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Association between Indoor Temperature in Winter and Serum Cholesterol: A Cross-Sectional Analysis of the Smart Wellness Housing Survey in Japan

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Aim: Issuance of the WHO Housing and health guidelines has paralleled growing interest in the housing environment. Despite accumulating evidence of an association between outdoor temperature and serum cholesterol, indoor temperature has not been well investigated. This study examined the association between indoor temperature and serum cholesterol.

Methods: We collected valid health checkup data of 2004 participants (1333 households), measured the indoor temperature for 2 weeks in winter, and divided participants according to whether they lived in a warm (average bedroom temperature ≥ 18℃), slightly cold (12–18℃) or cold house (<12°C). The relationship between bedroom temperature and serum cholesterol was analyzed using multivariate logistic regression models, adjusting for demographics, lifestyle habits and the season in which the health checkup was conducted, with a random effect of climate areas in Japan.

Results: The sample sizes for warm, slightly cold, and cold houses were 206, 940, and 858, respectively. Compared to those in warm houses, the odds ratio of total cholesterol exceeding 220 mg/dL was 1.83 (95%CI: 1.23–2.71, p=0.003) for participants in slightly cold houses and 1.87 (95%CI: 1.25–2.80, p=0.002) in cold houses. Similarly, the odds ratio of LDL/non-HDL cholesterol exceeding the standard range was 1.49 (p=0.056)/1.67 (p=0.035) for those in slightly cold houses and 1.64 (p=0.020)/1.77 (p=0.021) in cold houses. HDL cholesterol and triglycerides were not significantly associated with bedroom temperature.

Conclusion: Besides lifestyle modification, improving indoor thermal environment through strategies such as installing high thermal insulation and appropriate use of heating devices may contribute to better serum cholesterol condition.

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Clinical trial registration number: UMIN000030601.

Key words: **Housing, Indoor temperature, Total cholesterol, LDL cholesterol, Non-HDL cholesterol**

Introduction

Cardiovascular disease (CVD) continues to be the leading cause of death worldwide. In addition to hypertension (raised blood pressure), hyperlipidemia (raised serum cholesterol) is also considered a key intermediate risk factor for CVD[1, 2]. The Framingham Heart Study identified risk factors of coronary heart disease (CHD)[3, 4] and developed a risk score that includes blood pressure and serum cholesterol to estimate the 10-year risk of CHD[5]. In Japan, the Suita Study developed a risk score in a similar manner to the Framingham Heart Study for the Japanese population[6, 7]. The Evidence for Cardiovascular Prevention from Observational Cohorts in Japan (EPOCH-JAPAN) also examined lifetime risk of CHD using blood pressure and serum cholesterol[8]. Stroke is also an important outcome, with the Asia Pacific Cohort Studies Collaboration, which combines data from 29 cohorts in Asia and Australia, demonstrating an association between serum cholesterol and the risk of ischemic stroke[9]. Therefore, reducing cholesterol level and blood pressure is essential for preventing CVD. While serum cholesterol is affected by lifestyle-related factors such as diet[10-13], exercise[14, 15], and smoking[16-18], effects of improving lifestyle are limited because they depend on individual effort. A potentially complementary approach of improving one's life environment could enhance efforts to prevent CVD.

Consistent with the above context and the fact that modern humans spend between 60% and 70% of their time at home[19-21], the World Health Organization (WHO) has issued Housing and health guidelines[22]. The guideline focuses on "low indoor temperature and CVD" and summarizes studies on the relationship between indoor temperature and blood pressure but not serum cholesterol. A previous review[23] reported that one possible cause of increased serum cholesterol is air temperature, and evidence on the association between outdoor temperature and blood lipids has recently increased[24-27]. However, whether or not indoor temperature is associated with serum cholesterol remains largely unclear. Given that indoor temperature, unlike outdoor temperature, is a controllable factor, evidence of an association between indoor temperature and serum cholesterol would be beneficial for preventing CVD. Such a finding may be particularly pertinent in Japan, where 30% of about 50 million existing houses are not insulated and only 11% of houses were sufficiently insulated such that they meet the 1999 standards (the highest thermal insulation standards in Japan) as of 2018[28], indicating substantial room for improvement in managing the indoor thermal environment. In fact, a nationwide survey on indoor temperature revealed that the average living room temperature in Japan was 16.8℃[29], which is below the WHO recommendation of 18℃[22]. Such poor indoor thermal environments could have adverse health effects.

Aim

We conducted a nationwide non-randomized controlled trial on housing and health in Japan, named the Smart Wellness Housing (SWH) survey. In this paper, health checkup data obtained through the baseline survey were used to investigate the relationship between indoor temperature at home and serum cholesterol level according to several indices, namely total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), and non-HDL-C.

Methods

Ethics

The study was conducted according to the principles of the Declaration of Helsinki. The study protocol and informed consent procedure were approved by the ethics committee of the Hattori Clinic Institutional Review Board (Approval No. S1410-J03). The study protocol was registered at the University Hospital Medical Information Network Clinical Trials Registry (UMIN000030601). All of the participants provided written informed consent to participate and to have their data published as a group.

Study Design

The aims and study design of the SWH survey are reported elsewhere[30]. Briefly, this survey was conducted as a non-randomized controlled trial with an insulation retrofitting group and non-insulation retrofitting (control) group to examine the cardiovascular health benefits of living in insulation retrofitted houses. Participants were recruited by

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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-renovation house which did not meet S (Supreme) standards of the "Act on the Promotion of Dissemination of Long-Lasting Quality Housing" in Japan. The sample size of each prefecture is shown in **Supplemental Fig. 1** In this paper, we performed a cross-sectional analysis of data from the baseline (before insulation retrofitting) survey conducted in fiscal years 2014 to 2017. We focused on data obtained before insulation retrofitting to reflect the actual condition of houses in Japan, most of which have low insulation performance.

Serum Cholesterol Measurements

Participants were asked to submit the results of their health checkup. Among the items examined in the health checkup, we used TC, LDL-C, HDL-C, and TG. In Japanese health checkups, blood samples are collected after a fasting time of at least 10 hours in accordance with the Program for General Health Checkup and Guidance issued by the Ministry of Health, Labour and Welfare (MHLW). After excluding TG data ≥ 400 mg/dL, TC level was estimated using the Friedewald equation as follows[31]: TC (mg/dL) = LDL-C (mg/dL) + HDL-C (mg/dL) + TG (mg/dL)/5. Non-HDL-C, which is included in the current Japanese guideline[32] and closely associated with arteriosclerosis and CVD[33-37], was calculated using the following equation: Non-HDL-C (mg/dL) = TC (mg/dL) − HDL-C (mg/dL).

Indoor and Outdoor Temperature Measurements

Indoor temperature and relative humidity at 1.0 m above the floor were measured in the living room and bedroom at 10-min intervals (TR-72wf; T&D Corp., Nagano, Japan) in the winter season (November–March). The temperature and humidity logger was installed such that it was out of direct sunlight and far away from heating equipment or heat-generating devices like refrigerators and televisions to avoid extreme outliers. Outdoor temperature data were obtained from the closest local meteorological observatory to each participant's house.

Questionnaire and Diary Surveys

The questionnaire survey included housing conditions; demographics such as age, sex, height, weight, household income; lifestyle indicators such as dietary habits, exercise, smoking, alcohol consumption; and health conditions related to CVD. Participants indicated their household income by choosing from multiple options which were subsequently classified as low (<2 million Japanese yen (JPY)), middle (2–6 million JPY) or high (≥ 6 million JPY) in accordance with the National Health and Nutrition Survey. The salt check sheet score and frequency of vegetable intake were used as a measure of dietary habits. The salt check sheet score was classified into 4 groups (low (0–8 points), medium (9–13 points), high (14–19 points), or very high (≥ 20 points))[38] while responses related to vegetable intake were categorized according to whether or not participants ate vegetables regularly. Although the salt check sheet was not developed to assess serum cholesterol, it was used to indirectly evaluate whether or not participants' dietary habits were healthy. We confirmed in advance that some cholesterol indices gradually increased (HDL-C decreased) with higher salt check sheet score, as shown in **Supplemental Table 2**. Responses related to exercise, smoking and alcohol consumption were treated as two-valued variables: whether or not participants did regular moderate exercise, whether or not they were a current smoker, and whether or not they were a current drinker, respectively. A diary survey was also conducted, in which participants provided details of their waking time, bedtime, and time spent at home on a daily basis.

Statistical Analysis

First, cold, slightly cold and warm houses were defined. We extracted bedroom temperature during sleep based on a diary survey because participants, especially those of working age, are more likely to spend long periods of time in the bedroom when they are at home. Subsequently, we divided participants into three groups according to the average bedroom temperature: ≥ 18℃ (warm houses), 12–18℃ (slightly cold houses), and <12℃ (cold houses), in accordance with the temperature recommended by the WHO Housing and health guidelines (18℃)[22] and a UK report on the temperature at which CVD risk begins to increase (12℃)[39].

To examine the association between serum cholesterol indices and bedroom temperature, the Jonckheere-Terpstra trend test and the Cochran-Armitage trend test were performed on continuous and two-valued variables, respectively. Univariate and multivariate logistic regression analyses were also conducted with serum cholesterol as the objective variable (whether or not each item was within the standard range of the current[32] or previous[40] Japan Atherosclerosis Society Guidelines: TC ≥ 220 mg/dL, LDL-C ≥ 140 mg/dL, HDL-C <40 mg/dL, TG ≥ 150 mg/dL, and non-HDL-C ≥ 170 mg/dL). Bedroom temperature (warm vs slightly cold vs cold

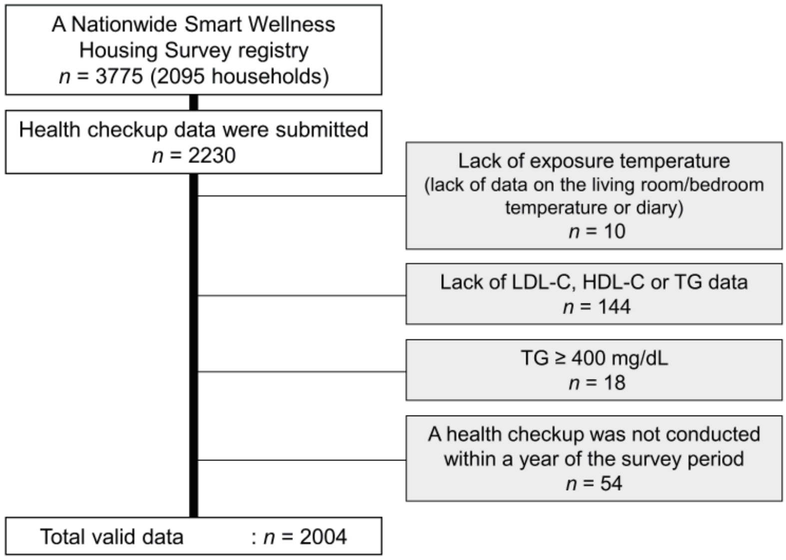

Fig. 1. Flow of the selection of valid samples

LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.

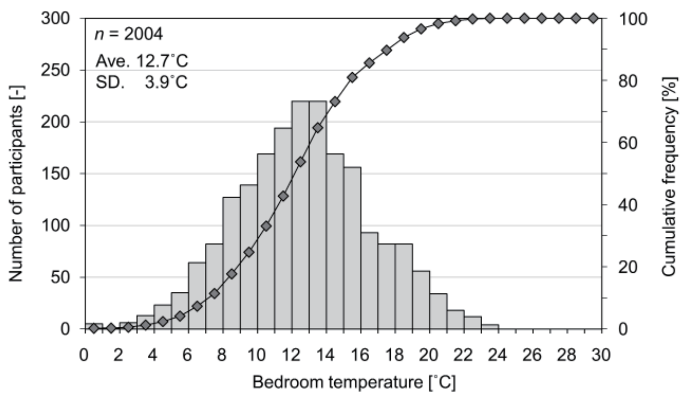

Fig. 2. Distribution of average bedroom temperature

houses) was inputted as the explanatory variable. The analysis was adjusted for the participants' basic characteristics, namely age, sex, body mass index (BMI, calculated as weight[kg]/height[m]^2), household income, salt check sheet score, vegetable intake, exercise, smoking, alcohol consumption and antihypertensive drug use. The season in which the health checkup was conducted (in winter or not) was also inputted into the model to account for seasonal variations in serum cholesterol[23, 41, 42]. Additionally, we included climate areas in Japan (**Supplemental Fig. 2**) as a random effect to account for regional differences. Sub-group analyses of participants without hyperlipidemia were also conducted to exclude the effects of medical treatment for cholesterol and confirm the robustness of the results.

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. 26 (SPSS Inc., Chicago, Illinois, USA).

Results

Definition of Cold, Slightly Cold and Warm Houses Based on Exposure Temperature

Fig. 1 shows the selection of valid samples. Of 3775 participants in the SWH survey, 2230 residents submitted health checkup data and 2004 residents (1333 households) were included as valid samples. Distribution of the bedroom temperature during sleep is shown in **Fig. 2**. The average bedroom temperature was 12.7℃. Participants were categorized as sleeping in warm, slightly cold or cold houses based on the results shown in **Fig. 2**. The sample sizes of the three

Table 1. Housing conditions in the baseline survey in winter

Variable	Overall (n=2004)	Warm (n=206)	Slightly cold (n=940)	Cold (n=858)
	n (%)	n (%)	n (%)	n (%)
Climate area				
Area 2	94 (5)	40 (19)	44 (5)	10 (1)
Area 3	59 (3)	6 (3)	17 (2)	36 (4)
Area 4	187 (9)	3 (1)	59 (6)	125 (15)
Area 5	533 (27)	32 (16)	229 (24)	272 (32)
Area 6	1025 (51)	114 (55)	527 (56)	384 (45)
Area 7	106 (5)	11 (5)	64 (7)	31 (4)
Heating devices in bedroom				
Oil fan heater, gas stove, etc.	422 (21)	30 (15)	204 (22)	188 (22)
Floor heating, heated floor mat, etc.	156 (8)	20 (10)	85 (9)	51 (6)
Self-rated coldness				
Feeling cold in bedroom	765 (39)	62 (31)	354 (38)	349 (41)
Variable	Overall (n=2004)	Warm (n=206)	Slightly cold (n=940)	ColdCold (n=858)
	Ave (SD)	Ave (SD)	Ave (SD)	Ave (SD)
Duration of residence in house, years	25.8 (15.3)	19.7 (13.4)	23.5 (14.7)	29.7 (15.5)
Outdoor temperature, ℃	5.8 (3.5)	5.8 (4.3)	6.9 (3.6)	4.5 (2.7)

groups were 206, 940 and 858, respectively.

Study Profile

Table 1 shows the housing conditions. Participants in Area 2 (which mostly consists of Hokkaido) lived in warmer houses than those in other areas. Older type heating devices such as oil fan heaters and gas stoves were more frequently used in colder houses. About 40% of participants reported feeling cold in the bedroom, and this percentage gradually increased with colder houses. Participants' average duration of residence in their current house was 25.8 years, with a difference of 10 years between warm and cold houses. The average outdoor temperature was 5.8℃ during the measurement period, and there was no clear association between bedroom temperature (warm vs slightly cold vs cold) and outdoor temperature.

Table 2 shows the baseline characteristics of the residents overall and by group. The average age was 58 years and approximately 30% were 65 years and older. About half were men, the average BMI was 22.8 kg/m^2 and approximately 20% were classified as overweight. Approximately 40% of participants belonged to high income households, which is greater than the proportion reported by the National Health and Nutrition Survey in Japan (27.4%). While the number of patients with stroke, angina/myocardial infarction and diabetes was small, those with hyperlipidemia and hypertension comprised more than 10%. The number of participants with systolic blood pressure exceeding 140 mmHg or diastolic blood pressure exceeding 90 mmHg in the health checkup was smaller than that with self-reported hypertension, indicating that some participants received antihypertensive drugs and had well controlled BP. Basic characteristics were adjusted in the subsequent multivariate logistic regression model to account for differences between the three groups.

Comparison of Serum Cholesterol among Cold, Slightly Cold and Warm Houses

Table 3 shows the average and standard deviation of serum cholesterol indices and **Table 4** shows the number of participants with serum cholesterol that exceeded the standard range in the baseline survey. According to data from both tables, TC significantly increased with colder houses. Although not significant (p<0.10), there was an increasing trend in LDL-C and non-HDL-C with colder houses.

The results of logistic regression analysis are shown in **Table 5**. Compared to participants living in warm houses (≥ 18℃), the adjusted odds ratio of exceeding the standard range for TC was 1.83 (95%CI: 1.23–2.71, p=0.003) for those living in slightly cold houses (12–18℃) and 1.87 (95%CI: 1.25–2.80, p=0.002) for those in cold houses (< 12℃). Similarly, the adjusted odds ratio of exceeding

Table 2. Basic characteristics of participants in the baseline survey in winter

Variable	Overall (n=2004)	Warm (n=206)	Slightly cold (n=940)	Cold (n=858)
	n (%)	n (%)	n (%)	n (%)
Demographics				
Age (≥ 65 years)	611 (30)	49 (24)	288 (31)	274 (32)
Men	1008 (50)	98 (48)	475 (51)	435 (51)
Body mass index (≥ 25 kg/m^2)	412 (21)	38 (18)	196 (21)	178 (21)
Household income				
Low (< 2 million JPY)	169 (9)	10 (5)	80 (9)	79 (10)
Middle (2–6 million JPY)	914 (50)	87 (47)	407 (47)	420 (53)
High (≥ 6 million JPY)	762 (41)	90 (48)	375 (44)	297 (37)
Lifestyle				
Salt check sheet				
Low (0–8 points)	254 (13)	28 (14)	112 (13)	114 (14)
Medium (9–13 points)	775 (41)	80 (41)	370 (41)	325 (40)
High (14–19 points)	739 (39)	73 (37)	348 (39)	318 (39)
Very high (≥ 20 points)	138 (7)	14 (7)	62 (7)	62 (8)
Eat vegetables regularly	1549 (78)	163 (80)	710 (76)	676 (79)
Regular exercise	646 (32)	61 (30)	281 (30)	304 (36)
Current smoker	270 (15)	24 (12)	128 (15)	118 (15)
Current drinker	1095 (55)	113 (55)	523 (56)	459 (54)
Antihypertensive drug use	481 (25)	37 (19)	225 (25)	219 (27)
Health condition				
Stroke	29 (1)	4 (2)	12 (1)	13 (2)
Angina/Myocardial infarction	62 (3)	4 (2)	25 (3)	33 (4)
Diabetes	140 (7)	17 (9)	62 (7)	61 (7)
Hyperlipidemia	377 (19)	25 (13)	183 (20)	169 (21)
Hypertension	463 (24)	34 (17)	222 (24)	207 (25)
Health checkup				
Systolic blood pressure ≥ 140 mmHg	295 (16)	29 (15)	145 (16)	121 (15)
Diastolic blood pressure ≥ 90 mmHg	168 (9)	14 (7)	82 (9)	72 (9)

Table 3. Average and standard deviation of serum cholesterol of participants in the baseline survey

Variable	Overall (n=2004)	Warm (n=206)	Slightly cold (n=940)	Cold (n=858)	p for trend
	Ave (SD)	Ave (SD)	Ave (SD)	Ave (SD)	
Blood lipids					
TC	209 (37)	202 (37)	209 (36)	211 (38)	0.007
LDL-C	124 (32)	119 (31)	123 (31)	125 (33)	0.061
HDL-C	64 (17)	63 (16)	64 (17)	65 (17)	0.130
TG	106 (61)	100 (57)	106 (59)	107 (63)	0.593
Non-HDL-C	145 (36)	140 (36)	145 (35)	146 (37)	0.083

TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.

the standard range for LDL-C/non-HDL-C was 1.49 (95%CI: 0.99–2.25, p=0.056)/1.67 (95%CI: 1.04–2.68, p=0.035) for those living in slightly cold houses and 1.64 (95%CI: 1.08–2.49, p=0.020)/1.77 (95%CI: 1.09–2.87, p=0.021) for those living in cold houses. HDL-C and TG were not significantly associated with bedroom temperature.

The results of sub-group analyses of participants without hyperlipidemia are shown in **Table 6**. As with the results shown in **Table 5**, the adjusted odds ratios

Table 4. Number of participants whose serum cholesterol exceeded the standard range in the baseline survey

Variable	Overall (n=2004)	Warm (n=206)	Slightly cold (n=940)	Cold (n=858)	p for trend
	n (%)	n (%)	n (%)	n (%)	
Blood lipids					
TC ≥ 220 mg/dL	725 (36)	57 (28)	345 (37)	323 (38)	0.032
LDL-C ≥ 140 mg/dL	590 (29)	52 (25)	270 (29)	268 (31)	0.071
HDL-C < 40 mg/dL	98 (5)	16 (8)	56 (6)	26 (3)	< 0.001
TG ≥ 150 mg/dL	369 (18)	31 (15)	182 (19)	156 (18)	0.662
Non-HDL-C ≥ 170 mg/dL	458 (23)	34 (17)	218 (23)	206 (24)	0.061

TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.

Table 5. Association between serum cholesterol and bedroom temperature (warm vs slightly cold vs cold houses)

Objective variable	Explanatory variable	Unadjusted			Adjusted*		
		Odds ratio	(95%CI)	p value	Odds ratio	(95%CI)	p value
TC ≥ 220 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.77	(1.20, 2.61)	0.004	1.83	(1.23, 2.71)	0.003
	Cold (< 12℃)	1.80	(1.22, 2.66)	0.003	1.87	(1.25, 2.80)	0.002
LDL-C ≥ 140 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.50	(1.00, 2.24)	0.051	1.49	(0.99, 2.25)	0.056
	Cold (< 12℃)	1.60	(1.06, 2.40)	0.025	1.64	(1.08, 2.49)	0.020
HDL-C < 40 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	0.93	(0.48, 1.83)	0.840	0.87	(0.45, 1.69)	0.678
	Cold (< 12℃)	0.62	(0.30, 1.27)	0.189	0.59	(0.29, 1.19)	0.138
TG ≥ 150 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.51	(0.94, 2.44)	0.090	1.43	(0.87, 2.36)	0.163
	Cold (< 12℃)	1.29	(0.79, 2.10)	0.309	1.29	(0.77, 2.15)	0.327
Non-HDL-C ≥ 170 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.71	(1.08, 2.73)	0.024	1.67	(1.04, 2.68)	0.035
	Cold (< 12℃)	1.75	(1.09, 2.81)	0.021	1.77	(1.09, 2.87)	0.021

*Adjusted for age, sex, body mass index, household income, salt check sheet score, vegetable consumption, exercise, smoking, alcohol consumption, antihypertensive drug use and season in which health checkup was conducted.
TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.

of exceeding the standard range for TC (1.94 for slightly cold houses and 1.93 for cold houses), LDL-C (1.63 for slightly cold houses and 1.67 for cold houses), and non-HDL-C (1.73 for cold houses) were significant, indicating the presence of associations of cold indoor environments with TC, LDL-C, and non-HDL-C even after excluding the effects of medical treatment for cholesterol.

Discussion

This cross-sectional analysis of 2004 participants in 1333 households showed that 1) the average bedroom temperature was 12.7℃, which is below the WHO recommendation of 18℃; 2) TC, LDL-C and non-HDL-C gradually increased with colder houses; 3) compared to warm houses, the adjusted odds ratio for TC exceeding 220 mg/dL was 1.83 and 1.87, that for LDL-C exceeding 140 mg/dL was 1.49 and 1.64, and that for non-HDL-C exceeding 170 mg/dL was 1.67 and 1.77, for those living in slightly cold houses and cold houses, respectively; and 4) participants without hyperlipidemia showed the same trends as those in the main analysis, indicating the robustness of the results. A potential mechanism that could explain our results is that cold stress activates the hypothalamus-pituitary-adrenal (HPA) axis, leading to secretion of cortisol, which is generated from cholesterol. Thus, persistent cold exposure and excess cortisol might result in high serum cholesterol levels. Previous studies have reported the mechanism of this process[43-45], the association between HPA activity/

Table 6. Association between serum cholesterol and bedroom temperature (warm vs slightly cold vs cold houses) in participants without hyperlipidemia

Objective variable	Explanatory variable	Unadjusted			Adjusted*		
		Odds ratio	(95%CI)	*p* value	Odds ratio	(95%CI)	*p* value
TC ≥ 220 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.83	(1.20, 2.81)	0.005	1.94	(1.25, 3.00)	0.003
	Cold (< 12℃)	1.84	(1.19, 2.85)	0.006	1.93	(1.24, 3.01)	0.004
LDL-C ≥ 140 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.60	(1.02, 2.50)	0.041	1.63	(1.03, 2.58)	0.036
	Cold (< 12℃)	1.62	(1.03, 2.54)	0.039	1.67	(1.05, 2.66)	0.030
HDL-C < 40 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	0.87	(0.41, 1.85)	0.711	0.81	(0.38, 1.71)	0.580
	Cold (< 12℃)	0.63	(0.28, 1.39)	0.250	0.60	(0.27, 1.32)	0.201
TG ≥ 150 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.34	(0.78, 2.30)	0.293	1.28	(0.73, 2.24)	0.390
	Cold (< 12℃)	1.15	(0.66, 1.99)	0.627	1.15	(0.65, 2.03)	0.638
Non-HDL-C ≥ 170 mg/dL	Warm (≥ 18℃)	Ref.			Ref.		
	Slightly cold (12–18℃)	1.68	(1.00, 2.82)	0.051	1.70	(1.00, 2.89)	0.052
	Cold (< 12℃)	1.69	(1.00, 2.86)	0.052	1.73	(1.01, 2.98)	0.048

*Adjusted for age, sex, body mass index, household income, salt check sheet score, vegetable consumption, exercise, smoking, alcohol consumption, antihypertensive drug use and season in which the health checkup was conducted.
TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.

cortisol and serum cholesterol[43, 46], and identified cold as an important physical stressor[43, 44].

Several studies have investigated the association between serum cholesterol levels and outdoor temperature. Hong *et al.*[25] showed that LDL-C increased and HDL-C decreased with decreasing outdoor temperature. Sartini *et al.*[27] also demonstrated an increase in TC and LDL-C with decreasing outdoor temperature. In contrast, Halonen *et al.*[24] and Basu *et al.*[26] showed the opposite association between blood lipids and outdoor temperature. One possible cause of these discrepant results is the indoor temperature, suggesting the need to examine its association with blood lipids. One study that examined the relationship between indoor temperature at home and blood lipids was conducted by Shiue *et al.*[47] The researchers analyzed the relationship between indoor temperature and biomarkers during nurses' interviews among 7997 participants and showed that those living in houses with indoor temperatures below 18℃ had high TC and LDL-C but not HDL-C and TG, which is consistent with the present results. However, because this relationship was examined at just one point in time – during the nurses' interviews – it is impossible to extrapolate the relationship between cholesterol and indoor temperature, to which the participants are exposed on a daily basis. The findings in the present paper suggest that the relationship between serum cholesterol level and indoor thermal environment at home may not be temporary.

We propose that improving the home thermal environment is an effective way to reduce serum cholesterol levels and future CVD risk. Many clinical trials have examined the relationship between serum cholesterol levels and CVD[48-51], and a guideline has been issued on how to reduce cholesterol levels, with improvements to lifestyle habits being one recommended measure[52, 53]. However, because improving lifestyle habits depends on individual effort, interventions on lifestyle habits have not been sufficiently effective in long-term studies[54] or community studies[55], thereby highlighting the inherent challenge of promoting lifestyle changes. It may be more effective to improve both lifestyle habits and living environment. However, at present, the guideline mentioned above does not address improvements to the living environment, such as protection from the cold in indoor environments like the home. We expect that evidence on the relationship between living environment and cholesterol levels will continue to accumulate, which we hope will prompt the promotion of interventions related to environmental factors.

Progression of arteriosclerosis, which is a known risk factor of CVD, occurs as vascular endothelial cells become injured due to high blood pressure, followed by the accumulation of cholesterol on these injuries.

When cholesterol accumulates and blood vessels become constricted, a vicious cycle arises leading to further increases in blood pressure[56, 57]. The present analysis identified a significant relationship between high cholesterol levels and residents living in houses with low room temperatures. Similarly, low room temperature environments increase blood pressure[30]. As such, compared to residents living in warm houses, those living in cold houses likely experience a vicious cycle of increasing blood pressure, accumulating cholesterol, and arteriosclerosis progression.

A major strength of the present study was that we used objective data from blood samples and 2-week indoor temperature measurements in our analyses, which might have reduced subjective biases. Nevertheless, the study also had several limitations. First, a degree of selection bias was likely present, given that we recruited residents who intended to conduct insulation retrofitting. To examine the possibility of this bias, we compared serum cholesterol indices in the present survey with those in the National Health and Nutrition Survey by sex and age in **Supplemental Fig. 3**. The two surveys showed the same patterns (e.g., TC and LDL-C in women were lower than those in men below the age of 50 years old, but rose rapidly and exceeded those in men after age 50 years), indicating that participants in the present study had comparable characteristics to those of the general Japanese population. However, we conducted the survey only on the Japanese population. Thus, future studies should examine the external validity and applicability of our findings to non-Japanese populations. Second, the timing of the health checkup varied from person to person. However, we adjusted for the season in which the health checkup was conducted in the logistic model to account for seasonal variations in CVD biomarkers. Third, we could not check whether or not blood samples were actually collected after at least a 10-hour fast, which could affect the TC level estimated from the Friedewald equation. However, as explained in the Methods section, health checkups in Japan are generally conducted after a fasting time of at least 10 hours. Additionally, we excluded TG data ≥ 400 mg/dL. Based on these two reasons, we believe the serum cholesterol data were unbiased. Finally, we cannot identify a clear biological mechanism to explain the discrepancy in several serum cholesterol indices. Thus, experimental studies examining more detailed physiological parameters are required to confirm our findings. The ultimate goal of this research is to clarify the relationship between arteriosclerosis progression and housing by comparing a cold housing group with a warm housing group in long-term follow-up studies.

Conclusion

The present study showed that residents in cold houses had high serum cholesterol levels. A clinical implication of our study is that a warmer indoor thermal environment may contribute to maintaining lower serum cholesterol levels. Thus, besides lifestyle modification, improving the indoor environment through strategies such as installing high thermal insulation and appropriate use of heating devices may lead to better cardiovascular health.

Acknowledgements

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Conflict of Interest

T Ikaga has received research grants from Tokyo Gas Co., Ltd., Osaka Gas Co., Ltd., Panasonic Homes Co. Ltd., Fuyo Home Co. Ltd., Asahi Kasei Homes Corp., LIXIL Corp., Azbil Corp., Kajima Corp., Shimizu Corp., Nice Corp., Japan Gas Association and Japan Sustainable Building Consortium. The above grants/funds/honorarium have been received outside the submitted work.

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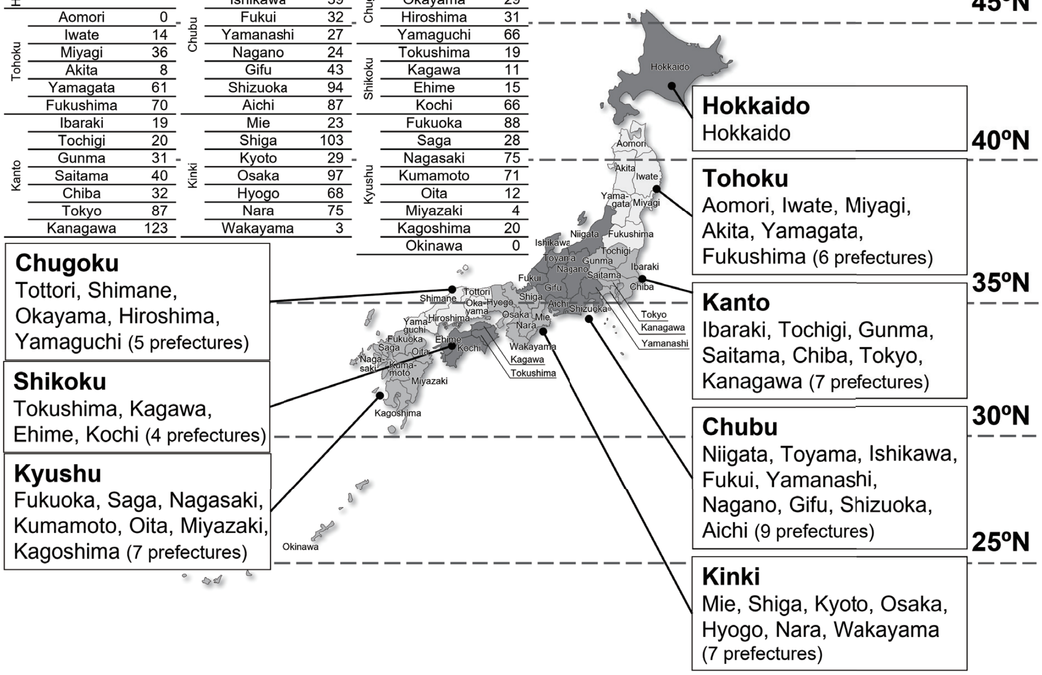
Region	Prefecture	n
Hokkaido	Hokkaido	107
Tohoku	Aomori	0
Tohoku	Iwate	14
Tohoku	Miyagi	36
Tohoku	Akita	8
Tohoku	Yamagata	61
Tohoku	Fukushima	70
Kanto	Ibaraki	19
Kanto	Tochigi	20
Kanto	Gunma	31
Kanto	Saitama	40
Kanto	Chiba	32
Kanto	Tokyo	87
Kanto	Kanagawa	123
Chubu	Niigata	51
Chubu	Toyama	17
Chubu	Ishikawa	39
Chubu	Fukui	32
Chubu	Yamanashi	27
Chubu	Nagano	24
Chubu	Gifu	43
Chubu	Shizuoka	94
Chubu	Aichi	87
Kinki	Mie	23
Kinki	Shiga	103
Kinki	Kyoto	29
Kinki	Osaka	97
Kinki	Hyogo	68
Kinki	Nara	75
Kinki	Wakayama	3
Chugoku	Tottori	5
Chugoku	Shimane	4
Chugoku	Okayama	29
Chugoku	Hiroshima	31
Chugoku	Yamaguchi	66
Shikoku	Tokushima	19
Shikoku	Kagawa	11
Shikoku	Ehime	15
Shikoku	Kochi	66
Kyushu	Fukuoka	88
Kyushu	Saga	28
Kyushu	Nagasaki	75
Kyushu	Kumamoto	71
Kyushu	Oita	12
Kyushu	Miyazaki	4
Kyushu	Kagoshima	20
	Okinawa	0



Supplemental Fig. 1. Sample size of each prefecture in Japan

Supplemental Table 1. Members of Smart Wellness Housing Survey Group

(a) Members of the Research Committee for the Promotion of Smart Wellness Housing	
Chairperson	
Shuzo MURAKAMI*	Institute for Built Environment and Carbon Neutral for SDGs
Vice-chairperson	
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Hiroshi YOSHINO*	Tohoku University
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Toshiharu IKAGA*	Keio University
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Mikio ARITA	Sumiya Rehabilitation Hospital
Michiya IGASE	Ehime University
Masayoshi ICHIBA	Saga University
Nami IMAI	Mie University
Masaki UEMURA	At Home, LLC
Hiroyuki UEHARA	National Assembly Promoting Healthy and Energy Conserving Housing
Haruo UGUISU	Tokushima Bunri University
Kensuke ESATO	Yamaguchi University
Akira EBOSHIDA	Hiroshima University
Yuko OGUMA	Keio University
Toshiyuki OJIMA	Hamamatsu University School of Medicine
Shimato ONO	Marugame Ono Clinic
Yoshio OMATA	Hoju, Co., Ltd.
Takahiko KATOH	Kumamoto University
Masahiko KATO	Tottori University
Shinya KUNO	University of Tsukuba
Kiyokage KUBO	Kubo Clinic
Yoshiki KURODA	University of Miyazaki
Yasuaki SAIJO	Asahikawa Medical University
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Tanji HOSHI*	Tokyo Metropolitan University
Satoshi HOSHIDE	Jichi Medical University
Takahiro MAEDA	Nagasaki University
Muneo MINOSHIMA	Minoshima Clinic
Takashi MURAWAKA	Yumemokuba, SNPC
Hidekazu YAMADA	Kindai University Nara Hospital
Misako YOSHINAGA	Kusunoki Hospital

(Cont. Supplemental Table 1)

(a) Members of the Research Committee for the Promotion of Smart Wellness Housing	
Committee member in architecture	
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Naoki TAKAGI	Shinshu University
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Takayuki TAMAI	National Institute of Technology, Yonago College
Mitsutaka TSUJI	Gifu Academy of Forest Science and Culture
Reiji TOMIKU	Oita University
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Daisaku NISHINA	Hiroshima University
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Teruaki MITAMURA	Maebashi Institute of Technology
Shinji YOSHIDA	Nara Women's University

*: members of the Research Planning Committee for the Promotion of Smart Wellness Housing

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Tatsuhiko KUBO	Hiroshima University
Committee member	
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Yuko OGUMA	Keio University
Naoki KAGI	Tokyo Institute of Technology
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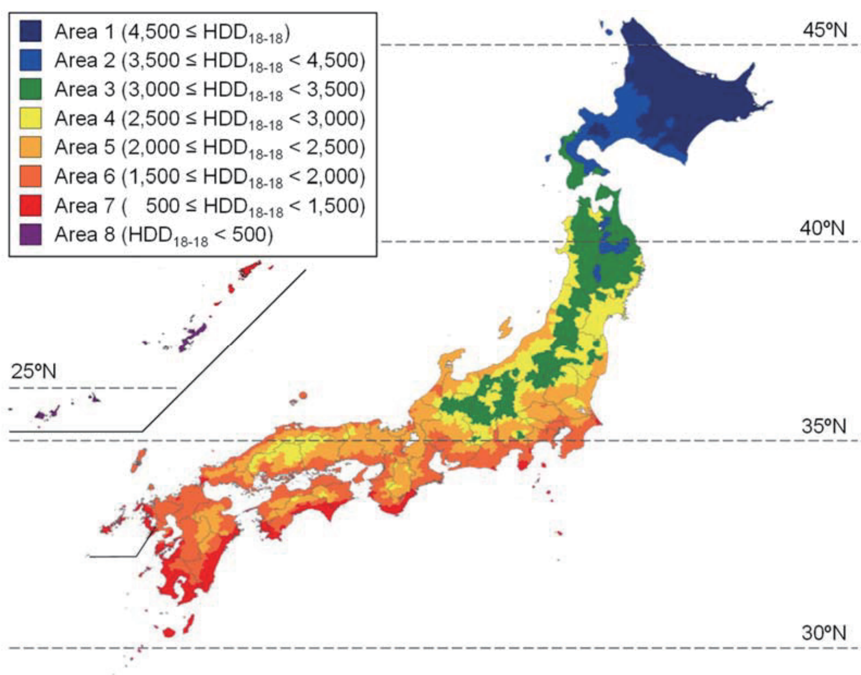
Tanji HOSHI*	Tokyo Metropolitan University

*: members of the Research Planning Committee for the Promotion of Smart Wellness Housing

Supplemental Table 2. Serum cholesterol level and salt check sheet points

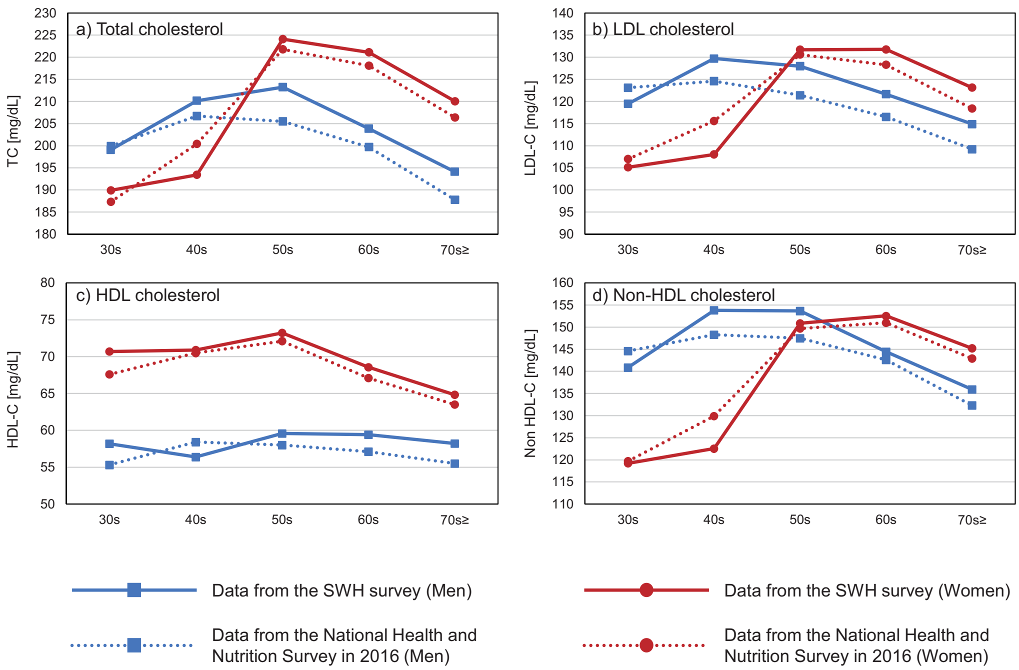
Variable	Low (0–8 points)	Medium (9–13 points)	High (14–19 points)	Very high (≥ 20 points)	*p* for trend
	Ave (SD)	Ave (SD)	Ave (SD)	Ave (SD)	
Blood lipids					
TC	209 (38)	209 (38)	209 (35)	210 (37)	0.990
LDL-C	122 (32)	123 (32)	125 (31)	125 (31)	0.218
HDL-C	68 (17)	66 (16)	62 (16)	61 (17)	<0.001
TG	97 (52)	103 (59)	111 (65)	117 (65)	0.002
Non-HDL-C	141 (36)	144 (36)	147 (36)	149 (38)	0.028

TC, total cholesterol; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; TG, triglyceride.



Supplemental Fig. 2. Eight climate areas in Japan as of 2013

$HDD_{18\text{-}18}$ means the heating degree days value (difference between indoor temperature of 18℃ and daily mean outdoor temperature, where the daily mean outdoor temperature is less than 18℃.



Supplemental Fig. 3. Comparison of cholesterol indices in the SWH survey and the National Health and Nutrition Survey by sex and age category

Non-HDL-C was calculated by Non-HDL-C (mg/dL) = TC (mg/dL) – HDL-C (mg/dL).
Men and women in 20s were excluded because the sample size of the SWH survey was too small (men: n = 8, women; n = 13).