Disparities of indoor temperature in winter: a cross-sectional analysis of the nationwide Smart Wellness Housing survey in Japan

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Abstract

Background

In modern society, humans spend 60–70% of their time at home, housing environment is of great importance to health. In support of the importance, WHO issued Housing and Health Guidelines in 2018. The guidelines show that cold indoor temperatures have adverse health consequences, and suggest a recommended indoor temperature of 18°C. However, it is unclear who lives in cold homes in real-world settings. We aimed to examine "what are the common characteristics of residents who live in low-indoor-temperature environments."

Methods

We conducted a nationwide survey on indoor temperature who intended to conduct insulation retrofitting in Japan. Indoor temperature was measured in the living room, bedroom, and changing room for 2 weeks in winter seasons (November–March) of 2014 to 2019. The relationship between characteristics of residents and living room temperature was analyzed using a multilevel model.

Results

Cross-sectional analyses involving 2,190 households showed that the average temperature in the living room, bedroom and changing room was 16.8°C, 12.8°C and 13.0°C, respectively. Living room temperature was highest (19.8˚C) in Hokkaido, where outdoor temperatures are lower than in other areas, and lowest (13.1˚C) in Kagawa, which is considered to have a mild climate. A multilevel analysis showed that the odds ratio for living room temperature in the morning falling below 18˚C was 1.38 (95% CI: 1.04–1.84) for the middle income group and 2.07 (95% CI: 1.28–3.33) for the low income group, compared to the high income group. The odds ratio was 1.96 (95% CI: 1.19–3.22) for single-person households, compared to households living with housemates. Furthermore, lower room temperature was also correlated with kotatsu (traditional Japanese local heating device) use and a larger amount of clothes.

Conclusions

There were disparities in living room temperature within Japan, and they related to socioeconomic status, single-person households and the way of living. These housing disparities have the potential to cause health disparities. We expect these results will be useful in the development of prevention strategies for residents who live in cold homes and the reduction in health disparities.

Background

In recent years, clear health disparities have been identified not only between nations, but also within nations. These cannot be ignored, and reducing them has become a global issue. The World Health Organization (WHO), which promotes the concept of "Health for all," emphasizes the importance of the social determinants of health[1]- namely the conditions in which people are born, raised, work, live, and age - to correct these disparities.[2] Even in Japan, the National Health Promotion Movement in the 21st Century (Health Japan 21 (the Second Term)) holds "reduction of health disparities" and "establishment of a social environment" as its key values and states that the "health of an individual is affected by such social environment as family, schools, the community, and workplaces".[3] In particular, given that humans spend 60–70% of their time at home,[4–6] and that elderly people with declining physiological function or children with undeveloped physiological function spend even more time at home,[7] the living environment at home is of great importance to health.

Based on these background factors, WHO issued Housing and Health Guidelines in October 2018.[8] One of the five priority areas of the guideline is "low indoor temperatures and insulation." The guideline suggests a recommended indoor temperature of 18 °C, primarily to prevent cardiovascular and respiratory diseases. However, an investigation of the indoor environment of 602 houses across Japan reported that the average living room temperature during winter was 17 °C,[9] indicating that many houses did not achieve the recommended indoor temperature. Accordingly, there is concern that indoor temperature may greatly affect health, especially in Japan.

We conducted a nationwide survey named the "Smart Wellness Housing (SWH) Survey" in Japan which aimed to quantitatively evaluate the relationship between housing and health. A previous report[10] in this survey revealed that systolic blood pressure in the morning and evening increased by 8.2 mmHg and 6.5 mmHg per 10 °C decrease in indoor ambient temperature, indicating that the risk of hypertension increased at low indoor temperature. Therefore, it is considered useful from a population strategy viewpoint to discover "who lives in a cold home (what are the common characteristics of residents who live in low-indoor-temperature environments) in real-world settings." The present results were therefore focused on the relationship between the characteristics of residents and indoor temperature.

Methods

Study design

The SWH Survey was administered to households that had the intention of conducting insulation retrofitting of their homes. This survey was conducted as a non-randomized controlled trial with groups defined according to participants' choice to actually conduct or not conduct insulation retrofitting.

Participants were recruited through construction companies throughout all 47 prefectures of Japan. Inclusion criteria were (1) intention to conduct insulation retrofitting, (2) age over 20 years, and (3) pre-retrofitting house did not meet S (Supreme) standards of the "Act on the Promotion of Dissemination of Long-Lasting Quality Housing" in Japan.[11] Two participants per household (generally a husband and wife pair) were asked to conduct actual measurements.

In this paper, we performed a cross-sectional analysis of data from the baseline (before insulation retrofitting) survey in the winter seasons (November – March) of 2014 to 2019. We focused on data before insulation retrofitting to reflect the actual condition of houses in Japan, most of which have low insulation performance.[12]

Area Classification In Japan

In Japan (Fig. 1), a total of eight areas are defined based on the heating degree days (HDD) value (difference between indoor temperature of 18 °C and daily mean outdoor temperature, where the daily mean outdoor temperature is less than 18 °C, Additional file 1: Figure S1). The required insulation performance standards have been defined for each area in Japan. The analysis in this paper examined this area classification under the variable "area." An approximate area classification at the prefectural level is shown in Table 1. Detailed area classification at the municipal level is shown elsewhere.[13] Area 6, which is the most populous area among the eight areas, was used as a reference variable in the analysis.

Table 1
Area classification at the prefectural level based on heating degree days value

Area	HDD [°C day]	Prefecture in area classification
1	4,500 ≤ HDD	Hokkaido
2	3,500 ≤ HDD < 4,500	
3	3,000 ≤ HDD < 3,500	Aomori, Iwate, Akita
4	2,500 ≤ HDD < 3,000	Miyagi, Yamagata, Fukushima, Tochigi, Niigata, Nagano
5	2,000 ≤ HDD < 2,500	Ibaraki, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Toyama, Ishikawa, Fukui, Yamanashi, Gifu, Shizuoka, Aichi, Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama, Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita
6	1,500 ≤ HDD < 2,000	
7	500 ≤ HDD < 1,500	Miyazaki, Kagoshima
8	HDD < 500	Okinawa

HDD indicates heating degree days.

Indoor Temperature And Other Measurements

Indoor temperature and relative humidity at 1.0 m above the floor were measured in the living room, bedroom, and changing room (the room the resident typically used to changed clothes) at 10-min intervals for 2 weeks (TR-72wf; T&D Corp.). Outdoor temperature ($Temp_{Out}$) was obtained from the closest local meteorological observatory to each participant's house.

Participants were also asked to measure their home blood pressure (HBP) in the living room, twice after getting out of bed in the morning and twice before getting into bed in the evening (HEM-7251G; Omron Healthcare Co., Ltd.). The clock time of the HBP measurement was automatically stored with the HBP data and uploaded to the internet via 3G mobile networks.

A questionnaire survey was conducted enquired about individual attributes, such as age, sex, and weight; socioeconomic status, such as household income, single-person household; and lifestyle, such as kotatsu use (traditional Japanese local heating device, Additional file 1: Figure S2), and patterns of clothes worn. Household income was chosen from multiple choices that defined the range of household income (< 0.5 million JPY, 0.5 – 1 million JPY, ..., ≥ 10 million JPY), and classified as low (< 2 million JPY), middle (2 – 6 million JPY) and high (≥ 6 million JPY) in reference to the National Health and Nutrition Survey, led by the Ministry of Health, Labour and Welfare. Patterns of clothes were chosen from multiple-choice selections, and the amount of clothes was calculated from the patterns of clothes in accordance with ISO 7730:2005[14] and ANSI/ASHRAE Standard 55-2013.[15] A diary survey was also conducted, in which participants provided details of their daily waking time, bedtime, and time spent at home.

Statistical analysis

The relationship between characteristic and indoor temperature was analyzed by multilevel linear regression. The dependent variable was living room temperature at the time of HBP measurement in the morning, on the basis that cardiovascular conditions frequently occur in the morning.[16–19] The model was developed with random intercepts, consisting of two levels: repeatedly measured day-level variables ($Temp_{Out}$) were nested within household-level variables (age, duration of residence in the house, household income, single-person households, kotatsu use, amount of clothes and area). These variables were selected based on a univariate analysis of average living room temperature which showed differences between groups at a two-sided P value < 0.05 (Additional file 1: Table S1). The variable "sex" was strongly correlated with single-person households (r = 0.41), and was therefore excluded in consideration of multicollinearity. Multilevel logistic regression analysis was also performed (dependent variable: living room temperature in the morning < 18 °C or not). Details of the model are shown in the online supplementary file (Additional file 2). Day-level variables were centered around means for individual participants, while household-level variables were centered around the overall mean. Regression coefficients were estimated using the maximum likelihood method. All P values were two sided, and a two-sided P value less than 0.05 was considered statistically significant. All analyses were performed using SPSS Ver. 25 (SPSS Inc., Chicago, Illinois, USA).

Results

Baseline characteristics of residents and indoor temperatures

Table 2 shows the characteristics of heads of households in 2,190 houses. The average age was 59 years, and 81.5% were men. About one-third of households had high household income, and about 10% of households were single-person households.

Figure 2 – 4 show the average and minimum temperatures in the living room, bedroom, and changing room when participants were at home or during sleep. The average temperature in the living room, bedroom and changing room was 16.8 °C, 12.8 °C and 13.0 °C, respectively. The minimum temperature in the living room, bedroom and changing room were below 18 °C (the recommended minimum temperature by the WHO guidelines) in more than 90% of households.

The average living room temperature in each prefecture is shown in Fig. 5, excluding prefectures with 5 households or less. Of 43 prefectures, temperatures exceeded 18˚C in only 4 prefectures. Living room temperature was highest (19.8˚C) in Hokkaido, where outdoor temperature is lower and houses have a higher thermal insulation level than other areas. In contrast, living room temperature was lowest (13.1˚C) in Kagawa, which is located in the southwestern area of Japan and considered to have a mild climate.

Table 2
Characteristics of heads of households in the baseline survey

Variable	**Mean**	**(SD)**
Age, years	59.4	(13.3)
BMI, kg/m^2	23.5	(3.6)
Duration of residence in house, years	26.8	(17.0)
Amount of clothes, clo*	0.95	(0.20)
Variable	Number	(%)
Sex		
Men	1,784	(81.5)
Women	406	(18.5)
Household income		
Low (< 2 million JPY)	259	(12.8)
Middle (2–6 million JPY)	1,041	(51.3)
High (≥ 6 million JPY)	730	(36.0)
Number of housemates		
1 (single-person household)	213	(9.9)
≥2	1,931	(90.1)
Kotatsu** use		
None	1,304	(60.2)
Currently used	862	(39.8)
Area		
Area 2	69	(3.2)
Area 3	69	(3.2)
Area 4	250	(11.4)
Area 5	562	(25.7)
Area 6	1,109	(50.7)
Area 7	130	(5.9)

* clo is a unit that represents the thermal resistance of clothes. 1 clo = 0.155(m^{2}K)/W.

** traditional Japanese local heating device, consisting of a low table with an electric heater attached to the underneath surface and covered by a thick blanket.

Identification Of Residents Living In Low-indoor-temperature Environments

The results of multilevel linear regression analyses are shown in Table 3. Regarding day level variable, outdoor temperature was significantly correlated with living room temperature ($p < 0.001$). Regarding household level variable, living room temperature in area 2 (including Hokkaido) was significantly higher by 3.7˚C compared with area 6, which accounts for the majority of Japan. In contrast, indoor temperature was significantly lower in area 4 (including Miyagi, Niigata, etc.) than area 6, by 1.2˚C. Lower household income and single-person household were significantly correlated with lower living room temperatures. Moreover, longer period of residence in the same house, kotatsu use, and wearing larger amounts of clothes were correlated with lower living room temperatures.

The results of multilevel logistic regression analyses are shown in Table 4. Compared to the high income (≥ 6 million JPY) group, the odds ratio for living room temperature falling below 18˚C was 1.38 (95% CI: 1.04 – 1.84) for the middle income (2–6 million JPY) group and 2.07 (95% CI: 1.28 – 3.33) for the low income (< 2 million JPY) group. The odds ratio was 1.96 (95% CI: 1.19 – 3.22) for single-person households compared to households living with housemates. Kotatsu use (odds ratio = 2.60; $p < 0.001$) and wearing larger amounts of clothes (odds ratio = 6.86; $p < 0.001$) were also correlated with lower living room temperatures.

Table 3. Multilevel linear regression model of living room temperature in the morning

(Table 3 is uploaded as an an Excel spreadsheet.)

n = 22518 observations (1701 households × ave. 13 observations/household)

CI indicates confidence interval; $Temp_{Out}$, outdoor temperature.

* clo is a unit that represents the thermal resistance of clothes. 1 clo = 0.155(m2K)/W.

** traditional Japanese local heating device, consisting of a low table with an electric heater attached to the underneath surface and covered by a thick blanket.

Table 4. Odds ratio for living room temperature in the morning falling below 18˚C

(Table 4 is uploaded as an an Excel spreadsheet.)

n = 22518 observations (1701 households × ave. 13 observations/household)

CI indicates confidence interval; $Temp_{Out}$, outdoor temperature.

* clo is a unit that represents the thermal resistance of clothes. 1 clo = 0.155(m2K)/W.

** traditional Japanese local heating device, consisting of a low table with an electric heater attached to the underneath surface and covered by a thick blanket.

Discussion

Summary of findings

This study analyzed the relationship between living room temperature in the winter season and the characteristics of residents based on a baseline (before insulation retrofitting) survey of 2,190 households. The cross-sectional analysis showed that 1) the average temperature in the living room, bedroom and changing room was 16.8 °C, 12.8 °C and 13.0 °C, respectively; 2) living room temperature was highest (19.8˚C) in Hokkaido, where outdoor temperature is lower than other areas, but lowest (13.1˚C) in Kagawa, which is considered to have a mild climate; 3) lower household income and single-person households were correlated with lower indoor temperatures; and 4) use of a kotatsu (traditional Japanese local heating device) and wearing larger amounts of clothes were correlated with lower indoor temperatures.

Housing Disparities Between Nations And Within Japan

The results of actual measurements of indoor temperature from 2,190 houses across Japan indicate that the average living room temperature in winter was 16.8 °C. Similarly, as described in the Introduction, the average living room temperature of 602 houses across Japan was 17 °C during winter.[9] In contrast, a large-scale room temperature survey in the UK, “The comprehensive English House Condition Survey 1996,” reported that the average living room temperature in winter in the UK was 18.1 °C.[20] In addition, the Energy Follow-Up Survey 2011 involving 823 dwellings in the UK revealed that the mean monthly temperature for the whole house/apartment was 18.1 °C in December.[21] Furthermore, an investigation that targeted apartments in New York, USA, reported an average living room temperature in winter of 23.3 °C.[22]

Currently, 39% of existing houses in Japan are not insulated, which means that a large proportion of houses have low insulation performance.[12] In addition, energy consumption in houses in Japan is minimal compared to that of other countries, with energy used for heating only one-quarter of that used in European and American countries.[23] This is because, while continuous heating of the entire building is the norm in Europe and the USA, in Japan, partial intermittent heating is used, and in the living room only. Due to these two factors - low insulation performance and difference in heating use - room temperature in Japan is considered to be of a lower standard than that in European and American countries.

The present analysis also showed that there is a major disparity in indoor temperatures even within Japan. Comparison of indoor temperature between prefectures revealed a maximum difference of 6.7 °C (average living room temperature in Hokkaido minus that in Kagawa). Furthermore, the results of multilevel analysis showed that the indoor temperature in area 2 (which includes Hokkaido) was significantly higher - by 3.7˚C - compared with that in area 6 (which accounts for the majority of Japan, including Tokyo). Although the insulation specification of house is determined based on the HDD in each area, there may be still scope for improvement in insulation standards within Japan.

WHO has emphasized the risk of low indoor temperature to health in its guideline.[8] Consistent with this, concern has been raised that housing disparities between and within nations have the potential to cause health disparities.[24, 25] We expect that our present results will contribute to regulatory developments for thermal insulation standards in Japan and a reduction in health disparities.

Residents At High Risk Of Hypertension And Cardiovascular Disease

Our previous analyses[10] indicated that indoor temperature is strongly related to blood pressure, and that hypertension occurs in low-room-temperature environments. Furthermore, hypertension during the winter season can lead to the development of cardiovascular diseases (CVDs), and has been known to cause excess winter deaths.[26, 27] In other words, residents living in low-room-temperature environments have a high risk of hypertension and CVDs.

Studies of the determinants of room temperature conducted in the UK[28, 29] suggest that resident attributes such as house composition and employment status significantly affect room temperature. Our present analysis showed that, in addition to low household income, single-person households, and lifestyle factors such as the use of heating and amount of clothes worn also affect the indoor temperature. Low household income may force residents to limit the use of heating or to live in housing with low performance insulation. A certain number of fuel-poverty households are unable to afford heating expenses and live in cold homes.[30] Recent research has shown that fuel-poverty households also exist in Japan.[31] Our data confirmed that the indoor temperature is lower in single-person households. A previous study[32] suggested that people living alone have a higher risk of hypertension, and low room temperature is hypothesized to be a contributing factor. Households using kotatsu had lower indoor temperatures. Kotatsu is a form of local heating which does not allow heating of an entire room or house. Similarly, wearing more clothes was correlated with lower indoor temperatures, which suggests that some residents attempt to brave the cold by wearing more clothes.

The method used in this study allowed the identification of residents who live in cold homes. We expect that these results will be useful in the development of prevention strategies for these residents.

Strengths And Limitations

The strengths of this study are following three points. First, this is one of the largest surveys on the relationship between the characteristics of residents and indoor temperature in winter, involving 2,190 households in Japan. Second, participants were recruited throughout all 47 prefectures of Japan. The length of the Japanese archipelago stretches in a north to south direction, resulting in large regional differences in climate. We can evaluate housing disparities within Japan, taking differences in climate into account. Third, actual measurement on indoor temperature have been conducted for 2 weeks in real-world settings. This objective data for a certain period of time may reduce observational bias.

This study has the following limitations. First, the survey was conducted on households which had relatively low thermal insulation levels. In Japan, the majority of existing houses have low insulation performance,[12] so the present results may be broadly applicable throughout the country. Second, we were unable to survey details of the design specifications of participants' houses because few residents had retained design drawings of their house, and they were generally unfamiliar with the installed insulation. We took the age of the house into consideration by adding the duration of residence into the multilevel model as an independent variable. However, it is necessary to consider floor area, house structure and so on for more detailed analysis. We therefore suggest that future research should be done in cooperation with housing experts. Finally, because the present results were based on a cross sectional analysis, they are limited to showing only the actual conditions of houses in Japan and are unable to suggest how low indoor temperatures can be improved. Further studies are needed to examine an effective way to improve indoor temperature.

Conclusions

This real-world survey involving 2,190 households in Japan showed that the minimum indoor temperature in winter was below 18 °C (the recommended minimum temperature by the WHO guidelines) in more than 90% of households. Also, there were disparities in living room temperature within Japan, and they related to socioeconomic status, single-person households and the way of living. These housing disparities have the potential to cause health disparities. We expect these results will be useful in the development of prevention strategies for residents who live in cold homes and the reduction in health disparities.

Abbreviations

CI, confidence interval; CVDs, cardiovascular diseases; HBP, home blood pressure; HDD, heating degree days; JPY, Japanese yen; SWH, Smart Wellness Housing; $Temp_{Out}$, outdoor temperature; WHO, World Health Organization

Declarations

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Availability of data and materials

The data that support the findings of this study are available from the SWH survey group but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the SWH survey group.

Authors' contributions

TI, YF, SA, TK, TH, MS, KK, TY, HY and SM designed the study. WU and YN carried out the analyses and WU drafted the manuscript. All authors contributed to data interpretation, and critically reviewed the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study protocol and informed consent procedure were approved by the ethics committee of the Hattori Clinic Institutional Review Board (Approval No. S1410-J03). All of the participants provided written informed consent to participate in the study.

Consent for publication

Not applicable.

Competing interests

WU is an employee of Kajima Corp. TI has received research grants from Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd., HyAS & Co. Inc., Fuyo Home Co. Ltd., Asahi Kasei Homes Corp., OM Solar Co. Inc., Kajima Corp., Shimizu Corp., Nice Corp., Japan Gas Association and Japan Sustainable Building Consortium. TH has received an honorarium from LIXIL Corp. MS has received non-restrictive research funds from Taiyo Nippon Sanso Corp. The other authors have no competing interests. KK received a research grant from Omron Healthcare Co., Ltd.

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Figures

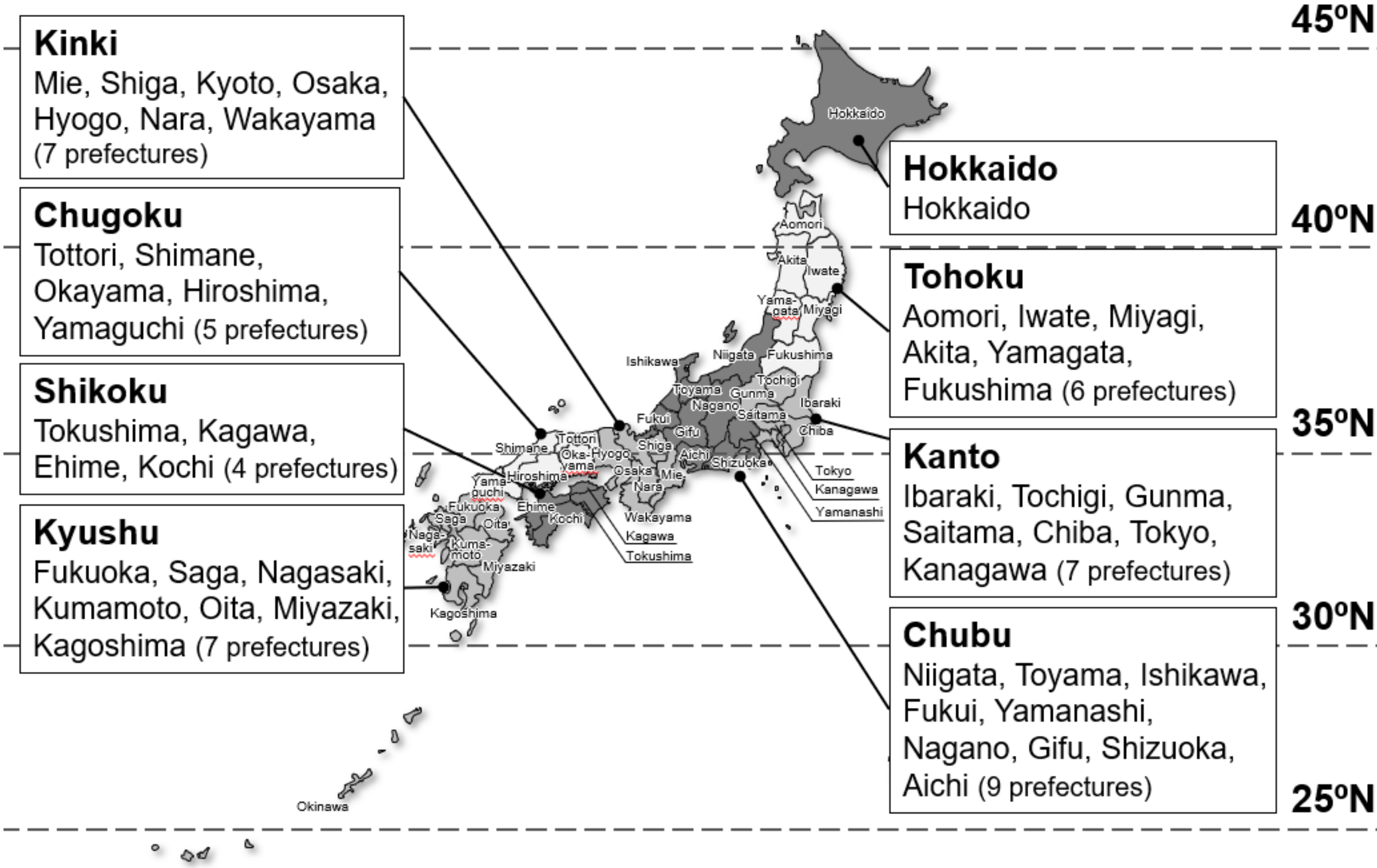

Figure 1

Prefectures in Japan

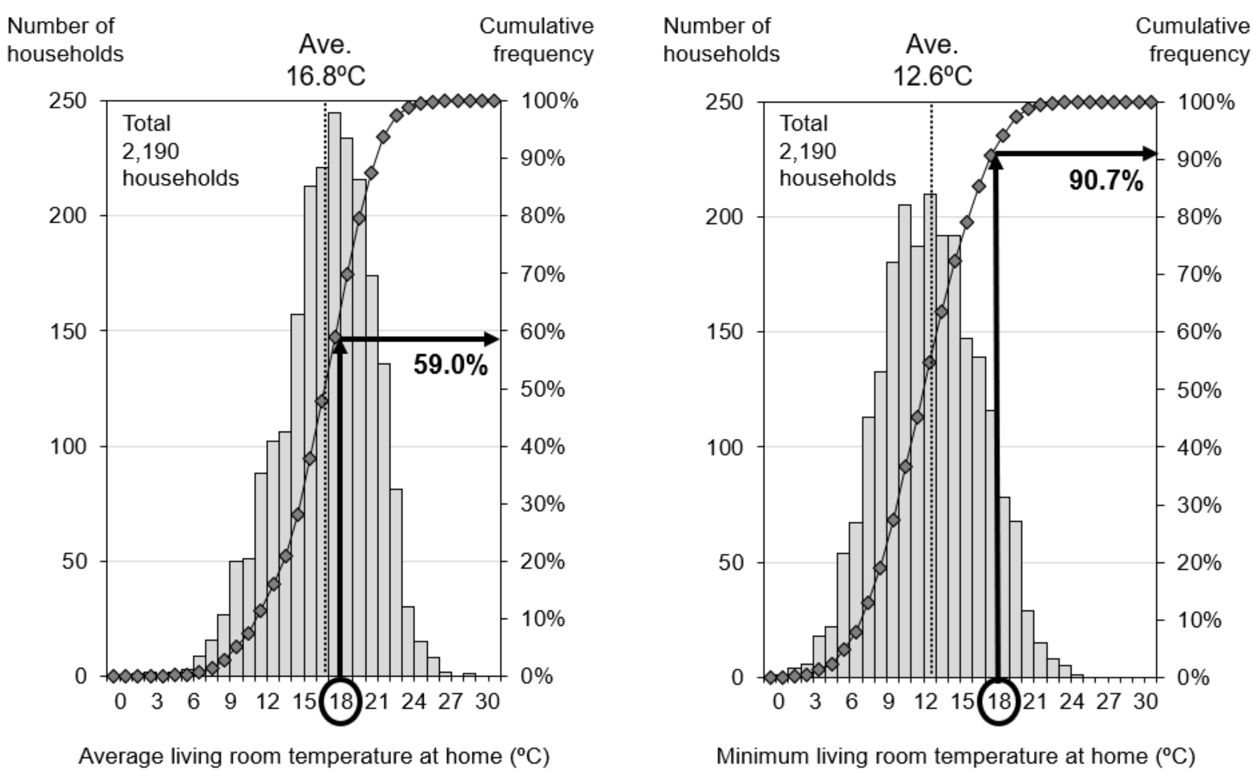

Figure 4

Average (left) and minimum (right) living room temperature at home

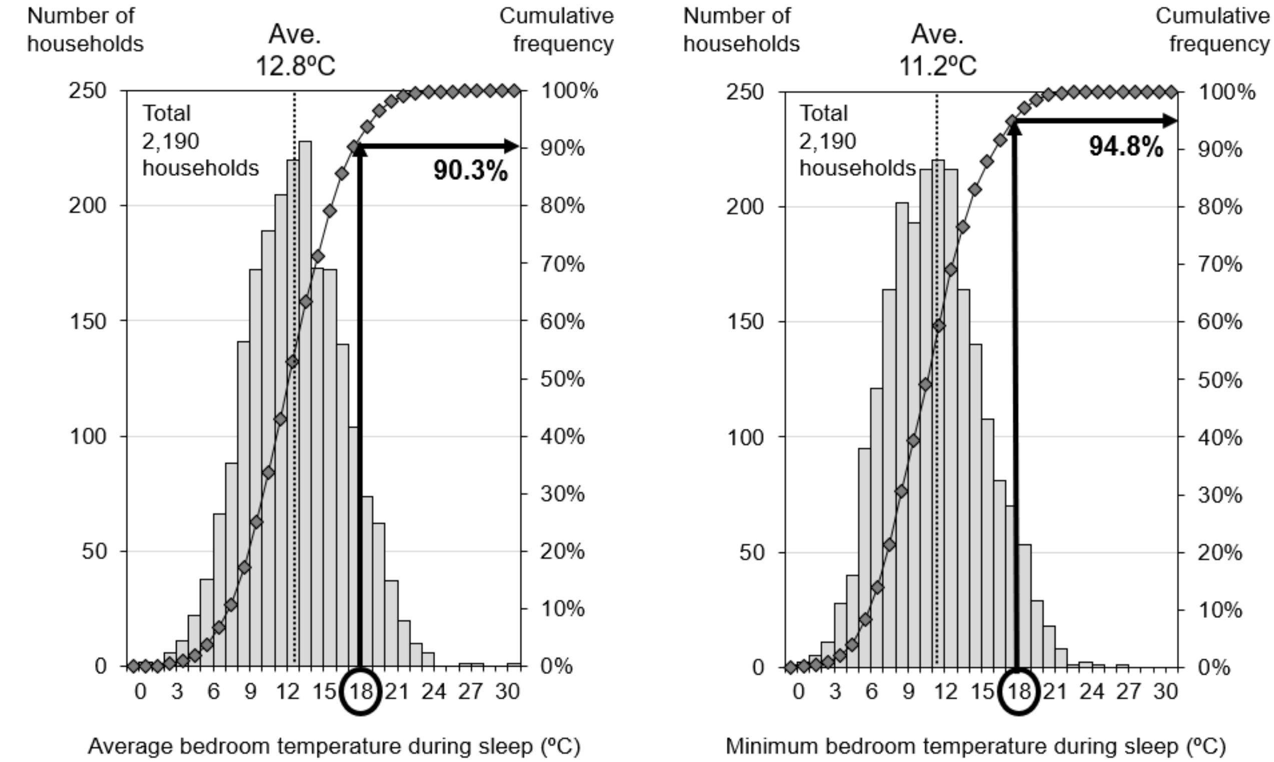

Figure 6

Average (left) and minimum (right) bedroom temperature during sleep

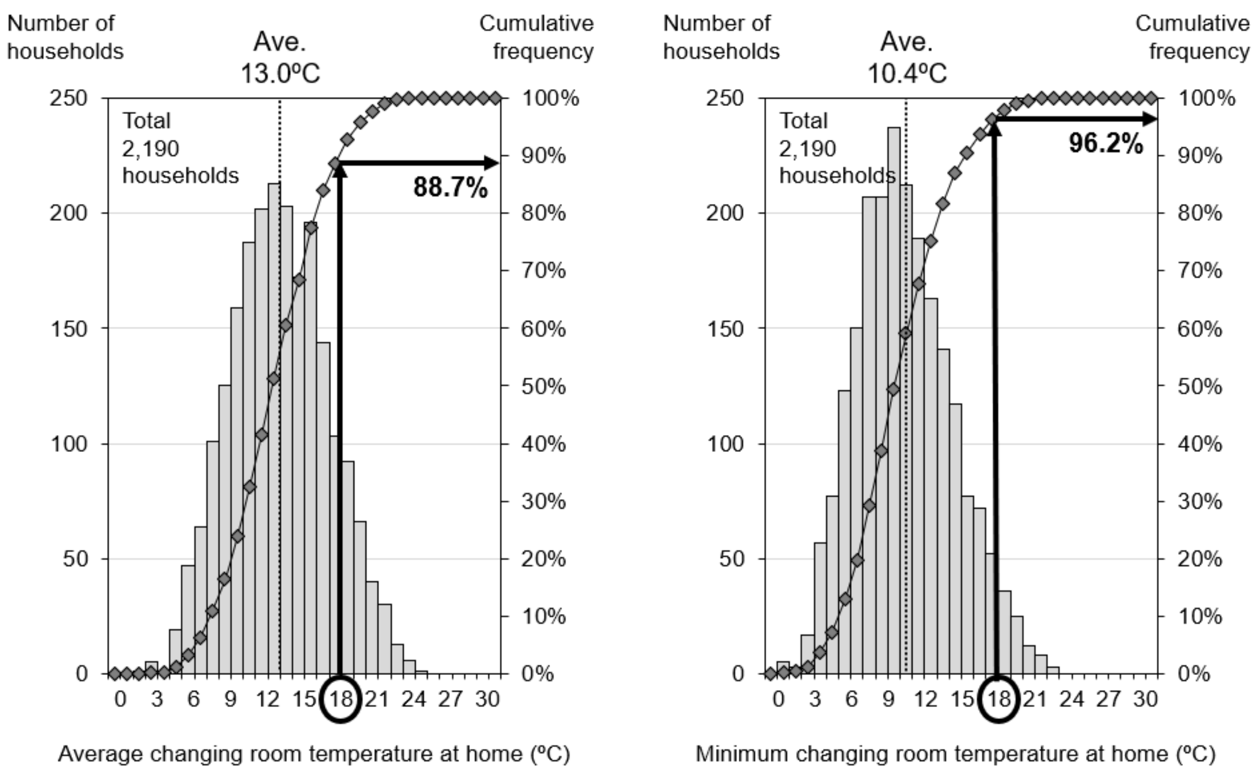

Figure 7

Average (left) and minimum (right) changing room temperature at home

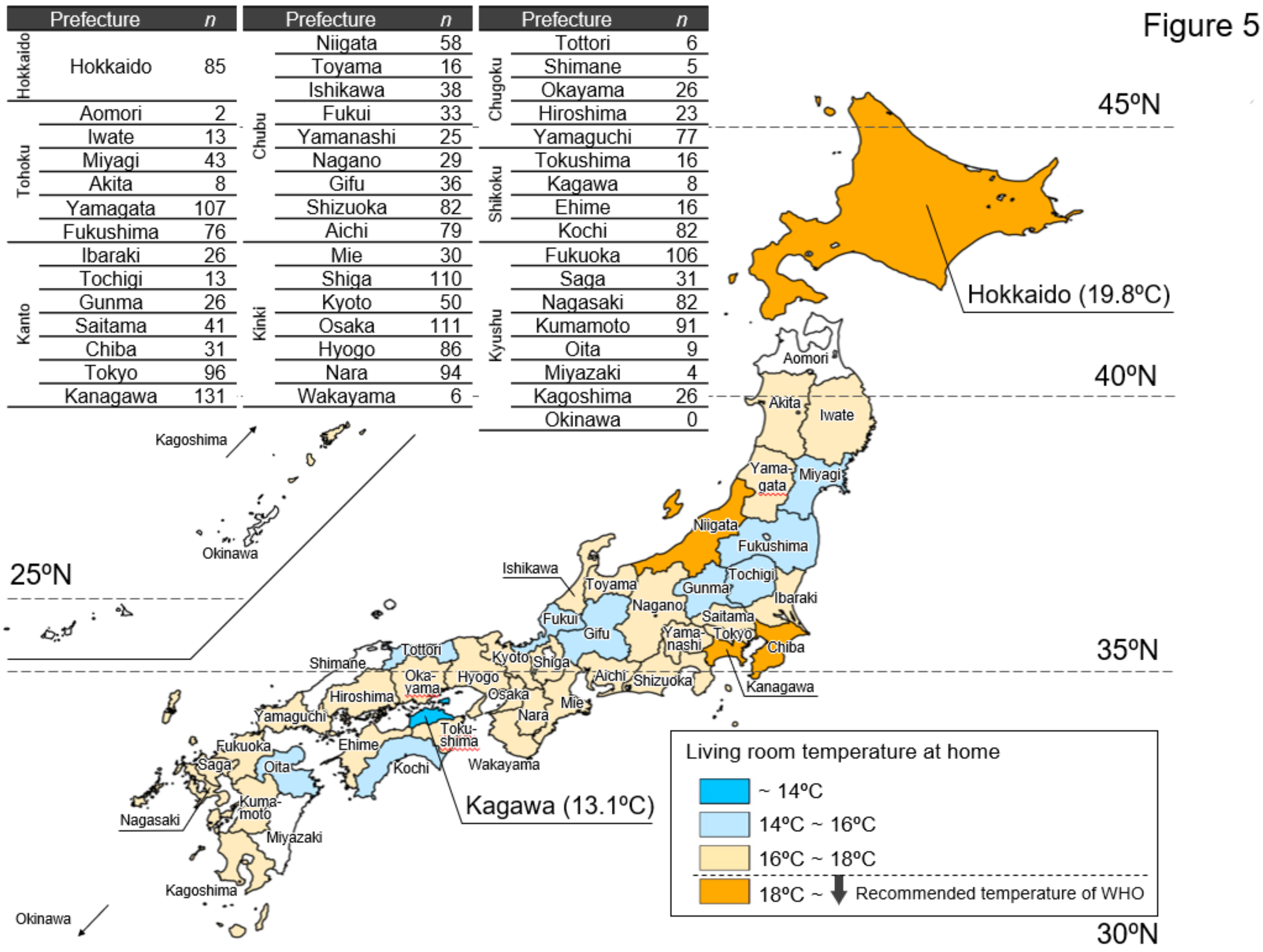

Figure 9

Average living room temperature at home in each prefecture * Excluding prefectures with 5 households or less (displayed in white)

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