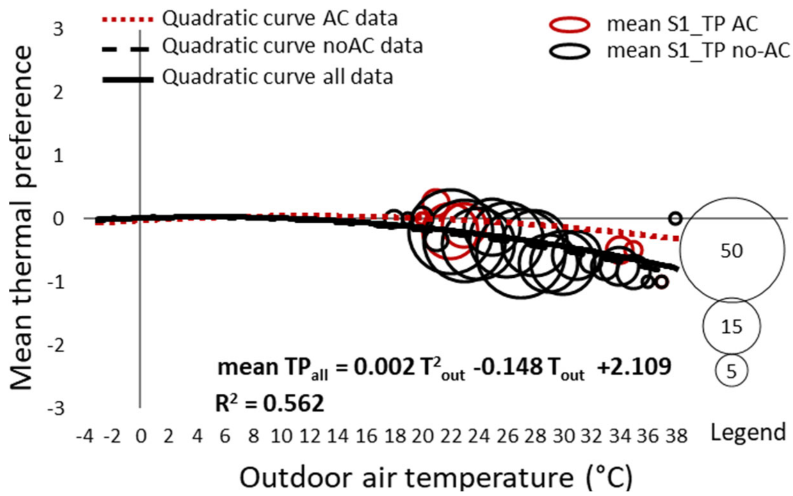
Appendix P. Correlation between mean thermal responses and Tout



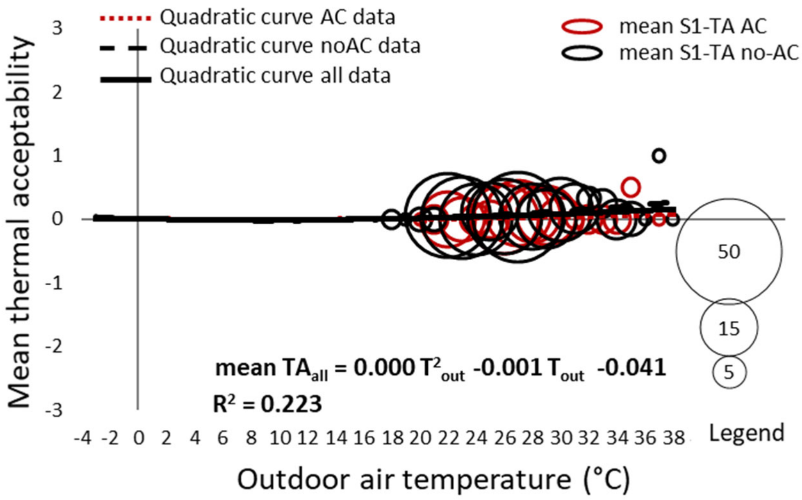
Appendix Figure P-1 Correlation between mean weighted values of thermal sensation to outdoor temperature in AC and no-AC modes (in summer)



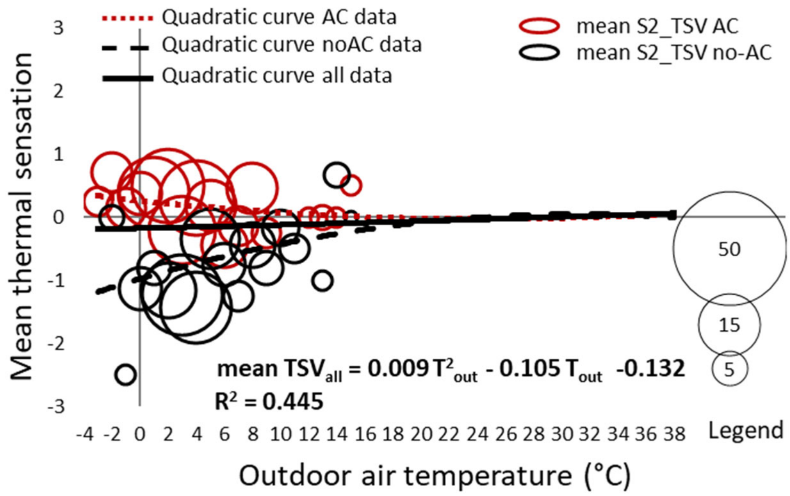
Appendix Figure P-2 Correlation between mean weighted values of thermal evaluation to outdoor temperature in AC and no-AC modes (in summer)



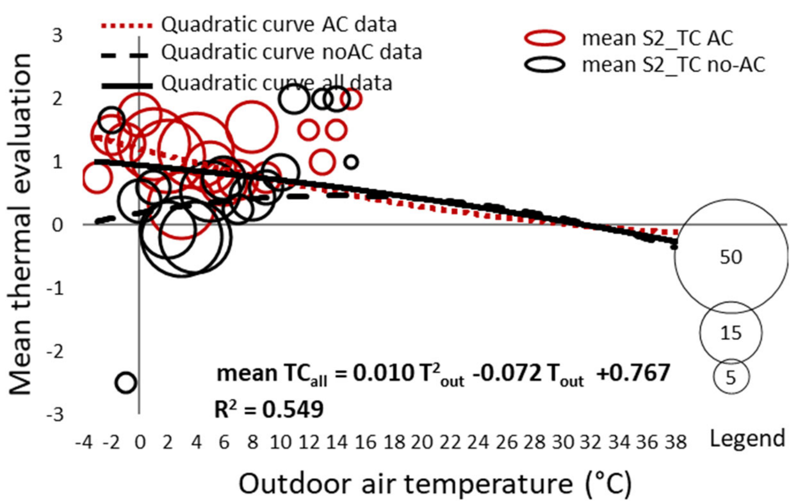
Appendix Figure P-3 Correlation between mean weighted values of thermal preference to outdoor temperature in AC and no-AC modes (in summer)



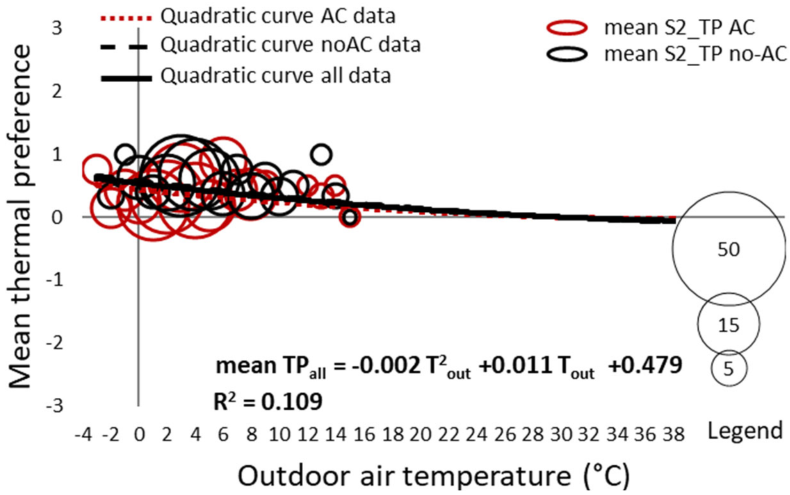
Appendix Figure P-4 Correlation between mean weighted values of thermal acceptability to outdoor temperature in AC and no-AC modes (in summer)



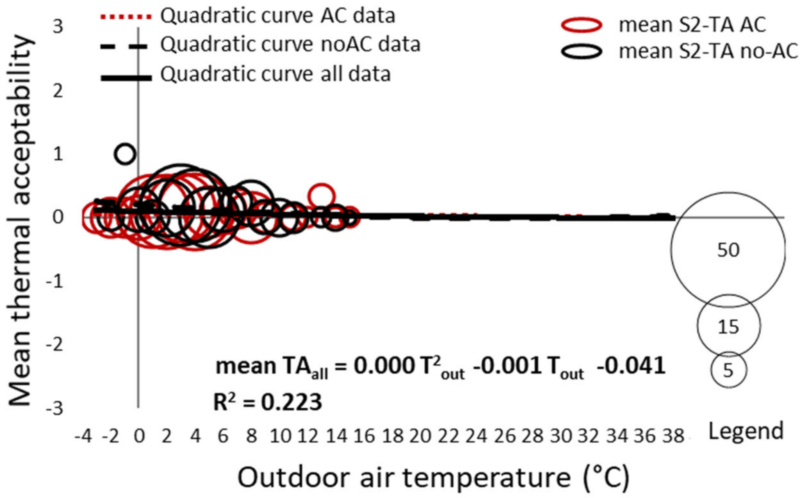
Appendix Figure P-5 Correlation between mean weighted values of thermal sensation to outdoor temperature in AC and no-AC modes (in winter)



Appendix Figure P-6 Correlation between mean weighted values of thermal evaluation to outdoor temperature in AC and no-AC modes (in winter)

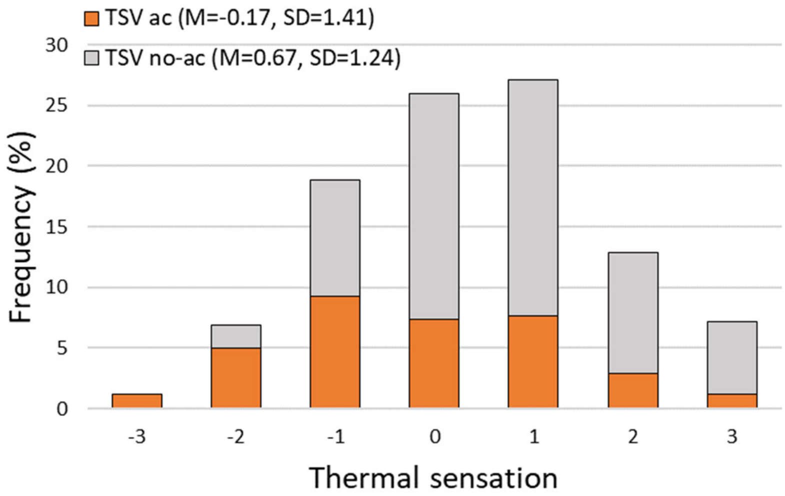


Appendix Figure P-7 Correlation between mean weighted values of thermal preference to outdoor temperature in AC and no-AC modes (in winter)

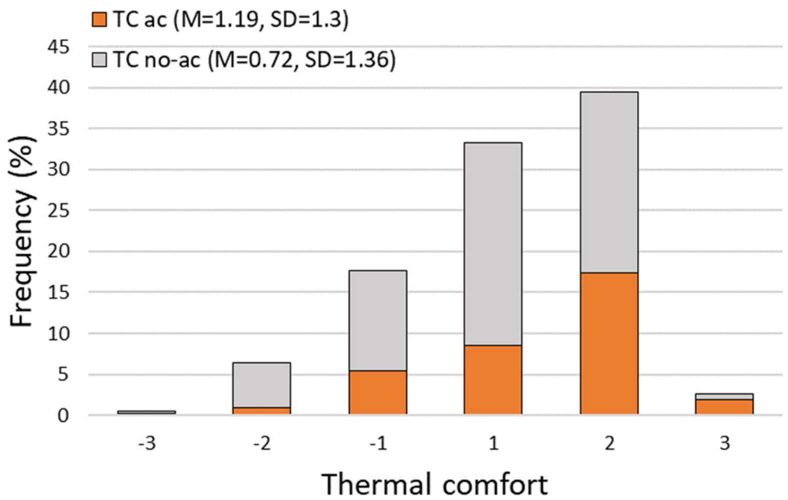


Appendix Figure P-8 Correlation between mean weighted values of thermal acceptability to outdoor temperature in AC and no-AC modes (in winter)

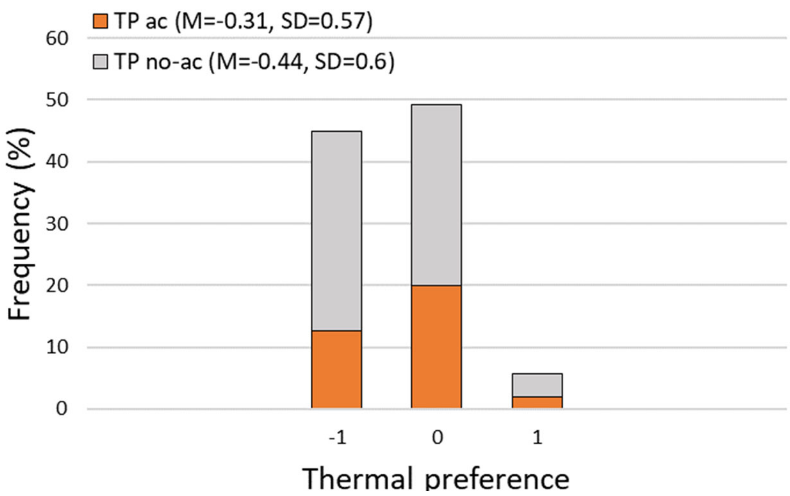
Appendix Q. Frequency distributions of thermal responses



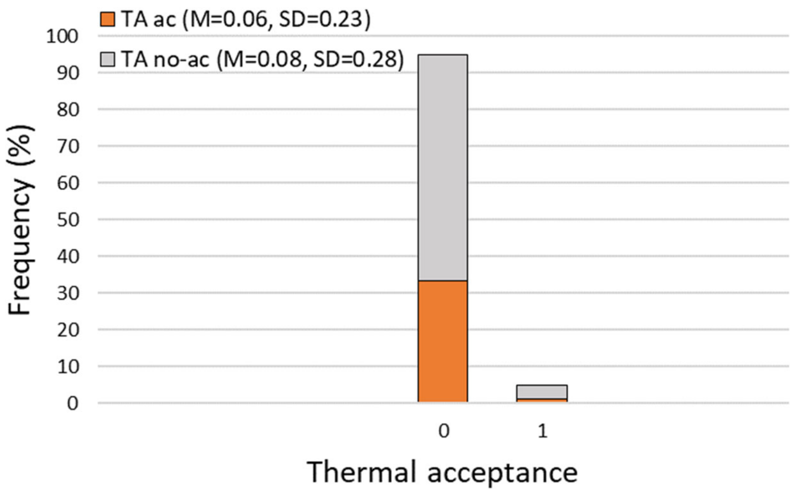
Appendix Figure Q-1 Frequency distributions of thermal sensation in summer. ** ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



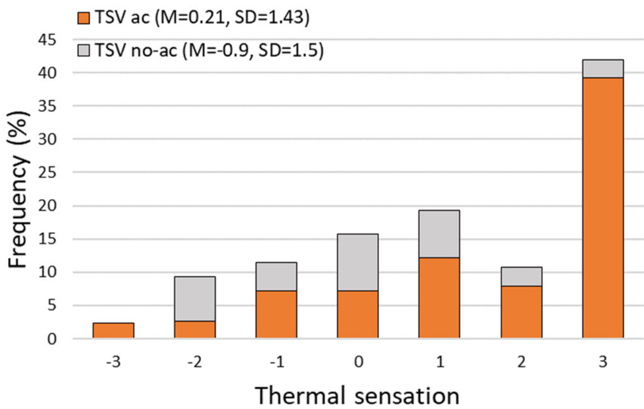
Appendix Figure Q-2 Frequency distributions of thermal evaluation in summer. ** ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



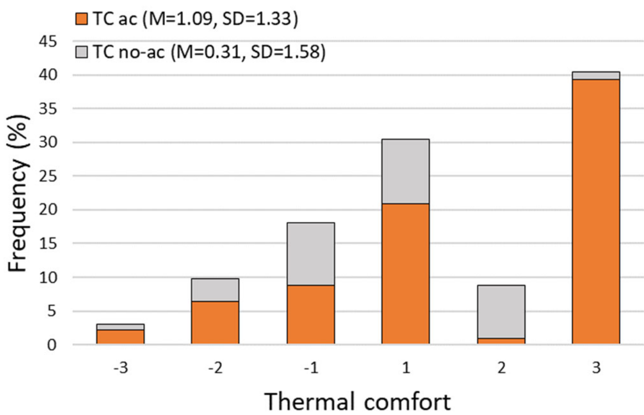
Appendix Figure Q-3 Frequency distributions of thermal preference in summer. ** ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



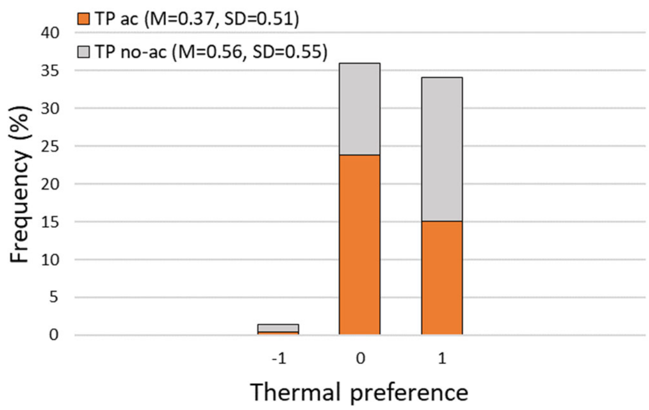
Appendix Figure Q-4 Frequency distributions of thermal acceptability in summer. ** ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



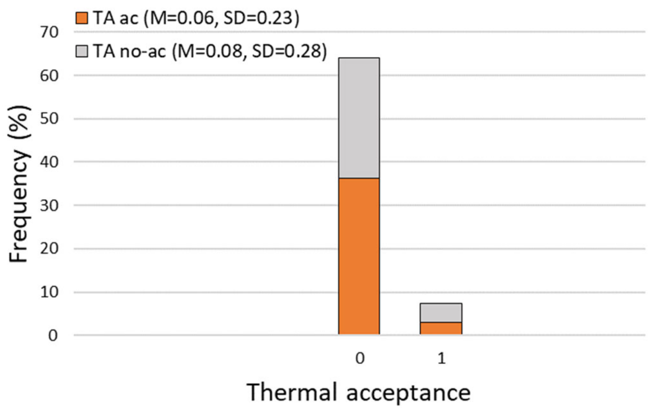
Appendix Figure Q-5 Frequency distributions of thermal sensation in winter. ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{HT}$=165)



Appendix Figure Q-6 Frequency distributions of thermal evaluation in winter. ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{HT}$=165)

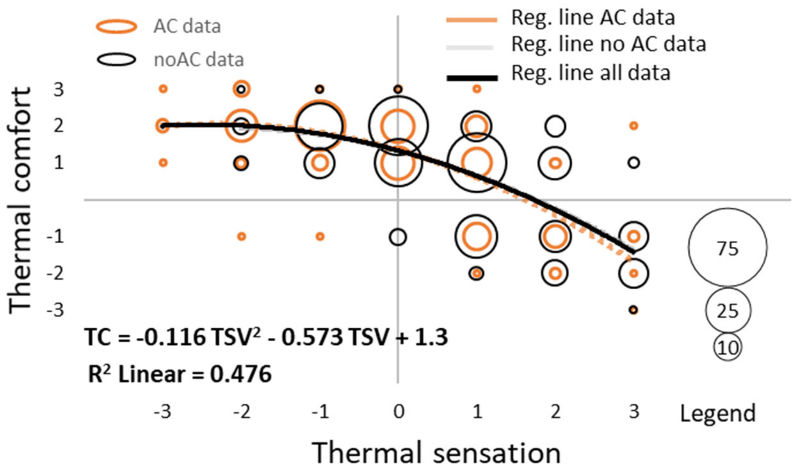


Appendix Figure Q-7 Frequency distributions of thermal preference in winter. ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{HT}$=165)

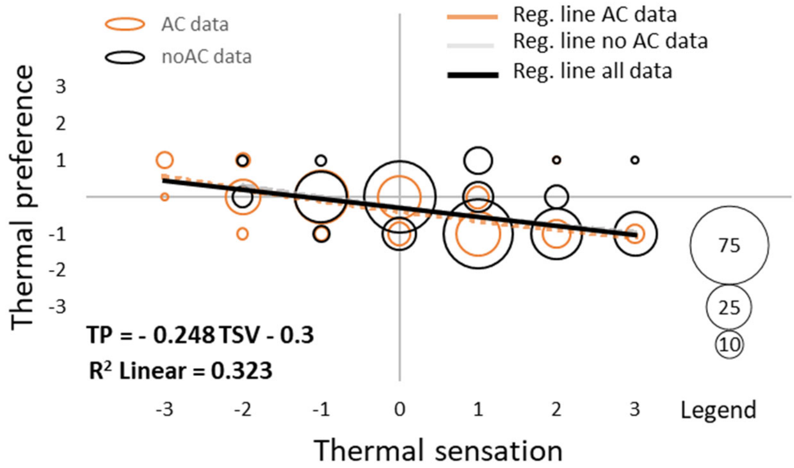


Appendix Figure Q-8 Frequency distributions of thermal acceptability in winter. ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{HT}$=165)

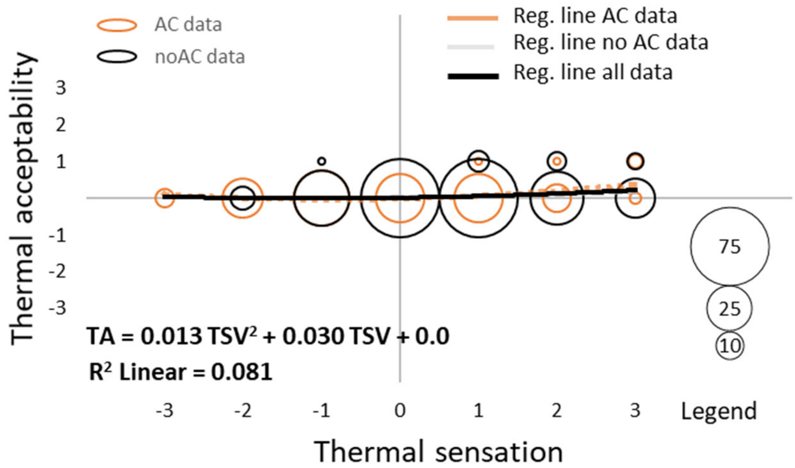
Appendix R. Correlation between thermal responses



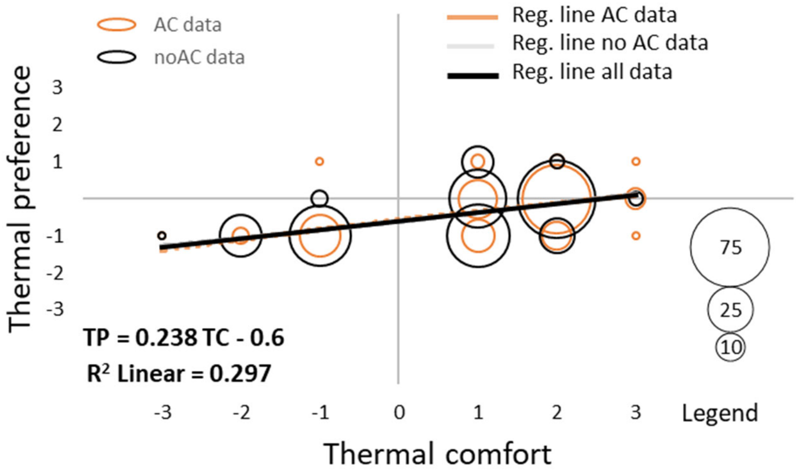
Appendix Figure R-1 Correlations TC: TSV in summer ($_{n}N_{all}$=420; $_{n}N_{FR}$=275; $_{n}N_{CL}$=145)



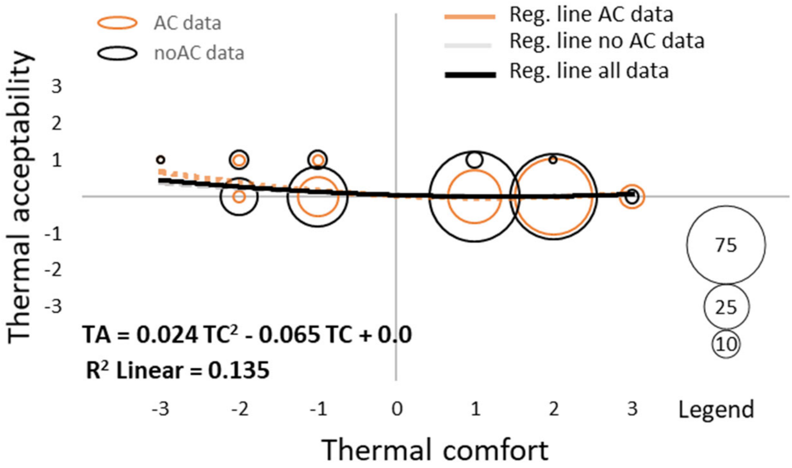
Appendix Figure R-2 Correlations TP: TSV in summer ($_{n}N_{all}$=420; $_{n}N_{FR}$=275; $_{n}N_{CL}$=145)



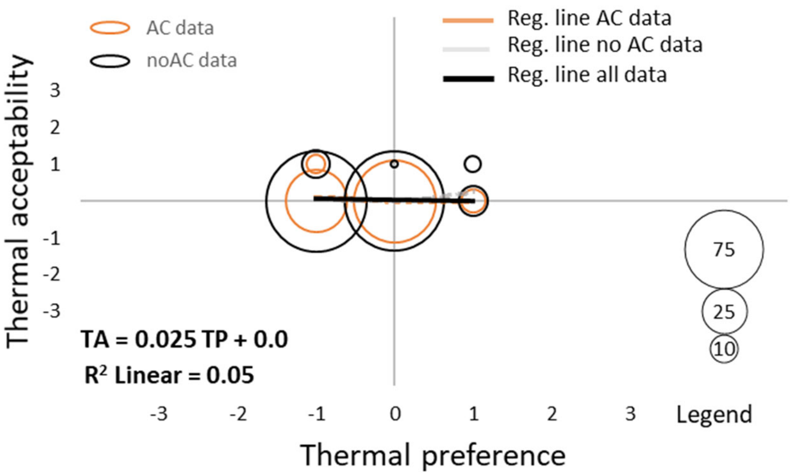
Appendix Figure R-3 Correlations TA: TSV in summer ($_{n}N_{all}$=420; $_{n}N_{FR}$=275; $_{n}N_{CL}$=145)



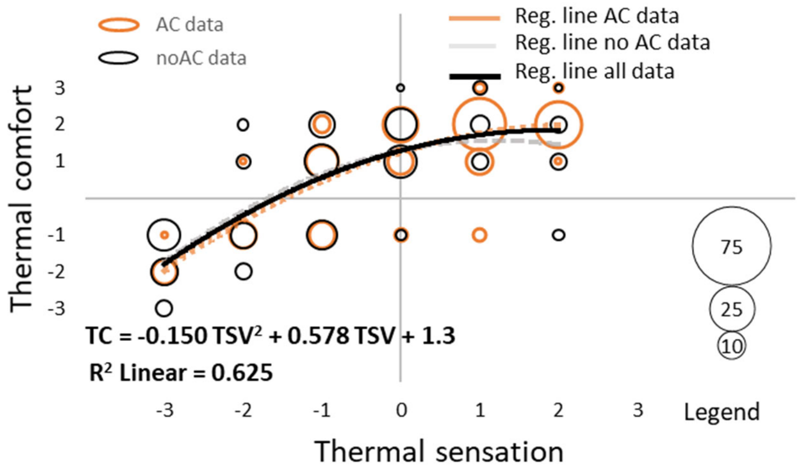
Appendix Figure R-4 Correlations TP: TC in summer ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



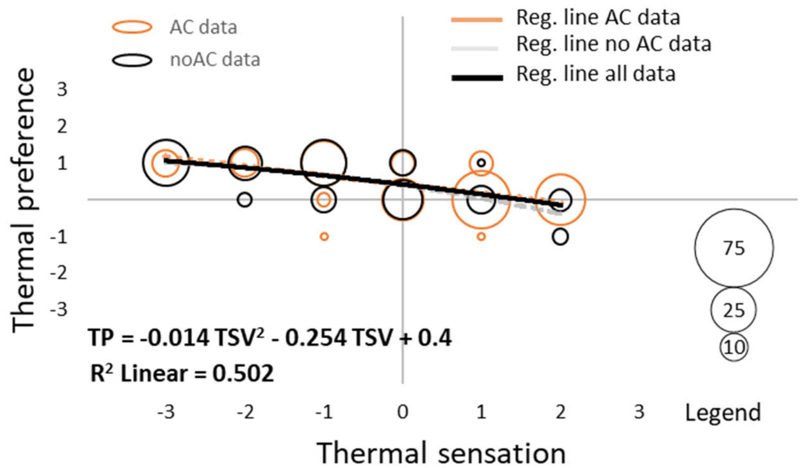
Appendix Figure R-5 Correlations TA: TC in summer ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



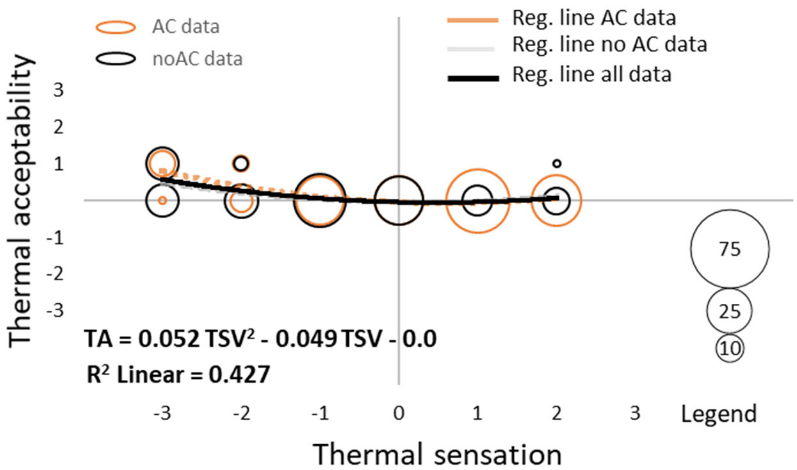
Appendix Figure R-6 Correlations TA: TP in summer ($_nN_{all}$=420; $_nN_{FR}$=275; $_nN_{CL}$=145)



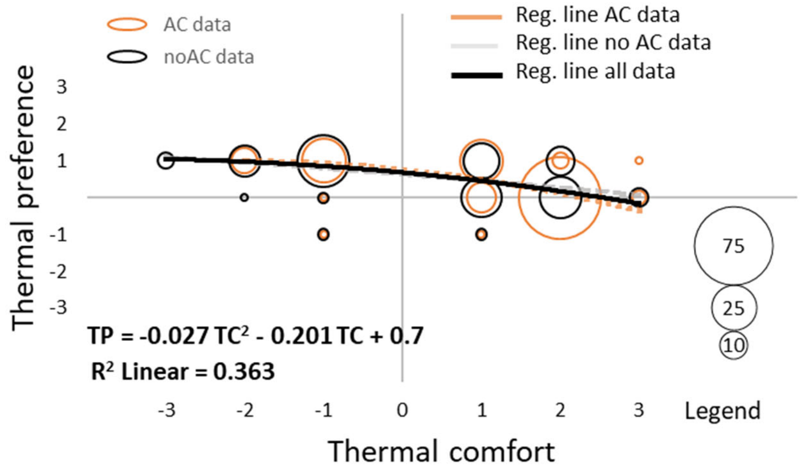
Appendix Figure R-7 Correlations TC: TSV in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)



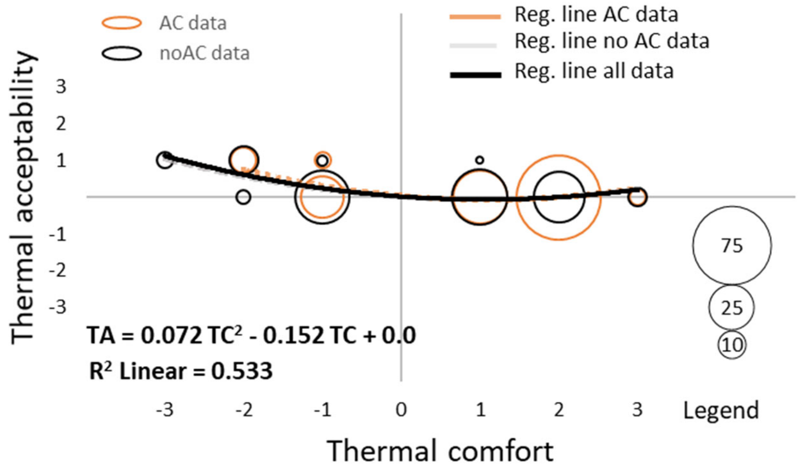
Appendix Figure R-8 Correlations TP: TSV in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)



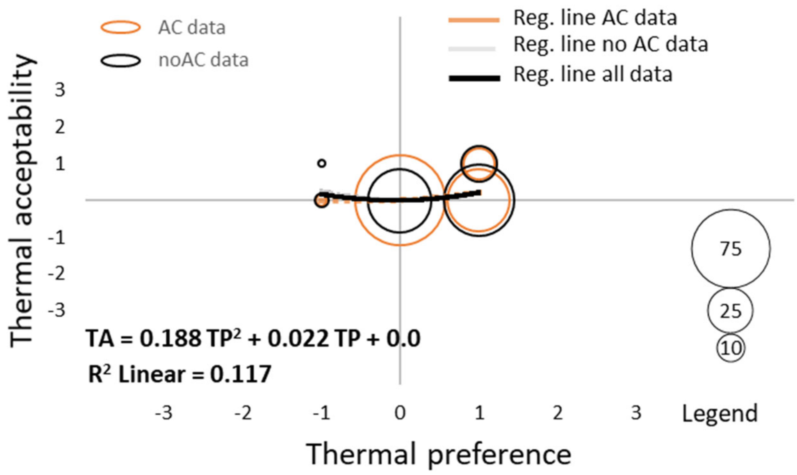
Appendix Figure R-9 Correlations TA: TSV in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)



Appendix Figure R-10 Correlations TP: TC in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)



Appendix Figure R-11 Correlations TA: TC in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)



Appendix Figure R-12 Correlations TA: TP in winter ($_nN_{all}$=300; $_nN_{FR}$=135; $_nN_{CL}$=165)

Appendix S. Linear regressions of thermal responses at the investigated sub-divisions

Appendix Table S-1 Linear regression equations of thermal responses at certain sub-divisions (summer and winter survey)

Thermal index	Subjective range		Measured range (°C)		n	Mean temperature for given vote (°C)							Regression equation	R^2	p
	M	SD	M	SD		-3	-2	-1	0	1	2	3			
TSV	0.10	1.49	23.9	4.98	720	16.8	21.1	22.8	24.3	25.6	25.6	27.9	$TSV = 0.133 T_i-3.1$	0.198	< 0.001
TSV_{day}	0.14	1.52	23.9	5.19	397	17.2	19.2	22.8	24.1	25.5	26.5	28.5	$TSV_{day} = 0.150 T_i-3.4$	0.261	< 0.001
TSV_{night}	0.06	1.45	24.0	4.71	323	16.1	22.5	22.9	24.7	25.7	24.4	27.3	$TSV_{night} = 0.108 T_i-2.5$	0.125	< 0.001
$TSV_{AC\ on}$	0.03	1.44	23.9	4.22	310	19.3	23.3	24.0	24.2	24.1	24.4	27.2	$TSV_{AC\ on} = 0.063 T_i-1.5$	0.035	< 0.05
$TSV_{AC\ off}$	0.15	1.52	24.0	5.49	410	15.5	18.3	21.8	24.4	26.9	26.6	28.1	$TSV_{AC\ off} = 0.164 T_i-3.8$	0.349	< 0.001
TSV_{GSD}	0.01	1.55	23.9	4.65	359	16.7	23.2	23.8	24.5	24.2	25.2	27.7	$TSV_{GSD} = 0.120 T_i-2.9$	0.130	< 0.001
TSV_{Kaikan}	0.19	1.42	24.0	5.29	361	17.0	18.3	21.6	24.2	26.5	26.0	28.3	$TSV_{Kaikan} = 0.142 T_i-3.2$	0.283	< 0.001
TSV_{Male}	0.22	1.47	24.1	4.71	512	17.8	20.2	22.3	24.4	25.7	25.9	28.1	$TSV_{Male} = 0.150 T_i-3.4$	0.233	< 0.001
TSV_{Female}	-0.19	1.50	23.6	5.57	208	15.5	22.5	24.0	24.3	25.1	24.5	27.5	$TSV_{Female} = 0.099 T_i-2.5$	0.133	< 0.001
TSV_{JP}	0.00	1.54	23.5	4.71	311	16.2	22.8	23.3	23.9	24.2	24.7	27.5	$TSV_{JP} = 0.118 T_i-2.8$	0.130	< 0.001
TSV_{Intl}	0.18	1.44	24.3	5.15	409	17.4	19.3	22.3	24.6	26.4	26.3	28.4	$TSV_{Intl} = 0.142 T_i-3.3$	0.257	< 0.001
TC	0.82	1.42	23.9	4.98	720	19.5	23.0	22.7		24.8	24.2	23.3	$TC = 0.037 T_i-0.1$	0.017	< 0.05
TC_{day}	0.76	1.43	23.9	5.19	397	20.3	22.4	22.7		25.0	24.2	21.1	$TC_{day} = -0.036 T_i-0.1$	0.017	< 0.05
TC_{night}	0.90	1.40	24.0	4.71	323	15.5	24.2	22.8		24.4	24.3	25.1	$TC_{night} = 0.037 T_i+0.0$	0.016	< 0.05
$TC_{AC\ on}$	1.14	1.32	23.9	4.22	310	26.1	21.1	23.0		24.6	24.0	24.0	$TC_{AC\ on} = 0.039 T_i+0.2$	0.015	< 0.05
$TC_{AC\ off}$	0.59	1.45	24.0	5.49	410	18.2	23.6	22.5		24.8	24.5	22.3	$TC_{AC\ off} = 0.037 T_i-0.3$	0.020	< 0.05
TC_{GSD}	0.69	1.46	23.9	4.65	359	18.9	23.2	23.0		24.8	23.9	26.2	$TC_{GSD} = 0.037 T_i-0.2$	0.014	< 0.05
TC_{Kaikan}	0.95	1.36	24.0	5.29	361	20.8	22.7	22.3		24.7	24.6	22.6	$TC_{Kaikan} = 0.036 T_i+0.1$	0.019	< 0.05
TC_{Male}	0.82	1.37	24.1	4.71	512	26.1	24.0	23.3		24.6	24.2	23.1	$TC_{Male} = 0.012 T_i+0.5$	0.002	0.347
TC_{Female}	0.84	1.53	23.6	5.57	208	18.2	20.9	20.9		25.5	24.4	24.2	$TC_{Female} = 0.081 T_i-1.1$	0.087	< 0.001
TC_{JP}	0.74	1.37	23.5	4.71	311	-	24.2	22.4		23.4	24.2	26.2	$TC_{JP} = 0.036 T_i-0.1$	0.016	< 0.05
TC_{Intl}	0.89	145	24.3	5.15	409	19.5	22.4	23.2		25.7	24.3	22.6	$TC_{Intl} = 0.036 T_i+0.0$	0.016	< 0.05
TP	-0.04	0.71	23.9	4.98	720			27.6	24.2	19.1			$TP = -0.085 T_i+2.0$	0.357	< 0.001
TP_{day}	-0.04	0.71	23.9	5.19	397			27.9	24.1	19.1			$TP_{day} = -0.082 T_i+1.9$	0.361	< 0.001
TP_{night}	-0.04	0.70	24.0	4.71	323			27.2	24.4	19.1			$TP_{night} = -0.089 T_i+2.1$	0.353	< 0.001
$TP_{AC\ on}$	0.05	0.64	23.9	4.22	310			26.9	24.3	20.5			$TP_{AC\ on} = -0.073 T_i+1.8$	0.235	< 0.001
$TP_{AC\ off}$	-0.11	0.75	24.0	5.49	410			27.8	24.2	18.0			$TP_{AC\ off} = -0.090 T_i+2.1$	0.431	< 0.001
TP_{GSD}	-0.06	0.63	23.9	4.65	359			27.1	24.1	18.6			$TP_{GSD} = -0.076 T_i+1.8$	0.314	< 0.001
TP_{Kaikan}	-0.02	0.78	24.0	5.29	361			27.9	24.4	19.4			$TP_{Kaikan} = -0.092 T_i+2.2$	0.392	< 0.001
TP_{Male}	-0.04	0.73	24.1	4.71	512			27.4	24.5	19.6			$TP_{Male} = -0.092 T_i+2.2$	0.360	< 0.001
TP_{Female}	-0.04	0.66	23.6	5.57	208			27.9	23.8	17.7			$TP_{Female} = -0.072 T_i+1.7$	0.368	< 0.001
TP_{JP}	-0.05	0.63	23.5	4.71	311			26.7	24.0	17.8			$TP_{JP} = -0.079 T_i+1.8$	0.341	< 0.001
TP_{Intl}	-0.03	0.76	24.3	5.15	409			28.1	24.5	19.8			$TP_{Intl} = -0.090 T_i+2.1$	0.372	< 0.001
TA	0.07	0.26	23.9	4.98	720				24.1	21.5			$TA = -0.007 T_i+0.2$	0.019	< 0.001
TA_{day}	0.09	0.29	23.9	5.19	397				24.2	21.1			$TA_{day} = -0.010 T_i+0.3$	0.030	< 0.001
TA_{night}	0.05	0.21	24.0	4.71	323				24.1	22.5			$TA_{night} = -0.003 T_i+0.1$	0.005	0.205
$TA_{AC\ on}$	0.06	0.23	23.9	4.22	310				24.1	20.5			$TA_{AC\ on} = -0.011 T_i+0.3$	0.041	< 0.001
$TA_{AC\ off}$	0.08	0.28	24.0	5.49	410				24.2	22.0			$TA_{AC\ off} = -0.005 T_i+0.2$	0.012	< 0.05
TA_{GSD}	0.09	0.28	23.9	4.65	359				24.1	21.7			$TA_{GSD} = -0.009 T_i+0.3$	0.021	< 0.05
TA_{Kaikan}	0.06	0.23	24.0	5.29	361				24.2	21.3			$TA_{Kaikan} = -0.006 T_i+0.2$	0.017	< 0.05
TA_{Male}	0.06	0.25	24.1	4.71	512				24.2	22.4			$TA_{Male} = -0.005 T_i+0.184$	0.009	< 0.05
TA_{Female}	0.09	0.29	23.6	5.57	208				23.9	19.9			$TA_{Female} = -0.011 T_i+0.3$	0.043	< 0.05
TA_{JP}	0.06	0.24	23.5	4.71	311				23.5	23.1			$TA_{JP} = -0.001 T_i+0.1$	0.000	0.713
TA_{Intl}	0.08	0.27	24.3	5.15	409				24.6	20.6			$TA_{Intl} = -0.011 T_i+0.4$	0.046	< 0.001

Note: R^2: Regression coefficient of determination; p:- confidence interval

Appendix Table S-2 Linear regression equations of thermal responses at certain sub-divisions (summer survey)

Thermal index	Subjective range		Measured range (°C)		n	Mean temperature for given vote (°C)							Regression equation	R^2	p
	M	SD	M	SD		-3	-2	-1	0	1	2	3			
TSV	0.38	1.36	27.0	2.04	420	22.2	25.5	26.2	27.0	27.6	28.0	27.9	TSV = 0.271 Ti-7.0	0.166	< 0.001
TSV_{day}	0.54	1.33	27.2	2.00	234	21.8	25.8	26.3	27.1	27.4	28.0	28.3	$TSV_{day} = 0.268 T_i-6.7$	0.162	< 0.001
TSV_{night}	0.18	1.38	26.9	2.09	186	22.8	25.4	26.0	26.8	27.9	27.8	27.3	$TSV_{night} = 0.264 T_i-6.9$	0.160	< 0.001
$TSV_{AC\ on}$	-0.17	1.41	26.5	2.15	145	22.2	25.2	26.4	26.6	27.3	27.8	27.2	$TSV_{AC\ on} = 0.284 T_i-7.7$	0.188	< 0.001
$TSV_{AC\ off}$	0.67	1.24	27.3	1.92	275	-	26.3	26.0	27.1	27.7	28.0	28.1	$TSV_{AC\ off} = 0.213 T_i-5.2$	0.109	< 0.001
TSV_{GSD}	0.26	1.43	27.0	1.67	212	-	26.6	26.5	27.0	26.8	27.9	27.7	$TSV_{GSD} = 0.219 T_i -5.6$	0.065	< 0.05
TSV_{Kaikan}	0.50	1.27	27.1	2.37	208	22.2	23.1	25.6	27.0	28.1	28.0	28.3	TSV_{Kaikan} = 0.295 Ti-7.5	0.299	< 0.001
TSV_{Male}	0.52	1.36	26.9	2.07	296	22.2	24.4	25.8	26.6	27.6	27.9	28.1	$TSV_{Male} = 0.340 T_i-8.6$	0.267	< 0.001
TSV_{Female}	0.06	1.31	27.4	1.93	124	-	26.8	26.7	27.8	27.6	28.3	27.5	$TSV_{Female} = 0.142 T_i-3.8$	0.044	< 0.05
TSV_{JP}	0.22	1.42	26.7	1.48	183	-	26.4	26.2	26.5	26.8	27.6	27.5	$TSV_{JP} = 0.285 T_i-7.4$	0.089	< 0.001
TSV_{Intl}	0.50	1.30	27.3	2.35	237	22.2	24.3	26.1	27.2	28.0	28.2	28.4	$TSV_{Intl} = 0.262 T_i-6.6$	0.223	< 0.001
TC	0.88	1.36	27.0	2.04	420	27.6	28.2	27.3		27.4	26.5	25.4	$TC = -0.147 T_i+4.9$	0.049	< 0.001
TC_{day}	0.83	1.31	27.2	2.00	324	27.6	28.6	27.4		27.3	26.7	24.4	$TC_{day} = -0.144 T_i+4.8$	0.049	< 0.05
TC_{night}	0.95	1.42	26.9	2.09	186	-	27.7	27.2		27.6	26.3	25.6	$TC_{night} = -0.147 T_i+4.9$	0.047	< 0.05
$TC_{AC\ on}$	1.19	1.30	26.5	2.15	145	26.1	27.8	26.9		27.4	26.0	25.0	$TC_{AC\ on} = -0.135 T_i+4.8$	0.050	< 0.05
$TC_{AC\ off}$	0.72	1.36	27.3	1.92	275	29.1	28.3	27.5		27.4	26.9	26.4	$TC_{AC\ off} = -0.128 T_i+4.2$	0.033	< 0.05
TC_{GSD}	0.75	1.40	27.0	1.67	212	29.1	27.9	27.0		27.1	26.7	26.2	$TC_{GSD} = -0.147 T_i+4.7$	0.031	< 0.05
TC_{Kaikan}	1.01	1.31	27.1	2.37	208	26.1	28.5	27.7		27.8	26.4	24.9	$TC_{Kaikan} = -0.152 T_i+5.1$	0.075	< 0.001
TC_{Male}	0.78	1.37	26.9	2.07	296	26.1	28.0	27.5		27.3	26.1	24.8	$TC_{Male} = -0.193 T_i+6.0$	0.085	< 0.001
TC_{Female}	1.13	1.29	27.4	1.93	124	29.1	28.9	26.7		27.9	27.2	26.8	$TC_{Female} = -0.061 T_i+2.8$	0.008	0.312
TC_{JP}	0.80	1.37	26.7	1.48	183	-	27.0	27.1		26.6	26.5	26.2	$TC_{JP} = -0.156 T_i-5.0$	0.029	< 0.05
TC_{Intl}	0.95	1.35	27.3	2.35	237	27.6	28.9	27.6		27.9	26.6	24.9	$TC_{Intl} = -0.156 T_i+5.2$	0.074	< 0.001
TP	-0.39	0.59	27.0	2.04	420			27.7	26.6	25.7			$TP = -0.091 T_i+2.1$	0.098	< 0.001
TP_{day}	-0.40	0.59	27.2	2.00	234			27.9	26.6	26.1			$TP_{day} = -0.099 T_i+2.3$	0.112	< 0.001
TP_{night}	-0.39	0.60	26.9	2.09	186			27.4	26.5	25.2			$TP_{night} = -0.082 T_i+1.8$	0.083	< 0.001
$TP_{AC\ on}$	-0.31	0.57	26.5	2.15	145			26.9	26.5	23.7			$TP_{AC\ on} = -0.068 T_i+1.5$	0.067	< 0.05
$TP_{AC\ off}$	-0.44	0.60	27.3	1.92	275			28.0	26.7	26.7			$TP_{AC\ off} = -0.102 T_i+2.4$	0.106	< 0.001
TP_{GSD}	-0.36	0.50	27.0	1.67	212			27.4	26.7	26.8			$TP_{GSD} = -0.065 T_i +1.4$	0.047	<0.05
TP_{Kaikan}	-0.43	0.68	27.1	2.37	208			27.9	26.4	25.6			$TP_{Kaikan} = -0.103 T_i+2.4$	0.131	< 0.001
TP_{Male}	-0.41	0.61	26.9	2.07	296			27.6	26.3	25.7			$TP_{Male} = -0.099 T_i+2.3$	0.114	< 0.001
TP_{Female}	-0.36	0.56	27.4	1.93	124			27.9	27.1	25.7			$TP_{Female} = -0.077 T_i+1.8$	0.071	< 0.05
TP_{JP}	-0.34	0.50	26.7	1.48	183			27.1	26.5	26.8			$TP_{JP} = -0.064 T_i-1.4$	0.036	< 0.05
TP_{Intl}	-0.43	0.66	27.3	2.35	237			28.0	26.7	25.6			$TP_{Intl} = -0.098 T_i+2.2$	0.123	< 0.001
TA	0.05	0.22	27.0	2.04	420					27.0	27.6		$TA = 0.006 T_i-0.1$	0.004	0.223
TA_{day}	0.06	0.23	27.2	2.00	234					27.1	27.9		$TA_{day} = 0.010 T_i-0.2$	0.008	0.183
TA_{night}	0.04	0.20	26.9	2.09	186					26.8	27.0		$TA_{night} = 0.002 T_i-0.0$	0.000	0.815
$TA_{AC\ on}$	0.03	0.18	26.5	2.15	145					26.5	26.1		$TA_{AC\ on} = -0.003 T_i+0.1$	0.001	0.712
$TA_{AC\ off}$	0.06	0.23	27.3	1.92	275					27.3	28.0		$TA_{AC\ off} = 0.011 T_i-0.2$	0.008	0.142
TA_{GSD}	0.05	0.22	27.0	1.67	212					26.9	28.2		$TA_{GSD} = 0.023 T_i-0.6$	0.029	< 0.05
TA_{Kaikan}	0.05	0.21	27.1	2.37	208					27.1	26.9		$TA_{Kaikan} = -0.002 T_i+0.1$	0.000	0.782
TA_{Male}	0.05	0.22	26.9	2.07	296					26.9	27.3		$TA_{Male} = 0.004 T_i-0.1$	0.002	0.486
TA_{Female}	0.05	0.21	27.4	1.93	124					27.3	28.4		$TA_{Female} = 0.012 T_i-0.3$	0.013	0.214
TA_{JP}	0.04	0.20	26.7	1.48	183					26.6	27.5		$TA_{JP} = 0.016 T_i-0.4$	0.014	0.110
TA_{Intl}	0.05	0.23	27.3	2.35	237					27.3	27.6		$TA_{Intl} = 0.003 T_i-0.0$	0.001	0.642

Note: R^2: Regression coefficient of determination; p:- confidence interval.

Appendix Table S-3 Linear regression equations of thermal responses at certain sub-divisions (winter survey)

Thermal index	Subjective range		Measured range (ºC)		n	Mean temperature for given vote (ºC)							Regression equation	R^2	p
	M	SD	M	SD		-3	-2	-1	0	1	2	3			
TSV	-0.29	1.57	19.6	4.65	300	16.1	16.6	18.8	19.6	21.9	22.6	–	$TSV = 0.159 T_i-3.4$	0.222	< 0.001
$\mathbf{TSV}_{day}$	-0.45	1.59	19.2	4.77	163	16.7	16.0	18.4	18.2	22.2	23.4	-	$TSV_{day} = 0.161 T_i–3.5$	0.233	< 0.001
$\mathbf{TSV}_{night}$	-0.10	1.52	20.1	4.47	137	15.0	17.5	19.3	21.1	21.5	22.1	-	$TSV_{night} = 0.151 T_i-3.1$	0.197	< 0.001
$\mathbf{TSV}_{AC\ on}$	0.21	1.43	21.6	4.26	165	17.8	19.7	20.9	21.6	22.1	23.1	–	$TSV_{AC\ on} = 0.101 T_i-2.0$	0.090	< 0.001
$\mathbf{TSV}_{AC\ off}$	-0.90	1.50	17.2	3.94	135	15.5	14.7	17.1	17.5	21.1	21.1	–	$TSV_{AC\ off} = 0.176 T_i-3.9$	0.211	< 0.001
$\mathbf{TSV}_{GSD}$	-0.36	1.64	19.4	3.90	147	16.7	17.9	18.6	20.1	20.7	21.7	-	$TSV_{GSD} = 0.177 T_i-3.8$	0.177	< 0.001
$\mathbf{TSV}_{Kaikan}$	-0.22	1.49	19.8	5.27	153	15.2	15.5	19.0	19.1	23.0	23.5	-	$TSV_{Kaikan} = 0.149 T_i-3.2$	0.276	< 0.001
$\mathbf{TSV}_{Male}$	-0.19	1.51	20.3	4.65	216	16.8	17.1	19.4	20.0	22.3	23.4	–	$TSV_{Male} = 0.149 T_i-3.2$	0.211	< 0.001
$\mathbf{TSV}_{Female}$	-0.55	1.69	17.9	4.19	84	15.5	15.4	16.3	18.7	20.6	20.4	–	$TSV_{Female} = 0.192 T_i-4.0$	0.227	< 0.001
$\mathbf{TSV}_{JP}$	-0.32	1.66	18.9	3.91	128	16.2	17.7	17.6	19.3	20.5	21.5	-	$TSV_{JP} = 0.195 T_i-4.0$	0.212	< 0.001
$\mathbf{TSV}_{Intl}$	-0.27	1.50	20.1	5.07	172	16.1	15.8	19.6	19.7	22.9	23.6	-	$TSV_{Intl} = 0.146 T_i-3.2$	0.243	< 0.001
TC	0.74	1.50	19.6	4.65	300	15.5	16.8	17.6		19.9	21.1	20.8	$TC = 0.113 T_i-1.5$	0.123	< 0.001
$\mathbf{TC}_{day}$	0.65	1.59	19.2	4.77	163	15.5	17.1	17.3		19.7	20.7	20.2	$TC_{day} = 0.104 T_i-1.3$	0.097	< 0.001
$\mathbf{TC}_{night}$	0.85	1.37	20.1	4.47	137	15.5	15.8	17.8		20.2	21.6	23.1	$TC_{night} = 0.122 T_i-1.6$	0.159	< 0.001
$\mathbf{TC}_{AC\ on}$	1.09	1.33	21.6	4.26	165	–	18.1	19.7		21.9	22.4	22.0	$TC_{AC\ on} = 0.089 T_i-0.8$	0.082	< 0.001
$\mathbf{TC}_{AC\ off}$	0.31	1.58	17.2	3.94	135	15.5	16.0	16.1		18.1	17.8	19.9	$TC_{AC\ off} = 0.101 T_i-1.4$	0.064	< 0.05
$\mathbf{TC}_{GSD}$	0.61	1.55	19.4	3.90	147	15.5	17.8	18.1		19.7	20.5	–	$TC_{GSD} = 0.124 T_i-1.8$	0.098	< 0.001
$\mathbf{TC}_{Kaikan}$	0.87	1.44	19.8	5.27	153	15.5	15.6	16.9		20.1	21.8	20.8	$TC_{Kaikan} = 0.105 T_i-1.2$	0.149	< 0.001
$\mathbf{TC}_{Male}$	0.87	1.37	20.3	4.65	216	–	17.1	18.2		20.3	21.8	21.4	$TC_{Male} = 0.097 T_i-1.1$	0.109	< 0.001
$\mathbf{TC}_{Female}$	0.42	1.75	17.9	4.19	84	15.5	16.5	16.2		17.2	19.7	16.3	$TC_{Female} = 0.145 T_i-2.2$	0.121	< 0.05
$\mathbf{TC}_{JP}$	0.65	1.37	18.9	3.91	128	–	19.5	17.0		18.3	20.8	–	$TC_{JP} = 0.115 T_i-1.5$	0.109	< 0.001
$\mathbf{TC}_{Intl}$	0.81	1.58	20.1	5.07	172	15.5	15.9	18.3		21.3	21.3	20.8	$TC_{Intl} = 0.111 T_i-1.4$	0.127	< 0.001
TP	0.46	0.54	19.6	4.65	300			23.0	21.0	18.0			$TP = -0.039 T_i+1.2$	0.116	< 0.001
$\mathbf{TP}_{day}$	0.48	0.52	19.2	4.77	163			24.3	20.4	17.9			$TP_{day} = -0.031 T_i+1.1$	0.081	< 0.001
$\mathbf{TP}_{night}$	0.42	0.55	20.1	4.47	137			22.3	21.7	18.1			$TP_{night} = -0.049 T_i+1.4$	0.161	< 0.001
$\mathbf{TP}_{AC\ on}$	0.37	0.51	21.6	4.26	165			25.6	22.4	20.1			$TP_{AC\ on} = -0.034 T_i+1.1$	0.079	< 0.001
$\mathbf{TP}_{AC\ off}$	0.56	0.55	17.2	3.94	135			21.7	18.3	16.3			$TP_{AC\ off} = -0.044 T_i+1.3$	0.099	< 0.001
$\mathbf{TP}_{GSD}$	0.37	0.55	19.4	3.90	147			21.4	20.1	18.3			$TP_{GSD} = -0.034 T_i+1.0$	0.059	< 0.05
$\mathbf{TP}_{Kaikan}$	0.54	0.51	19.8	5.27	153			30.9	22.2	17.8			$TP_{Kaikan} = -0.043 T_i+1.4$	0.199	< 0.001
$\mathbf{TP}_{Male}$	0.46	0.55	20.3	4.65	216			23.0	22.0	18.5			$TP_{Male} = -0.045 T_i+1.4$	0.143	< 0.001
$\mathbf{TP}_{Female}$	0.44	0.50	17.9	4.19	84			-	18.9	16.6			$TP_{Female} = -0.033 T_i-1.0$	0.078	< 0.05
$\mathbf{TP}_{JP}$	0.38	0.56	18.9	3.91	128			21.4	19.9	17.4			$TP_{JP} = -0.047 T_i+1.3$	0.109	< 0.001
$\mathbf{TP}_{Intl}$	0.51	0.51	20.1	5.07	172			30.9	22.0	18.3			$TP_{Intl} = -0.039 T_i+1.3$	0.152	< 0.001
TA	0.10	0.30	19.6	4.65	300				19.9	17.4			$TA = -0.011 T_i+0.3$	0.027	< 0.05
$\mathbf{TA}_{day}$	0.15	0.35	19.2	4.77	163				19.5	17.4			$TA_{day} = -0.012 T_i+0.4$	0.025	< 0.05
$\mathbf{TA}_{night}$	0.05	0.22	20.1	4.47	137				20.2	17.3			$TA_{night} = -0.007 T_i+0.2$	0.021	0.089
$\mathbf{TA}_{AC\ on}$	0.08	0.27	21.6	4.26	165				21.9	18.3			$TA_{AC\ on} = -0.014 T_i+0.4$	0.052	< 0.05
$\mathbf{TA}_{AC\ off}$	0.13	0.34	17.2	3.94	135				17.3	16.7			$TA_{AC\ off} = -0.004 T_i+0.2$	0.002	0.569
$\mathbf{TA}_{GSD}$	0.14	0.34	19.4	3.90	147				19.6	18.1			$TA_{GSD} = -0.012 T_i+0.4$	0.019	0.099
$\mathbf{TA}_{Kaikan}$	0.07	0.26	19.8	5.27	153				20.1	16.1			$TA_{Kaikan} = -0.010 T_i-0.3$	0.039	< 0.05
$\mathbf{TA}_{Male}$	0.08	0.28	20.3	4.65	216				20.5	18.3			$TA_{Male} = -0.007 T_i+0.2$	0.016	0.064
$\mathbf{TA}_{Female}$	0.15	0.36	17.9	4.19	84				18.2	16.0			$TA_{Female} = -0.016 T_i+0.4$	0.036	0.082
$\mathbf{TA}_{JP}$	0.09	0.28	18.9	3.91	128				18.8	19.9			$TA_{JP} = 0.005 T_i-0.0$	0.006	0.391
$\mathbf{TA}_{Intl}$	0.12	0.32	20.1	5.07	172				20.7	16.0			$TA_{Intl} = -0.019 T_i+0.5$	0.088	< 0.001

Note: R^2: Regression coefficient of determination; p:- confidence interval.

Appendix T. Chi square test results

Appendix Table T-1 Chi-square results: Dependence of thermal responses on selected factors in summer and winter

		Sub-division	n	df	χ^2 critical	χ^2	p	Interpretation of result
TSV	All	Day: Night	397: 323	6	12.59	7.75	0.257	TSV is independent from Day/Night vote
TC	All	Day: Night	397: 323	5	11.07	13.50	< 0.05	TC depends on Day/Night vote
TP	All	Day: Night	397: 323	2	5.99	0.16	0.924	TP is independent from Day/Night vote
TA	All	Day: Night	397: 323	1	3.84	5.81	< 0.05	TA depends on Day/Night vote
TSV	All	AC: no AC	310: 410	6	12.59	19.11	< 0.05	TSV depends on AC/ no AC vote
TC	All	AC: no AC	310: 410	5	11.07	40.81	< 0.001	TC depends on AC/ no AC vote
TP	All	AC: no AC	310: 410	2	5.99	27.72	< 0.001	TP depends on AC/ no AC vote
TA	All	AC: no AC	310: 410	1	3.84	1.63	0.202	TA is independent from AC/ no AC vote
TSV	All	GSD: Kaikan	359: 361	6	12.59	14.21	< 0.05	TSV depends on GSD/ Kaikan vote
TC	All	GSD: Kaikan	359: 361	5	11.07	14.07	< 0.05	TC depends on GSD/ Kaikan vote
TP	All	GSD: Kaikan	359: 361	2	5.99	30.91	< 0.001	TP depends on GSD/ Kaikan vote
TA	All	GSD: Kaikan	359: 361	1	3.84	2.13	0.144	TA is independent from GSD/ Kaikan vote
TSV	All	Male: Female	512: 208	6	12.59	13.30	< 0.05	TSV depends on Male/ Female vote
TC	All	Male: Female	512: 208	5	11.07	24.76	< 0.001	TC depends on Male/ Female vote
TP	All	Male: Female	512: 208	2	5.99	4.29	0.117	TP is independent from Male/ Female vote
TA	All	Male: Female	512: 208	1	3.84	1.60	0.206	TA is independent from Male/ Female vote
TSV	All	JP: non JP	311: 409	6	12.59	14.78	< 0.05	TSV depends on JP/ non JP vote
TC	All	JP: non JP	311: 409	5	11.07	24.25	< 0.001	TC depends on JP/ non JP vote
TP	All	JP: non JP	311: 409	2	5.99	21.08	< 0.001	TP depends on JP/ non JP vote
TA	All	JP: non JP	311: 409	1	3.84	1.01	0.314	TA is independent from JP/ non JP vote

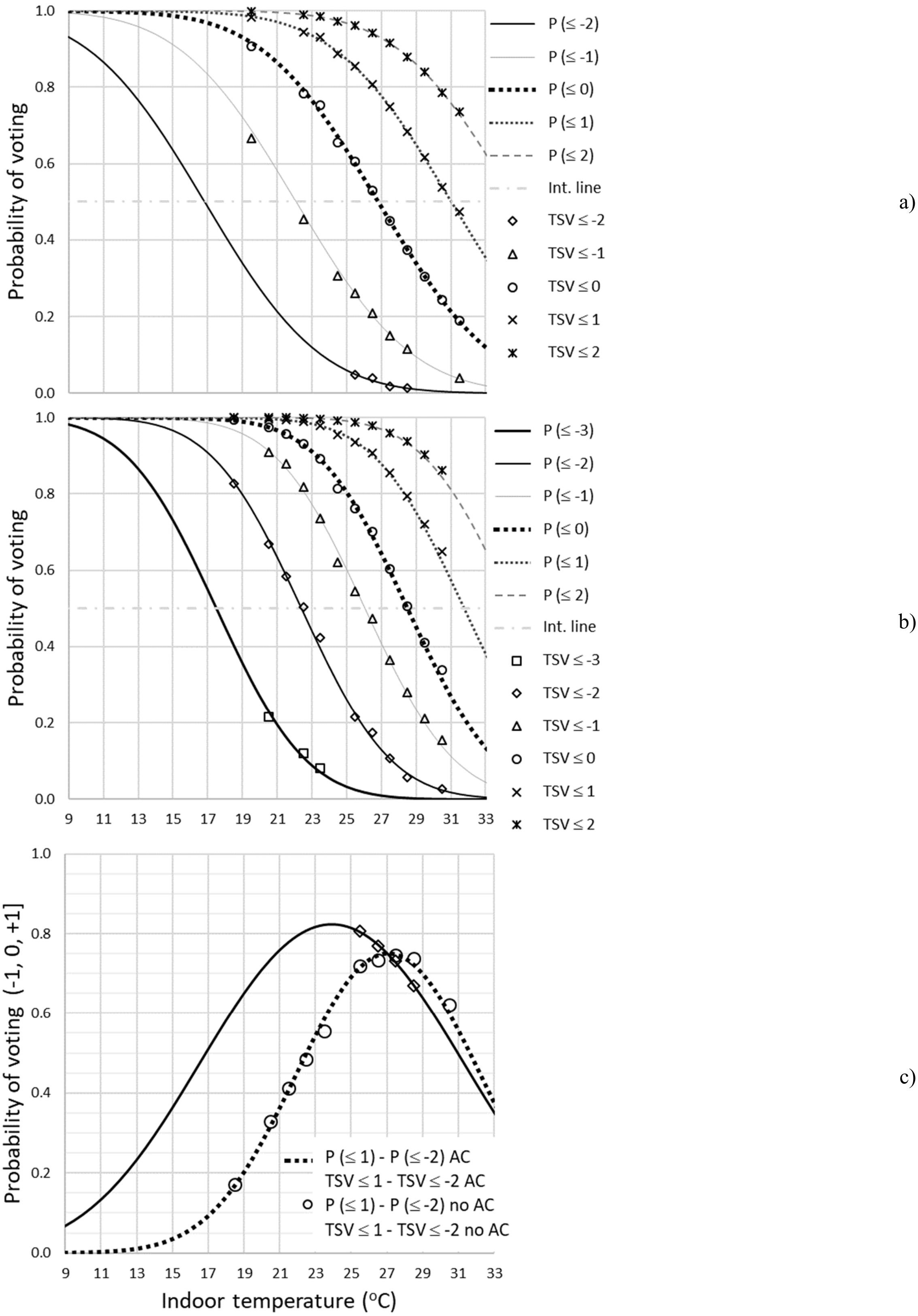
Appendix Table T-2 Chi-square results: Dependence of thermal responses on selected factors in summer

		Sub-division	n	df	χ^2 critical	χ^2	p	Interpretation of result
TSV	Summer	Day: Night	234: 186	6	12.59	12.96	< 0.05	TSV depends on Day/Night vote
TC	Summer	Day: Night	234: 186	5	11.07	18.02	< 0.05	TC depends on Day/Night vote
TP	Summer	Day: Night	234: 186	2	5.99	0.04	0.982	TP is independent from Day/Night vote
TA	Summer	Day: Night	234: 186	1	3.84	0.34	0.558	TA is independent from Day/Night vote
TSV	Summer	AC: no AC	145: 275	6	12.59	47.33	< 0.001	TSV depends on AC/ no AC vote
TC	Summer	AC: no AC	145: 275	5	11.07	23.71	< 0.001	TC depends on AC/ no AC vote
TP	Summer	AC: no AC	145: 275	2	5.99	6.89	< 0.05	TP depends on AC/ no AC vote
TA	Summer	AC: no AC	145: 275	1	3.84	1.12	0.289	TA is independent from AC/ no AC vote
TSV	Summer	GSD: Kaikan	212: 208	6	12.59	32.30	< 0.001	TSV depends on GSD/ Kaikan vote
TC	Summer	GSD: Kaikan	212: 208	5	11.07	5.07	0.407	TC is independent from GSD/ Kaikan vote
TP	Summer	GSD: Kaikan	212: 208	2	5.99	38.09	< 0.001	TP depends on GSD/ Kaikan vote
TA	Summer	GSD: Kaikan	212: 208	1	3.84	0.03	0.858	TA is independent from GSD/ Kaikan vote
TSV	Summer	Male: Female	296: 124	6	12.59	18.29	< 0.05	TSV depends on Male/ Female vote
TC	Summer	Male: Female	296: 124	5	11.07	11.69	< 0.05	TC depends on Male/ Female vote
TP	Summer	Male: Female	296: 124	2	5.99	3.17	0.205	TP is independent from Male/ Female vote
TA	Summer	Male: Female	296: 124	1	3.84	0.01	0.922	TA is independent from Male/ Female vote
TSV	Summer	JP: non JP	183: 237	6	12.59	30.00	< 0.001	TSV depends on JP/ non JP vote
TC	Summer	JP: non JP	183: 237	5	11.07	9.69	0.084	TC is independent from JP/ non JP vote
TP	Summer	JP: non JP	183: 237	2	5.99	31.68	< 0.001	TP depends on JP/ non JP vote
TA	Summer	JP: non JP	183: 237	1	3.84	0.27	0.604	TA is independent from JP/ non JP vote

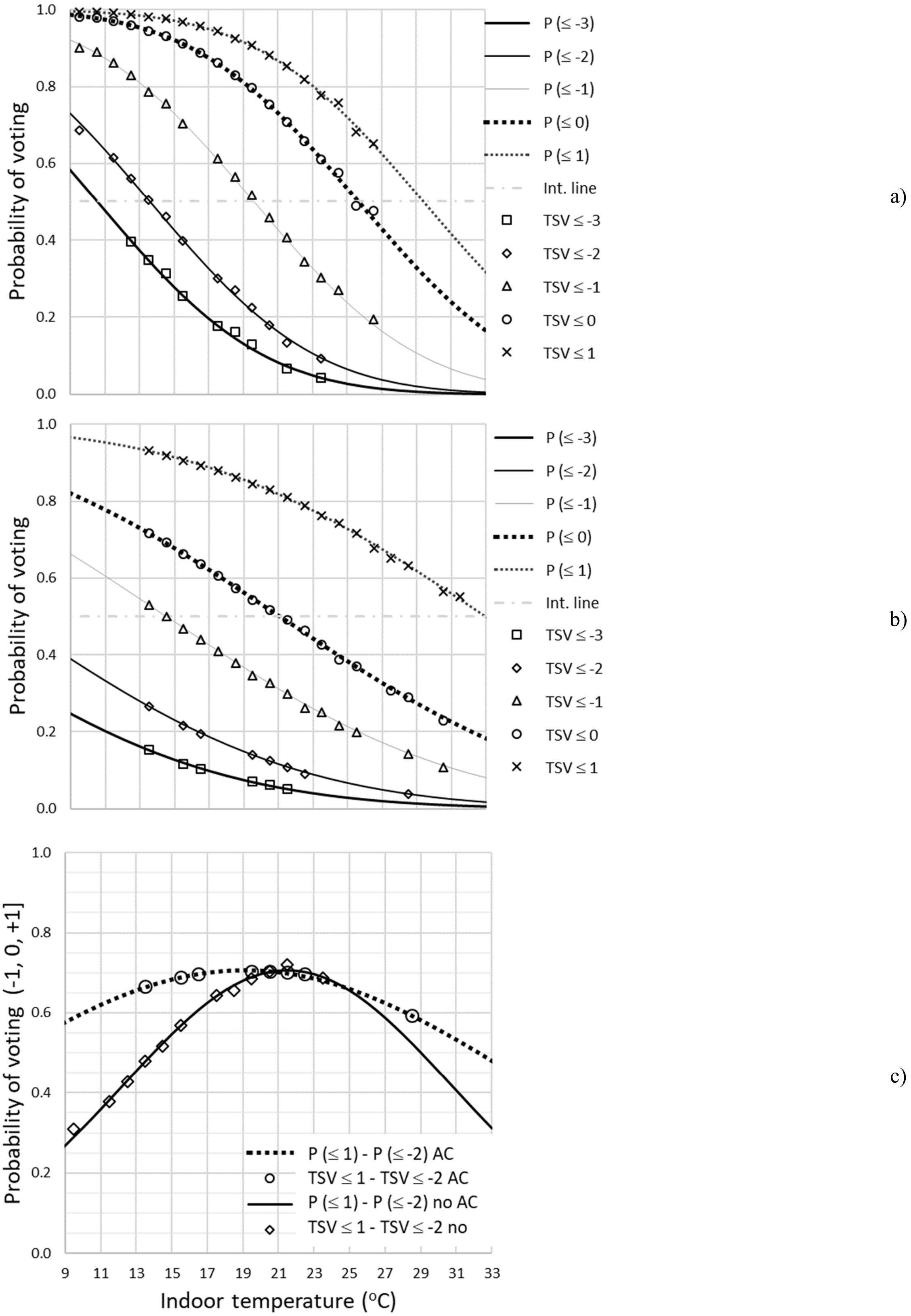
Appendix Table T-3 Chi-square results: Dependence of thermal responses on selected factors in winter

		Sub-division	n	df	χ^2 critical	χ^2	p	Interpretation of result
TSV	Winter	Day: Night	163: 137	5	11.07	7.32	0.198	TSV is independent from Day/Night vote
TC	Winter	Day: Night	163: 137	5	11.07	9.27	0.099	TC is independent from Day/Night vote
TP	Winter	Day: Night	163: 137	2	5.99	1.49	0.476	TP is independent from Day/Night vote
TA	Winter	Day: Night	163: 137	1	3.84	7.43	< 0.05	TA depends on Day/Night vote
TSV	Winter	AC: no AC	165: 135	5	11.07	43.34	< 0.001	TSV depends on AC/ no AC vote
TC	Winter	AC: no AC	165: 135	5	11.07	29.79	< 0.001	TC depends on AC/ no AC vote
TP	Winter	AC: no AC	165: 135	2	5.99	15.75	< 0.001	TP depends on AC/ no AC vote
TA	Winter	AC: no AC	165: 135	1	3.84	2.38	0.123	TA is independent from AC/ no AC vote
TSV	Winter	GSD: Kaikan	147: 153	5	11.07	4.00	0.549	TSV is independent from GSD/ Kaikan
TC	Winter	GSD: Kaikan	147: 153	5	11.07	15.25	< 0.05	TC depends on GSD/ Kaikan vote
TP	Winter	GSD: Kaikan	147: 153	2	5.99	8.41	< 0.05	TP depends on GSD/ Kaikan vote
TA	Winter	GSD: Kaikan	147: 153	1	3.84	3.33	0.068	TA is independent from GSD/ Kaikan vote
TSV	Winter	Male: Female	216: 84	5	11.07	12.93	< 0.05	TSV depends on Male/ Female vote
TC	Winter	Male: Female	216: 84	5	11.07	25.52	< 0.001	TC depends on Male/ Female vote
TP	Winter	Male: Female	216: 84	2	5.99	3.39	0.184	TP is independent from Male/ Female vote
TA	Winter	Male: Female	216: 84	1	3.84	3.33	0.068	TA is independent from Male/ Female vote
TSV	Winter	JP: non JP	128: 172	5	11.07	3.20	0.670	TSV is independent from JP/ non JP vote
TC	Winter	JP: non JP	128: 172	5	11.07	18.73	< 0.05	TC depends on JP/ non JP vote
TP	Winter	JP: non JP	128: 172	2	5.99	6.03	< 0.05	TP depends on JP/ non JP vote
TA	Winter	JP: non JP	128: 172	1	3.84	0.73	0.393	TA is independent from JP/ non JP vote

Appendix U. Probit analysis for summer and winter season separately



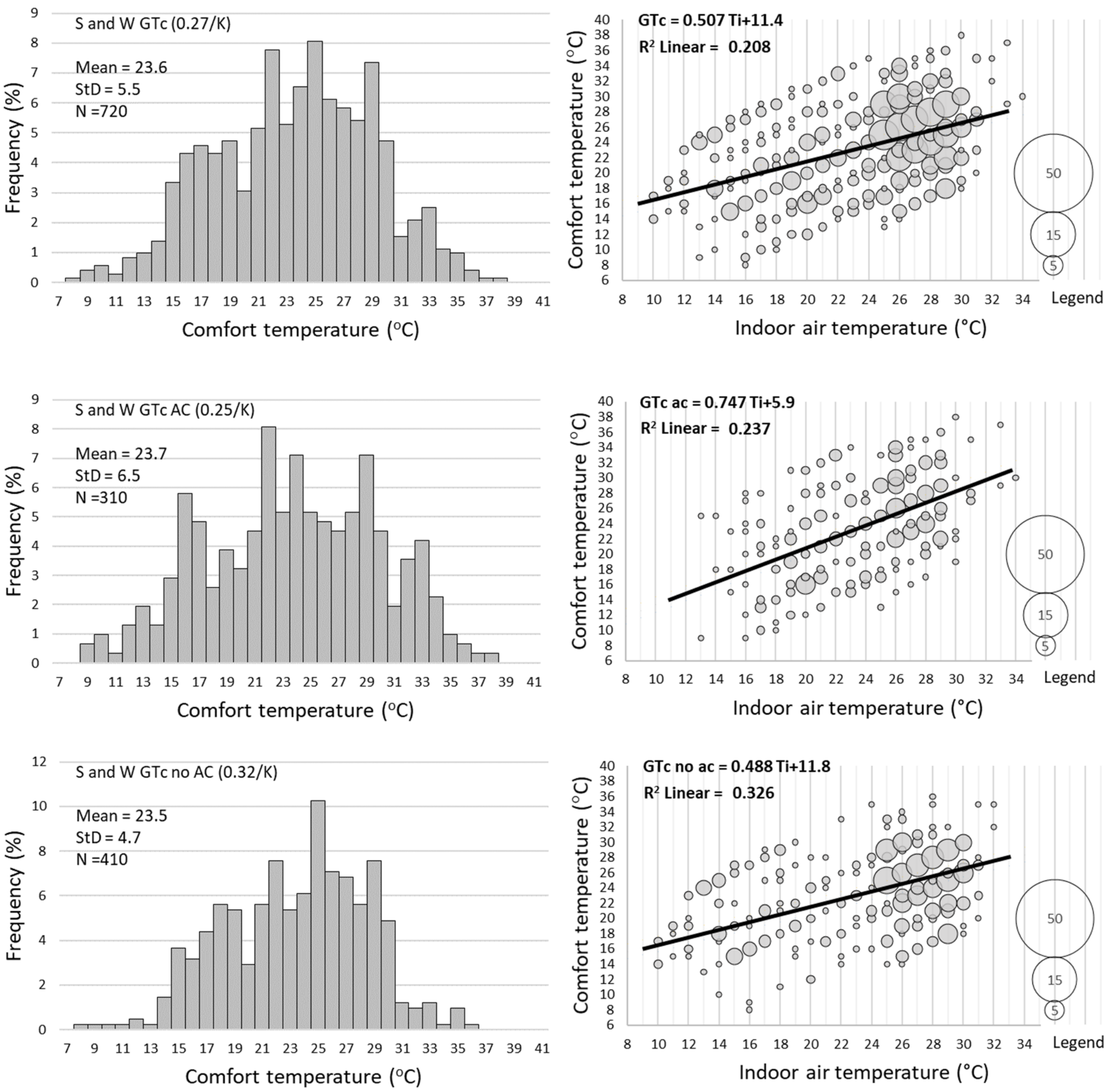
Appendix Figure U-1 Graphical representation of summer probit analysis: a) Probability of voting a certain TSV in FR mode; b) Probability of voting a certain TSV in CL mode; c) Proportion voting within the "extended neutral range" of TSV scale – from -1 to +1 in summer relative to the use of air conditioning. **Marker points represent the actual proportion voting.



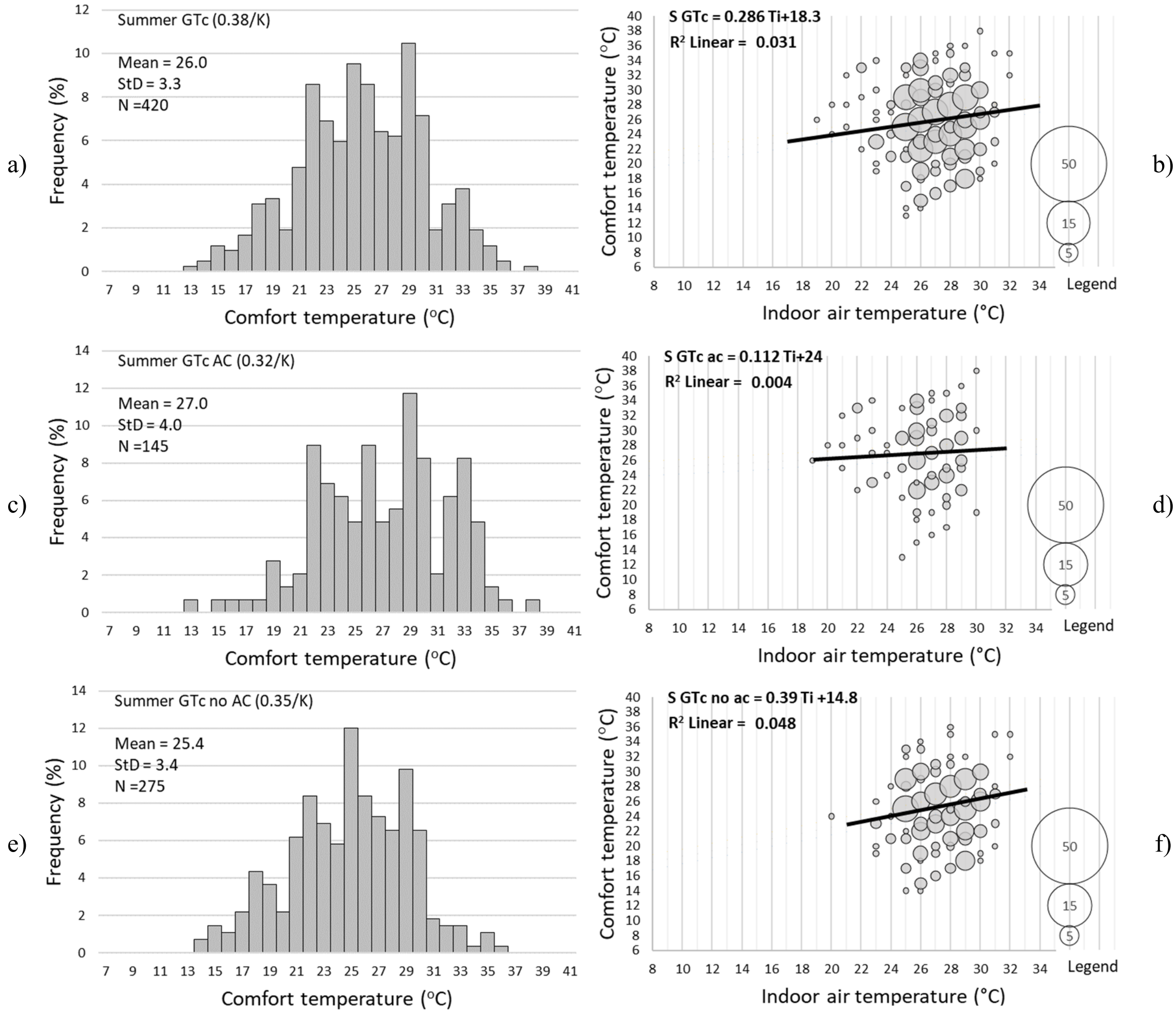
Appendix Figure U-2 Graphical representation of winter probit analysis: a) Probability of voting a certain TSV in FR mode; b) Probability of voting a certain TSV in HT mode; c) Proportion voting within the "extended neutral range" of TSV scale – from -1 to +1 in winter relative to the use of air conditioning. **Marker points represent the actual proportion voting.

Appendix V. Griffiths' comfort temperature to indoors relative to season and AC mode

a) b) c) d) e) f)

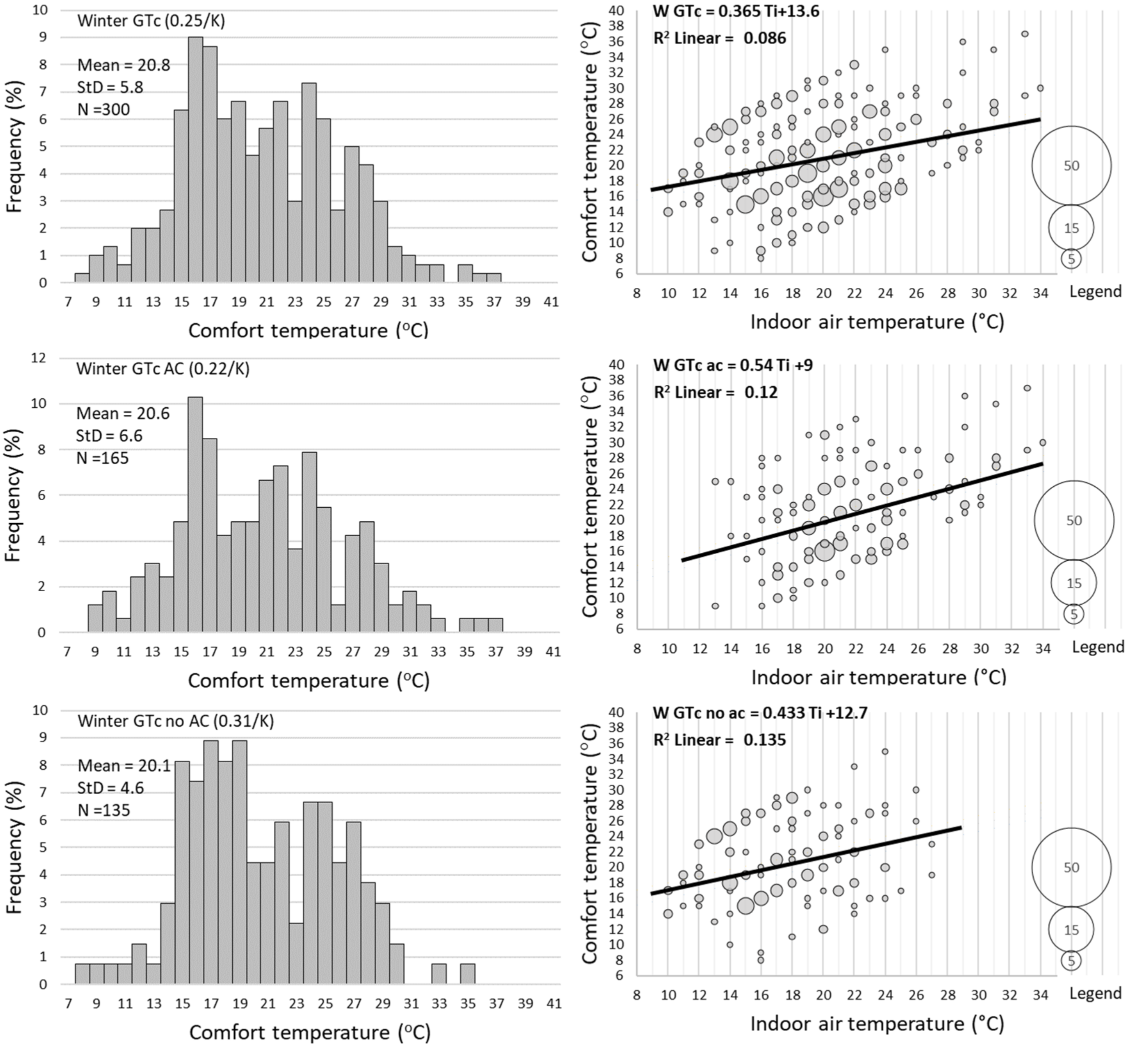


Appendix Figure V-1 Griffiths' temperature in summer and winter. Relation to indoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_i irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_i in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_i in no-AC mode. ** The numerical values for the regressions are in Table 44



Appendix Figure V-2 Griffiths' temperature in summer. Relation to indoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_i irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_i in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_i in no-AC mode. ** The numerical values for the regressions are in Table 44

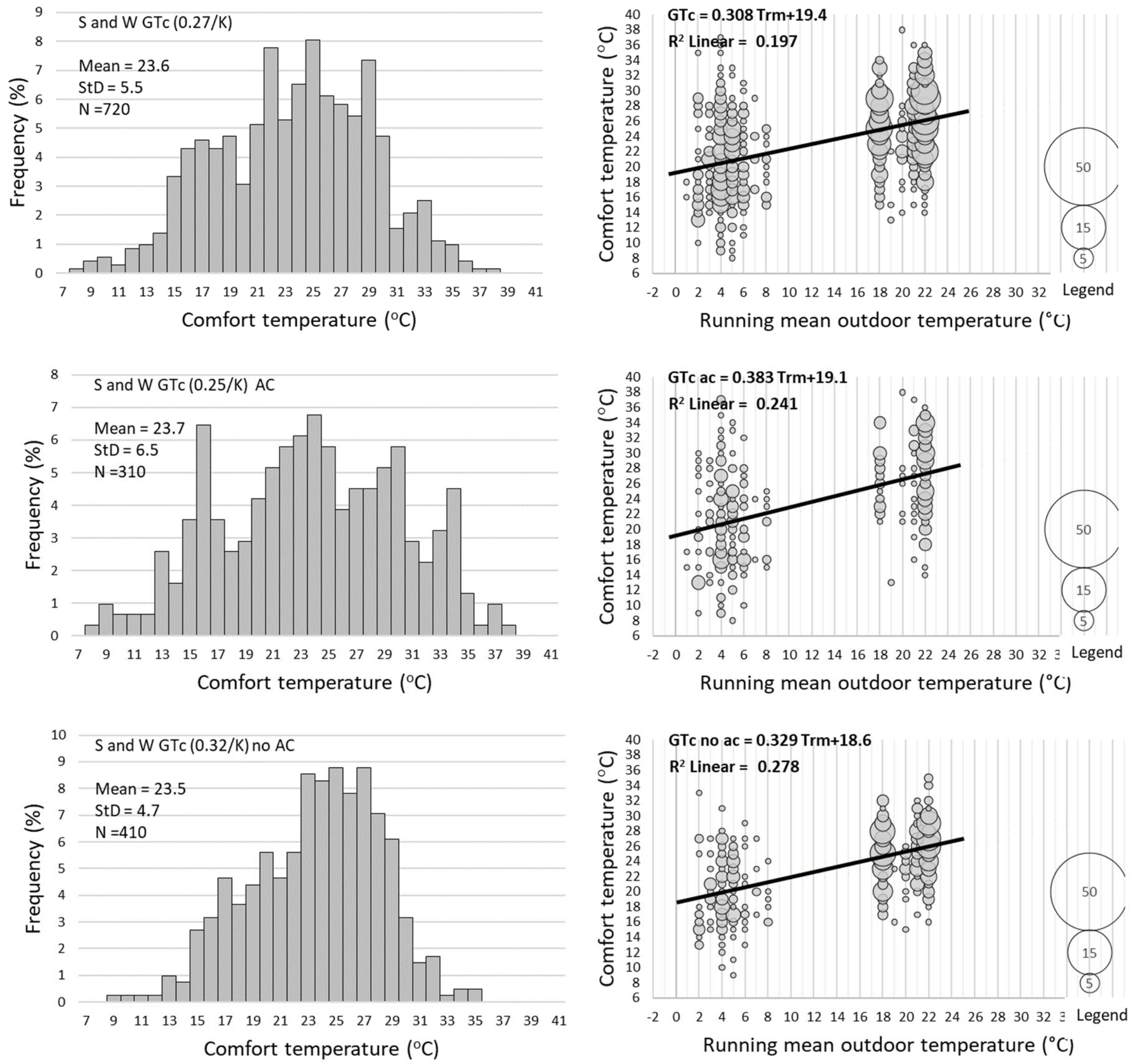
a) b) c) d) e) f)



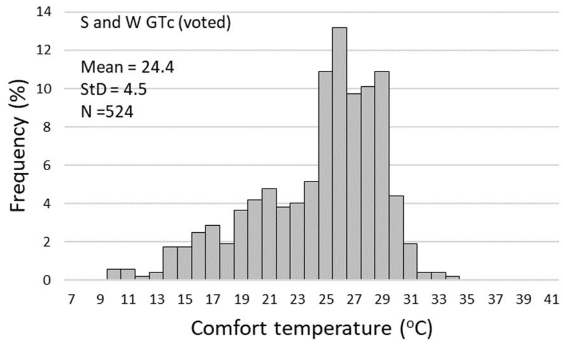
Appendix Figure V-3 Griffiths' temperature in winter. Relation to indoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_i irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_i in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_i in no-AC mode. ** The numerical values for the regressions are in Table 44

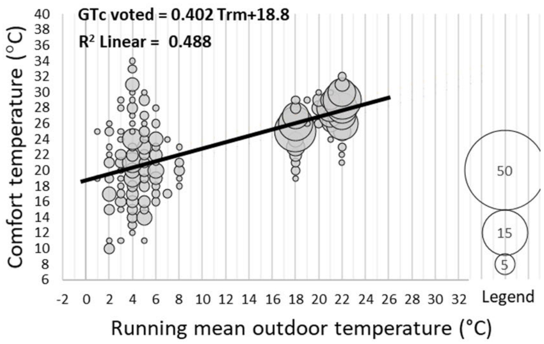
Appendix W. Griffiths' comfort temperature to outdoors relative to season and AC mode

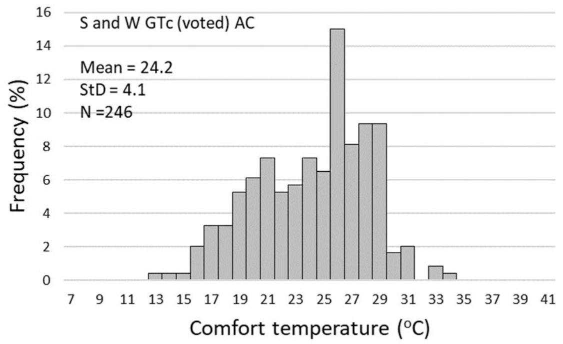
a) b) c) d) e) f)

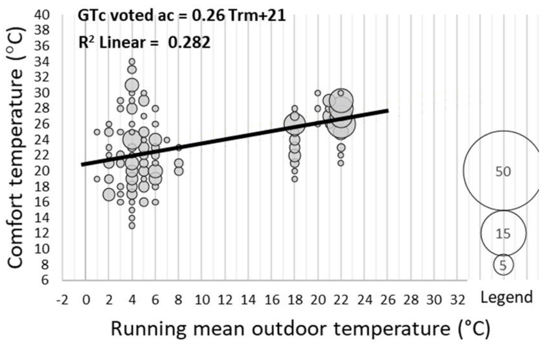


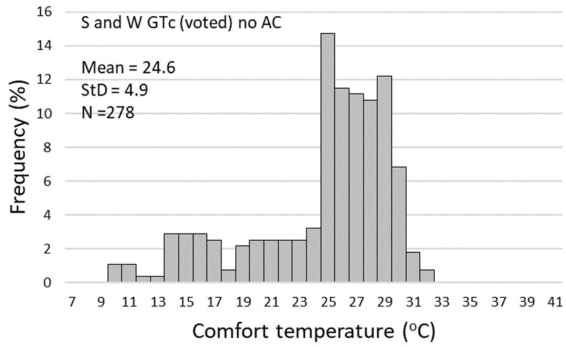
Appendix Figure W-1 Griffiths comfort temperature in summer and winter. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45

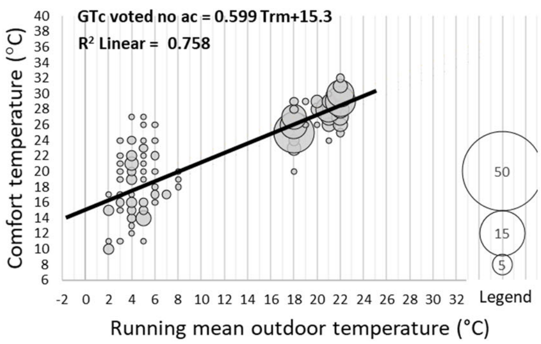
a) 

 b)

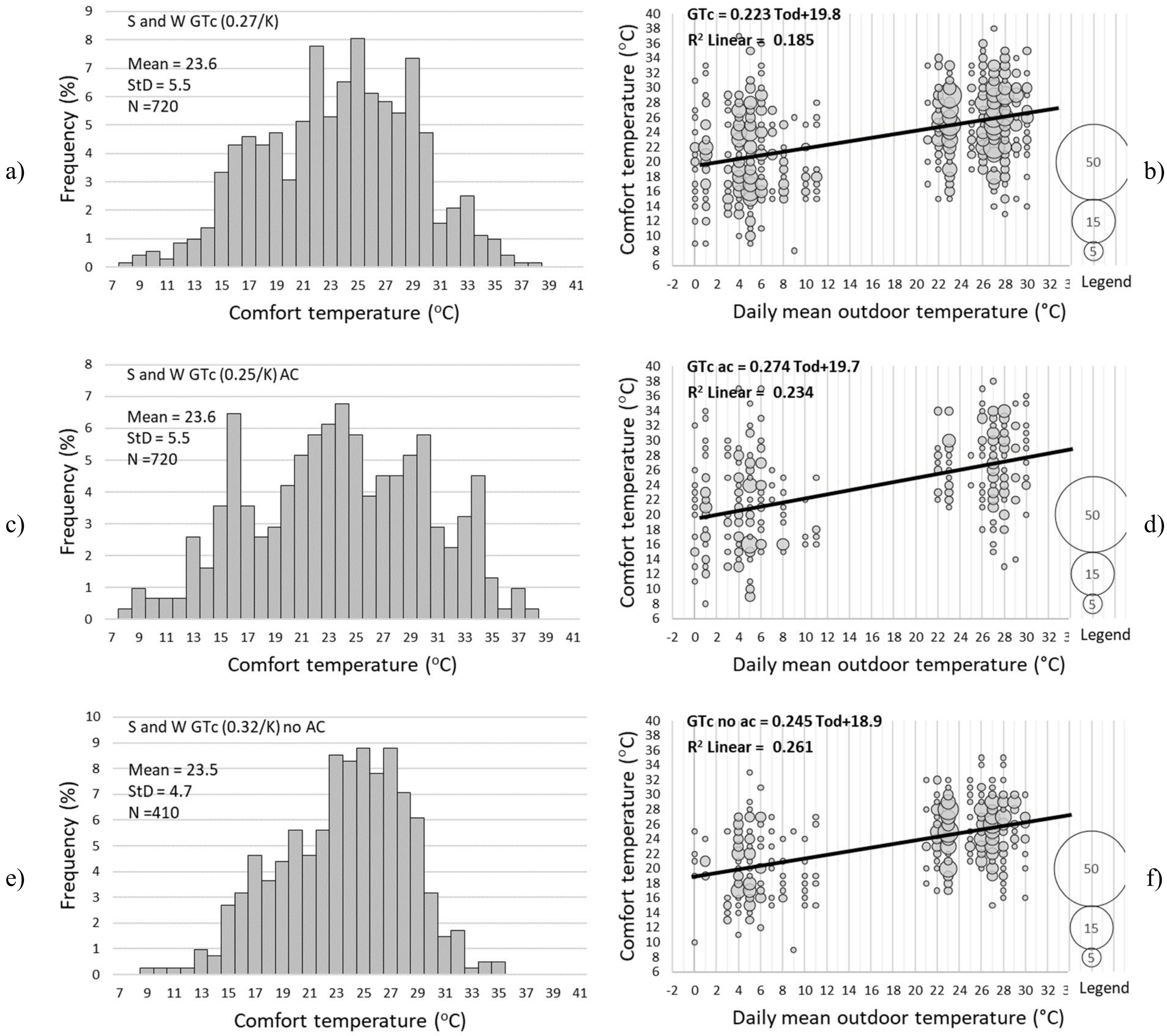
c) 

 d)

e) 

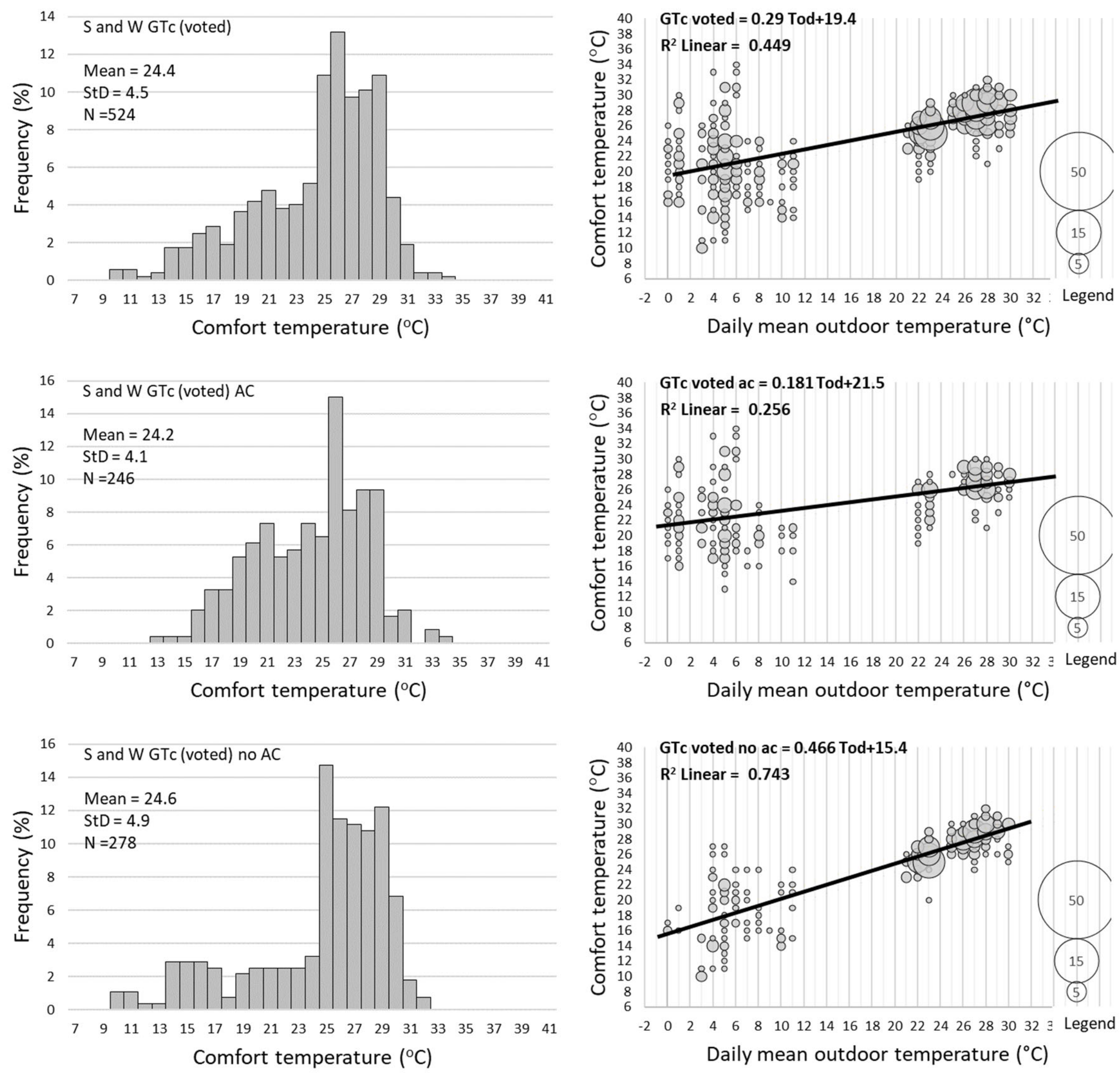
 f)

Appendix Figure W-2 Actually voted comfort temperature in summer and winter. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45

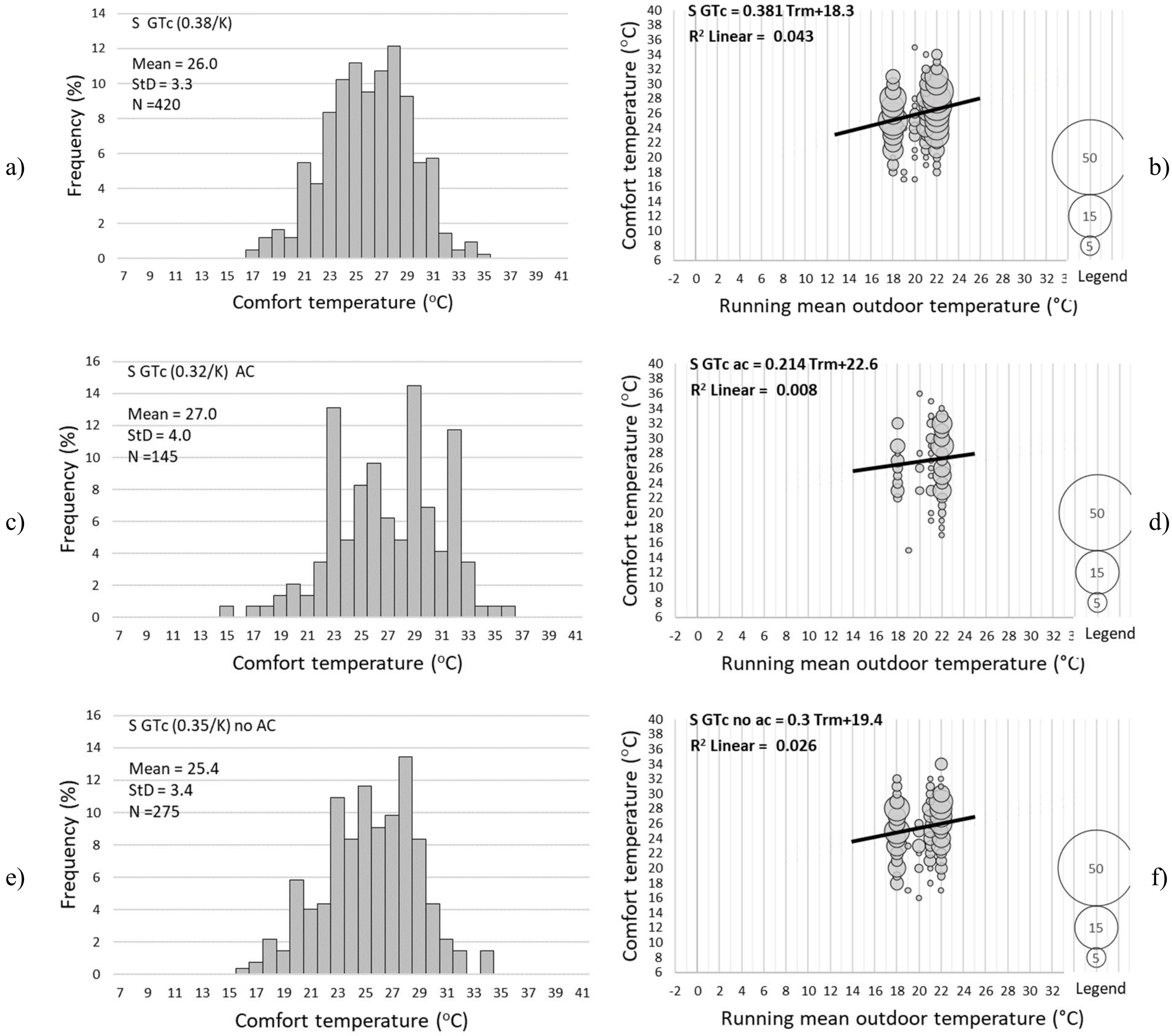


Appendix Figure W-3 Griffits' comfort temperature in summer and winter. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45

a) b) c) d) e) f)

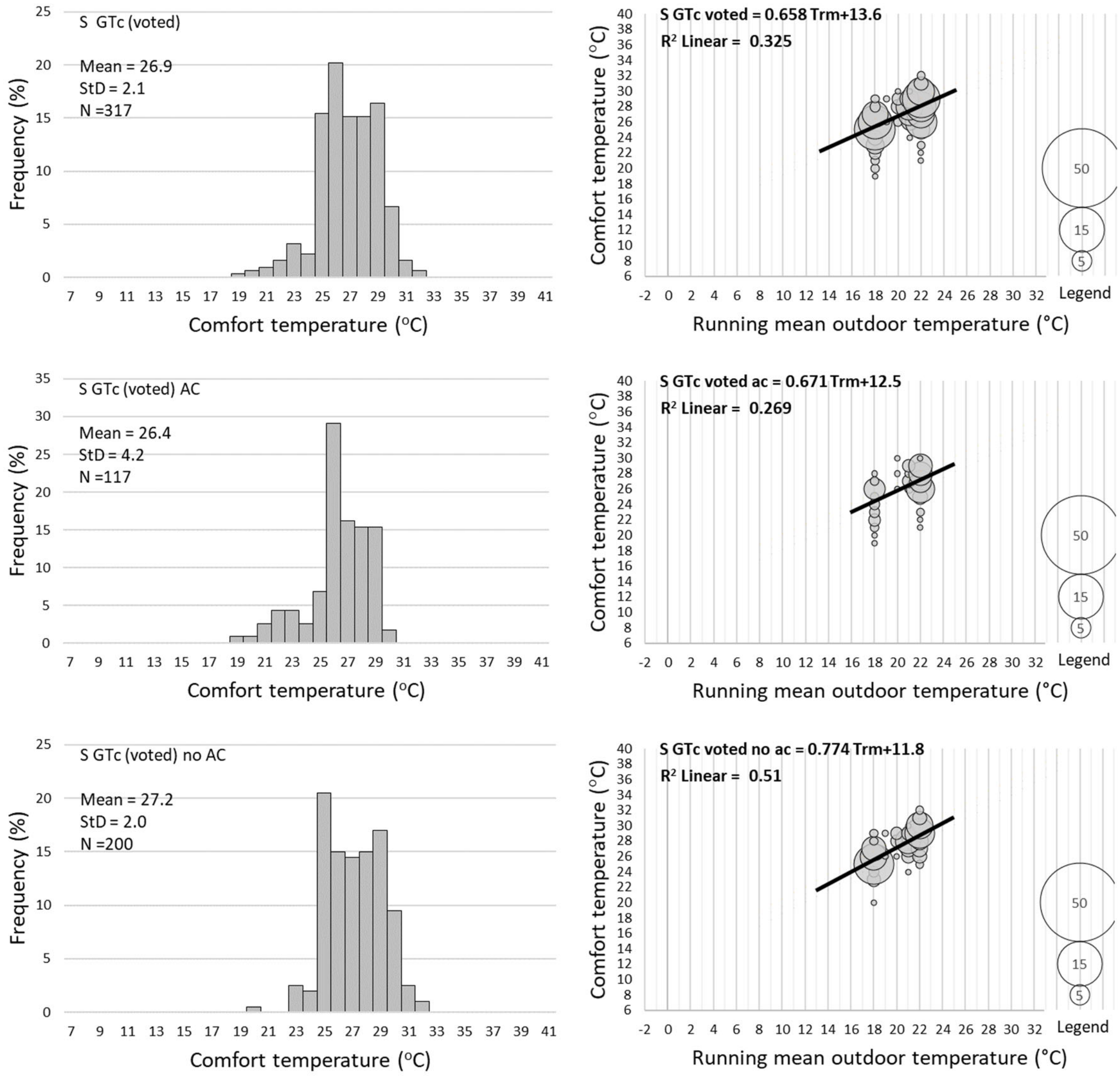


Appendix Figure W-4 Actually voted comfort temperature in summer and winter. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45

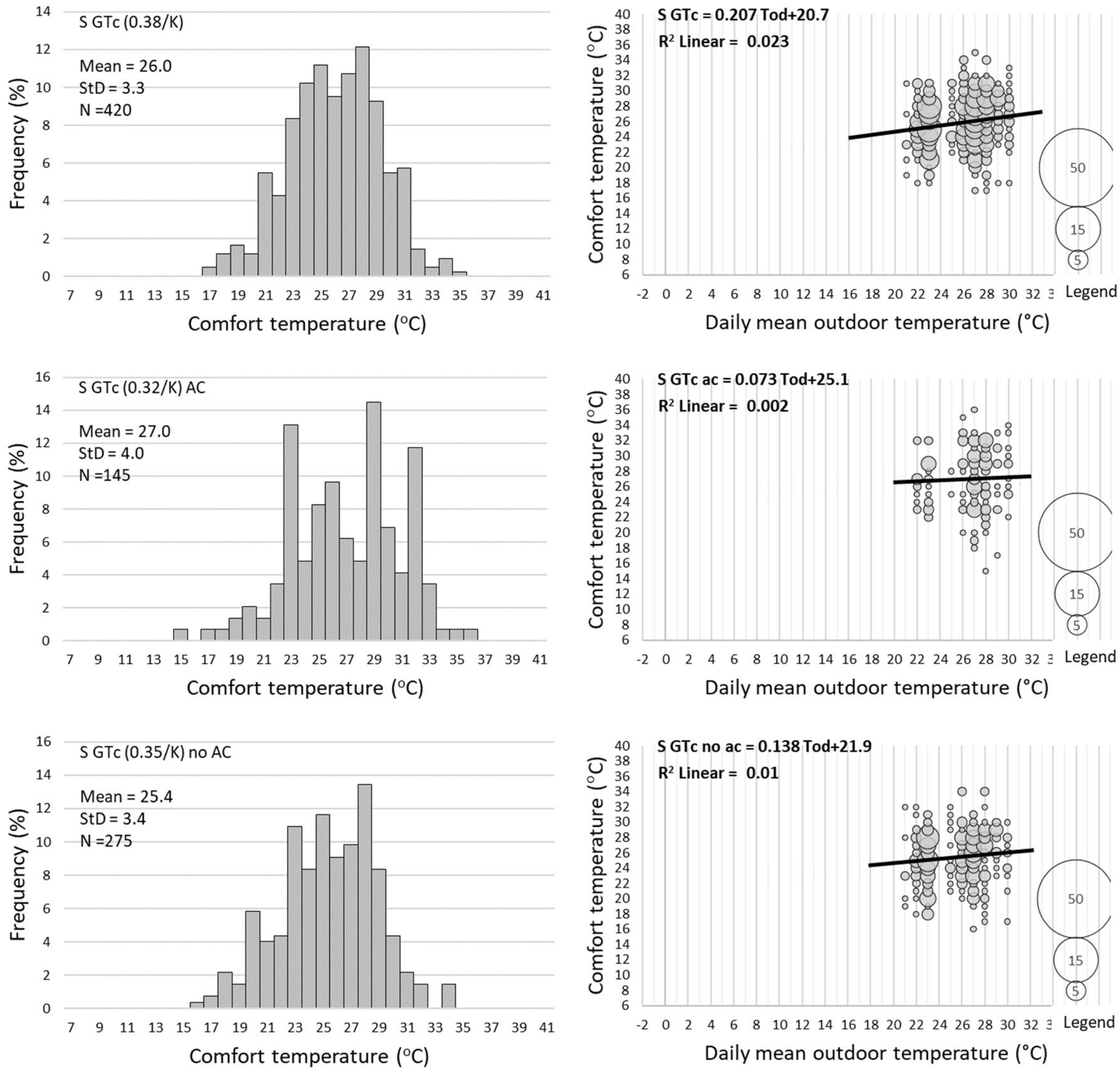


Appendix Figure W-5 Griffiths comfort temperature in summer. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45

a) b)
c) d)
e) f)

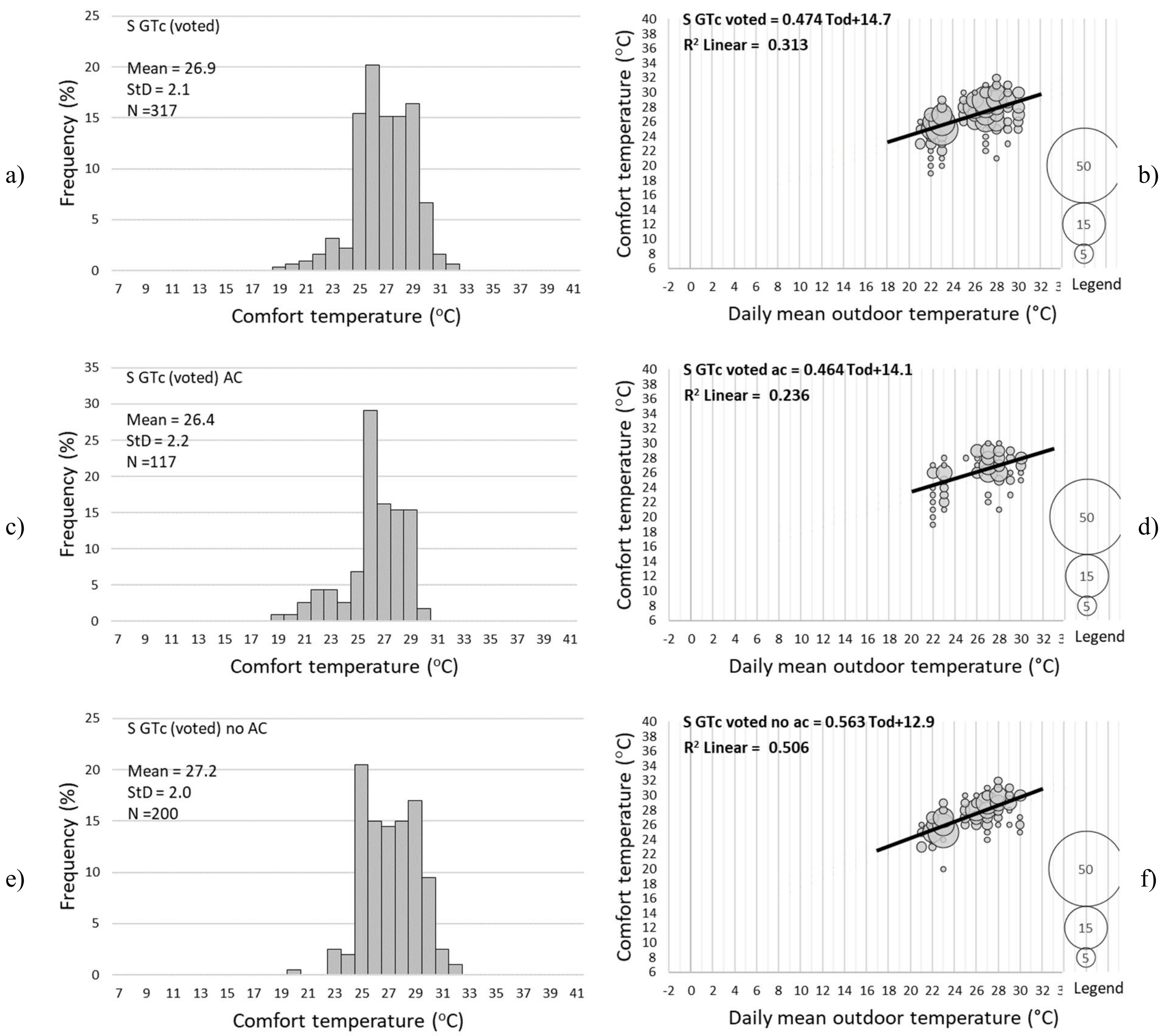


Appendix Figure W-6 Actually voted comfort temperature in summer. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45

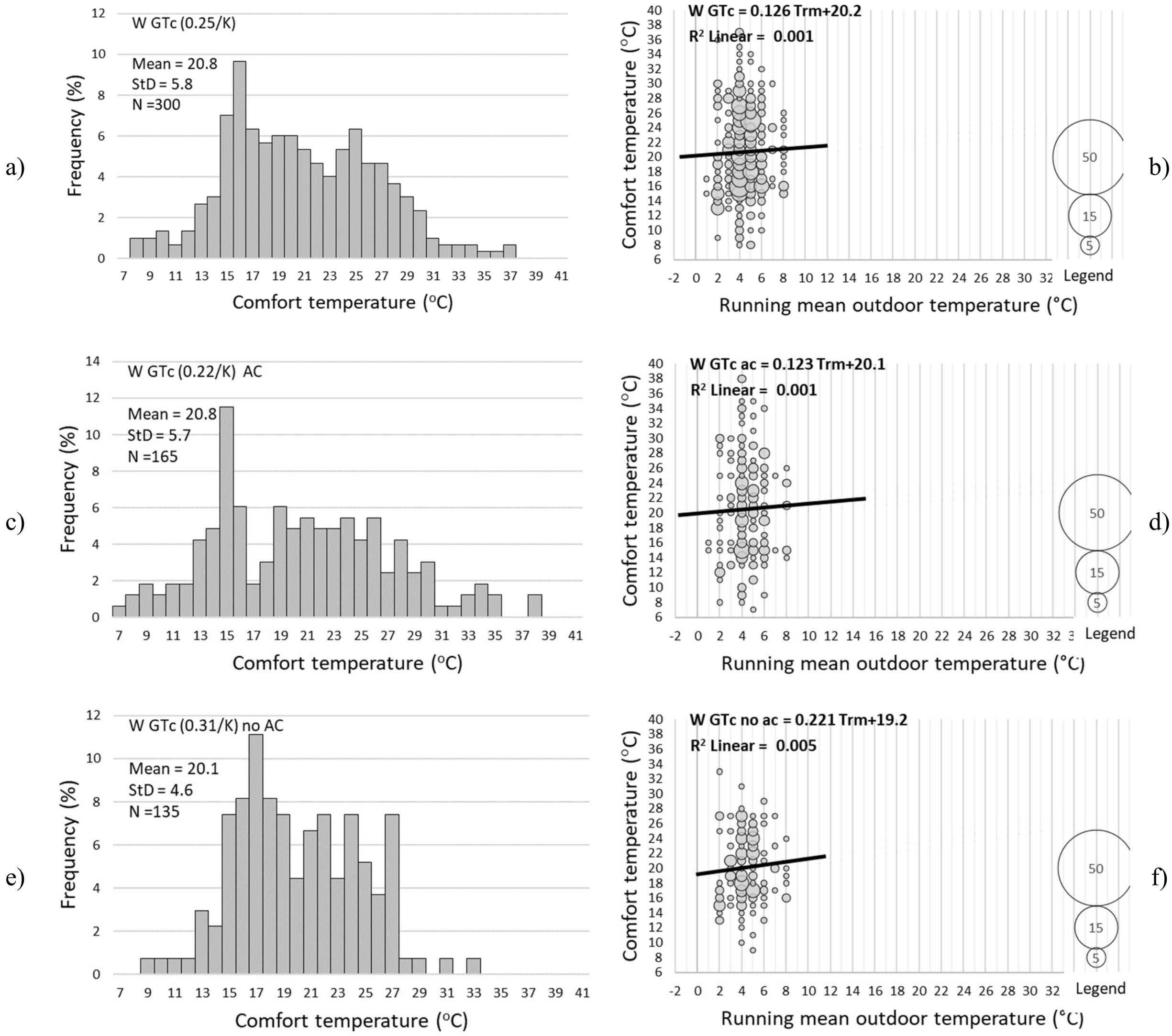


a) b) c) d) e) f)

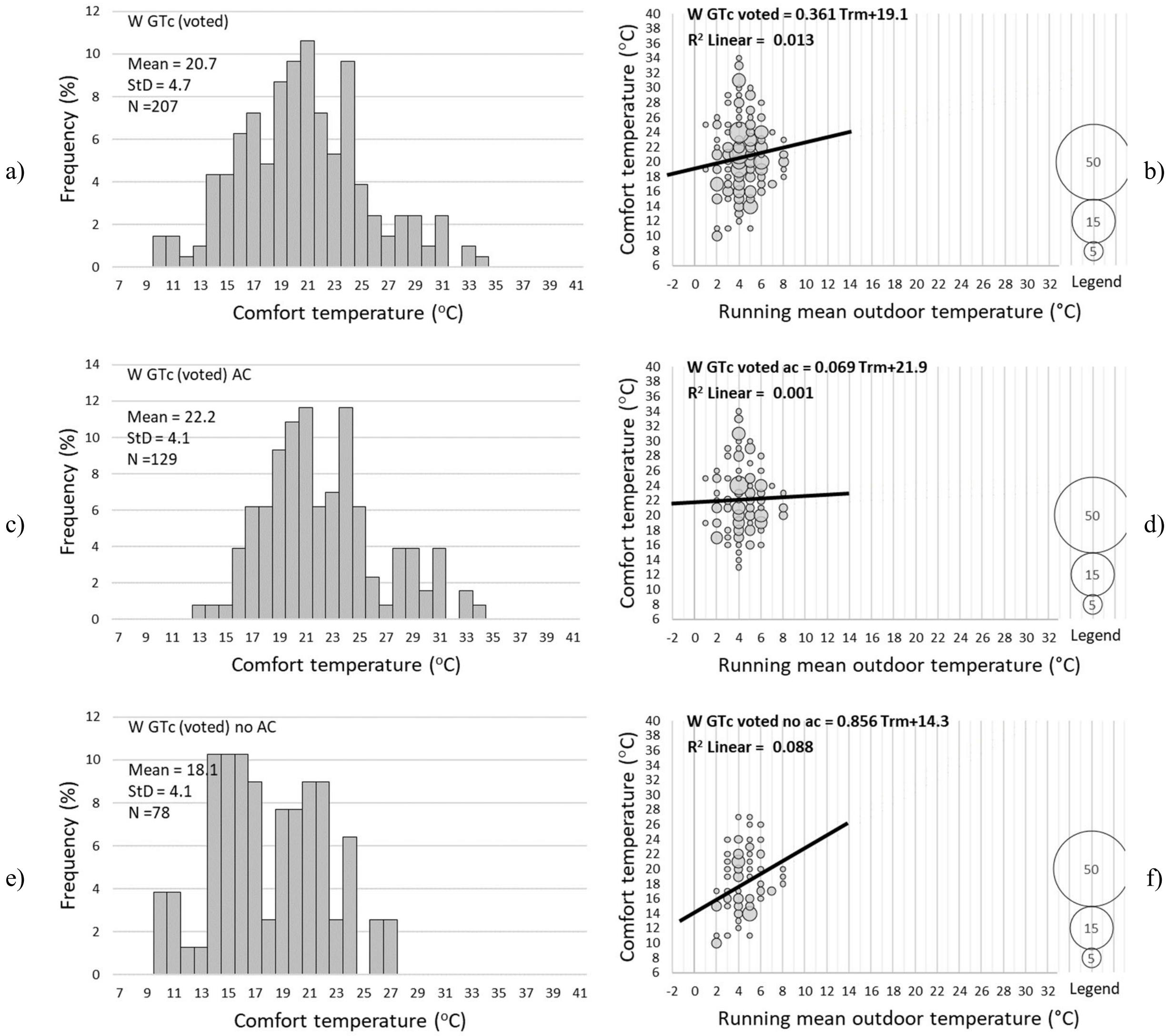
Appendix Figure W-7 Griffits' comfort temperature in summer. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45



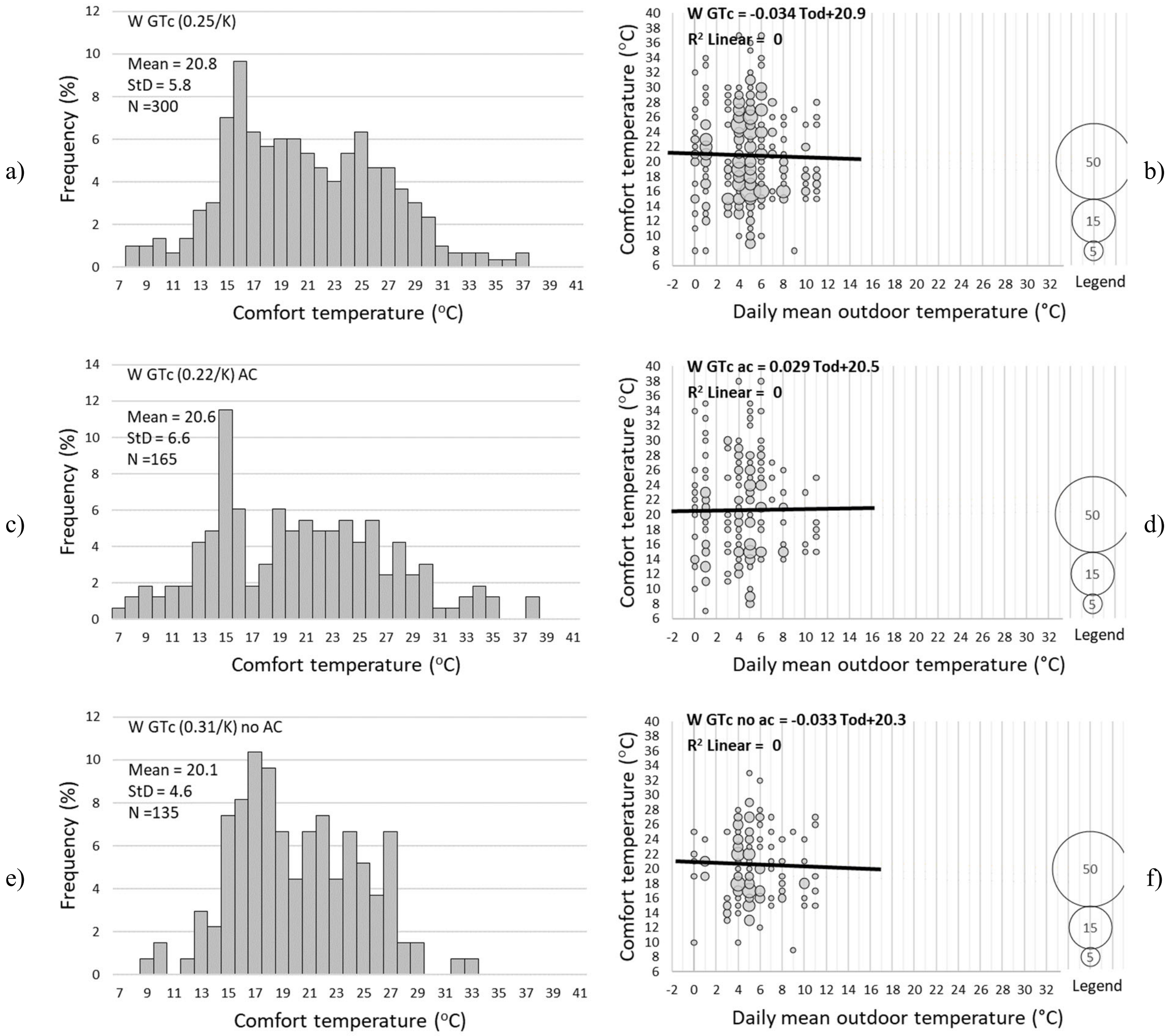
Appendix Figure W-8 Actually voted comfort temperature in summer. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45



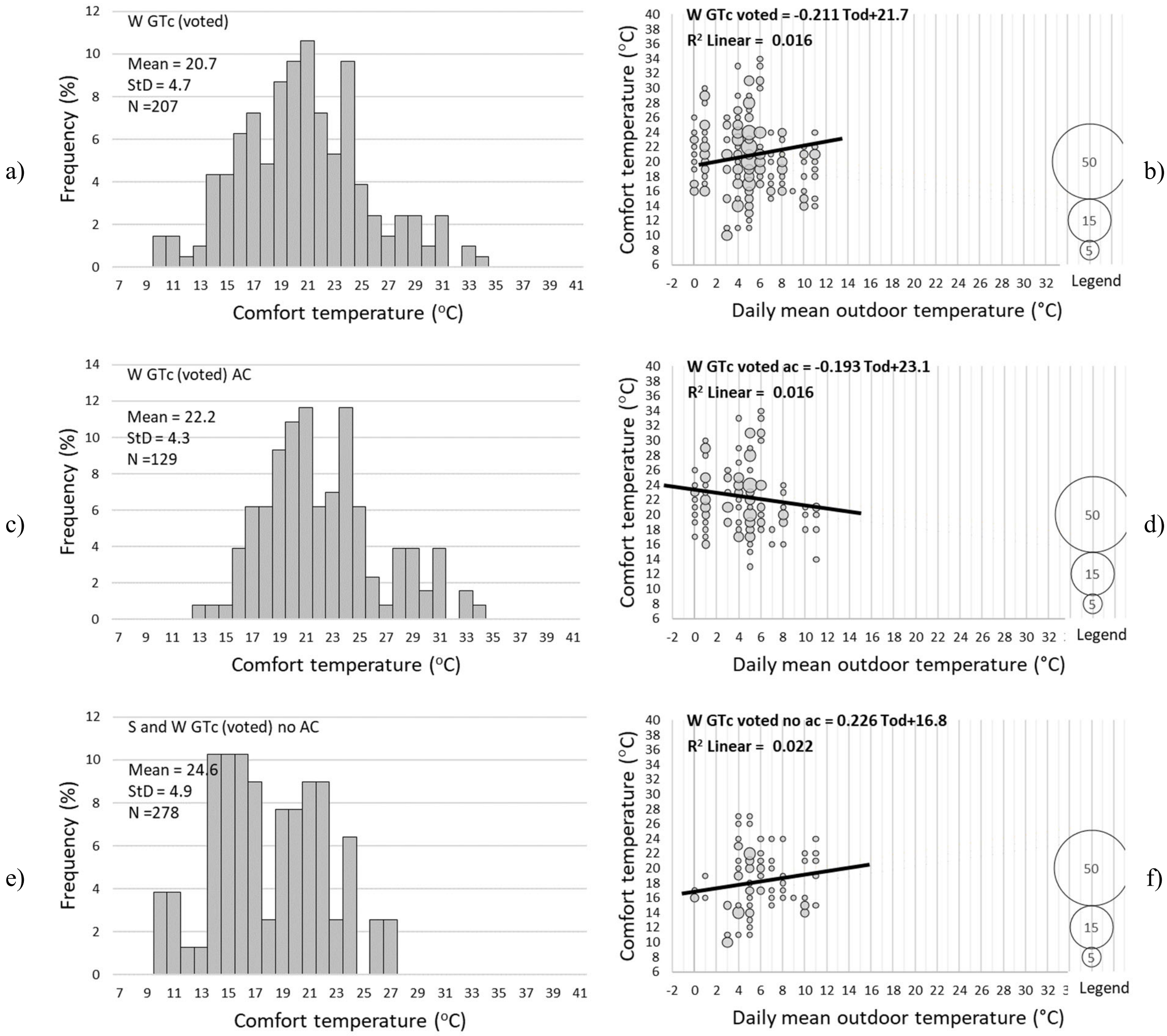
Appendix Figure W-9 Griffiths comfort temperature in winter. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45



Appendix Figure W-10 Actually voted comfort temperature in winter. Relation to running mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{rm} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{rm} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{rm} in no-AC mode. ** The numerical values for the regressions are in Table 45

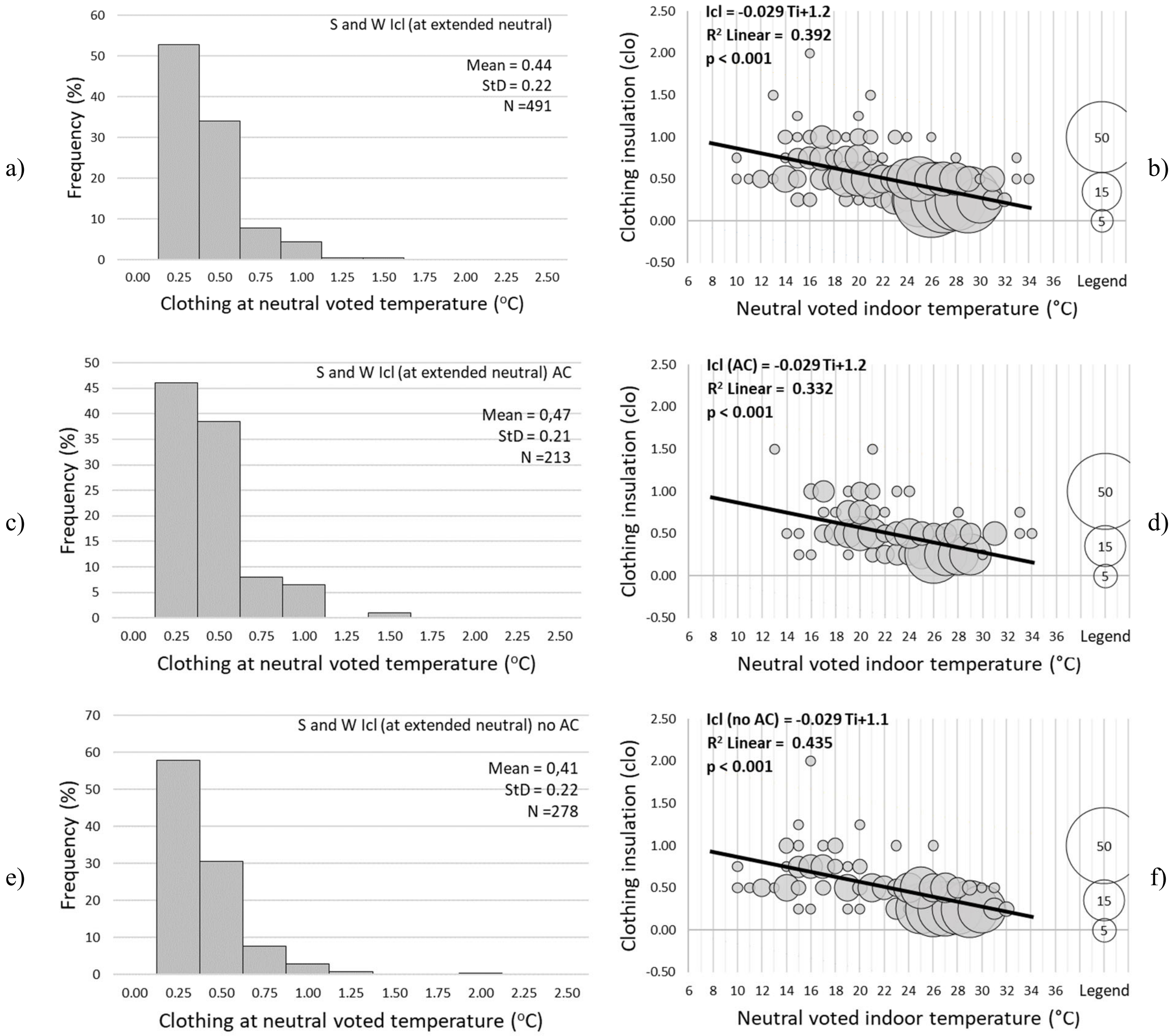


Appendix Figure W-11 Griffits' comfort temperature in winter. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45

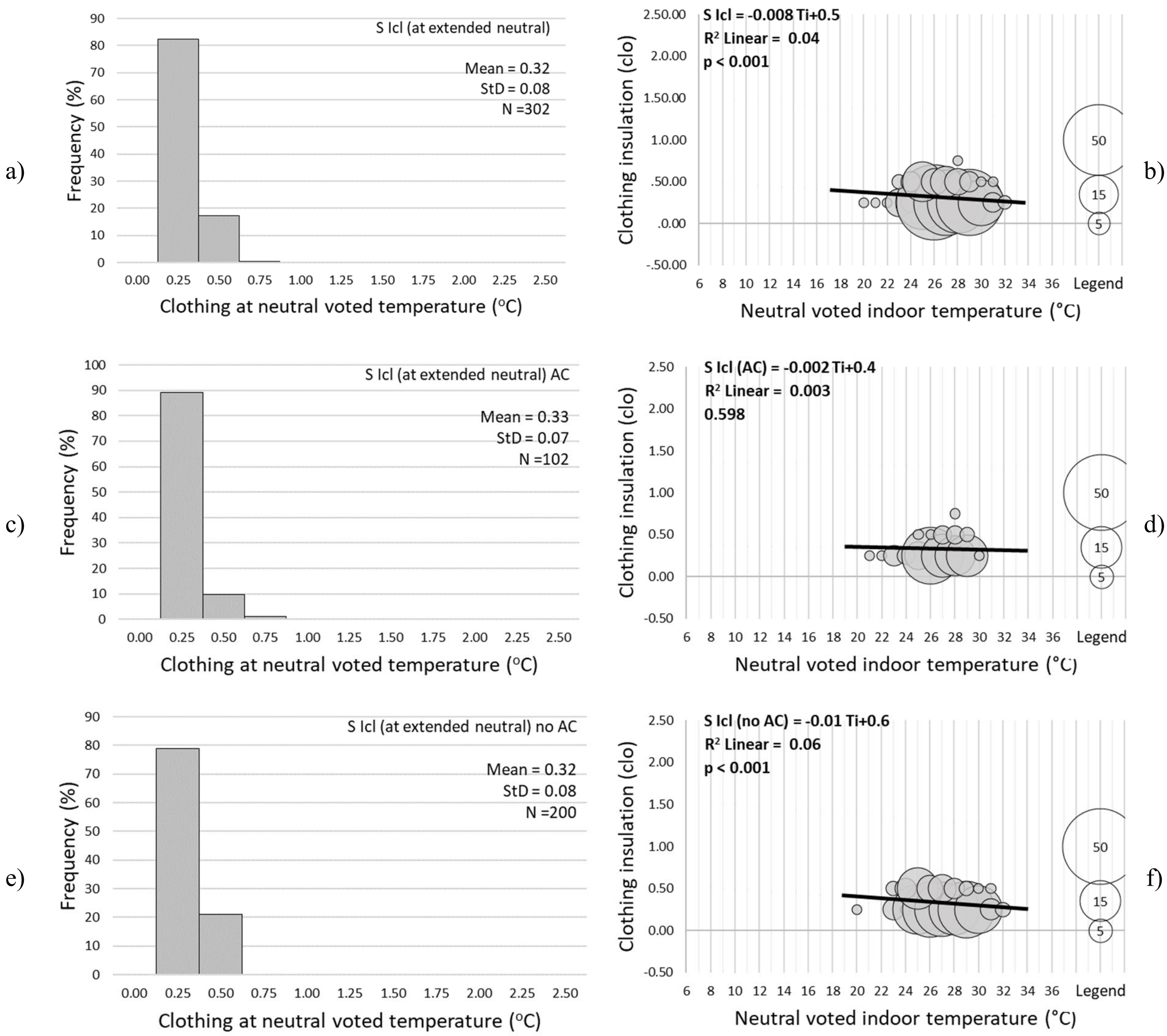


Appendix Figure W-12 Actually voted comfort temperature in winter. Relation to mean outdoor temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_{od} irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_{od} in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_{od} in no-AC mode. ** The numerical values for the regressions are in Table 45

Appendix X. Correlation between clothing and indoor neutral temperature

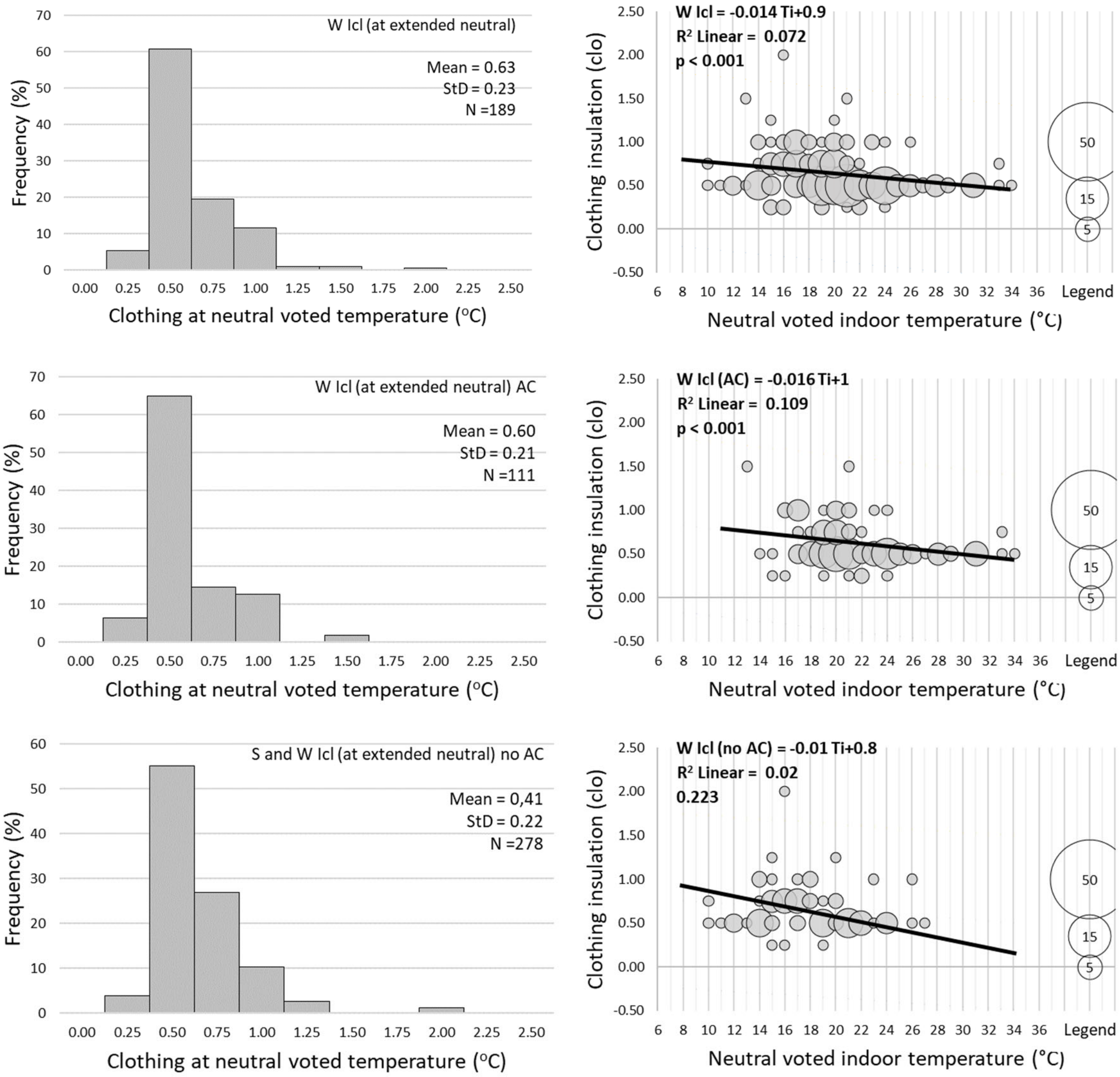


Appendix Figure X-1 Clothing insulation observed in summer and winter. Relation to indoor neutral temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_n irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_n in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_n in no-AC mode. ** The numerical values for the regressions are in Table 40



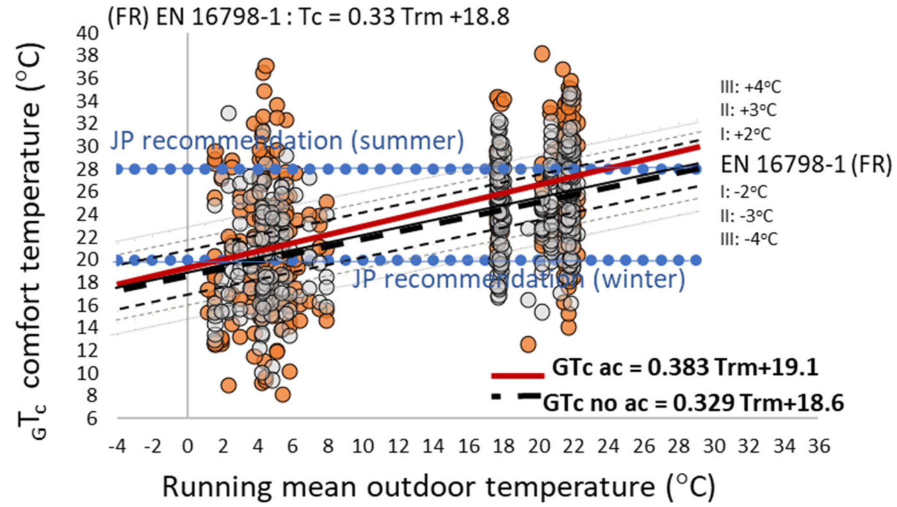
Appendix Figure X-2 Clothing insulation observed in summer. Relation to indoor neutral temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_n irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_n in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_n in no-AC mode. ** The numerical values for the regressions are in Table 40

a) b) c) d) e) f)

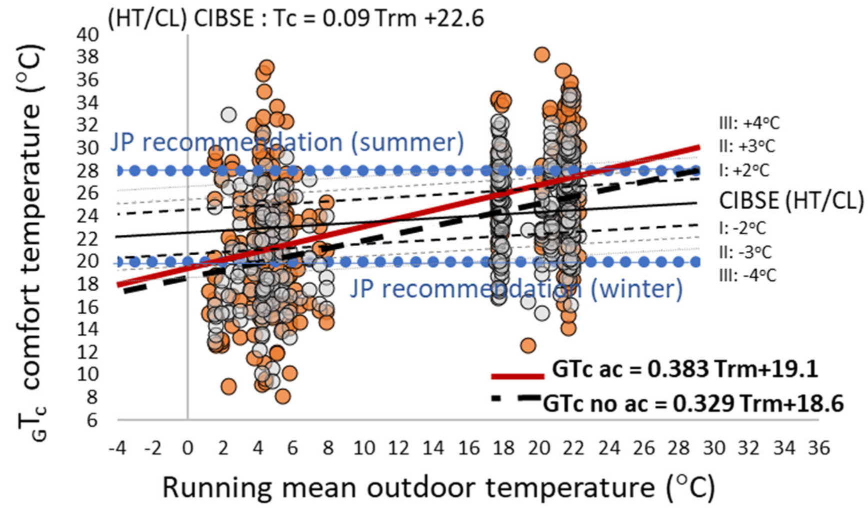


Appendix Figure X-3 Clothing insulation observed in winter. Relation to indoor neutral temperature: a) Frequency distribution irrelevant of mode; b) Correlation to T_n irrelevant of mode; c) Frequency distribution in AC mode; d) Correlation to T_n in AC mode; e) Frequency distribution in no-AC mode; f) Correlation to T_n in no-AC mode. ** The numerical values for the regressions are in Table 40

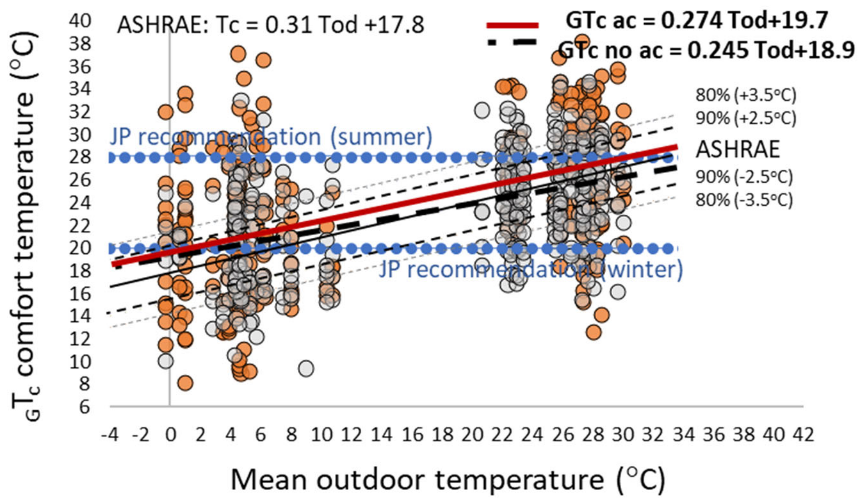
Appendix Y. Comparing comfort temperature and related standards



a)

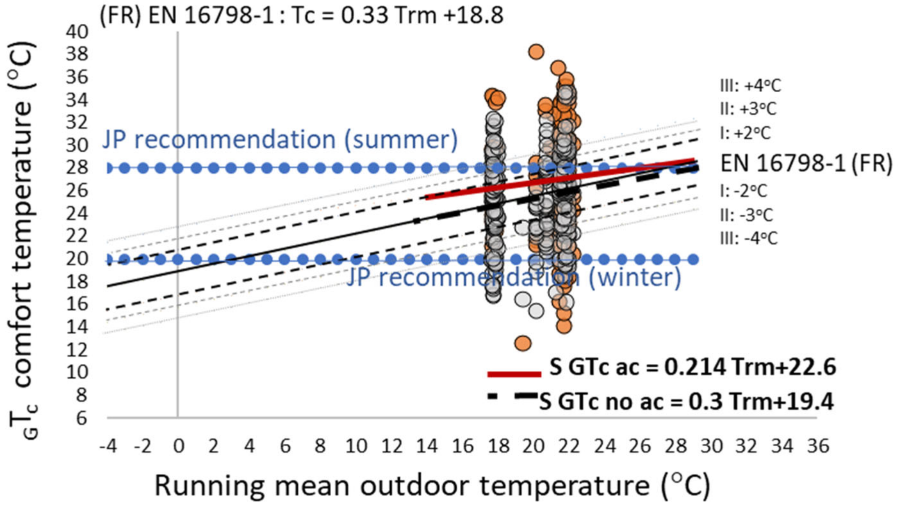


b)

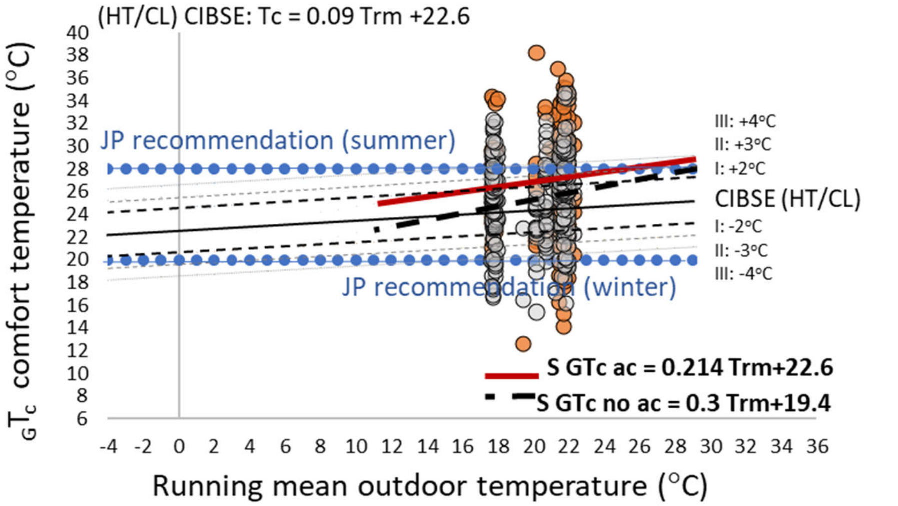


c)

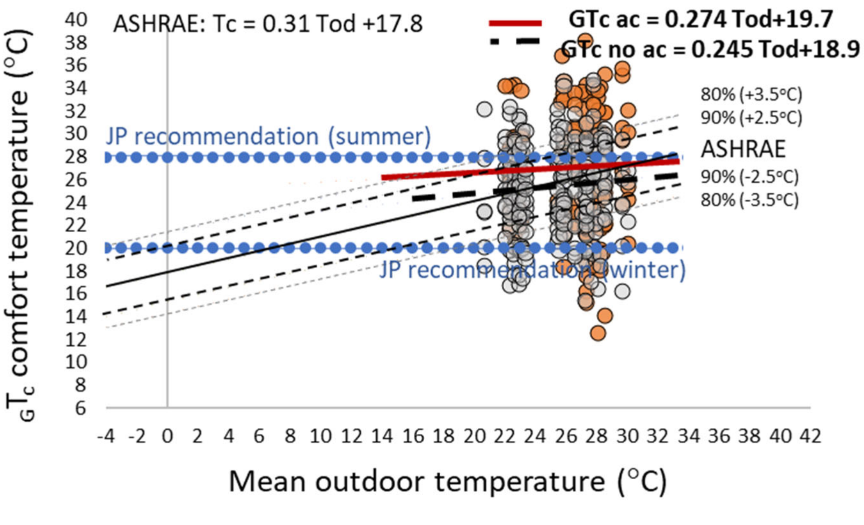
Appendix Figure Y-1 Comparing Griffiths' comfort temperature to standards and recommendations for summer and winter: a) (FR) EN 16798-1 $_GT_c$: T_{rm}; b) (HT/CL) CIBSE $_GT_c$: T_{rm} ; c) (FR) ASHRAE $_GT_c$: T_{od};



a)

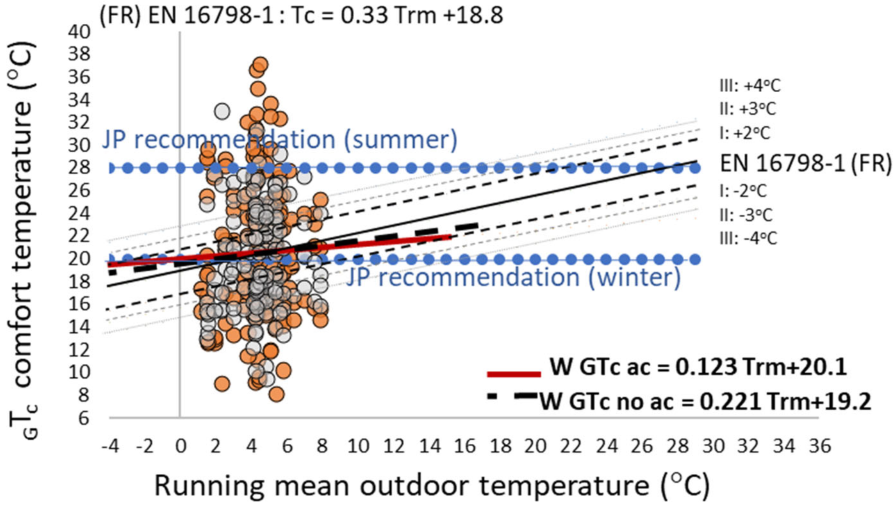


b)

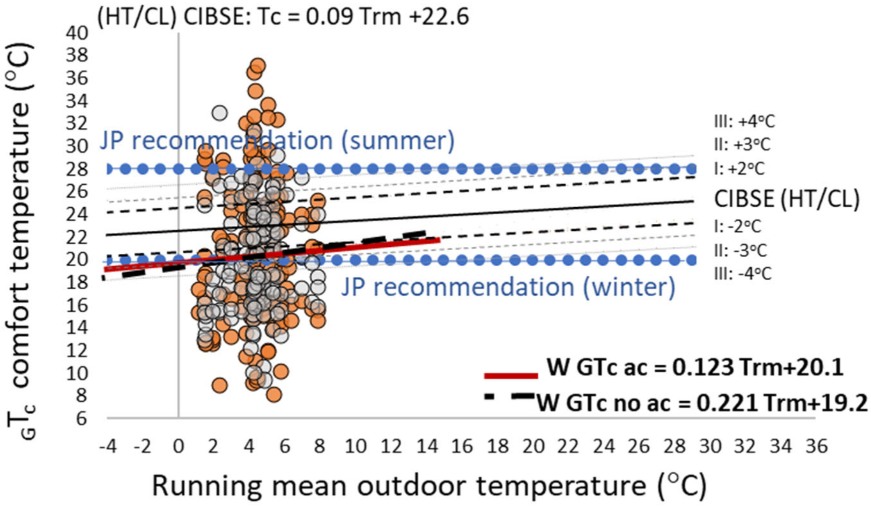


c)

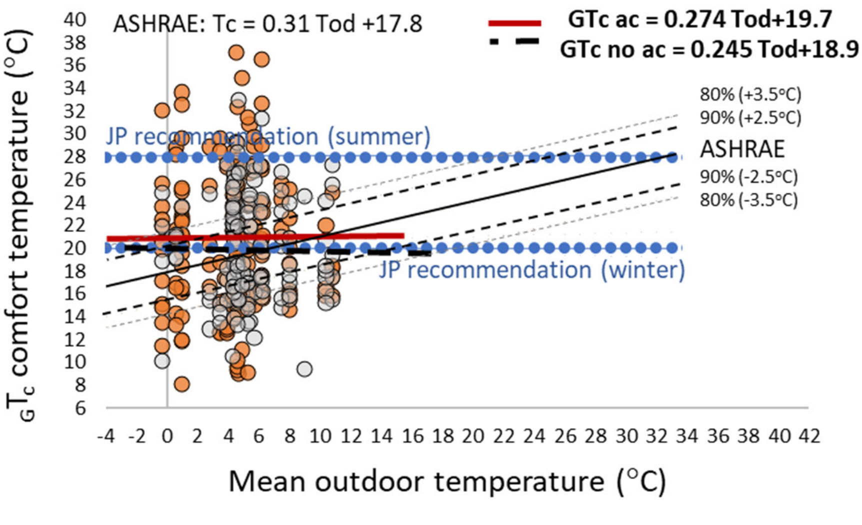
Appendix Figure Y-2 Comparing Griffiths' comfort temperature to standards and recommendations for summer: a) (FR) EN 16798-1 $_GT_c$: T_{rm}; b) (HT/CL) CIBSE $_GT_c$: T_{rm} ; c) (FR) ASHRAE $_GT_c$: T_{od};



a)



b)



c)

Appendix Figure Y-3 Comparing Griffiths' comfort temperature to standards and recommendations for winter: a) (FR) EN 16798-1 $_GT_c$: T_{rm}; b) (HT/CL) CIBSE $_GT_c$: T_{rm} ; c) (FR) ASHRAE $_GT_c$: T_{od};