Science and Technology for the Built Environment, (2022) **28**, 843–863

ISSN: 2374-4731 print / 2374-474X online
DOI: 10.1080/23744731.2022.2091859

Indoor thermal environment during heating season and the health of elderly in China

BAI SONG[1], HIROSHI YOSHINO[2*], TOMONOBU GOTO[3], HUIBO ZHANG[4], JUN GUAN[5], KENICHI HASEGAWA[6], NAOKI KAGI[7], NIANPING LI[8], ZHENHAI LI[9], JING LIU[10], YANG LV[11], JINGCHAO XIE[12], U. YANAGI[13], and QINGYUAN ZHANG[14]

[1]*Technology Department, Daikin (China) Investment Co., Ltd, North China General Term Dept, Beijing, China*
[2]*Tohoku University, Sendai, Japan*
[3]*Department of Architecture and Building Science, Graduate School of Engineering, Tohoku University, Sendai, Japan*
[4]*School of Design, Shanghai Jiao Tong University, Shanghai, China*
[5]*School of Energy and Power Engineering, Nanjing University of Science and Technology, Nanjing, China*
[6]*Department of Architecture and Environment Systems, Akita Prefectural University, Akita, Japan*
[7]*School of Environment and Society, Tokyo Institute of Technology, Tokyo, Japan*
[8]*College of Civil Engineering, Hunan University, Changsha, China*
[9]*School of Mechanical Engineering, Tongji University, Shanghai, China*
[10]*School of Architecture, Harbin Institute of Technology, Harbin, China*
[11]*School of Civil Engineering, Dalian University of Technology, Dalian, China*
[12]*Beijing Key Laboratory of Green Built Environment and Energy Efficient Technology, Beijing University of Technology, Beijing, China*
[13]*School of Architecture, Kogakuin University, Tokyo, Japan*
[14]*Faculty of Urban Innovation, Graduate School, Yokohama National University, Yokohama, Japan*

In this study, questionnaire surveys and field measurements were conducted at houses with elderly people in urban and rural areas across six regions of China. The prevalence of hypertension was approximately 40% in both urban and rural areas. The logistic analysis results indicated a greater prevalence of hypertension in the elderly of rural residences and a low indoor temperature-induced hypertension. According to the field measurement survey, the room temperature was stable at around 23 °C in the housing in northern urban areas equipped with district heating systems, and fluctuated from being equivalent to outdoor temperature to around 15 °C in the southern regions where air-conditioners were used. For housing in the northern rural areas where Chinese Kangs were used, the daily fluctuation in room temperature was significant, and room temperature was stable at a low level in the southern part without space heating. The room temperature and blood pressure were negatively correlated. Therefore, to maintain the health of the elderly in houses with low room temperatures in winter, it is necessary to improve the thermal environment by enhancing the thermal performance of the building and the heating equipment.

Introduction

According to Chinese statistics (National Bureau of Statistics of China 2019), the proportion of the population over 65 years of age reached 11.9% by 2018 and continues to grow owing to recent economic development. In addition, WHO health statistics on non-communicable diseases (2016) reported that almost half of the elderly die from cardiovascular and cerebrovascular diseases. According to a report on cardiovascular diseases (CVD) in China by the National Center of Cardiovascular Diseases (2019), CVD is continuously increasing. Approximately 290 million people suffer from CVD, accounting for approximately 20% of the total population. Hypertension is one of the most frequently reported causes of cardiovascular disease (CVD). It is necessary to improve lifestyle habits to prevent hypertension. In recent years, it has become clear that lower room temperature leads to increased blood pressure. A WHO report (2018) indicated that cold indoor temperatures have been associated with increased blood pressure, asthma symptoms, and poor mental health. Thus, maintaining temperatures

Received June 15, 2021; accepted June 9, 2022
Bai Song, ME, Hiroshi Yoshino, Fellow ASHRAE, PhD, Prof. Emeritus, Tomonobu Goto, PhD, Assoc. Prof., Huibo Zhang, PhD, Assoc. Prof., Jun Guan, PhD, Assoc. Prof., Kenichi Hasegawa, PhD, Prof., Naoki Kagi, PhD, Prof., Niaping Li, PhD, Prof., Zenhai Li, PhD, Prof., Jing Liu, PhD, Prof., Yang Lv, PhD, Assoc. Prof., Jingchao Xie, PhD, Prof., U Yanagi, PhD, Prof., Qingyuan Zhang, PhD. Prof.
*Corresponding author e-mail: yoshino@sabine.pln.archi.tohoku.ac.jp

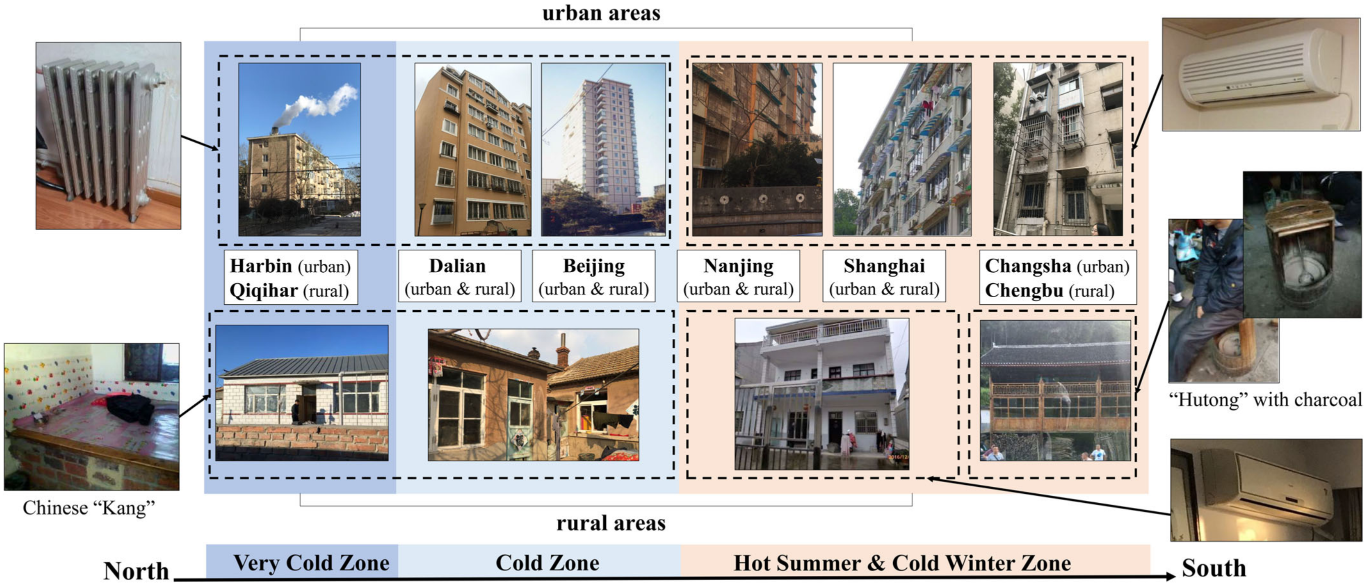


Fig. 1. Photoes of examples of buildings and equipment corresponding to investigated areas.
Note: The building style is multi-family in urban areas and detached in rural areas. As for the heating equipment, district heating with radiators is used in Harbin and in the urban areas of Beijing and Dalian. The Chinese Kang is used in Qiqihar and in the rural areas of Beijing and Dalian. Air conditioners are mainly used in Changsha and the urban areas of Nanjing and Shanghai. A heater called Huotong was used in Chengbu.

above 18 °C is crucial to prevent bodily damage caused by low indoor temperatures. In addition, based on previous research reviews, Public Health England (2014) recommends maintaining a room temperature of 18 °C or higher in winter during the day and at bedtime to maintain health.

In 1982, Hasegawa et al. (1985) studied the relationship between the indoor temperature of a house and stroke in Yamagata Prefecture, Japan. It was reported for the first time that lower indoor temperatures, specifically those of unheated bedrooms and lavatories, can affect the occurrence of stroke. Saeki et al. (2014) surveyed 868 elderly Japanese individuals and showed that a drop in indoor temperature significantly increased blood pressure. Umishio et al. (2019) investigated 3,514 elderly individuals in Japan. The survey results showed that higher systolic blood pressure (SBP) in the morning appeared more frequently in elderly men who lived at lower indoor temperatures. Moreover, Shiue and Shiue (2014) performed a large-scale (number of the sample: 17,253) study in Scotland and reported that indoor temperatures above 18 °C can contribute to the prevention of high blood pressure. Based on the results of an experiment with the elderly and young subjects, Collins et al. (1985) proposed that an exposure temperature of 15 °C or higher should be maintained to suppress an increase in blood pressure in the elderly.

Yoshino et al. (2004, 2006), Li et al. (2018), and Zhang and Yoshino (2010) investigated the thermal environments of Chinese residences. However, only a few studies have focused on the relationship between the thermal environment of residences and diseases among the occupants.

In this study, a questionnaire survey of the elderly (aged over 60 years old) residences was conducted during winter in different regions of China to explore the relationship between the health of the elderly and indoor environment, building conditions, space heating equipment, and lifestyle, considering the climate conditions and differences in urban or rural areas. Simultaneously, field measurements were conducted to clarify the association between indoor temperature and blood pressure in the elderly. We focused on defining the relationship between the indoor thermal environment and the health status of occupants, along with the differences in this relationship between northern and southern China and between urban and rural areas. Many indoor environmental factors, including indoor temperature, humidity, volatile organic compounds, particulate matter, molds, and mites, influence human health. This study did not target these factors comprehensively and concentrated on the relationship between cardiovascular diseases (CVDs) and indoor thermal environments. However, CO_2, CO, NOx, VOCs, SVOCs, fungi, and mites were measured in this study. Fan et al. (2018) reported the measurement results of these factors for residential buildings in urban and rural areas in Beijing.

Methodology

In this study, questionnaire surveys and field measurements were conducted on houses with elderly persons in urban and rural areas in six regions of China during the 2016–2017 and 2017–2018 heating periods. Figure 1 shows photos of typical building types and heating equipment in the investigated areas.

The purpose of the questionnaire was to understand the entire situation, including the health conditions, while that of the field measurement was to obtain detailed information on the indoor thermal environment, including its changes with time. We attempted to clarify the relationship between the

Table 1. Numbers of subjective houses for the questionnaire surveys.

Climate zone	Subject city		Survey period	Distributing number: Individual section /	Distributing number: Housing section	Number of respondents: Individual section /	Number of respondents: Housing section	Number of houses for temperature measurement
Severe cold zone	Harbin	Urban area	1/2017	87	50	87	50	45
	Qiqihar	Rural area		84	50	84	50	32
Cold zone	Dalian	Urban area	11/2017-1/2018	50	50	50	50	37
		Rural area		50	50	50	50	46
	Beijing	Urban area	2/2017	50	50	48	50	47
		Rural area		50	50	50	50	45
Hot-summer and Cold-winter zone	Nanjing	Urban area	12/2017-1/2018	51	51	51	51	24
		Rural area		63	63	63	63	5
	Shanghai	Urban area	12/2016-1/2017	46	46	46	46	46
		Rural area		113	60	113	60	60
	Changsha	Urban area	1/2018	55	55	49	55	51
	Chengbu	Rural area		50	50	46	46	46
Sub total		Urban area		339	302	331	302	250
		Rural area		410	323	406	319	234
Total				749	625	737	621	484

Note: Harbin and Qiqihar belong to Heilongjiang Province. Changsha and Chengbu belong to Hunan Province.

thermal environment and health through both surveys complementing each other. Tables 1 and 2 list the number of subjective houses. Target regions were selected from three climatic zones.

One of them is a severely cold zone, from which Harbin and Qiqihar in Heilongjiang Province were selected as the urban and rural areas, respectively. The second climate zone is the cold zone, from which Dalian and Beijing were selected. The third is the hot summer and cold winter zone, from which Nanjing and Shanghai were selected. From this zone, Changsha and Chengbu in Hunan Province were also selected as the urban and rural areas, respectively. In rural areas, all dwellings were detached houses (in Chengbu, a traditional wooden stilted building). In urban areas, all dwellings are typical multi-family apartment houses. It was necessary to randomly select survey participants; however, we searched for target persons who agreed to participate in the investigation through collaborators, colleagues, relatives of students who participated in the survey, and their acquaintances. We confirmed those willing to cooperate in the detailed survey and selected five to ten houses from among them considering factors such as sex, age, and health condition.

Questionnaires were administered to persons with at least 50 households in each urban and rural area. The questionnaire consisted of sections for individuals and housing. The individual section was used to fully understand the health status of the elderly, which included (1) general information, (2) dietary habits and health conditions diagnosed by a doctor, (3) thermal comfort levels of the elderly using the 7-point ASHARE scale of thermal sensation vote (TSV) following Chen et al. (2019), and (4) indoor temperatures after waking up in the morning and after dinner in the evening during the week, which were measured using liquid crystal thermometers. Yoshino et al. (2004, 2006) reported that the room temperature is stable throughout the day in houses with continuous heating. In houses with intermittent heating, the room temperature is relatively stable at night, including during supper times. In houses without heating, the room temperature was stable during the night. Therefore, we chose nighttime to measure the indoor temperature. The lowest temperature in the room was recorded in the morning soon after waking up, and as stated by Umishio et al. (2019), this is when the occupants' blood pressure is the highest. Thus, we chose the time after waking up for the measurement.

The elderly spends a lot of time either in the living room or in the bedroom. Therefore, we asked the participants to record their temperature in both rooms. Additionally, measurements were also recorded in the toilet, where the temperature was assumed to be the lowest, to determine the temperature distribution between rooms. In rural housing in Qiqihar, the living room and bedroom were integrated; thus, thermometers were installed in the bedroom and kitchen.

The housing section was used to investigate the residential environment of the elderly in detail, which included dwelling type, floor area, building completion time, thermal insulation installation, window type, heating system, and heating duration. The recovery ratios of the individual and housing sections were 98.4% and 99.4%, respectively. A total of 331 valid individual questionnaires (154 men and 177 women) from 302 households were collected in urban areas, and 406 valid individual questionnaires (199 males and 207 females) from 319 households were collected in rural areas. Most of the respondents were over 60 years old, but 19 respondents were under 60 years old. For the field measurements, at least five households were selected from the questionnaire-surveyed households. Table 3 shows the contents of the questionnaire surveys and field measurements. The latter included blood pressure measurements for the elderly in the morning and evening during the week and continuous monitoring of temperature and relative humidity indoors and outdoors for the same week.

Table 2. Numbers of subjective houses for field measurements.

Climate zone	Subject city		Survey period	Number of houses for temperature measurement	Number of occupants for blood pressure measurement	
					Male	Female
Severe cold zone	Harbin	Urban area	1/16-1/22. 2017	5	2	3
	Qiqihar	Rural area	1/13-1/21. 2017	12	10	9
Cold zone	Dalian	Urban area	11/27-12/3. 2017	5	4	4
		Rural area	12/6-12/14. 2017	5	3	5
	Beijing	Urban area	2/16-2/24. 2017	5	3	2
		Rural area	2/18-2/26. 2017	5	3	2
Hot-summer and Cold-winter zone	Nanjing	Urban area	12/26. 2017-1/2. 2018	4	3	3
		Rural area	12/17-12/25. 2017	5	4	4
	Shanghai	Urban area	12/29. 2016-1/4. 2017	4	3	2
		Rural area	12/29. 2016-1/4. 2017	5	5	4
	Changsha	Urban area	1/7-1/17. 2018	5	4	2
	Chengbu	Rural area	1/8-1/17. 2018	5	4	1
Sub total		Urban area		28	19	16
		Rural area		37	29	25
Total				65	48	41

Note: Harbin and Qiqihar belong to Heilongjiang Province. Changsha and Chengbu belong to Hunan Province.

For the room temperature measurement using liquid crystal thermometers, three thermal insulation boards that were 10 cm in length, 15 cm in width, and 5 mm in thickness, each with a liquid crystal thermometer, were attached to the walls or set on tables approximately 1 m above the floor in the living room, bedroom, and toilet. We selected placement locations that were not affected by heat, such as sunlight or air conditioners. The temperature was displayed in increments of 2 °C. Two adjacent values emitting light simultaneously indicated that the temperature was between the two. The accuracy is ±1 °C. The response time was 1 second.

For the continuous measurement of temperature and humidity in the detailed investigation, a thermo-hygrometer with a data logger (TR-76Ui, T&D Corporation, Japan) was used. The measurement accuracy was ±0.5 °C for temperature and ±5% for relative humidity. The valid ranges were 0–55 °C for temperature and 10%–95% for relative humidity. Temperature and humidity sensors were installed in the living room, bedroom, and toilet, approximately 1 m above the floor near the internal wall, in an area not affected by heat, such as sunlight and air conditioners.

The blood pressure (systolic blood pressure (SBD) and diastolic blood pressure (DBP)) of the elderly was measured using a UA-767PC sphygmomanometer (A&D Medical Corp., Japan) within one hour of waking up and before sleeping, and the data were continuously recorded for one week. The measurement was performed twice each time, and the average value was used for the analysis. The accuracy of the sphygmomanometer was ± 3 mmHg and the valid range was 0–280 mmHg.

Results of questionnaire surveys

Results of individual characteristics

Figure 2a presents the statistical data of the questionnaire survey conducted in both urban and rural areas. Elderly participants were mainly aged between 70 and 90 years. There is no significant difference in age between urban and rural areas; however, the age is slightly lower in Heilongjiang, Shanghai, and Hunan. The most significant body mass index (BMI) ranged from 18.5 to 25; the average BMI for urban and rural areas was 23.6 ± 3.5 and 23.0 ± 5.5, respectively. Thus, there is little difference in the individual characteristics between urban and rural areas.

Figure 2b shows the health conditions of the elderly. Hypertension is the most common disease in urban and rural areas. The prevalence of hypertension is relatively high (nearly 50%) in the urban areas of Beijing, Nanjing, and Shanghai, and in the rural areas of Dalian, Beijing, Nanjing, and Shanghai. No differences were found in the prevalence between urban and rural areas or between the northern and southern areas. The number of elderly individuals who were not diagnosed with diseases was listed as "No disease," and their number was higher in the rural areas than in the urban areas. However, there was little difference between the urban and rural areas in both Beijing and Shanghai. In urban areas of Dalian, the number of people who did not suffer from diseases was higher than that in rural areas. In rural areas, diabetes tends to occur more frequently than other diseases, except for hypertension. This indicates that hypertension and diabetes are

Table 3. Contents of the survey.

		Contents	Descriptions
Phase 1	Individual section	General information	Gender, Age, Weight, Height, Household income
		Health condition	Medical history, Family history of hypertension
		Living habit	Duration of staying outside, Smoking, Alcohol, Shower (frequency, duration), Taste preference, Pickles, Deep fried food
		Thermal sensation	Thermal comfort of living room, bedroom and toilet, respectively (after waking up, after dinner and before sleeping)
		Indoor temperature[a]	Indoor temperature of living room, bedroom and toilet (or room without heating equipment) in the morning and after dinner during a week
	Housing section	Building characteristics	Dwelling type, Floor area, Completion time, Thermal insulation material, Window (type)
		Space heating	Heating system, Heating period and duration
Phase 2	Field measurement		Continuously monitoring temperature[b] and relative humidity[b] indoors and outdoors for a week
			Blood pressure[c] of elderly occupants in the morning and after dinner of the same week

[a]Measured using liquid crystal thermometer.
[b]Measured using TR-76Ui T&D.
[c]Measured using electronic sphygmomanometer.

common diseases among the elderly people in rural areas. In urban areas, arrhythmia, high cholesterol, and diabetes are more prevalent than other diseases, except for hypertension. This indicates that hypertension, high cholesterol, and diabetes are common diseases in the elderly.

Figure 2c shows the living habits of elderly individuals. Although the duration spent outside is different in different regions and exceeds one hour in both urban and rural areas, the elderly spent a longer time in their homes. Regarding the frequency of showers, in urban areas, more than half of the elderly take them once a week, except for the elderly in Heilongjiang (Harbin). In rural areas, most of the elderly in Dalian and more than half of those in Heilongjiang (Qiqihar) and Nanjing do not bathe at home. It is presumed that they sometimes go into public baths. Regarding eating habits, light and neutral tastes were prominent in all the areas. Pickles consumption is common among the elderly. Nearly half of the respondents had the habit of eating pickles. However, in the rural areas of Heilongjiang (Qiqihar), half the participants consumed pickles only twice a day. Most respondents were against deep-fried food. There was no significant difference in eating habits between urban and rural areas or between the northern and southern areas. Other habits such as smoking and drinking, which are not shown in this figure, were also surveyed. The survey indicated that 74.1% of the respondents did not smoke. Most respondents did not have drinking habits, and the difference between urban and rural areas was negligible. The Clo-value is generally higher in the southern region than in the northern region, and higher in rural areas than in urban areas.

Figure 3 shows the results of the questionnaire regarding housing situations. The building completion time of “5 to 10 years ago” in urban areas was the largest in Hunan (Changsha). The completion time of “more than 10 years ago” was the largest for the other five urban areas. In all rural areas, “more than 20 years ago” of completion time was the largest. The samples were scattered across the floor area. However, the

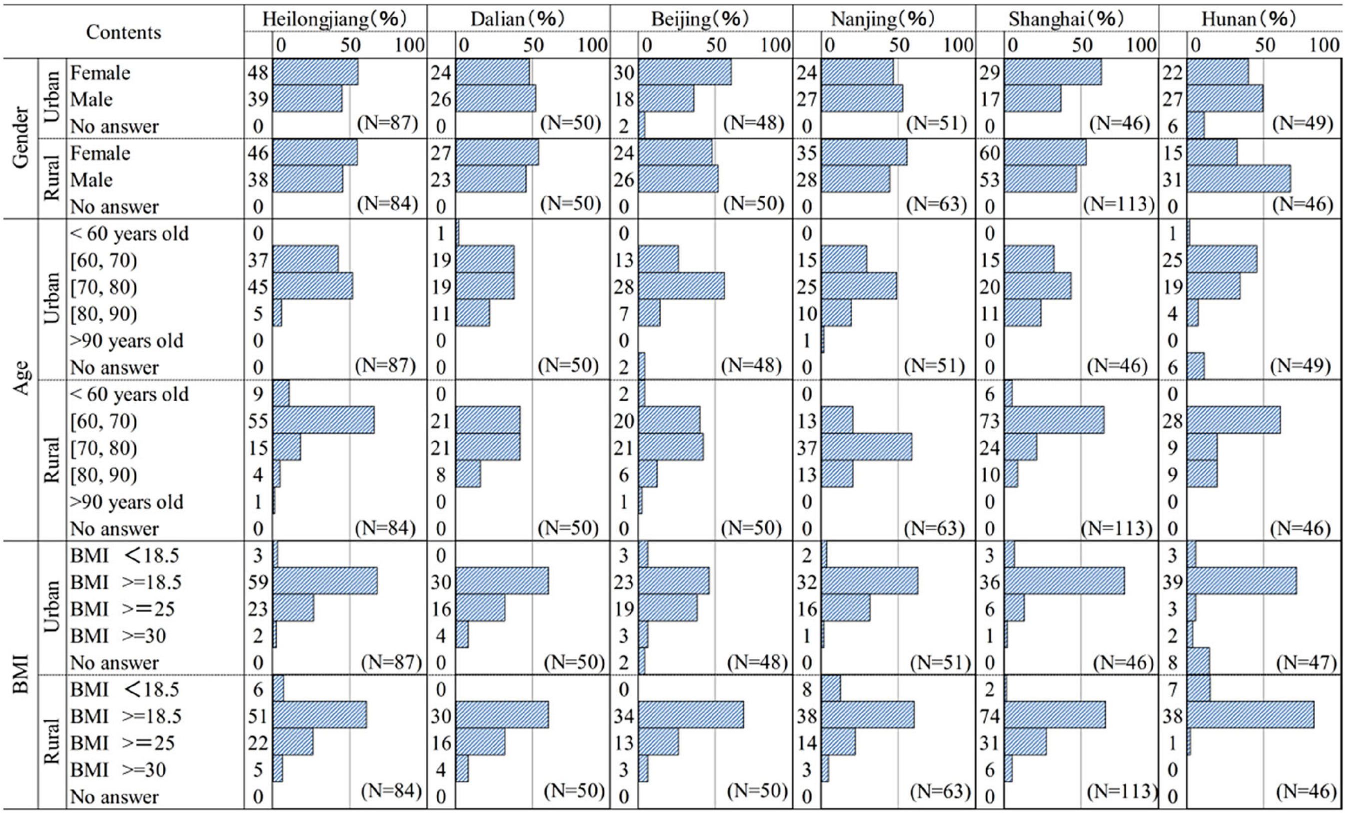


Fig. 2. (a) Results of survey questionnaires in urban and rural areas (Individual section-general information).
Note: Urban and rural areas of Heilongjiang Province are Harbin and Qiqihar, respectively, those of Hunan Province are Changsha and Chengbu, respectively.

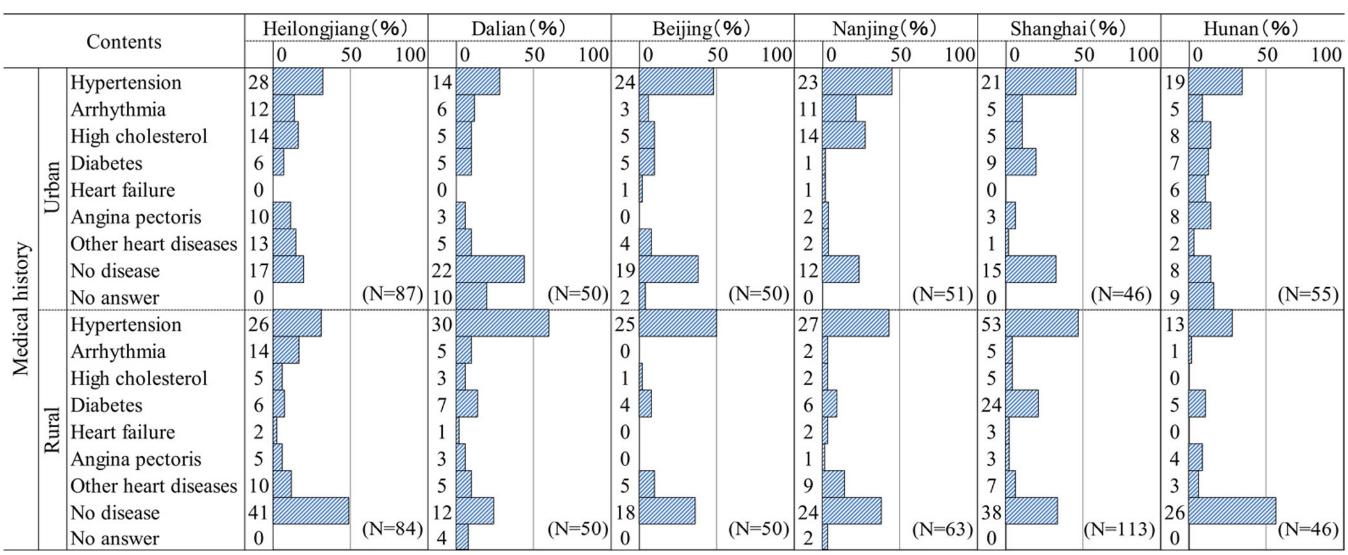


Fig. 2. (b) Results of survey questionnaires in urban and rural areas (Individual section-health condition).
Note: "No diseases" denotes the elderly who did not contract any diseases listed in the figure. Urban and rural areas of Heilongjiang Province are Harbin and Qiqihar, respectively. Those of Hunan Province are Changsha and Chengbu, respectively.

dwellings have larger areas in the urban areas of Hunan (Changsha) and Nanjing and rural areas of Shanghai and Hunan (Chengbu). In these rural areas, more than 50% of the dwellings have an area of 100–150 m^2.

Regarding the thermal performance of the building envelope, the number of houses equipped with thermal insulation in urban areas was more significant than that in rural areas. Most dwellings in urban areas, which are apartments, have double-

Contents			Heilongjiang (%)	Dalian (%)	Beijing (%)	Nanjing (%)	Shanghai (%)	Hunan (%)
Duration in outside	Urban	Rarely go outside	2	6	1	3	1	5
		1 h	23	11	15	12	21	19
		Half day	51	21	18	10	15	20
		Whole day	10	5	3	5	5	5
		Others	1	0	11	21	4	0
		No answer	0	7	2	0	0	6
			(N=87)	(N=43)	(N=48)	(N=51)	(N=46)	(N=49)
	Rural	Rarely go outside	10	0	2	27	12	11
		1 h	18	9	21	9	44	8
		Half day	28	11	14	3	35	9
		Whole day	28	30	4	10	19	18
		Others	0	0	9	13	3	0
		No answer	0	0	0	1	0	0
			(N=84)	(N=50)	(N=50)	(N=62)	(N=113)	(N=46)
Frequency of shower	Urban	More than twice a day	0	0	0	1	0	0
		Once a day	5	1	3	3	7	1
		Once two days	3	0	6	11	11	11
		Once a week	30	23	30	27	25	35
		Once about ten days	31	5	4	1	1	1
		Do not shower at home	18	21	1	3	1	0
		No answer	0	0	6	5	1	7
			(N=87)	(N=50)	(N=44)	(N=46)	(N=45)	(N=48)
	Rural	More than twice a day	0	0	0	1	0	0
		Once a day	2	0	0	1	11	14
		Once two days	2	0	3	2	19	19
		Once a week	13	1	20	17	54	5
		Once about ten days	14	2	6	8	12	8
		Do not shower at home	47	47	17	30	17	0
		No answer	6	0	4	4	0	0
			(N=78)	(N=50)	(N=46)	(N=59)	(N=113)	(N=46)
Taste preference	Urban	Restrictive	25	9	2	9	10	11
		Light taste	28	12	26	21	12	10
		Neutral taste	28	24	10	11	20	25
		Strong taste	6	5	10	10	4	1
		No answer	0	0	2	0	0	8
			(N=87)	(N=50)	(N=48)	(N=51)	(N=46)	(N=47)
	Rural	Restrictive	4	0	1	4	8	0
		Light taste	22	13	23	27	30	13
		Neutral taste	35	34	8	20	56	29
		Strong taste	23	3	18	12	19	4
		No answer	0	0	0	0	0	0
			(N=84)	(N=50)	(N=50)	(N=63)	(N=113)	(N=46)
Pickles	Urban	Do not eat	37	18	18	21	34	21
		Once a day	40	24	23	25	9	18
		Twice a day	7	4	4	3	1	8
		3 times a day	3	4	3	2	1	0
		No answer	0	0	2	0	1	8
			(N=87)	(N=50)	(N=48)	(N=51)	(N=45)	(N=47)
	Rural	Do not eat	11	23	24	23	62	21
		Once a day	15	21	22	25	45	21
		Twice a day	40	2	1	2	1	4
		3 times a day	18	4	2	9	5	0
		No answer	0	0	1	4	0	0
			(N=84)	(N=50)	(N=49)	(N=59)	(N=113)	(N=46)
Deep fried food	Urban	Do not eat	45	29	32	40	23	30
		Once a week	33	18	11	9	18	11
		2-5 times a week	7	3	2	1	4	6
		Every day	2	0	0	1	0	0
		No answer	0	0	5	0	1	8
			(N=87)	(N=50)	(N=45)	(N=51)	(N=45)	(N=47)
	Rural	Do not eat	63	36	32	48	75	23
		Once a week	15	14	13	5	35	20
		2-5 times a week	4	0	3	10	2	3
		Every day	2	0	1	0	1	0
		No answer	0	0	1	0	0	0
			(N=84)	(N=50)	(N=49)	(N=63)	(N=113)	(N=46)
Clo value	Urban	[0.6,0.7)	4	10	3	2	2	0
		[0.7,0.9)	34	23	14	12	6	1
		[0.9,1.1)	30	17	27	15	19	15
		1.37	16	0	4	22	19	33
		No answer	3	0	0	0	0	6
			(N=87)	(N=50)	(N=48)	(N=51)	(N=46)	(N=55)
	Rural	[0.6,0.7)	18	6	2	0	0	0
		[0.7,0.9)	32	16	30	0	10	1
		[0.9,1.1)	30	22	18	0	44	6
		1.37	0	6	0	63	59	39
		No answer	4	0	0	0	0	0
			(N=84)	(N=50)	(N=50)	(N=63)	(N=113)	(N=46)

Fig. 2. (c) Results of survey questionnaires in urban and rural areas (Individual section-living habit).

Note: Urban and rural areas of the Heilongjiang Province are Harbin and Qiqihar, respectively. Those of Hunan Province are Changsha and Chengbu, respectively.

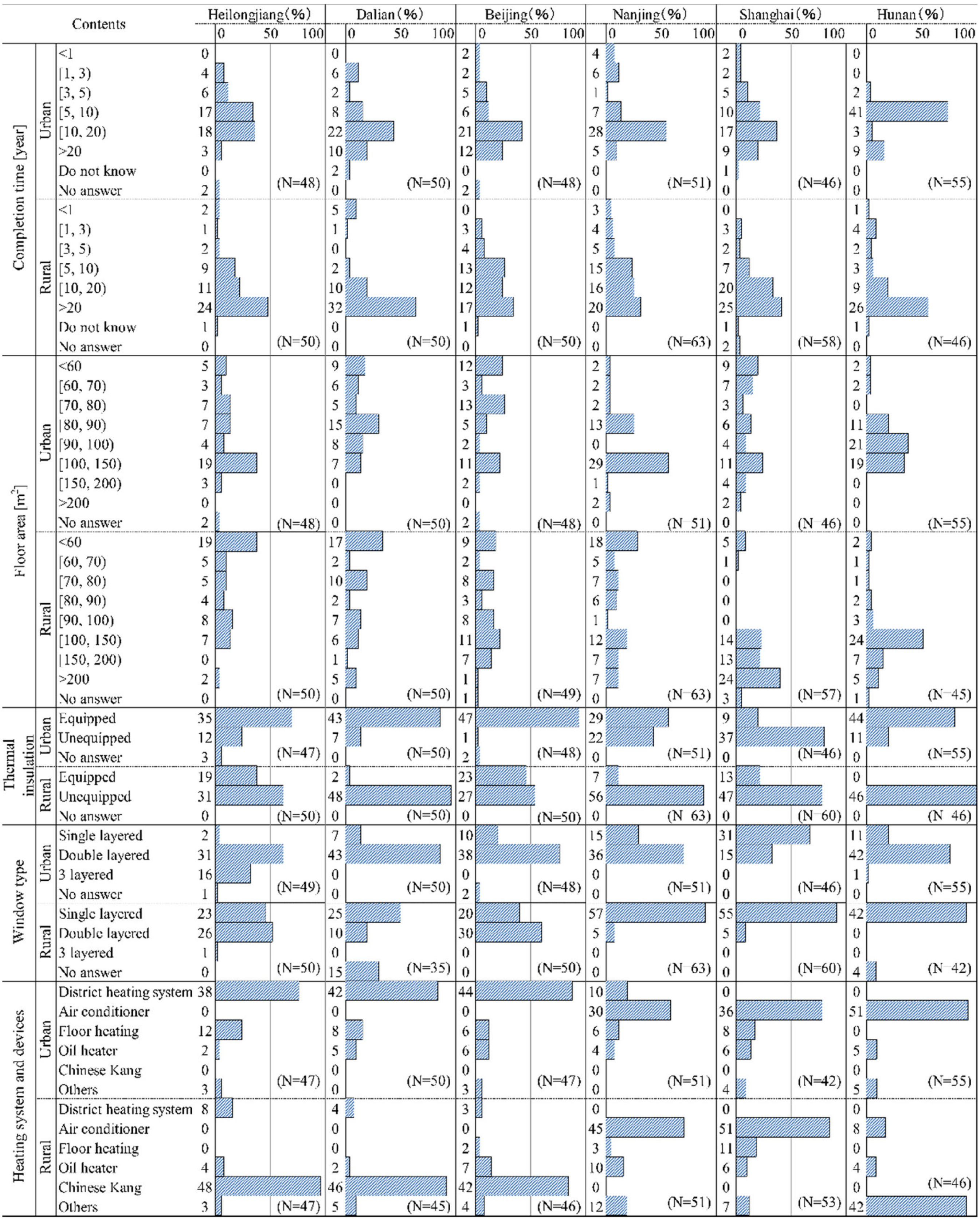


Fig. 3. Results of survey questionnaires in urban and rural areas (housing section).

Note: Urban and rural areas of Heilongjiang Province are Harbin and Qiqihar, respectively. Those of Hunan Province are Changsha and Chengbu, respectively.

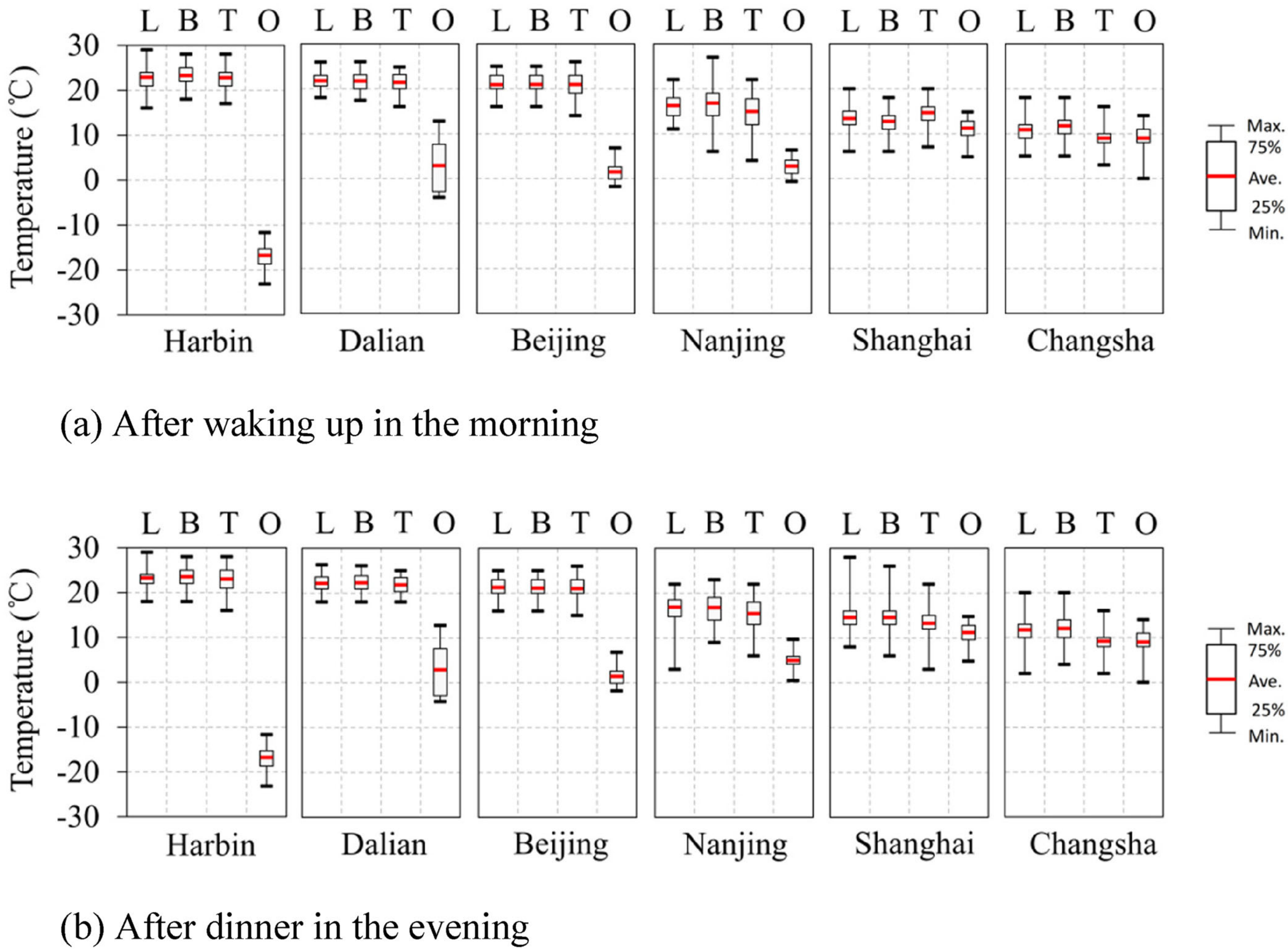


Fig. 4. Temperature records of three rooms and outdoor in urban areas (L, living room; B, bedroom; T, toilet; O, outdoor.).
Note: Harbin and Changsha belong to Heilongjiang and Hunan Provinces, respectively.

layered glass, and most dwellings in rural areas, which are detached houses, have a single-layered glass, specifically in the southern region. In Heilongjiang (Qiqihar), three-layered glass is used in some portions of the dwellings, as the outdoor temperature is much colder than that in the other areas.

There is a significant difference in the heating system between the northern and southern regions and between urban and rural areas. In northern urban areas (Heilongjiang (Harbin), Dalian, and Beijing), district heating systems are used in most houses, and hot water is supplied by municipal heat sources. However, the southern regions (Nanjing, Shanghai, and Changsha (Hunan)) had the highest number of air conditioner installations. In northern rural areas, "Chinese Kang" (a type of floor heating system that is warmed by burning coal or firewood and is applicable for cooking) is popular and is primarily used in bedrooms. In the rural areas of Nanjing and Shanghai, the occupants used air conditioners. In Hunan, most respondents answered with the option "Others". Moreover, they use the traditional "Huotong" (a traditional heating artifact in the southern region on which people can sit). The heat was supplied using charcoal.

Indoor temperature measurements

Figures 4 and 5 present the average temperatures measured by the occupants themselves in the morning and evening during a week in living rooms, bedrooms, and toilets, and the distribution of all urban and rural houses, respectively, except for Qiqihar, where the temperature was measured in the kitchen instead of the living room.

The outdoor temperatures of Heilongjiang, Dalian, Shanghai, and Changsha were monitored for one week by the authors, and those of Nanjing and Chengbu were recorded from the meteorological stations. All houses in the urban areas of Heilongjiang (Harbin), Dalian, and Beijing were equipped with district heating systems where the mean temperatures of the living room, bedroom, and toilet were nearly equal and stayed at approximately 20 °C under a low outdoor temperature. In the southern urban areas, the mean temperatures of the three rooms were approximately equal, although the values were as low as 10–15 °C. The difference between the indoor and outdoor environments was negligible. In all areas, the temperatures in the morning were generally lower than those in the evening, but the difference in the mean value between morning and evening was approximately 1 °C.

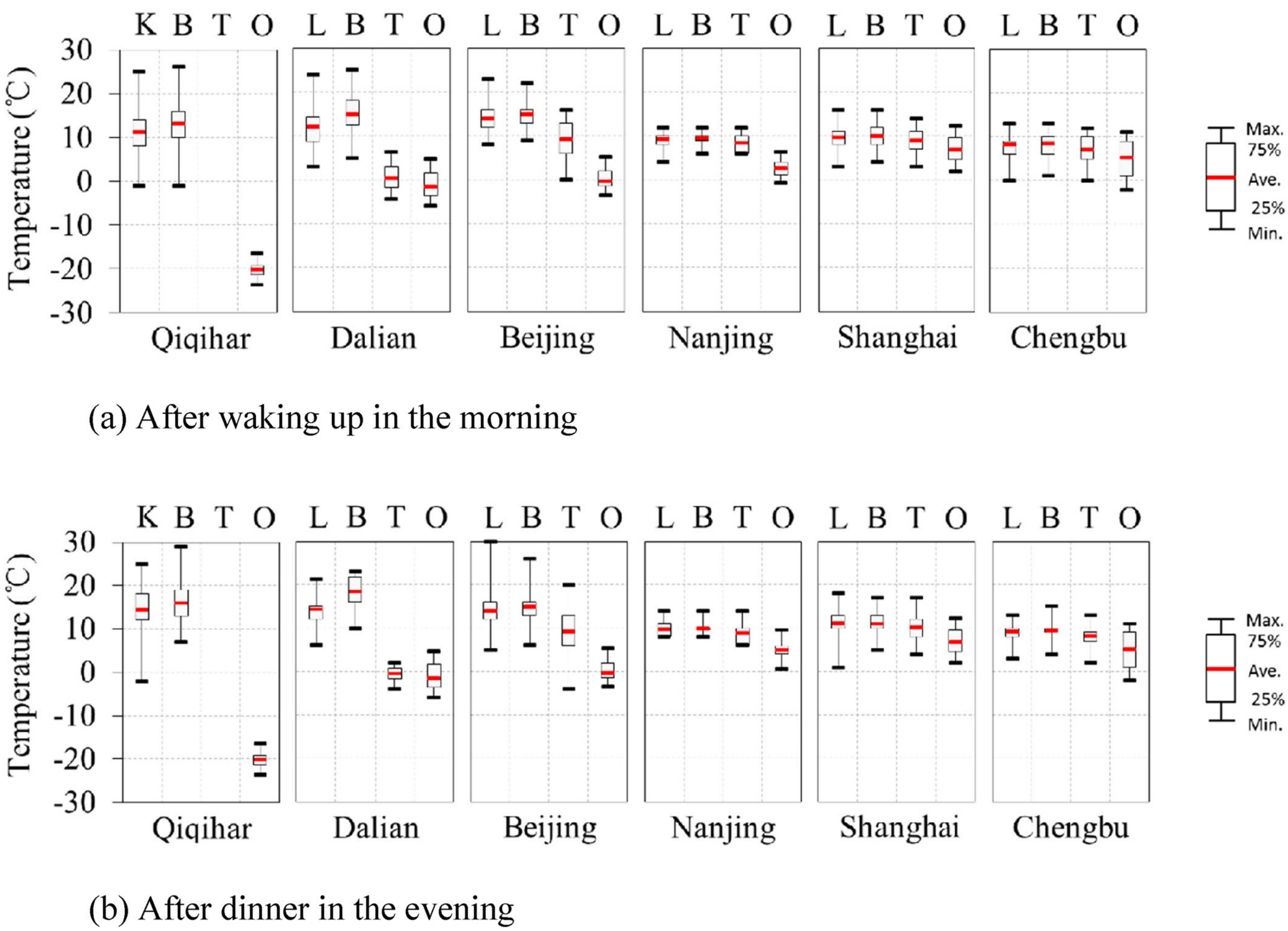


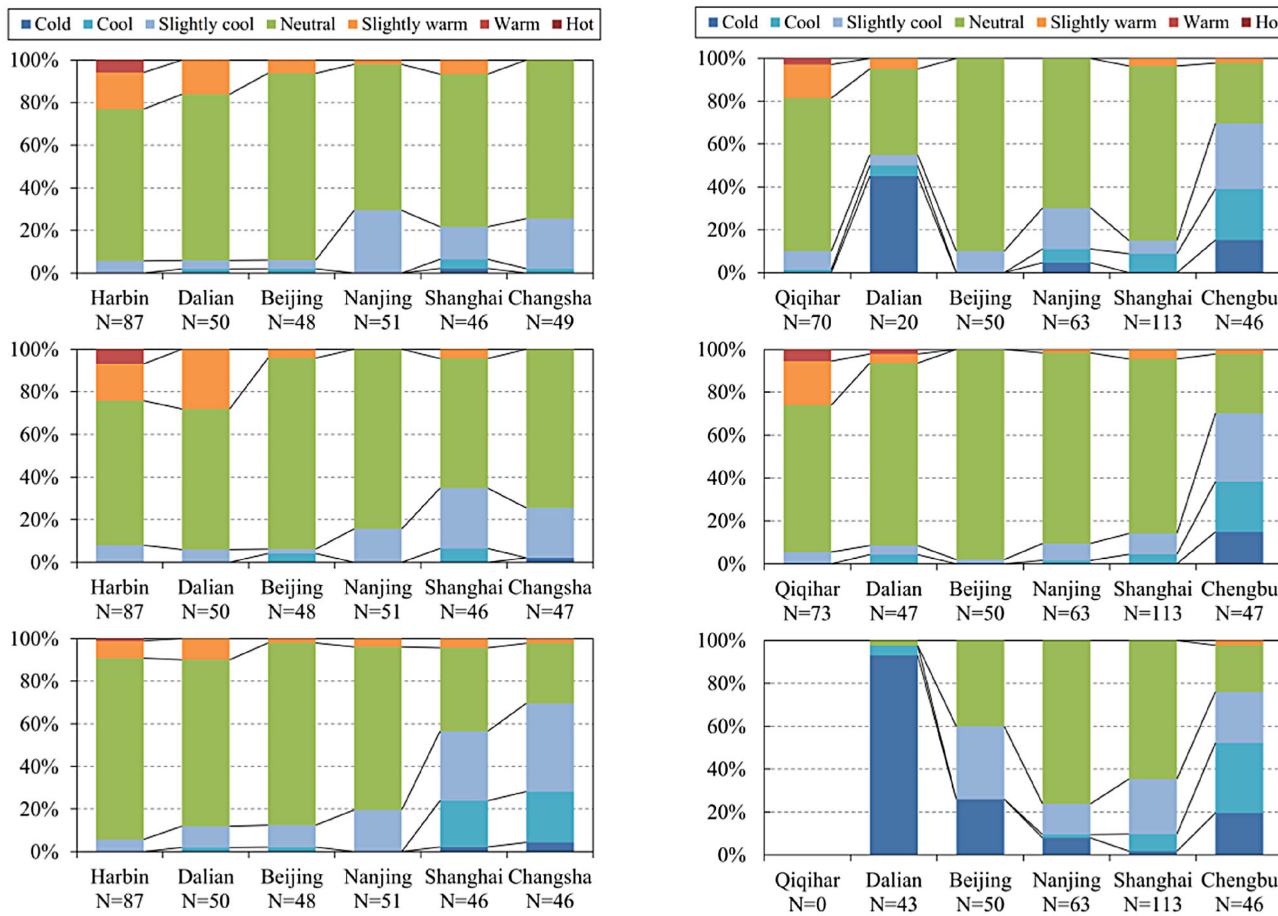
Fig. 5. Temperature records of three rooms and outdoor in rural areas (L, living room; K. kitchen, B, bedroom; T, toilet; O, outdoor.). Note: Qiqihar and Chengbu belong to Heilongjiang and Hunan Provinces, respectively. There is no data of toilet temperature from Qiqihar because the toilet was located outside.

In Qiqihar, the temperature in the toilet could not be measured because it was outdoors. In the other northern rural areas, even if the temperature could be measured, the temperature in the toilet was almost the same as the outside temperature, such as in Dalian, or lower than the temperature of the living room and bedroom, as in Beijing. The mean temperatures of the living rooms and bedrooms were much lower than those in urban areas. In Shanghai and Hunan (Chengbu) of the southern rural area, the mean indoor temperature of the three rooms is approximately 10 °C. In Hunan (Chengbu), the sample dwellings in this survey were selected from traditional wooden houses without thermal insulation. Hence, the difference between indoor and outdoor temperatures was the smallest, and the mean indoor temperature was less than 10 °C. Regarding the analysis of room temperature, since the difference in temperature between the living room, bedroom, and toilet was minimal in the urban and rural houses in the southern region, the living room temperature was used for the analysis. In rural houses in the northern region, as already described, the toilet temperature cannot be measured because it is outdoor. Even if the temperature can be measured, the temperature in the toilet is almost the same as the outside temperature or lower than the temperature of the living room and bedroom. For rural houses in the northern region, the temperature of the bedroom was used for analysis because the bedroom was heated by a Kang and occupied for long periods.

Thermal comfort

Results of the elderly thermal sensation vote

Figure 6 presents the distribution of the thermal sensation of the respondents in the indoor environment of the living room, bedroom, and toilet after dinner in the evening. In the urban dwellings of Heilongjiang (Harbin), Dalian, and Beijing, the thermal sensations in the three rooms were maintained within an acceptable range. This is because the district heating system heats the houses in these northern areas, and the room temperature is maintained at approximately 22 °C. Only a few responded to the option “slightly cool.” As for the southern regions, the difference among the three regions of Nanjing, Shanghai, and Hunan (Changsha) is evident owing to the difference in the indoor temperature and duration of heating.



(a) Urban areas (Living room, bedroom, and toilet, from the top)

(b) Rural areas (Living room, bedroom, and toilet, from the top. In Qiqihar, the top is for kitchen.)

Fig. 6. Thermal comfort of living room, bedroom, and toilet in the evening.

In rural areas, neutral responses were prominent, except in Dalian and Hunan (Chengbu), although the room temperature was low. In Hunan (Chengbu), wooden structures without thermal insulation caused most occupants to respond to the options "cool" and "cold" in all rooms. In addition, almost all respondents in Dalian felt "cold" in the toilet, and about half of respondents felt "cold" in the living room. This is because the toilet was located outside, and "Chinese Kang" was usually equipped in the bedroom but not in the living room. A questionnaire for thermal sensation after waking up in the morning was administered in urban and rural areas. Although the results are not shown here, the trend is similar to the after dinner temperatures in the evening, but more occupants felt "slightly cool" in the morning.

Relationship between thermal sensation and living room temperature

To explore the acceptable temperature range of the elderly in different areas, this study applied the bin method to analyze the relationship between thermal sensation in the elderly and the living room temperature. For the bin method, the mean of all the thermal sensation vote (TSV) values for each elderly were calculated in the interval selected as 0.5 °C. The neutral temperature can be obtained by setting TSV equal to 0. Figure 7 shows the relationship between the air temperature and the mean TSV value. For the urban area, a positive correlation was found between living room temperature and TSV. The thermal sensation of the elderly increases with increasing temperature. The living room temperature in the case where the elderly considered "neutral" was as follows: Harbin (morning 23.4 °C, evening 21.5 °C), Dalian (morning 23.7 °C, evening 22.8 °C), Beijing (morning 23.5 °C, evening 22.1 °C), Nanjing (morning 21.8 °C, evening 19.9 °C), Shanghai (morning 16.3 °C, evening 16.0 °C), and Changsha (morning 18.5 °C, evening 14.0 °C). The temperatures in the southern areas were lower than those in the northern areas.

In rural areas, there is also a positive correlation between living room temperature and TSV. The living (the kitchen in

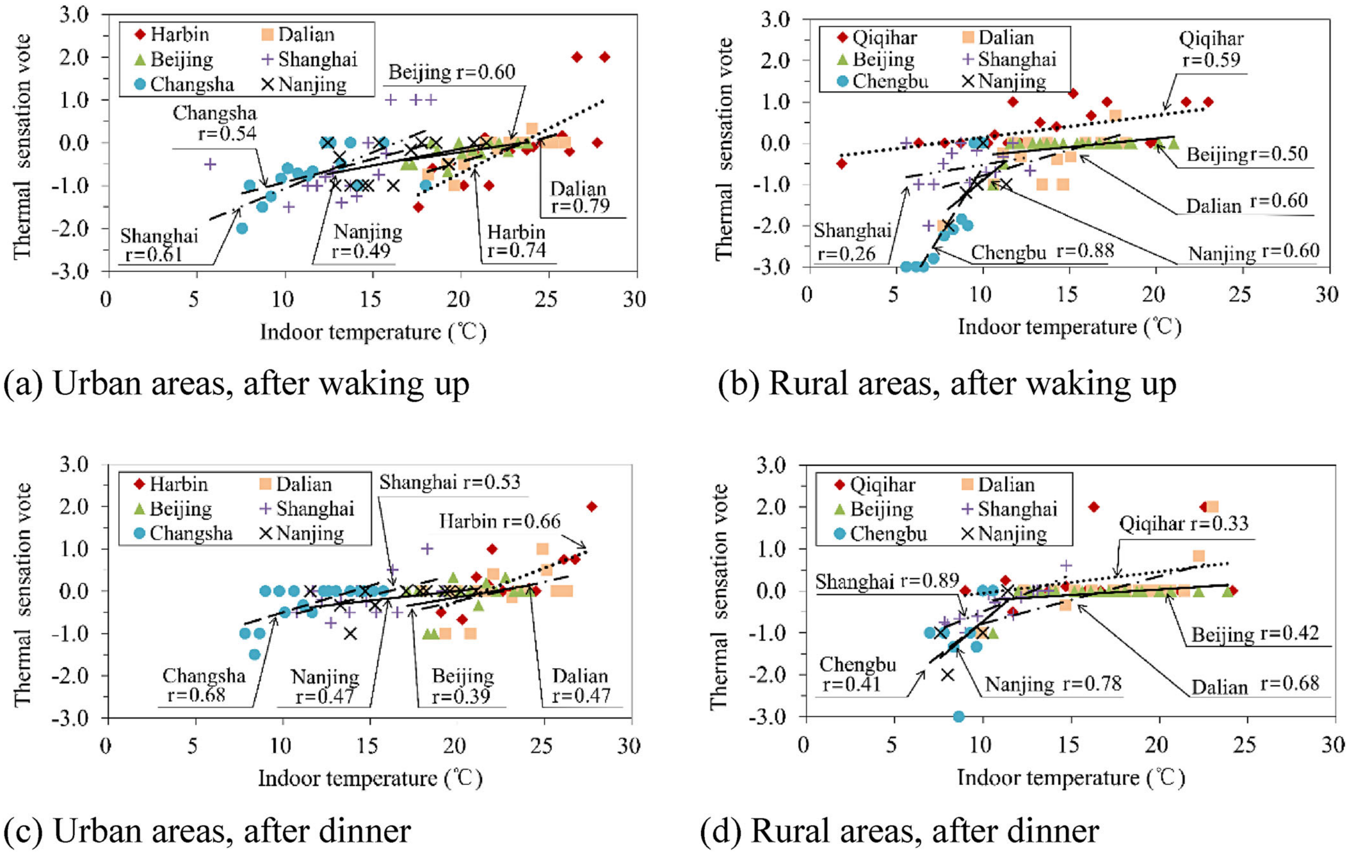


Fig. 7. Relationship between TSV and indoor temperature both in urban and rural areas.
Note: "r" indicates the correlation coefficient. Elderly people in Chengbu have the highest thermal sensitivity during winter. It is possibly due to the buildings being made of wood with a small heat capacity and high air leakage, and the people being acclimatized to the warm climate.

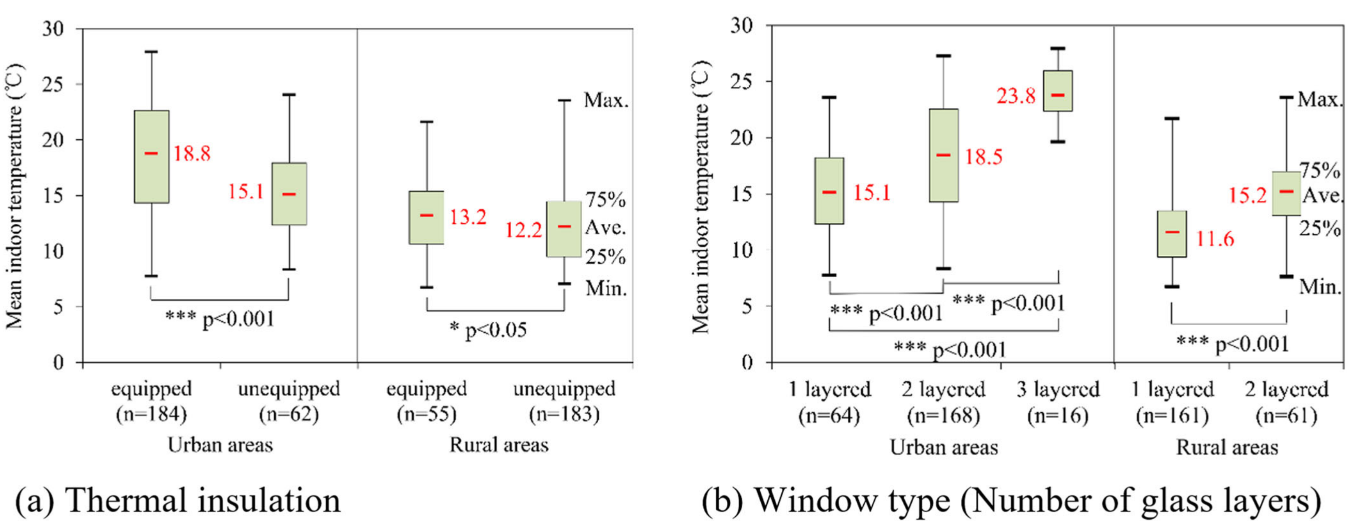


Fig. 8. Association between mean indoor temperature and building characteristics.

Qiqihar) room temperature in the case where the elderly considered "neutral" was as follows: Qiqihar (morning 12.2 °C, evening 8.2 °C), Dalian (morning 18.8 °C, evening 18.7 °C), Beijing (morning 17.6 °C, evening 16.7 °C), Nanjing (morning 12.6 °C, evening 12.0 °C), Shanghai (morning 17.8 °C, evening 12.8 °C), and Chengbu (morning 10.9 °C, evening 12.2 °C). Elderly people live in a very low-temperature environment, thereby indicating that they have adapted to the lower temperature of the living environment in winter.

Table 4. Different factor terms and categories.

Item	Sub-Item							
Region (X_1)	X_{11}	Rural area	X_{12}	Urban area				
Completion time (X_2, year)	X_{21}	<1	X_{22}	[1,3)	X_{23}	[3,5)	X_{24}	[5,10)
	X_{25}	[10,20)	X_{26}	≥20				
Floor area (X_3, m^2)	X_{31}	<60	X_{32}	[60, 70)	X_{33}	[70, 80)	X_{34}	[80, 90)
	X_{35}	[90, 100)	X_{36}	[100, 150)	X_{37}	[150, 200)	X_{38}	≥200
Thermal insulation material (X_4)	X_{41}	Unequipped	X_{42}	Equipped				
Window type (X_5)	X_{51}	1 layered	X_{52}	2 layered	X_{53}	3 layered		
Heating system and devices (X_6)	X_{61}	District heating system	X_{62}	Air conditioner	X_{63}	Eltrict /Oil heater	X_{64}	Chinese Kang
	X_{65}	Others						
Heating duration (X_7)	X_{71}	short[a]	X_{72}	long[b]	X_{73}	24 h		

[a]Long: occupants use heating system during in sleeping or longer than 12 hours;
[b]Short: occupants only use heating system in short time of one day.

Table 5. Operational result of the model.

		Quantification Theory I			
Item	Sub-item	Score	Score range	T-test	
Region (X_1)	X_{11} Rural area	0	1.709	–	
	X_{12} Urban area	1.709		2.758	0.006 **
Completion time (X_2, year)	X_{21} <1	0	1.670	–	
	X_{22} [1,3)	−0.235		−0.781	0.435
	X_{23} [3,5)	0.112		0.361	0.718
	X_{24} [5,10)	0.061		0.129	0.898
	X_{25} [10,20)	−1.558		−2.614	0.009 **
	X_{26} ≥20	−0.876		−1.037	0.300
Floor area (X_3, m^2)	X_{31} <60	0	2.207	–	
	X_{32} [60, 70)	−0.213		−0.441	0.659
	X_{33} [70, 80)	0.287		0.659	0.510
	X_{34} [80, 90)	1.221		3.071	0.002 **
	X_{35} [90, 100)	−0.917		−1.971	0.049 *
	X_{36} [100, 150)	0.993		1.973	0.049 *
	X_{37} [150, 200)	−0.986		−1.791	0.074
	X_{38} ≥200	0.766		1.464	0.144
Thermal insulation material (X_4)	X_{41} Unequipped	0	0.385	–	
	X_{42} Equipped	0.385		1.436	0.042 *
Window type (X_5)	X_{51} 1 layered	0	0.973	–	
	X_{52} 2 layered	0.066		0.211	0.833
	X_{53} 3 layered	0.973		1.700	0.090
Heating system and devices (X_6)	X_{61} District heating system	0	8.109	–	
	X_{62} Air conditioner	−6.614		−4.467	0.000 ***
	X_{63} Eltrict /Oil heater	−7.879		−4.950	0.000 ***
	X_{64} Chinese Kang	−5.090		−3.198	0.001 **
	X_{65} Others	−8.109		−5.159	0.000 ***
Heating duration (X_7)	X_{71} short	0	3.408	–	
	X_{72} long	1.744		3.157	0.002 **
	X_{73} 24 h	3.408		2.181	0.030 *

***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.

Association between building characteristics and indoor temperatures

First, the influence of building characteristics such as thermal insulation, window layers, floor area, and completion time of buildings on the mean living room temperature was analyzed. Figure 8a shows the indoor temperature of the houses with and without thermal insulation installed. There was a significant difference between houses in both urban

Table 6. Results of logistic analysis for hypertension prevalence.

Model 1							Model 2						
Item		AOR	P		95% CI		Item		AOR	P		95% CI	
Age	/year[a]	1.058	0.000	***	1.033	1.083	Age	/year[a]	1.055	0.000	***	1.028	1.083
BMI	/unit[a]	1.070	0.002	**	1.025	1.118	BMI	/unit[a]	1.088	0.001	**	1.035	1.144
Region	urban[b]	1.465	0.020	*	1.063	2.020	Indoor temperature	/°C[a]	0.959	0.036	*	0.922	0.997

***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.
[a]Regression work with continuous data, and variable increasing in one unit.
[b]For urban area, AOR is equal 1.0.

and rural areas. In urban areas, the average value is 18.8 °C and 15.1 °C and, in rural areas, it is 13.2 °C and 12.2 °C in houses with and without insulation, respectively.

Figure 8b shows the indoor temperatures of houses with different numbers of glass layers of windows. There was also a statistically significant difference between the three cases in urban areas and between the two cases in rural areas. In urban areas, the average values are 15.1 °C, 18.5 °C, and 23.8 °C in houses with single, double, and triple glass layers of windows, respectively. In rural areas, it is 11.6 °C and 15.2 °C in houses with single and double layers, respectively. Therefore, the indoor temperature is higher in houses with thermal insulation in the walls and multiple glass layers of windows. As for the floor area and completion time of the building, a clear relationship between the indoor temperature and these two factors was not found. However, the indoor temperature of houses built more than 20 years ago and situated in the rural area is as low as 13.9 °C.

Second, to explore the dominant factors of various building characteristics on indoor temperature, a regression model with different factors was established using quantification theory type I using SPSS 25. Table 4 lists the seven items and subitems of the model. The regression model was constructed using region (X_1), completion time (X_2), floor area (X_3), thermal insulation material (X_4), window type (X_5), heating system and devices (X_6), and heating duration (X_7).

The results are presented in Table 5, which shows that the score range of the seven items from high to low was as follows: heating system and devices (8.109), heating duration (3.408), floor area (2.207), region (1.709), completion time (1.670), window type (0.973), and thermal insulation (0.385). The sub-items that contribute to improving the indoor temperature are district heating among heating systems, 24 h heating duration, urban area, triple glass layers among window types, and installation of thermal insulation in the order of higher absolute value of the score. "Chinese Kang" also contributed to temperature increase, in addition to district heating.

Analysis of hypertension prevalence and influencing factors

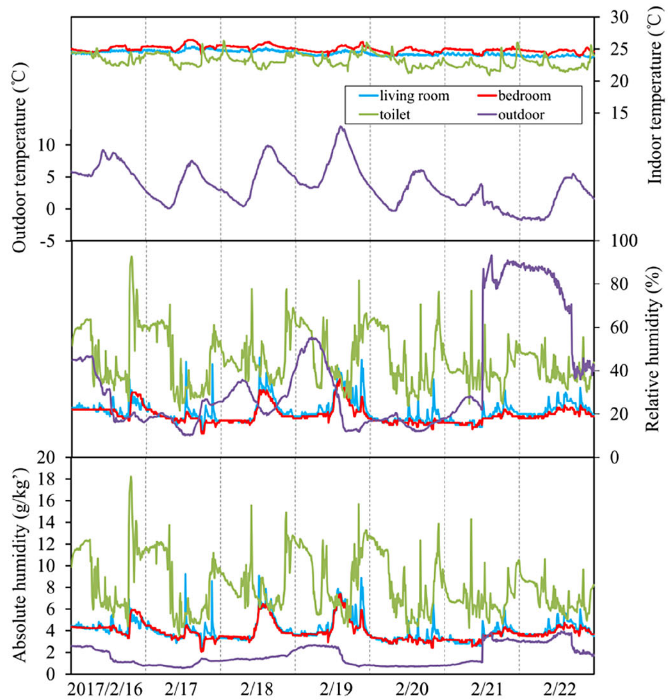
To analyze the factors influencing hypertension prevalence, a multivariate logistic analysis was performed using SPSS 25. Before logistic analysis, multicollinearity was examined to ensure the accuracy of the results. The examination proved that there may be multicollinearity in indoor temperature with other potential confounders according to the variance inflation factor (VIF) results. Therefore, the region and indoor temperature as target factors were forcibly entered into two models, which were adjusted for the following potential confounders stepwise: age, sex, BMI, smoking, alcohol, taste preference, pickles, and deep-fried food. Table 6 presents the results of the logistic analysis, which includes the region (Model 1) and indoor temperature (Model 2). The results of Model 1 indicate a greater prevalence in rural areas. The results of Model 2 show that an increase in hypertension is related to low indoor temperatures. Furthermore, both Model 1 and Model 2 showed that age and BMI as potential confounders had a greater influence on the prevalence of hypertension.

Results of field measurements

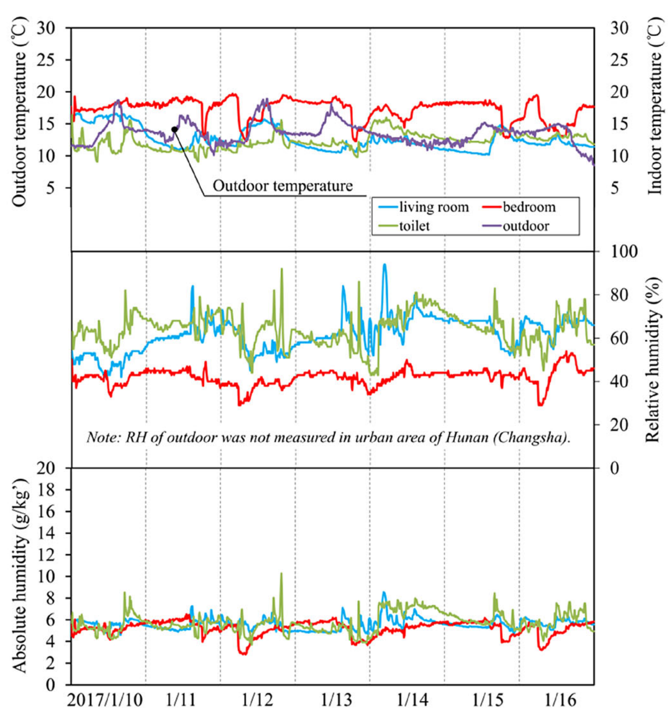
Changes of temperature and humidity

Apartments in urban areas

Figure 9a and b show the changes in temperature and relative humidity for two typical dwellings in urban areas with a central heating system and air conditioner, respectively. Different heating systems create different indoor thermal environments. An example in Beijing demonstrated the characteristics of an indoor thermal and humid environment under a central heating system. The living room and bedroom temperatures were approximately 25 °C, which remained stable owing to the central heating system operating throughout the day. The relative humidity in the living room and bedroom was very low and stable. However, the relative humidity of the toilets was relatively high and varied substantially. These features of the indoor thermal environment are common in apartments in the northern region that have a district heating system. Compared with apartments in the northern regions, the indoor environment in southern apartments using air conditioners operated intermittently was unstable. For example, in Changsha, the bedroom temperature was maintained at approximately 18 °C, except for some short periods, and the temperatures of the living room and toilet were relatively low and changed between 10 °C and

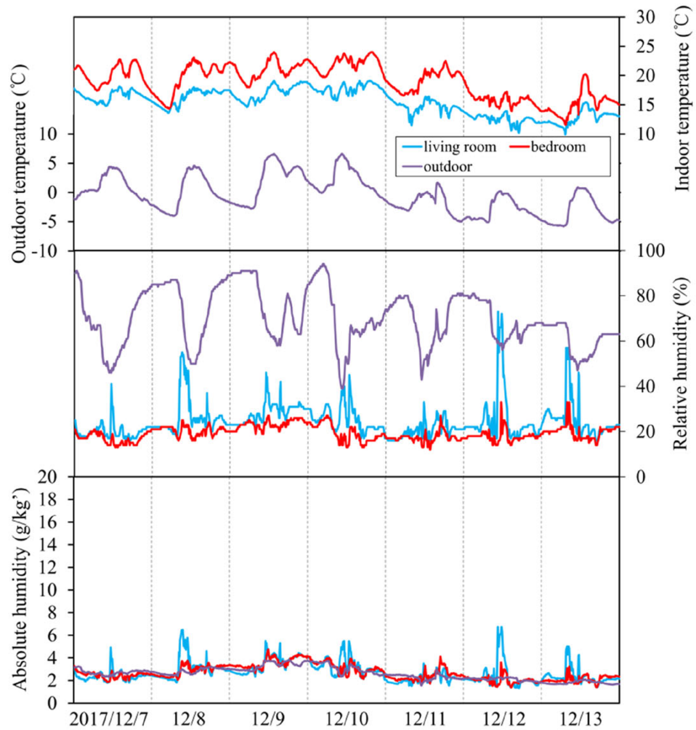


(a) Example of an apartment with central heating system (Beijing)

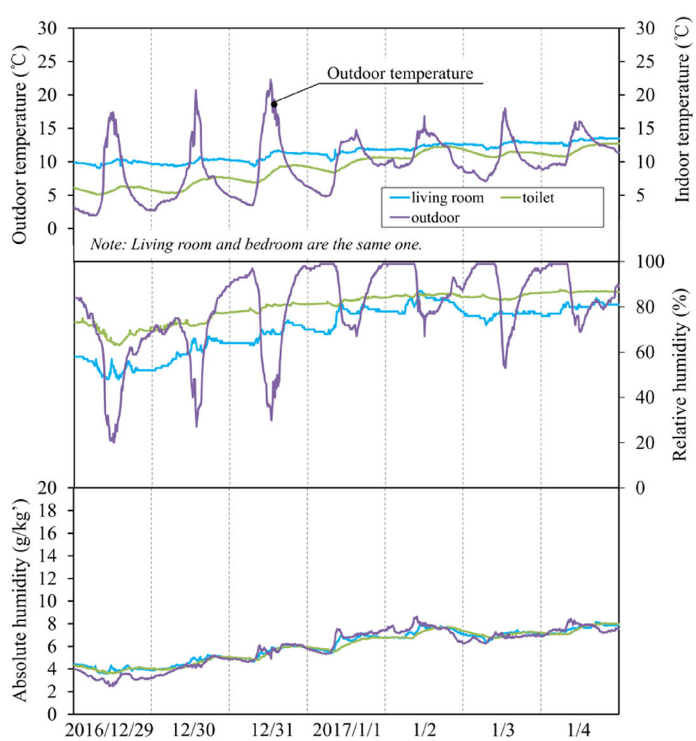


(b) Example of an apartment with air conditioner (Changsha)

Fig. 9. Changes of temperature and RH of dwellings in urban and rural areas.



(c) Example of a detached house with “Chinese Kang” (Dalian)



(d) Example of a detached house with no heating (Shanghai)

Fig. 9. Continued.

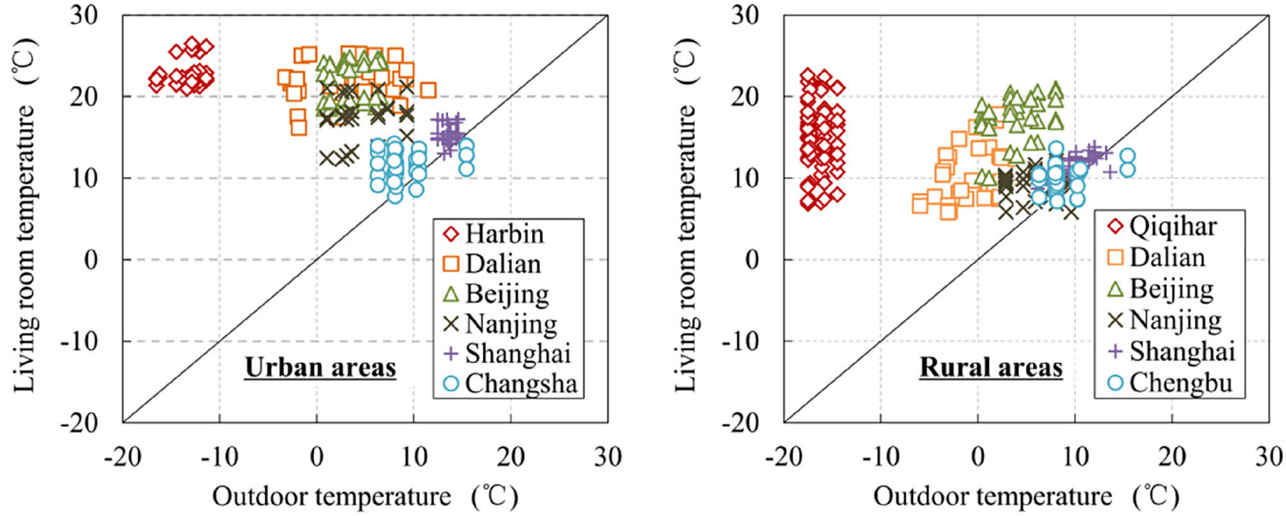


Fig. 10. Relationship between living room and outdoor temperatures (One plot indicates the mean value during one day of one living room).

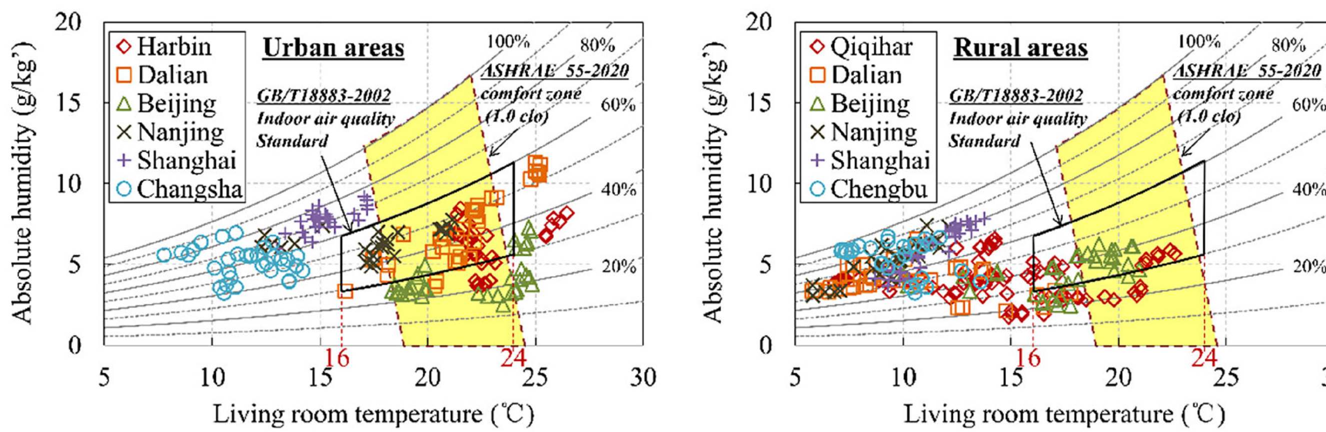


Fig. 11. Indoor temperatures and humidity of living room plotted on the psychrometric chart in dwellings in urban (left hand) and rural (right hand) areas.

Note: One plot indicates the daily mean value of one house. The x-axis is the dry-bulb temperature that we measured as the living room temperature, although the comfort zone of ASHRAE was defined based on operative temperature. The Chinese standard zone was defined based on dry-bulb temperature.

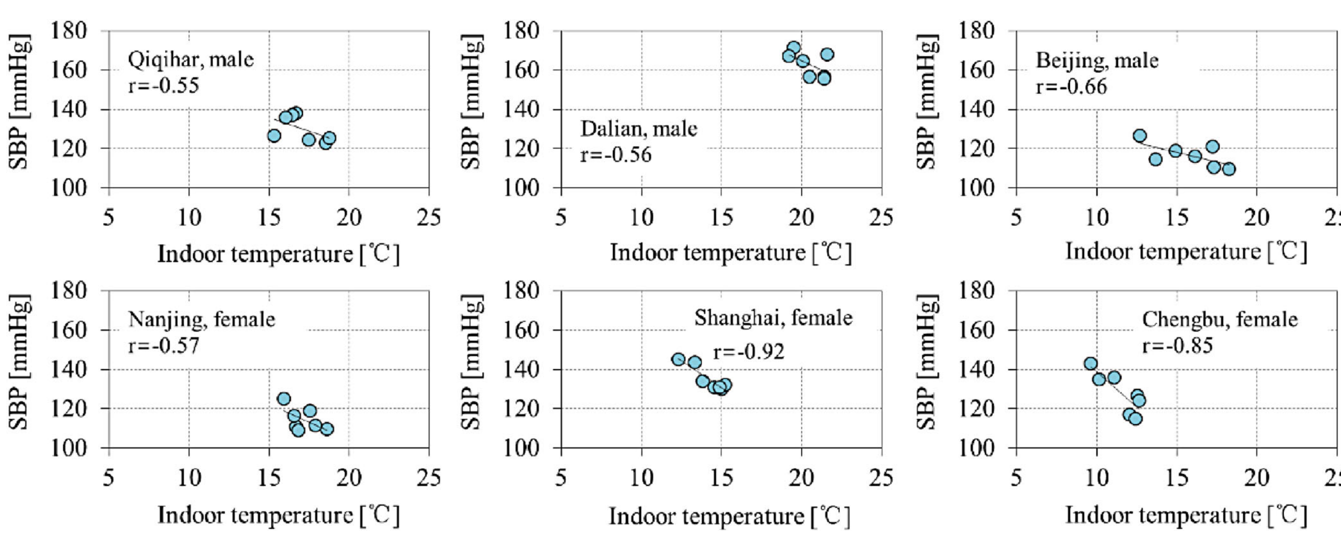


Fig. 12. Typical samples on morning blood pressure of the elderly in different cities.

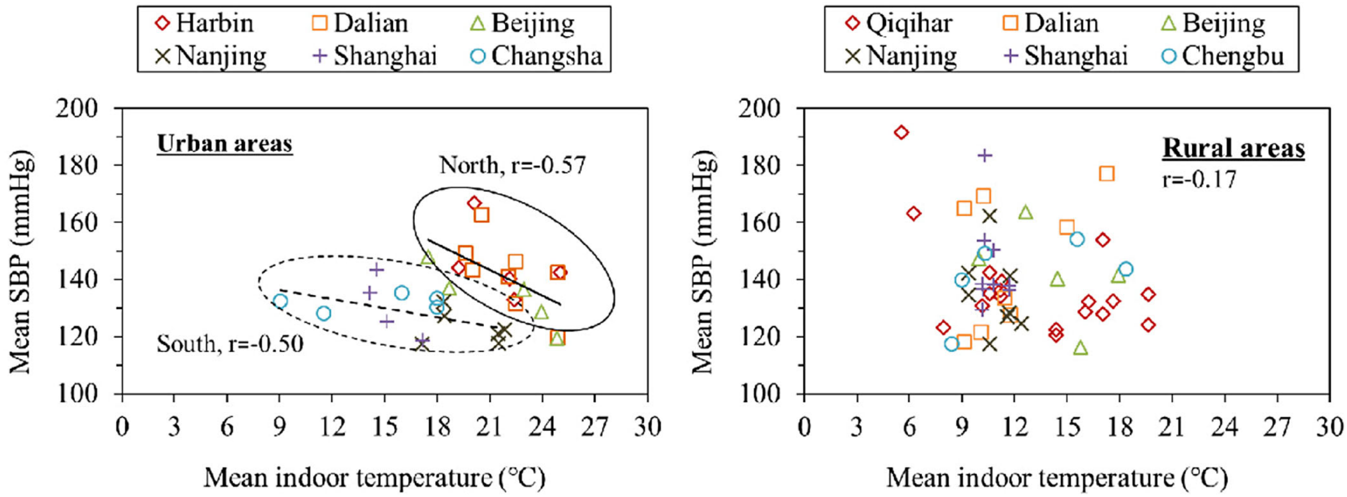


Fig. 13. Blood pressure of the long-term exposed temperature (1 mmHg = 133 Pa).

15 °C. The relative humidity of the bedroom varied between 30% and 50%, and that of the living room was high and varied between 50% and 90%.

Detached houses in rural areas

Figure 9c and d show the thermal environments of typical detached houses in rural areas with and without heating devices, respectively. The living room and bedroom temperatures of the example in Dalian, where the room was warmed by "Chinese Kang," changed between 13 °C and 23 °C. The bedroom temperature containing the "Chinese Kang" was higher than the living room's. The relative humidity of the bedroom varied between 20% and 50%, and that of the living room ranged between 40% and 60%. Contrarily, the living room temperatures of the example in Shanghai were stable and varied between 10 °C and 13 °C (for this example, the living room was also used as a bedroom). The maximum temperature difference between the living room and toilet was 5 °C, whereas the outdoor temperature changed significantly between 3 °C and 22 °C. The relative humidity of the living room was increased from 50% to 80%, and that of the toilet was maintained at 10% higher than that of the living room.

According to the field measurement survey in urban areas, the daily fluctuations in room temperature and the temperature difference between the rooms are small in the northern regions of houses equipped with district heating systems and vice versa in the southern region where air conditioners are used. For housing in rural areas, we found large daily fluctuations in room temperature in the northern region where Kangs were used. The room temperature was stable at a low level in the southern region where heating was not used.

Relationship between indoor and outdoor temperature

Figure 10 shows the relationship between the daily mean outdoor and living room temperatures in the urban and rural areas of the six regions during the measurement period. In the urban areas of Heilongjiang (Harbin), Dalian, and Beijing, the living room temperatures, recorded as between 18 °C and 26 °C, were not influenced by the outdoor temperature due to the operation of the district heating system.

In the apartments in Shanghai and Hunan (Changsha) in the southern urban areas, which contain individual heating devices, the indoor temperature was very close to the outdoor temperature, between 8 °C and 18 °C. The indoor temperature in Nanjing was included in the former group, although individual heating devices were used. For the rural areas, the indoor temperatures of dwellings with "Chinese Kang" in Heilongjiang (Qiqihar) were not influenced by the outdoors but were distributed from 17 °C to 22 °C. The outdoor temperature affected those of Dalian and Beijing and were greatly distributed from 5 °C to 21 °C. In the southern region, the temperatures of dwellings in Shanghai, Nanjing, and Chengbu (rural areas of Hunan) were close to the outdoor temperatures because many houses had no space heating.

Indoor thermal comfort

Figure 11 shows the daily mean indoor temperature and humidity of all houses in urban and rural regions plotted on a psychrometric chart with the comfort zone of the ANSI/ASHRAE Standard 55 and Chinese indoor air quality standard (GB/T 18883-2002). In the urban areas of Heilongjiang (Harbin), Dalian, and Nanjing, the indoor thermal environment in many cases fell within the comfort zone of the Chinese standard.

Most indoor thermal environments in Harbin and Dalian fell into the ASHRAE comfort zone. The indoor thermal environment was maintained in a comfortable zone because of the continuous operation of the district heating system. In the case of Beijing, which has a district heating system, the recorded indoor temperatures are either within or near the range provided by the Chinese standard, although the relative humidity is lower than this zone.

In contrast, the indoor thermal environments of Hunan (Changsha), Shanghai, and some Nanjing are plotted out of both the Chinese standard and the ASHRAE comfort zone because the indoor temperature is minimal. In rural areas, some indoor thermal environments in Beijing and Heilongjiang (Qiqihar) met the Chinese standard. Except for these houses, the temperatures of almost all the living rooms were very low. Additionally, one-third of the living room temperatures were less than 10 °C.

Association between daily mean room temperature and blood pressure

Figure 12 presents six typical samples of healthy elderly individuals based on the relationship between morning systolic blood pressure (SBP) of each day and living room temperature during the same time. These samples showed a negative correlation. This implies that the blood pressure increases with a decrease in indoor temperature.

Figure 13 shows the relationship between the room temperature and blood pressure of all subjects, which is the average of all measured values for each subject. In northern urban areas, both temperature and blood pressure were higher than in southern urban areas. There was a negative correlation between the two factors in both northern and southern areas. Conversely, there was a slight negative correlation between indoor temperature and blood pressure in rural areas. There were no clear differences between the two groups.

Discussion

The purpose of this study was to clarify the difference between the northern and southern regions of China and the difference between urban and rural areas in terms of the indoor thermal environment and health of the elderly. From the analysis, we found that urban housing in the northern region is fully equipped with district heating, and the indoor temperature is maintained at a comfortable level. However, in the southern region, where air conditioning is intermittently used, we found that the room temperature was as low as 10 to 18 °C. This finding was previously reported by Yoshino et al. (2004, 2006).

There are several surveys of the thermal environment in rural housing. Shao and Hong (2020), Liu et al. (2019) and Liu et al. (2018) investigated rural housing in a single climate region, respectively. Chen et al. (2019) investigated rural housing in Qiqihar and Shanghai. Xiong, Liu, and Kim (2019) investigated urban and rural housing in the climate region with hot summer and cold winter. On the other hand, this study is the first large-scale survey of urban and rural housing that included both the northern and southern regions of China.

Our analysis revealed that Kangs are widespread in rural houses in the northern region, while air conditioners and charcoal heaters are used in rural areas in the southern region. In the rooms where Kangs were used, the room temperature was approximately 15 °C around supper time in the evening. However, in the southern region, air conditioners are rarely used, and the window glasses are often single-layered, so the indoor temperature is as low as approximately 10 °C, with only an approximately 5 °C difference between the indoor and outdoor temperatures.

Hypertension was the most common illness among the surveyed elderly, but we found no clear difference in the prevalence of hypertension between the northern and southern regions.

On the other hand, we found that the risk of hypertension increased at lower room temperatures, and the elderly in rural areas had a higher risk of hypertension than those in urban areas. These findings are consistent because the room temperature in rural areas tended to be lower than that in urban areas. We also found that the higher the BMI and the older the age, the higher the risk of hypertension. Other factors such as eating habits and smoking, which may affect health, were also analyzed, but their effects on health were not found.

From the analysis of the field measurements, we found that the lower the room temperature, the higher the blood pressure of the residents, even though the number of samples was small. This finding complements the results of the questionnaire.

In terms of the prevalence of CVDs, we could find no clear difference between the northern and southern regions. However, Li et al. (2020) found that the risk of cardiovascular disease was statistically higher in the northeast and northern regions and lower in the southern region, and Xia et al. (2020) stated that the incidence of stroke was higher in the north and lower in the south in rural areas. Such difference could be due to the insufficient sample size in our questionnaire survey. Therefore, a large-scale, nationwide survey is needed. As mentioned before, we have indicated the relationship between room temperature and hypertension. We conclude that the indoor environment is important for maintaining good health. On the other hand, we did not analyze the effects of environmental factors other than the indoor thermal environment in this study, although these factors were measured. This analysis will be conducted in the future.

Conclusions

In this study, we administered a questionnaire and conducted a field measurement survey on the indoor environment of the houses of the elderly and their health conditions in both urban and rural areas in six regions spanning the three climate categories in China. The questionnaire results showed that the prevalence of hypertension was as high as 40% in both urban and rural areas. In addition, the room temperature in the houses tended to be lower in the southern regions than in the northern regions, and lower in rural areas than in urban areas. The indoor temperature was significantly increased by factors such as district heating, heating duration, three-layer glass windows, and thermal insulation. In addition, the lower the room temperature, the higher the prevalence of hypertension; this trend was statistically significant.

In the field measurement survey in urban areas, we found that the daily fluctuation in room temperature and the temperature difference between the rooms are negligible in the northern region, where the houses are equipped with district heating systems. In contrast, the opposite trend was observed in the southern region, where air conditioners were used.

For housing in rural areas, we found that the daily fluctuation in room temperature was significant in the northern region, where Kangs were used. The room temperature was stable at a low level in the southern regions, where heating was not used.

We found a negative correlation between room temperature and blood pressure. Therefore, to maintain the health of the elderly living in houses with low room temperatures in winter, it is necessary to improve the thermal environment by improving the thermal performance of the building and enhancing the heating equipment. In houses with outdoor toilets, it is important to install toilets indoors.

Although the survey target sample was not selected by random sampling, the findings clearly indicated differences between the northern and southern regions of China and between urban and rural areas in relation to the thermal environment and the characteristics of buildings. An analysis of the effects of environmental factors other than the thermal environment on health is a subject for future research.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Japan Society for the Promotion of Science for Projects Funded by Grants-in-Aid for Science Research under grant number 16H05751. The authors would like to express their deep gratitude to the elderly individuals involved in this study, for their substantial cooperation in this investigation.

References

Chen, Y., H. Zhang, H. Yoshino, J. Xie, U. Yanagi, H. Kenichi, N. Kagi, T. Goto, Q. Zhang, and J. Zhang. 2019. Winter indoor environment of elderly households: A case of rural regions in northeast and southeast China. *Building and Environment* 165: 106388. doi:10.1016/j.buildenv.2019.106388

Collins, K. J., J. C. Easton, H. Belfield-Smith, A. N. Exton-Smith, and R. A. Pluck. 1985. Effects of age on body temperature and blood pressure in cold environments. *Clinical Science (London, England : 1979)* 69 (4):465–70. doi:10.1042/cs0690465

Fan, G., J. Xie, H. Yoshino, U. Yanagi, K. Hasegawa, N. Kagi, T. Goto, Q. Zhang, C. Wang, and J. Liu. 2018. Indoor environmental conditions in urban and rural homes with older people during heating season: A case in cold region, China. *Energy and Buildings* 167:334–46. doi:10.1016/j.enbuild.2018.01.064

Hasegawa, F., H. Yoshino, H. Arai, K. Iwasaki, S. Akabayashi, and M. Kikuta. 1985. Investigation of the relationship between the indoor thermal environment of houses in the winter and cerebral vascular accident (CVA). *Japanese Journal of Public Health* 32 (4): 181–93.

Li, B., C. Du, R. Yao, W. Yu, and V. Costanzo. 2018. Indoor thermal environments in Chinese residential buildings responding to the diversity of climates. *Applied Thermal Engineering* 129:693–708. doi:10.1016/j.applthermaleng.2017.10.072

Li, X., C. Wu, J. Lu, B. Chen, Y. Li, Y. Yang, S. Hu, and J. Li. 2020. Cardiovascular risk factors in China: A nationwide population-based cohort study. *The Lancet. Public Health* 5 (12):e672–e681. doi:10.1016/S2468-2667(20)30191-2

Liu, D., Z. Ren, S. Wei, Z. Song, P. Li, and X. Chen. 2019. Investigations on the winter thermal environment of bedrooms in Zhongxiang: A case study in rural areas in hot summer and cold winter region of China. *Sustainability* 11 (17):4720. doi:10.3390/su11174720

Liu, Y., T. Li, C. Song, D. Wang, and J. Liu. 2018. Field study of different thermal requirements based on the indoor activities patterns of rural residents in winter in Northwest China. *Science and Technology for the Built Environment* 24 (8):867–77. doi:10.1080/23744731.2018.1435122

National Bureau of Statistics of China. 2019. China Statistical Yearbook 2019, Beijing.

National Center of Cardiovascular Diseases, China. 2019. Report on Cardiovascular Diseases in China 2018. Encyclopedia of China Publishing House, Beijing.

Public Health England. 2014. Minimum home temperature thresholds for health in winter - A systematic literature review, London.

Saeki, K., K. Obayashi, J. Iwamoto, N. Tone, N. Okamoto, K. Tomioka, and N. Kurumatani. 2014. The relationship between indoor, outdoor and ambient temperatures and morning BP surges from inter-seasonally repeated measurements. *Journal of Human Hypertension* 28 (8):482–8. doi:10.1038/jhh.2014.4

Shao, T., and J. Hong. 2020. A field investigation on the winter thermal comfort of residents in rural houses at different latitudes of northeast severe cold regions, China. *Journal of Building Engineering* 32:101476. doi:10.1016/j.jobe.2020.101476

Shiue, I., and M. Shiue. 2014. Indoor temperature below 18 °C accounts for 9% population attributable risk for high blood pressure in Scotland. *International Journal of Cardiology* 171 (1): e1-2–e2. doi:10.1016/j.ijcard.2013.11.040

Umishio, W., T. Ikaga, K. Kario, Y. Fujino, T. Hoshi, S. Ando, M. Suzuki, T. Yoshimura, H. Yoshino, and S. Murakami. 2019. Cross-sectional analysis of the relationship between home blood pressure and indoor temperature in winter: A nationwide smart wellness housing survey in Japan. *Hypertension (Dallas, Tex. : 1979)* 74 (4):756–66. doi:10.1161/HYPERTENSIONAHA.119.12914

World Health Organization. 2016. World health statistics 2016: Monitoring health for the SDGs Sustainable Development Goals, 60–1, Geneva.

World Health Organization. 2018. Housing and health guidelines, 34, Geneva.

Xia, F., X. Yu, Y. Li, Y. Chen, W. Zhang, C. You, and X. Hu. 2020. Geographic variations of stroke incidence in Chinese communities: An 18-year prospective cohort study from 1997 to 2015. *Journal of Stroke* 22 (3):345–56. doi:10.5853/jos.2020.02383

Xiong, Y., J. Liu, and J. Kim. 2019. Understanding differences in thermal comfort between urban and rural residents in hot summer and cold winter climate. *Building and Environment* 165:106393. doi:10.1016/j.buildenv.2019.106393

Yoshino, H., S. Guan, Y. F. Lun, A. Mochida, T. Shigeno, Y. Yoshino, and Q. Y. Zhang. 2004. Indoor thermal environment of urban residential buildings in China: Winter investigation in five major cities. *Energy and Buildings* 36 (12):1227–33. doi:10.1016/j.enbuild.2003.09.015

Yoshino, H., Y. Yoshino, Q. Zhang, A. Mochida, N. Li, Z. Li, and H. Miyasaka. 2006. Indoor thermal environment and energy saving for urban residential buildings in China. *Energy and Buildings* 38 (11):1308–19. doi:10.1016/j.enbuild.2006.04.006

Zhang, H., and H. Yoshino. 2010. Analysis of indoor humidity environment in Chinese residential buildings. *Building and Environment* 45 (10):2132–40. doi:10.1016/j.buildenv.2010.03.011