Effects of Night-time Bedroom Temperature on Morning Blood Pressure during Winter: A Multilevel Analysis

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Abstract

Purpose / Context - To analyse the association between night-time temperature in the bedroom and morning blood pressure (BP)

Methodology / Approach - Data were obtained from field surveys conducted from November 2014 to March 2015 on indoor temperature, home BP, sleep, and personal attributes. One hundred and twelve participants (73 households) were classified into three groups by the window glazing and the presence or absence of a solar floor heating system in their homes. Group 1 was single glazing and no solar floor heating system. Group 2 was double glazing and no solar floor heating system. Group 3 was double glazing and a solar floor heating system.

Results – The night-time temperature in the bedroom and morning temperature in the living room in Group 3 were higher than those of Groups 1 and 2. After adjusting for personal factors, a 1°C decrease of night-time temperature was significantly associated with a 0.61 mmHg increase of morning systolic blood pressure (SBP) in Group 1, and a 0.92 mmHg increase of morning SBP in Group 2. The temperature in Group 3 did not show a significant association with morning SBP.

Key Findings / Implications – There was no effect on morning BP when the night-time temperature was over 18°C, whereas on mornings below 18°C SBP increased as the temperature decreased.

Originality - The findings of this study may help improve indoor thermal environments to control hypertension and prevent cardiovascular disease, and thus reduce the medical costs associated with cardiovascular disease.

Keywords - Indoor Thermal Environment, Bedroom Temperature, Sleep, Morning Blood Pressure, Field Survey

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1. Introduction

In Japan, cardiovascular disease is a major cause of death, and deaths from cardiovascular disease occur in homes most frequently during the winter. Cardiovascular events occur frequently in the morning (Omama, 2006). The main risk factor for cardiovascular disease is hypertension, and it is estimated that in 2010, 43 million people in Japan—one-third of the population—had hypertension. Therefore, reducing the average blood pressure (BP) of the whole country via a population approach is an urgent priority. In recent years, early morning hypertension has attracted attention. There are two types of early morning hypertension: one where BP rapidly rises early in the morning, and one where BP rises during sleep and persists after waking (Kario, 2010). Morning home BP is a strong predictor of cardiovascular disease, such as coronary artery disease (Kario, 2016; Hoshide, 2016). Indoor temperature shows a stronger association than outdoor temperature with BP in colder months (Saeki, 2014). Therefore, a sufficient temperature needs to be maintained in the morning and also during sleep. However, there have been few studies focusing on night-time temperature and BP. Therefore, in this work, we analyse the association between night-time temperature in the bedroom and BP by multilevel analysis

2. Methods

2.1 Participants

The field study was conducted from November 2014 to March 2015. The study area included Tochigi, Ibaraki, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi, and Nagano prefectures. From among adult residents (men and women aged 35–74 years), 169 participants (100 households) were recruited through a local construction firm. The study was approved by the Keio University Science and Technology Bioethics Board (No. 26-11).t

2.2 Study protocol

The indoor temperatures, home BP, and sleep were measured for 2 weeks by the participants. Questionnaires about housing performance and personal attributes were also conducted. The questionnaire on personal attributes covered individual characteristics, such as age and sex; lifestyle indicators, such as smoking, alcohol consumption, antihypertensive drug use, clothing amount, heating devices, and bedclothes; and health conditions, such as diseases that can cause hypertension. Body mass index (BMI) was measured by using a body composition monitor (HBF-252F, Omron Healthcare Corporation). The questionnaire on housing performance covered aspects of the indoor thermal environment such as window glazing, window frames, and the presence or absence of a solar floor heating system. This system heats the under-floor with air heated by a solar heat-collecting device on the roof.

2.3 Indoor air temperature

The indoor temperatures, home BP, and sleep were measured for 2 weeks by the participants. Questionnaires about housing performance and personal attributes were also conducted. The questionnaire on personal attributes covered individual characteristics, such as age and sex; lifestyle indicators, such as smoking, alcohol consumption, antihypertensive drug use, clothing amount, heating devices, and bedclothes; and health conditions, such as diseases that can cause hypertension. Body mass index (BMI) was measured by using a body composition monitor (HBF-252F, Omron Healthcare Corporation). The questionnaire on housing performance covered aspects of the indoor thermal environment such as window glazing, window frames, and the presence or absence of a solar floor heating system. This system heats the under-floor with air heated by a solar heat-collecting device on the roof.

2.4 Home blood pressure

Home BP monitoring is an easy standardised tool for measuring BP at home. It was measured by participants twice a day, after getting up in the morning (morning BP) and before bedtime at night (evening BP) both in the living room. Participants measured their BP with an upper-arm BP monitor (HEM-7251G or HEM-7252G-HP, Omron Healthcare Corporation), in accordance with the guidelines of the Japanese Society of Hypertension (JSH, 2014). Participants were instructed to take two consecutive measurements on each occasion, and the average of the two values was used for the analysis.

2.5 Sleep

Sleep was measured by participants at home with a non-contact sleep monitor (HSL-102-M, Omron Healthcare Corporation), which determines sleep or wake by detecting body movement with an electric wave sensor. This monitor measures the time in bed, total sleep time (TST), sleep efficiency (SE), sleep onset latency (SOL), and wake after sleep onset (WASO). TST is the sum of all sleep epochs between sleep onset and wake time. SE is the ratio of the TST to time in bed multiplied by 100. SOL is the interval between bedtime and sleep onset (initial sleep epoch). WASO is the sum of all wake epochs between sleep onset and waking time (Hashizaki, 2014).

2.6 Definitions of night-time and morning temperature

We determined night-time and morning temperatures as follows.

1. Night-time temperature: mean temperature in the bedroom during time in bed, which was measured with a sleep monitor
2. Morning temperature: temperature when BP was measured in the morning

2.7 Statistical methods

For continuous variables, mean (standard deviation; SD) was reported. Mean values were compared by using the *t*-test. The proportions of the groups were compared by using the chi-squared test. The magnitude of the associations between night-time temperature and morning systolic blood pressure (SBP) were verified by using a two-level linear regression analysis consisting of day-level variables (temperature and SE) and participant-level variables (age, sex, BMI, smoking, antihypertensive drugs, clothing amount, and bedclothes). Regression coefficients were estimated by restricted maximum likelihood. The applicability of multilevel analysis was verified by the intraclass correlation coefficient (ICC) and the design effect (DE) of the null model. If the ICC was over 0.10 and the DE was over 2.0, the data were considered in its configuration (Shimizu, 2014). To suppress multicollinearity in multilevel models, correlation coefficients between independent variables were assessed. If the correlation coefficient was greater than 0.40, one variable was not introduced into the model. All *p*-values were two-sided, and $p < 0.05$ was considered statistically significant. All statistical analyses were performed by using SPSS 23.0 software

3. Results

3.1 Characteristics of housing and participants

In this study, 169 people aged 35 years or older (100 households) were recruited, and their eligibility was assessed according to the validation criteria. Of the 169 participants, 7 were excluded because of refusal to participate the study, 2 were excluded due to missing questionnaire data, 1 was excluded due to missing temperature data in the bedroom, 11 were excluded due to missing home BP data, and 36 were excluded due to missing sleep data (Figure 1, Table 1).

After exclusion of 57 people, 112 participants (73 households) were classified into three groups by window glazing and the presence or absence of a solar floor heating system in their house. Group 1 was single glazing with no solar floor heating system (36 participants, 22 households). Group 2 was double glazing with no solar floor heating system (40 participants, 26 households). Group 3 was double glazing with a solar floor heating system (36 participants, 25 households). There were no houses with single glazing and a solar floor heating system.

Of the 73 households (mean building age ± SD: 15.2 ± 14.7 years), 65 (89.0%) were detached houses. The building age of Group 1 was significantly higher than that of Group 2 and 3 (31.3 years vs. 11.2 and 5.2 years; $p < 0.001$). There were 21 houses (95.5%) with aluminium window frames in Group 1, 14 houses (53.8%) in Group 2, and 4 houses (16.0%) in Group 3. In contrast, there were no houses (0.0%) with insulated resin frames in Group 1, 6 houses (23.1%) in Group 2, and 13 houses (52.0%) in Group 3 (Table 2).

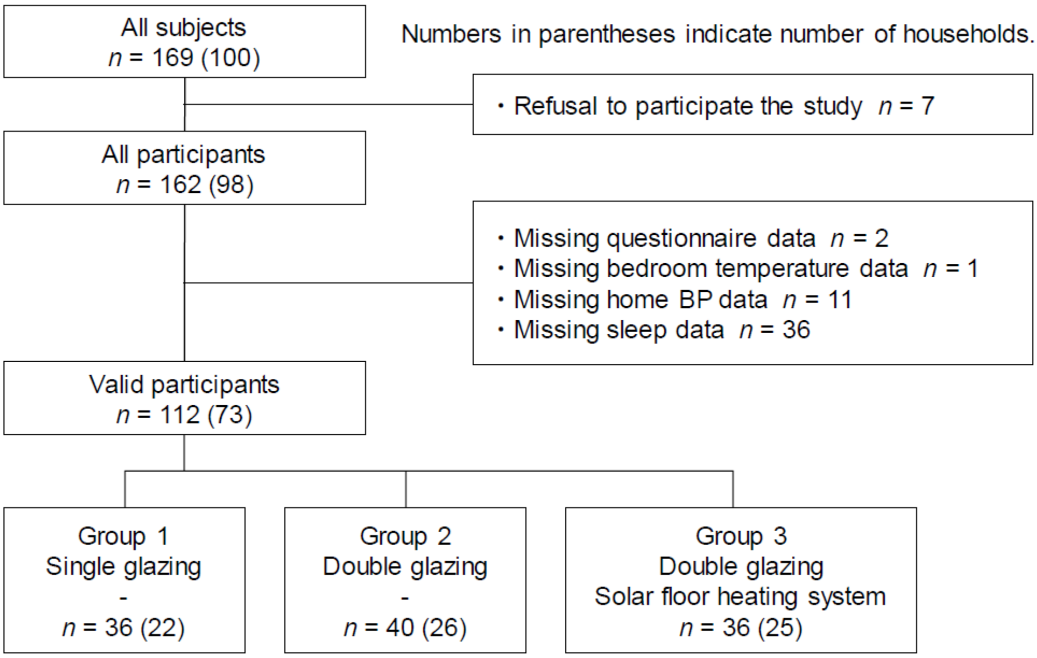

Figure 1 Flow diagram of participants

Table 1: Validation criteria of the measurements

Measurements	Validation criteria
Home BP	Measurement period: over 5 days
Temperature	No data logger error in the bedroom
Sleep	Measurement period: over 5 days which meet the following criteria -Time in bed over 3 h - SE within [$Av._{SE}$ ± 2 × SD_{SE}] [$Av._{SE}$: average SE of all participants] [SD_{SE}: SD of SE of all participants]

Table 2: Characteristics of the 73 houses

Characteristic	Total (*n* = 73)		Group 1 (*n* = 22)		Group 2 (*n* = 26)		Group 3 (*n* = 25)		*p*-value
Structure, *n* (%)									
Detached house	65	(89.0)	17	(77.3)	23	(88.5)	25	(100.0)	0.01
Multi-unit housing	8	(11.0)	5	(22.7)	3	(11.5)	0	(0.0)	
Building age, mean (SD), y	15.2	(14.7)	31.3	(13.5)	11.2	(10.4)	5.2	(3.7)	c, f, h
Window glazing, *n* (%)									
Single	21	(28.8)	21	(95.5)	0	(0.0)	0	(0.0)	<0.001
Double	50	(68.5)	0	(0.0)	26	(100.0)	24	(96.0)	
No answer	2	(2.7)	1	(4.5)	0	(0.0)	1	(4.0)	
Window frames, *n* (%)									
Old wooden	1	(1.4)	1	(4.5)	0	(0.0)	0	(0.0)	
New wooden	3	(4.1)	0	(0.0)	1	(3.8)	2	(8.0)	
Aluminium	39	(53.4)	21	(95.5)	14	(53.8)	4	(16.0)	<0.001
Aluminium (double)	7	(9.6)	0	(0.0)	4	(15.4)	3	(12.0)	
Insulation (resin)	19	(26.0)	0	(0.0)	6	(23.1)	13	(52.0)	
No answer	4	(5.5)	0	(0.0)	1	(3.8)	3	(12.0)	
Solar floor heating system, *n* (%)									<0.001
Present	25	(34.2)	0	(0.0)	0	(0.0)	25	(100.0)	

SD, standard deviation.
c: $p < 0.001$, Group 1 vs Group 2; f: $p < 0.001$, Group 1 vs Group 3;
h: $p < 0.01$, Group 2 vs Group 3 by paired *t*-test.

Of the 112 participants (mean age ± SD: 52.4 ± 10.4 years old), 62 (55.4%) were men. Slightly more participants in Group 1 compared with Groups 2 and 3 reported a current smoker (16.7% vs. 15.0% and 11.1 %; $p = 0.79$), slightly more were taking antihypertensive drugs (8.3% vs. 7.5% and 5.6%; $p = 0.41$), and slightly more reported a history of cardiac disease, cerebrovascular disease, diabetes, hyperlipidaemia, kidney disease, or hypertension (38.9% vs. 25.0% and 19.4%; $p = 0.16$) but the differences were not significant (Table 3). The amount of clothing of Group 2 was significantly more than that of Group 3 (0.69 vs. 0.62 clo; $p < 0.01$). The proportion who did not use a heating device in the bedroom was higher in Group 1 than in Groups 2 and 3 (41.7% vs. 27.5% and 13.9%; $p = 0.03$). Significantly more participants in Group 3 compared with Groups 1 and 2 reported using a bed instead of a futon (83.3% vs. 55.0% and 27.8 %; $p < 0.001$), and few used an electric blanket or hot-water bottle (13.9% vs. 25.0% and 38.9 %; $p = 0.10$) (Table 3).

3.2 Basic staus of participants

There were significant differences among the three groups in night-time and morning temperatures. The night-time temperatures in the bedroom in Group 3 were higher than those in Groups 1 and 2 (18.3°C vs. 11.6 and 13.6°C; p < 0.001 and p < 0.01). The morning temperature in the living room in Group 3 was also higher than those of Groups 1 and 2 (18.2°C vs. 14.8 and 17.1°C; p < 0.001 and p < 0.05).

The baseline survey of home BP and sleep showed similar results among the three groups for morning SBP (120.0 vs. 122.2 vs. 121.2 mmHg; not significant (n.s.), DBP (78.6 vs. 79.5 vs. 80.3 mmHg; n.s.), time in bed (399.7 vs. 420.6 vs. 406.4 min; n.s.), TST (359.4 vs. 385.5 vs. 372.0 min; n.s.), SE (90.4 vs. 92.4 vs. 92.2 %; n.s.), SOL (5.6 vs. 5.0 vs. 4.6 min; n.s.), and WASO (20.6 vs. 17.1 vs. 15.7 min; n.s.) (Table 4).

Table 3: Baseline characteristics of the 112 participants

Characteristic	Total (*n* = 112)		Group 1 (*n* = 36)		Group 2 (*n* = 40)		Group 3 (*n* = 36)		*p*-value
Age, mean (SD), y	52.4	(10.4)	52.5	(9.9)	51.5	(10.2)	53.2	(11.2)	n.s.
Male, *n* (%)	62	(55.4)	19	(52.8)	21	(52.5)	22	(61.1)	0.70
BMI, mean (SD), kg/m^2	22.9	(3.5)	22.8	(3.8)	22.7	(2.7)	23.4	(3.9)	n.s.
Current smoker, *n* (%)	16	(14.3)	6	(16.7)	6	(15.0)	4	(11.1)	0.79
Daily alcohol intake, *n* (%)	28	(25.0)	9	(25.0)	8	(20.0)	11	(30.6)	0.65
Antihypertensive drugs, *n* (%)	8	(7.1)	3	(8.3)	3	(7.5)	2	(5.6)	0.41
Disease history, *n* (%)	31	(27.7)	14	(38.9)	10	(25.0)	7	(19.4)	0.16
Clothing amount, mean (SD), clo									
Daytime	0.65	(0.14)	0.65	(0.17)	0.69	(0.11)	0.62	(0.12)	h
Night-time	0.69	(0.12)	0.69	(0.13)	0.70	(0.11)	0.69	(0.12)	n.s.
Heating device in bedroom, *n* (%)									
Air conditioner	34	(30.4)	8	(22.2)	16	(40.0)	10	(27.8)	0.22
Fan heater	7	(6.3)	3	(8.3)	4	(10.0)	0	(0.0)	0.11
Heater	24	(21.4)	9	(25.0)	11	(27.5)	4	(11.1)	0.18
Kotatsu (heated table)	3	(2.7)	2	(5.6)	1	(2.5)	0	(0.0)	0.14
Electric heating carpet	2	(1.8)	2	(5.6)	0	(0.0)	0	(0.0)	0.10
Floor heating system	28	(25.0)	0	(0.0)	0	(0.0)	28	(77.8)	<0.001
Nothing	31	(27.7)	15	(41.7)	11	(27.5)	5	(13.9)	0.03
Bedclothes, *n* (%)									
Bed	62	(55.4)	10	(27.8)	22	(55.0)	30	(83.3)	<0.001
Futon	50	(44.6)	26	(72.2)	18	(45.0)	6	(16.7)	
Additional bedclothes, *n* (%)									
Down quilt	77	(68.8)	18	(50.0)	31	(77.5)	28	(77.8)	0.01
Electric blanket/hot-water bottle	27	(24.1)	14	(38.9)	10	(25.0)	3	(13.9)	0.10

BMI, body mass index; SD, standard deviation.
'Heater' includes kerosene, gas, electric, far-infrared, and oil heaters, and wood stoves.
h: $p < 0.01$, Group 2 vs Group 3 by paired *t*-test.

3.3 Relationship between night-time temperature and morning systolic blood pressure

Figure 2 shows the results of the relationship between night-time temperature and morning SBP for Groups 1 to 3, with each point showing the temperature and SBP data for one day for one participant. The solid line shows the linear regression line of each participant. The ranges of night-time temper- ature were slightly different among the groups. Group 1 had many points at 5–10°C (range: 4.0–21.0°C), Group 2 had many points at 10–15°C (range: 3.0–21.5°C), Group 1 had many points at 15–20°C (range: 10.3–27.3°C). For SBP, Group 2 had some points over 155 mmHg. For each regression line, 71 (63%) participants showed a negative slope, indicating that an increase in SBP was associated with a decrease in temperature.

Table 4: Baseline status of 112 participants

Characteristic	Total (n = 112)		Group 1 (n = 36)		Group 2 (n = 40)		Group 3 (n = 36)		p-value
Temperature (°C)									
Night-time, mean (SD)									
Bedroom	14.5	(4.2)	11.6	(3.5)	13.6	(3.3)	18.3	(2.8)	a, f, i
Morning, mean (SD)									
Living room	16.7	(3.6)	14.8	(3.8)	17.1	(3.7)	18.2	(2.2)	a, f, g
Bedroom	13.8	(4.2)	10.8	(3.6)	13.1	(3.3)	17.5	(2.7)	b, f, i
Toilet	13.1	(4.3)	9.8	(2.6)	12.2	(3.7)	17.5	(2.0)	b, f, i
Morning home BP (mmHg)									
SBP, mean (SD)	121.2	(14.7)	120.0	(13.9)	122.2	(17.4)	121.2	(12.4)	n,s,
DBP, mean (SD)	79.4	(10.6)	78.6	(10.0)	79.5	(12.1)	80.3	(9.7)	n.s.
Sleep									
Time in bed, mean (SD), min.	409.3	(64.8)	399.7	(64.4)	420.6	(64.4)	406.4	(65.6)	n.s.
TST, mean (SD), min.	372.8	(65.3)	359.4	(63.4)	385.5	(63.9)	372.0	(67.8)	n.s.
SE, mean (SD), %	91.7	(6.1)	90.4	(6.7)	92.4	(6.2)	92.2	(5.3)	n.s.
SOL, mean (SD), min.	5.1	(3.4)	5.6	(3.5)	5.0	(3.4)	4.6	(3.1)	n.s.
WASO, mean (SD), min.	17.8	(20.3)	20.6	(25.0)	17.1	(20.9)	15.7	(13.5)	n.s.

SBP, systolic blood pressure; DBP, diastolic blood pressure; TST, total sleep time; SE, sleep effi- ciency; SOL, sleep onset latency; WASO, wake after sleep onset;
SD, standard deviation.
a: $p < 0.05$, b: $p < 0.01$, Group 1 vs Group 2; f: $p < 0.001$, Group 1 vs Group 3; g: $p < 0.05$, i: $p < 0.001$, Group 2 vs Group 3 by paired t-test

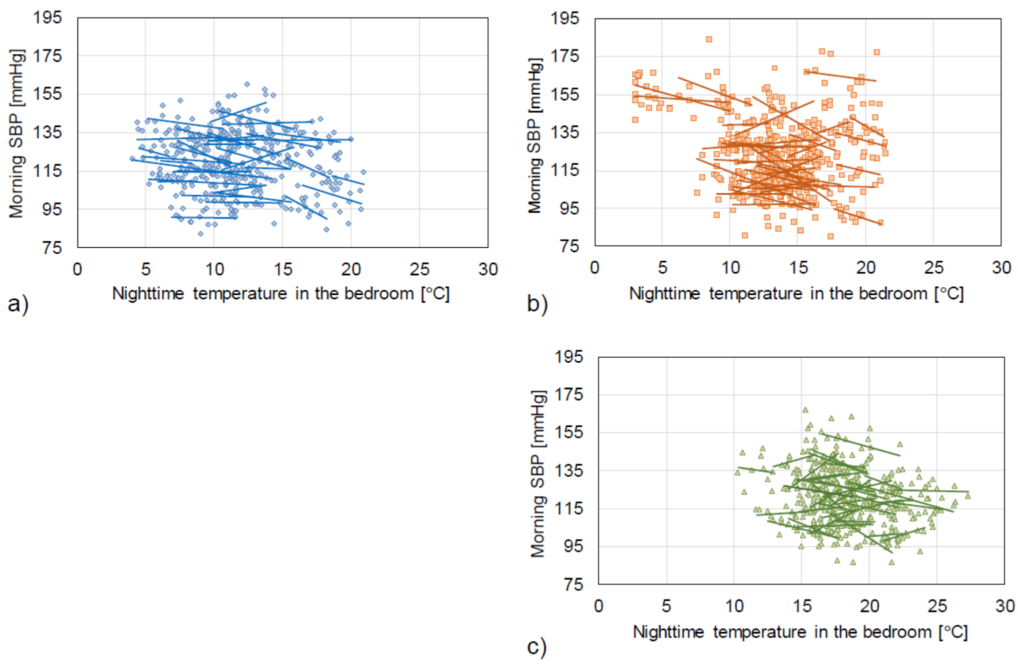

Figure 2 Relationship between night-time temperature and morning SBP for a) Group 1, b) Group 2, and c) Group 3.

3.4 Effect of night-time temperature on morning systolic blood pressure: multilevel analysis

Multilevel linear regression analysis was performed to clarify the association of night-time temperature with morning SBP adjusted for personal attributes (Table 5). The analysis was performed within each group because there were strong correlations between sex and daily alcohol intake, antihypertensive and disease history (correlation coefficient = 0.49, 0.45), daily alcohol intake and disease history were not used in the model, in order to suppress multicollinearity. Because the ICC of the three groups were over 0.10 and the DE of three groups were over 2.0, there was a hierarchical data structure and multilevel analysis was suitable for these data.

A 1°C decrease in night-time temperature was significantly associated with a 0.61 mmHg increase in morning SBP in Group 1, and a 0.92 mmHg increase of morning SBP in Group 2 independent of age, sex, BMI, current smoking, antihypertensive drugs, night-time clothing amount, bedclothes, and additional bedclothes. In contrast, night-time temperature in Group 3 and SE in all groups did not show a significant association with morning SBP.

Table 5: Multilevel analysis of the relationship between night-time temperature and morning SBP

Explanatory variables	Adjusted β (95% CI)	*p*-value	AIC	ICC	DE	*n*
Model 1 [Group 1]						
Night-time temperature	-0.61 (-1.06, -0.16)	<0.01	2694	0.19	2.92	36 s × days = 391
SE	-0.08 (-0.10, 0.27)	0.38				
Model 2 [Group 2]						
Night-time temperature	-0.92 (-1.55, -0.29)	<0.01	3399	0.18	2.92	40 s × days = 472
SE	-0.02 (-0.27, 0.22)	0.82				
Model 3 [Group 3]						
Night-time temperature	-0.45 (-1.23, 0.32)	0.23	3110	0.30	4.30	36 s × days = 437
SE	-0.11 (-0.42, 0.20)	0.45				

95% CI, 95% confidence interval; AIC, Akaike's information criterion; ICC, intraclass correlation coefficient; DE, design effect; SE, sleep efficiency.
Adjusted for age, sex, BMI, current smoking, antihypertensive drugs, night-time clothing amount, bedclothes, and additional bedclothes.
Adjusted β expresses the change of morning SBP per 1°C increase in night-time temperature or 1% increase in SE.

4. Discussion

Our data from 112 participants (73 households) were classified into three groups by window glazing and the presence or absence of a solar floor heating system in their houses (Figure 1). The housing for Group 1 was assumed to meet thermal insulation performance equivalent to the 1980 standards in Japan, because the housing had aluminium window frames and the buildings were older. The housing for Groups 2 and 3 were assumed to meet thermal insulation performance equivalent to the 1999 standards in Japan because the housing had double aluminium or insulated window frames and the buildings were newer (Takayanagi, 2011). Thus, Group 1 had low thermal insulation performance, and Groups 2 and 3 had high thermal insulation performance. The night-time and morning temperatures in Group 3 were significantly higher than those in Groups 1 and 2. The night-time temperature of Group 3 was over 18°C, as recommend in the Cold Weather Plan for England 2015 as follows: "Heating homes to at least 18 °C (65 °F) in winter poses minimal risk to the health of a sedentary person, wearing suitable clothing." (PHE, 2015). Because the temperature in Group 2 was not oever 18°C, it was necessary to increase the thermal insulation performance and use a suitable heating device to keep warm.

The night-time temperatures of Groups 1 and 2 showed significant associations with morning SBP (Group 1: adjusted *β*, -0.61; $p < 0.01$. Group 2: adjusted *β*, -0.92; $p < 0.01$) in the multilevel linear regression model adjusting for potential confounders, in contrast to the night-time temperature of Group 3, which did not show a significant association (adjusted *β*, -0.45; $p = 0.23$). This suggests that night-time temperatures over 18°C have no effect on morning SBP, whereas for night-time temperatures under 18°C, morning SBP increases with a decrease in temperature. Previous work has shown a 1 mmHg increase in the morning surge that is associated with a 3.3% increase (95% confidence interval, 0.8–5.8%) in the risk of cardiovascular events (Gosse, 2004). Therefore, our findings suggest that improving the indoor thermal environment should help prevent cardiovascular disease and moving to a well-insulated house may decrease the prevalence of hypertension (Ikaga, 2011)

The present study had sample selection bias; the number of elderly people who had high SBP was low, and thus the number of people taking antihypertensive drugs was also low. Therefore, the small numbers of these individuals became a factor in non-significant explanatory variables in the multi-level models. To confirm our results, it is necessary to increase the number of participants from a variety of age groups and with various characteristics.

Because this study is a cross-sectional study, it is possible to estimate only the effect of improved home environment on home BP. To confirm any actual effects implied by the data, it is necessary to perform prospective studies with the participants, such as observations of participant's BP after moving from a house with low thermal insulation to one with high thermal insulation.

5. Conclusion

This study analysed the relationship between night-time temperature and morning BP based on field surveys from November 2014 to March 2015. The following findings were obtained.

1) The night-time temperatures in the bedroom in Group 3 were higher than those in Groups 1 and 2 (18.3°C vs. 11.6 and 13.6°C; $p < 0.001$ and $p < 0.01$). The morning temperatures in the living room in Group 3 were also higher than those in Groups 1 and 2 (18.2°C vs. 14.8 and 17.1°C; $p < 0.001$ and $p < 0.05$).

2) After adjusting for personal factors, a 1°C decrease in night-time temperature was significantly associated with a 0.61 mmHg increase in morning SBP in Group 1, and a 0.92 mmHg increase in morning SBP in Group 2. The temperature in Group 3 did not show a significant association with morning SBP

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