Effect of Indoor Thermal Environment on Resident's Condition of Long-term Care Need

August 2020

Yukie Nakajima

A Thesis for the Degree of Ph.D. in Engineering

Effect of Indoor Thermal Environment on Resident’s Condition of Long-term Care Need

August 2020

Graduate School of Science and Technology
Keio University

Yukie Nakajima

Abstract

Increased expenses in healthcare and long-term care due to population ageing is a serious problem, and extension of healthy life expectancy is an urgent need. From the perspective of architectural environmental engineering, various studies have examined health problems related to cold temperatures. However, previous studies mainly focused on cross-sectional associations, and the ability to maximize healthy life expectancy by improving indoor thermal environment is yet unknown. A hypothesis was formulated stating, "a warm indoor environment can improve resident's health and contribute to the prevention of conditions that lead to long-term care (LTC)." To investigate this hypothesis, two studies were conducted among people certificated for LTC need and a third study used national data to assess the risk of fuel poverty.

Chapter 1 describes the background and outlines the LTC insurance system in Japan. Moreover, by summarizing domestic and foreign policies and previous research on health problems related to cold temperature and fuel poverty, objectives of the study were described.

Chapter 2 presents a study investigating whether and how a warmer indoor thermal environment could prevent or delay LTC certification among clients from outpatient rehabilitation facilities. Physical performance, frailty, and age at LTC certification were selected as outcomes and investigated in relation to the indoor thermal environment of their home.

Chapter 3 summarizes a study on the effect of indoor thermal environment in nursing homes on deterioration of care level of residents. The effect of indoor thermal environment on residents' health was investigated from two aspects: 1) the relationship between indoor temperature and blood pressure and 2) the relationship between relative humidity and oral dryness. Furthermore, the speed of decline of care level was investigated in relation to indoor thermal environment to understand which type of indoor thermal environment can prevent deterioration of care level.

Chapter 4 describes a nationwide analysis of fuel poverty based on administrative stats data. A methodology to determine fuel poverty households by using individual data of the Housing and Land Survey was suggested. The results were used to identify the attributes of the residents and houses under risk of fuel poverty.

Chapter 5 presents the conclusions of this thesis.

論文要旨

高齢化に伴う要介護認定者数の急激な増加や医療・介護費の増大といった問題が深刻さを増す中で、健康寿命の延伸は喫緊の課題である。建築環境工学的な視点からは室内温熱環境と健康に関しては様々な研究が行われている。しかしながら既往の知見は断面的な調査に基づく健康影響に限定されたものであり、室内温熱環境改善による健康寿命の延伸効果や介護予防効果といった、より長く健康に過ごせることによってもたらされる価値の大きさは未だ不明瞭である。そこで本研究では「温暖な室内温熱環境は居住者の健康性向上、ひいては介護予防に寄与する」という仮説のもと、要介護高齢者を対象とした調査を行った。その際、介護予防の概念が「要介護状態の発生をできる限り防ぐ（遅らせる）こと、そして要介護状態にあってもその悪化をできる限り防ぐこと、さらには軽減を目指すこと」と定義されることを受け、介護予防の各段階にアプローチする 2 種類の実態調査及び統計データの分析を実施した。

第 1 章では、序論として本研究の背景と日本の介護保険サービスの現状を解説した。また、寒さに起因する健康被害や燃料貧困の問題について国内外の政策および先行研究をまとめ、本研究の位置付けと目的を示した。

第 2 章では、通所型介護サービス施設利用者を対象に実施した実態調査の概要及び分析結果を示した。居住者の身体機能および Frail（虚弱）、初めて要介護認定を受けた際の年齢の 3 点を評価指標として自宅の温熱環境との関連を検討することで、住宅の温熱環境改善により要介護状態の発生をできる限り防ぐ（遅らせる）ことができるかどうかを、そのメカニズムも含め考察した。

第 3 章では、入居型介護サービス施設の温熱環境が利用者の要介護度の重度化スピードに及ぼす影響を検討するために実施した実態調査についてまとめた。分析ではまず 1) 室温と血圧の関係、2) 湿度と口腔内乾燥感の関係、という 2 つの側面から介護施設の温熱環境と利用者の健康について検討した。加えて介護施設の温熱環境による要介護度の重度化スピードの違いを検討することで、要介護状態の改善や重度化の予防に資する介護施設の室内温熱環境について考察した。

第 4 章では、第 2 章で特に Frail との関連が示唆された燃料貧困の問題について、非公開統計情報を活用して日本全国を対象とした分析を実施した。住宅・土地統計調査の個票から得られるデータを基に燃料貧困世帯を特定する方法論を提案し、判定結果から燃料貧困のリスクが高い居住者の特徴や住宅の特徴を明らかにした。

第 5 章では、本論文の結論と今後の展望を述べた。

Contents

List of figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of tables

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Abbreviations

ADL	Activities of daily living
AIC	Akaike’s information criterion
AIJ	Architectural Institute Japan
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
BEEA	Building Energy Efficiency Act
BMI	Body mass index
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CI	Confidence interval
COPD	Chronic obstructive pulmonary disease
CWP	Cold Weather Plan
DBP	Diastolic blood pressure
DE	Design effect
Delta (Δ)	Used as a prefix in formulas to indicate ‘change in’
EWM	Excess winter mortality
FIES	Family Income and Expenditure Survey
HHSRS	Housing Health and Safety Rating System
HLS	Housing and Land Survey
IADL	Instrumental activities of daily living
ISDC	Implementation status of dental care
IQR	Interquartile range
LTCHF	Long-term care health facility
LTC	Long-term care
LTCI	Long-term care insurance
MANCOVA	Multiple analysis of covariance
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MHLW	Ministry of Health, Labour and Welfare
MLIT	Ministry of Land, Infrastructure and Transport
NHHS	National Health Housing Standard
PNH	Pay nursing home

RH	Relative humidity
SBP	Systolic blood pressure
SD	Standard deviation
SENH	Special elderly nursing home
SPPB	Short physical performance battery
temp_{in}	Indoor temperature
temp_{out}	Outdoor temperature
TUG	Timed Up & Go
WHO	World Health Organisation
WoF	Warrant of Fitness

Acknowledgements

Undertaking this Ph.D. has been a truly life-changing experience for me and it would not have been possible to do without the support and guidance that I received from many people.

I would like to first say a very big thank you to my supervisor and principal mentor, Professor Toshiharu Ikaga of the Faculty of Science and Technology at Keio University, for his dedication and incredible guidance throughout this journey, for sharing your vast knowledge and wisdom and for doing so with an atmosphere of inspiration. Without his guidance and constant feedback, this Ph.D. would not have been achievable.

I greatly appreciate Associate Professor Steven M. Schmidt of Centre for Ageing and Supportive Environments (CASE) in Lund University. Also as a Guest Associate Professor (Global) of Faculty of Science and Technology at Keio University, he offered me such helpful perspectives and insights into gerontology and statistical methods and for all invaluable discussions.

My deep appreciation goes out to Emeritus Professor Tanji Hoshi of Tokyo Metropolitan University, for his insightful comments and for sharing with me his tremendous experience in the field of public health.

I am also very grateful to Professor Masaki Takahashi of Keio University, for reviewing the manuscript and for providing very valuable suggestions for improving the quality of the research and the manuscript.

This thesis was written within the context of JSPS KAKENHI Grant (Numbers 17J00520, JP17H06151, and JP26249083), a MHLW Grant-in-Aid for consignment study of geriatric health care business promotion (Principal Investigator: Emeritus Professor Tanji Hoshi), and a MEXT Grant-in-Aid for the Programme for Leading Graduate Schools.

My sincere gratitude to the participants in the studies: Mr. Fumiya Omata, representative of Fuji-Kousei Group; Mr. Masanori Koto, chairman of Fuji-Kousei Group; Ms. Satomi Omata, chairman of Fuji-Ohto Group; Mr. Toshiyuki Yajima of Obayashi Corporation; Ms. Naoko Ikeda of OM Solar Corporation; Dr. Yasushi Uchida, chairman of Josen Group; Ms. Fujiko Nagano, chairman of Furusato Group; Mr. Shinpei Okada, Director of Physical Education and Medicine Research Foundation; Mr. Ryosuke Yamamoto, President of Super Hotel Co., Ltd.; Mr. Akiyoshi Yamamoto and Mr. Tatsuki Azuma, President and staff in Super Court Co., Ltd. for their participation in the project, members in rehabilitation facilities and residents of nursing homes willingly participated in the interviews and the care staffs involved in data collection.

I would like to thank Lecturer Shintaro Ando of the Faculty of Environmental Engineering, University of Kitakyushu. Each time I see him, I was deeply inspired by his enthusiasm and sincere efforts in his research. I would be grateful for your continued guidance.

My thanks also go out to the support I received from the collaborative work I undertook during my international training. I am especially grateful to Associate Professor Agneta Malmgren Fänge of CASE at Lund University, Professor Philippa-Howden Chapman of Department of Public Health at University of Otago, Wellington, and Mr. Hideki Yuzawa of Nikken Sekkei Research Institute. I was lucky to have great opportunities at these orginisations, and the time I spent there was one of the most important I ever have in my life.

I gratefully acknowledge Emeritus Professor Shuzo Murakami of the University of Tokyo, Former Professor of Keio University and President of the Institute for Building Environment and Energy Conservation, for his encouragement and supervisory role.

I thank Professor Hiroto Izumi and Professor Masako Yoneda, Specially-Appointed Professors of the Keio Advanced Researched Centres. They shared stories about various fields based on their own vast experiences and provided me the opportunity to expand my horizons.

My deep appreciation goes out to Ms. Takako Suzuki and Ms. Miho Baba, the secretaries in the Ikaga Laboratory. They were very helpful in general during my time in and even out of the laboratory.

My appreciation also goes out to Joint researchers Mr. Hiroshi Kojima, Ms. Maki Ito, and Assistant Professor Wataru Umishio of Department of Architecture and Building Engineering, School of Environment and Society at Tokyo Institute of Technology, for the recurrent talks about the research and everything else.

I am indebted to all the senior to me in the Ikaga Laboratory, who have already graduated. In particular, my seniors on the research team, Mr. Naoto Takayama, Ms. Chika Ushiro, Ms. Kanoko Nishikawa, and Ms. Eri Honda supported my research activities and laboratory life in every way. Ms. Moeka Ota, Mr. Kentaro Suzuki, Mr. Ryota Tsuchiya, and Mr. Junya Yamasaki who were affiliated with the laboratory during my time there, provided me with support in many aspects of laboratory life. I also received a lot of support from those who were junior to me in the laboratory. Mr. Takuya Ishiwata, Mr. Toyohiro Kurabe, Mr. Kaichi Otsuka, Ms. Lucie Brohée, Mr. Takuro Ishito, Mr. Ryota Sato, Ms. Saeka Tsuchiya, Ms. Misa Matsumoto, Mr Hirotaka Asakura, and Mr. Yu Kuroki. I would like to send a very special thank you to Ms. Mari Ono. Her excellent work during data collection has made an invaluable contribution towards my Ph.D.

I would also like to say a heartfelt thank you to my parents and Haruna for always supporting me and my family through thick and thin. Thank you for helping me in whatever way they could during this challenging period.

And finally, to Yusuke, who has been by my side throughout this Ph.D., living every single minute of it, and without whom, I would not have had the courage to embark on this journey in the first place. And to darling Mei for being such a good little baby, and making it possible for me to complete what I started.

August 2020

Yukie Nakajima

Chapter 1

Introduction

Chapter 1

Introduction

1.1 Japanese aged population and care prevention strategy

The speed and magnitude of ongoing demographic ageing in Japan are unprecedented, which is one of the main challenges for Japanese policy-making. The number of people over 75 years old has increased for many years and will continue to increase in the future (Figure 1.1), while the total population is declining [1]. Japan is now experiencing "super-ageing" with more than 21 % of the population older than 65 years in both rural and urban areas. The ageing of the Japanese population is a result of one of the world's lowest fertility rates combined with the highest life expectancy. Japan's life expectancy in 2016 was 80.20 years for men and 86.61 years for women [2]. However, to predict future needs, evaluate health programmes, and plan for health care, social services, and long-term care (LTC), healthy life expectancy is an important indicator [3] in conjunction with life expectancy. Healthy life expectancy in 2016 was 71.19 years for men and 74.21 years for women [2], and the gap between life expectancy and healthy life expectancy indicates 9.01 – 12.40 unhealthy life-years (Figure 1.2). The combination of a smaller working population and a higher share of retired people will put additional strains on Japanese welfare systems. Cost for care in 2025 is estimated to reach 19.8 trillion yen which is two times higher than in 2015 (Figure 1.2). Filling the gap for long-term care demand is today one of the main priorities for Japan.

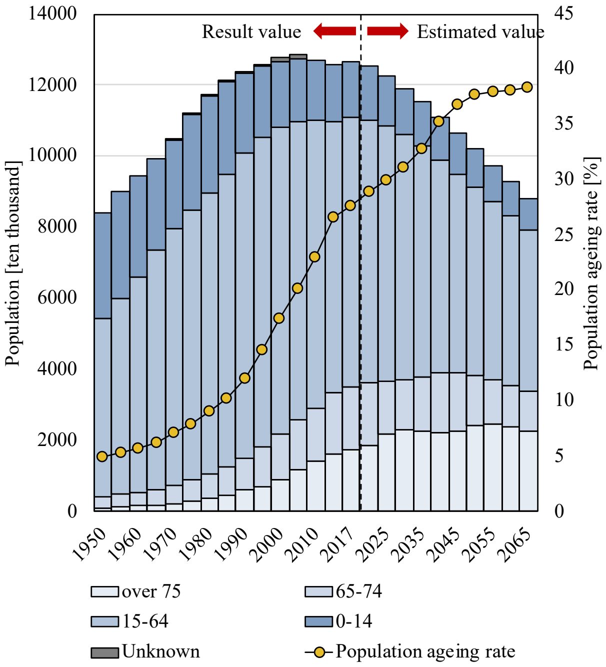


Figure 1.1 Ageing population in Japan [1]

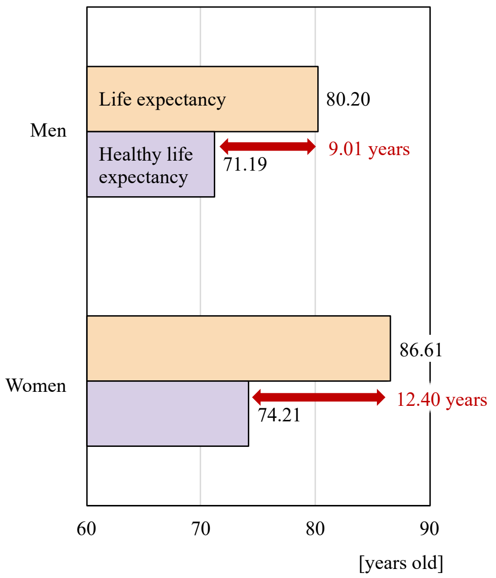


Figure 1.2 Life expectancy and healthy life expectancy in 2016 (modified from [2])

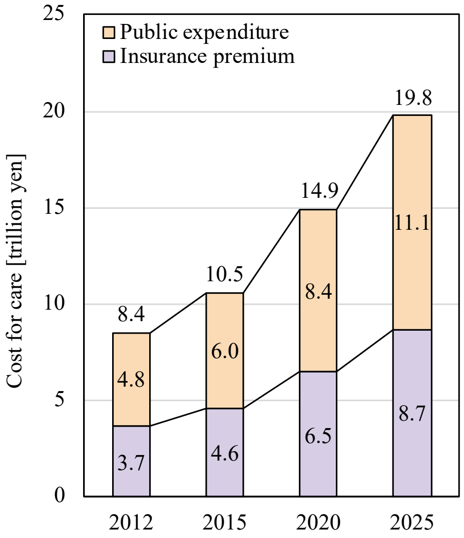


Figure 1.3 Cost for care in Japan [4]

Since the 1960s, Japan has successively implemented a series of different policies to address the societal challenge of care for an ageing population, and in 2000 a unique care providing system was implemented, whereby citizens can be assured that they will receive care and be supported by society as a whole (Table 1.1, [5]). In 1961, Japan achieved universal health coverage for medical care by introducing the National Health Insurance system. In 1973, the system started to provide free medical care for everyone aged 70 years or older. Although free medical care ended in 1983, the co-payment rate was set lower for older people. Meanwhile, there was an increasing trend in the number of nuclear families due to urbanization. Consequently, many older people were admitted and remained in hospitals because their families were unable or unwilling to care for them. This was called "social admission," and the associated increase in the medical expenditure on inpatient care became a significant issue for society. At the time, tax-supported in-home services were mainly for older people with low incomes and who received little care from their families. Although the Japanese government implemented a ten-year strategy for the health and welfare of older people (the "Gold Plan") in 1989, the system encountered a financial issue due to its reliance on tax revenue and its increasing expenditure.

Table 1.1 Development of welfare policies for the older adults [5]

Historical backdrops	Population ageing rate (year)	Major policies
1960s Beginning of welfare policies for the older adults	5.7 % (1960)	**1963** Enactment of the Act on Social Welfare Services for the Elderly ✧ Intensive care homes for the elderly created ✧ Legislation on home helpers for the elderly
1970s Expansion of healthcare expenditures for the elderly	7.1 % (1970)	**1973** Free healthcare for the elderly
1980s “Social hospitalization” and “bedridden elderly people” as social problems	9.1 % (1980)	**1982** Enactment of the Health and Medical Services Act for the Aged ✧ Adoption of the payment of co-payments for elderly healthcare, etc. **1989** Establishment of the Gold Plan (10-year strategy for the promotion of health and welfare for the elderly) ✧ Promotion of the urgent preparation of facilities and in-home welfare services
1990s Promotion of the Gold Plan	12.0 % (1990)	**1994** Establishment of the New Gold Plan (new 10-year strategy for the promotion of health and welfare for the elderly) ✧ Improvement of in-home long-term care
Preparation for adoption of the Long-Term Care Insurance System	14.5 % (1995)	**1997** Enactment of the Long-term Care Insurance Act
2000s Introduction of the Long-Term Care Insurance System	17.3 % (2000)	**2000** Enforcement of the Long-Term Care Insurance System

To tackle these problems, long-term care insurance (LTCI) [5] in Japan was introduced in 2000 to cover social care for 2 million people aged 65 years and older; the number of insured people under LTCI doubled by 2006. The first major revision of LTCI took place in 2005. The primary change made was the strengthening of LTC prevention measures; the provision of services and projects that aim to prevent people from needing LTC or additional LTC. More specifically, the “needing support” level, which was the one level in the LTC needs certification system, was divided into two levels. Services which aim to prevent LTC were added to all types of existing home-based and community-based services. In addition, those who have not reached the “needing support” levels became subject to LTC prevention programmes conducted by municipal governments, and it was decided that community comprehensive support centres would be responsible for the programmes. In the 2007 revision that followed the 2005 revision, it was decided that he residents of the institutions covered by LTCI must pay board and lodging costs in order to reduce the financial burden on the state. At the same time, it was also decided that low-income earners would be given additional benefits from the LTCI in order to reduce the burden on them. The next revision of the law took place in 2011. The policy goal of establishing community comprehensive care systems started to be talked about around this time. In the 2011 revision, an outline and the purpose of such systems were given in the provisions which stipulated the responsibilities of the state and local governments in establishing such systems.

Services that contribute to establishing such systems were created, including around-the-clock periodic visits and on-demand services as well as composite services.

As seen above, the revisions concerning LTCI which took place after the establishment of the scheme do not seem to have always been conducted under consistent principles. These might have been inevitable choices when considering the fact that these revisions were largely driven by the motivation of reducing state liability, which was required when compiling the budget. However, despite these inconsistent revisions, the number of people who became certified as needing LTC and started using the relevant services has continued to increase since the establishment of the scheme. This shows the high degree to which people need LTC services that are guaranteed by LTCI.

In the currently LTCI system, municipalities and special wards in the metropolitan area are the insurers. The LTC approval board investigates the mental and physical condition of the insured person and makes a judgement based on the opinions of a regular doctor. Eligibility is assessed using a 74-item questionnaire based on activities of daily living. In-home benefits are determined based on the level of LTC required (7 levels including 2 levels of Support-required, and care level 1 (least disabled) to 5 (most disabled)). Facility benefits are determined in accordance with facility types, depending on the level of LTC required. The availability of family caregiving is not taken into consideration, even though it was the key assessment point in the previous system (Figure 1.4).

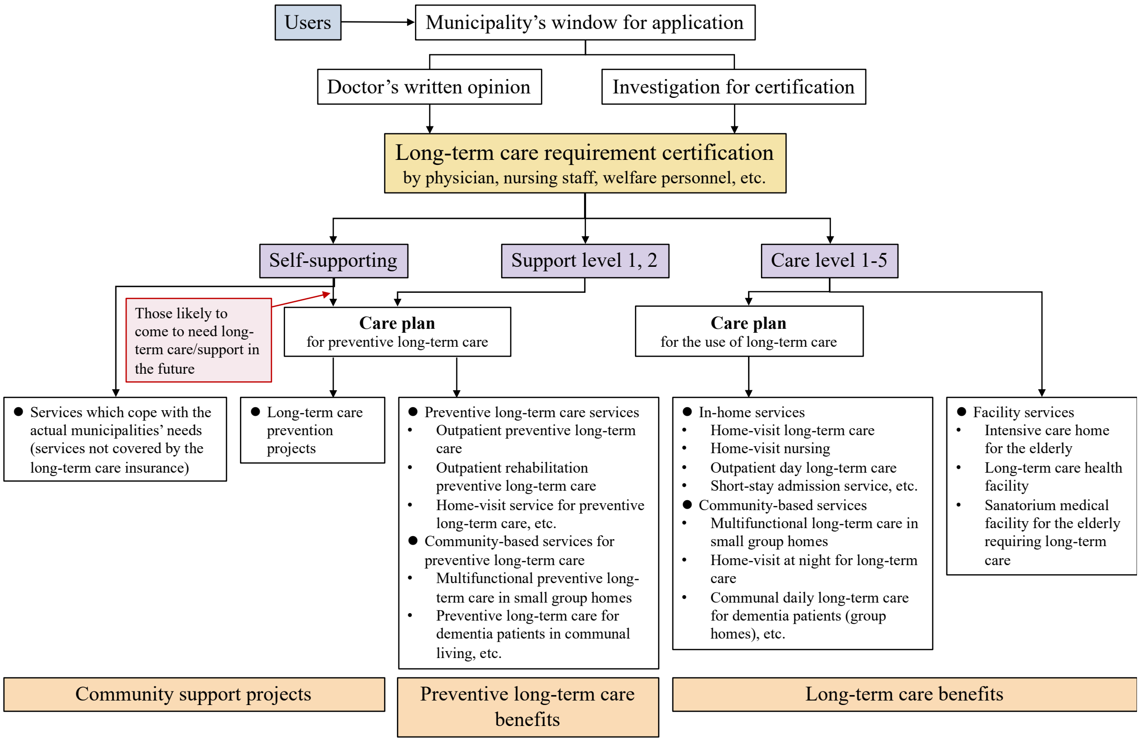


Figure 1.4 Application procedure of long-term care insurance service [5]

On the other hand, Ministry of Health, Labour and Welfare (MHLW) formulated a "Care Prevention Manual [6]" to generalize the conceptual idea of care prevention based on a scientific viewpoint, and to accelerate activities efficiently and effectively. In the manual, care prevention is defined as efforts to prevent or delay the occurrence of care needing condition, and even in people already certified for needing LTC, to prevent further deterioration, and aim to improve their condition (Figure 1.5). This highlights the importance of continued and intermittent approach to each stage of care prevention.

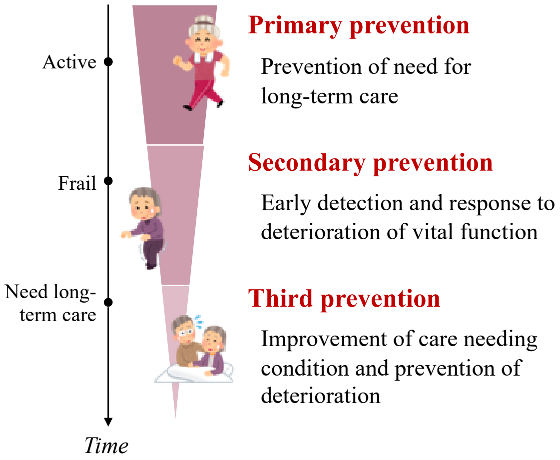


Figure 1.5 Definition of care prevention (modified and translated from [6]**)**

In the Care Prevention Manual, 1) improvement of exercise skill, 2) improvement of nutrition, 3) improvement of oral cavity, 4) prevention of isolation, 5) prevention of deterioration of cognitive function, and 6) prevention of depression, were intended as key pillars for care prevention. Regarding pillars 1) 2) and 5), Kamo et al [7] showed that nutrition indirectly affects deterioration of Activities of Daily Living (ADL) through deterioration of physical and cognitive function (Figure 1.6).

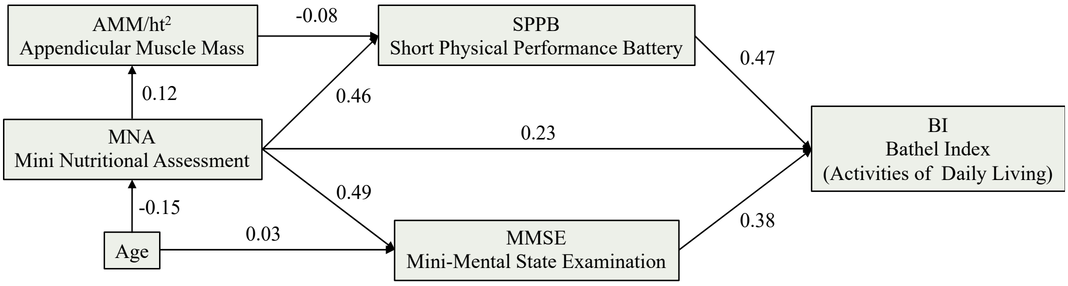


Figure 1.6 Path analysis of Mini Nutritional Assessment, Short Physical Performance Battery, Mini-Mental State Examination and Activities of Daily Living [7]

Moreover, factors effective for care prevention can be identified by breaking down the main cause that leads to a need for care. Sum of cerebrovascular disease and heart disease, which both relate to hypertension, accounted for 19.8 % (Figure 1.7, [8]). Among cases of dementia, the most prevalent disease to cause patients to require nursing care, 30.1 % were caused by cerebrovascular disease (Figure 1.7, [9]). These findings indicate that hypertension accounts for more than a quarter of nursing care cases. High blood pressure is also a risk factor for longer periods of care (Figure 1.8, [10]). On the other hand, articular diseases, fracture, and asthenia due to old age accounted for 36.5 % in total (Figure 1.7). These diseases are considered to be mainly caused by deterioration of physical performance [11] [12] [13] [14].

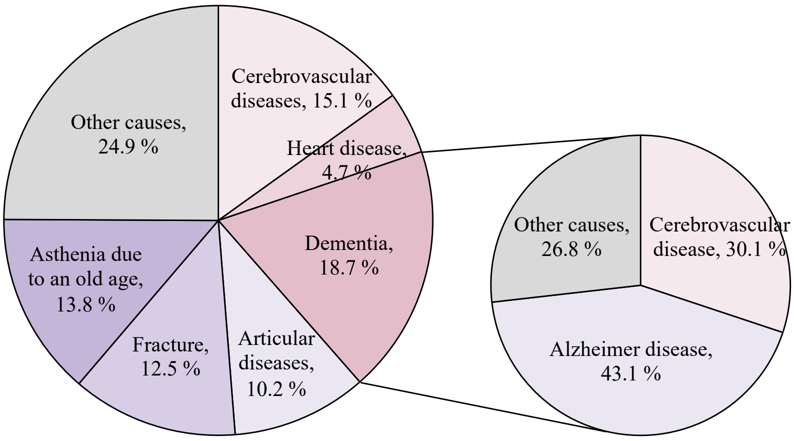


Figure 1.7 Percent distribution of main causes that lead to a need for care (modified and translated from [15] [9]**)**

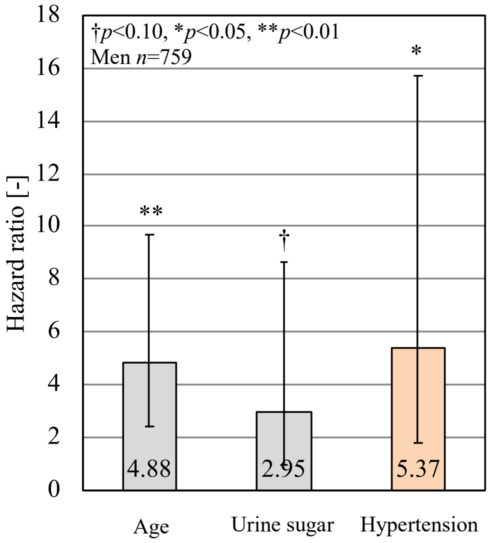


Figure 1.8 Risk factor for longer periods of care (modified and translated from [10]**)**

Another important indicator of health in older people is frailty. Frailty is regarded as a health condition of decreased functional reserves leading to a vulnerable state with the inherent risks of a multitude of adverse outcomes (Figure 1.9). Frailty is widely recognized as a considerable challenge for the society, but there is no single agreed definition or cause of the phenomenon. The definition suggested by Fried et al. [16] includes self-reported exhaustion, reduced grip strength, slow walking speed, and low level of physical activity. In addition to physical functioning, it has been suggested that definitions of frailty should also include aspects of mental health, such as cognition and mood [17]. Shinkai et al. [18] [19] include three domains in their definition of frailty: isolation risk, fall risk, and nutrition risk. With increasing age, frailty becomes more frequent and severe [20] [21] [22] [23] [24]. Frailty is associated with chronic disease [25], obesity [26], and female gender [24] [27] [28], as well as low education level and income [16]. When it comes to the impact of the environment, it is well known that being confined to the home is a risk factor for walking limitation and declining ADL [29] [30], thus increasing the risks of falling [31] [32] and subsequent mortality [33]. That is, different conditions in the environment may well contribute to worsen the consequences of frailty. Frailty most often leads to limitations in ADL, ultimately requiring nursing home placement [34] and increased use of health care resources [35]. For informal caregivers, care-recipient's frailty can be a significant predictor of caregiver burden [36] [37], which may lead to emotional distress [38], poor health, decreased quality of life [39] and increased health care consumption [40].

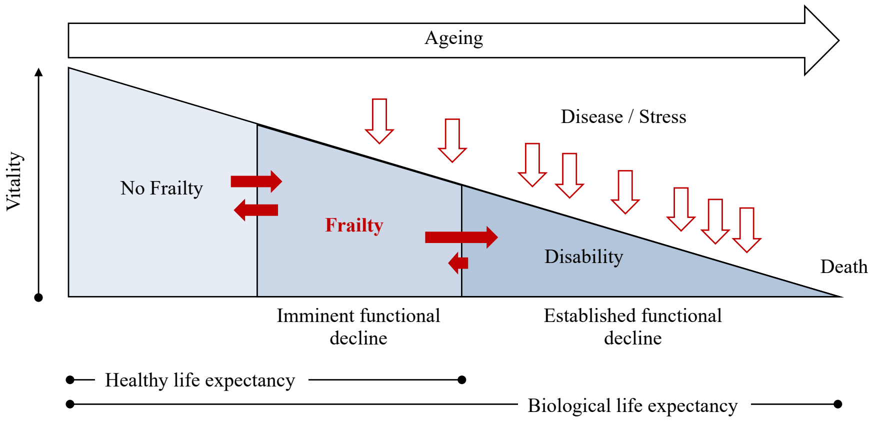


Figure 1.9 Concept of frailty (translated and modified from [41]**)**

1.2 Cold related health problems

Cold temperature has direct and indirect effects on health. Direct effects include increased incidence of respiratory and cardiovascular disease, falls and injuries, and hypothermia. Indirect effects include mental health effects from depression and increased absenteeism from school or work [42]. Cold related ill-health is a complex issue with many factors known to increase risk from cold. Figure 1.10 shows the relation between factors in housing conditions and their potential effects on health [43].

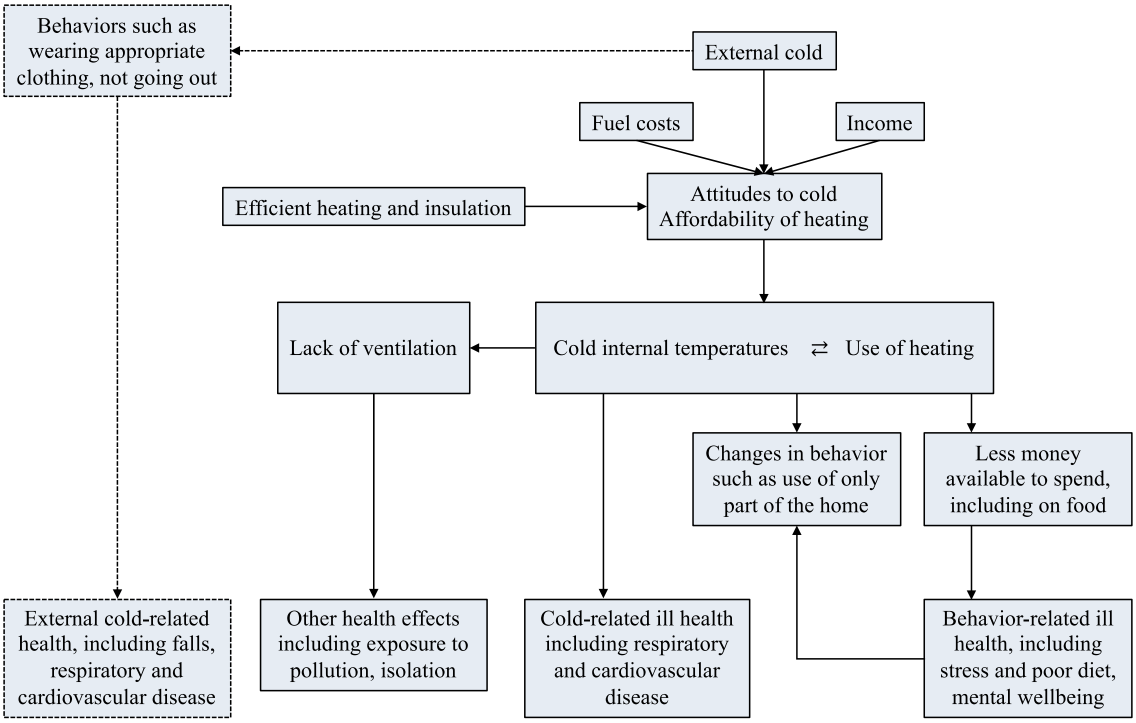


Figure 1.10 Factors linking cold temperatures to excess winter deaths and illness [43]

Excess winter deaths

Excess winter deaths are calculated as the number of deaths in winter in excess of the average for the rest of the year and represent a considerable public health burden. For example, 30 % more deaths occurred in winter compared to summer in a multi-country study [44] [45]. A 1 ˚C decrease in outdoor temperature ($temp_{out}$) was associated with a 1.35 % increase in the daily number of total natural deaths and a 1.72 %, 3.30 %, and 1.25 % increase in cardiovascular, respiratory, and cerebrovascular deaths [46]. Excess winter deaths are mostly amongst older people [47] [48] and are routinely linked to fuel poverty (FP) and living at low temperatures [49] [50]. It is suggested that 10 % of excess winter deaths could be directly attributed to FP, but some argue that this is too conservative an estimate [51]. In particular, elevated risk of death during winter for people living with Alzheimer's Disease and related dementias was found in the UK [52]. Excess winter deaths are greater in countries with milder climates than in those with more severe winter conditions [53], in part because countries with mild winters often have homes characterized by poor domestic thermal efficiency that are harder to heat than well insulated houses in more extreme climates. In addition, results from the Eurowinter [54] show that in relatively warm countries, older people often fail to wear protective clothing and do not remain indoors, so they are exposed to cold weather conditions outdoors.

Hospitalization

Some retrospective cohort studies investigated the association between cold temperature and hospitalization. Lower-than-average temperature and higher temperature fluctuations were associated with an increased risk of dementia hospitalizations in New England [55]. At the population-level, a 1 ˚C drop in $temp_{out}$ below a threshold of 15.6 ˚C was associated with a higher risk of hospitalizations by myocardial infarction [56]. To be more specific about indoor temperature ($temp_{in}$) in housing, a New Zealand study showed that insulation retrofit had a significant impact on reducing hospitalization and pharmaceutical costs for occupants of houses that had been remediated compared to those living in matched houses in the area who had not received insulation or heating as part of the research programme [57]. Individual characteristics of being a woman or older than 40 years [58], and having lower socioeconomic status [56] increased vulnerability to cold related hospitalization.

Cardiovascular disease: blood pressure

Elevated blood pressure, increased blood viscosity [59], and platelet activation [60] in moderate cold have been identified as important causal factors in the increased winter morbidity and mortality due to heart attacks and strokes. When it comes to blood pressure as an indicator, a cohort study in Japan called the HEIJO-KYO study explored multiple aspects of blood pressure and its relation to temp_{in}. In the cohort of 868 older people, 1 ˚C lower temp_{in} was significantly associated with 0.22 mmHg higher daytime Systolic blood pressure (SBP), while temp_{out} was not significantly associated [61]. A multivariate linear mixed effects regression showed that a 1˚C decrease in the ambient temperature was significantly associated with a 0.44 mmHg increase in the sleep-through blood pressure and 0.52 mmHg increase in the pre-waking blood pressure surge [62]. Moreover, an intervention that provided instructions in appropriate home heating increased the temp_{in} by 2.09 ˚C, and significantly decreased SBP by 4.43 mmHg after adjusting for confounders [63]. Another study in Japan that included a nationwide sample of 3,775 participants (2,095 households) found that SBP in the morning had significantly higher sensitivity to changes in temp_{in} (8.2 mmHg increase/ 10 ˚C decrease) than that in the evening (6.5 mmHg/ 10 ˚C decrease) [64]. Moreover, there was a nonlinear relationship between morning SBP and temp_{in} suggesting that the effect of temp_{in} on blood pressure varied depending on the range of temp_{in} [64]. A nationwide population-based study in Scotland recommended a minimal temp_{in} above 18 ˚C for the prevention of high blood pressure [65] since 9 % of hypertension cases could be prevented [66].

Respiratory disease

Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory lung disease that causes obstructed airflow from the lungs [67], and possible links have long been made between cold housing and COPD exacerbations. For people with COPD, maintaining 21 ˚C in living areas for at least 9 hours per day was associated with better health status [68]. Another cohort study from China among adults with COPD, reported reduced respiratory problems with a temp_{in} warmer than 18.2 ˚C regardless of whether indoor humidity was low, moderate or high [69].

Physical performance

There is evidence from experimental studies that cold exposure may reduce physical performance. It has been found that the working capacity of muscles [70] [71], maximal force production [72], and the time needed to attain maximal force [73] are all degraded by cooling. Furthermore, Oksa et al. [74] found that even mild cooling had a negative effect on physical performance. Lindemann et al. [75] showed that the physical performance of older women was worse in 15 ˚C room temperature compared with 25 ˚C room temperature. Moreover, in a cross-sectional study conducted among 2,012 non-institutionalized individuals aged over 60 years, the effect of poor housing conditions on the short physical performance battery (SPPB), mobility or agility limitations, frailty, and disability in instrumental activities of daily living (IADL) were investigated. As a result, the lack of heating was linked to lower scores in 3 SPPB tests, as well as with an increased frequency of frailty and 4 of its components (exhaustion, slow walking speed, low physical activity and weakness). Feeling cold was linked to increased exhaustion [76].

1.3 Fuel poverty

Qualitatively, FP is defined as the condition of being unable to afford to keep one's home adequately heated. A household is considered to be fuel poor if they have required fuel costs that are above the average (the national median level) and if they were to spend that amount, would be left with residual income below the official poverty line [77]. The image often portrayed is of an older person struggling to keep warm, using inefficient or ineffective heating technology in a poorly insulated home [78]. Policy measures have also to some degree prioritised older people over other groups in responding to what is generally termed FP.

Residential FP takes the form of thermal discomfort and is closely related to housing characteristics, e.g. heating system, energy efficiency, dampness, and mouldiness. Improving energy efficiency is the best long-term solution to tackling FP. Energy efficiency typically entails a tighter control of ventilation to avoid heat loss through the poorly controlled escape of heated air. In insulated dwellings, thermal insulation reduces conductive heat loss through the buildings' walls, ceilings and floors [79]. Choices of housing types, quality, size and location are shaped by a number of economic, social and demographic factors. These factors affect the features that the house will provide to its occupants and whether they can afford the cost of operating and maintaining it.

In comparison to other developed countries, Japan has one of the highest levels of inefficient housing stock. Figure 1.11 shows a comparison on heat transmission coefficient between Japan, the United States, and European countries, which is specified as one of energy conservation standard for thermal insulation performance. A lower heat transmission coefficient for the outer skin of the house (U_A-value) indicates higher thermal insulation performance of a house. In the figure, the heating degree-day ($D_{18\text{-}18}$) is defined as a day when the average daily temperature falls below 18 ˚C. The heating degree-day is calculated as the temperature difference between the average daily temperature and 18 ˚C. All countries establish energy conservation standards corresponding to the climatic conditions in respective regions, and require stricter standards in colder regions. The standard in Japan for a cold climate region corresponding to Sapporo and Asahikawa seems to be close to the same level as those of other countries. But the standards for other areas from Morioka to Sendai are easier to compare with other countries, although they have cold climates with heavy snow fall. Consequently, the standards in Japan are obviously behind those of other countries. Figure 1.12 shows a comparison on the coefficient of heat transmission for the window (U_W-value) in order to understand the thermal insulation performance of windows as positioned key components in the building envelope. The standards for U_W-value in Germany and the UK are twice as strict as those in Japan [80].

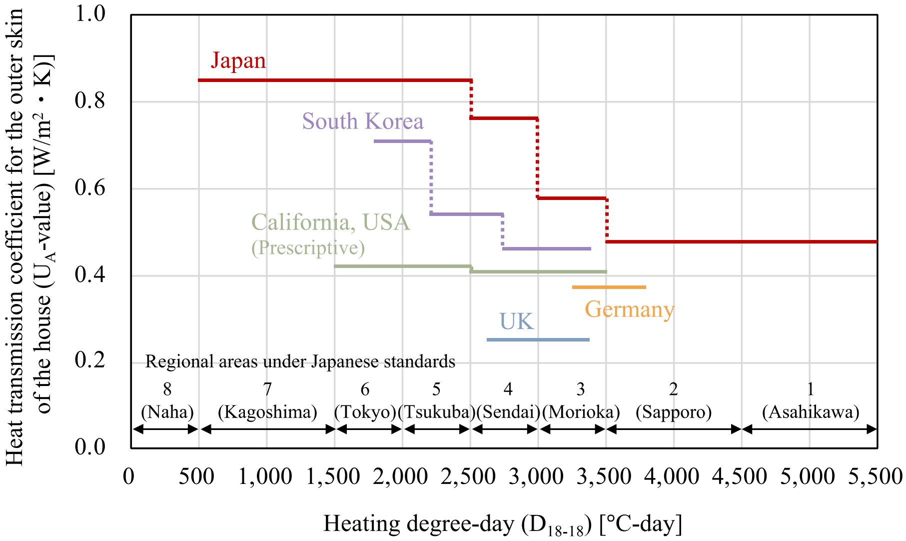


Figure 1.11 International comparison of standards for the average heat transmission coefficient for the outer skin of the house (U_A-value) [80]

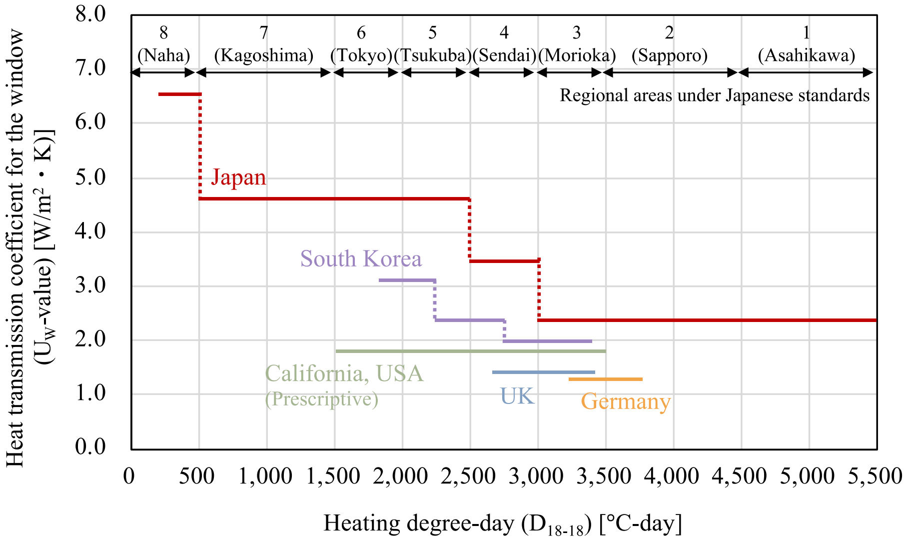


Figure 1.12 International comparison of standards for the average heat transmission coefficient for windows (U_W-value) [80]

However, residential energy consumption in Japan is relatively small compared with other countries (Figure 1.13, [81]). In Europe and US, it has become a general custom to live comfortably in a home uniformly heated with a central heating system even in winter. In contrast, the climate in Japan is relatively warm in winter and local heating in individual rooms in a house is most common in the Japanese culture. Only occupied rooms are heated by placing a heating unit, or rather kotatsu table, which is a unique Japanese table with heating electricity and a blanket. This leads to a great concern that people in Japan are living in a cold indoor environment, and suffering from high risk of health problems.

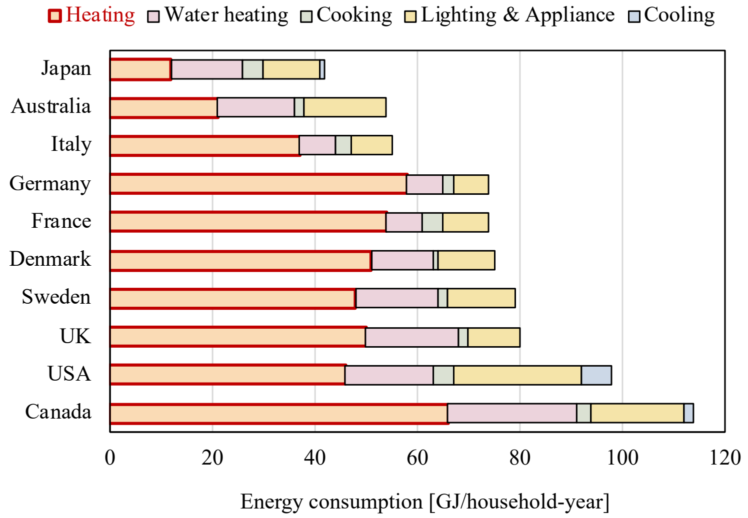


Figure 1.13 International comparison of mean residential energy consumption [81]

1.4 Efforts to prevent cold related health problems

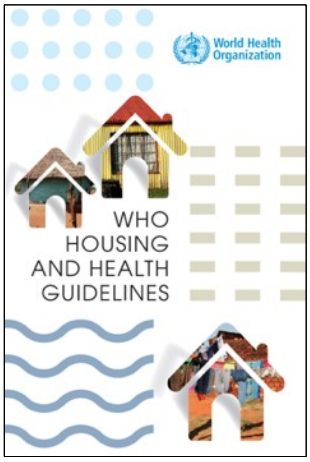
Strategies to avoid cold indoor thermal environments, which includes housing interventions can represent a major opportunity to promote "primary prevention" through intersectoral action [79]. Efforts in the UK are known to be particularly advanced. In this chapter, international and domestic efforts related to housing and health will be introduced.

1.4.1 International measures and efforts in foreign countries

1) Efforts by the World Health Orginisation

World Health Organisation Housing and Health Guidelines

In 2018, World Health Organisation (WHO) established the WHO Housing and Health Guidelines [79], aimed at informing housing policies and regulations at the national, regional and local level on the impact of housing on health. The Housing and Health Guidelines bring together the most recent evidence to provide practical recommendations to reduce the health burden due to unsafe and substandard housing conditions. They provide new guidance and recommendations relevant to inadequate living space (crowding), low and high indoor temperatures, injury hazards in the home, and accessibility of housing for people with functional impairments (Figure 1.14).



Topic	Recommendation	Strength of recommendation
Crowding	Strategies should be developed and implemented to prevent and reduce household crowding.	Strong
Indoor cold and insulation	Indoor housing temperatures should be high enough to protect residents from the harmful health effects of cold. For countries with temperate or colder climates, 18 ˚C has been proposed as a safe and well-balanced indoor temperature to protect the health of general populations during cold seasons.	Strong
	In climate zones with a cold season, efficient and safe thermal insulation should be installed in new housing and retrofitted in existing housing.	Conditional
Indoor heat	In populations exposed to high ambient temperatures, strategies to protect populations from excess indoor heat should be developed and implemented.	Conditional
Home safety and injuries	Housing should be equipped with safety devices (such as smoke and carbon monoxide alarms, stair gates and window guards) and measures should be taken to reduce hazards that lead to unintentional injuries.	Strong
Accessibility	Based on the current and projected national prevalence of populations with functional impairments and taking into account trends of ageing, an adequate proportion of the housing stock should be accessible to people with functional impairments.	Strong

Figure 1.14 Recommendations of the World Health Organisation Housing and Health Guidelines [79]

2) Efforts in England

Cold Weather Plan for England

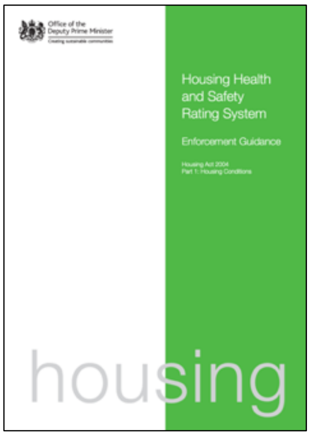
Since 2011 the UK Department of Health has published the National Cold Weather Plan (CWP) for England [42] (now published by Public Health England). The CWP aims to avoid the adverse health effects of cold weather by raising public awareness and triggering actions by those in contact with people who are most at risk. The CWP provides further detail about the evidence of the effects of cold on health (Figure 1.15) and what is known about the effectiveness of interventions in order to make the case for long term strategic planning and commissioning. The CWP covers the spectrum of action from planning to emergency response, including cold weather alerts [82] developed with the Met Office. The CWP was revised in 2014 to take into account research that found that the adverse effects of cold temperature on health can occur at relatively modest temperatures [83], suggesting that long-term interventions and the more general preparation for winter was more important than reactive interventions undertaken in response to severe weather.

Temperature	Effect
18 ˚C	Heating homes to at least 18 ˚C in winter poses minimal risk to the health of a sedentary person, wearing suitable clothing. Additional flexibility around advice for vulnerable groups and healthy people is outlined in the main Cold Weather Plan document.
Under 18 ˚C	May increase blood pressure and risk of cardiovascular disease.
Under 16 ˚C	May diminish resistance to respiratory diseases.
4-8 ˚C	Mean outdoor temperature threshold at which increased risk of death observed at population level.
5 ˚C	Poses a high risk of hypothermia.

Figure 1.15 The effects of temperatures on health shown in the Cold Weather Plan for England [42]

Housing Health and Safety Rating System

The Housing Act 2004 introduced a new risk assessment approach called the Housing Health and Safety Rating System (HHSRS) [84]. The HHSRS is used by local authorities to assess 29 housing hazards and the effect that each may have on the health and safety of current or future occupants of the property, such as damp, excess cold and electrical faults as well as risks for fire and falls (Figure 1.16). When a hazard is identified in a property, two tests must be applied: 1) What is the likelihood of a dangerous occurrence as a result of this hazard? and 2) If there is a dangerous occurrence, what would be the likely outcome? The likelihood and the severity of the outcome combine to generate a hazard score. Hazard scores are divided into 10 bands, with Band A being the most serious and Band J the least serious. Hazards which fall into bands A to C are called Category 1 hazards and those in bands D to J are Category 2 hazards. Councils have a duty to take some enforcement action where Category 1 hazards exist. They also have a discretionary power to take enforcement action where there are Category 2 hazards. Enforcement action involves the Council serving legal notices on the owner and/or manager of the property, and requiring them to carry out certain works in a specific timescale. In October 2018, the UK government launched a scoping review to consider whether HHSRS should be updated and, if so, to what extent. In late 2019, a comprehensive overhaul of the HHSRS began [85].



Physiological requirements

1. Damp & mould growth
2. Excess cold
3. Excess heat
4. Asbestos & MMF
5. Biocides
6. CO & fuel combustion products
7. Lead
8. Radiation
9. Uncombusted fuel gas
10. Volatile organic compounds

Psychological requirements

11. Crowding & space
12. Entry by intruders
13. Lighting
14. Noise

Protection against infection

15. Domestic hygiene, pests & refuse
16. Food safety
17. Personal hygiene sanitation & drainage
18. Water supply

Protection against accidents

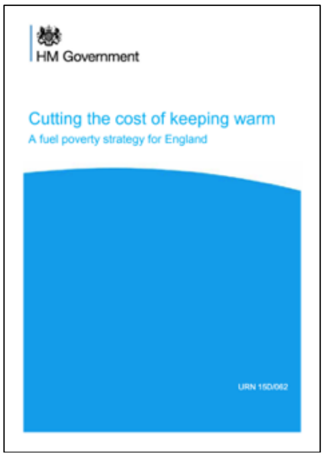
19. Falls associated with baths, etc.
20. Falling on level surfaces etc.
21. Falling on stairs etc.
22. Falling between levels
23. Electrical hazards
24. Fire
25. Flames, hot surfaces etc.
26. Collision and entrapment
27. Explosions
28. Position and operability of amenities etc.
29. Structural collapse and falling elements

MMF, manufactured mineral fibers; CO, carbon monoxide; VOCs, volatile organic compounds

Figure 1.16 Potential health and safety hazards in dwellings in the Housing Health and Safety Rating System [84]

Cutting the cost of keeping warm

The Department for Energy and Climate Change in England published a strategy – Cutting the cost of keeping warm: A FP strategy for England [86]. The strategy is underpinned by the FP target for as many fuel poor homes as reasonably practicable to achieve an energy efficiency standard of Band C by 2030, which became law in December 2014. Early measures to tackle the problem of FP and hit the new target include new regulations so that from April 2018 private landlords cannot rent out energy inefficient properties (homes with Energy Performance ratings below 'E'). Additionally, tackling the problem of FP in off gas grid properties with a new £25 million fund to help people install central heating systems for the first time. Plus, extending the successful ECO scheme to 2017, so that a further 500,000 properties will be made cheaper and easier to heat, building on the one million homes that ECO and Green Deal have helped in the last 2 years. Outcomes expected in the strategy are shown in Figure 1.17.


HM Government

Cutting the cost of keeping warm

A fuel poverty strategy for England

URN 15D/062

Outcomes
✓ Progress against the target and interim milestones
✓ Lower bills
✓ Increased comfort
✓ Improved health and wellbeing
✓ Improved partnership
✓ Improved evidence base and understanding
✓ Improved targeting
✓ Lower carbon emissions

Figure 1.17 Expected outcomes in the "Cutting the cost of keeping warm" strategy [86]

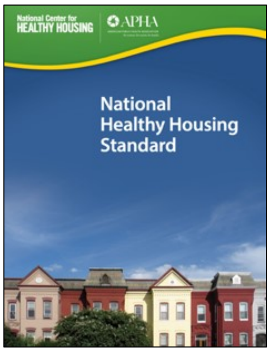
Excess winter deaths statistics

The Office for National Statistics [87] in England calculates excess winter mortality each year. This estimate is published on an annual basis in November each year and is available by region and age-group. PHE also undertakes weekly mortality surveillance which aims to detect and report acute significant excess mortality above usual seasonal levels in a timely fashion. This information is used to guide an urgent response to a public health threat such as an influenza epidemic or temperature extremes.

3) Efforts in the United States

National Healthy Housing Standard

National Healthy Housing Standard (NHHS) [88] was developed by the National Centre for Healthy Housing in cooperation with the American Public Health Association, to inform and deliver housing policy that reflects the latest understanding of the connections between housing conditions and health. A study by the National Centre for Healthy Housing found that 35 million – or 40 % – metropolitan US homes have one or more health and safety hazards. Moreover, progress on reducing exposure to these hazards is not improving as the number of homes with substandard conditions – 6.3 million units in the US – did not decrease from 2001 to 2011. The NHHS focuses on the over 100 million existing homes in the US [88]. In particular, NHHS focuses on the existing owner-occupied and rental housing, where regulations and industry practices have not kept pace with knowledge about housing-related disease and prevention of disease and injury through routine maintenance. The Standard provides a living tool for property owners, elected officials, code agency staff, and all who are concerned about housing as a platform for health. The NHHS provides health-based measures to fill gaps where no property maintenance policy exists and also serves as a complement to the International Property Maintenance Code and other housing policies already in use by local and state governments and federal agencies. Its recommendations, which are meant to constitute a set of minimum performance standards, are divided into seven chapters: owner and occupant duties; structures; lighting and electrical systems; thermal comfort, ventilation and energy efficiency; moisture control, solid waste, and pest management; and chemical and radiological agents (Figure 1.18). Each section includes stretch measures for those who may seek to go beyond the minimum requirements.



National Center for Healthy Housing
APHA
National Healthy Housing Standard

Duties of Owners and Occupants
1. Duties of Owners
2. Duties of Occupants

Structures, Facilities, Plumbing, and Space Requirements
1. Structure
2. Facilities
3. Plumbing System
4. Kitchen
5. Bathroom
6. Minimum Space
7. Floors and Floor Coverings
8. Noise

Safety and Personal Security
1. Egress
2. Locks/Security
3. Smoke Alarm
4. Fire Extinguisher
5. Carbon Monoxide Alarm
6. Walking Surfaces
7. Guards
8. Chemical Storage
9. Pools, Hot Tubs, and Other Water Features

Lighting and Electrical Systems
1. Electrical System
2. Outlets
3. Natural Lighting
4. Artificial Lighting

Thermal Comfort, Ventilation, and Energy Efficiency
1. Heating, Ventilation, and Air Conditioning Systems
2. Heating System
3. Ventilation
4. Air Sealing

Moisture Control, Solid Waste, and Pest Management
1. Moisture Prevention and Control
2. Solid Waste
3. Pest Management

Chemical and Radiological Agents
1. General Requirements
2. Lead-Based Paint
3. Asbestos
4. Toxic Substances in Manufactured Building Materials
5. Radon
6. Pesticides
7. Methamphetamine
8. Smoke in Multifamily Housing

Figure 1.18 Requirements and stretch provisions in the National Health Housing Standard [88]

4) Efforts in New Zealand

Rental Warrant of Fitness

The Rental Warrant of Fitness (WoF) [89] is a voluntary home assessment which residents can request to examine the basic health and safety components of a property delivered in New Zealand. The Rental WoF inspection has 63 questions and covers 29 criteria (Figure 1.19). An inspector comes to the property and the assessment takes about an hour to complete. The areas of the house that are assessed include ones which are known to have a direct impact on occupants' health and safety, can reduce work and school absences, and lead to greater household energy efficiency. The property receives a pass or fail on the spot, and a detailed report is emailed to the landlord. If a property doesn't pass the Rental WoF, the landlord has six months to make the improvements noted in the report and to book a re-assessment at no extra cost.

RENTAL HOUSING WOF

Criteria
1. Cooking facilities
2. Food preparation and storage
3. Potable water
4. Hot water temperature
5. Functional toilet
6. Provision of a bath or shower
7. Secure storage
8. Fixed space heating
9. Effective ventilation
10. Mould
11. Electrical safety
12. Indoor lighting
13. Working smoke alarms
14. Effective window latches
15. Window security stays
16. Curtains or blinds
17. Glass visibility strips
18. Ceiling insulation
19. Underfloor insulation
20. Ground vapour barrier
21. Weathertightness
22. Reasonable state of repair
23. Stormwater and waste water discharge
24. No ponding under house
25. Entrance way lighting
26. Structurally sound
27. Handrails and balustrades
28. Address clearly labelled and identifiable
29. Securely locking doors

Figure 1.19 Criteria in the Rental Warrant of Fitness [89]

1.4.2 Efforts in Japan

Building Energy Efficiency Act

The Japanese Building Energy Efficiency Act (BEEA) [90] has mainly focused on the reduction of energy consumption and CO_2 emissions, in response to a tightening of the electricity supply-demand balance after the oil crisis [91]. After the enacting the initial energy efficiency standard (S55 standard) in 1980, the standard was revised in 1992 (H4 standard) and 1999 (H11 standard) to enforce energy efficiency in-line with the energy conservation law. In 2011, the Great East Japan Earthquake highlighted the importance of energy conservation in the residential sector and led to another revision of the energy conservation law in 2013. The H25 standard was then established with the same energy efficiency level as the H11 standard. Subsequently, BEEA became independent from energy the conservation law in 2015 with the establishment of the H28 standard which also has the same energy efficiency level as the H11 standard (Table 1.2). BEEA provides for 1) regulatory measures for mandatory compliance with energy efficiency standards for large-scale non-residential buildings, and 2) incentive measures such as a labelling system displaying compliance with energy efficiency standards and exceptions to floor-area ratio regulations for certified buildings [90]. The key point is that complying with the energy efficiency standard is not mandatory and there is no duty to make efforts for residential building less than 300 m^2, and existing buildings.

Table 1.2 History of energy efficiency standard of residential building (translated and modified from [92]**)**

Standard	Revised point
1980 (S55) standard	Enactment of energy efficiency standard
1992 (H4) standard	Enhancement of energy efficiency performance of each member Application of air-tight house in area 1
1999 (H11) standard	Enhancement of energy efficiency performance of skeleton structure Application of air-tight house in all areas Additional provision for planned ventilation and heating systems Introduction of an evaluation standard for external insulation performance
2013 (H25) standard	Change in calculation method of the evaluation standard for external insulation performance Introduction of a primary energy consumption standard
2016 (H28) standard	Additional standard for primary energy consumption of equipment

The demand level of insulation performance and the primary energy consumption standard are established for each regional area (Figure 1.20) because Japan is long from north to south, and the climate varies distinctly across regions [93].

Regional division	Corresponded prefectures (Regional division is defined by municipality)
1 🟦	Hokkaido
2 🟦	
3 🟩	Aomori, Iwate, Akita
4 🟨	Miyagi, Yamagata, Fukushima, Tochigi, Niigata, Nagano
5 🟧	Ibaraki, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Toyama, Ishikawa, Fukui, Yamanashi, Gifu, Shizuoka, Aichi, Mie, Shiga, Kyoto, Osaka, Hyogo
6 🟧	Nara, Wakayama, Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita
7 🟪	Miyazaki, Kagoshima
8 🟥	Okinawa

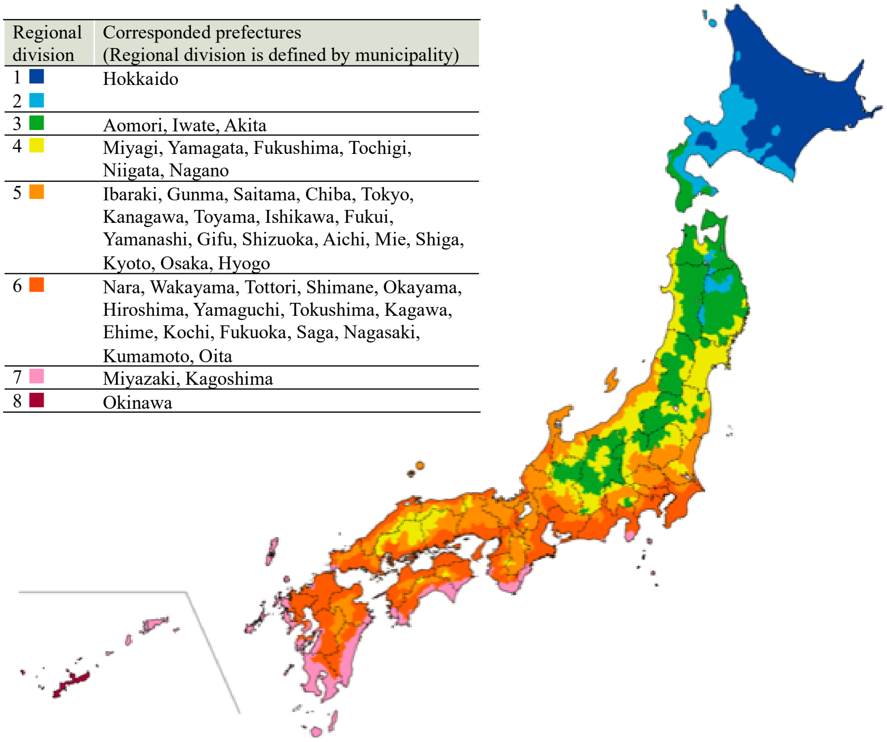
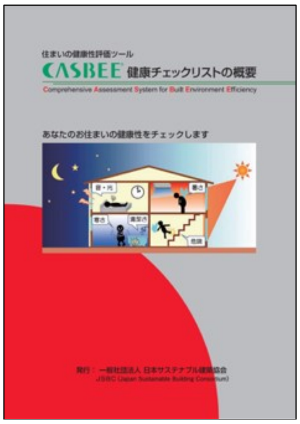


Figure 1.20 Regional division of energy efficiency standard [94]

Comprehensive Assessment System for Built Environment Efficiency Housing Health Checklist

Following the trends in foreign countries, investigative research on the relationship between the living environment and health has been conducted in Japan in recent years. At the centre of this movement was the "Health Maintenance Promoting Housing Research Council [95]," which was established under the Ministry of Land, Infrastructure and Transport (MLIT) between 2007 and 2013. Through several investigative research studies, design guides and evidence lists were published as deliverables of this movement. The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) Housing Checklist [96] is an easy evaluation tool used to assess the environmental problem in the house, which was developed as one of the deliverables in 2011. The checklist was created to help residents determine whether or not environmental factors and housing equipment pose any potential risks for their health. It consists of questions about the levels of heat in summer, cold in winter, noise, light, cleanliness, safety, and security of the living environment for each room in the house (Figure 1.21). Respondents are asked to mark the frequency of corresponding problems on a four-point sale: 1) often (0 point), 2) occasionally (1 point), 3) rarely (2 point), 4) not at all (3 point). The scores for each item are summed and higher scores indicate fewer problems in the living environment.



住まいの健康性評価ツール

CASBEE 健康チェックリストの概要

Comprehensive Assessment System for Built Environment Efficiency

あなたのお住まいの健康性をチェックします

発行：一般社団法人 日本サステナブル建築協会

JSBC (Japan Sustainable Building Consortium)

Rooms and places	Scores
1. Living room	21
2. Bedroom	21
3. Kitchen	15
4. Bathroom, dressing room, and washroom	21
5. Toilet	9
6. Entrance	9
7. Corridors, stairs, and storage	21
8. Surroundings	15
9. Optional	-

Health elements	Scores
1. Thermal environment	36
2. Acoustic environment	6
3. Light environment	12
4. Hygiene	27
5. Safety	45
6. Security	6

Figure 1.21 Evaluation item in Comprehensive Assessment System for Building Environment Efficiency Housing Health Checklist [96]

Standards for the indoor thermal environment in relation to older adults

Academic standards related to safety, hygiene, comfort, efficiency, and durability of residential buildings have been established by the Architectural Institute of Japan (AIJ). Academic standards are prepared from the standpoint of the institute and are referred to as a basis of administrative standards or technical standards. The working group on residential thermal environment for older people in AIJ has established standards for the indoor thermal environment for older people [97]. Since older people and people with serious medical conditions are known to be particularly vulnerable to the effects of cold temperature, the recommended indoor temperature for older people is set higher than for those in the general population (Table 1.3). However, the recommended relative humidity (RH) zone is the same for all groups (Table 1.4).

Table 1.3 Indoor temperature standards [97]

Target	Season	Living room	Bedroom	Kitchen	Corridor	Bathroom Dressing room	Toilet	Clothing
General	Winter	21±3˚C	18±3˚C	18±3˚C	18±3˚C	24±2˚C	22±3˚C	1.4-0.7clo
	Intermediate season	24±3˚C	22±3˚C	22±3˚C	22±3˚C	26±2˚C	24±2˚C	0.7-0.5clo
	Summer	27±2˚C	26±2˚C	26±2˚C	26±2˚C	28±2˚C	27±2˚C	0.5-0.2clo
Older people	Winter	23±2˚C	20±2˚C	22±2˚C	22±2˚C	25±2˚C	24±2˚C	1.4-0.7clo
	Intermediate season	24±2˚C	22±2˚C	22±2˚C	22±2˚C	26±2˚C	24±2˚C	0.7-0.5clo
	Summer	27±2˚C	25±2˚C	26±2˚C	26±2˚C	28±2˚C	27±2˚C	0.5-0.2clo
People with a disability	Winter	23±2˚C	20±2˚C	22±2˚C	22±2˚C	25±2˚C	24±2˚C	1.4-0.7clo
	Intermediate season	24±3˚C	22±2˚C	22±2˚C	22±2˚C	26±2˚C	24±2˚C	0.7-0.5clo
	Summer	25±2˚C	25±2˚C	25±2˚C	25±2˚C	27±2˚C	25±2˚C	0.5-0.2clo

Table 1.4 Relative humidity standards [97]

Season	All rooms
Winter	30-50%
Intermediate season	40-70%
Summer	60-80%

1.5 Thesis objective and outline

This thesis describes several strands of research examining the connection between resident's condition of needing LTC and the energy efficiency properties of the housing stock in Japan. The overarching objective was to contribute to the understanding of how the indoor thermal environment can promote health and prevent the need for LTC in aged people. Findings in this thesis are expected to provide useful knowledge for local authorities to protect individuals and communities from the effects of cold weather and encourage successful care prevention. Thus, the objective was to explore actual conditions and perceptions of health status, frailty, need of LTC among older people, and the indoor environment of housings or nursing homes. Additionally, this thesis investigated the relationships between personal and environmental factors in relation to FP. A further objective was to identify different types of housing conditions across the nation and explore the risks of FP. This investigation clarifies characteristics of housing and residents under higher risk of FP, which emphasises the role the housing sector and social care sector can play in tackling FP.

The specific objectives were:

1) To investigate the associations among health, frailty, age at LTC certification, and perceived temp_{in} of housing among community-dwelling older people in the context of FP.

2) To investigate the relationships between health, speed of deterioration of care level, and indoor thermal environment in Japanese nursing homes.

3) To identify different groups of housing conditions and resident characteristics which lead to higher risk of FP.

With regard to objective 1), chapter 2 presents a study investigating whether and how a warmer indoor thermal environment could prevent or delay LTC certification among clients from outpatient rehabilitation facilities. Physical performance, frailty, and age at LTC certification were selected as outcomes and investigated in relation to the indoor thermal environment of their home. Chapter 3 summarizes a study on the effects of indoor thermal environment in nursing homes on deterioration of the care level of residents. The effects of indoor thermal environment on residents' health was investigated from two aspects: 1) the relationship between temp_{in} and blood pressure and 2) the relationship between RH and oral dryness. Furthermore, the speed of decline of care level was investigated in relation to indoor thermal environment to understand which type of indoor thermal environment can prevent deterioration of care level. Chapter 4 describes a nationwide analysis of FP based on individual level data from the national Housing and Land Survey. A new methodology was suggested to identify the attributes of the residents and houses at risk for FP. Chapter 5 summarizes the studies and highlights the findings. The structure of this thesis is shown in Figure 1.22.

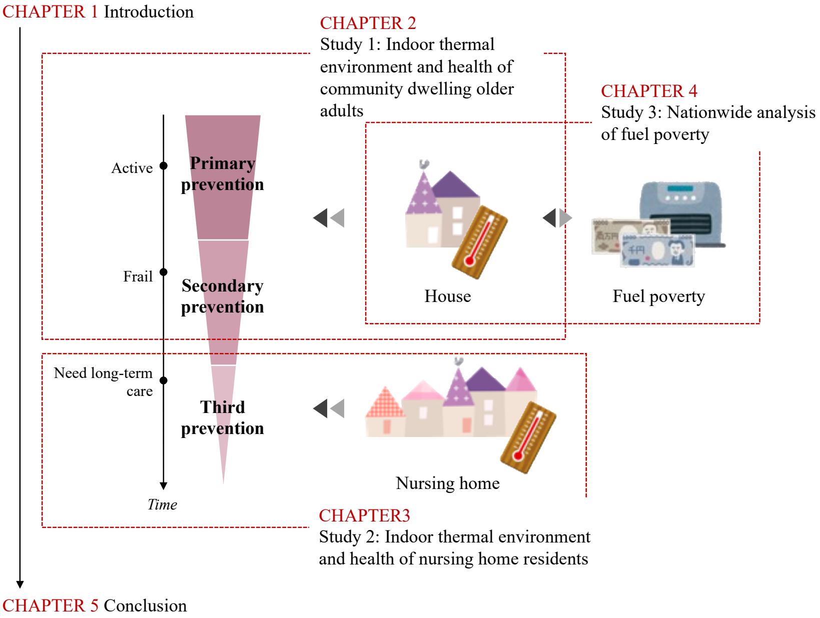


Figure 1.22 Structure of this Ph.D. thesis

Chapter 2

Study 1: Indoor thermal environment and health of community dwelling older adults

Chapter 2

Study 1: Indoor thermal environment and health of community dwelling older adults

2.1 Overview of study 1

In study 1, new knowledge regarding indoor thermal environment and the long-term care (LTC) needs of community-dwelling older people emerged from field work in several areas of Japan. Related to the definition of care prevention, study 1 used two approaches for prevention: primary prevention to prevent the need for LTC, and secondary prevention for early detection and response to deterioration of vital function. Several outcomes were selected to determine older adults' health and need for LTC: physical performance, frailty, and age at LTC certification. The results of the study also represent a broad knowledge of actual indoor thermal environment of individual houses of older people living in the community.

The overarching aim of study 1 was to investigate whether and how a warmer indoor thermal environment could support older adults to maintain health and independence, which would prevent or delay LTC certification. The specific aims were to: 1) reveal the winter indoor environment and use of heating system of community-dwelling older people in Japan, 2) explore the effect of seasonal temperature differences and cold indoor environment in winter on the physical performance, 3) investigate the relationships between self-reported risk for frailty and perceived indoor temperature, 4) determine whether economic satisfaction influences the relationship between self-reported risk for frailty and perceived indoor temperature, and 5) investigate whether older people who perceive their home as warm were older at LTC certification, which can be interpreted as successful care prevention. Works in study 1 are published in Journal of Environmental Research and Public Health [98] [99] and Journal of Environmental Engineering (Transactions of Architectural Institute Japan (AIJ)) [100] [101].

2.2 Methodology

2.2.1 Procedure and Participants

Data collection for this cross-sectional study was conducted during December of 2014, 2015, and 2017. Staff at outpatient rehabilitation facilities in Kochi, Osaka, and Yamanashi prefectures, Japan provided surveys to their clients. The surveys were either completed at the rehabilitation facility or at the participant's home, and 473 were returned. A sub group of participants were also included in data collection from long-term care insurance (LTCI) card and/or participated in measurement of indoor thermal environment of their home. The sample sizes of each survey are shown in Table 2.1. To be included in this study, participants had to be 65 years or older and use the facilities one to two times per week for physical rehabilitation. The study protocol was approved by the Keio University Ethics Review Board on 4 August 2014 (26-11), 29 July 2015 (27-31), and 29 August 2017 (29-79). All participants received oral and written information, and the questionnaires were filled out anonymously.

Participants in collection of data of physical performance measurement and LTCI card, and participants in measurement of indoor thermal environment received letters of information as well, and signed informed consent.

Table 2.1 Number of participants in each survey

Participants in questionnaire survey	473 older adults using an outpatient rehabilitation facility (Osaka n = 187, Kochi n = 190, Yamanashi n = 96)
Participants in collection of data of physical performance measurement	162 questionnaire survey participants (Osaka n = 162)
Participants in collection of data from long-term care insurance card	307 questionnaire survey participants (Osaka n = 137, Kochi n = 90, Yamanashi n = 80)
Participants in measurement of indoor thermal environment	104 questionnaire survey participants (Osaka n = 75, Kochi n = 17, Yamanashi n = 12)

2.2.2 Measures

Indoor temperature and relative humidity

Indoor temperature ($temp_{in}$) and relative humidity (RH) were measured at 10 min intervals 1.1 m above the floor in living rooms, bedrooms, and dressing rooms for approximately 2 weeks in the periods shown in Table 2.2. $Temp_{in}$ and RH in living rooms and bedrooms were measured by using data loggers RTR-503 (T&D Corporation, Japan) with an accuracy of ± 0.3 ˚C from 0 to 55 ˚C and a 0.1 ˚C resolution, and ± 5 % from 10 to 95 % and a 1 % resolution. $Temp_{in}$ in dressing rooms were measured using data loggers RTR-501 (T&D Corporation) with an accuracy of ± 0.5 ˚C from -40 to 80 ˚C and a 0.1 ˚C resolution. We had no control over the types of clothing people wore or use of heating systems when they were at home. Outdoor temperature ($temp_{out}$) during measurement periods were as shown in Table 2.3. Winter in 2015 was a mild winter and $temp_{out}$ was relatively high compared to the other years.

Table 2.2 Measurement periods

Period	Osaka	Kochi	Yamanashi
8 December 2014 – 26 December 2014	*		
7 December 2015 – 31 December 2015	*	*	
1 December 2017 – 21 December 2017		*	*

Table 2.3 Outdoor temperature during measurement periods, ˚C

	Mean	SD
Osaka		
8 December 2014 – 26 December 2014	5.39	2.01
7 December 2015 – 31 December 2015	8.96	3.05
Kochi		
7 December 2015 – 31 December 2015	10.85	3.06
1 December 2017 – 21 December 2017	6.78	2.06
Yamanashi		
1 December 2017 – 21 December 2017	2.94	1.82

SD, standard deviation.

Perceived indoor temperature

Perceived $temp_{in}$ was examined using the standardised questionnaire, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) Health Checklist [96]. Respondents are asked to mark the frequency of corresponding problems on a four-pointed scale: 1) often (0 point), 2) occasionally (1 point), 3) rarely (2 point), 4) not at all (3 point). The scores for each item are summed and higher scores indicate fewer problems in the living environment. In this study, six questions about feeling cold in the living room, bedroom, dressing room, bathroom, toilet, and corridor were used to evaluate the perceived $temp_{in}$ in winter. The scores on perceived $temp_{in}$ from the CASBEE Health Checklist were not normally distributed. Therefore, participants with higher scores (10 – 18 points) were classified into the Warm group, and participants with lower scores (0 – 9 points) were classified into the Cold group.

Participant characteristics

Participants' characteristics included self-reported age, gender, height, weight, level of education (junior high school or less/ senior high school/ university or higher), and number of family member. Body mass index (BMI) was calculated from height and weight. Whether living alone or not was determined from the number of family member (1 for living alone and more than 2 for living with someone).

Housing characteristics

Housing characteristics were asked in the standardised questionnaire, which included building age (less than 10 years/ 11 – 20 years/ 21 – 30 years/ 31 – 40 years/ more than 41 years), time at residence (same options as building age), energy efficiency of window glass (single pane/ double pane/ don't know) and use of heating systems in the living room, bedroom and dressing room (yes/no for each heating system).

Economic satisfaction

Economic satisfaction was measured with a study specific question, with four response choices: "Very satisfied", "Somehow satisfied", "Not very satisfied" and "Not satisfied at all". Economic satisfaction was dichotomized for the analyses: "Very satisfied" and "Somehow satisfied" were considered as "Satisfied", and "Not very satisfied" and "Not satisfied at all" were considered as "Unsatisfied".

Measurement of physical performance

All the data on physical performance were collected from records in the rehabilitation facility. The primary assessment was performed when people began using the facility and was then repeated every 3 months. Assessed items were grip strength (kg), static postural and balance control assessed by single-leg standing time (s), and balance and gait function assessed by the Timed Up & Go (TUG) test (s). Grip strengths were measured with dynamometer TKK 5001 (Takei Scientific Instruments Co., Japan) in the seated position. The best performance of two trials was selected for each side. Single-leg standings were performed with eyes open and arms on the hips without assistance on one leg and were timed in seconds from the time one foot was flexed off the floor to the time when either it touched the ground or the standing leg or an arm left the hips. Single-leg standing was assessed in both legs. Measurement of grip strength and single-leg standing were based on "the Deployment plan for a physical performance test" established by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) [102]. TUG tests were introduced in 1991 by Podsiadlo and Richardson [103] as a modification of the Get-Up and Go Test of Mathias et al. [104]. TUG tests were timed in seconds from the time to rise from the chair, walk 3 m, turn around a corner, walk back to the chair, and sit down. In TUG tests, both right turns and left turns around the corner were assessed.

Frailty Index

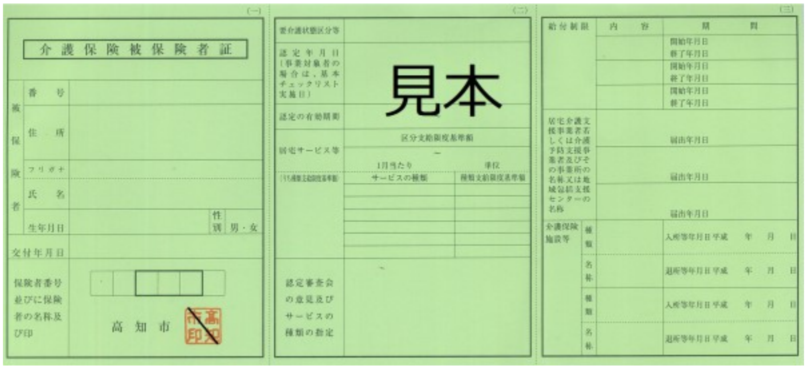
To measure frailty, we used the "Kaigo-Yobo Check-List" proposed by Shinkai et al. [18] [19], which can be easily self-administered by responding to 15 items (Table 2.4). All of the items are answered on a two-point scale, positive answer (0 point) or negative answer (1 point). The items are summed to calculate a total score ranging from 0 to 15 with higher scores indicating a higher risk of frailty. This checklist has three sub-scales that measure the risk of becoming frail: isolation risk, fall risk, and nutrition risk. Sum scores can also be calculated for each subscale: Isolation Risk (0 – 5), Fall Risk (0 – 6), and Nutrition Risk (0 – 4).

Table 2.4 The frailty index translated from Kaigo-Yobo Check-List (translated from [18] [19])

Category	Item
Isolation risk	1) Do you often stay at home and do not go outside for a day? Positive answer: No/ Negative answer: Yes
	2) How often do you go outside for work (including farming), shopping, walking, or hospital visits? *Does not include gardening or taking out the garbage. P: More than once in a couple of days / N: Less than once a week
	3) Do you have hobby(ies) in the house or outside the house? P: Yes/ N: No
	4) Do you have friend(s) in the neighbourhood? P: Yes/ N: No
	5) Do you have friend(s) other than your neighbours, family or relatives living apart who keep in touch? P: Yes/ N: No
Fall risk	6) Have you had a fall within the past one year? P: No/ N: Yes
	7) Can you walk 1 km continuously? P: Can do it without any discomfort/ N: Can do it, but with discomfort or cannot do it
	8) Do you have good eyesight? *You can use your glasses P: Yes, I can read a book/ N: No, T cannot see well or cannot see anything
	9) Do you often slip or stumble in the house? P: No/ N: Yes
	10)Do you avoid going outside because of fear of falling? P: No/ N: Yes
	11)Have you been hospitalised in the past year? P: No/ N: Yes
Nutrition risk	12)Do you have an appetite recently? P: Yes/ N: No
	13)How much can you chew now? *You can use the artificial tooth P: I can chew most things/ N: I cannot really chew and things to eat are limited
	14)Have you lost more than 3 kg of your weight in the past 6 months? P: No/ N: Yes
	15)Do you think that you have lost more muscle or fat than before in the past 6 months? P: No/ N: Yes

Age at long-term care certification

Valid period of LTC certification and care level was collected from LTCI card (Figure 2.1) stored in the rehabilitation facility. Care level has 7 levels including 2 levels of Support-required, and care level 1 (least disabled) to 5 (most disabled). In the certification process, eligibility is assessed by use of a 74-item questionnaire based on activities of daily living, with a preliminary categorisation into one of seven levels by a computer algorithm, then reviewed and finalised by an expert committee [5]. From the valid period of LTC certification and age, "age at LTC certification" was used to assess healthy life expectancy. Even if a participant had multiple times of certification for LTCI service on a long-term basis, only data at the first certification was used in the analysis. Older age at LTC certification was considered as successful care prevention.



（一）

介護保険被保険者証

被保険者
番号
住所
フリガナ
氏名
生年月日　性別　男・女

交付年月日

保険者番号並びに保険者の名称及び印　高知市

（二）

要介護状態区分等

認定年月日（事業対象者の場合は、基本チェックリスト実施日）

見本

認定の有効期間

居宅サービス等　区分支給限度基準額
1月当たり　単位
サービスの種類　種類支給限度基準額

認定審査会の意見及びサービスの種類の指定

（三）

給付制限	内容	期間
		開始年月日 終了年月日
		開始年月日 終了年月日
		開始年月日 終了年月日

居宅介護支援事業者若しくは介護予防支援事業者及びその事業所の名称又は地域包括支援センターの名称
届出年月日
届出年月日
届出年月日

介護保険施設等
種類　入所等年月日 平成　年　月　日
名称　退所等年月日 平成　年　月　日
種類　入所等年月日 平成　年　月　日
名称　退所等年月日 平成　年　月　日

Figure 2.1 Long-term care insurance card [105]

2.2.3 Data analysis

For continuous variables with a normal distribution, mean ± standard deviation (SD) was reported. As static postural and balance control had a skewed distribution, the logarithm value was used in the analysis. All *p*-values were two-sided, and $p < 0.05$ was considered statistically significant. All statistical analyses were performed with SPSS version 24.0 (IBM, Armonk, NY, USA).

Measured indoor temperature and relative humidity

By using the Student's *t*-test, minimum/ average/ maximum measured temp_{in} and RH were compared between the Warm group and Cold group, and between the group using and not using the heating system.

Indoor temperature and physical performance

In the investigation of physical performance, it was hypothesized that there are seasonal trends in the physical performance of older people, with worse physical performance in the winter compared to intermediate seasons such as autumn. The secondary hypothesis was that people living in colder houses would have a greater reduction in physical performance compared to those in warmer houses. Physical performance assessments from the rehabilitation facility in autumn (from September to November) and winter (from December to February) were compared by using a paired *t*-test. When we assessed the changing rate of physical performance between autumn and winter among individual attributes, a simple linear regression analysis was used and partial regression coefficients were reported. Participants who measured temp_{in} of their houses were classified into the Warm group and the Cold group based on the temp_{in} of 18 ˚C recommended in World Health Organisation (WHO) Housing and Health Guideline [79]. Because of cold housing in Japan due to low thermal insulation, the mean temp_{in} rather than the minimum temp_{in} of living room was used for classification. Using the 18˚C threshold, 8 participants were classified into the Warm group, and 28 participants were classified into the Cold group based on measured temp_{in} during winter. The characteristics of each group were compared using a chi-square test or Fisher's exact test for categorical variables and a Student's *t*-test for continuous variables. Physical performances in autumn and winter were compared for both groups by using a paired *t*-test in each group.

Perceived indoor temperature, economic satisfaction and frailty index

Analysis of covariance (ANCOVA) was used to test for differences between the perceived temp_{in} groups and the economic satisfaction groups with the frailty index as the dependent variable. Perceived temp_{in}, economic satisfaction, and the interaction between these two factors were in the model as independent variables. Since we know from previous research that they are associated with frailty, gender [24] [27] [28], living alone or not [106], education [16], age [107] and BMI [26], were in the model as covariates. Spearman's correlations between each covariate and the independent variables were not larger than 0.2. Multivariate analysis of covariance (MANCOVA) was used to test the three subscales of the frailty index (isolation risk, fall risk, and nutrition risk) using the same independent variables and covariates as the previous model. Wilks' Lambda was used as the omnibus test of the MANCOVA. Both models used the general linear model for the analyses.

Perceived indoor temperature and age at long-term care certification

Survival analysis was used to compare the speed of LTC certification between the Cold group and the Warm group. Overall survival was defined as the age at first LTC certification. The primary statistical analysis of Kaplan-Meier method that used the generalized Wilcoxon test was used, followed by Cox regression to estimate the hazard ratio (HR) and 95 % confidence interval (CI). A multivariable Cox proportional hazard model was fitted to investigate whether perceived temp_{in} was a risk factor of LTC certification. Furthermore, ANCOVA was used to test for differences between perceived temp_{in} groups with the age at LTC certification as the dependent variable. In the multivariable Cox proportional hazard model and ANCOVA, survey area and the same variables used in the ANCOVA or MANCOVA for frailty index were used as covariates.

Although effects from confounding factors were attempted to be adjusted in the multivariate Cox proportional hazard model and ANCOVA, healthy life expectancy is known to be different between gender and each survey area likely have different climate and natural features, which makes the confounding factors difficult to adjust. Therefore, differences of age at LTC certification between perceived temp_{in} groups in consideration of participant characteristics were tested. On this occasion, sample size by characteristic is considered to be small and therefore Student's *t*-test was used for the comparison.

The perception of older people is considered to be duller than perception of younger people [108]. Therefore, even in the Warm group, there might be a certain number of people living in a cold indoor environment yet perceive it as warm. Therefore, as a sub analysis, comparing the relation between measured temp_{in} and age at LTC certification was tested by using analysis of variance (ANOVA). The participants who participated in the actual measurement were divided by measured mean temp_{in} in units of 2 ˚C. However, the participants with a mean dressing room temperature over 18 ˚C were only 3 people, and the highest temperature group was set to be over 16 ˚C.

2.3 Results

2.3.1 Measured indoor temperature and relative humidity

For perceived $temp_{in}$ in the living room, bedroom, and dressing room, 46.8 %, 57.6 %, and 41.0 % of the participants responded “not at all (3 point)” for the frequency of feeling cold (Figure 2.2). Moreover, the total score of perceived $temp_{in}$ in the living room, bedroom, dressing room, bathroom, toilet, and corridor was not normally distributed, and 14.6 % of participants had the maximum score of 18 points (Figure 2.3).

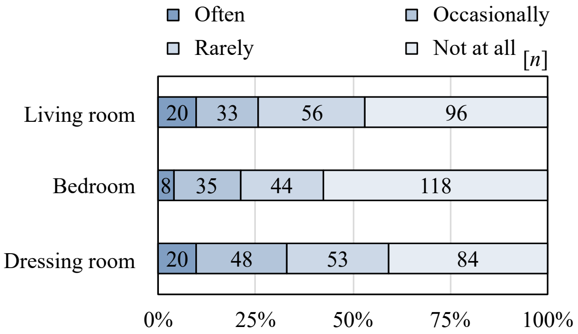


Figure 2.2 Perceived indoor temperature in each room

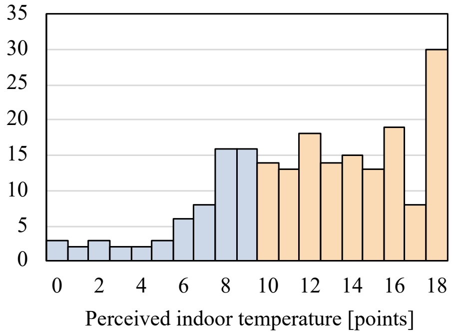


Figure 2.3 Distribution of total score of perceived indoor temperature

Use of heating systems in the living room, bedroom, and dressing room were aggregated for 163 participants in the 2015 and 2017 surveys (Figure 2.4). Air conditioner was the most used heating in the living room (n = 110, 67.5 %) and bedroom (n = 85, 52.1 %). In contrast, stove was the most used heating in the dressing room (n = 44, 27.0 %). Next to the air conditioner, kotatsu[1], electric blanket, and stove which heats the body locally can been seen.

---

[1] A traditional Japanese heating appliance. It is a low table with a thick blanket laid over it, and an upper table-top which holds the blanket in place. The inside of the kotatsu is heated, and people place their legs under it while sitting on the floor.

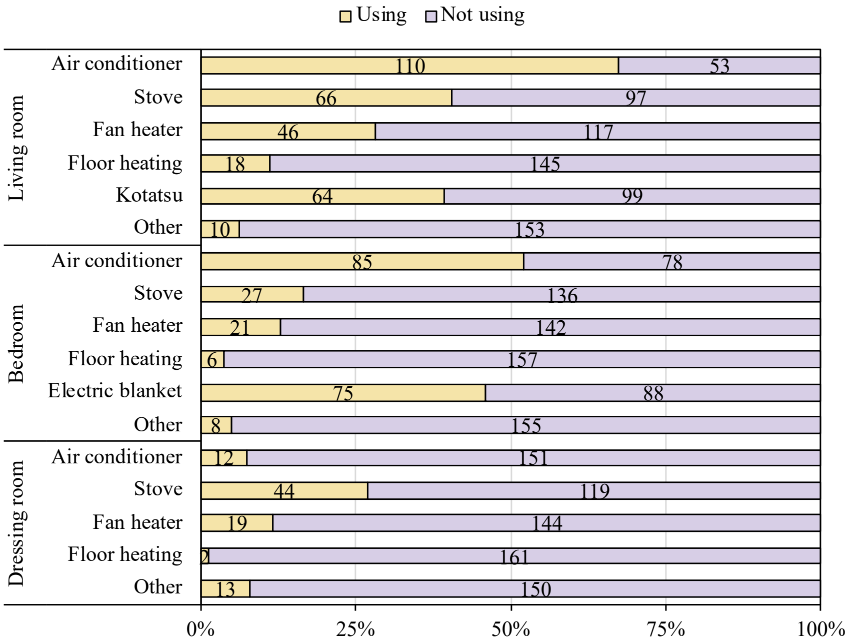


Figure 2.4 Heating use situation (multiple answers allowed)

The statistical tests for temp$_{\text{in}}$ and RH for the Warm and Cold groups are presented in Table 2.5. Mean temp$_{\text{in}}$ of the Cold group was lower in all rooms (Living room: Cold group, 14.7 ± 2.6 ˚C; Warm group, 17.0 ± 2.2 ˚C; $t(77) = -4.10$, $p < 0.01$. Bedroom: Cold group, 13.7 ± 3.4 ˚C; Warm group, 16.0 ± 3.0 ˚C; $t(77) = -3.19$, $p < 0.01$. Dressing room: Cold group, 12.0 ± 2.9 ˚C; Warm group, 14.7 ± 2.5 ˚C; $t(77) = -4.25$, $p < 0.01$) but mean RH was not significantly different between the Cold group and the Warm group (Living room: Cold group, 50 ± 7 %; Warm group, 48 ± 8 %; $t(77) = 1.29$, $p = 0.17$. Bedroom, Cold group, 52 ± 7 %; Warm group, 51 ± 11 %; $t(77) = 0.70$, $p = 0.42$). In the living room temperature, mean and minimum temp$_{\text{in}}$ significantly differ between the Cold group and the Warm group. Mean temp$_{\text{in}}$ was lower than the recommended room temperature 18 ˚C [79] even in the living room of the Warm group (17.0 ± 2.2 ˚C). In contrast, there were no significant differences in maximum temp$_{\text{in}}$ in the living room and bedroom (Living room: Cold group, 20.6 ± 4.1 ˚C; Warm group, 21.6 ± 2.7 ˚C; $t(77) = -1.24$, $p = 0.21$. Bedroom, Cold group, 19.1 ± 3.9 ˚C; Warm group, 20.6 ± 4.0 ˚C; $t(77) = -1.59$, $p = 0.12$). Comparisons of RH were significant only in the maximum RH in the living room, and the Warm group had lower maximum RH (Cold group, 64 ± 12 %; Warm group, 56 ± 9 %; $t(77) = 2.92$, $p < 0.01$). However, most houses had RH from 30 to 50 %, which meets the basis of indoor thermal environment standards recommended for older adults by the Architectural Institute of Japan [97].

Table 2.5 Student's *t*-test of indoor temperature and relative humidity by the Cold group (*n* = 26) and Warm group (*n* = 52)

	Minimum					Average					Maximum				
	Cold gr.		Warm gr.		*p*	Cold gr.		Warm gr.		*p*	Cold gr.		Warm gr.		*p*
	M	SD	M	SD		M	SD	M	SD		M	SD	M	SD	
Temp$_{\text{in}}$ [˚C]															
Living room	10.1	2.8	12.9	3.1	<0.01	14.7	2.6	17.0	2.2	<0.01	20.6	4.1	21.6	2.7	0.21
Bedroom	9.9	3.1	12.6	3.2	<0.01	13.7	3.4	16.0	3.0	<0.01	19.1	3.9	20.6	4.0	0.12
Dressing room	12.6	3.5	12.1	3.0	<0.01	12.0	2.9	14.7	2.5	<0.01	16.4	3.1	18.6	2.6	<0.01
RH [%]															
Living room	38	9	38	9	0.97	50	7	48	8	0.17	64	12	56	9	<0.01
Bedroom	41	9	42	12	0.77	52	7	51	11	0.42	62	8	59	12	0.20

gr., group; M, mean; SD, standard deviation; Temp$_{\text{in}}$, indoor temperature; RH, relative humidity.

Difference of temp$_{\text{in}}$ and RH by type of heating system used in each room are presented in Table 2.6. Floor heating in the dressing room was not tested because there was only one person using floor heating in the dressing room. As a result, use of air conditioner was associated with higher average temp$_{\text{in}}$ in all rooms (Living room: using, 16.1 ± 2.0 ˚C; not using, 15.3 ± 3.1 ˚C; $t(45) = 0.90$, $p = 0.37$. Bedroom: using, 16.3 ± 2.7 ˚C; not using, 13.9 ± 3.9 ˚C; $t(45) = 2.49$, $p = 0.02$. Dressing room: using, 14.4 ± 3.7 ˚C; not using, 14.0 ± 3.2 ˚C; $t(45) = 0.27$, $p = 0.79$). On the other hand, use of fan heater made the maximum temp$_{\text{in}}$ higher (using, 22.8 ± 2.6 ˚C; not using, 20.5 ± 2.6 ˚C; $t(45) = 2.58$, $p = 0.01$) but the minimum temp$_{\text{in}}$ lower (using, 9.2 ± 4.2 ˚C; not using, 12.4 ± 2.9 ˚C; $t(45) = -2.95$, $p = 0.01$) in the living room. But in the dressing room, use of fan heater made both average temp$_{\text{in}}$ (using, 10.4 ± 4.3 ˚C; not using, 14.7 ± 2.6 ˚C; $t(45) = -3.63$, $p = 0.04$) and minimum temp$_{\text{in}}$ (using, 6.3 ± 5.2 ˚C; not using, 11.8 ± 3.4 ˚C; $t(45) = -3.67$, $p < 0.01$) lower. Moreover, use of kotatsu table in the living room was associated with lower average (using, 13.3 ± 2.7 ˚C; not using, 16.7 ± 1.6 ˚C; $t(45) = -5.24$, $p < 0.01$) and minimum (using, 8.3 ± 3.5 ˚C; not using, 12.6 ± 2.9 ˚C; $t(45) = -4.05$, $p < 0.01$) living room temp$_{\text{in}}$.

Table 2.6 Student's *t*-test of indoor temperature and relative humidity by use of heating system

	Minimum					Average					Maximum				
	Using		Not using		*p*	Using		Not using		*p*	Using		Not using		*p*
	M	SD	M	SD		M	SD	M	SD		M	SD	M	SD	
Living room temp$_{\text{in}}$ [˚C]															
Air conditioner[a]	11.2	3.1	10.8	4.1	0.17	16.1	2.0	15.3	3.1	0.37	21.8	2.5	20.7	2.4	0.24
Stove[b]	11.4	3.0	11.7	3.9	0.73	15.3	2.4	16.4	2.3	0.14	20.3	3.0	21.7	2.4	0.06
Fan heater[c]	9.2	4.2	12.4	2.9	0.01	15.4	2.9	16.1	2.2	0.39	22.8	2.6	20.5	2.6	0.01
Floor heating[d]	12.9	1.6	11.3	3.8	0.05	15.9	1.9	15.9	2.5	0.99	19.5	2.3	21.5	2.8	0.05
Kotatsu[e]	8.3	3.5	12.6	2.9	<0.01	13.3	2.7	16.7	1.6	<0.01	20.6	3.6	21.2	2.5	0.48
Living room RH [%]															
Air conditioner[a]	38	11	38	8	0.74	50	8	48	6	0.30	63	11	59	11	0.23
Stove[b]	41	11	37	9	0.22	51	7	49	7	0.36	62	9	61	13	0.73
Fan heater[c]	32	8	41	10	0.01	47	7	59	7	0.21	61	12	61	11	0.96
Floor heating[d]	45	7	37	10	0.03	50	7	49	7	0.70	56	7	62	11	0.11
Kotatsu[e]	36	10	40	10	0.25	50	7	49	7	0.70	66	10	59	11	0.07
Bedroom temp$_{\text{in}}$ [˚C]															
Air conditioner[f]	12.2	3.3	10.4	4.2	0.10	16.3	2.7	13.9	3.9	0.02	21.5	3.4	19.1	4.1	0.04
Stove[g]	11.5	2.4	11.5	4.1	0.98	15.2	2.2	15.4	3.8	0.86	19.8	4.1	20.8	5.8	0.47
Fan heater[h]	11.6	3.5	11.5	3.8	0.98	16.2	2.5	15.2	3.5	0.47	22.4	2.8	20.2	3.9	0.16
Floor heating[i]	13.3	1.7	11.4	3.9	0.33	15.7	1.4	15.3	3.5	0.81	19.4	1.2	20.7	4.0	0.55
Electric blanket[j]	10.7	4.4	12.2	3.0	0.17	14.6	4.3	16.0	2.2	0.17	19.9	4.3	21.1	3.4	0.38
Bedroom RH [%]															
Air conditioner[f]	40	12	44	9	0.25	51	9	53	7	0.49	62	10	61	8	0.89
Stove[g]	47	11	40	11	0.09	55	8	51	9	0.22	63	7	61	10	0.45
Fan heater[h]	37	10	43	11	0.25	49	8	53	9	0.31	60	12	62	9	0.75
Floor heating[i]	51	1	41	1	<0.01	55	1	52	9	0.44	61	1	62	10	0.86
Electric blanket[j]	42	11	41	11	0.79	53	9	51	8	0.46	62	9	61	10	0.67
Dressing room temp$_{\text{in}}$ [˚C]															
Air conditioner[k]	10.9	4.7	11.0	4.1	0.95	14.4	3.7	14.0	3.2	0.79	19.5	2.2	18.3	2.8	0.31
Stove[l]	9.6	3.8	11.8	4.1	0.09	13.1	2.9	14.6	3.4	0.14	18.5	2.8	18.5	2.8	0.97
Fan heater[m]	6.3	5.2	11.8	3.4	<0.01	10.4	4.3	14.7	2.6	0.04	17.3	3.4	18.7	2.6	0.23

M, mean; SD, standard deviation; temp$_{\text{in}}$, indoor temperature; RH, relative humidity.

Sample size and proportion of "Using", *n* (%): [a]29 (63.0), [b]21 (45.7), [c]12 (26.1), [d]9 (19.6), [e]11 (23.9), [f]28 (60.9), [g]10 (21.7), [h]6 (13.0), [i]4 (8.7), [j]22 (47.8), [k]6 (13.0), [l]17 (37.0), [m]7 (15.2).

2.3.2 Indoor temperature and physical performance

Baseline analysis

Of the 98 participants included in the analysis of physical performance, the mean age was 79.4 ± 7.7 years, and 54 (55.1 %) were women. Most houses had only single pane in the windows, and the mean temperature was less than 18 ˚C in all three rooms. For more details, see Table 2.7.

Table 2.7 Basic characteristics of participants and their housing environments

	Participants from physical performance assessment (*n* = 98)		Participants with $temp_{in}$ measurement (*n* = 36)	
Age [years], mean (SD)	79.4	(7.7)	81.4	(5.8)
BMI [kg/m^2], mean (SD)	22.7	(3.1)	22.9	(3.1)
Women, *n* (%)	54	(55.1)	19	(52.8)
Economic satisfaction, *n* (%)				
Very satisfied	9	(9.2)	6	(16.7)
Somewhat satisfied	67	(63.4)	20	(55.6)
Not very satisfied	14	(15.3)	7	(19.4)
Not satisfied at all	7	(7.1)	3	(8.3)
No answer	1	(1.0)	0	(0.0)
Window glass, *n* (%)				
Single pane	71	(72.5)	26	(72.2)
Double pane	27	(27.6)	10	(27.8)
Building age, *n* (%)				
Less than 10 years	11	(11.2)	5	(13.9)
11 – 20 years	9	(9.2)	2	(5.6)
21 – 30 years	24	(24.5)	7	(19.4)
31 – 40 years	18	(18.4)	9	(25.0)
More than 41 years	35	(35.7)	13	(36.1)
$Temp_{in}$ [˚C], mean (SD)				
Living room			16.8	(1.6)
Bedroom			15.5	(1.8)
Dressing room			14.6	(1.9)

BMI, body mass index; SD, standard deviation; $Temp_{in}$, indoor temperature.

Seasonal differences of physical performance

Performance on grip strength and logarithm transformed static postural and balance control were worse in the winter compared with the autumn (Grip strength, right: autumn, 21.47 ± 7.33 kg; winter, 20.05 ± 7.25 kg; $t(97) = 4.75$, $p < 0.001$. Grip strength, left: autumn, 19.71 ± 6.84 kg; winter, 19.09 ± 7.12; $t(97) = 2.65$, $p = 0.009$. Static postural and balance control, right: autumn, 0.71 ± 0.41; winter, 0.61 ± 0.50; $t(93) = -2.41$, $p = 0.018$. Static postural and balance control, left: autumn, 0.68 ± 0.46; winter, 0.59 ± 0.45; $t(92) = -2.37$, $p = 0.020$), while performance of balance and gait function were not significantly different between autumn and winter (Balance and gait function, right: autumn, 12.57 ± 8.7 sec; winter, 12.61 ± 7.39 sec; $t(97) = -0.08$, $p = 0.938$. Balance and gait function, left: autumn, 12.79 ± 10.30 sec; winter, 12.58 ± 7.32 sec; $t(97) = 0.33$, $p = 0.743$. Table 2.8). The differences on grip strength ranged from 3 to 7 %.

Table 2.8 Paired *t*-test of physical performance assessed in autumn and winter

	Autumn		Winter		p
	Mean	SD	Mean	SD	
Grip strength[a] [kg], R, $n = 98$	21.47	7.33	20.05	7.25	<0.001
Grip strength[a] [kg], L, $n = 98$	19.71	6.84	19.09	7.12	0.009
Static postural and balance control[b], [-], R, $n = 94$	0.71	0.41	0.61	0.50	0.018
Static postural and balance control[b], [-], L, $n = 93$	0.68	0.46	0.59	0.45	0.020
Balance and gait function[c] [sec], R, $n = 98$	12.57	8.77	12.61	7.39	0.938
Balance and gait function[c] [sec], L, $n = 98$	12.79	10.30	12.58	7.32	0.743

L, left; SD, standard deviation; R, right.

[a]As measured with dynamometer. [b]As measured by single-leg standing time. [c]As measured by Timed Up & Go test.

The changing rate of physical performance between autumn and winter had no significant association with individual attributes in the simple linear regression analysis (Table 2.9).

Table 2.9 Beta coefficient of physical performance and individual attributes

	Age [years]	BMI [kg/m^2]	Gender[c]	Economic satisfaction[d]
Grip strength[a] [kg], R, $n = 98$	0.00	0.00	-0.02	0.01
Grip strength[a] [kg], L, $n = 98$	0.00	0.00	0.00	-0.02
Static postural and balance control[b], [-], R, $n = 94$	0.00	-0.01	-0.04	-0.26
Static postural and balance control[b], [-], L, $n = 93$	-0.01	0.00	0.30	0.02

All variables were not significant.

BMI, body mass index; L, left; R, right.

[a]As measured with dynamometer. [b]As measured by single-leg standing time. [c]Men vs Women. [d]Satisfied vs Unsatisfied.

Influence from cold housing on seasonal differences of physical performance

The Cold group had significantly weaker grip strength in the right hand (Autumn, 21.98 ± 8.08 kg; winter, 20.50 ± 8.40 kg; $t(27) = 3.06$, $p < 0.01$), while the Warm group did not have significant differences between autumn and winter (Autumn, 22.91 ± 4.67 kg; winter, 22.31 ± 6.20 kg; $t(7) = 0.87$, $p = 0.41$) in the right hand (Figure 2.5 a). Grip strength in the left hand showed a divergent pattern between the groups. The Cold group had significantly weaker grip strength in winter (Autumn, 19.46 ± 7.75 kg; winter, 18.86 ± 7.40 kg; $t(27) = 1.94$, $p = 0.06$), while the warm group had stronger grip strength in winter, but the differences were not significant (Autumn, 19.75 ± 8.83 kg; winter, 20.38 ± 9.11 kg; $t(7) = -1.23$, $p = 0.26$. Figure 2.5 b). Logarithmic single-leg standing on right and left leg was longer in the winter in both groups, and the Warm group had the greatest difference between seasons in terms of the single-leg standing time (Right, Cold group: autumn, 0.69 ± 0.41; winter, 0.72 ± 0.42; $t(26) = -0.25$, $p = 0.80$. Warm group: autumn, 0.60 ± 0.67; winter, 0.81 ± 0.46; $t(8) = -1.25$, $p = 0.24$. Left, Cold group: autumn, 0.62 ± 0.42; winter, 0.74 ± 0.46; $t(26) = -1.62$, $p = 0.12$. Warm group: autumn, 0.50 ± 0.46; winter, 0.72 ± 0.42; $t(8) = -1.63$, $p = 0.14$. Figure 2.5 c, d). Although the clinical relevance of the amount of differences between seasons in the physical performance in our study may be low, all results point in the same direction. However, this difference was opposite of that of the population trend shown in Table 2.8.

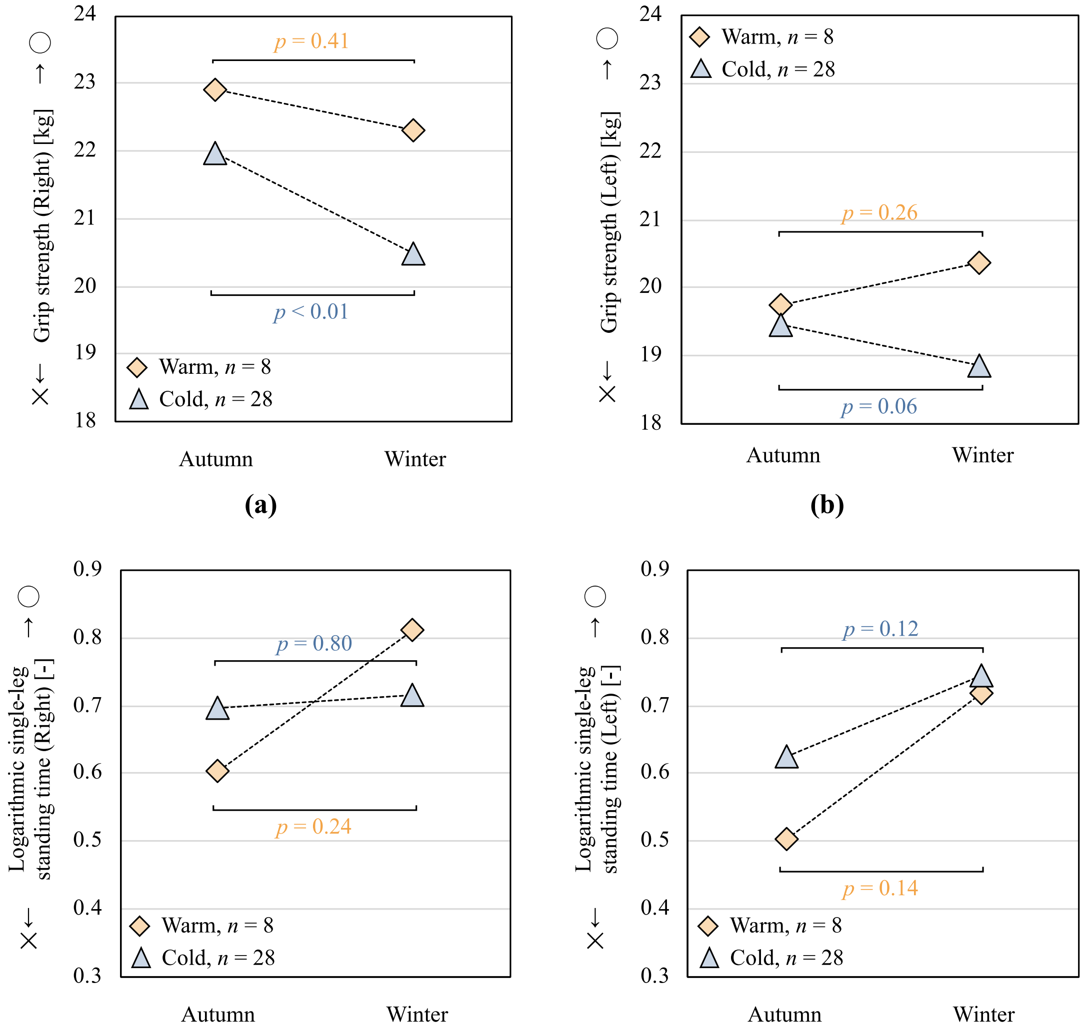


Figure 2.5 Paired *t*-test of physical performance assessed in autumn and winter grouped by living room temperature: (a) Grip strength, Right; (b) Grip strength, Left; (c) Static postural and balance control, Right; (d) Static postural and balance control, Left

Moreover, there were no significant difference in characteristics between people living in cold and warm houses (Table 2.10).

Table 2.10 Student's *t*-test and Fisher's exact tests of characteristics between the Cold (n = 28) and Warm (n = 8) groups

	Cold group (n = 28)[a]		Warm group (n = 8)[a]		t	p[b]
Gender, n (%)						
Men	12	(42.9)	5	(62.5)		0.43
Women	16	(57.1)	3	(37.5)		
Age [years], mean (SD)	82.08	(5.78)	79.1	(6.10)	3.03	0.22
BMI [kg/m^2], mean (SD)	22.79	(3.14)	23.1	(3.46)	-0.42	0.85
Economic satisfaction, n (%)						
Satisfied	12	(42.9)	5	(62.5)		0.54
Not satisfied	16	(57.1)	3	(37.5)		

BMI, body mass index; SD, standard deviation.

[a]Classified based on mean living room temperature of 18 °C, [b]p-values of Student's t-test for continuous variables and Fisher's exact test for categorical variables were reported.

2.3.3 Perceived indoor temperature, economic satisfaction and frailty index

Baseline analysis

Among the 342 participants included in the analysis for frailty index, the mean age was 81.7 ± 7.3 years, and 215 (62.9 %) were women. For more details, see Table 2.11.

Table 2.11 Participant characteristics by perceived indoor temperature and for total sample

	Total (n = 342)	Cold group (n = 107)	Warm group (n = 235)
Age [years], mean (SD)	81.7 (7.3)	80.0 (8.5)	82.5 (7.0)
Women, n (%)	215 (62.9)	61 (57.0)	154 (65.5)
BMI, n (%)			
Underweight (<18.5)	46 (13.5)	17 (15.9)	29 (12.3)
Normal (18.5≤BMI<25)	192 (56.1)	61 (57.0)	131 (55.7)
Obese (25≤)	62 (18.1)	17 (15.9)	45 (19.1)
No answer	42 (12.3)	12 (11.2)	30 (12.8)
Economic satisfaction, n (%)			
Satisfied	63 (18.4)	28 (26.2)	35 (14.9)
Unsatisfied	279 (81.6)	79 (73.8)	200 (85.1)
Education, n (%)			
Junior high school or less	29 (8.5)	16 (15.0)	13 (5.5)
Senior high school	134 (39.2)	41 (38.3)	93 (39.6)
University or higher	130 (38.0)	41 (38.3)	89 (37.9)
No answer	49 (14.3)	9 (8.4)	40 (17.0)
Household composition, n (%)			
Living alone	80 (23.4)	18 (16.8)	62 (26.4)
Living with someone	255 (74.6)	87 (81.3)	168 (71.5)
No answer	7 (2.0)	2 (1.9)	5 (2.1)
Frailty index[a], mean (SD)			
Total score	5.01 (2.70)	5.51 (2.90)	4.79 (2.58)
Isolation risk	1.91 (1.34)	2.02 (1.44)	1.86 (1.30)
Fall risk	2.14 (1.56)	2.49 (1.72)	1.98 (1.46)
Poor nutrition risk	0.97 (0.96)	1.01 (1.04)	0.95 (0.92)

BMI, body mass index; SD, standard deviation.

[a]As measured by Kaigo-Yobo Checklist [18] [19].

Differences of frailty index between the perceived indoor temperature groups and the economic satisfaction groups

In the ANCOVA for total score of frailty index with the perceived temp_{in} and economic satisfaction groups (Table 2.12), there was a significant interaction effect, $F(1, 328) = 5.28$, $p = 0.02$. The levels of reported frailty risk were not significantly different, $F(1, 328) = 0.04$, $p = 0.82$, between the Warm Group and Cold Group among those participants who were satisfied with their economic status. In contrast, the levels of frailty risk were significantly higher, $F(1, 328) = 7.33$, $p < 0.01$, among those in the Cold Group who were also unsatisfied with their economic status (Figure 2.6).

Table 2.12 Analysis of covariance of total frailty score by perceived indoor temperature and participant characteristics

	df	Total score in frailty index[d]		
		F		η^2
Perceived temp_{in}[a]	1	6.17	*	0.018
Economic satisfaction[b]	1	7.01	**	0.021
Perceived temp_{in} * Economic satisfaction	1	5.28	*	0.016
Gender[c]	1	0.28		0.001
Age	1	1.86		0.006
BMI				
Underweight vs Normal (A)	1	8.96	**	0.027
Obese vs No answer (B)	1	1.95		0.006
(A) vs (B)	1	2.58		0.008
Education				
Junior high school or less vs Senior high school (C)	1	0.97		0.003
University or higher vs No answer (D)	1	2.52		0.008
(C) vs (D)	1	2.18		0.007
Household composition				
Living alone vs Living with someone (E)	1	5.81	*	0.017
(E) vs No answer	1	0.02		0.000

BMI, body mass index; *df*, degree of freedom; temp_{in}, indoor temperature; η^2, Eta-squared.
[a]Cold group vs Warm group, [b]Satisfied vs Unsatisfied, [c]Men vs Women, [d]As measured by "Kaigo-Yobo Checklist" [18] [19].
$n = 342$, $*p < 0.05$, $**p < 0.01$, Adjusted $R^2 = 0.077$

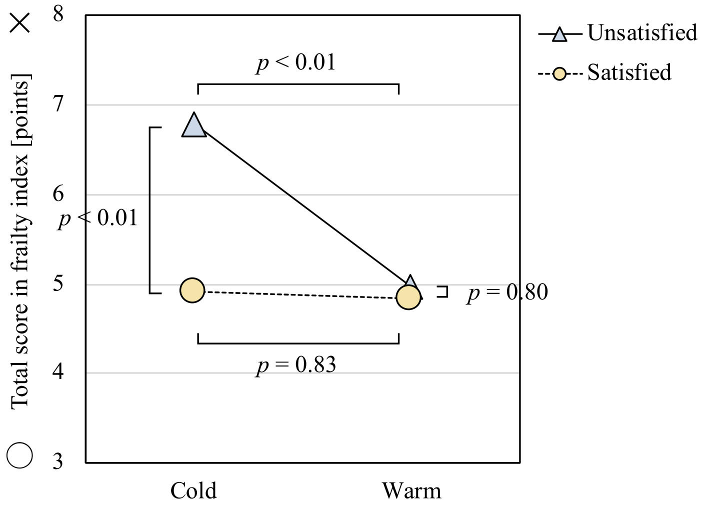


Figure 2.6 Interaction effect between perceived indoor temperature and economic satisfaction on the total frailty score ($n = 342$)

Differences of three subscales of the frailty index between the perceived indoor temperature groups and the economic satisfaction group

The omnibus test of the MANCOVA was significant with Wilks' Lambda = 0.98, $F(3, 326) = 2.78$, $p = 0.04$. The main effects and interaction effects for isolation risk and nutrition risk were not significant, but there were significant differences in the fall risk subscale (Table 2.13). The Warm Group and Cold Group were not significantly different, $F(1, 328) = 0.31$, $p = 0.58$ on the fall risk subscale among those participants who were satisfied with their economic status. In contrast, the Cold Group scored significantly higher on the fall risk subscale, $F(1, 328) = 12.15$, $p < 0.01$ among those who were also unsatisfied with their economic status (Figure 2.7).

Table 2.13 Multivariate analysis of covariance of three subscales of the frailty score by perceived indoor temperature and participant characteristics

	df	Isolation risk[d]		Fall risk[d]		Nutrition risk[d]	
		F	η^2	*F*	η^2	*F*	η^2
Perceived temp$_{in}$[a]	1	0.52	0.002	11.10**	0.033	0.20	0.001
Economic satisfaction[b]	1	1.53	0.005	6.04*	0.018	2.63	0.008
Perceived temp$_{in}$ * Economic satisfaction	1	0.19	0.001	8.00**	0.024	1.37	0.004
Gender[c]	1	2.20	0.007	0.05	0.000	0.05	0.000
Age	1	6.85**	0.020	0.62	0.002	1.29	0.004
BMI							
Underweight vs Normal (A)	1	4.02*	0.012	0.15	0.000	24.38**	0.069
Obese vs No answer (B)	1	6.27*	0.019	0.24	0.001	0.15	0.000
(A) vs (B)	1	0.04	0.000	0.09	0.000	13.81	0.040
Education							
Junior high school or less vs Senior high school (C)	1	0.02	0.000	0.73	0.002	1.34	0.004
University or higher vs No answer (D)	1	0.57	0.002	2.82	0.009	0.38	0.001
(C) vs (D)	1	0.86	0.003	1.58	0.005	1.58	0.002
Household composition							
Living alone vs Living with someone (E)	1	11.41**	0.034	2.48	0.007	0.33	0.001
(E) vs No answer	1	0.79	0.002	0.06	0.000	1.70	0.005

BMI, body mass index; *df*, degree of freedom; temp$_{in}$, indoor temperature; η^2, Eta-squared.
[a]Cold group vs Warm group, [b]Satisfied vs Unsatisfied, [c]Men vs Women, [d]As measured by "Kaigo-Yobo Checklist" [18] [19].
$n = 342$, $*p < 0.05$, $**p < 0.01$, Adjusted R^2: Isolation risk = 0.069, Fall risk = 0.041, Nutrition risk = 0.067

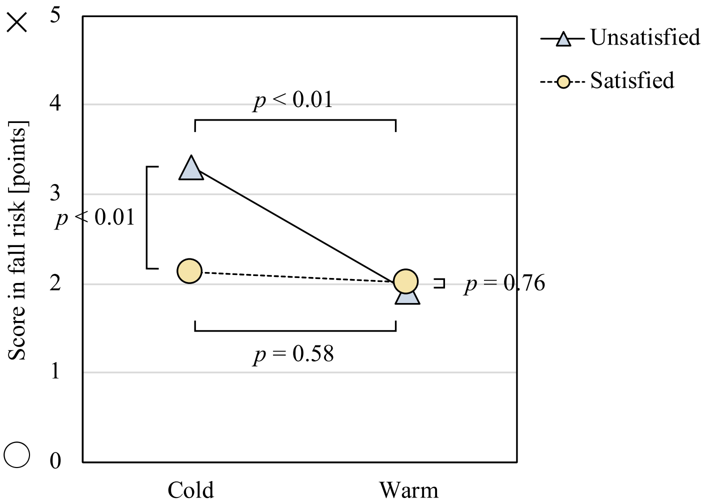


Figure 2.7 Interaction effect between perceived indoor temperature and economic satisfaction and its relation to fall risk score

2.3.4 Perceived indoor temperature and age at long-term care certification

Baseline analysis

Among the 205 participants included in the analysis for age at LTC certification, the mean age was 81.7 ± 6.6 years, and 115 (56.1 %) were women. Since the study target population was people using outpatient rehabilitation facilities, participants' care levels were low; support level 1 ~ care level 2 was the majority (95.4 %). Participants' houses were relatively old and had low energy efficiency standard; 110 houses (53.7 %) were more than 31 years, and 157 houses (76.6 %) had single pane windows. Same tabulation result for participants in the measurement survey showed that care level for this group was lower (see Table 2.14 for more details).

Table 2.14 Participant characteristics and housing characteristics in questionnaire survey and measurement of indoor thermal environment

Participant characteristics	Questionnaire (*n* = 205)		Measurement of temp$_{in}$ (*n* = 78)	
Age [years], mean (SD)	81.7	(6.6)	80.7	(6.9)
Women, *n* (%)	115	(56.1)	40	(51.3)
BMI [kg/m^2], mean (SD)	22.5	(3.7)	22.7	(3.6)
Economic satisfaction, *n* (%)				
Satisfied	165	(80.5)	60	(76.9)
Unsatisfied	40	(19.5)	18	(23.1)
Education, *n* (%)				
Junior high school or less	14	(6.8)	4	(5.1)
Senior high school	100	(48.8)	35	(44.9)
University or higher	91	(44.4)	39	(50.0)
Household composition, *n* (%)				
Living alone	61	(29.8)	18	(23.1)
Living with someone	144	(70.2)	60	(76.9)
Age at LTC certification [years], mean (SD)	79.8	(6.4)	79.7	(6.8)
Care level, *n* (%)				
Support level 1	40	(19.5)	25	(32.1)
Support level 2	47	(22.9)	20	(25.6)
Care level 1	61	(29.8)	20	(25.6)
Care level 2	31	(15.1)	8	(10.3)
Care level 3	8	(3.9)	2	(2.6)
Care level 4	9	(4.4)	3	(3.8)
Care level 5	1	(0.5)	0	(0.0)
Unknown	8	(3.9)	0	(0.0)
Survey area, *n* (%)				
Osaka	104	(50.7)	58	(74.4)
Kochi	53	(25.9)	13	(16.7)
Yamanashi	48	(23.4)	7	(9.0)

Housing characteristics	Questionnaire (*n* = 205)		Measurement of temp$_{in}$ (*n* = 78)	
Window glass, *n* (%)				
Single pane	157	(76.6)	63	(80.8)
Double pane	41	(20.0)	14	(17.9)
Don’t know/ No answer	7	(3.4)	1	(1.3)
Building age, *n* (%)				
Less than 10 years	14	(6.8)	6	(7.7)
11 – 20 years	31	(15.1)	13	(16.7)
21 – 30 years	46	(22.4)	14	(17.9)
31 – 40 years	45	(22.0)	17	(21.8)
More than 41 years	65	(31.7)	28	(35.9)
No answer	3	(1.5)	0	(0.0)
Time at residence, *n* (%)				
Less than 10 years	36	(17.6)	18	(23.1)
11 – 20 years	37	(18.0)	16	(20.5)
21 – 30 years	36	(17.6)	13	(16.7)
31 – 40 years	36	(17.6)	16	(20.5)
More than 41 years	56	(27.3)	15	(19.2)
No answer	4	(2.0)	0	(0.0)

BMI, body mass index; LTC, long-term care; SD, standard deviation; temp$_{in}$, indoor temperature.

In the Kaplan-Meier analysis, the Cold group had more rapid decline in the percentage of people uncertified for need of LTC than did the Warm group (Generalised Wilcoxon test, $p < 0.01$). Mean age at LTC certification was 77.8 years in the Cold group and 80.6 years in the Warm group, where the difference was 2.8 years (Figure 2.8).

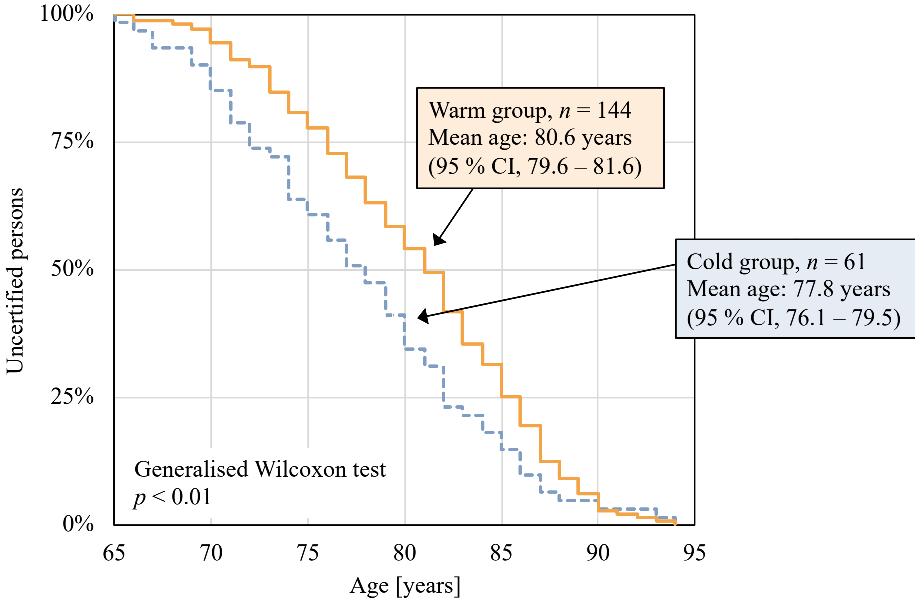


Figure 2.8 Kaplan-Meier analysis of age at long-term care certification and perceived indoor temperature

In the multivariate Cox proportional hazard model (Table 2.15) for the age at LTC certification, the HR of perceived temp_{in} was 0.65 (95 % CI = 0.47 − 0.90, $p = 0.009$) indicating that the Warm group had lower hazard of LTC certification than the Cold group.

Table 2.15 Multivariate Cox proportional hazard model of age at long-term care certification by perceived indoor temperature and participants characteristics

	HR	95 % CI	*p*
Perceived temp_{in}[a]	0.65	0.47 − 0.90	0.009
Gender[b]	0.82	0.61 − 1.10	0.175
BMI	1.00	0.96 − 1.04	0.983
Education			
Junior high school or less	1.44	1.01 − 1.93	0.017
Senior high school	0.76	0.41 − 1.41	0.381
University or higher (ref.)			
Economic satisfaction[c]	0.55	0.38 − 0.80	0.002
Household composition[d]	1.06	0.75 − 1.51	0.743
Survey area			
Osaka	1.42	0.97 − 2.08	0.071
Kochi	0.95	0.63 − 1.42	0.785
Yamanashi (ref.)			

BMI, body mass index; CI, confidence interval; *df*, degree of freedom; HR, hazard ratio; temp_{in}, indoor temperature; ref., reference.

[a]Cold group (ref.) vs Warm group, [b]Men (ref.) vs Women, [c]Satisfied vs Unsatisfied (ref.), [d]Living alone vs Living with someone (ref.).

$n = 205$, Variable selection method: forced selection, -2 log likelihood = 1764.02, chi-square = 35.73 ($df = 9$, $p < 0.001$)

In the ANCOVA for age at LTC certification with the perceived temp$_{in}$ (Table 2.16), there was a significant main effect, $F(1, 197) = 9.27$, $p = 0.05$. The estimated marginal mean of age at LTC certification was 77.8 years in the Cold group and 80.7 years in the Warm group (Figure 2.9).

Table 2.16 Analysis of covariance of age at long-term care certification by perceived indoor temperature and participants characteristics

	df	*F*	*p*	η^2
Perceived temp$_{in}$[a]	1	9.27	0.003	0.045
Gender[b]	1	3.92	0.049	0.020
BMI	1	0.11	0.737	0.001
Education (ref. University or higher)				
Junior high school or less	1	0.51	0.475	0.003
Senior high school	1	7.27	0.008	0.036
Economic satisfaction[c]	1	4.14	0.043	0.021
Household composition[d]	1	0.32	0.570	0.002
Survey area (ref. Yamanashi)				
Osaka	1	3.63	0.058	0.018
Kochi	1	0.03	0.865	<0.001

BMI, body mass index; *df*, degree of freedom; temp$_{in}$, indoor temperature; ref., reference; η^2, Eta-squared.

[a]Cold group vs Warm group, [b]Men vs Women, [c]Satisfied vs Unsatisfied, [d]Living alone vs Living with someone.

$n = 205$, Adjusted $R^2 = 0.076$

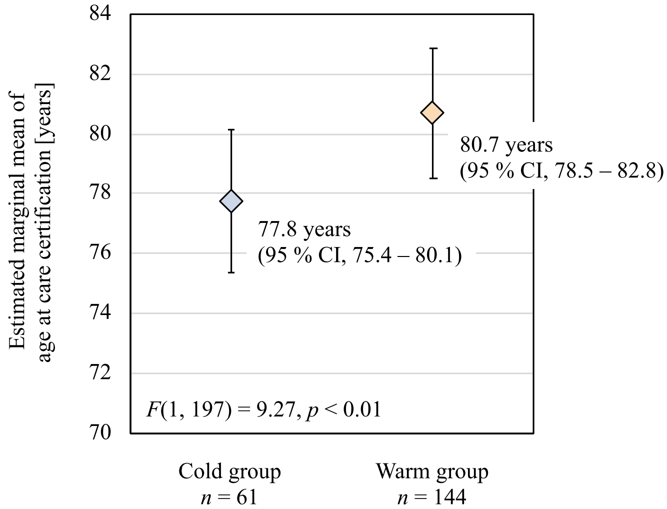


Figure 2.9 Estimated marginal mean of age at long-term care certification by perceived indoor temperature group

In the Student's *t*-test of age at LTC certification by perceived temp$_{in}$ group across participants' demographic characteristics (Table 2.17), the Warm group had a higher age at LTC certification for nearly all characteristic. However, women did not have a significant difference in age at LTC certification between the Cold and Warm groups (Cold group, 79.2 ± 6.8 years; Warm group, 81.3 ± 6.2 years; $t(115) = -1.61$, $p = 0.11$).

Table 2.17 Student's *t*-test of age at long-term care certification by perceived indoor temperature group across participants' demographic characteristics

	Cold group			Warm group			*t*	*p*
	n	Mean	SD	*n*	Mean	SD		
Gender								
Men	30	76.5	6.7	60	79.8	5.9	-2.41	0.02
Women	31	79.2	6.8	84	81.3	6.2	-1.61	0.11
BMI								
Underweight (< 18.5)	8	78.6	9.4	15	82.8	5.9	-1.31	0.20
Normal (18.5 ≤ BMI < 25.0)	41	77.7	6.5	95	81.1	6.1	-2.93	<0.01
Obese (≥ 25.0)	12	78.0	6.7	34	78.8	6.1	-0.39	0.70
Education								
Junior high school or less	7	80.3	9.0	7	83.7	4.6	-0.90	0.39
Senior high school	29	76.5	5.2	71	79.6	6.4	-2.29	0.02
University or higher	25	78.7	7.6	66	81.6	5.8	-1.98	0.09
Economic satisfaction								
Satisfied	17	75.8	4.5	23	78.7	5.0	-1.83	0.08
Unsatisfied	44	78.6	7.4	121	81.1	6.3	-2.13	0.04
Cohabitation status								
Living alone	15	77.0	5.7	36	82.0	6.0	-2.53	0.02
Living with someone	46	78.1	7.1	108	80.3	6.2	-2.01	0.05
Survey area								
Osaka	24	76.0	4.8	80	79.7	5.7	-2.78	0.04
Kochi	18	80.8	7.5	35	81.1	6.7	-0.17	0.87
Yamanashi	19	77.5	7.7	29	83.0	6.2	-2.92	0.01

BMI, body mass index; SD, standard deviation.

In the ANOVA of age at LTC certification by measured temp_{in} in each room, there was no significance in the omnibus test (Table 2.18). However, mean age at LTC certification was higher in groups of temp_{in} lower than 14 ˚C and over 18 ˚C, for the living room (<14 ˚C, 80.8 ± 5.2 years; 14 – 16 ˚C, 79.4 ± 7.8 years; 16 – 18 ˚C, 79.3 ± 6.8 years; ≥ 18 ˚C, 81.1 ± 4.8 years; $F(3, 56) = 0.290$, $p = 0.833$) and bedroom (<14 ˚C, 79.9 ± 8.0 years; 14 – 16 ˚C, 78.8 ± 6.5 years; 16 – 18 ˚C, 81.0 ± 5.9 years; ≥ 18 ˚C, 81.8 ± 6.7 years; $F(3, 56) = 0.631$, $p = 0.598$) temperature. For the dressing room, age at LTC certification was higher in the group of over 16 ˚C (<14 ˚C, 79.5 ± 6.5 years; 14 – 16 ˚C, 79.4 ± 7.2 years; ≥ 16 ˚C, 82.0 ± 4.6 years; $F(2, 57) = 0.669$, $p = 0.516$).

Table 2.18 Analysis of variance of age at long-term care certification by measured indoor temperature group

	< 14 ˚C			14 – 16 ˚C			16 – 18 ˚C			≥ 18 ˚C			*F*	*p*
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD		
Living room	8	80.8	5.3	28	79.4	7.8	24	79.3	6.8	18	81.1	4.8	0.290	0.833
Bedroom	14	79.9	8.0	32	78.8	6.5	20	81.0	5.9	12	81.8	6.7	0.631	0.598
Dressing room[a]	27	79.5	6.5	35	79.4	7.2	16	82.0	4.6	–	–	–	0.669	0.516

SD, standard deviation.

[a] Participants with a mean dressing room temperature over 18 ˚C were only 3 people, and the highest temperature group was set to be over 16 ˚C.

2.4 Discussion

The overarching aim of study 1 was to investigate whether and how a warmer indoor thermal environment could support older adults to maintain health and independence, which would prevent or delay LTC certification. Overall, the findings confirm that older people with warm perception or rather warm room temperature in their home likely to prevent deterioration of physical performance and frailty, and thus had older age at LTC certification. Older age at LTC certification in people with warm perception in their home indicated the possibility of successful care prevention by improving indoor thermal environment in older people's home in winter.

The sub-sample of participants with measured temp_{in} was relatively small compared to the full sample size. Therefore, to generate more robust results with a larger sample perceived temperature was used as a proxy in most of the analyses about the relationships between temperature and health status. It has been reported that thermal sensitivity declines with ageing [108], and the perceived temp_{in} might not reflect the actual temp_{in} in all cases. This concern becomes larger especially in this study because all participants were older people with health needs that required physical therapy, and their thermal sensitivity might be less sensitive than among healthier older people. However, when screening large populations, measurement-based investigations can be difficult to conduct because they are time consuming and costly and often require trained investigators' support for installing thermometers in participants' houses due to reduced independence of participants.

Measured indoor temperature and relative humidity

Measurement of temp_{in} and RH in clients from outpatient rehabilitation facilities highlighted the extent to which Japanese older adults' homes are cold. Most previous studies measured the temp_{in} of healthy older people's houses [109] [110] [111], but this study adds an insight into the indoor thermal environment of older people with health problems. Interestingly, despite having cold temperatures in nearly all homes measured, few participants reported feeling cold. Luo et al. [112] reported that people who had lived their entire lives in cold wintertime indoor climates had slither physiological response and felt less uncomfortable in mild cold exposures than people who lived in neutral-to-warm winter time indoor climates. On the other hand, although feeling dissatisfaction to the coldness in the house, Japanese older people tend to think that there is nothing for it [113], which suggests that older people included in this study has acclimated or thought natural to cold living environment by living in a cold home for a long time.

Maximum temp_{in} might reflect temperature while using the heating, and the average and minimum temp_{in} might reflect different operating hours of heating systems or lower temperatures while the heating is turned off. Use of fan heaters made the maximum temp_{in} higher but the minimum temp_{in} lower. Fan heaters are generally operated intermittently, which makes the temp_{in} higher when the heating is on, but hours without using the heating are long and temp_{in} might drop excessively [114, 115]. Accordingly, people with warm perception in their home were using the heating more consistently, or living in houses where temperature variations were milder. Such trends were seen in the living room and bedroom. However, Igarashi et al. [116] reported that even people using heating system perceived cold near the windows or doors, and also were concerned about temperature gap when moving to non-living room from living room. In general, dressing rooms are not heated in Japanese homes [113], and Mori et al. [117] showed that insulation retrofit of window glass was particularly efficient for improvement of temp_{in} in non-living rooms such as dressing room, bathroom, and toilet. Hence, people with warm perception in their home might be consciously using heating in dressing rooms or bathrooms or living in highly insulated houses. Four of the six rooms assessed for perceived temp_{in} were non-living rooms, which are less likely to be heated, and therefore, non-living rooms were predominant in the total scores. However, we do not know how much time participants spent in each of these rooms. Conscious use of a heating system even in the non-living rooms or high energy efficiency of the house might have affected the classification by perceived $temp_{in}$.

Indoor temperature and physical performance

Our results about physical performance demonstrated seasonal trends and differences in physical performances between residents in cold versus warm houses. The results of grip strength and single-leg standing tests confirm our hypothesis that physical performance is worse in the winter compared to the autumn, which is an intermediate season in Japan. Furthermore, it seems quite probable that people living in colder houses had even worse grip strength. These results suggested that keeping warm during the winter may prevent a decline of physical performance. People in cold houses might only be using partial heating systems in the form of an electric foot warmer, which can narrow their activity scope inside houses, and may easily deteriorate their physical performance.

On the other hand, balance and gait function showed no relationship with seasonal variation. In a recent review, Schoene [118] found that in high-functioning older adults, TUG tests had a ceiling effect, making it difficult to identify or detect differences in this cohort. Since the participants in this study using the facility for physical rehabilitation had various kinds of impairments ranging from more acute rehabilitation to long term disability, some participants had a ceiling effect and some did not, which made it difficult for us to detect the effect of thermal environment. Moreover, the single-leg standing test may have difficulty identifying non-seasonal factors since it had a skewed distribution in changing rate between autumn and winter. This trend matches other studies [119] and, furthermore, follow-up data reviewed by Howe et al. [120] including 173 participants in 3 studies [121] [122] [123] reported that the effectiveness of exercise on single-leg standing time showed no statistically significant difference between these and control groups at six months.

Regardless, this study provides some evidence for the clinical importance of maintaining a warm indoor environment to improve/maintain grip strength. Prolonged exposure to cold $temp_{in}$ may result in clinically relevant decreases in grip strength, especially in frail older people, which is associated with increased risk for future disability [124] [125] [126] [127], hospitalization [128], and all-cause mortality [125] [127] [128]. A warm indoor environment can be a preventive measure against these negative outcomes.

The effects of temperature on physical performance may have been underestimated because the value of physical performance used in this study was assessed in a rehabilitation facility rather than in participants' own houses. $Temp_{in}$ in the rehabilitation facility was not actually measured, but we assumed that it was kept generally comfortably warm. Suggesting a direct association between temperature and physical performance, this fact was not considered in the analyses. This practice was confirmed by comparable results during different seasons. Ramos et al. [129] showed that, in mild climate countries, $temp_{in}$ has great variability in the winter but not in the autumn. If we could assess physical performances in their houses, the exact environments to which participants are exposed, the difference in physical performance between warm houses and cold houses may have been found to be significantly larger. This can also be said for the seasonal differences in physical performance, with even poorer performances in the winter compared to the autumn. Moreover, if we could measure $temp_{in}$ in the autumn as well, it may have been indicated that autumn had a warmer $temp_{in}$ than did the winter. This would have helped us to strengthen the evidence we acquired regarding the seasonal change of $temp_{in}$, but unfortunately we could not secure thermometers in this case for additional data collection.

The results of this study cannot be generalized, as this was a convenience sample, although they are in line with other studies based on experiments with older adults [130]. Although residents in colder houses had the lowest grip strength, we must note that the sample size for this result was limited to 8 and 28 in the Warm and Cold groups, respectively. Because the average insulation is low in Japan, we could not find a larger warm sample. With this sample size, we were not able to evaluate other relevant factors that could influence physical performance, such as gender, age, chronic illness, and obesity, all of which are related to frailty [131]. Although we were not able to conduct a multivariate analysis including these factors due to our small sample size, we did confirm that there were no differences in individual attributes between people living in cold houses and warm houses. Then, by comparing physical performances in each individual participant using paired *t*-tests, we attempted to exclude an effect of an individual difference. As a potential association between physical performance and $temp_{in}$ was found in this study, despite the small sample size and given the other limitations discussed, this study may serve as a feasibility study, which could be used to guide the design and implementation of a larger cohort study in the future. In addition, to better document chronic conditions and disease progression during the study period, a standardized research questionnaire would provide better data than relying on available clinical data.

Perceived indoor temperature, economic satisfaction and frailty index

In the present study of perceived $temp_{in}$, economic satisfaction and frailty index, we found that those who were unsatisfied with their economic situation and also perceived the $temp_{in}$ in their home as cold reported a higher risk of frailty than other groups. In contrast, people who were satisfied with their economic status reported similar frailty risks regardless of perceived $temp_{in}$. We also found that the reported fall risk had the strongest relationship with perceived temperature and economic satisfaction compared with nutrition and isolation risks.

The most interesting finding was the interaction between economic satisfaction and reported frailty risk. We found that the people who both perceived a cold indoor winter temperature and were unsatisfied with their economic situation reported the highest risk of frailty. This same pattern was also seen for the specific indicator of fall risks but not for nutrition risk or isolation risk. Hence, the total frailty risk in our sample seems to be accounted for by the fall risk. Previous research found that poverty risk was associated with increased levels of frailty, and rather than educational or behavioural factors, material and in particular, psychosocial factors such as perceived control and social isolation explained a large part of poverty-risk-related differences in frailty [132]. To be more specific, it has been reported that low income is associated with under-nutrition [133] and loneliness or depression [134] in the older adults, but those relationships did not seem to hold in our study in relation to frailty risk. When it came to people who were satisfied with their economic situation, there was no difference in reported frailty risk regardless of perceived $temp_{in}$. As previously reported, higher income seems to reduce the risk for frailty as those with higher incomes are more likely to survive into old age through better health status [135].

Hence, we found that it was not just lower economic status that was related to frailty risk, but it was the specific group that also reported living in a colder house that had the strongest relationship with frailty risk. This finding argues for encouraging heating up the homes of older people as a means to reduce risk of frailty and potentially promote healthy ageing. Specifically, different approaches to frailty prevention may be necessary for different subgroups. One possibility was that people unsatisfied with their economic situation were the people having difficulty warming up their house [136] and at risk of fuel poverty. In fact, older people are at great risk from fuel poverty, since they are more likely to be retired or on fixed incomes [137]. This study highlights the potential importance of preventing fuel poverty to prevent frailty and suggests that health promotion strategies must include low-income older people as a target group to improve their housing by installing proper insulation and heating systems.

Out of the three specific indicators of frailty, fall risks had the strongest association with perceived $temp_{in}$ and economic satisfaction. That is, those with poor economic status and perceived cold homes had a higher fall risks, while those satisfied with their economic status had a lower fall risks regardless of perceived $temp_{in}$. The result that fall risks was the only specific indicator of frailty with a significant association with perceived $temp_{in}$ was expected and in line with previous findings. For example, we have reported physical performance decline among older people due to cold season and cold $temp_{in}$ in this thesis, and similar findings have also been reported by Lindemann et al. [130]. Yeung et al. [138] reported that there are higher incidences of falls in winter than in other seasons. Additionally, they highlighted that a higher proportion of fallers during winter had lower limb weakness than those who fell in non-winter seasons [138], as also indicated in our study.

From a health perspective, there is much to win from reducing the risks of frailty, and to prevent physical decline and subsequent falls. Regular physical activity has strong effects on reducing risk of premature death and chronic diseases [139] [140]. Ultimately, the prevention of frailty improves perceived health since physical health, mental health and participation in physical activities all contribute to quality of life [141]. Furthermore, there are benefits for the society such as reduced needs for health care and social services and thus, the public expenditure.

One limitation in this study was that, due to the cross-sectional design we could not conduct an assessment of causality. Exploring casual association is important since it may play an instrumental role in terms of identifying reasons behind a wide range of processes, as well as assessing the impacts of changes on existing norms or processes. However, in order to study causal associations, follow-up studies are required. Another limitation was that, we chose not to ask about actual income; instead we used economic satisfaction as an indicator of economic status. In fact, actual income may not have been a better measure, as the structure of a household in Japan can be very complex. In three-generation households, the employment income of the younger generations is likely to be the main household income, whereas in households where older people live alone, a public pension is likely to provide the main income [142]. Therefore, the economic status of older people changes with household structure and level of public pension.

Perceived indoor temperature and age at long-term care certification

The findings in this study imply the possibility of successful care prevention by warming up homes of older people. Older people with perceived warm homes had older age at LTC certification, and thus lower risk of LTC certification. Moreover, adjustment for confounding factors did not reduce the magnitude of the results, indicating that current perception of a warm indoor thermal environment may have an influence on healthy life expectancy beyond that expected simply from socio-economic status [143] attained over the lifetime. To the best of our knowledge, our study is the first to investigate the association between indoor thermal environment and age at LTC certification among community dwelling older people. Given that Japan has expected and promoted ageing in place for older adults [144], the need for "primary prevention" at home is greater. Frailty or condition before certification for care need attracts policy makers' attention as a good target for interventions in the context of aiming at healthy ageing [16] [145]. Indeed, WHO [146] argues that governments can reverse or slow declining capacity of older people, and encouraging warming up frail older adults' homes can play an important role in preventing or delaying LTC need. While interventions focusing on social participation may widen the disparity in healthy ageing because people who have poor health, low SES, and are isolated are less likely to participate in social activities [147] [148], interventions within the home where older people spend much of their daily time have great potential to contribute to maintaining health of older adults.

The strength of this study was that we collected data about the care requiring condition through LTCI card, which is an objective indicator of being certified for need for LTC. In the LTCI application process, eligibility is determined by a 74-item form assessed by a local government employee and reviewed by a local expert committee which includes physicians [5]. This enabled us to have objectivity in the evaluation, but at the same time, there was a concern that the certification rate and political policies on offering LTCI service may have differed between municipalities. Therefore, the survey area was included as a dependent variable in the multivariate model.

In the ANOVA of age at LTC certification by measured mean $temp_{in}$, the mean age at LTC certification was higher in groups with $temp_{in}$ lower than 14 °C and over 18 °C for the living room and bedroom temperatures. In the ANOVA of dressing room temperature, age at LTC certification was higher in the group with over 16 °C. In this study, we could not investigate daily time out of home. People in the group less than 14 °C might be going out actively and using the heating only for short time periods when home, which could lead to a low mean $temp_{in}$, even if their age at LTC certification was high. However, in the Student's *t*-test of age at LTC certification by individual characteristics group, the people with warm perception in their home had a higher age at LTC certification in every individual characteristic group even if several were not statistically significant. Although women had a relatively large sample size, there was no significant difference in age at LTC certification by perceived $temp_{in}$ group. Aged women are known to have good interpersonal relationships and have a strong intention to go out [149], which may have made them less susceptible to the environment in their house.

When it comes to methodology, the current study has some limitations. First, some potential risk factors, such as congenital disease, dementia [150], and other detailed information about medications were not included in the analysis because they were not available in the dataset. Some variables, such as objective physical performance measures were only available for participants from Osaka prefecture and were inconsistent throughout the study period from 2014 to 2017; thus, they were not included in the analysis. In addition, it is possible that the association is attributable not only to age at LTC certification itself but also other unmeasured variables associated with risk of earlier LTC certification. Therefore, future studies must take these limitations into account when designing the study protocol. The second limitation was that the participants were not randomly selected. Participants included in the analysis had a slightly higher risk of poor nutrition than those who were excluded. However, the rehabilitation facilities were located in different parts of Japan, and the age distribution of the participants was similar to other Japanese studies targeting frail older people living in the community and using rehabilitation services [151] [152] [153]. Hence, we are confident that results represent the sub-population receiving rehabilitation services. Finally, the study method can be classified as a retrospective study with collecting data of past LTC certification. In this situation, the living environment in which the perception of thermal environment depends on was assumed to be the same in the certification timing and the survey timing. Therefore, moving and retrofitting of the house was not considered in the analysis. However, most responded that the building age was relatively old and the responses to the period of residence followed the same trend. This indicates that the majority of the participants were living in the same house for a long time and being affected by the same indoor thermal environment for a fixed period.

2.5 Conclusion

In study 1, whether and how a warmer indoor thermal environment could support older adults to maintain health and independence were investigated. The results highlighted the extent to which Japanese older adults' homes are cold, and showed that older people with warm perception or rather warm room temperature in their homes likely led to prevention of deterioration of physical performance and frailty, and thus had older age at LTC certification. This knowledge can serve as a method to prevent decline of physical performance by improving housing environments, and thus prevent frailty and LTC need.

Chapter 3

Study 2: Indoor thermal environment and health of nursing home residents

Chapter 3

Study 2: Indoor thermal environment and health of nursing home residents

3.1 Overview of study 2

Study 2 focused on the health of older people living in nursing homes and the relationship to the indoor thermal environment. In light of the definition of care prevention formulated by the Ministry of Health, Labour and Welfare (MHLW) [154], when a condition that requires care already exists, preventing deterioration and aiming to improve the condition are no less important than preventing a condition from arising. However, the mean care level in nursing homes is still increasing, and current care prevention strategies are not sufficient to prevent future increase. Although the indoor environment in nursing homes is a critical factor for the health of residents, proper maintenance is the responsibility of individual facility managers, and actual conditions in the facilities are not known [155]. Accordingly, the overarching objective of study 2 was to understand the actual conditions of nursing homes' indoor thermal environments and to investigate its' role in maintaining health among nursing home residents. Blood pressure and dry mouth were selected as indicators of health of residents, since high blood pressure is known to be a risk factor of longer period of care [10], and dry mouth is known to lead to fungal and bacterial infectious diseases [156]. The specific objectives are to: 1) investigate the association between blood pressure and indoor temperature ($temp_{in}$), 2) investigate the association between oral cavity and relative humidity (RH), and 3) identify differences in speed of deterioration of care level between residents living at different levels of $temp_{in}$ and RH in nursing home facilities. New knowledge regarding nursing home residents' blood pressure, oral cavity, and deterioration speed of care level emerged through actual measurement of $temp_{in}$ and RH, and a questionnaire survey to care staff. Works in study 2 are published in Journal of Environmental Engineering (Transactions of Architectural Institute Japan (AIJ)) [157].

3.2 Methodology

3.2.1 Procedure and Participants

The field study was conducted in winter and summer of 2015 and 2016, which included 1,337 residents in 27 facilities located in Yamanashi, Nagano, Osaka, Nara, Hyogo, and Kyoto prefectures (Table 3.1). Two facilities in Yamanashi prefecture were located at the same site, and had different structures, heating systems, and building ages. Another facility in Yamanashi prefecture had retrofitted the insulation after winter 2015, and the same survey was conducted in winter 2016 after insulation retrofit. The facilities were special elderly nursing homes (SENH), long-term care health facilities (LTCHF), or pay nursing homes (PNH) (Table 3.2). SENH are living facilities for older people who require long-term care, and LTCHF are rehabilitation facilities for older people who require long-term care to return home or to the community. PNH are living facilities for both older people who require long-term care and those who are independent. Meals, cleaning, care, and rehabilitation services are provided and mainly managed by private parties. All facilities in Kinki area, located in several prefectures, were run by the same private party.

The field study included measurement of temp$_{in}$ and RH in the nursing home, and a questionnaire survey. Care staff in the nursing homes received oral and written information and instructions from the research team before the survey. Data loggers and questionnaire sheets were sent to each facility, and installation of data loggers and questionnaires were all completed by either a facility manager or care staff. After the measurement period, data loggers and questionnaire sheets were sent back to the research team. The study protocol was approved by the Tokyo Metropolitan University Ethics Review Board (2015-042).

Table 3.1 Study period for each facility

Area	ID	Winter 2015	Summer 2015	Winter 2016
Kinki	1 – 20 (20 facilities)	*		
Nagano	21 – 24 (4 facilities)	*		
Yamanashi	25, 26 (2 facilities)	*	*	
	27 (1 facility)	*	*	* (After retrofit)

Table 3.2 Characteristics of facilities

ID	Prefecture	Facility type	Number of residents	Number of care staff
1	Osaka	PNH	49	31
2	Osaka	PNH	56	18
3	Nara	PNH	66	29
4	Osaka	PNH	58	33
5	Hyogo	PNH	64	35
6	Hyogo	PNH	95	47
7	Kyoto	PNH	72	37
8	Osaka	PNH	59	28
9	Kyoto	PNH	56	35
10	Osaka	PNH	57	30
11	Kyoto	PNH	56	33
12	Osaka	PNH	61	31
13	Nara	PNH	65	37
14	Hyogo	PNH	50	35
15	Osaka	PNH	60	24
16	Osaka	PNH	88	40
17	Osaka	PNH	56	31
18	Kyoto	PNH	72	29
19	Osaka	PNH	44	26
20	Kyoto	PNH	61	25
21	Nagano	SENH	54	57
22	Nagano	LTCHF	51	37
23	Nagano	LTCHF	88	53
24	Nagano	SENH	90	64
25	Yamanashi	SENH	50	38
26	Yamanashi	SENH	29	22
27	Yamanashi	LTCHF	96	63

LTCHF, long-term care health facility; PNH, pay nursing home; SENH, special elderly nursing home.

3.2.2 Measures

Indoor temperature and relative humidity

Temp_{in} and RH were measured 1.1 m and 0.1 m above floor level to verify local chill around feet. However, data loggers were installed for only 1.1 m above the floor in the measurement in summer. Regarding to the floor area of each facility, from 17 to 30 rooms including private rooms, dining halls, corridors, and dressing rooms were selected to install data loggers. Multiple private rooms and dining halls were selected to install the data logger, by considering the balance of every direction of north, south, east, and west. Measurement was at 20 min intervals in the periods shown in Table 3.3. For the measurement in facility 27, 2 days during the winter had unseasonably warm temp_{out} (equivalent to the average temp_{out} in April) in 2016 and were therefore excluded, leaving 12 days of temp_{in} measurements for each of February 2015 and 2016 analysis. Measurements were taken using Thermochron data loggers (KN Laboratories) in Yamanashi prefecture and AD-5696 (A&D Company) in other prefectures. Thermochron data loggers had an accuracy of ± 0.5 ˚C from -20 to 70 ˚C and a 0.1 ˚C resolution, and ± 5 % from 0 to 95 % and a 0.1 % resolution. AD-5696 had ± 1.0 ˚C from 0 to 50 ˚C and 0.1 ˚C resolution, and ± 5 % from 5 to 95 % and a 0.1 % resolution. We had no control over the types of clothing and bedding people wore or use of heating systems. At the same time, thermal image photographs were taken in three facilities in Yamanashi prefecture during the measurement period in winter. Data of outdoor temperature (temp_{out}) recorded in 10-min intervals was provided from the nearest local meteorological office in each study area.

Table 3.3 Measurement period and analysis period for each facility

Area	ID	Measurement period	Analysis period
Kinki	1 – 20	1 Jan 2015 – 14 Feb 2015 (45 days)	17 Jan 2015 – 13 Feb 2015 (28 days)
Nagano	21 – 24	19 Jan 2015 – 17 Feb 2015 (30 days)	20 Jan 2015 – 16 Feb 2015 (28 days)
Yamanashi	25, 26	19 Jan 2015 – 17 Feb 2015 (30 days)	20 Jan 2015 – 16 Feb 2015 (28 days)
		3 Aug 2015 – 2 Sep 2015 (31 days)	4 Aug 2015 – 31 Aug 2015 (28 days)
	27	6 Feb 2015 – 19 Feb 2015 (14 days)	7 Feb 2015 – 18 Feb 2015 (12 days)
		13 Jan 2016 – 16 Feb 2016 (35 days)	2 Feb 2016 – 15 Feb 2016 (12 days)[a]
		3 Aug 2015 – 2 Sep 2015 (31 days)	4 Aug 2015 – 31 Aug 2015 (28 days)

Aug, August; Feb, February; Jan, January.

[a] 13 Feb 2016 and 14 Feb 2016 were unseasonably warm (equivalent to the average outdoor temperature in April) and were therefore excluded.

Basic characteristics of facility buildings and residents

Two types of questionnaires were used to collect data about the facility building and residents. Questionnaire A was recorded by facility managers, which included questions about building age, structure, insulation performance, and number of residents and staff. Responses to questionnaire A are shown in Table 3.4. Questionnaire B was distributed for each resident and included questions about basic personal characteristics such as age, gender, body mass index (BMI), daily blood pressure, oral cavity, activities of daily living (ADL), medical history at occupancy, and LTC certification after nursing home admission. Because of the difficulties involved with residents' ability to complete questionnaires, they were completed by care staff.

Table 3.4 Building characteristics of facilities

ID	Building age [years old]	Structure	Number of floors	Double glazing	Insulation
1	7	S	3	N	N
2	6	RC	5	N	Y
3	4	RC	3	N	Unknown
4	4	RC	3	N	No answer
5	5	RC	5	N	Unknown
6	4	RC	4	N	Y
7	3	RC	6	Y	Unknown
8	3	RC	3	N	N
9	2	Unknown	4	N	Y
10	2	S	3	N	Unknown
11	2	RC	3	N	No answer
12	2	RC	6	N	Unknown
13	2	RC	4	N	Y
14	2	RC	4	N	Unknown
15	2	S	4	N	Unknown
16	2	S	5	N	Unknown
17	2	S	4	Y	Unknown
18	2	RC	5	N	Unknown
19	1	S	3	N	Y
20	1	RC	4	N	Unknown
21	20	RC	1	Y	Y
22	14	S	2	Y	Y
23	16	S	2	N	Y
24	2	S	3	Y	Y
25	10	RC	1	Y	Y
26	3	W	1	Y	Y
27	16	RC	6	N	Unknown

N, no; RC, reinforced concrete; S, steel; W, wooden; Y, yes.

Blood pressure

Daily systolic blood pressure (SBP) and diastolic blood pressure (DBP) were recorded once or twice a week by the care staff. For this study, SBP and DBP during the measurement period were collected in questionnaire sheet B, by copying the record which each nursing home has regardless of this survey. In addition, use of antihypertensive drugs during each season was asked in the questionnaire.

Oral dryness

Oral dryness and implementation status of dental care (ISDC) were recorded to characterise the oral health of residents. Because of the difficulties involved in presenting actual measurements of oral dryness to nursing home residents, or to ask residents themselves to respond about their oral dryness, standardised questionnaires about oral dryness and ISDC were completed by care staff in questionnaire B. Oral dryness was recorded with one of three choices: a) Dry, b) Cannot say, c) Moist; and ISDC was answered with one of four choices: a) Dental care is done independently every day, b) Dental care is done every day though help is sometimes needed, c) Dental care is done every day though help is always needed, d) Dental care is not often done though it can be done independently.

Long-term care certification

Care levels and their certification periods were collected for all residents during the period of residency. Care level has 7 levels including 2 levels of Support-required, and care level 1 (least disabled) to 5 (most disabled). In the certification process, eligibility is assessed by use of a 74-item questionnaire based on activities of daily living, with a preliminary categorisation into one of seven levels by a computer algorithm, then reviewed and finalised by an expert committee [5]. These data were provided from the insurance card of LTCI which each facility preserves. Data was recorded in questionnaire B, by copying the insurance card.

Medical history at occupancy

Medical history of cerebrovascular disease, heart disease, articular disease, dementia, fracture and fall, and weakness due to ageing were collected in questionnaire B. Care staff recorded the statement at occupancy for each disease with one of three choices: a) None, b) Cured, c) Under treatment.

3.2.3 Data analysis

Multiple rooms were measured in each facility, and the mean, standard deviation (SD), minimum, and maximum $temp_{in}$ and RH for daytime and night time were calculated. Daytime was defined as 6:00 to 17:59 and night time was defined as 18:00 to 5:59 the following day, based on the definition by the Japan Meteorological Agency [158]. Then, mean variables for private room and dining hall in each facility was calculated and used for the analysis. Most previous studies [65] [66] use a categorical cut-off point for $temp_{in}$ of 18 ˚C to protect health based on the conclusions of a World Health Organization (WHO) working group on indoor environment [79]. However, vulnerable groups including older people, children and those with chronic illness, particularly cardiorespiratory disease are considered to require a higher $temp_{in}$ threshold [159]. Therefore, the 27 facilities were classified into two groups on the basis of indoor thermal environment standards recommended for the older people by the Architectural Institute Japan (AIJ) [160]. $Temp_{in}$ is suggested to be kept over 21 ˚C in the main living rooms and 18˚C in the bedroom during night, and RH is suggested to be kept in the range of 30 – 50 % in winter. Facilities were classified into the Cold group if $temp_{in}$ fell below 21 ˚C during daytime in private rooms and the dining hall, and/or fell below 18 ˚C during night time in private rooms; other facilities were classified into the Warm group. For analysis of RH, facilities were classified into the Dry group if the mean RH fell below 30 % during daytime and night time in private rooms, or during daytime in dining halls; other facilities were classified into the Moist group.

All continuous variables were normally distributed, and means ± SDs were reported. For categorical variables, n (%) were reported. All p-values were two-sided, and $p < 0.05$ was considered statistically significant. All statistical analyses were performed with SPSS ver. 24.0 software for Windows (IBM).

Indoor temperature and blood pressure

Before investigating the association between $temp_{in}$ and blood pressure, associations between residents' characteristics and blood pressure were analysed in order to detect characteristics that could potentially affect blood pressure. To focus on cold-related influence on blood pressure, SBP in January was used. Moreover, SBP in January, March, August, and November in the Cold group and Warm group was compared by Student's t-test. Although there was a difference between seasonal changes of SBP due to $temp_{in}$ in winter, SBP is known to have a large difference among individuals, and this individual variation might affect the result. Therefore, in order to exclude the influence of personal differences as much as possible, "SBP change in winter" was defined as the difference of blood pressure between January and August to minimize individual variation. Student's *t*-test was used to investigate the difference in SBP change in winter of the Cold group and Warm group.

Since there was a seasonal change in blood pressure, the seasonal change of indoor thermal environment was investigated. In this investigation, weather conditions should be unified when indoor thermal environments were compared. The two facilities (facility 25 and 26) in Yamanashi prefecture which are located in a same site were used for this comparison because they have different indoor thermal environments even though they are located at the same site. They have different heating systems and the buildings are different ages. In particular, facility 26 uses a solar powered floor blowout heating system, which contributes to a warm indoor thermal environment in winter. Air warmed on the roof top by solar heat is guided to the underfloor by a duct, which warms the entire floor before being discharged from floor blowout ports. This type of system contributes to reduced differences in upper/lower temperatures and between temp_{in} of rooms. Linear regression analysis and Student's *t*-test were used to investigate the association between temp_{in} and temp_{out} in winter and summer, and the difference of temp_{in} between facility 25 and 26 in each season. In addition, daily temp_{in} at 1.1 m and 0.1 m above the floor were compared by using Student's *t*-test to investigate the difference of upper/lower temperature difference in facility 25 and 26.

The *t*-test of temp_{in} and SBP change in winter, the effect of temp_{in} on blood pressure was not ambiguous, and other factors which could affect blood pressure were not considered. Therefore, multilevel analysis was used to clarify the association between temp_{in} and change in blood pressure from summer to winter considering configurative effects of individual differences. 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 DE was over 2.0, the data were considered in its configuration. After confirming that multilevel analysis was not suitable with this sample, multiple linear regression analysis was used to investigate the association between blood pressure change in winter and mean temp_{in} adjusting for age, gender, BMI, period of residence, care level, SBP in August, and use of antihypertensive drugs in January. Covariates were selected by using the stepwise method.

Facility 27 which had an insulation retrofit and measured temp_{in} before and after the retrofit was extracted to investigate whether temp_{in} increased after the insulation retrofit and to assess the change in residents' blood pressure due to the change in temp_{in}. Of the 50 residents in facility 27 who participated in the 2015 survey, 8 withdrew from the study or died, leaving 42 in the 2016 survey. Changes of SBP and DBP between 2015 and 2016 (ΔSBP and ΔDBP) were aggregated and showed that some residents had a dramatic change of SBP; 54.5 mmHg was the maximum. This dramatic change is considered to be affected by causes other than the change of temp_{in}, and were therefore excluded from the analysis. At that time, participant who had ΔSBP or ΔDBP greater than mean $\pm 2\alpha$ were considered as outliers and excluded. Thereby 40 residents were considered in the analysis. Because ΔSBP and ΔDBP had large individual variations, Spearman's correlation analysis and Student's *t*-test were used to detect if residents' characteristics affected a change of blood pressure.

Paired *t*-test was used to compare SBP before and after insulation retrofit, for the full sample and a subsample of 14 residents who had before the retrofit. In the comparison of DBP before and after insulation retrofit, 11 residents who had hypotension due to low DBP were excluded, and paired *t*-test was used for a subsample of residents with normotension or hypertension before the retrofit.

Relative humidity and oral dryness

RH in winter and summer were compared to determine which season to focus on in the analysis. Facilities 25 – 27 which measured temp_{in} and RH in both winter and summer were included.

Of the three choices asked for oral dryness, "Cannot say" was excluded and residents with "Dry (n = 102)" or "Moist (n = 656)" oral cavity were used in the analysis. Before investigating the association between RH and oral dryness, the association between residents' characteristics, ISDC, and oral dryness was investigated in order to detect specific characteristic capable of affecting oral dryness. Age was compared by using Student's *t*-test and proportion of gender, BMI, care level, and ISDC were compared by using chi-squared test, by oral dryness. Moreover, oral dryness of residents in the Dry group and the Moist group was compared using chi-squared test.

However, result of the chi-square test does not include other co-variates that are capable of affecting oral dryness. Therefore, multiple logistic regression analysis was used as a multivariate analysis to investigate the association between oral dryness (0 = dry, 1 = moist) and RH environment adjusting for age, gender, BMI, care level, ISDC. Covariates were selected by using the stepwise method.

Indoor thermal environment and deterioration speed of care level

Generally, care level gradually deteriorates due to ageing and worsened chronic diseases. Care prevention is defined as preventing a care-requiring condition from occurring, and when a care-requiring condition already exists, preventing deterioration and aiming to improve the condition [161]. Therefore, not only preventing a new condition but preventing deterioration is still an important issue in care prevention. As a follow-up to deteriorated health status such as hypertension or dry mouth, changes in care level and the relationship with indoor thermal environment of the nursing home was investigated.

The different types of nursing homes provided different services based on the level of care needed by their residents, and these services could have an influence on the outcomes measured in this study. Therefore, to avoid such differences, PNH (20 facilities in Kinki area), LTCHF (3 facilities in Nagano prefecture and 2 facilities in Yamanashi prefecture), were considered as subgroups. There were not enough SENH (1 facility each in Nagano and Yamanashi prefecture), so they were excluded from the analysis.

Possibility of deterioration depends on the period of residence, and the longer the period of residence is, the possibility of deterioration will become higher. In order to consider this time series, the Kaplan-Meier method was used as a univariate analysis using the log-rank test, and Cox proportional hazards regression analysis was used as a multivariate analysis to assess the effect of indoor thermal environment on the deterioration speed of care level of residents in nursing homes. Both were survival analyses and two questions were evaluated: "Did the care level deteriorate?" and "If so, how long did it take for the care level to deteriorate?" The outcome was defined as deterioration of care level, and overall survival was defined as the period of residence after occupation.

3.3 Results

3.3.1 Measured indoor temperature and relative humidity

Measured temp_{in} and RH in private rooms and dining halls, and temp_{out} and RH are shown in Table 3.5, Table 3.6 and Table 3.7. Of the 27 facilities measured in winter, mean daytime temp_{in} in private rooms was 20.3 ± 1.6 ˚C and 20.5 ± 1.6 ˚C for the night time. And, mean daytime RH in private rooms was 22.8 ± 3.8 % and 22.9 ± 3.6 % for the night time. Daytime and night time temp_{in} in private rooms did not differ greatly across all facilities and were generally warm, but the RH was under 30 % in most facilities, which indicates that the air was dryer than recommended.

Table 3.5 Measured indoor temperature and relative humidity of daytime and night time in private rooms, at 1.1 m above floor level

	Temperature								Relative humidity							
ID	Daytime[a]				Night time[b]				Daytime[a]				Night time[b]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
1	20.2	0.9	18.2	22.8	19.7	0.8	18.2	22.1	26.6	4.8	18.2	43.5	24.9	4.5	14.6	39.4
2	20.1	3.1	11.8	25.7	22.2	1.5	12.9	24.3	22.4	4.4	14.1	37.0	22.7	4.2	13.8	34.8
3	18.7	2.7	11.2	24.7	22.4	2.1	13.1	24.7	22.9	4.8	13.9	39.8	22.6	5.0	14.5	43.6
4	21.5	1.6	18.3	24.6	21.9	1.2	19.7	25.3	26.6	5.1	18.2	45.5	26.0	5.0	18.9	43.4
5	20.5	1.2	18.4	23.1	20.8	1.4	18.5	24.9	21.9	4.8	13.9	38.8	21.9	4.4	12.9	35.7
6	19.5	0.5	18.4	20.9	19.4	0.5	18.3	20.5	28.4	4.5	20.6	46.8	28.4	4.3	42.6	19.7
7	21.0	0.9	18.9	22.5	21.5	0.7	18.9	22.8	30.2	4.1	21.7	47.5	30.8	4.9	21.2	46.8
8	19.9	0.8	17.9	21.8	19.4	0.6	18.4	21.0	22.2	4.7	12.6	42.0	22.0	4.5	11.6	35.9
9	18.4	3.0	12.2	23.9	21.6	2.5	14.0	26.9	28.1	7.1	17.7	44.9	27.6	6.6	17.3	42.7
10	22.5	1.2	17.9	27.7	20.8	2.4	10.4	25.7	22.0	5.1	12.0	41.8	21.5	4.2	12.5	34.7
11	17.6	0.7	11.7	23.9	18.1	0.5	15.3	21.0	29.4	5.3	19.3	50.0	29.1	4.6	18.4	43.0
12	21.1	2.3	14.3	24.9	19.8	2.3	14.9	23.9	23.2	4.0	16.1	37.7	23.2	4.0	29.7	50.6
13	17.4	1.2	13.7	20.8	16.7	1.3	13.7	20.3	15.8	3.6	8.4	27.3	15.1	3.5	8.1	25.3
14	18.5	0.8	16.7	20.7	18.6	0.7	16.8	20.6	20.4	5.2	11.2	36.8	19.7	5.0	9.9	37.4
15	20.8	1.8	15.7	23.7	20.5	1.8	15.8	23.4	20.5	5.0	11.5	33.7	20.5	5.2	11.3	37.3
16	22.0	1.0	17.8	25.1	21.8	1.3	19.9	23.4	21.5	4.9	11.8	38.9	21.1	4.4	10.6	35.5
17	20.9	0.5	19.7	22.3	21.0	0.8	18,8	23.0	21.6	4.7	11.1	38.1	21.1	4.6	12.4	35.8
18	18.7	2.6	15.3	24.0	19.3	3.1	15.6	24.0	19.4	4.0	11.8	33.4	22.8	4.6	13.0	38.8
19	22.6	1.8	19.5	26.7	22.8	1.7	17.4	25.9	23.7	5.3	13.1	43.2	24.1	5.1	14.0	40.2
20	20.9	3.8	13.5	26.6	20.7	3.8	15.0	27.1	28.1	3.8	19.2	39.6	27.9	3.7	18.9	39.8
21	21.6	1.8	14.2	24.6	21.8	1.9	14.4	24.4	18.4	4.4	7.4	34.5	20.5	3.5	12.3	31.1
22	21.5	1.5	17.8	24.7	21.2	1.3	18.0	23.8	16.2	3.1	9.5	25.5	18.0	2.9	12.6	27.8
23	18.4	1.6	14.1	21.9	17.7	1.4	14.2	21.7	21.3	3.4	13.1	30.7	24.1	4.1	16.3	37.7
24	23.1	1.6	17.2	27.6	23.1	1.3	17.4	26.8	18.4	3.7	9.8	29.9	17.7	3.5	9.5	27.8
25	19.0	1.5	15.2	24.3	19.1	1.7	14.6	23.3	23.9	5.1	12.3	38.0	19.7	4.8	12.1	36.3
26	22.5	2.5	13.2	28.4	21.8	1.6	14.6	24.6	20.8	8.7	5.4	47.2	23.8	4.9	11.6	38.3
27	18.3	1.2	15.8	20.9	18.5	1.0	16.6	20.5	22.1	6.4	11.7	37.2	23.4	5.6	13.3	35.6
27[c]	20.8	0.8	18.9	23.6	20.7	1.4	17.7	23.6	21.3	7.2	7.3	48.6	22.4	6.6	9.0	44.6
25[d]	26.5	1.0	23.9	29.3	26.4	1.0	23.9	29.3	71.2	3.9	55.6	82.7	69.1	3.2	58.7	79.7
26[d]	25.9	1.0	23.1	28.5	25.8	1.0	21.5	26.7	61.7	7.0	45.2	81.7	61.4	7.8	45.5	81.8
27[d]	25.7	0.8	22.3	27.8	24.8	0.8	22.3	25.7	60.6	7.7	49.0	78.8	62.5	6.0	47.7	76.4

Max, maximum; Min, minimum; SD, standard deviation.

[a]6:00 to 17:59, [b]18:00 to 5:59 the following day, [c]After insulation retrofit, [d]Measurement in summer.

Table 3.6 Measured indoor temperature and relative humidity of daytime and night time in dining halls, at 1.1 m above floor level

ID	Temperature								Relative humidity							
	Daytime[a]				Night time[b]				Daytime[a]				Night time[b]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
1	22.8	1.6	18.4	25.2	20.5	1.6	18.1	25.1	29.6	7.9	14.6	61.1	27.7	6.1	17.0	47.4
2	23.8	1.5	17.7	26.7	21.9	1.9	17.8	25.6	26.8	5.7	15.9	48.4	30.9	7.2	15.9	52.8
3	25.3	0.9	21.9	27.7	25.1	1.0	21.9	27.5	22.2	5.5	11.8	41.3	21.0	5.8	10.4	41.8
4	23.8	1.1	19.1	26.4	22.1	1.5	17.0	25.8	27.6	6.7	15.3	54.9	29.9	8.7	12.1	52.6
5	25.6	2.0	18.1	31.2	22.5	2.6	17.8	30.8	25.1	6.4	10.9	60.3	25.3	5.2	14.1	52.6
6	24.9	0.7	20.2	26.1	23.8	1.5	19.9	26.0	23.8	5.0	13.7	42.8	21.8	5.1	12.6	43.0
7	21.8	1.3	17.6	24.6	21.4	1.6	17.8	23.1	30.6	4.4	46.8	22.3	36.0	4.7	22.2	49.8
8	24.1	1.3	19.6	26.7	22.3	1.6	18.6	26.3	25.7	5.1	14.3	42.5	23.5	5.5	11.6	41.0
9	20.7	2.5	11.6	25.0	19.9	2.4	12.4	24.9	31.9	6.2	15.7	46.5	33.1	6.0	13.4	48.6
10	20.8	1.9	10.4	25.8	20.8	2.4	10.4	25.7	25.8	6.4	14.7	53.2	30.2	7.2	15.8	53.6
11	22.2	1.3	17.6	24.3	20.8	1.7	17.5	24.3	32.7	6.3	21.5	58.7	33.7	5.5	22.0	50.0
12	22.4	1.9	15.9	25.1	20.1	2.6	15.9	24.7	25.6	6.7	15.4	53.9	27.4	7.2	13.0	57.6
13	19.0	2.5	12.7	24.8	17.3	2.1	12.8	24.2	40.4	11.8	16.1	71.7	39.5	10.3	17.7	70.7
14	24.2	1.5	16.2	27.4	21.5	3.1	14.1	26.9	21.3	5.8	11.0	40.4	23.6	7.7	8.7	55.2
15	22.4	2.3	13.1	25.3	18.6	3.2	13.1	24.9	26.3	6.3	13.4	53.9	28.3	6.9	13.4	53.6
16	24.2	1.1	18.9	26.2	21.6	2.0	18.2	25.7	24.3	5.0	13.2	41.8	26.1	5.3	12.5	43.9
17	20.7	2.7	15.9	25.9	19.4	1.9	15.9	25.7	27.8	6.6	16.8	54.9	27.1	5.9	14.4	47.6
18	18.8	2.6	13.8	25.4	17.0	1.8	13.8	24.5	28.8	6.8	13.8	56.4	31.0	5.7	16.3	48.9
19	21.2	1.5	17.7	24.6	20.8	1.4	17.8	23.8	30.5	6.7	17.2	51.4	28.7	6.4	14.6	49.3
20	24.6	1.5	20.1	30.1	22.6	1.4	20.1	27.2	28.2	5.1	12.1	46.0	30.5	5.2	16.7	46.3
21	21.6	0.9	19.2	23.6	21.4	1.0	19.4	23.6	29.1	6.1	15.2	44.4	29.6	5.4	15.6	42.6
22	22.0	1.7	16.3	24.4	20.5	1.9	16.3	24.4	19.8	3.3	12.2	32.1	18.0	3.1	12.1	28.4
23	23.0	1.4	19.9	26.0	22.0	1.6	17.9	25.8	20.9	4.0	13.7	37.5	19.6	3.8	13.1	34.1
24	24.2	0.9	21.2	26.4	23.5	1.1	18.7	26.4	18.6	3.0	10.4	29.1	19.2	3.0	10.6	28.8
25	20.4	2.5	15.5	24.0	19.1	1.9	14.6	23.6	23.2	5.3	12.0	40.7	26.9	5.5	14.3	43.5
26	22.8	1.6	15.5	30.4	22.5	1.2	14.6	24.5	33.5	8.2	18.8	88.6	36.8	7.7	24.9	89.6
27	17.2	3.8	8.4	23.4	12.8	1.7	8.7	18.2	25.4	5.4	11.1	40.0	27.4	5.4	17.5	38.5
27[c]	20.6	1.3	17.8	24.7	21.0	1.7	16.8	24.7	26.4	5.9	16.6	53.0	27.9	5.7	17.5	52.4
25[d]	26.9	0.9	22.2	28.5	25.8	0.6	24.1	27.5	66.1	3.7	54.2	78.4	70.2	2.8	57.7	82.5
26[d]	25.6	0.8	22.5	26.5	25.4	0.8	23.5	28.2	62.9	6.6	42.4	82.1	62.5	5.8	46.3	76.0
27[d]	25.7	1.3	22.8	28.3	24.0	0.9	21.1	26.4	68.7	5.4	51.7	80.1	67.2	6.3	53.3	81.5

Max, maximum; Min, minimum; SD, standard deviation.

[a]6:00 to 17:59, [b]18:00 to 5:59 the following day, [c]After insulation retrofit, [d]Measurement in summer.

Table 3.7 Outdoor temperature and relative humidity of daytime and night time

ID	Temperature								Relative humidity							
	Daytime[a]				Night time[b]				Daytime[a]				Night time[b]			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
1	6.8	2.8	-0.4	14.4	4.8	2.4	-1.2	11.8	—	—	—	—	—	—	—	—
2	6.5	2.9	-0.9	13.8	4.7	2.4	-0.3	10.6	—	—	—	—	—	—	—	—
3	5.4	3.1	-2.6	13.5	3.2	2.4	-1.7	8.9	68.8	17.6	34.0	100.0	77.7	12.9	40.0	100.0
4	6.7	2.7	0.1	13.9	5.3	2.2	0.3	10.6	60.2	14.9	35.0	95.0	65.1	12.3	33.0	97.0
5	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
6	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
7	5.7	2.9	-0.9	12.7	4.0	2.3	-0.5	9.6	66.9	15.2	30.0	97.0	75.1	10.8	41.0	96.0
8	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
9	5.7	2.9	-0.9	12.7	4.0	2.3	-0.5	9.6	66.9	15.2	30.0	97.0	75.1	10.8	41.0	96.0
10	6.0	2.9	-1.6	13.0	4.0	2.3	-1.1	9.9	—	—	—	—	—	—	—	—
11	5.7	2.9	-0.9	12.7	4.0	2.3	-0.5	9.6	66.9	15.2	30.0	97.0	75.1	10.8	41.0	96.0
12	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
13	5.4	3.1	-2.6	13.5	3.2	2.4	-1.7	8.9	68.8	17.6	34.0	100.0	77.7	12.9	40.0	100.0
14	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
15	6.7	2.7	0.1	13.9	5.3	2.2	0.3	10.6	60.2	14.9	35.0	95.0	65.1	12.3	33.0	97.0
16	6.2	3.0	-1.9	15.0	4.0	2.6	-1.5	9.7	—	—	—	—	—	—	—	—
17	6.7	2.7	0.1	13.9	5.3	2.2	0.3	10.6	60.2	14.9	35.0	95.0	65.1	12.3	33.0	97.0
18	5.7	2.9	-0.9	12.7	4.0	2.3	-0.5	9.6	66.9	15.2	30.0	97.0	75.1	10.8	41.0	96.0
19	6.7	2.7	0.1	13.9	5.3	2.2	0.3	10.6	60.2	14.9	35.0	95.0	65.1	12.3	33.0	97.0
20	5.7	2.9	-0.9	12.7	4.0	2.3	-0.5	9.6	66.9	15.2	30.0	97.0	75.1	10.8	41.0	96.0
21	-1.6	3.6	-12.0	9.0	-4.1	3.1	-11.4	4.6	—	—	—	—	—	—	—	—
22	-1.6	3.6	-12.0	9.0	-4.1	3.1	-11.4	4.6	—	—	—	—	—	—	—	—
23	-1.6	3.6	-12.0	9.0	-4.1	3.1	-11.4	4.6	—	—	—	—	—	—	—	—
24	-1.6	3.6	-12.0	9.0	-4.1	3.1	-11.4	4.6	—	—	—	—	—	—	—	—
25	3.9	4.7	-7.1	15.6	0.0	2.7	-6.9	10.3	—	—	—	—	—	—	—	—
26	3.9	4.7	-7.1	15.6	0.0	2.7	-6.9	10.3	—	—	—	—	—	—	—	—
27	3.9	4.7	-7.1	15.6	0.0	2.7	-6.9	10.3	—	—	—	—	—	—	—	—
27[c]	4.3	4.4	-4.4	12.6	0.6	3.4	-4.2	14.7	—	—	—	—	—	—	—	—
25[d]	26.3	2.4	21.6	29.1	22.6	2.5	21.1	24.4	—	—	—	—	—	—	—	—
26[d]	26.3	2.4	21.6	29.1	22.6	2.5	21.1	24.4	—	—	—	—	—	—	—	—
27[d]	26.3	2.4	21.6	29.1	22.6	2.5	21.1	24.4	—	—	—	—	—	—	—	—

Max, maximum; Min, minimum; SD, standard deviation.

[a]6:00 to 17:59, [b]18:00 to 5:59 the following day, [c]After insulation retrofit, [d]Measurement in summer.

The classification of the facilities regarding the measured temp$_{in}$ and RH during daytime and night time are plotted in Figure 3.1. Plots in the shaded area indicate facilities that are meeting the indoor thermal environment recommendations; the Warm group or the Moist group, and others were classified into the Cold group or the Dry group. All facility had temp$_{in}$ over 21 ˚C during the night time. However, cold temp$_{in}$ occurring only during the daytime was considered as a negative indoor environment based on previous reports of cold related hypertension [162] and deterioration of muscle strength [163].

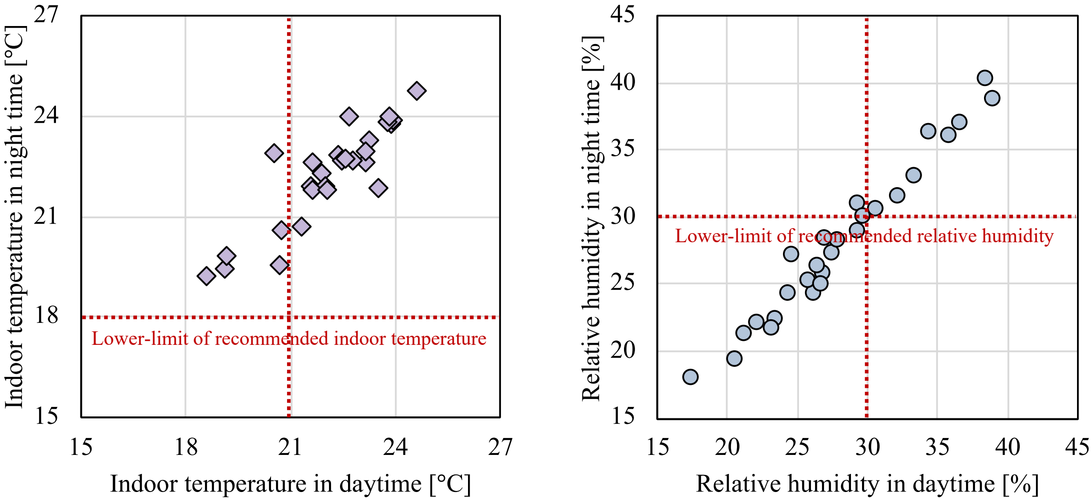


Figure 3.1 Indoor temperature and relative humidity in daytime and night time [left, indoor temperature; right, relative humidity]

$Temp_{in}$ at 1.1 m and 0.1 m high are shown in Figure 3.2. Mean temperature differences between 1.1 m and 0.1 m high were 0.6 ± 1.8 ˚C in private rooms and 1.5 ± 1.0 ˚C in dining halls. Particularly in dining halls, there were great upper/lower differences in $temp_{in}$, so the feet were likely to be colder than the rest of the body.

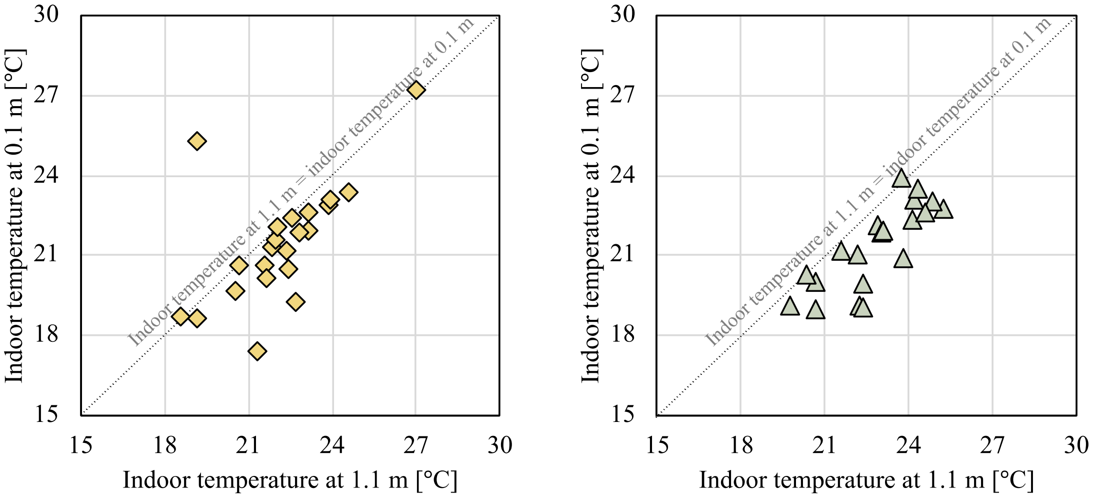


Figure 3.2 Indoor temperature at 1.1 m and 0.1 m [left, private room; right, dining hall]

3.3.2 Characteristics of the residents

For the 1,337 residents, mean age was 86.5 ± 7.0 years and 1,015 (75.9 %) were women. Mean BMI was 20.3 ± 3.5 kg/m^2 and 466 (34.9 %) were underweight (BMI < 18.5). Mean period of residence was 2.1 ± 1.8 years and most residents were living in the present facility for less than 5 years. Mean SBP in January was 127.3 ± 16.0 mmHg for men and 128.2 ± 15.6 mmHg for women. Among all residents, 35.0 % had SBP over 135 mmHg which indicates that they had hypertension [164]. The number of residents using antihypertensive drugs in January was almost the same as residents not using them, when “No answer” was excluded. In order to capture oral health of the residents, ISDC and oral dryness were aggregated. It has been mentioned that ISDC is essential for oral health [165], and thus 795 (59.5 %) of residents in this study were working on ISDC with/without help. 656 (49.1 %) of the residents had a moist oral cavity. The care level at occupancy was widely distributed. Since SENH was included in this study, there were people with support levels 1 and 2. For more details, see Table 3.8.

Table 3.8 Characteristics of the residents

	All (*n* = 1,337)		Men (*n* = 322)		Women (*n* = 1,015)	
Age, years, mean (SD)	86.5	(7.0)	84.3	(8.8)	87.1	(6.2)
BMI, kg/m^2, mean (SD)	20.3	(3.5)	20.5	(3.2)	20.2	(3.6)
BMI, *n* (%)						
< 18.5	466	(34.9)	124	(38.5)	338	(33.3)
18.5 ≤ BMI < 25	191	(14.3)	41	(12.7)	150	(14.8)
≥ 25	69	(5.2)	17	(5.3)	52	(5.1)
No answer	611	(45.7)	140	(43.5)	475	(46.8)
Period of residence, years, mean (SD)	2.1	(1.8)	1.9	(1.9)	2.2	(1.8)
SBP, mmHg, mean (SD)						
January	128.0	(15.7)	127.3	(16.0)	128.2	(15.6)
March	128.7	(16.1)	127.4	(15.5)	129.1	(16.3)
August	126.9	(15.7)	126.1	(14.9)	127.0	(15.9)
November	128.3	(15.9)	128.3	(15.5)	128.3	(16.1)
Using antihypertensive drugs						
January, *n* (%)						
Yes	552	(41.3)	128	(39.8)	424	(41.8)
No	451	(33.7)	104	(32.3)	347	(34.2)
No answer	334	(25.0)	90	(28.0)	244	(24.0)
March, *n* (%)						
Yes	437	(32.7)	100	(31.1)	337	(33.2)
No	363	(27.2)	81	(25.2)	282	(27.8)
No answer	537	(40.2)	141	(43.8)	396	(39.0)
August, *n* (%)						
Yes	510	(38.1)	116	(36.0)	394	(38.8)
No	432	(32.3)	101	(31.4)	331	(32.6)
No answer	395	(29.5)	105	(32.6)	290	(28.6)
November, *n* (%)						
Yes	542	(40.5)	125	(38.8)	417	(41.1)
No	449	(33.6)	108	(33.5)	341	(33.6)
No answer	346	(25.9)	89	(27.6)	257	(25.3)
ISDC, *n* (%)						
Done independently every day	326	(24.4)	73	(22.7)	253	(24.9)
Done every day though help is sometimes needed	332	(24.8)	78	(24.2)	254	(25.0)
Done every day though help is always needed	137	(10.2)	45	(14.0)	92	(9.1)
Not often done though it can be done independently	521	(39.0)	120	(37.3)	401	(39.5)
No answer	21	(1.6)	6	(1.9)	15	(1.5)
Oral dryness, *n* (%)						
Dry	102	(7.6)	26	(8.1	76	(7.5
Cannot say	552	(41.3)	128	39.8)	424	41.8
Moist	656	(49.1)	157	48.8	495	48.8)
No answer	27	(2.0)	7	2.2	20	2.0

Continued from Table 3.8

	All (*n* = 1,337)	Men (*n* = 322)	Women (*n* = 1,015)
Care level at occupancy, *n* (%)			
Support level 1	85 (6.4)	27 (8.4)	58 (5.7)
Support level 2	72 (5.4)	17 (5.3)	55 (5.4)
Care level 1	267 (20.0)	53 (16.5)	214 (21.1)
Care level 2	291 (21.8)	66 (20.5)	225 (22.2)
Care level 3	257 (19.2)	59 (18.3)	198 (19.5)
Care level 4	188 (14.1)	45 (14.0)	143 (14.1)
Care level 5	93 (7.0)	22 (6.8)	71 (7.0)
No answer	84 (6.3)	33 (10.2)	51 (5.0)
Care level at 2015, *n* (%)			
Support level 1	56 (4.2)	19 (5.9)	37 (3.6)
Support level 2	43 (3.2)	13 (4.0)	30 (3.0)
Care level 1	219 (16.4)	40 (12.4)	179 (17.6)
Care level 2	232 (17.4)	57 (17.7)	175 (17.2)
Care level 3	254 (19.0)	74 (23.0)	180 (17.7)
Care level 4	254 (19.0)	58 (18.0)	196 (19.3)
Care level 5	186 (13.9)	34 (10.6)	152 (15.0)
No answer	93 (7.0)	27 (8.4)	66 (6.5)

BMI, body mass index; ISDC, implementation status of dental care; SBP, systolic blood pressure; SD, standard deviation.

Medical history at occupancy is shown in Figure 3.3. 625 (46.7 %) of the residents were under treatment for dementia at occupancy.

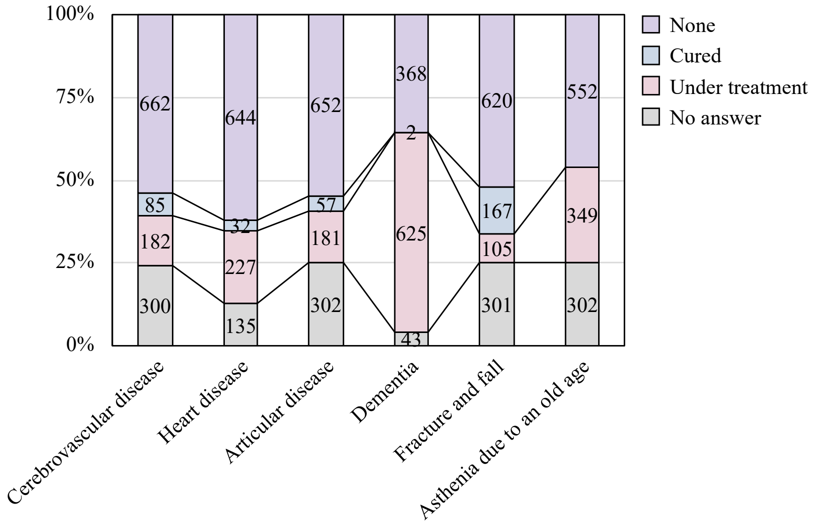


Figure 3.3 Medical history at occupancy

3.3.3 Indoor temperature and blood pressure

Characteristics of residents in relation to blood pressure

In the relationships between gender, age, BMI and SBP, no differences in SBP between gender (Men, 127.3 ± 16.0 mmHg; Women, 128.2 ± 15.6 mmHg; $t(1190) = -0.86$, $p = 0.390$) nor age (< 75, 126.2

± 17.2 mmHg; ≥ 75, 128.1 ± 15.6 mmHg; $t(1,183) = 0.92$, $p = 0.357$) were confirmed. SBP was lower in underweight (BMI < 18.5) residents (BMI < 18.5, 124.0 ± 17.2 mmHg; 18.5 ≤ BMI < 25, 127.7 ± 15.3 mmHg; BMI ≥ 25, 126.2 ± 14.0 mmHg; $F(2, 626) = 3.40$, $p = 0.034$). Medical history of cerebrovascular disease (Recovered/none, 128.1 ± 15.5 mmHg; Treating, 125.4 ± 16.4 mmHg; $t(926) = 1.78$, $p = 0.163$) and heart disease (Recovered/none, 129.1 ± 16.0 mmHg; Treating, 126.0 ± 14.3 mmHg; $t(927) = 1.62$, $p = 0.267$) had a week association with SBP, and residents treating those diseases had slightly lower SBP. On the other hand, residents using antihypertensive drugs (Yes, 130.0 ± 14.8 mmHg; No, 125.5 ± 16.3 mmHg; $t(982) = 4.46$, $p < 0.001$), with lower care levels (Support level 1, 130.9 ± 17.2 mmHg; Support level 2, 133.5 ± 11.3 mmHg; Care level 1, 130.8 ± 14.9 mmHg; Care level 2, 130.9 ± 15.6 mmHg; Care level 3, 127.0 ± 15.2 mmHg; Care level 4, 124.8 ± 15.9 mmHg; Care level 5, 121.7 ± 15.9 mmHg; $F(6, 1,108) = 3.40$, $p < 0.001$) had higher SBP (Table 3.9).

Table 3.9 Student's *t*-test and analysis of variance of Systolic Blood Pressure in January by characteristics of the residents

	n	Mean	SD	*t*	*F*	p^{a}
Gender						
Men	277	127.3	16.0	-0.86		0.390
Women	915	128.2	15.6			
Age in years						
< 75	64	126.2	17.2	0.92		0.357
≥ 75	1,121	128.1	15.6			
BMI						
< 18.5	169	124.0	17.2		3.40	0.034
18.5 ≤ BMI < 25	398	127.7	15.3			
≥ 25	62	126.2	14.0			
Care level at 2015						
Support level 1	53	130.9	17.2		9.61	<0.001
Support level 2	41	133.5	11.3			
Care level 1	211	130.8	14.9			
Care level 2	219	130.9	15.6			
Care level 3	223	127.0	15.2			
Care level 4	214	124.8	15.9			
Care level 5	154	121.7	15.9			
Using antihypertensive drugs in January						
Yes	542	130.0	14.8	4.46		<0.001
No	442	125.5	16.3			
Cerebrovascular disease						
Recovered/none	777	128.1	15.5	1.78		0.163
Treating	151	125.4	16.4			
Heart disease						
Recovered/none	725	129.1	16.0	1.62		0.267
Treating	204	126.0	14.3			

BMI, body mass index; SD, standard deviation.

[a] *p*-values of Student's *t*-test for two-sided variables and of analysis of variance for multiple categorical variables were reported.

Seasonal differences in blood pressure

In the Student's *t*-test of SBP in each season by temp$_{\text{in}}$ groups, SBP of residents in the Cold group (January, 128.8 ± 15.3 mmHg; November, 129.0 ± 15.7 mmHg) was higher than in the Warm group (January, 126.4 ± 16.4 mmHg; November, 127.0 ± 16.3 mmHg) in both January, $t(1,118) = -2.37$, $p = 0.018$, and November, $t(1,118) = -1.97$, $p = 0.049$, respectively (Table 3.10). In contrast, there were no significant differences in SBP between the Cold group (March, 129.0 ± 16.5 mmHg; August, 127 ± 15.5 mmHg) and the Warm group (March, 128.2 ± 15.3 mmHg; August, 126.5 ± 16.2 mmHg) in March, $t(1,118) = -0.67$, $p = 0.501$, and August, $t(1,118) = -0.56$, $p = 0.573$, respectively (Table 3.10).

Table 3.10 Student's *t*-test of Systolic Blood Pressure by indoor temperature group

	n	Mean	SD	*t*	*p*
January					
Cold group	345	128.8	15.3	-2.37	0.018
Warm group	775	126.4	16.4		
March					
Cold group	345	129.0	16.5	-0.67	0.501
Warm group	775	128.2	15.3		
August					
Cold group	345	127.0	15.5	-0.56	0.573
Warm group	775	126.5	16.2		
November					
Cold group	345	129.0	15.7	-1.97	0.049
Warm group	775	127.0	16.3		

SD, standard deviation.

SBP change in winter defined as the difference of blood pressure between January and August was 1.7 ± 13.2 mmHg in the Cold group and -0.4 ± 16.6 mmHg in the Warm group, indicating that the Warm group had lower SBP change in winter, $t(1,118) = -2.08$, $p = 0.038$ (Table 3.11).

Table 3.11 Student's *t*-test of Systolic Blood Pressure change in winter by indoor temperature group

	n	Mean	SD	*t*	*p*
Cold group	345	1.7	13.2	-2.08	0.038
Warm group	775	-0.4	16.6		

SD, standard deviation.

Seasonal difference of indoor temperature

Daily temp_{in} in private rooms, 1.1 m above floor level and temp_{out} are shown in Figure 3.4. Seasonal comparison associations of temp_{in} and temp_{out} were weak in winter and temp_{in} differed between facilities regardless of the temp_{out} (Facility 25, $y = 0.03x + 20.5$, $R^2 = 0.01$; Facility 26, $y = 0.10x + 24.3$, $R^2 = 0.02$), though temp_{in} in summer were influenced by temp_{out}, especially in facility 26 (Facility 25, $y = 0.05x + 23.8$, $R^2 = 0.18$; Facility 26, $y = 0.28x + 18.0$, $R^2 = 0.70$). Difference of temp_{in} between in facility 25 and 26 was 4.0 ˚C in winter (Facility 25, 20.6 ± 0.6 ˚C; Facility 26, 24.6 ± 1.1 ˚C; $t(54) = -13.32$, $p < 0.001$) and 0.5 ˚C in summer (Facility 25, 25.2 ± 0.4 ˚C; Facility 26, 24.7 ± 1.0 ˚C; $t(54) = 2.05$, $p = 0.048$, Table 3.12).

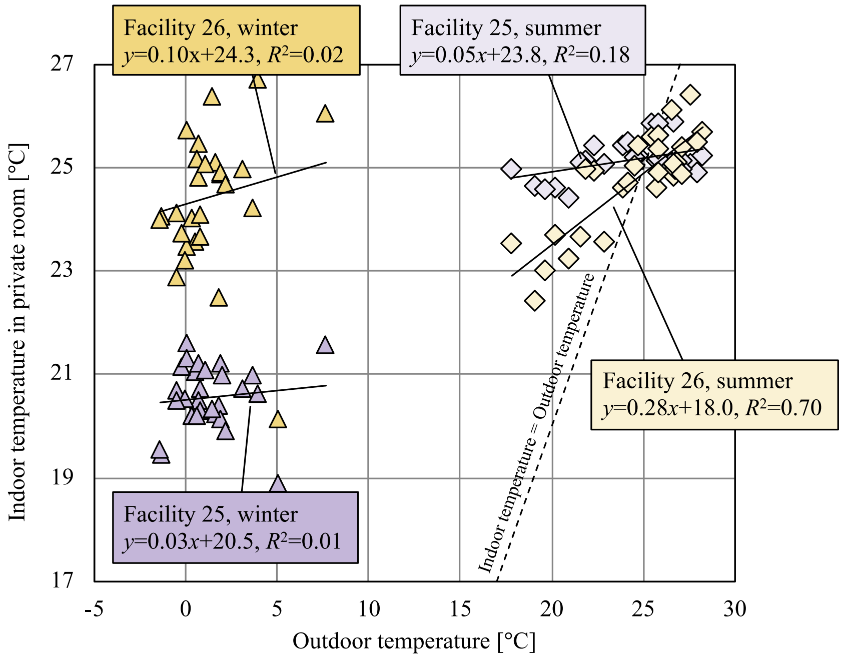


Figure 3.4 Daily mean indoor temperature in private room and outdoor temperature in facility 25 and 26

Table 3.12 Student's *t*-test of daily mean indoor temperature in private rooms in facility 25 and 26, in winter and summer

	n	Mean	SD	*t*	*p*
Winter					
Facility 25	28	20.6	0.6	-13.32	<0.001
Facility 26	28	24.6	1.1		
Summer					
Facility 25	28	25.2	0.4	2.05	0.048
Facility 26	28	24.7	1.0		

SD, standard deviation.

Temp_{in} at 1.1 m and 0.1 m above the floor was significantly different in facility 25 (1.1 m, 20.6 ± 0.6 ˚C; 0.1 m, 20.0 ± 0.4 ˚C; $t(54) = 4.45$, $p < 0.001$), though there was no significant difference in facility 26 (1.1 m, 24.6 ± 1.1 ˚C; 0.1 m, 24.8 ± 1.0 ˚C; $t(54) = -0.59$, $p = 0.850$) which indicates that the upper/lower temperature difference was small (Table 3.13).

Table 3.13 Student's *t*-test of mean indoor temperature in private rooms 1.1 m and 0.1 m above the floor in facility 25 and 26

	n	Mean	SD	*t*	*p*
Facility 25					
1.1 m	28	20.6	0.6	4.45	<0.001
0.1 m	28	20.0	0.4		
Facility 26					
1.1 m	28	24.6	1.1	-0.59	0.850
0.1 m	28	24.8	1.0		

SD, standard deviation.

A similar tendency was seen among the thermal image photographs as well. Figure 3.5 – Figure 3.8 are photographs and thermal image photographs in representative private rooms. The floor in facility 25 was generally cold and approximately 18 ˚C on the surface. In contrast, the overall temperature in facility 26 was 25 – 27 ˚C, which was more consistent between the floor and at 1.1 m.


Figure 3.5 A private room in facility 25


Figure 3.6 A private room in facility 26

Figure 3.7 Thermal image photograph in facility 25

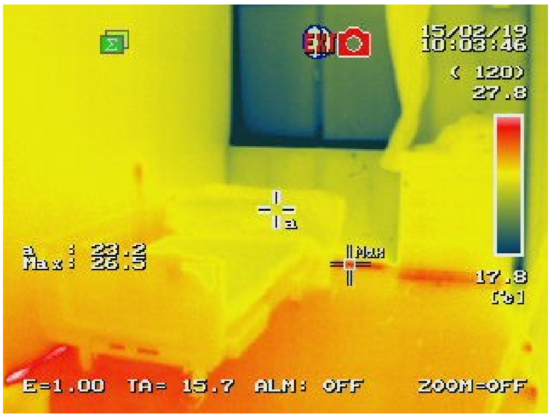


Figure 3.8 Thermal image photograph in facility 26

Effects of indoor temperature on blood pressure

In the null model with SBP change in winter as the objective variable, ICC was 0.02, and DE was 1.81, which shows that there were no configurative effects for SBP change in winter among study participants (Table 3.14).

Table 3.14 Intraclass correlation coefficient and design effect of the null model of systolic blood pressure change in winter

	Estimated value	SD		
Fixed components			AIC	8.99×10^3
Intercept	1.07*	0.43	ICC	0.02
Random components			DE	1.81
Variance of residual	203***	8.76	*n*	1,100
Variance of intercept	3.46	2.30		

AIC, Akaike’s information criterion; DE, design effect; ICC, intraclass correlation coefficient; SD, standard deviation.
$^*p < 0.05$, $^{***}p < 0.001$

Because multilevel analysis was not suitable for this sample, multiple linear regression analysis was used. In the multiple linear regression model, the $temp_{in}$ of private rooms showed a significant inverse association with SBP change in winter (Table 3.15). A 1 °C decrease in $temp_{in}$ was significantly associated with a 0.74 mmHg increase in SBP change in winter for daytime mean $temp_{in}$ (Model 1, $p < 0.01$) and a 0.72 mmHg increase for night time mean $temp_{in}$ (Model 2, $p < 0.01$).

Table 3.15 Multiple linear regression model of systolic blood pressure change in winter, resident characteristics and mean indoor temperature in private rooms

	Unstandardized coefficients		Standardized coefficients	*t*	*p*
	B	SE	*β*		
Model 1: $R^2 = 0.25, F = 54.04, p < 0.001$					
Constant	71.83	7.59		9.47	<0.001
SBP in August	-0.45	0.04	-0.49	-12.34	<0.001
Antihypertensive drugs in January[a]	3.09	1.13	0.11	2.73	<0.01
Daytime mean $temp_{in}$	-0.74	0.28	-0.10	-2.62	<0.01
Model 2: $R^2 = 0.25, F = 54.04, p < 0.001$					
Constant	71.16	6.85		10.39	<0.001
SBP in August	-0.44	0.04	-0.48	-12.21	<0.001
Antihypertensive drugs in January[a]	2.90	1.13	0.10	2.57	<0.05
Night time mean $temp_{in}$	-0.72	0.24	-0.12	-2.97	<0.01

SBP, systolic blood pressure; SE, standard error; $temp_{in}$, indoor temperature.
[a] Using vs Not using.
n=1,100, Variable selection method: stepwise method.

Effects of insulation retrofit on blood pressure

As shown in the previous sections, residents in warmer nursing homes had lower increases of blood pressure in winter. However, that result was based on the study which had a cross-sectional design preventing us from inferring any causal relationship between $temp_{in}$ and blood pressure. Therefore, in this section, facility 27 which had an insulation retrofit and measured $temp_{in}$ before and after the retrofit was extracted to investigate whether $temp_{in}$ increased after the insulation retrofit and to assess the change in residents' blood pressure due to the change in $temp_{in}$.

The insulation retrofit was completed between surveys in 2015 and 2016. In the insulation retrofit, 528 single-glazed windows (620 m^2 in area) were replaced with double-glazed windows. The *U*-value of 11 window frames was lowered for bathroom windows that were difficult to secure adequate insulation performance without replacing the window frame (Table 3.16).

Table 3.16 Insulation performance of windows and window frames before and after insulation retrofit in facility 27

	Before insulation retrofit	After insulation retrofit
Windows		
Glass material	Float plate glass	Vacuum multiple glass
Construction	FL5	FL3+Vacuum layer 0.2+FL3
U-value	5.9	1.4
η-value	0.86	0.66
Window frames		
U-value	4.2	1.6

FL, float plate glass.

Temp$_{in}$ at 1.1 m above the floor increased from 20.3 ± 0.7 ˚C to 21.5 ± 0.7 ˚C due to the insulation retrofit (Figure 3.9). Moreover, the correlation between temp$_{in}$ and temp$_{out}$ became weaker after the retrofit (Before retrofit, $y = 0.14x + 19.90$, $R^2 = 0.39$; After retrofit, $y = 0.02x + 21.47$, $R^2 = 0.02$). Temp$_{in}$ at 0.1 m above the floor increased as temp$_{in}$ at 1.1 m did (Before retrofit, $y = 0.87x + 1.19$, $R^2 = 0.85$; After retrofit, $y = 0.69x + 4.82$, $R^2 = 0.57$, Figure 3.10). The proportion of time with a temp$_{in}$ below 21 ˚C decreased from 83.7 % to 21.5 % (Figure 3.11).

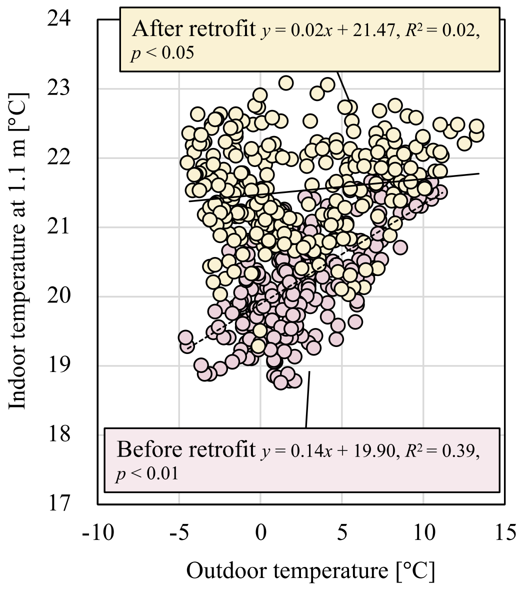


Figure 3.9 Indoor temperature at 1.1 m above the floor and outdoor temperature

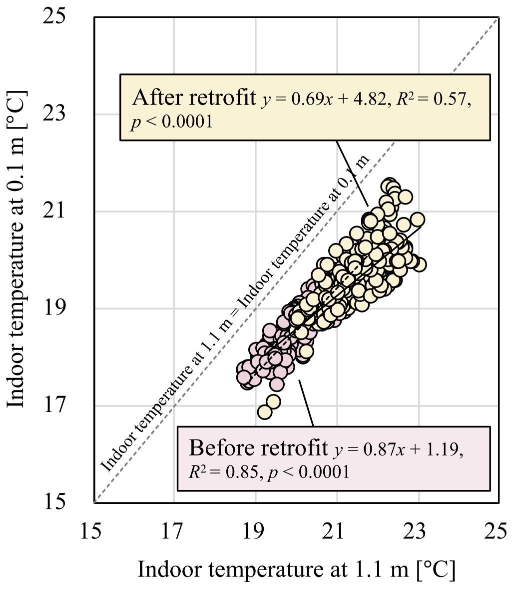
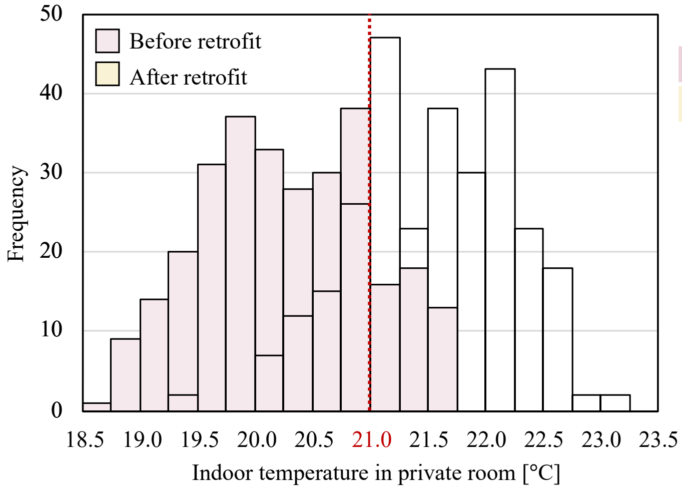


Figure 3.10 Indoor temperature at 1.1 m and 0.1 m above the floor



■ Time with Indoor temperature under 21 °C

Before retrofit	83.68%
After retrofit	21.53%

Figure 3.11 Distribution of indoor temperature

Of the 40 residents in facility 27, mean age was 86.8 ± 8.7 years-old and 35 (83.3 %) were women. For more details, see Table 3.17.

Table 3.17 Characteristics of the residents in facility 27

	Residents in facility 27 (n = 40)	
Women, n (%)	35	(83.3)
Age, years, mean (SD)	86.8	(8.7)
BMI, n (%)		
< 18.5	11	(27.5)
$18.5 \leq$ BMI < 25	22	(55.0)
≥ 25	4	(10.0)
No answer	3	(7.5)
SBP, mmHg, mean (SD)		
Before insulation retrofit	129.4	(20.0)
After insulation retrofit	125.4	(16.7)
DBP, mmHg, mean (SD)		
Before insulation retrofit	68.8	(10.6)
After insulation retrofits	66.3	(11.6)
Using antihypertensive drugs in January, n (%)	26	(61.9)
Care level at 2015, n (%)		
Care level 1	5	(11.9)
Care level 2	9	(21.4)
Care level 3	8	(19.0)
Care level 4	9	(21.4)
Care level 5	9	(21.4)
No answer	2	(4.8)

BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation.

The absolute values of SBP or DBP before insulation retrofit had the strongest correlations with ΔSBP (-.491, p = 0.001) and ΔDBP (-.594, p < 0.001), respectively, and no other characteristics were significantly associated (Table 3.18, Table 3.19).

Table 3.18 Spearman's correlation analysis of changes of systolic blood pressure and diastolic blood pressure between before and after insulation retrofit

	ΔSBP		ΔDBP	
	Correlation coefficient	p	Correlation coefficient	p
Age	.084	0.599	.006	0.969
BMI	-.111	0.500	-.192	0.242
Care level at 2015	-.101	0.533	.090	0.582
SBP before retrofit	-.491	0.001	-.184	0.244
DBP before retrofit	-.297	0.056	-.594	<0.001

Δ, difference between before and after insulation retrofit; BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.

Table 3.19 Student's *t*-test of changes of systolic blood pressure and diastolic blood pressure between before and after insulation retrofit

		ΔSBP			ΔDBP		
	n	Mean	SD	p	Mean	SD	p
Gender							
Men	7	-1.57	13.07	0.667	-6.21	4.79	0.579
Women	33	-4.55	17.02		-2.73	16.19	
Using antihypertensive drugs in January							
Yes	24	-3.19	14.62	0.696	-3.73	15.04	0.841
No	16	-5.28	18.95		-2.75	15.02	

Δ, difference between before and after insulation retrofit; DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation.

Paired *t*-test (Table 3.20) showed that mean SBP across all residents decreased only slightly after the insulation retrofit (Before insulation retrofit, 129.4 ± 20.0 mmHg; After insulation retrofit, 125.4 ± 16.7 mmHg; *t*(38) = 0.52, *p* = 0.606). However, a subsample of 14 residents who had hypertension before the retrofit showed a significant decrease in SBP (Before insulation retrofit, 150.3 ± 14.2 mmHg; After insulation retrofit, 134.3 ± 16.1 mmHg; *t*(12) = 4.26, *p* = 0.001). Paired *t*-test for all residents showed that DBP decreased only slightly (Before insulation retrofit, 68.8 ± 10.6 mmHg; After insulation retrofit, 66.3 ± 11.6 mmHg; *t*(38) = 1.50, *p* = 0.142). When 11 residents who had hypotension due to low DBP were excluded, paired *t*-test for a subsample of residents with normotension or hypertension before the retrofit showed a significant decrease in DBP (Before insulation retrofit, 73.8 ± 7.8 mmHg; After insulation retrofit, 67.3 ± 12.6 mmHg; *t*(29) = 2.47, *p* = 0.020).

Table 3.20 Paired *t*-test of changes of systolic blood pressure and diastolic blood pressure between before and after insulation retrofit

	n	Before insulation retrofit		After insulation retrofit		*t*	*p*
		Mean	SD	Mean	SD		
SBP							
All residents	40	129.4	20.0	125.4	16.7	0.52	0.606
Subsample[a]	14	150.3	14.2	134.3	16.1	4.26	0.001
DBP							
All residents	40	68.8	10.6	66.3	11.6	1.50	0.142
Subsample[b]	31	73.8	7.8	67.3	12.6	2.47	0.020

DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation.
[a]Subsample of residents who had hypertension before the retrofit, [b]Subsample of residents who had normotension before the retrofit.

3.3.4 Relative humidity and oral dryness

Seasonal difference of relative humidity

In Figure 3.12, deep coloured plots indicate temp$_{in}$ and RH in summer, light coloured plots indicate temp$_{in}$ and RH in winter, and highlighted area indicates recommended RH [97] in each season. The average RH in summer met the recommendation in all facilities, but in 2 facilities the average RH was lower than the recommendation during winter. Taking these results, the RH in winter and its' association with oral dryness of residents was focused on in the further analysis.

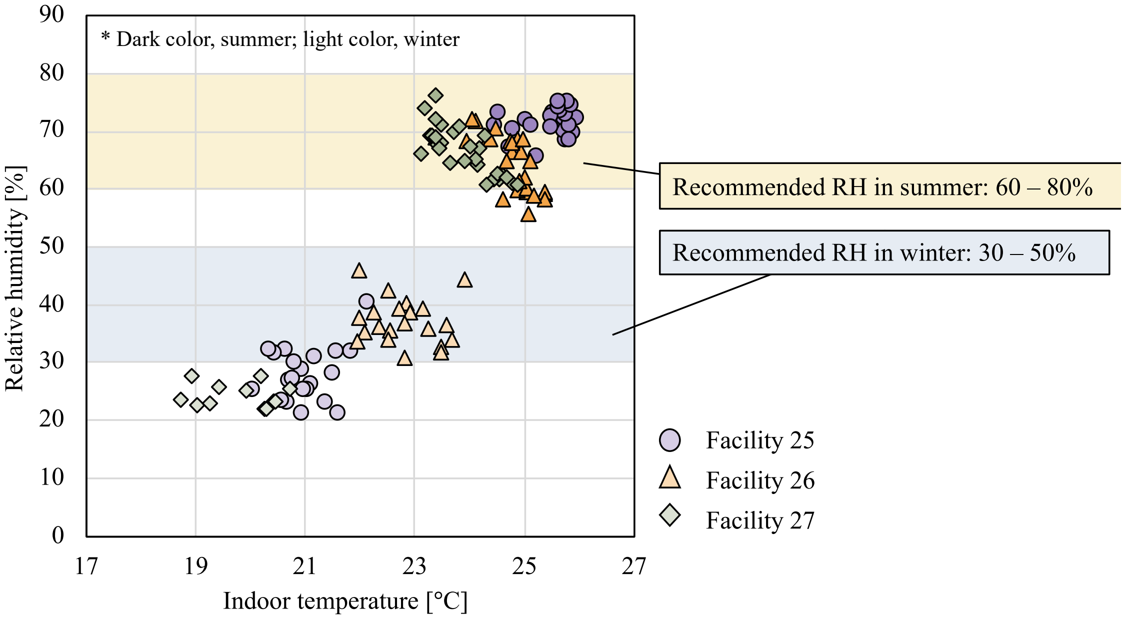


Figure 3.12 Daily indoor temperature and relative humidity in private room of facility 25 – 27 in summer and winter

Characteristics of residents in relation to oral dryness

There were significant associations between BMI, care level, ISDC, and oral dryness (Table 3.21). Underweight residents had a higher proportion of residents with dry oral cavity, chi-square (χ^2)(1) = 13.16, $p = 0.001$. Care level was significantly associated with dry oral cavity, $\chi^2(4) = 52.20$, $p < 0.001$, which suggested that residents certified at a higher care level are more likely to have dry oral cavity. The proportion of residents with oral dryness was higher among those who lacked frequent dental care, $\chi^2(3) = 90.78$, $p < 0.001$.

Table 3.21 Student's *t*-tests and chi-squared tests of residents' characteristics, implementation status of oral cavity, and oral dryness

	Dry (n = 102)		Moist (n = 656)		t	χ^2	p[a]
Age, years, mean (SD)	86.4	(7.0)	86.0	(7.1)	0.49		0.624
Gender, n (%)							
Men	24	(13.4)	155	(86.6)		0.00	0.957
Women	78	(13.6)	497	(86.4)			
BMI, n (%)							
< 18.5	30	(26.8)	82	(73.2)		13.16	0.001
≥ 18.5	38	(12.1)	275	(87.9)			
Care level at 2015, n (%)							
Support level 1, 2, and Care level 1	14	(7.7)	311	(92.3)		52.20	<0.001
Care level 2	11	(8.3)	122	(91.7)			
Care level 3	14	(9.4)	106	(90.6)			
Care level 4	18	(14.1)	27	(85.9)			
Care level 5	36	(35.3)	34	(64.7)			
ISDC, n (%)							
D1	14	(3.8)	351	(96.2)		90.78	<0.001
D2	56	(33.7)	110	(66.3)			
D3	21	(12.7)	144	(88.9)			
D4	6	(11.1)	48	(88.9)			

BMI, body mass index; ISDC, implementation status of dental care; SD, standard deviation, χ^2, chi-square.

ISDC definitions: D1, dental care is done independently every day; D2, dental care is done every day though help is sometimes needed; D3, dental care is done every day though help is always needed; D4, dental care is not often done though it can be done independently.

[a] p-values of Student's t-test for continuous variables and chi-squared test for categorical variables were reported.

Residents' oral dryness and relative humidity

The proportion of residents with oral dryness was higher among residents in the Dry group (17.0 %) than did the Moist group (6.6 %), $\chi^2(1) = 15.63$, $p < 0.001$ (Table 3.22).

Table 3.22 Chi-squared test of relative humidity group and oral dryness

	Dry (n = 102)		Moist (n = 656)		χ^2	p
RH group, n (%)						
Dry group	85	(17.0)	416	(83.0)	15.63	<0.001
Moist group	17	(6.6)	240	(93.3)		

RH, relative humidity, χ^2, chi-square.

Table 3.23 shows the final multiple logistic model of residents' oral dryness, RH group, and ISDC. RH group was significantly associated with oral dryness, Exp(β) = 2.68, 95 % CI = 1.65 – 4.35, $p < 0.001$, indicating that residents of facilities in the Moist group were more likely to have a moist oral cavity than those of the Dry group.

Table 3.23 Multiple logistic regression analysis of oral dryness by relative humidity group and implementation status of dental care

	Exp(β)	95 % CI	p
ISDC			
D1 (ref.)			
D2	0.31	0.11 – 0.85	0.023
D3	0.26	0.13 – 0.52	<0.001
D4	0.07	0.04 – 0.13	<0.001
RH group			
Dry group (ref.)			
Moist group	2.68	1.65 – 4.35	<0.001

CI, confidence interval; ISDC, implementation status of dental care; RH, relative humidity.
ISDC definitions: D1, dental care is done independently every day; D2, dental care is done every day though help is sometimes needed; D3, dental care is done every day though help is always needed; D4, dental care is not often done though it can be done independently.
n = 750, Variable selection method: stepwise method, -2 log likelihood = 477.6, chi-square = 100.1 (df = 4, p < 0.001).

3.3.5 Indoor thermal environment and deterioration speed of care level

Difference of deterioration speed of care level between groups

Care level at occupancy and at 2015 among residents included in the study are shown in Figure 3.13 – Figure 3.20, to check the change of care level. In all cases, plots concentrated on the diagonal line in the figure indicate that there were no changes in care level between at occupancy and in 2015. However, plots in lower left had slightly larger proportion than the plots in upper right, which means that there were a larger number of residents who deteriorated in their care level than those who improved.

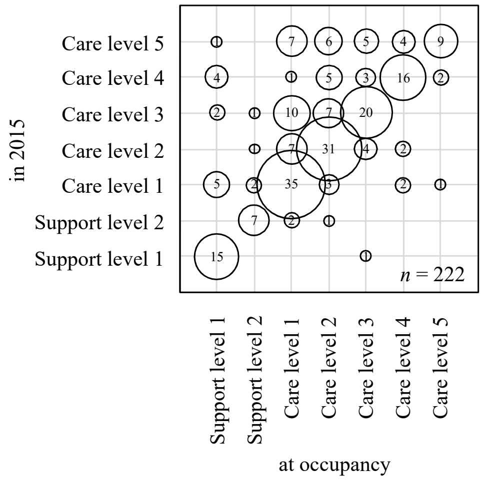


Figure 3.13 Care level at occupancy and in 2015 (Pay nursing home, the Cold group)

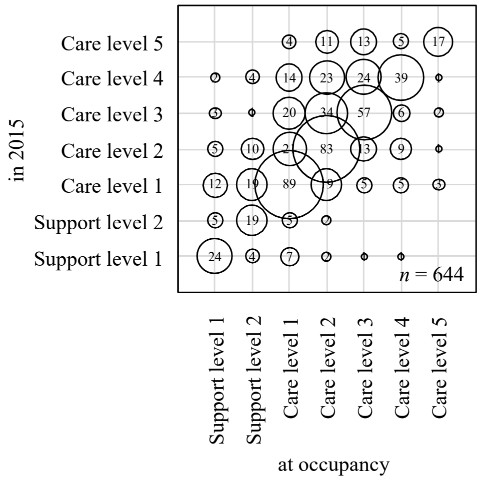


Figure 3.14 Care level at occupancy and in 2015 (Pay nursing home, the Warm group)

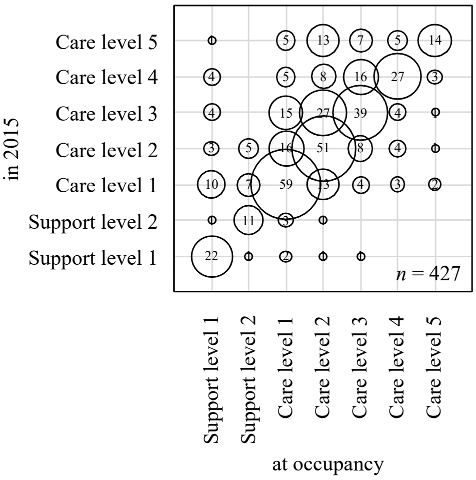


Figure 3.15 Care level at occupancy and in 2015 (Pay nursing home, the Dry group)

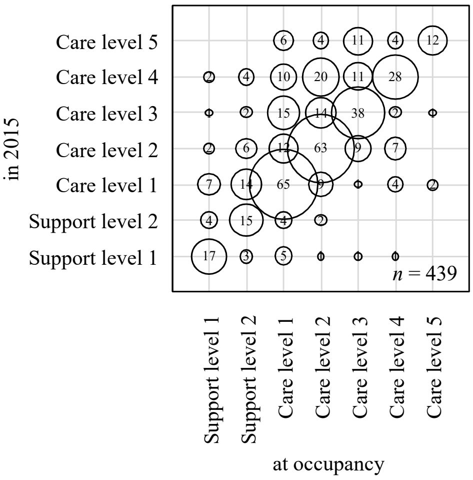


Figure 3.16 Care level at occupancy and in 2015 (Pay nursing home, the Moist group)

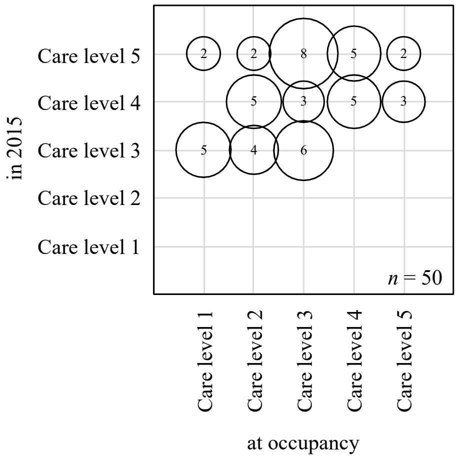


Figure 3.17 Care level at occupancy and in 2015 (Long-term care health facility, the Cold group)

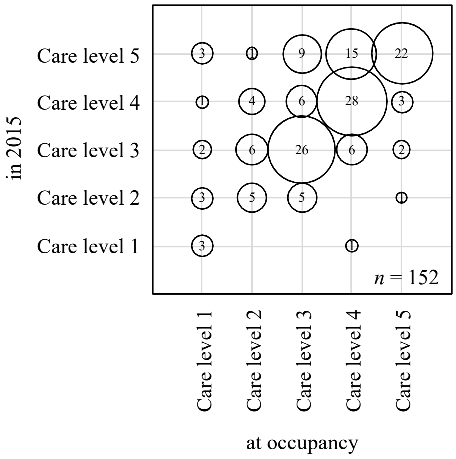


Figure 3.18 Care level at occupancy and in 2015 (Long-term care health facility, the Warm group)

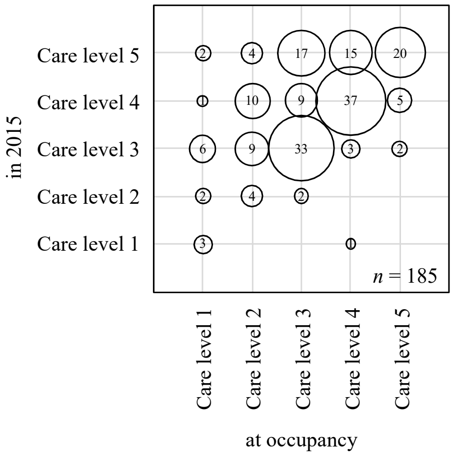


Figure 3.19 Care level at occupancy and in 2015 (Long-term care health facility, the Dry group)

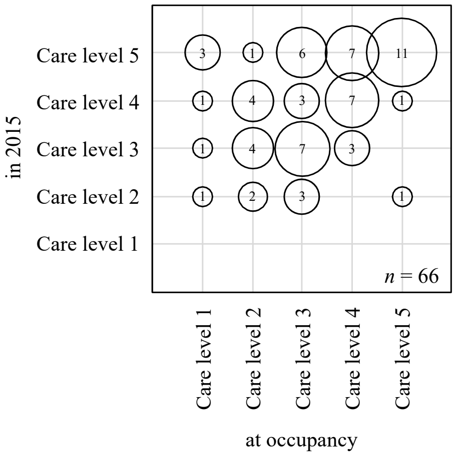


Figure 3.20 Care level at occupancy and in 2015 (Long-term care health facility, the Moist group)

In the result of Kaplan-Meier analysis in Figure 3.21 – Figure 3.24, the horizontal axis shows the period of residence and the vertical axis shows the ratio of residents maintaining their care level, and therefore a steep slope in the graphs indicates that there were many residents who experienced a rapid deterioration in care level after nursing home admission. In PNH, although there was no significant difference in the speed of deterioration of care level between the Cold and Warm groups (Figure 3.21), the difference between the Dry and Moist groups was significant at the 0.1 % level in the log-rank test and the residents in the dry group showed a rapid deterioration of care level (Figure 3.22). On the other hand, the difference between the cold and warm group was only significant in LTCHF (Figure 3.23, Figure 3.24).

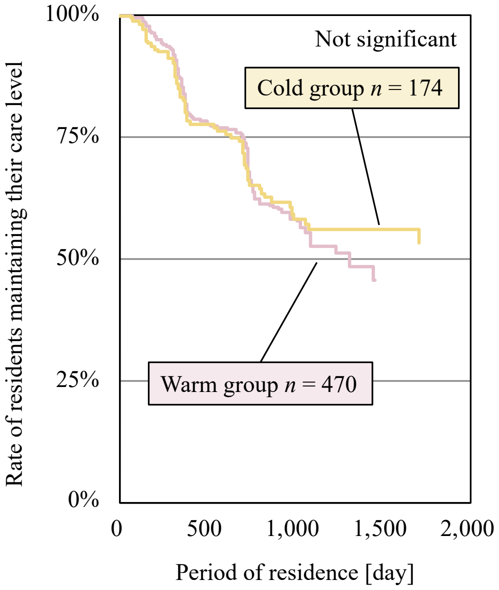


Figure 3.21 Kaplan-Meier analysis for the Cold group and Warm group at pay nursing homes

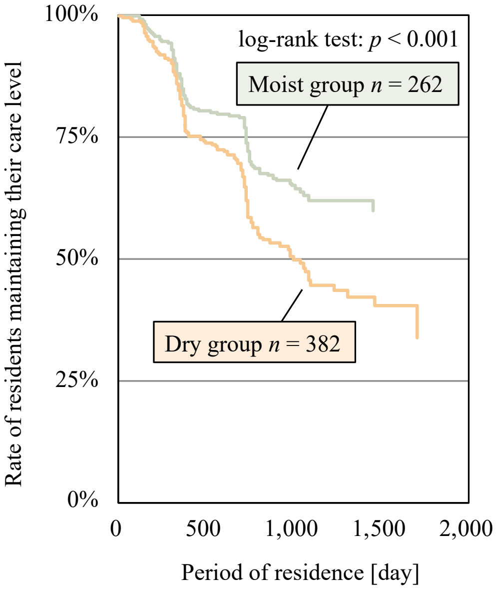


Figure 3.22 Kaplan-Meier analysis for the Dry group and Moist group at pay nursing homes

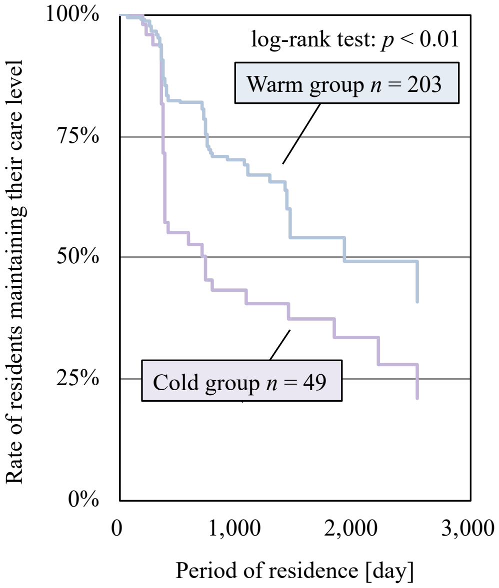


Figure 3.23 Kaplan-Meier analysis for the Cold group and Warm group at long-term care health facilities

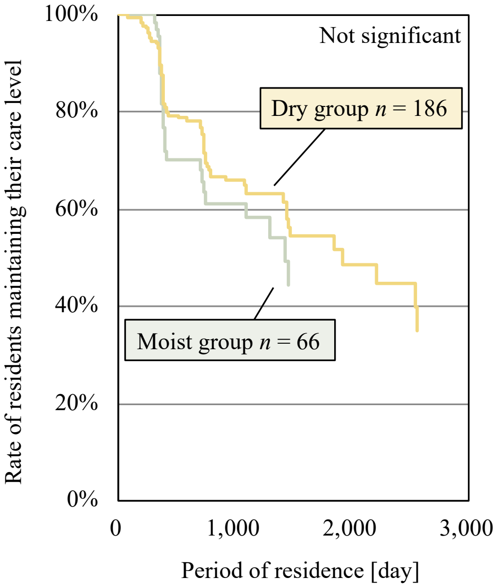


Figure 3.24 Kaplan-Meier analysis for the Dry group and Moist group at long-term care health facilities

Characteristics capable of affecting speed of deterioration speed in care level

Care level is decided by considering an individual's health, and can be affected by various individual attributes in addition to the indoor thermal environment. The Kaplan-Meier method cannot consider these confounding factors. Therefore, to determine the factors that can affect the care level, we compared the individual attributes of residents who showed deterioration in their care level and residents who maintained or showed an improvement in their care level (Table 3.24 for PNH and Table 3.25 for LTCHF). Residents who showed a deterioration in their care level tended to live longer in the PNH (Deteriorated, 1.7 ± 1.3 years; Maintained or improved, 1.2 ± 1.3 years; $t(716) = 2.28$; $p < 0.001$) or LTCHF (Deteriorated, 3.6 ± 3.1 years; Maintained or improved, 2.0 ± 2.7 years; $t(186) = 2.93$; $p < 0.001$), had a lower care level (PNH, $\chi^2(5) = 67.30$, $p < 0.001$; LTCHF, $\chi^2(3) = 76.14$, $p < 0.001$), and had dementia at nursing home admission (PNH, $\chi^2(1) = 11.20$, $p = 0.001$; LTCHF, $\chi^2(1) = 10.66$, $p = 0.008$).

Table 3.24 Student's *t*-test and chi-squared test of residents' characteristics by change of care level at pay nursing home

	Deteriorated		Maintained or improved		t	χ^2	p
Gender, *n* (%)							
Men	62	(20.6)	145	(25.7)		2.77	0.112
Women	239	(79.4)	420	(74.3)			
Age at occupancy, years, mean (SD)	85.4	(6.2)	84.6	(6.7)	1.81		0.004
BMI, kg/m^2, mean (SD)	19.7	(3.2)	20.7	(3.7)	-2.48		0.014
BMI, *n* (%)							
< 18.5	73	(62.9)	141	(61.0)		10.23	0.006
$18.5 \leq$ BMI < 25	38	(32.8)	55	(23.8)			
≥ 25	5	(4.3)	35	(15.2)			
Period of residence, years, mean (SD)	1.7	(1.3)	1.2	(1.3)	2.28		<0.001
Care level at occupancy, *n* (%)							
Support level 1	39	(13.0)	39	(6.9)		67.30	<0.001
Support level 2	38	(12.6)	30	(5.3)			
Care level 1	84	(27.9)	138	(24.4)			
Care level 2	86	(28.6)	141	(25.0)			
Care level 3	45	(15.0)	101	(17.9)			
Care level 4 and 5	9	(3.0)	116	(20.6)			
Medical history at occupancy							
Cerebrovascular disease, *n* (%)	13	(7.0)	29	(8.0)		1.19	0.551
Heart disease, *n* (%)	40	(21.4)	73	(20.1)		1.51	0.471
Articular disease, *n* (%)	31	(16.5)	46	(12.7)		2.12	0.347
Dementia, *n* (%)	130	(65.7)	199	(51.2)		11.20	0.001
Fractures and falls, *n* (%)	13	(7.0)	25	(6.8)		0.81	0.666
Weakness due to aging, *n* (%)	61	(32.6)	87	(24.6)		3.91	0.054
Temp$_{in}$ group, *n* (%)							
Cold group	230	(76.4)	414	(73.3)		1.01	0.175
Warm group	71	(23.6)	151	(26.7)			
RH group, *n* (%)							
Dry group	275	(48.7)	152	(50.5)		0.26	0.618
Moist group	290	(51.3)	149	(49.5)			

BMI, body mass index; SD, standard deviation; Temp$_{in}$, indoor temperature; RH, relative humidity; χ^2, chi-square..

[a] *p*-values of Student's *t*-test for continuous variables and chi-squared test for categorical variables were reported.

Table 3.25 Student's *t*-test and chi-squared test of residents' characteristics by change of care level at long-term care facility

	Deteriorated	Maintained or improved	*t*	χ^2	*p*
Gender, *n* (%)					
Men	21 (20.0)	34 (23.4)		0.42	0.540
Women	84 (80.0)	111 (76.6)			
Age, years, mean (SD)	83.9 (8.0)	85.4 (8.5)	-1.36		0.822
BMI, kg/m^2, mean (SD)	19.9 (3.3)	20.5 (3.4)	-1.42		0.156
BMI, *n* (%)					
< 18.5	69 (65.7)	91 (64.1)		2.92	0.232
18.5 ≤ BMI < 25	31 (29.5)	36 (25.4)			
≥ 25	5 (4.8)	15 (10.6)			
Period of residence, years, mean (SD)	3.6 (3.1)	2.0 (2.7)	2.93		<0.001
Care level at occupancy, *n* (%)					
Care level 1	17 (16.0)	3 (2.1)		76.14	<0.001
Care level 2	32 (30.2)	6 (4.1)			
Care level 3	35 (33.0)	45 (31.0)			
Care level 4 and 5	22 (20.8)	91 (62.8)			
Medical history at occupancy					
Cerebrovascular disease, *n* (%)	50 (52.1)	63 (48.8)		1.78	0.412
Heart disease, *n* (%)	33 (37.9)	45 (36.9)		0.02	0.886
Articular disease, *n* (%)	40 (48.8)	45 (37.2)		3.23	0.199
Dementia, *n* (%)	93 (91.2)	104 (78.2)		10.66	0.008
Fractures and falls, *n* (%)	31 (38.8)	22 (18.5)		10.66	0.005
Weakness due to aging, *n* (%)	60 (65.9)	90 (73.8)		2.58	0.276
Temp_{in} group, *n* (%)					
Cold group	34 (32.1)	16 (11.0)		17.00	<0.001
Warm group	72 (67.9)	129 (89.0)			
RH group, *n* (%)					
Dry group	31 (29.2)	35 (24.1)		0.82	0.386
Moist group	75 (70.8)	110 (75.9)			

BMI, body mass index; SD, standard deviation; Temp_{in}, indoor temperature; RH, relative humidity; χ^2, chi-square.

[a] *p*-values of Student's *t*-test for continuous variables and chi-squared test for categorical variables were reported.

Multivariate analysis of deterioration speed of care level and indoor thermal environment

Since possibility of deterioration of care level can differ due to care level at occupancy, injury and disease at occupancy, multivariate analysis was used to consider these co-variates. Before conducting the Cox proportional hazards regression analysis, correlation coefficient between factors were checked by Spearman's correlation analysis (Table 3.26 – Table 3.31). Most correlations were not significant, and even in significant pairs, the correlation coefficient was lower than 0.3.

Table 3.26 Spearman’s correlation analysis between residents’ characteristics at pay nursing homes

	Gender	Age	BMI	Care level	Habitant period
Gender		0.06	-0.04	0.00	0.02
Age			-0.07	-0.04	-0.14 ***
BMI				-0.05	-0.04
Care level					-0.05
Habitant period					

BMI, body mass index; Care level, Care level at occupancy.
***$p < 0.001$

Table 3.27 Spearman’s correlation analysis between injury and diseases at pay nursing homes

	Cardio. d.	Heart d.	Arti. d.	Dementia	Frac. & falls	Asthenia
Cardio. d.		0.07	-0.01	-0.03	0.01	0.07
Heart d.			-0.03	-0.07	-0.07	0.09 *
Arti. d.				-0.10 **	0.07	0.13 **
Dementia					-0.04	0.04
Frac. & falls						0.19 ***
Asthenia						

Arti. d., Articular disease; Asthenia, Asthenia due to an old age; Cardio. d., Cardiovascular disease; Frac. & falls, Fractures and falls; Heart d., Heart disease.
**$p < 0.01$, ***$p < 0.001$

Table 3.28 Spearman’s correlation analysis between residents’ characteristics, injury and diseases at pay nursing homes

	Gender	Age	BMI	Care level	Habitant period
Cardio. d.	0.07	0.04	-0.02	-0.11 **	0.06
Heart d.	0.04	-0.13 **	-0.06	0.00	0.02
Arti. d.	-0.10 *	-0.02	0.05	0.01	-0.11 *
Dementia	-0.04	0.01	0.03	-0.03	-0.05
Frac. & falls	-0.11 **	-0.09 *	0.01	-0.06	-0.03
Asthenia	-0.03	-0.08 *	0.14 *	-0.05	-0.01

Arti. d., Articular disease; Asthenia, Asthenia due to an old age; BMI, body mass index; Cardio. d., Cardiovascular disease; Care level, Care level at occupancy; Frac. & falls, Fractures and falls; Heart d., Heart disease.
**$p < 0.01$, ***$p < 0.001$

Table 3.29 Spearman’s correlation analysis between residents’ characteristics at long-term care health facilities

	Gender	Age	BMI	Care level	Habitant period
Gender		0.14 **	-0.08	0.09	0.10
Age			-0.05	-0.04	-0.26 ***
BMI				0.20 ***	-0.02
Care level					-0.16
Habitant period					

BMI, body mass index; Care level, Care level at occupancy.
*$p<0.05$, **$p<0.01$, ***$p<0.001$

Table 3.30 Spearman's correlation analysis between injury and diseases at long-term care health facilities

	Cardio. d.	Heart d.	Arti. d.	Dementia	Frac. & falls	Asthenia
Cardio. d.		0.12	-0.01	-0.06	-0.06	0.23 ***
Heart d.			0.24 ***	-0.03	0.15 *	-0.06
Arti. d.				-0.02	0.14	-0.02
Dementia					0.18 *	-0.06
Frac. & falls						-0.06
Asthenia						

Arti. d., Articular disease; Asthenia, Asthenia due to an old age; Cardio. d., Cardiovascular disease; Frac. & falls, Fractures and falls; Heart d., Heart disease.
*p < 0.05, ***p < 0.001

Table 3.31 Spearman's correlation analysis between residents' characteristics, injury and diseases at long-term care health facilities

	Gender	Age	BMI	Care level	Habitant period
Cardio. d.	0.15 *	0.03	0.02	-0.04	0.08
Heart d.	-0.08	-0.23 ***	-0.02	0.06	0.04
Arti. d.	-0.18 **	-0.12	-0.02	0.10	-0.06
Dementia	-0.10	-0.11	0.11	0.09	0.03
Frac. & falls	-0.10	-0.11	-0.07	0.09	-0.01
Weakness	0.12	-0.21 ***	0.19 ***	-0.12	0.06

Arti. d., Articular disease; Asthenia, Asthenia due to an old age; BMI, body mass index; Cardio. d., Cardiovascular disease; Care level, Care level at occupancy; Frac. & falls, Fractures and falls; Heart d., Heart disease.
*p < 0.05, **p < 0.01

The result of the Cox proportional hazard analysis showed that both the Cold group, Hazard ratio (HR) = 1.50, 95 % CI = 1.09 – 2.05, p = 0.012 (

Table **3.32**) and the Dry group, HR = 2.03, 95 % CI = 1.51 – 2.74, p < 0.001 (Table 3.33) had a higher risk of deterioration of care level in PNH. Furthermore, residents in facilities that were both warm and moist had the lowest risk of deterioration (Cold and moist: HR = 1.18, 95 % CI = 0.87 – 1.61, p = 0.280. Warm and dry: HR = 1.93, 95 % CI = 1.33 – 2.82, p = 0.001, Table **3.34**). In LTCHF, only the analysis of $\mathrm{Temp_{in}}$ was performed because the RH group did not satisfy the proportional hazard assumption (Figure 3.24). The effect of $\mathrm{Temp_{in}}$ was significant and the Cold group, HR = 1.92, 95 % CI = 1.24 – 2.98, $p = 0.004$, had a higher risk of deterioration of care level (Table 3.35).

Table 3.32 Cox proportional hazards regression model of deterioration of care level by indoor temperature group and resident's characteristics at pay nursing homes

	HR	95 % CI	*p*
Care level at occupancy			
Support level 1 (ref.)			
Support level2	0.83	0.43 – 1.61	0.578
Care level 1	0.64	0.38 – 1.08	0.094
Care level 2	0.62	0.38 – 1.04	0.068
Care level 3	0.47	0.27 – 0.81	0.007
Care level 4	0.46	0.24 – 0.91	0.026
Care level 5	0.28	0.09 – 0.95	0.041
Dementia			
Under treatment (ref.)			
None or cured	0.75	0.64 – 0.88	<0.001
$\mathrm{Temp_{in}}$ group			
Warm group (ref.)			
Cold group	1.50	1.09 – 2.05	0.012

CI, confidence interval; HR, hazard ratio; $\mathrm{Temp_{in}}$, indoor temperature; ref., reference.
$n = 524$, -2 log likelihood = 2217.15, Chi-square = 27.78***($df = 8$), ***$p < 0.001$

Table 3.33 Cox proportional hazards regression model of deterioration of care level by relative humidity group and resident's characteristics at pay nursing homes

	HR	95 % CI	*p*
LTCI level at occupancy			
Support level 1 (ref.)			
Support level 2	0.59	0.30 – 0.87	0.124
Care level 1	0.52	0.38 – 0.87	0.013
Care level 2	0.48	0.29 – 0.80	0.005
Care level 3	0.36	0.21 – 0.64	<0.001
Care level 4	0.37	0.18 – 0.74	0.005
Care level 5	0.28	0.08 – 0.93	0.038
Dementia			
Under treatment (ref.)			
None or cured	0.80	0.68 – 0.94	0.007
RH group			
Moist group (ref.)			
Dry group	2.03	1.51 – 2.74	<0.001

CI, confidence interval; HR, hazard ratio; ref., reference; RH, relative humidity.
$n = 524$, -2 log likelihood = 2142.08, Chi-square = 38.14***($df = 8$), ***$p < 0.001$

Table 3.34 Cox proportional hazards regression model of deterioration of care level by indoor temperature group, relative humidity group and resident's characteristics at pay nursing homes

	HR	95 % CI	*p*
Dementia			
Under treatment (ref.)			
None or cured	0.85	0.74 – 0.97	0.020
Temp_{in} and RH group			
Warm and moist (ref.)			
Cold and moist	1.18	0.87 – 1.61	0.280
Warm and dry	1.93	1.33 – 2.82	0.001

CI, confidence interval; HR, hazard ratio; Temp_{in}, indoor temperature; ref., reference; RH, relative humidity.

$n = 524$, -2 log likelihood = 2522.39, Chi-square = 18.00***($df = 3$) , ***$p < 0.001$

Table 3.35 Cox proportional hazards regression model of deterioration of care level by indoor temperature group and resident's characteristics at long-term care health facilities

	HR	95 % CI	*p*
Care level at occupancy			
Care level 1 (ref.)			
Care level 2	0.82	0.43 – 1.54	0.531
Care level 3	0.30	0.16 – 0.57	<0.001
Care level 4	0.35	0.18 – 0.66	0.001
Care level 5	0.06	0.02 – 0.22	<0.001
Temp_{in} group			
Warm group (ref.)			
Cold group	1.92	1.24 – 2.98	0.004

CI, confidence interval; HR, hazard ratio; Temp_{in}, indoor temperature; ref., reference.

$n = 234$, -2 log likelihood = 858.03, Chi-square = 56.83***($df = 5$) , ***$p < 0.001$

3.4 Discussion

The overarching objective of study 2 was to understand the actual conditions of the indoor thermal environment of nursing homes and to investigate the role of the environment on maintaining health among nursing home residents. Both associations of "temp_{in} and blood pressure" and "RH and oral dryness" confirm that health status of tenants is affected by the indoor thermal environment of the nursing home. The findings on the investigation on deterioration speed of care level show that a warm, moist nursing home environment likely helps to maintain the care level of residents.

Measured indoor temperature and relative humidity

Nursing homes included in this study were relatively warm, but dry environments with similar results have been seen in a previous study in Japan [155]. In high-income countries, around 70 % of people's time is spent inside their home [166]. However, older people included in this study were spending 100 % of their time inside the nursing home and are therefore more exposed to health risks associated with the indoor environment. However, the targets in the present law for the maintenance of buildings doesn't include social welfare facilities for elderly, and handling of the maintenance of room temperature and air ventilation are the responsibility of each facility manager. Kitahara et al. [167]

reported that dry air was the most frequent complaint among nursing home residents and speculated that RH could be as low as 20 % during the heating season, but they did not conduct measurements. Our study provides objective data on the humidity in nursing homes, revealing that the measured RH in most nursing homes was lower than 30 %.

Indoor temperature and blood pressure

To the best of our knowledge, this is the first study to evaluate the association between temp_{in} and blood pressure of residents in nursing homes. Our findings from this field study on nursing home residents expand on experimental evidence from previous studies [168] [169] on thermoregulation and blood pressure in controlled settings, and previous studies on healthy older people [61] [62] [63] [64] in real life situations. The results showed that people living in warmer nursing home had lower rise of SBP in winter compared to summer. Prevention of blood pressure rise could delay deterioration in care need and could decrease risk of disease [170]. Japan's Health Japan 21 government policy claimed that a 2 mmHg decrease in blood pressure could prevent 10,000 cases of stroke and 3,500 age-related decline crises [171]. Our results show that a 3 ˚C increase in temp_{in} may decrease SBP by 2.16 – 2.22 mmHg, which meets the requirements of Health Japan 21.

In the investigation of before and after insulation retrofit, temp_{in} increased due to the insulation retrofit and blood pressure consequently decreased. The increased temp_{in} and decreased strength of correlation between temp_{in} and temp_{out} after insulation retrofit suggests that improving building performance can mitigate exposure to cold. At this nursing home, increased insulation performance contributed to maintaining a warm temp_{in} despite having a cold temp_{out}. For a subsample of residents who had SBP of 135 mmHg or higher, the impact of insulation retrofit was larger and was effective in ameliorating hypertension. Since residents who already had low blood pressure before the insulation retrofit had no room for further decreases in blood pressure, DBP was compared in a subsample of residents with DBP of 90 mmHg or higher. For this subsample, DBP decreased significantly due to the insulation retrofit. However, the difference in blood pressure was small and there were large individual differences in the effect of the insulation retrofit. Even though the decrease in blood pressure was small in our study, most statements of health promotion and disease prevention goals for the elderly acknowledge that expected outcomes for older adults – especially those who already have chronic illnesses or disabilities – may be different from those for younger adults who do not yet have such illnesses or disabilities [172]. Cure, or a full restoration of health or function, may not be a realistic general goal for very old people. More realistic goals might involve tertiary prevention efforts such as maintenance or stabilisation of existing health and function, amelioration of the effects of disease and disability, and prevention or delay of further disability and functional limitations [172]. Even small gains in the ability to maintain current health and to reduce functional disability may make a major difference in the quality of life experienced by older adults.

Relative humidity and oral dryness

Measurement of RH in 27 facilities revealed that 19 (70.4 %) had RH lower than 30 %, which is lower than recommendations for winter. Results showed that residents living in moist nursing homes (RH higher than 30 %) were more likely to have a moist oral cavity than those living in dry nursing homes, even after accounting for ISDC. These results suggest that maintaining high RH during winter may help prevent dry mouth among nursing home residents. Evaporation of saliva is caused mainly by mouth opening or mouth breathing, which often occurs at night with no apparent decrease in salivary flow [173]. Our findings support the suggestion by Han et al. [174] that using a room humidifier to add moisture to the night time environment may give some relief during sleep. Sunwoo et al. [175] conducted a controlled 3-hour study of 8 young men (mean age 22 years) and 8 older men (mean age 72 years) at 25 ˚C and 10 %, 30 %, or 50 % RH. They reported that saccharin clearance time, a metric of mucociliary clearance, was lower at 10 % RH in the older group compared with the young group, potentially leaving the older men more susceptible to disease transmission. Although the indicator used in our study was oral dryness, the same trend was found. Nonspecific palliative management of dry mouth includes sipping water and sucking on ice chips frequently throughout the day to provide moisture [176] [177]. However, older residents of nursing homes often have difficulty with self-care because of reduced independence. Furthermore, the timing of water or ice chips consumption by older patients should not be dependent on sensations of thirst, since satiety and thirst reflexes are obtunded in older individuals [178]. Mouth moisteners in the form of sprays, liquids, or gels also exist, but these treatments may need to be applied frequently (at least 3 – 4 times throughout the day) depending on their adherence and/or lasting ability [174]. Increased care burden due to the requirement of additional supervision to ensure proper treatment is thus a concern. A large number of systemic agents have been proposed as secretagogues, but only a few have shown consistent salivary enhancing properties in well-designed, controlled trials [179]. There are no easy answers as to the best course of dry mouth treatment for particular individuals, and both personal and environmental measures should be employed to help prevent this condition. Control of the environmental humidity is especially important for older people who have difficulty performing self-care.

Indoor thermal environment and deterioration speed of care level

In PNH facilities, residents had a more rapid deterioration of care level in dry environments compared to those living in moister environments, and In LTCHF facilities, those living in a colder environment deteriorated more rapidly than those in warm environments. Moreover, analysis of PNH residents showed that both $temp_{in}$ and RH were significantly associated with deterioration of care level after adjusting for the effects of potential confounders, such as care level at nursing home admission and medical history of dementia. The results also indicated that people living in cold nursing homes had a 1.5 times higher hazard of deterioration of care level and people living in dry nursing homes had a 2.0 times higher hazard. Furthermore, warm and moist nursing homes had the lowest hazard for residents deteriorating their care level, which suggests that both $temp_{in}$ and RH are important for care prevention. In LTCHF, only $temp_{in}$ was significantly associated with the deterioration of care level. We could not obtain a large sample size of moist nursing home facilities for these analyses.

The care level of many residents deteriorated after 1 or 2 year of nursing home admission. The valid period of LTCI is generally 1 year [180], so a change of care level would generally occur after this period. However, insured people can apply for change of care level regardless of the period of validity, due to a mental and physical condition. To reflect this change and period in the analysis, period of residence as an overall survival was used with small time unit such as date.

This study had some limitations. First, we recruited facilities using non-random sampling, so the generalisability of the study may be limited. $Temp_{in}$ of the nursing homes was higher than in previous studies of individual housing. To clarify the effect of cold $temp_{in}$, we should include participants living in colder $temp_{in}$ and vary the indoor thermal climate. To be more specific, while evaluating the effects of both $temp_{in}$ and RH, 1) the association between $temp_{in}$ and care requiring conditions of residents in nursing homes with the same RH environment and 2) the association between RH and care requiring conditions of residents in nursing homes with the same $temp_{in}$ environment, should be compared. However, we could not obtain a large enough sample and variation in indoor thermal environment to conduct this analysis. Second, there were a large amount of missing data or response such as “don’t know,” in the questionnaire survey. The high prevalence of missing data, however, limits the generalisation of the results. Third, we did not measure $temp_{in}$ during the blood pressure measurement. These data could provide stronger associations, but this was not possible using our method. To obtain this information, we would have required the time and room in which blood pressure was measured, which would have increased the burden on the care staff. Because our research was based on the normal operation of nursing homes, it was not possible to use this method. When it comes to the measurement of oral dryness, although salivary gland hypofunction (SGH) is an objective sign that can be measured clinically, some studies assume that everyone who experiences xerostomia has SGH, and vice versa [181]. Evidence suggests that the two conditions are not necessarily concurrent, and in order to limit the burden imposed on nursing home staff by this study, a questionnaire was used to collect data regarding oral dryness. Xerostomia, the subjective symptom of dry mouth, can be measured by a single-item question or multi-item approaches, including batteries of items or summated rating scales [182]. Nevertheless, there are limitations to this method for capturing the severity and variability of xerostomia. Furthermore, because oral dryness was recorded by care staff rather than by the residents themselves, this subjective assessment may not reflect residents' actual oral condition. The most common cause of long-standing dry mouth, particularly in older adults, is the use of xerogenic medications [183]; however, we could not consider medication use in our model. The complexity of oral health status among our study participants may have been affected by the presence of numerous coexisting systemic diseases and the use of multiple medications. Further exploration including the cohort and intervention study of possible confounding factors could help identify characteristics that increase the impact of environmental humidity and increase the risk of dry mouth due to exposure to a dry environment.

3.5 Conclusion

Study 2 investigated the relationships between health, speed of deterioration of care level, and indoor thermal environment in Japanese nursing homes. The results revealed actual conditions of nursing home indoor thermal environment and highlighted its' role in maintaining health of nursing home residents. Warmer $temp_{in}$ and a moist environment can contribute to health promotion of nursing home residents, by decreasing blood pressure and reducing dry mouth. The investigation on speed of deterioration of care level shows that care level likely maintains in warm and moist nursing home environment.

Chapter 4

Study 3: Nationwide analysis of fuel poverty

Chapter 4

Study 3: Nationwide analysis of fuel poverty

4.1 Overview of study 3

A number of studies have highlighted the negative impact of living in cold, poorly heated homes on the physical and mental health of individuals [184] [49], and thus study 1 in this thesis has demonstrated the potential importance of preventing fuel poverty (FP) to further prevent frailty in particular. Despite the spread of FP and its recognition as a social, public health and environmental policy issue in a context of ever-increasing energy prices, Japan has not yet adopted a common definition nor common indicators to measure it [185]. A good understanding of different levels of vulnerability and how they are shaped by poor quality housing and economic circumstances, as well as an appreciation of which measures are most appropriate in which setting, is therefore essential for policy makers to be able to most effectively target FP alleviation measures. Of the three components related to FP: energy efficiency, energy prices, and income, this study mainly focused on energy efficiency, from the view point of building environmental engineering. Here, based on observational large-scale data, I aim to investigate the actual overall condition of FP in Japan. Moreover, there are three specific aims which are 1) to develop a method to estimate energy efficiency levels of houses, 2) to describe the characteristics of residents and housing that place households at a higher risk for FP, and 3) to demonstrate the spatial distribution of FP in Japan.

4.2 Methodology

Many indicators and definitions of FP have been developed in countries across the EU, for instance Ireland, Slovakia, France and the United Kingdom (UK) all have official frameworks [186]. The FP status of households depends on the interaction between three key drivers: energy efficiency, energy prices, and income [77]. Regarding to the existing literature of FP [187] [188], a commonly used approach to measuring FP is the proportion of income that households spend on fuel or energy. Research has shown that poorer households tend to spend higher proportions of their income on energy-related expenses in the home, relative to high-income households [189] [190]. Another commonly used measure of FP considers households as FP if the proportion of their income spent on energy exceeds a certain threshold. This measure is consistent with the mainstream poverty literature which sets a poverty line. Previous research has suggested the adoption of a 10 % ‘energy-poverty line’ [189]. Hence, households are FP if they spend more than 10 % of their income on energy. The above two measures, however, have been subject to criticism that the expenditure-income approach fails to acknowledge differences between actual energy expenditure made by households and the energy expenditure necessary to realise the recommended ambient indoor temperature. This distinction is important because in many low-income households, actual expenditure on energy falls short of what is needed to provide adequate lighting, heating and appliance use. In such instances, measures of FP based on actual energy expenditure may underestimate the true rate of FP [51] [191] [192] [193]. To address this concern, calculated energy cost on the basis of dwelling characteristics and household characteristics rather than actual energy spending was used in recent studies [194] [195], and so thus in this study. This ensures that we do not overlook those households that have low energy bills simply because they actively limit their use of energy at home, for example, by not heating their home [77]. For example, in the UK, FP is modelled using data from the English Housing Survey [196] and other sources of fuel prices [197] [198] [199]. The English Housing Survey is an annual national survey of people's housing circumstances, household income and the condition and energy efficiency of housing, which covers all tenures (private and social) and involves a detailed physical inspection of properties by professional surveyors. In Japan, there are no statistics about directly measured housing energy efficiency on a national level. However, the most comprehensive statistical survey conducted on housing conditions in Japan is the Housing and Land Survey (HLS) [200]. In this study, a methodology to estimate energy efficiency levels of houses from data provided from HLS was developed to objectively model the required expenditure on energy per household. Based on the estimated energy efficiency levels, annual energy cost was calculated by using data from HLS and the Family Income and Expenditure Survey (FIES) [201]. Related to the definition of FP in the UK [77], FP and FP gap was measured using the Low Income High Costs indicator.

4.2.1 Housing and Land Survey

HLS [200] is a national survey to acquire basic information to guide various housing-related policy measures by investigating the actual conditions of houses and other occupied buildings. Households throughout Japan are surveyed to clarify the present circumstances and trends for the whole country, major metropolitan areas, and prefectures. HLS has been conducted since 1998 following the former Housing Survey, which had been conducted every five years since 1948, based on revised survey content. In this study, the 2013 HLS conducted for approximately 210,000 units districts on October 1st, 2013 was used for the analysis. However, some districts were excluded from sampling, as they had been designated as evacuation areas due to the effect of the Fukushima nuclear accident caused by the Great East Japan Earthquake[2].

---

[2] Entire area of the following districts are excluded: Naraha-machi, Tomioka-machi, Okuma-machi, Futaba-machi, Namie-machi, Katsurao village, Iitate village. Some part of the following districts are excluded: Tamura City, Minamisoma City, Kawamata-machi, Hirono-machi, Kawauchi village

Table 4.1 Topics investigated in the Housing and Land Survey [200]

On buildings	Number and area of dwelling rooms
	Tenure of dwelling
	Site area
	Tenure of site
On dwellings	Construction materials
	Situation of dilapidation
	Stories of building
	Type of building
	Type of dwelling
	Total number of dwellings in the building
	Year of construction
	Area of floor space
	Building area
	Situation of house/ground rent
	Situation of facilities
	Situation of enlargement or remodelling, or refurbishing work
	Type of dwellings without any occupants
On households	Name of head or representative of household
	Type of household
	Number of household members
	Age, gender of each household member (maximum 8 members)
	Annual income of household
On main earner or head of household	Employment status
	Commuting time
	Situation of moving due to the Great East Japan Earthquake
	Year of last relocation
	Previous residence
	Situation of children

Statistical data collected nationally in Japan are open to the public on “The Portal Site of Official Statistics of Japan (e-Stat) [202].” There, statistics can be generated on their website based on the needs of researchers. However, e-Stat has several limitations for users: only aggregate data is provided, combinations of variables are limited, and all necessary data may not be present in e-Stat. Based on article 33 of the statistical law established in 1947, revised in 2007, Fundamental Statistics and General Statistics are to be provided under fixed condition. Hence, individual level data can be requested if it is used for research funded by official institutions. Therefore, we requested the use of HLS data for this study. Statistics of Japan processed the individual level data into forms that do not enable identification of the specific individual but can be used for analysis of individual attributes, and the data was delivered to the researchers.

4.2.2 Family Income and Expenditure Survey

FIES [201] is a survey conducted by the Statistics Bureau each month. It aims to grasp actual conditions of income and expenditures of households in order to provide a basis for social and economic policies. The survey covers households excluding one-person student households, inpatients in hospitals, inmates of reformatory institutions, etc. In the FIES, sample households are selected based on statistical methodologies so that they represent all households in the whole country. The FIES in 2013 included 8,076 households in 168 strata. Data in this survey are obtained in four kinds of questionnaires, namely, Household Schedule, Family Account Book, Yearly Income Schedule and

Savings Schedule. Enumerators fill in the Household Schedule with the number of household members, occupation and industry of earners, type of the dwelling, etc. Households are requested to fill in the Family Account Books with daily incomes and expenditures. In addition, two-or-more-person households are also requested to complete the Savings Schedule with amounts of savings and liabilities held and plans to purchase houses or land. Family Account book, Yearly Income Schedule and Savings Schedule are filled in by households themselves, and Household Schedule is completed by enumerators through interview. The income and expenditure data thus obtained are tabulated into average monthly receipts and disbursements per household by districts.

4.2.3 Evaluation of fuel poverty and fuel poverty gap

Required energy costs were calculated for each household included in HLS. The calculation method suggested by Konno et al. [185] was used as a reference and was reconstructed to be used with individual level data.

First, heating cost was calculated using formula (1), and the annual energy cost was calculated using formula (2).

$$E'_{heat} = HDD_{14-10} \cdot H_L \cdot S \cdot \eta - (350 + 60 \cdot n \cdot \eta) \cdot t_{heating} \tag{1}$$

$$E_{all} = \frac{E'_{heat} \cdot (24 \cdot 3600)}{0.9 \cdot 1000000} \cdot \frac{24.33}{3.6} + E_{base} \cdot 12 \tag{2}$$

E'_{heat}: Energy consumption for heating [W] E_{all} : Annual energy cost [yen]
E_{base}: Energy cost for lighting, hot water supply, etc. [yen]
HDD: Heating degree − day [°C] H_L: Coefficient of overall heat transmission [W/m^2 · K]
S: Floor area [m^2] η: Time ratio of staying at home [−]
n: Number ofamily member [person] t: Heating period[days]

In formula (1), S is floor area and n is the number of family members, both extracted from responses on the HLS. η is the time ratio of staying at home which we assigned 0.66 [203]. Heating degree-day (*HDD*) is a measure designed to quantify the demand for energy needed to heat a building [204]. In Japan, days which have a mean outdoor temperature (temp_{out}) below 10 ˚C are defined as the heating period ($t_{heating}$ [days]), and *HDD* is calculated as an integral of the daily mean temp_{out} and 14 ˚C. The average year value of temp_{out} was downloaded from "Weather observation data search [205]", and *HDD* was calculated for each prefecture. Equipment heat and human heat were defined at 350 W and 60 W respectively [206], and were then multiplied by the heating period. In formula (2), heating efficiency was defined as 0.9 [185], and the electricity bill was assumed to be 24.33 yen/kWh [207]. H_L is the coefficient of overall heat transmission (*Q*-value) of the house. Since the actual coefficient of overall heat transmission for each sample in the HLS is unknown, we tried to estimate it based on the year of construction, presence of double-glazed windows, location, and housing type. Energy efficiency standards are generally considered to be correlated with the year of construction and presence of double-glazed windows [208]. A score was calculated corresponding to the year of construction and presence of double-glazing, and consequently samples were classified into one of 5 energy efficiency standard levels (Figure 4.1). The postal zip code was used to define the minimum standard level of energy efficiency based on the regional division of climate for each location (Figure 4.2). With the combination of estimated energy efficiency standard, regional division, and housing type ("detached house" or "apartment and flat"), the *Q*-value was specified as shown in Table 4.2. However, in the energy efficiency standard revision of 2017, the indicator for heat transmission changed from *Q*-value to U_A-value. *Q*-value for the H28 standard was estimated from the specific U_A-value, but there might be a discrepancy in some cases, due to calculation of floor area. As a result, published value [209] and estimated value of the penetration ratio of energy efficiency house (over H11 standard) in this study generally corresponded (Figure 4.3).

Year of construction	
2013	5
2001 ~ 2012	4
1991 ~ 2000	3
1981 ~ 1990	2
Older than 1980	1

+

Double glazing	
Present in all window	3
Present in some window	2
Absent	1

=

Energy efficiency standard	
8	H25 standard
7	H11 standard
5 ~ 6	H4 standard
3 ~ 4	S55 standard
2	No insulation

Figure 4.1 Calculation of energy efficiency standard based on year of construction and presence of double glazing

Regional division	Corresponded prefectures (Regional division is defined by municipality)
1 🟦	Hokkaido
2 🟦	
3 🟩	Aomori, Iwate, Akita
4 🟨	Miyagi, Yamagata, Fukushima, Tochigi, Niigata, Nagano
5 🟧	Ibaraki, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Toyama, Ishikawa, Fukui, Yamanashi, Gifu, Shizuoka, Aichi, Mie, Shiga, Kyoto, Osaka, Hyogo
6 🟧	Nara, Wakayama, Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita
7 🟪	Miyazaki, Kagoshima
8 🟥	Okinawa

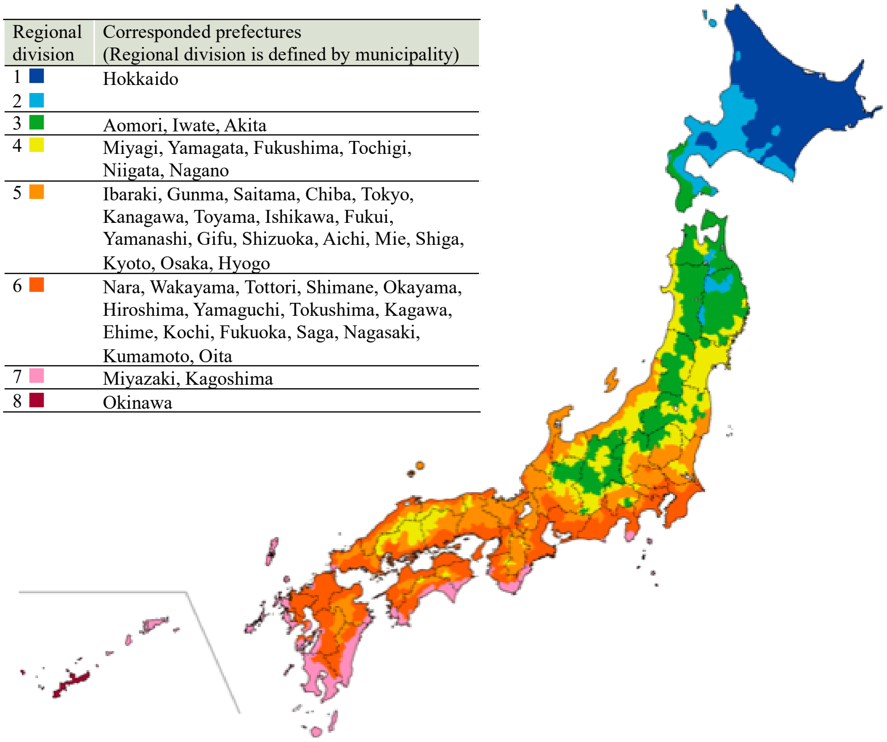


Figure 4.2 Regional division of energy efficiency standard [94]

Table 4.2 Coefficient of overall heat transmission by energy efficiency standard and regional division, W/m^2•K (modified and calculated from [210] [211] [212]**)**

Regional division	1	2	3	4	5	6	7	8
Detached house								
H25 standard	1.4	1.4	1.4	1.9	1.9	1.9	1.9	3.7
H11 standard	1.6	1.6	1.9	2.4	2.7	2.7	2.7	3.7
H4 standard	1.8	1.8	2.7	3.3	4.2	4.2	4.6	8.0
S55 standard	2.8	2.8	4.0	4.7	5.2	5.2	8.3	8.3
No insulation	3.2	3.2	4.9	5.6	6.3	6.3	8.3	8.3
Apartment and flat								
H25 standard	1.2	1.2	1.2	1.5	1.5	1.5	1.5	2.9
H11 standard	1.3	1.3	1.5	1.9	2.2	2.2	2.2	2.9
H4 standard	1.5	1.5	2.2	2.4	2.8	2.8	3.1	4.8
S55 standard	2.2	2.2	3.1	3.4	3.8	3.8	5.5	5.5

No insulation	2.5	2.5	3.8	4.0	4.6	4.6	5.5	5.5

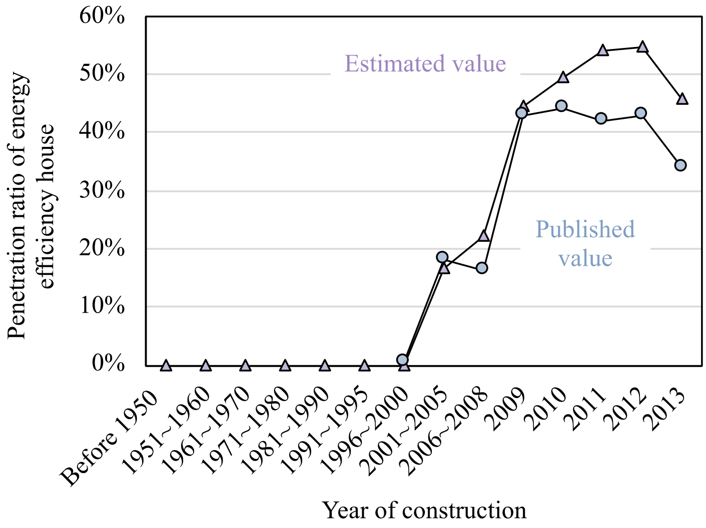


Figure 4.3 Published value [209] **and estimated value of the penetration ratio of energy efficiency house (over H11 standard) by year of construction**

In this study, monthly electricity, gas and other energy bills were estimated because these bills contain not only heating and cooling costs, but lighting or hot-water supply etc. together. To separate heating and cooling costs from other energy costs, we focused on monthly fluctuations of energy costs and assumed that heating and cooling costs fluctuate due to temperature differences between inside and outside during heating or cooling seasons (Figure 4.4). Hence, the mean energy cost of the mild season was defined as base energy cost (E_{base}).

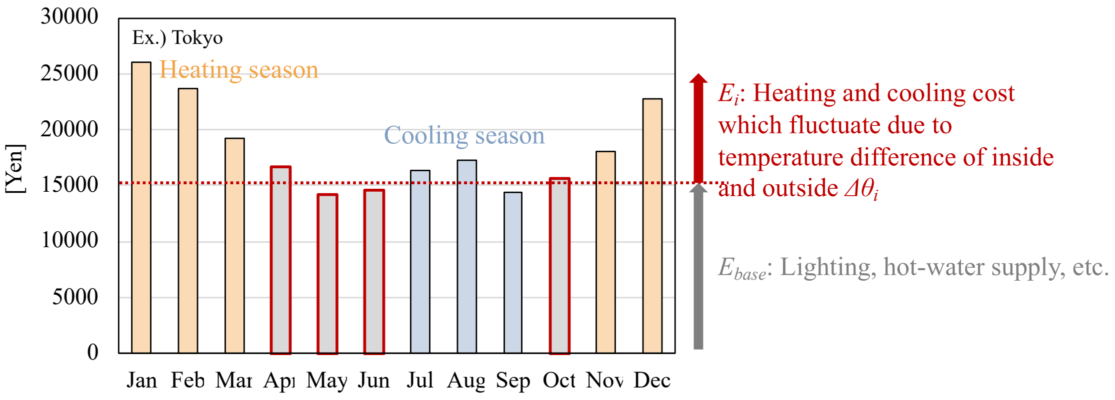


Figure 4.4 Monthly energy costs from the Family Income and Expenditure Survey [201]

By using formula (1) and (2), annual energy cost E_{all} was calculated for each sample in the HLS. Calculated value of E_{all} generally corresponded to the published value in the FIES [201], but was slightly higher (Figure 4.5).

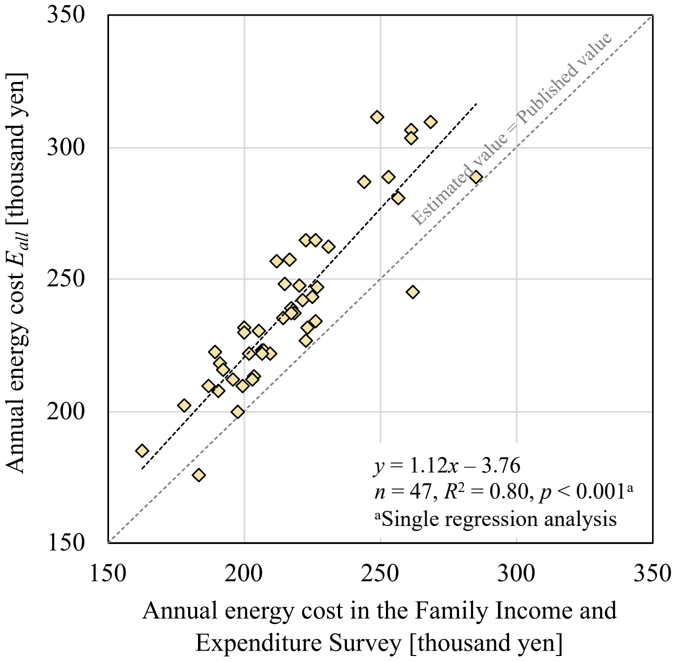


Figure 4.5 Single regression analysis of calculated annual energy cost E_{all} and annual energy cost in the Family Income and Expenditure Survey [201] **at prefecture level**

FP was measured using the Low Income High Costs indicator [77], which considers a household to be FP if:

- they have required energy costs (E_{all}) that are above average (originally, they have required fuel costs that are above average (the national median level) [77]); and
- were they to spend that amount, they would be left with a residual income below the poverty line. The income threshold was set at 60 % of median income plus calculated E_{all} [51].

Low Income High Costs is a dual indicator, which allows us to measure not only the extent of the problem (how many FP households there are), but also the depth of the problem (how badly affected each FP household is). The depth of FP is calculated by taking account of the fuel poverty gap. This is a measure of the additional fuel costs faced by FP households to meet the threshold that would make them non-FP. This is illustrated in Figure 4.6 where the indicator consists of:

- the number of households that have both low incomes and high fuel costs (shown by the shaded area in the bottom left and quadrant in Figure 4.6); and
- the depth of FP among these FP households. This is measured through a fuel poverty gap (FPG, shown by the vertical arrows in Figure 4.6), which represents the difference between required energy costs (E_{all}) for each household and the nearest FP threshold (in yen).

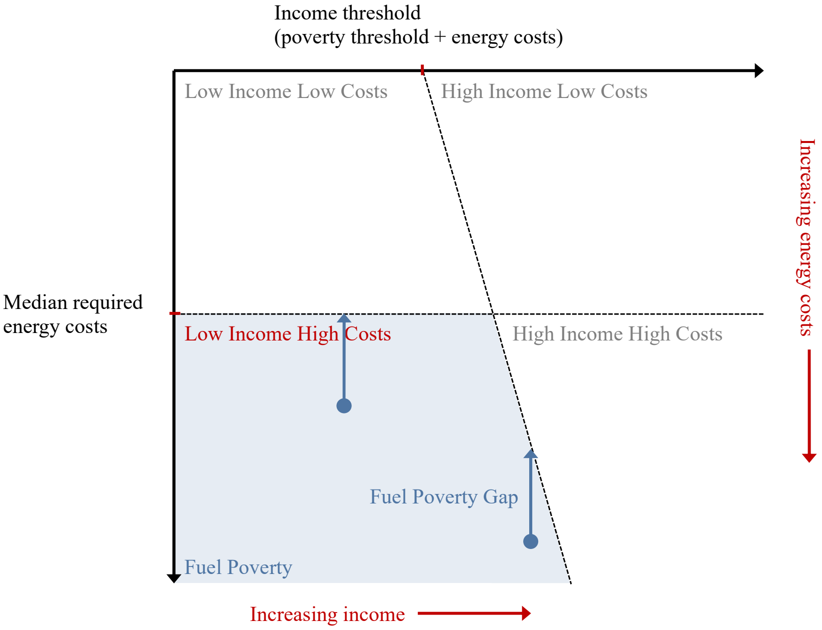


Figure 4.6 Fuel poverty under the Low Income High Costs indicator [77]

4.2.4 Exclusion criteria

To be included in this study, data had to be present for the questions “Number of household members”, “Floor area”, “Year of construction” in the Housing and Land Survey. Of the 3,451,893 households sampled, 276,366 households responded. In order to exclude extreme cases, samples which responded more than 11 to “Number of household members” and responded less than the minimum residential floor area (25 m^2) to “Floor area” were excluded. Accordingly, E_{all} was calculated for 220,687 households. Additionally, for the evaluation of FP, only households that answered “Annual income of household” could be included. Thus the final sample included 106,853 households.

4.2.5 Data analysis

For continuous variables with a normal distribution, means ± standard deviations (SDs) were reported. As FPG had a skewed distribution, medians and interquartile ranges were reported. Mean and median values were compared using the *t*-test and the Mann-Whitney test or Kruskal-Wallis test, respectively, and categorical data were analysed with chi-square (χ^2) or Fisher’s exact tests.

A multivariable logistic regression model was prepared to estimate the risk of FP associated with potential predictors, including resident and housing characteristics. Inclusion of variables in the models was based on existing knowledge of risk factors for FP. Spearman’s correlations between each independent variable were tested and “Double glazing” was rejected from the model because it had a high correlation with “Energy efficiency standard.” In the specific group of FP household, associations between resident and housing characteristics and the extent of FPG were assessed using ANOVA. Since FPG had a skewed distribution, scores were log-transformed and included in the model. The same variables as in the multivariable logistic regression model of FP were used in the ANOVA of FPG.

Of the independent variable, age could be analysed in two different ways: age of the oldest member of the household which identifies younger households; age of the youngest member of the household which identifies older households. Age of the youngest member of the household is important to consider when looking at the effects of age on FP [77], and was used in this study.

All *p*-values were two-sided, and $p < 0.05$ was considered statistically significant. All statistical analyses were performed with SPSS version 24.0 (IBM, Armonk, NY, USA). In order to grasp the nationwide distribution of evaluated index graphically, the Geographic Information System (GIS, Esri Japan Corporation, Tokyo, Japan) was used to colour-code the Japanese map in accordance with mean value or percentage.

4.3 Results

4.3.1 Residents and housing characteristics of fuel poverty household

Of the 106,853 households, 15,762 (14.75 %) were classified as FP (Figure 4.7). Annual energy cost was 235.5 ± 73.8 thousand yen on average per household. Moreover, annual energy cost of FP households (288.8 ± 90.5 thousand yen) was significantly higher than those of non-FP households (226.2 ± 66.3 thousand yen), t (106,851) = 868.12, $p < 0.001$ (Table 4.3).

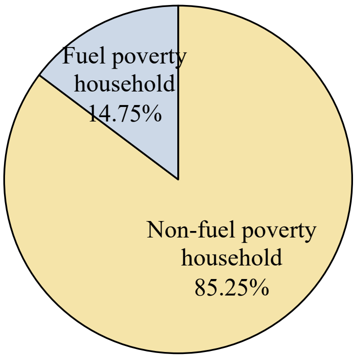


Figure 4.7 Percentage of fuel poverty and non-fuel poverty household

Table 4.3 Annual energy cost of all household and Student's *t*-test of annual energy cost between fuel poverty and non-fuel poverty household, thousand yen

	n	Mean	SD	*t*	*p*
All household	106,853	235.5	73.8		
Fuel poverty household	15,762	288.8	90.5	868.12[a]	<0.001[b]
Non-fuel poverty household	91,091	226.2	66.3		

SD, standard deviation.

[a,b] *t*-value and *p*-value of Student's *t*-test between fuel poverty and non-fuel poverty household.

Table 4.4 shows resident and housing characteristics of FP and non-FP household. Annual income, $\chi^2(2) = 28614.41$, $p < 0.001$, and number of housing composition $\chi^2(1) = 8247.08$, $p < 0.001$, were strongly associated with FP. When it comes to the housing characteristics, lower energy efficiency standard level, $\chi^2(4) = 11815.01$, $p < 0.001$, is associated with a higher proportion of FP households, and so did the absence of double-glazed windows, $\chi^2(2) = 5128.42$, $p < 0.001$. However, regional division, $\chi^2(7) = 2211.87$, $p < 0.001$, did not have a linear association to FP. Regional division is defined due to climatic conditions though, differences of prevalence of FP tend to reflect not only climatic conditions but other various confounders such as the age of the housing stock and relative income levels.

Table 4.4 Student's *t*-test, chi-squared test and Fisher's exact test of characteristics of the fuel poverty and non-fuel poverty household groups

Resident characteristics	FP household (n = 15,762)	non-FP household (n = 91,091)	t	χ^2	p
Age of youngest family member, n (%)					
< 65 years-old	11,424 (11.7)	86,467 (88.3)		8837.52	<0.001[a]
≥ 65 years-old	4,445 (49.6)	4,517 (50.4)			
Housing composition, n (%)					
Living alone	5,026 (42.8)	6,722 (57.2)		8247.08	<0.001[a]
Living with someone	10,736 (11.3)	84,369 (88.7)			
Annual income, n (%)					
< 2 million yen	8,016 (63.2)	4,659 (36.8)			<0.001[b]
2 – 7 million yen	7,746 (10.9)	63,575 (89.1)			
≥ 7 million yen	0 (0.0)	22,857 (100.0)			
Housing characteristics	**FP household (n = 15,762)**	**non-FP household (n = 91,091)**	t	χ^2	p^a
Housing type, n (%)					
Detached house	14,191 (14.4)	84,450 (85.6)		135.68	<0.001[a]
Apartment or flat	1,571 (19.1)	6,641 (80.9)			
Floor area, m^2, mean (SD)	62.30 (34.5)	51.69 (26.1)	235.22		<0.001[c]
Structure, n (%)					
Wood	7,301 (22.6)	24,989 (77.4)		2366.45	<0.001[a]
Fireproof wood	7,216 (11.4)	56,015 (88.6)			
Steel-reinforced concrete	525 (9.8)	4,855 (90.2)			
Steel frame	584 (10.8)	4,825 (89.2)			
Others	136 (25.0)	407 (75.0)			
Double glazing, n (%)					
Absent	2,165 (5.6)	36,578 (94.4)		5128.42	<0.001[a]
Present in some window	2,459 (12.9)	16,675 (87.1)			
Present in all window	11,138 (22.7)	37,838 (77.3)			
Energy efficiency standard, n (%)					
H25 standard	102 (2.2)	4,503 (97.8)		11815.01	<0.001[a]
H11 standard	1,412 (4.3)	31,202 (95.7)			
H4 standard	4,298 (11.5)	33,155 (88.5)			
S55 standard	5,263 (25.4)	15,463 (74.6)			
No insulation	4,687 (40.9)	6,768 (59.1)			
Regional division, n (%)					
1	557 (19.8)	2,257 (80.2)			<0.001[b]
2	735 (16.6)	3,697 (83.4)			
3	1,343 (27.3)	3,573 (72.7)			
4	2,113 (34.0)	6,679 (76.0)			
5	4,016 (15.9)	21,210 (84.1)			
6	5,707 (10.8)	46,967 (89.2)			
7	1,291 (18.5)	5,692 (81.5)			
8	0 (0.0)	1,016 (100.0)			

FP, fuel poverty; SD, standard deviation.

[a] *p*-value of chi-squared test, [b] *p*-value of Fisher's exact test, [c] *p*-value of Student's *t*-test.

In the comparison of percentage of FP by age of the youngest member, as age of the household gets older, prevalence of FP gets higher, and annual income gets lower in aged household (Figure 4.8).

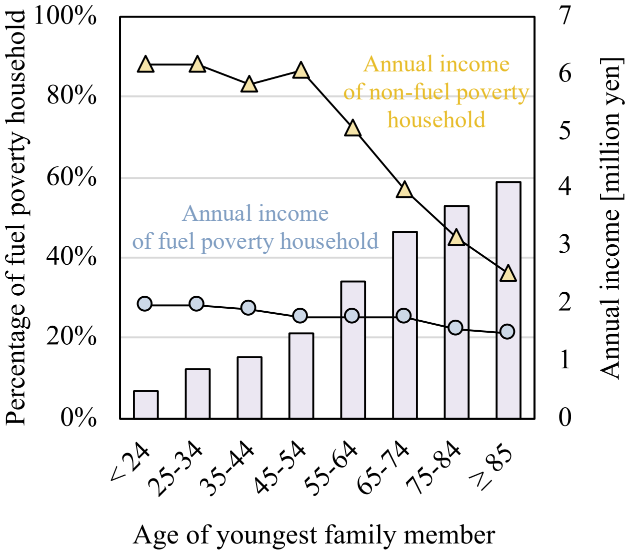


Figure 4.8 Percentage of fuel poverty household and annual income by age of youngest family member

4.3.2 Factors that cause fuel poverty

Before investigating factors that cause FP, correlation coefficients between independent variables were assessed with the Spearman's correlation analysis (Table 4.5). Energy efficiency standard and double glazing were strongly correlated at 0.808, $p < 0.001$, which suggested that both should not be included in the same multiple logistic model in the following analysis. Therefore, double glazing was rejected from the model since energy efficiency standard had higher correlation coefficient to fuel poverty household.

Table 4.5 Spearman's correlation coefficient between resident and housing characteristics

	a	b	c	d	e	f	g	h	i	j
a. Age of youngest family member		-.338	-.297	.053	.082	-.077	.104	.133	-.014	.290
b. Household composition			.300	-.170	.015	.068	-.157	-.193	.028	-.278
c. Annual income				-.137	.119	.150	-.263	-.306	.043	-.429
d. Housing type					-.031	.121	.132	.120	-.058	.036
e. Floor area						.021	-.065	-.042	-.051	.161
f. Structure							-.166	-.190	-.018	-.134
g. Double glazing								.808	.210	.219
h. Energy efficiency standard									.064	.312
i. Regional division										-.100
j. Fuel poverty household										

All p<0.001

^{a}< 65 years old vs ≥ 65 years old, ^{b}Living alone vs living with someone, ^{c}1 = Under 2 million yen, 2 = 2 – 7 million yen, 3 = over 7 million yen, ^{d}Detached house vs apartment or flat, ^{f}1 = Wood, 2 = Fireproof wood, 3 = Steel-reinforced concrete, 4 = Steel frame, 5 = Others, ^{g}1 = Absent, 2 = Present in some window, 3 = Present in all window, ^{h}1 = H25 standard, 2 = H11 standard, 3 = H4 standard, 4 = S55 standard, 5 = No insulation, ^{j}Fuel poverty household vs non-fuel poverty household.

Table 4.6 shows the final multiple logistic regression model for FP. The findings suggest that aged households, living alone, and low income were risk factor of FP. Housing characteristics indicated as risk factors of FP were detached house, larger floor area, wood structure, and low energy efficiency standard. Furthermore, houses located in areas 3 and 4 have had higher risk of FP, while area 5 – 8 have had lower risk than in area 1.

Table 4.6 Multiple logistic regression analysis of fuel poverty by resident and housing characteristics

	Exp(β)	95 % CI	p
Age of youngest family member			
< 65 years-old	(ref.)		
≥ 65 years-old	2.78	2.62 – 2.96	<0.001
Household composition			
Living alone	(ref.)		
Living with someone	0.64	0.61 – 0.68	<0.001
Annual income			
< 2 million yen	(ref.)		
≥ 2 million yen	0.07	0.07 – 0.08	<0.001
Housing type			
Detached house	(ref.)		
Apartment and flat	0.47	0.43 – 0.51	<0.001
Floor area [m^2]	1.02	1.02 – 1.02	<0.001
Structure			
Wood	(ref.)		
Fireproof wood	0.79	0.76 – 0.83	<0.001
Steel-reinforced concrete	0.46	0.41 – 0.51	<0.001
Steel frame	0.94	0.84 – 1.05	0.258
Others	0.69	0.54 – 0.90	0.006
Energy efficiency standard			
H25 standard	(ref.)		
H11 standard	2.15	1.72 – 2.69	<0.001
H4 standard	6.06	4.87 – 7.56	<0.001
S55 standard	15.08	12.10 – 18.79	<0.001
No insulation	25.68	20.56 – 32.09	<0.001
Regional division			
1	(ref.)		
2	0.98	0.84 – 1.14	0.778
3	1.75	1.52 – 2.02	<0.001
4	1.42	1.24 – 1.62	<0.001
5	0.88	0.78 – 1.00	0.051
6	0.50	0.44 – 0.56	<0.001
7 & 8	0.36	0.31 – 0.42	<0.001

$n = 106{,}853$, Nagelkerke $R^2 = 0.46$, Chi-square = 414.52 ($df = 8$, $p < 0.001$)

4.3.3 Factors that worsen the fuel poverty gap

Of the 15,762 FP households, FPG was compared by residents and housing characteristics (Table 4.7, Table 4.8, Table 4.9). Older age, living alone, detached house, low energy efficiency standard, location in area 3 or 4 were the characteristics with a greater FPG. In contrast, annual income, $Z = -0.86$, $p = 0.388$, did not affect the FPG.

Table 4.7 Mann-Whitney *U* test of fuel poverty gap, thousand yen

	n	median	IQR	*Z*	*p*
Age of youngest family member					
< 65 years-old	11,424	43.3	18.7 – 8.95	-7.84	<0.001
≥ 65 years-old	4,293	51.7	22.8 – 102.8		
Household composition					
Living alone	5,026	48.1	21.5 – 94.3	-3.67	<0.001
Living with someone	10,736	44.4	18.8 – 91.8		
Annual income					
< 2 million yen	8,016	46.2	19.8 – 94.2	-0.86	0.388
≥ 2 million yen	7,746	45.1	19.5 – 91.2		
Housing type					
Detached house	14,191	46.6	20.4 – 94.3	-8.62	<0.001
Apartment and flat	1,571	35.4	13.1 – 79.1		

IQR, interquartile range.

Table 4.8 Median and interquartile range of fuel poverty gap by structures, energy efficiency standards, and regional divisions, thousand yen

	n	median	IQR	χ^2	*df*	*p*
Structure						
Wood	7,301	45.2	19.6 – 92.0			
Fireproof wood	7,216	47.0	20.4 – 94.6			
Steel-reinforced concrete	525	35.7	14.2 – 76.0	31.5	4	<0.001
Steel frame	584	41.7	17.2 – 86.8			
Others	136	47.4	24.1 – 84.5			
Energy efficiency standard						
H25 standard	102	32.8	14.8 – 65.7			
H11 standard	1,412	33.8	14.6 – 69.5			
H4 standard	4,298	35.8	14.5 – 73.4	475.9	4	<0.001
S55 standard	5,263	51.2	23.0 – 100.5			
No insulation	4,687	55.1	24.6 – 110.0			
Regional division						
1	557	52.0	21.5 – 118.6			
2	735	51.8	23.8 – 98.7			
3	1,343	74.0	36.0 – 141.5			
4	2,113	81.4	36.1 – 15.4	1400.9	6	<0.001
5	4,016	51.4	22.8 – 97.1			
6	5,707	33.6	14.5 – 65.2			
7 & 8	1,291	30.0	12.2 – 58.1			

IQR, interquartile range.

Table 4.9 Kruskal-Wallis test and post-hoc pairwise comparisons for fuel poverty gap, thousand yen

Variable	Pairwise comparison	χ^2	*df*	*p*
Structure		31.5	4	<0.001
Wood	Fireproof wood			0.311
Wood	Steel-reinforced concrete			<0.001
Wood	Steel frame			0.196
Wood	Others			<0.001
Fireproof wood	Steel-reinforced concrete			0.720
Fireproof wood	Steel frame			0.319
Fireproof wood	Others			0.014
Steel-reinforced concrete	Steel frame			0.840
Steel-reinforced concrete	Others			0.091
Steel frame	Others			0.903
Energy efficiency standard		475.9	4	<0.001
H25 standard	H11 standard			0.622
H25 standard	H4 standard			0.487
H25 standard	S55 standard			<0.001
H25 standard	No insulation			<0.001
H11 standard	H4 standard			0.532
H11 standard	S55 standard			<0.001
H11 standard	No insulation			<0.001
H4 standard	S55 standard			<0.001
H4 standard	No insulation			<0.001
S55 standard	No insulation			0.002
Regional division		1400.9	6	<0.001
1	2			0.004
1	3			<0.001
1	4			<0.001
1	5			<0.001
1	6			<0.001
1	7 & 8			<0.001
2	3			<0.001
2	4			<0.001
2	5			<0.001
2	6			<0.001
2	7 & 8			<0.001
3	4			0.751
3	5			0.146
3	6			<0.001
3	7 & 8			<0.001
4	5			0.345
4	6			<0.001
4	7 & 8			<0.001
5	6			<0.001
5	7 & 8			<0.001
6	7 & 8			0.387

df, degrees of freedom; χ^2, chi-square.

In the ANOVA of FPG by resident and housing characteristics (Table 4.10), age of youngest family member, household composition, housing type, energy efficiency standard, regional division, and floor area were significantly associated with FPG. In contrast, FPG did not differ between different annual income groups, $F(1, 15697) = 1.53$, $p = 0.217$.

Table 4.10 Analysis of variance of fuel poverty gap by resident and housing characteristics

	df	*F*	*p*	η^2
Age of youngest family member[a]	1	26.68	<0.001	0.002
Household composition[b]	1	30.69	<0.001	0.002
Annual income[c]	1	1.53	0.217	0.000
Housing type[d]	1	681.67	<0.001	0.042
Structure				
Wood (ref.)				
Fireproof wood	1	0.94	0.221	0.000
Steel-reinforced concrete	1	0.39	0.533	0.000
Steel frame	1	4.20	0.040	0.000
Others	1	2.02	0.155	0.000
Energy efficiency standard				
H25 standard (ref.)				
H11 standard	1	70.35	<0.001	0.004
H4 standard	1	217.20	<0.001	0.014
S55 standard	1	454.21	<0.001	0.028
No insulation	1	576.46	<0.001	0.035
Regional division				
1 (ref.)				
2	1	0.09	0.763	0.000
3	1	99.30	<0.001	0.006
4	1	100.71	<0.001	0.006
5	1	0.04	0.850	0.000
6	1	174.74	<0.001	0.011
7 & 8	1	257.81	<0.001	0.016
Floor area	1	10253.72	<0.001	0.395

[a]< 64 years-old vs ≥ 65 years-old, [b]Living alone vs Living with someone, [c]< 2 million yen vs ≥ 2 million yen, [d]Detached house vs apartment and flat.

η^2, Eta-squared, Adjusted $R^2 = 0.474$

4.3.4 Distributions of evaluated indexes

The distributions of percentage of FP (Figure 4.9), age of youngest family member (Figure 4.11), mean income (Figure 4.12), annual energy cost (Figure 4.13), penetration ratio of double glazing (Figure 4.14), and mean floor area (Figure 4.15) were colour-coded using GIS. Prefectures with a higher percentage of FP were mainly seen in Tohoku (regional division = 3 or 4), Hokuriku (regional division = 4 or 5), Shikoku (regional division = 5, 6, or 7), and Kyushu regions (regional division = 5, 6, or 7). Tohoku and Hokuriku regions are known for heavy snowfalls. On the contrary, Shikoku and Kyushu regions are known to have relatively mild winters. This result indicates that risk of FP is not only related to climate but other individual characteristics of residents and housing. In particular, even though Tohoku region had a high penetration ratio of double glazing, the percentage of FP was high among those with older age, lower income, higher energy costs, and larger floor areas which have all been shown as significant risk factors of FP [77]. Although not as extreme, the same trend was seen in all rural areas.

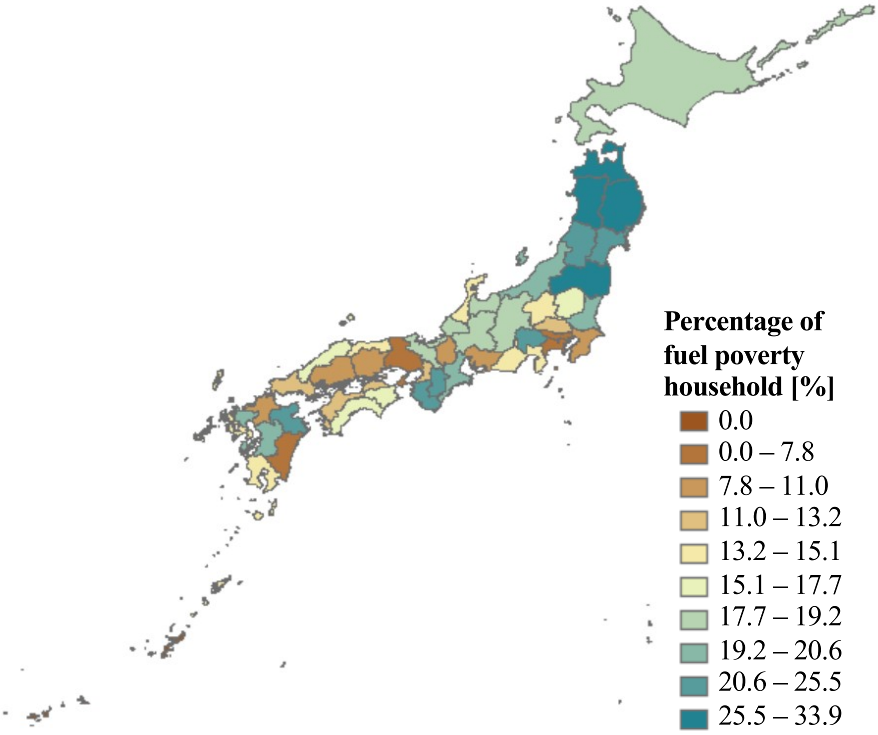


Figure 4.9 Distribution of the percentage of fuel poverty household

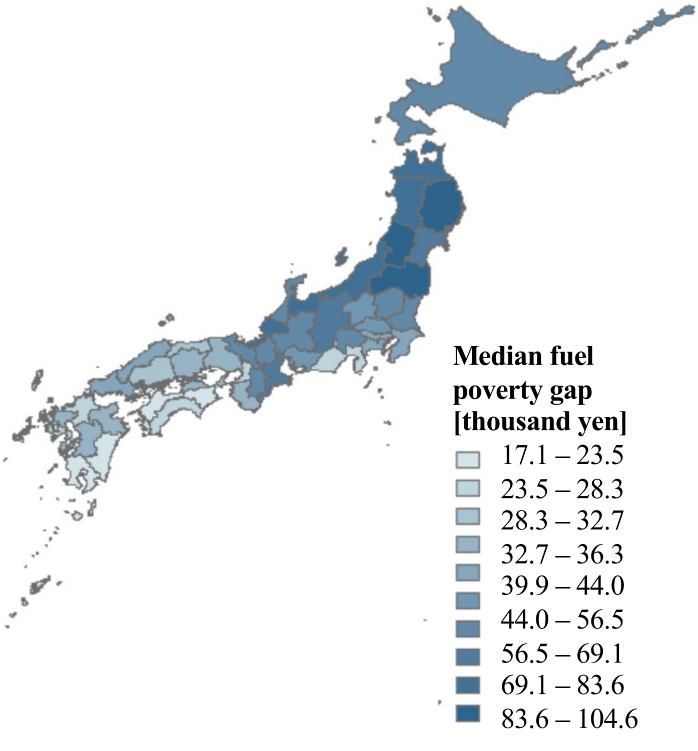


Figure 4.10 Distribution of the median fuel poverty gap

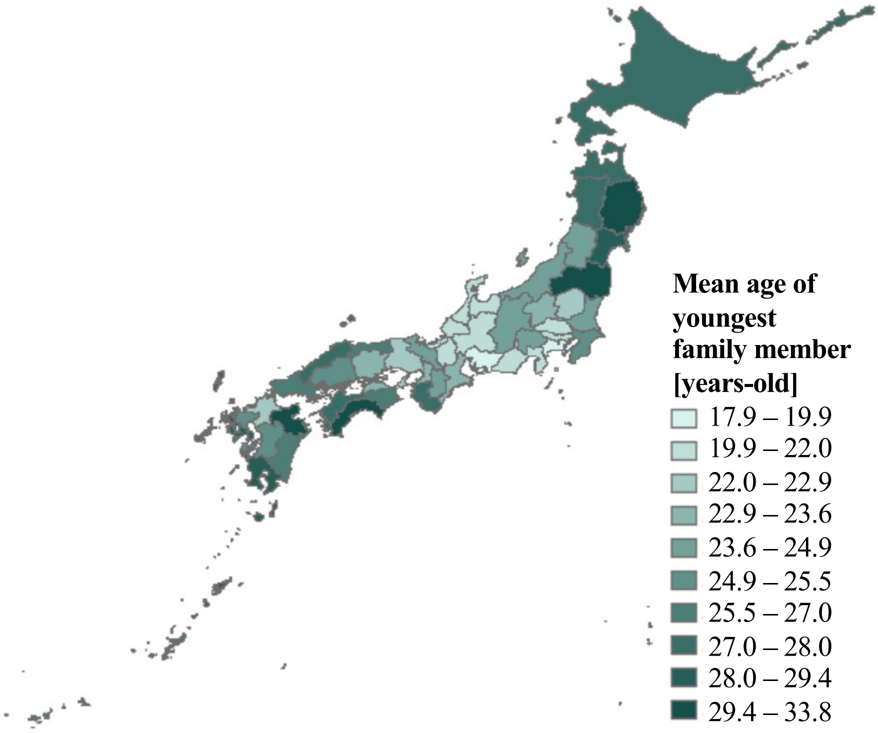


Figure 4.11 Distribution of the mean age of youngest family member

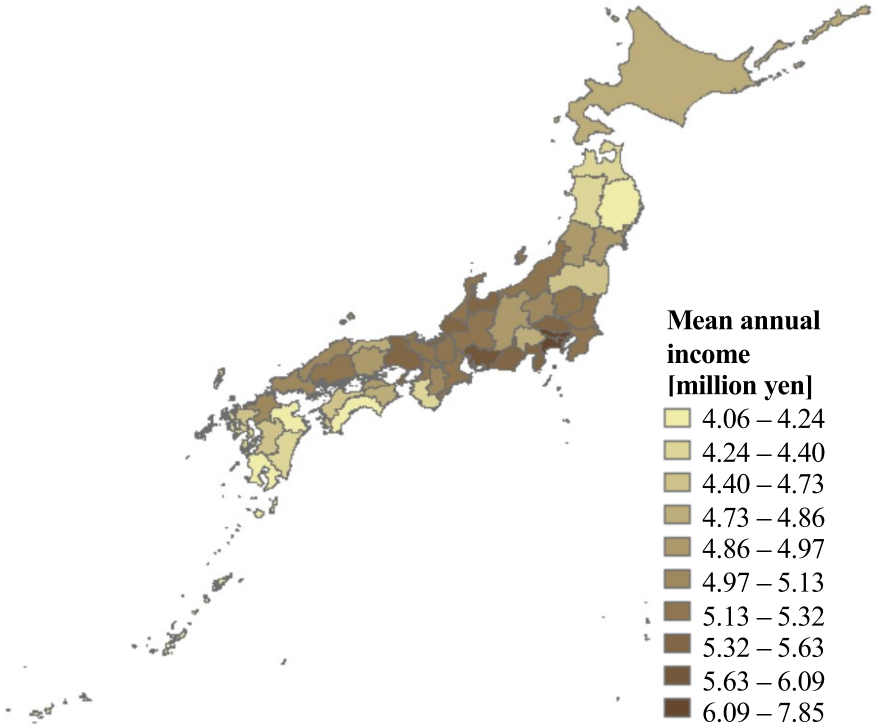


Figure 4.12 Distribution of the mean annual income

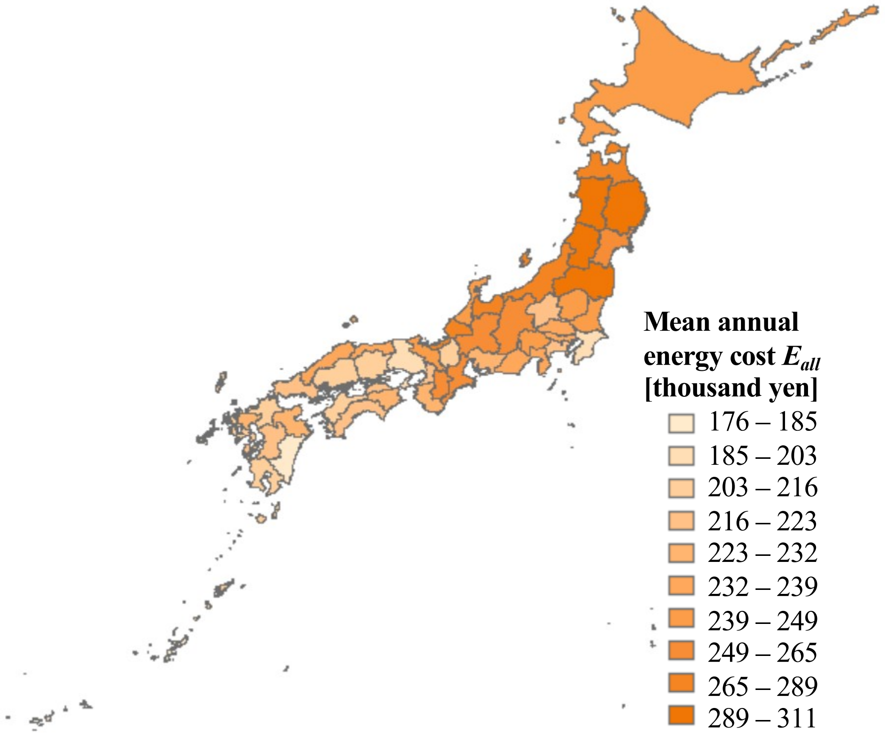


Figure 4.13 Distribution of the mean annual energy cost E_{all}

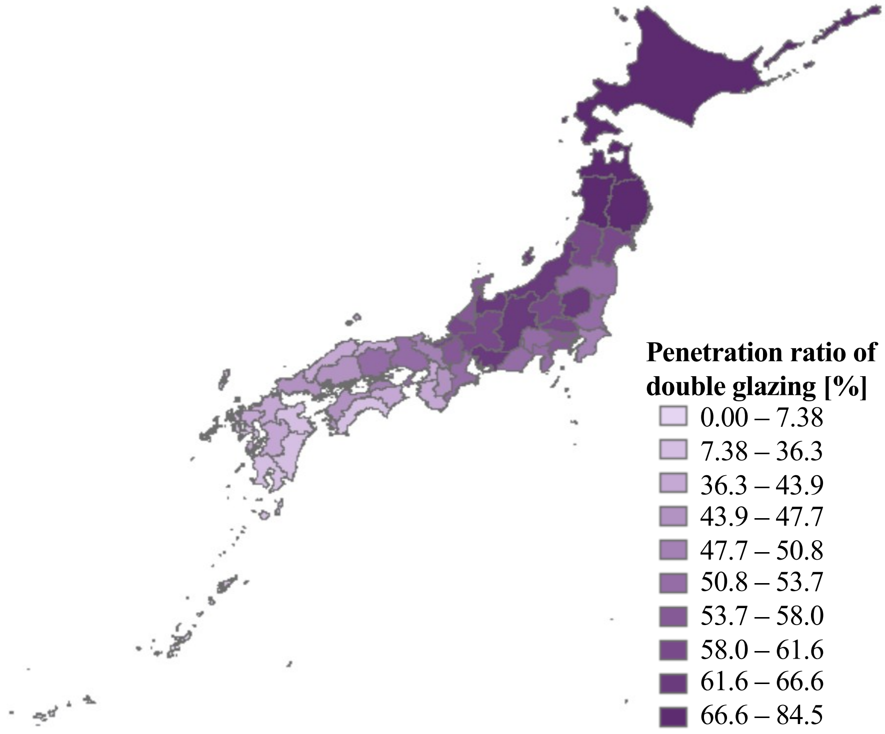


Figure 4.14 Distribution of the penetration ratio of double glazing

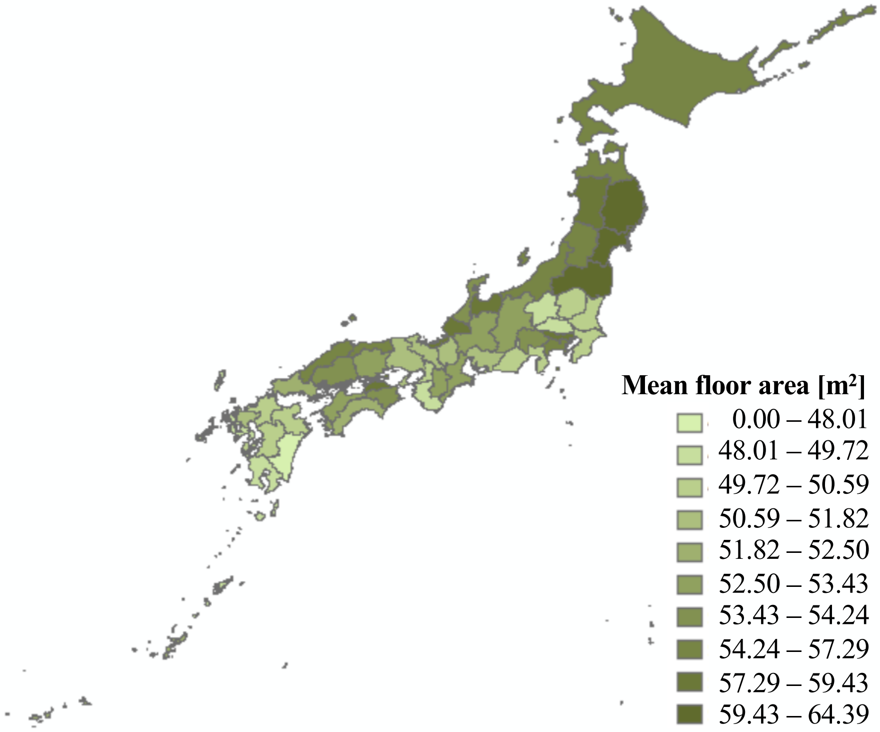


Figure 4.15 Distribution of the mean floor area

4.4 Discussion

Using individual level nationally representative data, this study described the overall condition of FP in Japan. For the evaluation of FP, a method to estimate energy efficiency levels of houses and annual required energy cost were developed. An association between residents' characteristics and FP indicated that older people and/or living alone are the most vulnerable to cold weather and having difficulty warming up their homes properly. In contrast, an association between housing characteristics and FP highlighted the need for improvement of energy efficiency performance of housing. Evaluation of the spatial distribution of FP showed that FP was not equally distributed in individual areas, nor follow the climate area. The results lead to a deeper understanding of FP within the context of Japan in which the patterns of poverty and housing standards are different from other countries. Moreover, the results enhance the understanding of the complexity of FP and is, consequently, a first step towards the development of more effective spatially and content-adapted strategies and policies for tackling FP.

Many countries including Japan do not have an official definition nor an official way of measuring FP [213]. This is concerning because every discussion and every policy design requires a clear definition of the subject, as policies cannot be tailored if the target group remains unclear. It is essential to have a clear understanding of FP and its measurement to design policies that are effective in tackling FP and reaching those who are most in need. Required data for measuring FP such as energy efficiency level on the macro scale is lacking, and there are no local scale data. Simple indicators such as age or income are inadequate for explaining the complexity of FP, and more comprehensive proxy indicators are required. The discussion about measurement metrics is essential, but while data availability on the local scale remains poor, supporting indicators are a good compromise for identifying and pinpointing FP. In this study, published value [209] and estimated value of the penetration ratio of energy efficiency house (over H11 standard) generally corresponded. Moreover, mean calculated annual energy cost of each prefecture generally corresponded to the published value in the FIES [201]. Accuracy of the estimation of energy efficiency standard will improve if published value of penetration rate of multiple energy efficiency standards is provided, but was not able to be done at this time due to lack of data.

Annual energy costs were calculated at 235.5 thousand yen on average per household, which was higher than the 171 thousand yen reported in "Actual Conditions Survey of CO_2 Emission in the Residential Sector [214]." In the process of calculating the energy costs, the main advantage of this study was the use of individual level data in the analyses rather than relying on aggregate population data. This enabled the consideration of the combination of energy efficiency, and residents' characteristics including income for each household. A concern related to the calculation of energy costs is the Japanese way of heating which warms up only occupied rooms by placing a heating unit, or rather kotatsu table in a room. Our calculations were based on the costs to heat an entire home using a central heating system, or using multiple heating units, which might lead to higher required costs for heating energy. However, exposure to a short-term decrease in air temperature due to great temperature gap between heated and un-heated rooms can trigger health problems such as increased blood pressure [215] and pulse pressure [216], and a decrease in endothelial function [217]. Therefore, considering energy cost for heating up the whole home is rational in its relation to health aspects.

Evaluation of the spatial distribution of FP allows for funding and support to be channelled to high risk areas. However, in the Japanese Building Energy Efficiency Act [90], the target groups are not effectively reached and this must be improved if FP is to be addressed. "Hot-spots" and "cold-spots" of FP households and FPG exist and these require different policy solutions. Boardman [218] proposes the introduction of Low Carbon Zones focusing on the worst housing and poorest people, in regard to the hot-spots. The establishment of such zones offers several advantages that policies can be developed to specifically target these zones, or these zones can receive more help than other areas. In particular in terms of energy efficiency improvements to the housing stock, an area-based approach could be more cost-effective [219]. Such zonal approaches could also be integrated into the existing energy efficiency improvement programme by providing higher grants for housing owners whose buildings are located in such zones. Fuel Allowance [220], for example, is awarded as income support for paying winter fuel bills in some Hokkaido companies. It is a unique wage system of Hokkaido, and is not seen in other prefectures. Fuel Allowance does not differentiate between FP households and non-FP households, and rates of leakage are quite high as only 18.16 % of households in Hokkaido are FP estimated in this study. Moreover, income supports which do not take account of the energy efficiency of the home, are thus sometimes insufficient to tackle FP effectively [221].

Quantifying FP across Japan highlights the high prevalence of excess winter deaths in prefectures with relatively mild winter climates [222]. Interest in the spatial distribution of FP ranges from a recognition that the condition is locally contingent upon different regional context, to acknowledgement within different resident and household phenomena. At a more localized scale, the likelihood of experiencing FP varies between different household types and demographics and therefore also geographically, as households with similar characteristics tend to cluster in particular locales. It is also common within FP research for a distinction to be made between rural and urban areas. For example, in rural areas that are expensive to supply, cross-subsidies from more lucrative urban areas have been stopped resulting in reliance upon expensive fuel types (primarily oil) in isolated households not connected to the gas network [223] [224]. Moreover, in rural areas there is a higher concentration of under-occupancy leaving some smaller households in disproportionately large properties that require excessive heating to maintain adequate warmth [225]. These concerns in rural areas demonstrate a need to address related issues such as household's ability to access appropriate domestic energy services and access to affordable housing.

This study has several limitations. First, only the costs for electrical energy heating systems was used in the calculation, and gas or kerosene, which are relatively cheap, were not taken into account. This is due to the absence of data about energy source or heating type in the HLS. Additionally, while we took into account the age of the houses in estimating energy efficiency, newer houses might have also been built with more efficient heating systems, which led to a reduction of energy consumption. Second, in the exclusion criteria, most apartments and flats were excluded due to the large number of family members, which was overestimated. In many cases of apartments and flats, the number of family members included multiple households living in the building. Third, the HLS is a sampling survey and final totalization is limited to prefecture level. Even in the UK, the English Housing Survey relies on sample sizes which are too small to assist in targeting affordable warmth strategies and can only provide FP data at broad regional level [226]. In Europe, data also is based on limited sample sizes and reported data at the national level [227]. However, our study has an advantage that the data from the HLS could be analyzed at the individual level, which enabled the detection of strong associations between household characteristics and risk of FP. Finally, in regard to study 2, nationwide analysis on nursing homes are still needed, but was not able to be done at this time due to lack of statistical data about nursing home facilities.

4.5 Conclusion

Study 3 described the overall condition of FP in Japan by estimating energy efficiency levels of houses and annual required energy cost from individual level nationally representative data. The results highlight the importance of including low-income older people as a target group to improve their housing by installing proper insulation. People likely to live in cold homes are less likely to be able to afford to install insulation or pay for heating energy costs. Therefore, it is essential to ensure that low-income people can afford to live in improved buildings, potentially through public support for housing costs; otherwise improvements in insulation might increase inequities. Evaluation of the spatial distribution of FP showed that FP was not equally distributed in individual areas, which highlighted the importance of developing policies to specifically target high risk areas.

Chapter 5

Conclusion

Chapter 5

Conclusion

5.1 Conclusion

This thesis examined the connection between resident's condition of needing long-term care (LTC) and the energy efficiency properties of the housing stock in Japan, through several strands of research. The overarching objective was to contribute to the understanding of how the indoor thermal environment can promote health and prevent the need for LTC in older people. The following is a summary of the conclusions drawn in this thesis.

Indoor thermal environment and health of community dwelling older people

This study aimed to investigate the associations among health, frailty, age at LTC certification, and perceived indoor temperature ($temp_{in}$) of housing among community-dwelling older people in the context of fuel poverty (FP). While most previous studies [109] [110] [111] that measured $temp_{in}$ in homes focused on healthy older people, this study added an insight into the thermal environment in the homes of older people experiencing declines in health and function. An indoor temperature of 18 ˚C or higher is recommended to maintain health [79]. Our results showed that the homes of older people in Japan are below this standard. Among those who reported that they rarely felt cold in their homes, the actual indoor temperature, 17.0 ˚C, was still below the recommended level. Furthermore, those who reported feeling cold often in their homes had an indoor temperature, 14.7 ˚C, that was far below this standard. Despite the cold $temp_{in}$ in the homes, most participants responded a low frequency of feeling cold. This result suggests that older people included in this study had acclimated [112] or thought natural to cold living environment [113] by living in a cold home for a long time.

Results about physical performance demonstrated seasonal trends and differences in physical performances between residents in cold or warm houses. The results of grip strength and single-leg standing tests showed that physical performance is worse in the winter compared to the autumn. Furthermore, it seems quite probable that people living in colder houses had even worse grip strength. Since decreased grip strength is known to be associated with increased risk for future disability [124] [125] [126] [127], hospitalization [128], and all-cause mortality [125] [127] [128], this study highlighted the importance of keeping warm during winter to prevent these negative outcomes by preventing decline of physical performance.

In the investigation about perceived $temp_{in}$ and frailty, people who were unsatisfied with their economic situation and also perceived the $temp_{in}$ in their home as cold reported a higher risk of frailty than other groups. Hence the result suggested that it was not just lower economic status [132] that was related to frailty risk, but it was the specific group that also reported living in a colder house that had the strongest relationship with frailty risk. The finding argues for new policies to support older people who do not have the economic capacity to adequately heat their homes as a means to reduce the risks of frailty. It was also found that the reported fall risk had the strongest relationship with perceived $temp_{in}$ and economic satisfaction compared with isolation and nutrition risks. This result indicates that a warmer housing environment can contribute to better prevention of frailty resulting from declining physical performance.

The findings related to perceived $temp_{in}$ and age at LTC certification imply opportunities for better care prevention by warming the homes of older people. The older people who reported living in a warm home had an older age at LTC certification, and thus a lower risk of LTC certification. Moreover, even after adjusting for confounding factors, the magnitude of the results did not change, which indicates that the perception of a warm indoor thermal environment may have an influence on preventing or delaying LTC certification beyond that expected simply from socio-economic status [143] attained over the lifetime.

Indoor thermal environment and health of nursing home residents

This study investigated the relationships between health, speed of deterioration of care level, and indoor thermal environment in Japanese nursing homes. The nursing homes included in this study had relatively warm but dry environments. The results of measured $temp_{in}$ and relative humidity (RH) provided objective data about the indoor thermal environment in Japanese nursing homes.

The daytime and night time $temp_{in}$ were significantly associated with higher blood pressure in winter, even after adjusting for the effects of potential confounders. Moreover, in the investigation of the impact of insulation retrofit in one nursing home, the $temp_{in}$ increased after the retrofit and blood pressure consequently decreased among the residents. Prevention of blood pressure rise could reduce risk of longer period of care [10] and could decrease disease risk [170]. To the best of our knowledge, this is the first study to evaluate the association between $temp_{in}$ and blood pressure of residents in nursing homes. Our findings from this field study on nursing home residents expand on experimental evidence from previous studies [168] [169] on thermoregulation and blood pressure in controlled settings, and previous studies on healthy older people [61] [62] [63] [64] in real life situations.

Investigation of the relationship between RH environment and oral cavity showed that residents of moist nursing homes (RH higher than 30 %) were more likely to have a moist oral cavity compared to those of dry nursing homes. This result suggest that control of environmental humidity is especially important for older people who have difficulty performing self-care, since it is known that dry mouth can lead to fungal and bacterial infectious diseases [156]. Our findings support the suggestion by Han et al. [174] that using a room humidifier to add moisture to the night time environment may give some relief during sleep.

When it comes to the effect of indoor thermal environment in nursing homes on the speed of deterioration of the care level of residents, people living in colder nursing homes had a 1.5 times higher hazard of deterioration in the level of care that they need compared to those living in warmer facilities. Furthermore, residents in dryer nursing homes were twice as likely to have a deterioration in health requiring more care compared to those in nursing homes that maintained recommended levels of humidity. These findings suggest that both $temp_{in}$ and RH are important for care prevention. In Japanese nursing homes, facility managers are responsible for the environment in the facilities [155], and standards for the environment are crucial to prevent/delay declines in health in such facilities. From a public health perspective, there would be benefits to maintain a warm and moist indoor thermal environment in nursing home. For older people and care staff, such efforts would probably lead to improved quality of life and reduced care burden. For society, such measures would reduce needs for health care and social services and potentially reduce public expenditure.

Nationwide analysis of fuel poverty based on administrative stats data

Using individual level data from national surveys, this study identified and described characteristics of Japanese housings and residents that lead to higher risk of FP. Overall, the findings confirm the complexity of contextual factors, among both residents and housing, related to FP risk. In relation to FP risk, the individual characteristics of residents in households that had the most difficulty in being able to warm their homes included older age, living alone, and lower income. On the other hand, the housing characteristics that were most related to the FP risk focused on factors associated with energy efficiency. Evaluation of the spatial distribution of FP showed that FP was not equally distributed in individual areas, nor follow the climate area. This result indicates that the target groups with higher risk of FP are not effectively reached in the Japanese building energy efficiency standard [90], and this must be improved if FP is to be addressed.

5.2 Implications for practice

The findings suggest that health promotion for older people and interventions intended to promote care prevention should add environmental improvements as a component to prevent people from living in cold or dry environment. This study highlights the potential importance of preventing FP to prevent frailty and suggests that health promotion strategies must include low-income older people as a target group to improve their housing by installing adequate insulation and affordable heating systems that warm the entire house. At an individual level, there is a clear trade-off between investment costs (installing or retrofitting insulation and heating) and running costs (paying for energy). The people who are most likely to live in cold homes are also the people who are least likely to be able to afford new insulation or cost needed to adequately warm their homes. Therefore, it is essential to ensure that low-income people can afford to live in improved buildings, potentially through providing public support for housing costs. In nursing homes, facility managers are responsible for the environment in the facilities, so residents have little direct influence to improve their thermal environment, which could help them to maintain their health status. Hence, mechanisms to establish and enforcement standards for the indoor environment are crucial to prevent/delay declines in health in such facilities. Key instruments for policy-makers at the national level to improve thermal conditions of all housing types are: improving building standards and mandating insulation, efficient heating systems, and humidification systems. Specific focus at the national level should also focus policies that can make such changes affordable for older low-income households. Moreover, funding and support should be channelled to high risk areas of FP. The findings in this study may also be considered as an incentive towards improving energy efficiency of housing as a means to reduce costs for care.

5.3 Implications for future study

This thesis investigated the association between the indoor thermal environment and care requiring condition of older people in Japan. Particularly in the study of older people living in the community, houses included have had relatively low energy efficiency with a cold indoor thermal environment, which did not enable the investigation of the composite effect of housing and heating systems on the indoor thermal environment. Moreover, the temperature gap between living rooms and non-living rooms might have had an effect on health status such as blood pressure [215]; however, it was not practical to evaluate it in these studies. On the other hand, nursing homes included in this thesis had a warm indoor thermal environment, and future studies should include more facilities with colder environments in order to study variations in the indoor thermal climate. From the point of view of reducing burden of participants and care staffs, the questionnaire sheet did not include variables that could be associated with risks of earlier certification of need for LTC. Therefore, future studies must take these limitations into account when designing the study protocol.

By taking the form of a retrospective study in the data collection, data was obtained at low cost compared to a longitudinal follow-up survey, which could have allowed stronger causal inferences. However, this investigation had to be based on an assumption that there was no large change of the living environment over a long period before the study. Changes such as insulation retrofitting or installation of heating systems could not be considered. To tackle this problem, a longitudinal follow-up survey for people not certificated for long-term care should be conducted. Moreover, a randomized controlled trial will be effective to avoid selection bias. In this situation, interventions could also be evaluated such as control of the indoor thermal environment at specified levels or the effectiveness of retrofitting houses or nursing homes. Structural equation modeling can be effective to model complex relationships between directly and indirectly observed factors.

Nationwide analysis of FP in this study revealed the resident and housing characteristics which lead to higher risk of FP. Previous studies [228] [229] [230] has reported association between FP and health problems. Correlations between FP indicator and national surveys of health and LTC insurance will provide us further insight on public health in Japan. Statistics of Long-term Care Benefit Expenditures [231], Patient Survey [232], and National Health and Nutrition Survey [233] can be used to detect population's condition of LTC certification and health status. Link of FP and other statistical data is not provided at individual level, and correlation at prefecture or municipality level can be investigated. Moreover, mitigation of data disclosure is processing [234] and investigation at individual level is expected to be done in the future study.

Care level is an index which has a time gap between actual health status and its certification, and it is a categorical factor that does not maintain equal intervals between categories. This leads to a challenge in correctly matching a person's actual health status with the level of care. However, the importance of extending the period of healthy life expectancy rose, and since the WHO [235] advocated the concept of healthy life expectancy in 2000, it is significant to consider the "period" as an evaluation index. Of the six countries (Germany, Netherlands, Australia, Israel, Japan, and Korea) introducing a LTC insurance system, Japan is the only country that has adopted trackable data with a standardized system [236]. Therefore, considering Japanese LTC insurance as a health index has high academic and political value.

References

[1] Cabinet Office, “Annual Report on the Ageing Society: 2018 (Summary),” 2018. [Online]. Available: https://www8.cao.go.jp/kourei/whitepaper/w-2018/html/zenbun/s1_1_1.html.

[2] Ministry of Health, Labour and Welfare, “Committee for the promotion of Health Japan 21 (second),” 9 3 2018. [Online]. Available: https://www.mhlw.go.jp/file/05-Shingikai-10601000-Daijinkanboukouseikagakuka-Kouseikagakuka/0000166296_7.pdf. [Accessed 28 4 2020].

[3] M. I. Tareque, Y. Saito and K. Kawahara, “Healthy life expectancy and the correlates of self-rated health in Bangladesh in 1996 and 2002,” *BMC Public Health,* vol. 15, p. 312, 2015.

[4] Ministry of Health, Labour and Welfare, “Future estimation of cost for social insurance,” 2016. [Online]. Available: https://www.mhlw.go.jp/file/06-Seisakujouhou-12600000-Seisakutoukatsukan/0000053805.pdf.

[5] Ministry of Health, Labor and Welfare, “Long-Term Care Insurance System of Japan,” 2016. [Online]. Available: https://www.mhlw.go.jp/english/policy/care-welfare/care-welfare-elderly/dl/ltcisj_e.pdf. [Accessed 21 5 2020].

[6] Ministry of Health, Labor and Welfare, “Care Prevention Manual: Revised Edition,” 2012. [Online]. Available: https://www.mhlw.go.jp/topics/2009/05/dl/tp0501-1_1.pdf. [Accessed 10 4 2020].

[7] T. Kamo, Y. Nishida, H. Wakabayashi, H. Ishii and K. Takayama, “Effect of mini nutritional assessment on short physical performance battery, mini-mental state examination and ADL of frail elderly -Investigation by a path analysis-,” *Report of research grant 2015,* vol. 43, no. 2, pp. 152-153, 2016.

[8] Cabinet Office, “White Paper on Aged Society,” 2018. [Online]. Available: https://www8.cao.go.jp/kourei/whitepaper/w-2018/html/zenbun/s1_2_2.html.

[9] T. Fukui, M. Kawashima and Y. Okuma, A book to read when your family gets sick: Dementia, Kodensha, 2006.

[10] Y. Gohgi and H. Une, “Risk factors for requiring long-term care among middle-aged and elderly people,” *Japanese Journal of Public Health,* vol. 52, no. 3, pp. 226-234, 2005.

[11] M. K. Karlsson, E. Ribom, J.-Å. Nilsson, Ö. Ljunggren, C. Ohlsson, D. Mellström, M. Lorentzon, H. Mallmin, M. Stefanick, J. Lapidus, P. C. Leung, A. Kwok, E. Barrett-Connor, E. Orwoll and Rosengren, “Inferior physical performance tests in 10,998 men in the MrOS study is associated with recurrent falls,” *Age and Ageing,* vol. 41, no. 6, pp. 740-746, 2012.

[12] J. M. Moler, C. S. Wendel, R. E. Taylor-Piliae, N. Toosizadeh and B. Najafi, “Motor Performance and Physical Activity as Predictors of Prospective Falls in Community-Dwelling Older Adults by Frailty Level: Application of Wearable Technology,” *Gerontology,* vol. 62, pp. 654-664, 2016.

[13] K. Delbaere, G. Crombez, G. Vanderstaeten, T. Willems and D. Cambier, “Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study,” *Age and Ageing,* vol. 33, no. 4, pp. 368-373, 2004.

[14] C. Beaudart, J.-Y. Reginster, J. Petermans, S. Gillain, A. Quabron, M. Locquet, J. Slomian, F. Buckinx and O. Bruyère, “Quality of life and physical components linked to sarcopenia: The SarcoPhAge study,” *Experimental Gerontology,* vol. 69, pp. 103-110, 2015.

[15] Cabinet Office, “White Paper on Aged Society,” 2018. [Online]. Available: https://www8.cao.go.jp/kourei/whitepaper/w-2018/html/zenbun/s1_2_2.html. [Accessed 10 4 2020].

[16] L. P. Fried, C. M. Tangen, A. B. Newman, C. Hirsch, J. Gottdiener, T. Seeman, R. Tracy, W. J. Kop, G. Burke and M. A. McBurnie, “Frailty in Older Adults: Evidence for a Phenotype,” *The Journals of Gerontology: Series A,* vol. 56, no. 3, pp. M146-M157, 2001.

[17] H. Bergman, L. Ferrucci, J. Guralnik, D. B. Hogan, S. Hummel, S. Karunananthan and C. Wolfson, “Frailty: An Emerging Research and Clinical Paradigm—Issues and Controversies,” *The Journals of Gerontology: Series A,* vol. 62, no. 7, pp. 731-737, 2007.

[18] S. Shinkai, N. Watanabe, H. Yoshida, Y. Fujiwara, H. Amano, S. Lee, M. Nishi and Y. Tsuchiya, “Research on screening for frailty: Development of “the Kaigo-Yobo Checklist”,” *Japanese Journal of Public Health,* vol. 57, no. 5, pp. 345-354, 2010.

[19] S. Shinkai, N. Watanabe, H. Yoshida, Y. Fujiwara, M. Nishi, T. Fukaya, S. Lee, M.-J. Kim, K. Ogawa, H. Murayama, Y. Taniguchi and Y. Shimizu, “Validity of the “Kaigo-Yobo Check-List” as a frailty index,” *Japanese Journal of Public Health,* vol. 60, no. 5, pp. 262-274, 2013.

[20] B. Casado and P. Sacco, “Correlates of Caregiver Burden Among Family Caregivers of Older Korean Americans,” *The Journals of Gerontology: Series b,* vol. 67B, no. 3, pp. 331-336, 2012.

[21] C. L. Chan and E. W. Chui, “Association between cultural factors and the caregiving burden for Chinese spousal caregivers of frail elderly in Hong Kong,” *Aging & Mental Health,* vol. 15, no. 4, pp. 500-509, 2011.

[22] G. Kojima, S. Iliffe, Y. Yaniguchi, H. Shimada, H. Rakugi and K. Walters, “Prevalence of frailty in Japan: A systematic review and meta-analysis,” *Journal of Epidemiology,* vol. 27, no. 8, pp. 347-353, 2017.

[23] N. Lu, J. Liu and V. W. Lou, “Exploring the reciprocal relationship between caregiver burden and the functional health of frail older adults in China: A cross-lag analysis,” *Geriatric Nursing,* vol. 37, no. 1, pp. 19-24, 2016.

[24] R. M. Collard, H. Boter, R. A. Schoevers and R. C. Oude Voshaar, “Prevalence of Frailty in Community-Dwelling Older Persons: A Systematic Review,” *Journal of the American Geriatrics Society,* vol. 60, no. 8, pp. 1487-1492, 2012.

[25] J. E. Morley, “Diabetes, Sarcopenia, and Frailty,” *Clinics in Geriatric Medicine,* vol. 24, no. 3, pp. 455-469, 2008.

[26] E. Ferriolly, F. Amador dos Santos Pessanha, V. G. Moreira, L. A. Neri, R. C. Dias and A. Lourenço, “Body composition and frailty profiles in Brazilian older people: Frailty in Brazilian Older People Study-FIBRA-BR,” *Archives of Gerontology and Geriatrics,* vol. 71, pp. 99-104, 2017.

[27] L. Dong, X. Qiao, X. Tian, N. Liu, Y. Jin, H. Si and C. Wang, “Cross-Cultural Adaptation and Validation of the FRAIL Scale in Chinese Community-Dwelling Older Adults,” *Journal of the American Medical Directors Association,* vol. 19, no. 1, pp. 12-17, 2018.

[28] K. Rockwood, S. E. Howlett, C. MacKnight, L. B. Beattie, H. Bergman, R. Hébert, D. B. Hogan, C. Wolfson and I. McDowell, “Prevalence, Attributes, and Outcomes of Fitness and Frailty in Community-Dwelling Older Adults: Report From the Canadian Study of Health and Aging,” *The Journals of Gerontology: Serias A,* vol. 59, no. 12, pp. 1310-1317, 2004.

[29] I. D.-R. Celeiro, S. Santos-del-Riego and J. M. Gracía, “Homebound status among middle-aged and older adults with disabilities in ADLs and its associations with clinical, functional, and environmental factors,” *Disability and Health Journal,* vol. 10, no. 1, pp. 145-151, 2017.

[30] J. Woo, R. Yu, M. Wong, F. Yeung, M. Wong and C. Lum, “Frailty Screening in the Community Using the FRAIL Scale,” *Journal of American Medical Directors Association,* vol. 16, no. 5, pp. 412-419, 2015.

[31] P. Jari, P. Kannus, M. Palvanen, A. Natri, J. Vainio, I. M. Vuori and M. Järvinen, “Majority of Hip Fractures Occur as a Result of a Fall and Impact on the Greater Trochanter of the

Femur: A Prospective Controlled Hip Fracture Study with 206 Consecutive Patients," *Calcified Tissue International,* vol. 65, pp. 183-187, 1999.

[32] G. Peeters, N. M. van Schoor and P. Lips, "Fall risk: the clinical relevance of falls and how to integrate fall risk with fracture risk," *Best Practice & Research Clinical Rheumatology,* vol. 23, no. 6, pp. 797-804, 2009.

[33] R. Hasserius, M. K. Karlsson, B. Jónsson, I. Redlund-Johnell and O. Johnell, "Long-Term Morbidity and Mortality After a Clinically Diagnosed Vertebral Fracture in the Elderly—a 12- and 22-Year Follow-up of 257 Patients," *Calcified Tissue International,* vol. 76, pp. 235-242, 2005.

[34] L. E. Ferrante, M. A. Pisani, T. E. Murphy, E. A. Gabauer, L. S. Leo-Summers and T. M. Gill, "The Association of Frailty With Post-ICU Disability, Nursing Home Admission, and Mortality: A Longitudinal Study," *Chest,* vol. 153, no. 6, pp. 1378-1386, 2018.

[35] U. Sambamoorthi, X. Tan and A. Deb, "Multiple chronic conditions and healthcare costs among adults," *Expert Review of Pharamacoeconomics & Outcomes Research,* vol. 15, no. 5, pp. 823-832, 2015.

[36] N. Lu, J. Liu and V. W. Lou, "Caring for frail elders with musculoskeletal conditions and family caregivers' subjective well-being: The role of multidimensional caregiver burden," *Archives of Gerotology and Geriatrics,* vol. 61, no. 3, pp. 411-418, 2015.

[37] M. Pinquart and S. Sörensen, "Associations of Stressors and Uplifts of Caregiving With Caregiver Burden and Depressive Mood: A Meta-Analysis," *The Journals of Gerontolgy: Series B,* vol. 58, no. 2, pp. 112-128, 2003.

[38] L. D. Clyburn, M. J. Stones, T. Hadjistavropoulos and H. Tuokko, "Predicting caregiver burden and depression in Alzheimer's disease," *The Journals of Gerotology: Series B,* vol. 55, no. 1, pp. S2-13, 2000.

[39] E. Iecovich, "Caregiving Burden, Community Services, and Quality of Life of Primary Caregivers of Frail Elderly Persons," *Journal of Applied Gerontology,* vol. 27, no. 3, pp. 309-330, 2008.

[40] E. Dent, E. D. Grande, K. Price and A. W. Taylor, "Frailty and usage of health care systems: Results from the South Australian Monitoring and Surveillance System (SAMSS)," *Maturitas,* vol. 104, pp. 36-43, 2017.

[41] Ministry of Health, Labor and Welfare, "Guideline of health service in consideration of the characteristics of elderly," 4 2018. [Online]. Available: https://www.mhlw.go.jp/file/05-Shingikai-12401000-Hokenkyoku-Soumuka/0000205007.pdf. [Accessed 11 4 2020].

[42] Public Health England, "Cold Weather Plan For England, Making the Case: Why long-term strategic planning for cold weather is essential to health and wellbeing," 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652568/Cold_Weather_Plan_Making_the_Case_2017.pdf.

[43] National Institute for Health and Care Excellence, "Excess winter deaths and illness and the health risks associated with cold homes - NICE guideline," 2015.

[44] H. Marti-Soler, S. Gonseth, C. Gubelmann, S. Stringhini, P. Bovet, P.-C. Chen, B. Wojtyniak, F. Paddaud, D.-H. Tsai, T. Zdrojewski and P. Marques-Vidal, "Seasonal Variation of Overall and Cardiovascular Mortality: A Study in 19 Countries from Different Geographic Locations," *PLoS One,* vol. 9, no. 11, p. e113500, 2014.

[45] S. Gonseth, S. Nusslé, P. Bovet, F. Panese and J. L. Wiemels, "Excess winter deaths caused by cardiovascular diseases are associated with both mild winter temperature and socio-economic inequalities in the U.S.," *International Jouranl of Cardiology,* vol. 187, pp. 642-644, 2015.

[46] A. Analitis, K. Katsouyanni, A. Biggeri, M. Baccini, B. Forsberg, L. Bisanti, U. Kirchmayer, F. Ballester, E. Cadum, P. G. Goodman, A. Hojs, J. Sunyer, P. Tiittanen and P. Michelozzi,

"Effects of cold weather on mortality: results from 15 European cities within the PHEWE project," *American Journal of Epidemiology,* vol. 168, no. 12, pp. 1397-1408, 2008.

[47] S. P. Pin, J. L. Golmard, E. Cotto, M. Rothan-Tondeur, K. C. Pharm and F. Piette, "Excess Winter Mortality in France: Influence of Temperature, Influenza Like Illness, and Residential Care Status," *Jouranl of the American Medical Directors Association,* vol. 13, no. 3, pp. 309.e1-309.e7, 2012.

[48] R. Maheswaran, D. Chan, P. T. Fryers, C. McManus and H. McCabe, "Socio-economic deprivation and excess winter mortality and emergency hospital admissions in the South Yorkshire Coalfields Health Action Zone, UK," *Public Health,* vol. 118, no. 3, pp. 167-176, 2004.

[49] J. Rudge and R. Gilchrist, "Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough," *Journal of Public Health,* vol. 27, no. 4, pp. 353-358, 2005.

[50] P. Wilkinson, S. Pattenden, B. Armstrong, A. Fletcher, S. R. Kovats, P. Mangtani and A. McMichael, "Vulnerability to winter mortality in elderly people in Britain: population based study," *BMJ,* vol. 329, pp. 647-651, 2004.

[51] J. Hills, "Getting the measure of fuel poverty," Centre for Analysis of Social Exclusion, 2012.

[52] C. Liddell, C. Morris, B. Gray, A. Czerwinska and B. Thomas, "Excess winter mortality associated with Alzheimer's Disease and related dementias in the UK: A case for energy justice," *Energy Research & Social Science,* vol. 11, pp. 256-262, 2016.

[53] J. D. Healy, "Excess winter mortality in Europe: a cross country analysis identifying key risk factors," *Journal of Epidemiology and Community Health,* vol. 57, no. 10, pp. 784-789, 2003.

[54] Group TE, "Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Eueope," *Lancet,* vol. 349, no. 9062, pp. 1341-1346, 1997.

[55] Y. Wei, Y. Wang, C.-K. Lin, K. Yin, J. Yang, L. Shi, L. Li, A. Zanobetti and J. D. Schwartz, "Associations between seasonal temperature and dementia-associated hospitalizations in New England," *Environment International,* vol. 126, pp. 228-233, 2019.

[56] J. Cheng, H. Bambrick, S. Tong, H. Su, H. Xu, Z. Xu and W. Hu, "Winter temperature and myocardial infarction in Brisbane, Australia: Spatial and temporal analyses," *Science of The Total Environment,* vol. 715, no. 1368601, pp. 1-9, 2020.

[57] L. T. Barnard, N. Preval, P. Howden-Chapman, R. Arnold, C. Young, A. Grimes and T. Denne, "The impact of retrofitted insulation and new heaters on health services utilisation and costs, pharmaceutical costs and mortality: Evaluation of Warm Up New Zealand: Heat Smart," 2011.

[58] R. Pan, X. Zhang, J. Gao, W. Yi, Q. Wei, Z. Zu, J. Duan, L. Bai, Q. Cheng, Y. Zhang and H. Su, "Impacts of heat and cold on hospitalizations for schizophrenia in Hefei, China: An assessment of disease burden," *Science of The Total Environment,* vol. 694, no. 133582, pp. 1-8, 2019.

[59] K. J. Collins, "Low indoor temperatures and morbidity in the elderly," *Age and Ageing,* vol. 15, no. 4, pp. 212-220, 1986.

[60] K. Saeki, K. Obayashi and N. Kurumatani, "Platelet count and indoor cold exposure among elderly people: A cross-sectional analysis of the HEIJO-KYO study," *Journal of Epidemiology,* vol. 27, no. 12, pp. 562-567, 2017.

[61] K. Saeki, K. Obayashi, J. Iwamoto, N. Tone, N. Okamoto, K. Tomioka and N. Kurumatani, "Stronger association of indoor temperature than outdoor temperature with blood pressure in colder months," *Journal of Hypertension,* vol. 32, no. 8, pp. 1582-1589, 2014.

[62] K. Saeki, K. Obayashi, J. Iwamoto, N. Tone, N. Okamoto, K. Tomioka and N. Kurumatani, "The relationship between indoor, outdoor and ambient temperatures and morning BP surges from inter-seasonally repeated measurements," *Journal of Human Hypertension,* vol. 28, no. 8, pp. 482-488, 2014.

[63] K. Saeki, K. Obayashi and N. Kurumatani, "Short-term effects of instruction in home heating on indoor temperature and blood pressure in elderly people: a randomized controlled trial," *Journal of Hypertension,* vol. 33, no. 11, pp. 2338-2343, 2015.

[64] W. Umishio, T. Ikaga, K. Kario, Y. Fujino, T. Hoshi, S. Ando, M. Suzuki, T. Yoshimura, H. Yoshino, S. Murakami and on behalf of the SWH Survey Group, "Cross-Sectional Analysis of the Relationship Between Home Blood Pressure and Indoor Temperature in Winter: A Nationwide Smart Wellness Housing Survey in Japan," *Hypertension,* vol. 74, no. 4, pp. 756-766, 2019.

[65] I. Shiue, "Cold homes are associated with poor biomarkers and less blood pressure check-up: English Longitudinal Study of Ageing, 2012–2013," *Environmental science and Pollution Research,* vol. 23, no. 7, pp. 7055-7059, 2016.

[66] I. Shiue and M. Shiue, "Indoor temperature below 18°C accounts for 9% population attributable risk for high blood pressure in Scotland," *International Journal of Cardiology,* vol. 171, no. 1, pp. E1-E2, 2014.

[67] World Health Organization, "COPD: Definition," [Online]. Available: https://www.who.int/respiratory/copd/definition/en/. [Accessed 27 4 2020].

[68] L. M. Osman, J. G. Ayres, C. Garden, K. Reglitz, J. Lyon and G. J. Douglas, "Home warmth and health status of COPD patients," *The European Journal of Public Health,* vol. 18, no. 4, pp. 399-405, 2008.

[69] Z. Mu, P.-L. Chen, F.-H. Geng, L. Ren, W.-C. Gu, J.-Y. Ma, I. Peng and Q.-Y. Li, "Synergistic effects of temperature and humidity on the symptoms of COPD patients," *International Journal of Biometeorology,* vol. 61, no. 9, pp. 1919-1925, 2017.

[70] S. S. Cheung, L. F. Reynolds, M. A. Macdonald, C. L. Tweedie, R. L. Urquhart and D. A. Westwood, "Effects of local and core body temperature on grip force modulation during movement-induced load force fluctuations," *Europian Journal of Applied Physiology,* vol. 103, pp. 59-69, 2008.

[71] H. Piedrahita, J. Oksa, H. Rintamäki and C. Malm, "Effect of local leg cooling on upper limb trajectories and muscle function and whole body dynamic balance," *European Journal of Applied Physiology,* vol. 105, no. 429, 2009.

[72] H. Piedrahita, J. Oksa, C. Malm, E. Sormunen and H. Rintamäki, "Effects of cooling and clothing on vertical trajectories of the upper arm and muscle functions during repetitive light work," *European Journal of Applied Physiology,* vol. 104, no. 2, pp. 183-191, 2008.

[73] B. F. Albert, "Thermal dependence of muscle function," *American Journal of Physiology,* vol. 247, pp. 217-229, 1984.

[74] J. Oksa, H. Rintamäki and S. Rissanen, "Muscle performance and electromyogram activity of the lower leg muscles with different levels of cold exposure," *European Journal of Applied Physiology and Occupational Physiology,* vol. 75, no. 6, pp. 484-490, 1997.

[75] U. Lindemann, J. Oksa, D. A. Skelton, N. Beyer, J. Klenk, J. Zscheile and C. Becker, "Effect of cold indoor environment on physical performance of older women living in the community," *Age and Ageing,* vol. 43, no. 4, 2014.

[76] E. García-Esquinas, B. Pérez-Hernández, P. Guallar-Castillón, J. R. Banegas, J. L. Ayuso-Mateos and F. Rodríguez-Artalejo, "Housing conditions and limitations in physical function among older adults," *Journal of epidemiology and community health,* vol. 70, no. 10, pp. 954-960, 2016.

[77] Department for Buisiness, Energy & Industrial Strategy, "Annual Fuel Poverty Statistics Report 2019 (2017 data)," 2019.

[78] R. Chard and G. Walker, “Living with fuel poverty in olde age: Coping strategies and their problematic implications,” *Energy Research & Social Science,* vol. 18, pp. 62-70, 2016.

[79] WHO, “WHO Housing and Health Guidelines,” 2018. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/276001/9789241550376-eng.pdf.

[80] Nomura Research Institute, “NRI Public Management Review Vol.138,” 2015. [Online]. Available: https://www.nri.com/-/media/Corporate/jp/Files/PDF/knowledge/publication/region/2015/ck201501.pdf?la=ja-JP&hash=8B69ED1EBD83B059C3194002A9092036F4EBF2D5.

[81] Jyukankyo Research Institute, “Research report of life and energy around the world 2004,” 2005.

[82] Met Office, “Cold weather alert,” [Online]. Available: https://www.metoffice.gov.uk/public/weather/cold-weather-alert/?tab=coldWeatherAlert&season=normal. [Accessed 10 4 2020].

[83] S. Hajat, S. Vardoulakis, C. Heaviside and B. Eggen, “Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s,” *Journal of Epidemiology & Community Health,* vol. 68, no. 7, pp. 641-648, 2014.

[84] Department for Communities and Local Government, UK, “Housing Health and Safety Rating System: Guidance for Landlords and Property Related Professionals,” 2006. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/9425/150940.pdf. [Accessed 10 4 2020].

[85] Ministry of Housing, Communities & Local Government, UK, “Outcomes of report on Housing Health and Safety Rating System (HHSRS) scoping review,” 11 7 2019. [Online]. Available: https://www.gov.uk/government/publications/housing-health-and-safety-rating-system-outcomes-of-the-scoping-review/outcomes-of-report-on-housing-health-and-safety-rating-system-hhsrs-scoping-review. [Accessed 28 4 2020].

[86] Department for Energy and Climate Change, "Cutting the cost of keeping warm: a fuel poverty strategy for England," 2015. [Online]. Available: https://www.gov.uk/government/publications/cutting-the-cost-of-keeping-warm.

[87] Office for National Statistics, UK, “Excess winter mortality in England and Wales Statistical bulletins,” 27 11 2019. [Online]. Available: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/excesswintermortalityinenglandandwales/previousReleases. [Accessed 28 4 2020].

[88] American Public Health Association, “National Health Housing Standard,” 2018. [Online]. Available: https://nchh.org/resource-library/national-healthy-housing-standard.pdf.

[89] NZ Rental WOF, “New Zealand Rental Warrant of Fitness,” [Online]. Available: https://www.nzrentalwof.co.nz/.

[90] Institute for Building Environment and Energy Conservation, “Overview of the Act on the Improvement of Energy Consumption Performane of Buildings (Building Energy Efficiency Act),” 2016. [Online]. Available: https://www.mlit.go.jp/common/001134876.pdf.

[91] Ministry of Economy, Trade and Industry, “METI Illustrates the Contents of the Report on the ZEH Roadmap in an Easy-toUnderstand Way,” 2016. [Online]. Available: https://www.meti.go.jp/english/policy/energy_environment/energy_efficiency/zeh.html.

[92] Ministry of Land, Infrastructure, Transport and Tourism, “Energy saving policy of residential and non-residential buildings in the future,” 2018. [Online]. Available: https://www.mlit.go.jp/common/001064004.pdf. [Accessed 10 4 2020].

[93] Institute for Building Environment and Energy Conservation, “Energy efficiency standard for housing,” [Online]. Available: http://www.ibec.or.jp/ee_standard/build_standard.html. [Accessed 28 4 2020].

[94] Ministry of Land, Infrastructure and Transport, “Regional division,” 2017. [Online]. Available: https://alumi.st-grp.co.jp/sumai/shouene/pdf/tiiki.pdf.

[95] Ministry of Land, Infrastructure, Transport and Tourism, “Health Maintenance Promoting Housing Research Council,” 2012. [Online]. Available: http://www.mlit.go.jp/jutakukentiku/house/jutakukentiku_house_tk4_000068.html. [Accessed 9 4 2020].

[96] Japan Sustainable Building Consortium, “CASBEE Housing Health Checklist,” 2011. [Online]. Available: http://www.ibec.or.jp/CASBEE/casbee_health/files/pamphlet.pdf. [Accessed 9 4 2020].

[97] Architectural Institute Japan, Building Environment for Older People, Shokokusha Publishing, 1994.

[98] Y. Hayashi, S. M. Schmidt, A. M. Fänge, T. Hoshi and T. Ikaga, “Lower Physical Performance in Colder Seasons and Colder Houses: Evidence from a Field Study on Older People Living in the Community,” *International Journal of Environmental Research and Public Health,* vol. 14, no. 6, p. 651, 2017.

[99] Y. Nakajima, S. M. Schmidt, A. M. Fänge, M. Ono and T. Ikaga, “Relationship between Perceived Indoor Temperature and Self-Reported Risk for Frailty among Community-Dwelling Older People,” *International Journal of Environmental Research and Public Health,* vol. 16, no. 4, p. 613, 2019.

[100] Y. Hayashi, T. Ikaga, T. Hoshi and S. Ando, “Event History Analysis of Indoor Thermal Environment and Care Prevention of Residents: A field survey on the effect of winter indoor thermal enironment on care requirements,” *Journal of Environmental Engineering (Transactions of AIJ),* vol. 82, no. 729, pp. 901-908, 2016.

[101] Y. Nakajima, T. Ikaga, M. Ono, T. Hoshi and S. Ando, “Multivariate Analysis of Perceived Indoor Tmperature and Age at Need for Long-Term Care Insurance: A field survey on the effect of winter indoor thermal environment on care requirements Part 2,” *Journal of Environmental Engineering (Transactions of AIJ),* vol. 84, no. 763, pp. 795-803, 2019.

[102] Ministry of Education, Culture, Sports, Science and Technology, “Deployment plan for a physical perforamnce test,” 2010. [Online]. Available: https://www.mext.go.jp/component/a_menu/sports/detail/__icsFiles/afieldfile/2010/07/30/1295079_04.pdf. [Accessed 16 4 2020].

[103] D. Podsiadlo and S. Richardson, “The Timed “Up & Go”: A Test of Basic Functional Mobility for Frail Elderly Persons,” *Journal of the American Geriatrics Society,* vol. 39, no. 2, pp. 142-148, 1991.

[104] U. Nayak, U. Nayak and B. Isaacs, “Balance in elderly patients: the "get-up and go" test.,” *Archives of Physical Medicine and Rehabilitation,* vol. 67, no. 6, pp. 387-389, 1986.

[105] Kochi City, “Long-term care insurance card,” 2012. [Online]. Available: https://www.city.kochi.kochi.jp/soshiki/24/shou.html. [Accessed 16 4 2020].

[106] G. Kojima, Y. Taniguchi, A. Kitamura and Y. Fujiwara, “Is living alone a risk factor of frailty? A systematic review and meta-analysis,” *Ageing Research Reviews,* vol. 59, no. 101048, 2020.

[107] P. Pérez-Ros, R. Vila-Candel and F. M. Martínez-Arnau, “A home-based exercise program focused on proprioception to reduce falls in frail and pre-frail community-dwelling older adults,” *Geriatric Nursing,* Vols. S0197-4572, no. 20, pp. 30053-30057, 2020.

[108] Y. Inoue, N. Gerrett, T. Ichinose-Kuwahara, Y. Umino, S. Kiuchi, H. Ueda, G. Havenith and N. Kondo, “Sex differences in age-related changes on peripheral warm and cold innocuous thermal sensitivity,” *Physiology & Behavior,* vol. 164, no. A, pp. 86-92, 2016.

[109] K. Kanda, J. Tsuchiya, M. Seto, T. Ohnaka and Y. Tochihara, “Thermal Conditions in the Bathroom in Winter and Summer, and Physiological Responses of the Elderly during Bathing,” *Japanese Journal of Hygiene,* vol. 50, no. 2, pp. 595-603, 1995.

[110] Y. Kanawaku, T. Tanifuji and Y. Ohno, "Association between sudden unexpected deaths in bathtubs and ambient temperature among elderly Japanese adults: A time-series regression study," *Legal Medicine,* vol. 36, pp. 21-27, 2019.

[111] K. Saeki, K. Obayashi and N. Kurumatani, "Platelet count and indoor cold exposure among elderly people: A cross-sectional analysis of the HEIJO-KYO study," *Journal of Epidemiology,* vol. 27, no. 12, pp. 562-567, 2017.

[112] M. Luo, B. Cao, Q. Ouyang and Y. Zhu, "Indoor climate and thermal physiological adaptation: Evidences from migrants with different cold indoor exposures," *Building and Environment,* vol. 98, pp. 30-38, 2016.

[113] Y. Sato and K. Kohri, "A study on the thermal environment and the style of living in detached houses in Tochigi prefecture: The thermal environment in the heated or the unheated rooms and the consciousness and the style of living during winter," *Jouranl of Architecture and Planning (Transations of AIJ),* vol. 64, no. 522, pp. 7-14, 1999.

[114] H. Ohno, Y. Koide, S. Kuno, T. Mano and M. Yamaha, "The heating equipments for aged at the changingroom berfore and after mathing in winter," *Journal of Architecture and Planning (Transactions of AIj),* vol. 63, no. 509, pp. 1-7, 1998.

[115] K. Tsuzuki, K. Yokoyama, T. Yokoi, G. Ogi, H. Taya, M. Yoshioka and K. Nakamura, "Thermal environments and indoor air quality in the elderly houses in a rural area," *Japanese Journal of Biometeorology,* vol. 38, no. 1, pp. 23-32, 2001.

[116] Y. Igarashi, K. Takahashi, T. Yanase, R. Obuchi, S. Hashimoto and H. Kitahara, "A study on the relationships between heating methods and the health conditions of the elderly in their houses," *Housing Research Foundation Annual Report,* vol. 27, pp. 231-242, 2001.

[117] I. Mori, K. Tsuzuki, A. Yasuoka, Y. Sakamoto and R. Takahashi, "Effects of renovation using well-insulated windows on indoor thermal environment and the health of elderly occupants," *Journal of Envrionmental Engineering (Transactions of AIJ),* vol. 79, no. 706, pp. 1061-1069, 2014.

[118] D. Schone, T. Valenzuela, S. R. Lord and E. D de Bruin, "The effect of interactive cognitive-motor training in reducing fall risk in older people: a systematic review," vol. 14, 2014.

[119] L. R. Wood, M. Blagojevic-Bucknall, S. Stynes, D. D'Cruz, R. Mullis, G. Peat and N. E. Foster, "Impairment-targeted exercises for older adults with knee pain: a proof-of-principle study (TargET-Knee-Pain)," vol. 17, 2016.

[120] E. T. Howe, L. Rochester, F. Neil, D. A. Skelton and C. Ballinger, "Exercise for improving balance in older people," vol. 9, 2011.

[121] G. Johansson and G.-B. Jarnlo, "Balance training in 70-year-old woman," vol. 7, no. 2, pp. 121-125, 1991.

[122] V. Weerdesteyn, R. Hennie, A. C. Geurts, B. Smits-Engelsman, T. Mulder and J. Duysens, "A Five-Week Exercise Program Can Reduce Falls and Improve Obstacle Avoidance in the Elderly," vol. 52, no. 3, pp. 131-141, 2006.

[123] L. Wolfson, R. Whipple, C. Derby, J. Judge, M. King, P. Amerman, J. Schmidt and D. Smyers, "Balance and Strength Training in Older Adults: Intervention Gains and Tai Chi maintenance," vol. 44, no. 5, 1996.

[124] J. Sallinen, S. Stenholm, T. Rantanen, M. Heliövaara, P. Sainio and S. Koskinen, "Hand-Grip Strength Cut Points to Screen Older Persons at Risk for Mobility Limitation," vol. 58, no. 9, 2010.

[125] T. Rantanen, "Muscle strength, disability and mortality," vol. 13, no. 1, pp. 3-8, 2003.

[126] D. G. Taekema, J. Gussekloo, A. B. Maier, R. G. Westendorp and A. J. de Craen, "Handgrip strength as a predictor of functional, psychological and social health. A prospective population - based study among the oldest old," vol. 39, no. 3, pp. 331-337, 2010.

[127] R. Bohannon, "Hand-Grip Dynamometry Predicts Future Outcomes in Aging Adults," vol. 31, no. 1, pp. 3-10, 2008.

[128] C. H. Ling, D. Taekema, A. J. de Craen, J. Gussekloo, R. G. Westendorp and A. B. Maier, “Handgrip strength and mortality in the oldest old population: the Leiden 85-plus study,” vol. 182, no. 5, pp. 429-435, 2010.

[129] N. M. Ramos, R. M. Almeida, L. M. Simões and P. F. Pereira, “Knowledge discovery of indoor environment patterns in mild climate countries based on data mining applied to in-situ measurements,” vol. 30, pp. 37-48, 2017.

[130] U. Lindemann, J. Oksa, D. A. Skelton, N. Beyer, J. Klenk, J. Zscheile and C. Becker, “Effect of cold indoor environment on physical performance of older women living in the community,” vol. 43, no. 4, pp. 571-575, 2014.

[131] C. Trevisan, N. Veronese, S. Maggi, G. Baggio, E. D. Toffanello, S. Zambon, L. Sartori, E. Musacchio, E. Perissinotto, G. Crepaldi, E. Manzato and G. Sergi, “Factors Influencing Transitions Between Frailty States in Elderly Adults: The Progetto Veneto Anziani Longitudinal Study,” vol. 65, no. 1, 2016.

[132] E. Stolz, H. Mayerl, A. Waxengger and W. Freidl, “Explaining the impact of poverty on old-age frailty in Europe: material, psychosocial and behavioural factors,” *European Journal of Public Health,* vol. 27, no. 6, pp. 1003-1009, 2017.

[133] K. Selvaraj, A. Yousuf, R. Jayalakshmy, R. Gomathi, T. Pruthu and P. Chinnakali, “Prevalence of under-nutrition, associated factors and perceived nutritional status among elderly in a rural area of Puducherry, South India,” *Archives of Gerontology and Geriatrics,* vol. 65, pp. 156-160, 2016.

[134] R. Aylaz, Ü. Aktürk, B. Erci, H. Öztürk and H. Aslan, “Relationship between depression and loneliness in elderly and examination of influential factors,” *Archives of Gerontology and Geriatrics,* vol. 55, no. 3, pp. 548-554, 2012.

[135] M. Hirazawa and A. Yakita, “Labor supply of elderly people, fertility, and economic development,” *Journal of Macroeconomics,* vol. 51, pp. 75-96, 2017.

[136] I. Hamilton, A. J. O'Sullivan, G. M. Huebner, T. Oreszczyn, D. Shipworth, A. Summerfield and M. E. Davies, “Old and cold? Findings on the determinants of indoor temperatures in English dwellings during cold conditions,” *Energy and Buildings,* vol. 141, pp. 142-157, 2017.

[137] F. Wright, “Old and Cold: Older People and Policies Failing to Address Fuel Poverty,” *Social Policy & Administration,* vol. 38, no. 5, pp. 488-503, 2004.

[138] P.-Y. Yeung, P.-H. Chau, J. Woo, V. W.-T. Yim and T. H. Rainer, “Higher incidence of falls in winter among older people in Hong Kong,” *Journal of Clinical Gerontology and Geriatrics,* vol. 2, no. 1, pp. 13-16, 2011.

[139] M. J. Annear, G. Cushman and B. Gidlow, “Leisure time physical activity differences among older adults from diverse socioeconomic neighborhoods,” *Health & Olace,* vol. 15, no. 2, pp. 482-490, 2009.

[140] D. E. Warburton, C. W. Nicol and S. S. Bredin, “Health benefits of physical activity: the evidence,” *Canadian medical Association Journal,* vol. 174, no. 6, pp. 801-809, 2006.

[141] A. Hickey, M. Barker, H. McGee and C. O'Boyle, “Measuring health-related quality of life in older patient populations,” *Pharmacoeconomics,* vol. 23, pp. 971-993, 2005.

[142] S. Shirahase, “Income inequality among older people in rapidly aging Japan,” *Research in Social Stratification and Mobility,* vol. 41, pp. 1-10, 2015.

[143] F.-L. Kong, T. Hoshi, B. Ai, Z.-M. Shi, N. Nakayama, S. Wang and S.-W. Yang, “Association between socioeconomic status (SES), mental health and need for long-term care (NLTC)—A Longitudinal Study among the Japanese Elderly,” *Archives of Gerontology and Geriatrics,* vol. 59, no. 2, pp. 372-381, 2014.

[144] Ministry of Health, Labour and Welfare, “Toward realization of integrated community care system,” 2015. [Online]. Available:

https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/hukushi_kaigo/kaigo_koureisha/chiiki-houkatsu/. [Accessed 18 4 2020].

[145] J. Vermeulen, J. C. Neyens, E. van Rossum, M. D. Spreeuwenverg and L. P. de Witte, "Predicting ADL disability in community-dwelling elderly people using physical frailty indicators: a systematic review," *BMC Geriatrics,* vol. 11, no. 33, 2011.

[146] WHO, "World report on ageing and health," 2015. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/186463/9789240694811_eng.pdf;jsessionid=F95AF1443DDA70EC88E083DF577110EB?sequence=1. [Accessed 18 4 2020].

[147] J. Niebuur, L. van Lente, A. C. Liefbroer, N. Steverink and N. Smidt, "Determinants of participation in voluntary work: a systematic review and meta-analysis of longitudinal cohort studies," *BMC Public Health,* vol. 18, no. 1213, 2018.

[148] H. Hikichi, J. Aida, K. Kondo and I. Kawachi, "Can Community Social Cohesion Prevent Posttraumatic Stress Disorder in the Aftermath of a Disaster? A Natural Experiment From the 2011 Tohoku Earthquake and Tsunami," *American Journal of Epidemiology,* vol. 183, no. 10, pp. 902-910, 2016.

[149] T. Takahashi, K. Nonaka, H. Matsunaga, M. Hasebe, H. Murayama, T. Koike, Y. Murayama, E. Kobayashi and Y. Fujiwara, "Factors relating to social isolation in urban Japanese older people: A 2-year prospective cohort study," *Archives of Gerontology and Geriatrics,* vol. 86, p. 103936, 2020.

[150] D. T. Steven and O. Jean-Marc, "Alzheimer Disease: Diagnosis, Costs, and Dimensions of Treatment," *Alzheimer Disease & Associated Disorders,* vol. 15, pp. S3-S7, 2001.

[151] K. Yamasaki, N. Morizaki, S. Moriya and Y. Sumi, "Factors influencing oral health-related quality of life (OHRQoL) among the frail elderly residing in the community with their family," *Archives of Gerontology and Geriatrics,* vol. 51, no. 3, pp. e62-e65, 2010.

[152] S. Ota, H. Goto, R. Fujita, M. Haruta, Y. Noda and K. Tamakoshi, "Application of Pole Walking to Day Service Centers for Use by Community-dwelling Frail Elderly People," *International Journal of Gerontology,* vol. 8, no. 1, pp. 6-11, 2014.

[153] H. Shimada, T. Ishizaki, M. Kato, A. Morimoto, A. Tamate, Y. Uchiyama and S. Yasumura, "How often and how far do frail elderly people need to go outdoors to maintain functional capacity?," *Archives of Gerontology and Geriatrics,* vol. 50, no. 2, pp. 140-146, 2010.

[154] The Ministry of Health, Labour and Welfare, "Manual for preventive care (revised edition)," 2012. [オンライン]. Available: http://www.mhlw.go.jp/topics/2009/05/dl/tp0501-1_1.pdf.

[155] M. Bando, H. Kim , H. Osawa, "Survey on indoor environment in nursing homes for the elderly," *J. Natl. Inst. Public Health,* 第 巻 63, 第 4, pp. 359-367, 2014.

[156] Y. Hayashi, T. Saito, T. Ohshima, Y. Nakagawa and N. Maeda, "Alterations of the oral microbiota and oral clinical findings in dry mouth," *Journal of Oral Biosciences,* vol. 57, no. 4, pp. 171-174, 2015.

[157] Y. Hayashi, T. Ikaga, S. Ando and T. Hoshi, "The Impact of Indoor Thermal Environment in Winter on Deterioration of Care Level in Nursing Home Residents: A field survey on indoor thermal environment of nursing home and resident's care condition," *Journal of Environmental Engineering (Transactions of AIJ),* vol. 83, no. 745, pp. 225-233, 2018.

[158] Japan Meteorological Agency, "Words for forecast, Words about time," [Online]. Available: https://www.jma.go.jp/jma/kishou/know/yougo_hp/toki.html.

[159] WHO, Health Impact of Low Indoor Temperatures: Report on a WHO Meeting - Copenhagen 11-14 November 1985, Environmental Health, 1987.

[160] AIJ, Building Environment for Elderly, Shokokusha Publishing Co., 1994, p. 58.

[161] MHLW, "Manual for preventive care (revised edition)," 2012. [Online]. Available: http://www.mhlw.go.jp/topics/2009/05/dl/tp0501-1_1.pdf.

[162] K. Saeki, K. Obayashi, J. Iwamoto, N. Tone, N. Okamoto, K. Tomioka and N. Kurumatani, “Stronger association of indoor temperature than outdoor temperature with blood pressure in colder months,” *Journal of Hypertension,* vol. 32, no. 8, pp. 1582-1589, 2014.

[163] U. Lindemann, J. Oksa, D. A. Skelton, N. Beyer, J. Klenk, J. Zxcheile and C. Becker, “Effect of cold indoor environment on physical performance of older women living in the community,” *Age and Ageing,* vol. 43, no. 4, pp. 571-575, 2014.

[164] The Japanese Society of Hypertension, The Japanese Society of Hypertension Guidelines for the Management of Hypertension (JSH 2019), The Japanese Society of Hypertension, 2019.

[165] Y. Sumi, “Oral care fore the elderly,” *Japanese Journal of National Medical Services,* vol. 56, no. 10, pp. 594-600, 2002.

[166] M. Baker, M. Keall, E. L. Au and P. Howden-Chapman, “Home is where the heart is - most of the time,” *The New Zealand Medical Journal,* vol. 120, no. 1264, pp. 113-116, 2007.

[167] H. Kitahara, T. Shimazu, M. Kawabe, T. Hayakawa, T. Okamoto, H. Shimomae and T. Mishina, “Development of air-conditioning systems for the elderly,” *Elsvier Ergonomics Book Series,* vol. 3, pp. 277-281, 2005.

[168] Y. Tochihara, T. Ohnaka, Y. Nagai, T. Tokuda and Y. Kawashima, “Physiological responses and thermal sensations of the elderly in cold and hot environments,” *Journal of Thermal Biology,* vol. 18, no. 5-6, pp. 355-361, 1993.

[169] Z. Wang, H. Yu, Y. Jiao, X. Chu and M. Luo, “Chinese older people's subjective and physiological responses to moderate cold and warm temperature steps,” *Building and Environment,* vol. 149, pp. 526-536, 2019.

[170] Y. Gohgi and H. Une, “Risk factors for requiring long-term care among middle-aged and elderly people,” *Japanese Journal of Public Health,* vol. 52, no. 3, pp. 226-234, 2005.

[171] MHLW, “A Basic Direction for Comprehensive Implementation of National Health Promotion,” 2012. [Online]. Available: https://www.mhlw.go.jp/file/06-Seisakujouhou-10900000-Kenkoukyoku/0000047330.pdf.

[172] National Research Council (US) Panel on Statistics for an Ageing Population, “The Aging Population in the Twenty-First Century: Statistics for Health Policy,” National Academies Press, 1988.

[173] Y. Nakagawa, “Management of dry mouth in Sjören's syndrome,” *Japanese Dental Science Review,* vol. 47, no. 2, pp. 115-123, 2011.

[174] P. Han, P. Suarez-Durall and R. Mulligan, “Dry mouth: A critical topic for older adult patients,” *Journal of Prosthodontic Research,* vol. 59, no. 1, pp. 6-19, 2015.

[175] Y. Sunwoo, C. Chou, J. Takeshita, M. Murakami and Y. Tochihara, “Physiological and Subjective Responses to Low Relative Humidity in Young and Elderly Men,” vol. 25, no. 3, pp. 229-238, 2006.

[176] S. R. Porter, C. M. Scully and A. M. Hegarty, “An update of the etiology and management of xerostomia,” *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology,* vol. 97, no. 1, pp. 28-46, 2004.

[177] T. O. Närhi, J. H. Meurman and A. Ainamo, “Xerostomia and Hyposalivation: Causes, Consequences and Treatment in the Elderly,” *Drugs & Aging,* vol. 15, no. 2, pp. 103-116, 1999.

[178] K. W. Larry and C. Percy, “Influence of age on thirst and fluid intake,” *Medicine & Science in Sports & Exercise,* vol. 33, no. 9, pp. 1524-1532, 2001.

[179] P. C. Fox, “Salivary Enhancement Therapies,” *Caries Research,* vol. 38, pp. 241-246, 2004.

[180] Ministry of Health, labour and Welfare, “Laws of Long-Term Care Insurance System,” [Online]. Available: https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/hukushi_kaigo/kaigo_koureisha/nintei/gaiyo4.html. [Accessed 23 4 2020].

[181] N. D. Ying Joanna and W. M. Thomson, “Dry mouth - An overview,” *Singapore Dental Journal,* vol. 36, pp. 12-17, 2015.

[182] T. O. Närhi, “Prevalence of Subjective Feelings of Dry Mouth in the Elderly,” *Journal of Dental Research,* vol. 73, no. 1, pp. 20-25, 1994.

[183] A. E. Spolarich, “Risk management strategies for reducing oral adverse drug events,” *The Journal of Evidence-based Dental Practice,* vol. 14, pp. 87-94.e1, 2014.

[184] C. Liddell and C. Morris, “Fuel poverty and human health: A review of recent evidence,” *Energy Policy,* vol. 38, no. 16, pp. 2987-2997, 2010.

[185] Y. Konno, T. Mori and Y. Iwama, “Research on actual conditon of fuel poverty in Hokkaido,” *Jounal of Environmental Engineering (Transactions of AIJ),* vol. 83, no. 751, pp. 729-736, 2018.

[186] H. Thomson, C. Snell and C. Liddell, “Fuel poverty in the European Union: a concept in need of definition?,” *People, Place and Policy,* vol. 10, no. 1, pp. 5-24, 2016.

[187] P. Biermann, “How fuel poverty affects subjective well-being: Panel evidence from Germany,” Oldenburg Discussion Papers in Economics, 2016.

[188] C. Robinson, S. Bouzarovski and S. Lindley, “'Getting the measure of fuel poverty': The geography of fuel poverty indicators in England,” *Energy Resesarch & Social Science,* vol. 36, pp. 79-93, 2018.

[189] B. Boardman, Fuel Poverty: From Cold Homes to Affordable Warmth, John wiley & Sons Ltd, 1991.

[190] J. D. Healy and P. J. Clinch, “Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland,” *Energy Policy,* vol. 32, no. 2, pp. 207-220, 2004.

[191] K. C. O'Sullivan, P. L. Howden-Chapman and G. Fougere, “Making the connection: The relationship between fuel poverty, electricity disconnection, and prepayment metering,” *Energy Policy,* vol. 39, no. 2, pp. 733-741, 2011.

[192] C. W. Price, K. Brazier, K. Pham, L. Mathieu and W. Wang, “Identifying Fuel Poverty Using Objective and Subjective Measures,” Centre for Competition Policy Working Paper 07-11, 2007.

[193] C. W. Price, K. Brazier and W. Wang, “Objective and subjective measures of fuel poverty,” *Energy Policy,* vol. 49, pp. 33-39, 2012.

[194] S. A. Churchill, R. Smyth and L. Farrell, “Fuel poverty and subjective wellbeing,” *Energy Economics,* vol. 86, p. 104650, 2020.

[195] F. Belaïd, “Exposure and risk to fuel poverty in France: Examining the extent of the fuel precariousness and its salient determinants,” *Energy Policy,* vol. 114, pp. 189-200, 2018.

[196] Ministry of Housing, Communities & Local Government, UK, “English Housing Survey: Headline Report, 2018-19,” 23 1 2020. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/860076/2018-19_EHS_Headline_Report.pdf. [Accessed 21 4 2020].

[197] Department for Buisiness, Energy & Industrial Strategy, “Quarterly Energy Prices: United Kingdom, Quarter 4 (October - December) 2019,” 3 2020. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/875777/QEP_Q4_2019.pdf. [Accessed 21 4 2020].

[198] Office for National Statistics, UK, “Consumer price inflation, UK: February 2020,” 3 2020. [Online]. Available: https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/consumerpriceinflation/february2020. [Accessed 21 4 2020].

[199] Sutherland Tables, “Sutherland Tables,” 2020. [Online]. Available: http://www.sutherlandtables.co.uk/. [Accessed 21 4 2020].

[200] Statistics Japan, “Housing and Land Survey,” 2018. [Online]. Available: https://www.stat.go.jp/data/jyutaku/index.html.

[201] Statistics Bureau of Japan, “Family Income and Expenditure Survey,” 2019. [Online]. Available: https://www.stat.go.jp/english/data/kakei/index.html. [Accessed 12 4 2020].

[202] Statistics Bureau, “Portal Site of Official Statistics of Japan (e-Stat) website,” [Online]. Available: https://www.e-stat.go.jp/en. [Accessed 21 4 2020].

[203] NHK Broadcasting Culture Research Institute, 2016. [Online]. Available: https://www.nhk.or.jp/bunken/research/yoron/pdf/20160217_1.pdf.

[204] Ministry of Land, Infrastructure, Transport and Tourism, “Evaluation of enveronmental loading,” 2010. [Online]. Available: http://www.mlit.go.jp/kokudokeikaku/iten/information/council/shuto-research/c_kfh/c_kf15.html.

[205] Japan Meteorological Agency, 2019. [Online]. Available: https://www.data.jma.go.jp/obd/stats/etrn/index.php?prec_no=44&block_no=&year=&month=&day=&view=.

[206] T. Mori, T. Ozawa and A. Tamakoshi, “Research on fuel povert in Japanese cold climate region,” Housing Research Foundation JUSOKEN, 2017.

[207] Ministry of Economy, Trade and Industry, “Prior inspection of revised law (3): Inspection of electric charge,” 2018. [Online]. Available: https://www.meti.go.jp/shingikai/enecho/denryoku_gas/denryoku_gas/pdf/014_08_00.pdf. [Accessed 21 4 2020].

[208] E. Takayanagi, T. Ikaga, S. Murakami and J. Nakano, “Validation of the effectiveness of residential environment assessment tool for health promotion,” *Journal of Environmental Engineering (Transactions of AIJ),* vol. 76, no. 670, pp. 1101-1108, 2011.

[209] Ministry of Land, Infrastructure, Transport and Tourism, “Energy-saving measures of housings and buildings in the future,” 2014. [Online]. Available: https://www.mlit.go.jp/common/001064004.pdf. [Accessed 17 6 2020].

[210] Building Research Institute, “Technical information about evaluation of energy consumption performance based on the H28 energy efficiency standard,” 2016. [Online]. Available: https://www.kenken.go.jp/becc/house.html. [Accessed 12 4 2020].

[211] Ministry of Land, Infrastructure and Tourism, “Evaluation standard of residential building performance: Public Notice from MILT No.354,” 2009. [Online]. Available: https://www.mlit.go.jp/common/000052960.pdf. [Accessed 12 4 2020].

[212] M. Ishikawa, K. Matsuhashi, S. Hori and T. Ariga, “Reduction of primary energy consumption per household: Reconstruction to high-insulation housing,” *Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research),* vol. 73, no. 6, pp. II_45-II_52, 2017.

[213] European Fuel Poverty and Energy Efficiency Project, “Diagnosis of causes and consequences of fuel poverty in Belgium, France, Italy, Spain and United Kingdom,” 2009.

[214] Ministry of the Environment, “Actual Conditions Survey of CO2 Emission in Residential Sector,” 2017. [Online]. Available: http://www.env.go.jp/earth/ondanka/ghg/kateiCO2tokei.html. [Accessed 13 4 2020].

[215] J. M. Hanna, “Climate, Altitude, and Blood Pressure,” *Human,* vol. 71, no. 4, pp. 553-582, Biology.

[216] S. Lanzinger, R. Hampel, S. Breitner, R. Rückerl, U. Kraus, J. Cyrys, U. Geruschkat, A. Peters and A. Schneider, “Short-term effects of air temperature on blood pressure and pulse pressure in potentially susceptible individuals,” *International Journal of Hygiene and Environmental Health,* vol. 217, no. 7, pp. 775-784, 2014.

[217] S. Alexandra, N. Lucas, H. Margaret, C. Martin, C. Wayne, H. Alan, P. Annette and D. Robert, “Associations of Endothelial Function and Air Temperature in Diabetic Individuals,” *Epidemiology,* vol. 20, no. 6, p. S31, 2009.

[218] B. Boardman, Fixing Fuel Poverty: Challenges and Solutions, Routledge, 2013.

[219] R. Walker, P. McKenzie, C. Liddell and C. Morris, “Area-based targeting of fuel poverty in Northern Ireland: An evidenced-based approach,” *Applied Geography,* vol. 34, pp. 639-649, 2012.

[220] Asahikawa Chamber of Commerce & Industry, “Fuel allowance survey,” 2019. [Online]. Available: https://www.ccia.or.jp/infomation/fuel/index.html. [Accessed 31 5 2020].

[221] J. D. Healy and P. J. Clinch, “Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland,” *Energy Policy,* vol. 32, no. 2, pp. 207-220, 2004.

[222] Ministry of Health, Labour and Welfare, “Summary of the Vital Statistics in 2014,” 2015. [Online]. Available: https://www.mhlw.go.jp/toukei/saikin/hw/jinkou/kakutei14/dl/00_all.pdf. [Accessed 20 4 2020].

[223] H. Suzuki, M. Saito and H. Yoshino, “A field survey on the living room winter temperature in terms of building types, heating space and operation throughout Hokkaido,” *Journal of Environmental Engineering (Transactions of AIJ),* vol. 76, no. 662, pp. 369-376, 2011.

[224] Y. Iwafune and K. Nishio, “Analisys of standards of space heating services and energy consumption in residential buildings,” *Journal of Environmental Engineering (Transactions of AIJ),* vol. 75, no. 650, pp. 371-379, 2010.

[225] J. D. Healy and P. J. Clinch, “Fuel poverty, thermal comfort and occupancy: results of a national household-survey in Ireland,” *Applied Energy,* vol. 73, no. 2-4, pp. 329-343, 2002.

[226] C. Liddell, C. Morris, P. McKenzie and G. Rae, “Defining Fuel Poverty in Northern Ireland: A preliminary review,” 2011. [Online]. Available: https://pure.ulster.ac.uk/ws/portalfiles/portal/11272278/FuelPovertyReport%28WEB%29-5Sept2011.pdf. [Accessed 21 4 2020].

[227] R. Walker, P. McKenzie, C. Liddell and C. Morris, “Estimating fuel poverty at household level: An integrated approach,” *Energy and Buildings,* vol. 80, pp. 469-479, 2014.

[228] M. Llorca, A. Rodriguez-Alvarez and T. Jamasb, “Objective vs. subjective fuel poverty and self-assessed health,” *Energy Economics,* vol. 87, p. 104736, 2020.

[229] E. Lacroix and C. Chaton, “Fuel poverty as a major determinant of perceived health: the case of France,” *Public Health,* vol. 129, no. 5, pp. 517-524, 2015.

[230] C. Liddell and C. Morris, “Fuel poverty and human health: A review of recent evidence,” *Energy Policy,* vol. 38, no. 6, pp. 2987-2997, 2010.

[231] Ministry of Health, Labour and Welfare, “Survey of Long-term Care Benefit Expenditures,” 2016. [Online]. Available: https://www.mhlw.go.jp/english/database/db-hss/soltcbe.html. [Accessed 3 8 2020].

[232] Ministry of Health, Labour and Welfare, “Patient Survey,” 2014. [Online]. Available: https://www.mhlw.go.jp/english/database/db-hss/ps.html. [Accessed 3 8 2020].

[233] National Institute of Health and Nutrition, “National Health and Nutrition Survey,” 2016. [Online]. Available: https://www.nibiohn.go.jp/eiken/english/research/project_nhns.html. [Accessed 3 8 2020].

[234] Ministry of Internal Affairs and Communications, “Management of Statistical law 33,” 2014. [Online]. Available: https://www5.cao.go.jp/keizai-shimon/kaigi/special/reform/wg3/280405/shiryou2-5.pdf. [Accessed 3 8 2020].

[235] World Health Organization, “Estimates of healthy life expectancy for 191 countries in the year 2000: methods and results,” 11 2001. [Online]. Available: https://www.who.int/healthinfo/paper38.pdf. [Accessed 30 4 2020].

[236] M. Fukuma and K. Shiwaku, “Changes of Care Levels of Frail Elderly Individuals After Introduction of Long-Term Nursing Care Insurance System,” *Journal of the Japanese Association of Rural Medicine,* vol. 58, no. 5, pp. 516-525, 2010.

[237] Ministry of Health, Labour and Welfare, “Status Report for Project of Long-term Care,” 2019. [Online]. Available: https://www.mhlw.go.jp/topics/kaigo/osirase/jigyo/17/dl/h29_gaiyou.pdf.

[238] Ministry of Health, Labor and Welfare, “Current situation and future role of public long-term care insurance system,” 2018. [Online]. Available: https://www.mhlw.go.jp/content/0000213177.pdf. [Accessed 9 4 2020].

Publications

1. Peer-reviewed journals

(1) Yukie Nakajima, Toshiharu Ikaga, Mari Ono, Tanji Hoshi, and Shintaro Ando, Multivariate analysis of perceived indoor temperature and age at need for long-term care insurance: A field survey on the effect of winter indoor thermal environment on care requirements (Part 2), *Journal of Environmental Engineering (Transaction of AIJ)*, Vol.84, No.763, pp.795-803, 2019.9, DOI: doi.org/10.3130/aije.84.795

(2) Yukie Nakajima, Steven M. Schmidt, Agneta Malmgren Fänge, Mari Ono, and Toshiharu Ikaga, Relationship between perceived indoor temperature and self-reported risk for frailty among community-dwelling older people, *International Journal of Environmental Research and Public Health*, Vol.16, No.4, p.613, DOI: doi.org/10.3390/ijerph16040613

(3) Yukie Hayashi, Toshiharu Ikaga, Shintaro Ando, and Tanji Hoshi, The impact of indoor thermal environment in winter on deterioration of care level in nursing home residents: A field survey on indoor thermal environment of nursing home and resident's care condition, *Journal of Environmental Engineering (Transaction of AIJ)*, Vol.83, No.745, pp.225-233, 2018.3 (in Japanese), DOI: doi.org/10.3130/aije.83.225

(4) Yukie Hayashi, Steven M. Schmidt, Agneta Malmgren Fänge, Tanji Hoshi, and Toshiharu Ikaga, Lower physical performance in colder seasons and colder houses: Evidence from a field study on older people living in the community, *International Journal of Environmental Research and Public Health*, Vol.14, No.6, p.651, 2017.6, DOI: doi.org/10.3390/ijerph14060651

(5) Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Event history analysis of indoor thermal environment and care prevention of residents: A field survey on the effect of winter indoor thermal environment on care requirements, *Journal of Environmental Engineering (Transaction of AIJ)*, Vol.81, No.729, pp.901-908, 2016.11 (in Japanese), DOI: doi.org/10.3130/aije.81.901

Total 5 papers

2. Other peer-reviewed journals

(1) Mari Ono, Toshiharu Ikaga, Yukie Nakajima, and Tanji Hoshi, Perceived indoor temperature and change in nursing care level in community-dwelling elderly: A field survey on the effect of winter indoor thermal environment on care requirements (Part 3), *Journal of Environmental Engineering (Transaction of AIJ)*, Vol.85, No.769, pp.197-204, 2020.3, DOI: 10.3130/aije.85.197

Total 1 paper

3. Peer-reviewed international conference papers

(1) *Saeka Shiraishi, Toshiharu Ikaga, and Yukie Nakajima, Effect of the thermal environment in kindergartens on children's physical activity and athletic, *ISAIA 2018*, Pyeongchang, Korea, 2018.10

(2) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamanaka, Yasufumi Uchida, Shuzo Murakami, Shitnaro Ando, Yasue Mitsukura, and Yukie Nakajima, Relationship between indoor temperature in winter and Brain Healthcare Quotient, *Indoor Air 2018*, Philadelphia, Pennsylvania, USA, 2018.7

(3) *Yukie Nakajima, Toshiharu Ikaga, Shintaro Ando, and Tanji Hoshi, Influence of environmental humidity on oral dryness among nursing home residents in Japan, *Indoor Air 2018*, Philadelphia, Pennsylvania, USA, 2018.7

(4) *Toyohiro Kurabe, Tanji Hoshi, Yukie Hayashi, and Toshiharu Ikaga, Effects of the housing envelope and living behaviour on body temperature in the elderly: A field survey, *Healthy Buildings 2017*, Lublin, Poland, 2017.7

(5) *Takuya Ishiwata, Junichiro Hirata, Yusuke Nakajima, Yukie Hayashi, and Toshiharu Ikaga, Experimental study on blood pressure effect of thermal insulation and flooring in winter, *Healthy Buildings 2017*, Lublin, Poland, 2017.7

(6) *Yukie Hayashi, Toshiharu Ikaga, Shintaro Ando, and Tanji Hoshi, Event history analysis of indoor thermal environment and care-requiring conditions of residents in nursing homes, *Science, Technology, and Innovation for Inclusive Development (17th Conference of the Science Council of Asia)*, Manila, Philippine, 2017.6

(7) *Moeka Ubukata, Toshiharu Ikaga, and Yukie Hayashi, Effect of indoor thermal environment on children's physical activity and body temperature, *ICEERB 2016*, Brisbane, Australia, 2016.11

(8) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Effects of indoor air temperature on blood pressure among nursing home residents in Japan, *ICEERB 2016*, Brisbane, Australia, 2016.11

(9) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Field study on the effects of cold indoor environment on long-term care of the frail elderly, *Indoor air 2016*, Ghent, Belgium, 2016.7

Total 9 papers

4. Conference proceedings (International)

(1) *Yukie Nakajima, Mari Ono, Shintaro Ando, Tanji Hoshi, and Toshiharu Ikaga, Retrospective study of cold indoor temperature and healthy life expectancy among community-dwelling older adults, *ICEERB 2018*, Wellington, New Zealand, 2018.11

(2) *Mari Ono, Yukie Nakajima, Saeka Shiraishi, Misa Matsumoto, and Toshiharu Ikaga, Field survey of medical history and use of the Japanese "Kotatsu" heating system in winter among older adults in Japan, *ICEERB 2018*, Wellington, New Zealand, 2018.11

(3) *Hirotaka Asakura, Toshiharu Ikaga, Yukie Nakajima, Emi Morita, Daisuke Hori, Shinichiro Sasahara, Ichiyo Matsuzaki, Masashi Yanagisawa, Sakae Miyagi, Hiromasa Tsujiguchi, Akinori Hara, and Hiroyuki Nakamura, Field survey on bedroom thermal environment and sleep quality in Japan, *ICEERB 2018*, Wellington, New Zealand, 2018.11

(4) *Yukie Nakajima, Steven M. Schmidt, Agneta Malmgren Fänge, Tanji Hoshi, Mari Ono, and Toshiharu Ikaga, Cold, poor and frail: a Cross-sectional study on community dwelling older people in Japan, *GSA 2018 Annual Scientific Meeting*, Boston, Massachusetts, USA, 2018.11

(5) *Yukie Hayashi, Toshiharu Ikaga, Shintaro Ando, and Tanji Hoshi, Ameliorating hypertension by regulating indoor temperature: Blood pressure of nursing home residents before and after insulation retrofitting, *International council for research and innovation in building and construction 2017*, Munich, Germany, 2018.3

(6) *Mari Ono, Yukie Hayashi, Takuya Ishiwata, Toyohiro Kurabe, Saeka Shiraishi, Misa Matsumoto, and Toshiharu Ikaga, Relationship between perceived indoor temperature and contributory factors of frailty, *International council for research and innovation in building and construction 2017*, Munich, Germany, 2018.3

(7) *Yukie Hayashi, Toshiharu Ikaga, Shintaro Ando, Steven M. Schmidt, and Tanji Hoshi, Regulating indoor temperature and humidity, Successful care prevention in warmer nursing homes in Japan, *International Association of Gerontology and Geriatrics 2017*, San Francisco, California, USA, 2017.7

(8) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Relationship of cold indoor environment with long-term care in Japanese nursing homes: A multiple logistic regression analysis, *World Engineering Conference and Convention 2015*, Kyoto, Japan, 2015.12

Total 8 papers

5. Conference proceedings (Japan)

(1) *Mari Ono, Toshiharu Ikaga, Yukie Nakajima, Saeka Shiraishi, and Misa Matsumoto, Logistic multiple regression analysis of perceived indoor temperature and change of care level, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4021, No.89, pp.73-76, 2019.3 (in Japanese)

(2) *Hirotaka Asakura, Toshiharu Ikaga, Toru Shiba, Yuko Fujimoto, Yukie Nakajima, Saeka Shiraishi, and Misa Matsumoto, Intervention survey on bedroom thermal environment to improve sleep quality in summer and winter, *Proceedings of SHASEJ annual conference*, Daido University, Aichi, E-20, pp.97-100, 2018.9 (in Japanese)

(3) *Mari Ono, Toshiharu Ikaga, Yukie Nakajima, Saeka Shiraishi, and Misa Matsumoto, Multivariate analysis on indoor thermal environment in winter and blood pressure of elderly people living in the community, *Proceedings of SHASEJ annual conference*, Daido University, Aichi, F-3, pp.105-108, 2018.9 (in Japanese)

(4) *Yukie Nakajima, Toshiharu Ikaga, Steven M. Schmidt, Mari Ono, Tanji Hoshi, and Shintaro Ando, Field survey on indoor thermal environment and subordinate concept of frailty of elderly people in need of care, *Proceedings of SHASEJ annual conference*, Daido University, Aichi, F-4, pp.113-116, 2018.9 (in Japanese)

(5) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamakawa, Yasushi Uchida, Shuzo Murakami, Shintaro Ando, Yasue Mitsukura, and Yukie Nakajima, Comparison of the influence of the indoor thermal environment on grey matter volume and fractional anisotropy, *Proceedings of SHASEJ annual conference*, Daido University, Aichi, F-10, pp.137-140, 2018.9 (in Japanese)

(6) *Saeka Shiraishi, Toshiharu Ikaga, and Yukie Nakajima, Effect of thermal environment of kindergarten on infants' physical activity and athletic ability, *Proceedings of SHASEJ annual conference*, Daido University, Aichi, F-60, pp.337-340, 2018.9 (in Japanese)

(7) *Hirotaka Asakura, Toshiharu Ikaga, Nanaomi Kario, Mitsuomi Kuwabara, Shogo Nakamura, Yukie Nakajima, Saeka Shiraishi, and Misa Matsumoto, Evaluation of the impact on blood

pressure by the horizontal and vertical room temperature difference in winter, *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40029, pp.67-68, 2018.9 (in Japanese)

(8) *Yukie Nakajima, Toshiharu Ikaga, Steven M. Schmidt, Mari Ono, Tanji Hoshi, and Shintaro Ando, Relationship between indoor temperature in winter and frailty of elderly in need of care considering economic satisfaction, *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40030, pp.69-70, 2018.9 (in Japanese)

(9) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamakawa, Yasushi Uchida, Shuzo Murakami, Shintaro Ando, Yasue Mitsukura, and Yukie Nakajima, Relationship between indoor temperature in winter and Brain Healthcare Quotient using adjusted temperature based on field survey: Field survey on effect of indoor environment on brain function (Part 5), *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40031, pp.71-72, 2018.9 (in Japanese)

(10) *Mari Ono, Toshiharu Ikaga, Yukie Nakajima, Saeka Shiraishi, and Misa Matsumoto, A field study on thermal indoor environment in winter and seasonal blood pressure of elderly people in need of nursing care, *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40034, pp.77-78, 2018.9 (in Japanese)

(11) *Saeka Shiraishi, Toshiharu Ikaga, Yoshirou Murata, Maki Ichihara, Kazuyoshi Harimoto, and Yukie Nakajima, Daily comparison on the thermal environment of kindergarten and the physical activity of children in winter, *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40046, pp.101-102, 2018.9 (in Japanese)

(12) *Katsuyuki Mabuchi, Toshiharu Ikaga, Yukie Nakajima, Takuro Ishito, Ryota Sato, and Maki Ito, Evaluation of effect of regional environment on walking time, *Proceedings of AIJ annual conference*, Tohoku University, Miyagi, 40495, pp.1027-1028, 2018.9 (in Japanese)

(13) *Yu Kuroki, Toshiharu Ikaga, Shuzo Murakami, Shun Kawakubo, Shintaro Ando, Yukie Hayashi, Takuya Ishito, and Ryota Sato, Derivation of stochastic model of winter indoor temperature based on national survey, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4019, No.88, pp.67-70, 2018.3 (in Japanese)

(14) *Yukie Hayashi, Toshiharu Ikaga, Mari Ono, Tanji Hoshi, and Shintaro Ando, Retrospective study on indoor thermal environment in winter and age at care certification of community-dwelling elderly, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4023, No.88, pp.81-84, 2018.3 (in Japanese)

(15) *Mari Ono, Toshiharu Ikaga, Yukie Hayashi, Takuya Ishiwata, Toyohiro Kurabe, Saeka Shiraishi, and Misa Matsumoto, Logistic regression analysis on subjective evaluation of thermal environment and frailty index, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4025, No.88, pp.87-90, 2018.3 (in Japanese)

(16) *Saeka Shiraishi, Toshiharu Ikaga, Yukie Hayashi, Takuya Ishiwata, and Toyohiro Kurabe, Relationship between indoor thermal environment in winter and hypothermia of children based on national survey, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4027, No.88, pp.93-96, 2018.3 (in Japanese)

(17) *Hirotaka Asakura, Toshiharu Ikaga, Wataru Umishio, Takuya Ishiwata, Yukie Hayashi, Toyohiro Kurabe, Saeka Shiraishi, and Misa Matsumoto, Multiple logistic regression analysis on indoor thermal environment and bathing method in winter, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4030, No.88, pp.105-108, 2018.3 (in Japanese)

(18) *Katsuyuki Mabuchi, Toshiharu Ikaga, Yuko Oguma, Yoshinobu Saito, Yukie Hayashi, Takuro Ishito, and Ryota Sato, Relationship of regional environment and physical activity of elderly in two districts of suburban residential area, *AIJ Kanto Branch research report collection*, Nihon

University, Tokyo, 4033, No.88, pp.117-120, 2018.3 (in Japanese)

(19) *Saeka Shiraishi, Toshiharu Ikaga, Yukie Hayashi, Takuya Ishiwata, and Toyohiro Kurabe, Effect of indoor environment of kindergarten on childminder's health and job satisfaction, *Proceedings of SHASEJ annual conference*, Kochi University of Technology, Kochi, G-28, pp.117-120, 2017.9 (in Japanese)

(20) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamakawa, Yasushi Uchida, Shuzo Murakami, Shintaro Ando, Yasue Mitsukura, and Yukie Hayashi, Effect of room temperature difference in winter on Brain Healthcare Quotient, *Proceedings of SHASEJ annual conference*, Kochi University of Technology, Kochi, G-54, pp.221-224, 2017.9 (in Japanese)

(21) *Yukie Hayashi, Toshiharu Ikaga, Shintaro Ando, and Tanji Hoshi, Ordered logistic regression analysis of humidity environment and dryness in the oral cavity of nursing home residents, *Proceedings of SHASEJ annual conference*, Kochi University of Technology, Kochi, G-73, pp.297-300, 2017.9 (in Japanese)

(22) *Toyohiro Kurabe, Toshiharu Ikaga, Makiko Tanaka, Masahiro Yokoyama, Kaichi Otsuka, and Yukie Hayashi, Intervention study of the effect of guidance on style of living in winter on blood pressure, *Proceedings of SHASEJ annual conference*, Kochi University of Technology, Kochi, I-72, pp.333-336, 2017.9 (in Japanese)

(23) *Toshiharu Ikaga, Yoshinori Yamakawa, Yasushi Uchida, Shuzo Murakami, Shintaro Ando, Yasue Mitsukura, Misa Matsumoto, and Yukie Hayashi, Field survey on effect of indoor environment on brain function (Part 1): Summary of Brain Healthcare Quotient obtained by the Magnetic Resonance Imaging (MRI) examination and indoor environment survey, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40012, pp.35-36, 2017.9 (in Japanese)

(24) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamakawa, Yasushi Uchida, Shuzo Murakami, Shintaro Ando, Yasue Mitsukura, and Yukie Hayashi, Field survey on effect of indoor environment on brain function (Part 2): Analysis of relationship between indoor environment in winter and Brain Healthcare Quotient, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40013, pp.37-38, 2017.9 (in Japanese)

(25) *Takuya Ishiwata, Toshiharu Ikaga, Junichiro Hirata, and Yukie Hayashi, Effect of insulation performance and floor material on blood flow and blood pressure in winter in consideration of pulse pressure, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40017, pp.45-46, 2017.9 (in Japanese)

(26) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Effect of indoor temperature and humidity in pay nursing home on deterioration of care level of residents, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40053, pp.117-118, 2017.9 (in Japanese)

(27) *Saeka Shiraishi, Toshiharu Ikaga, Yukie Hayashi, Takuya Ishiwata, and Toyohiro Kurabe, Effect of indoor thermal environment of kindergarten and home on absence rate of kindergarten, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40054, pp.119-120, 2017.9 (in Japanese)

(28) *Toyohiro Kurabe, Toshiharu Ikaga, Makiko Tanaka, Masahiro Yokoyama, Kaichi Otsuka, and Yukie Hayashi, Intervention effect of life style guidance on indoor thermal environment in winter, *Proceedings of AIJ annual conference*, Hiroshima University, Hiroshima, 40547, pp.1139-1140, 2017.9 (in Japanese)

(29) *Toyohiro Kurabe, Toshiharu Ikaga, Tanji Hoshi, Yusuke Nakajima, and Yukie Hayashi, Actual condition of outdoor and bedroom temperature during sleeping period, and elderlys' housing

envelope and living behaviour in summer, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4045, No.87, pp.155-156, 2017.2 (in Japanese)

(30) *Misa Matsumoto, Toshiharu Ikaga, Yoshinori Yamashita, Shuzo Murakami, Yasue Mitsukura, Shintaro Ando, Yukie Hayashi, and Kohei Fujita, Relationship between housing thermal environment and brain health indicators by magnetic resonance imaging (MRI), *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4046, No.87, pp.157-160, 2017.2 (in Japanese)

(31) *Takuya Ishiwata, Toshiharu Ikaga, Junichiro Hirata, Yusuke Nakajima, and Yukie Hayashi, Experimental study on effect of insulation performance and floor material on winter blood pressure through decline of foot skin temperature, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4047, No.87, pp.161-164, 2017.2 (in Japanese)

(32) *Saeka Shiraishi, Toshiharu Ikaga, Moeka Ubukata, Yusuke Nakajima, Yukie Hayashi, Takuya Ishiwata, and Toyohiro Kurabe, Relationship of winter indoor environment, disease, and absence rate of kindergarten infant, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4048, No.87, pp.165-168, 2017.2 (in Japanese)

(33) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Study on changes in blood pressure of nursing home residents by partial insulation retrofit, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4065, No.87, pp.229-232, 2017.2 (in Japanese)

(34) *Moeka Ubukata, Toshiharu Ikaga, Junichiro Hirata, and Yukie Hayashi, Effect of thermal environment of kindergarten to physical activity of preschool children, *Proceedings of SHASEJ annual conference*, Kagoshima University, Kagoshima, G-51, pp.217-220, 2016.9 (in Japanese)

(35) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, and Shintaro Ando, Relationship of a cold indoor environment with change in nursing care level of residents in special nursing homes: a multiple logistic regression analysis, *Proceedings of SHASEJ annual conference*, Kagoshima University, Kagoshima, G-47, pp.201-204, 2016.9 (in Japanese)

(36) Toyohiro Kurabe, Toshiharu Ikaga, Tanji Hoshi, Yusuke Nakajima, and Yukie Hayashi, Actual condition of housing envelope, living behaviour and physiological indices of elderly from the viewpoint of heatstroke risk, *Proceedings of SHASEJ annual conference*, Kagoshima University, Kagoshima, G-49, pp.209-212, 2016.9 (in Japanese)

(37) *Takuya Ishiwata, Toshiharu Ikaga, Junichiro Hirata, Yusuke Nakajima, and Yukie Hayashi, Experimental study on change of blood pressure affected by thermal insulation and flooring in winter, *Proceedings of SHASEJ annual conference*, Kagoshima University, Kagoshima, G-3, pp.25-28, 2016.9 (in Japanese)

(38) *Moeka Ubukata, Toshiharu Ikaga, Junichiro Hirata, and Yukie Hayashi, Relationship between floor elasticity of kindergarten and children's physical activity and body temperature, *Proceedings of AIJ annual conference*, Fukuoka University, Fukuoka, 40025, pp.49-50, 2016.8 (in Japanese)

(39) *Toyohiro Kurabe, Toshiharu Ikaga, Tanji Hoshi, Maki Ito, Yusuke Nakajima, and Yukie Hayashi, Summer field survey on effect of housing envelope and living behaviour on initial symptom of heatstroke in aged residents, *Proceedings of AIJ annual conference*, Fukuoka University, Fukuoka, 40027, pp.53-54, 2016.8 (in Japanese)

(40) *Takuya Ishiwata, Toshiharu Ikaga, Junichiro Hirata, Maki Ito, Yusuke Nakajima, and Yukie Hayashi, Experimental study and computational fluid dynamics on blood pressure in winter affected by thermal insulation performance and flooring, *Proceedings of AIJ annual conference*, Fukuoka University, Fukuoka, 40085, pp.187-188, 2016.8 (in Japanese)

(41) *Yukie Hayashi, Shuzo Murakami, Tsuyoshi Seike, Junta Nakano, and Toshiharu Ikaga, Development and validation of the effectiveness of residential environment assessment tool for advanced age, *Proceedings of AIJ annual conference*, Fukuoka University, Fukuoka, 40553, pp.1179-1180, 2016.8 (in Japanese)

(42) *Junichiro Hirata, Toshiharu Ikaga, Takuya Ishiwata, Maki Ito, Chika Ohashi, Eri Honda, Yusuke Nakajima, and Yukie Hayashi, Experiment on effect of insulation performance and floor material on indoor thermal environment and blood pressure (Part 1): Experimental overview and result of thermal environment measurement, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4041, No.86, pp.161-164, 2016.3 (in Japanese)

(43) *Takuya Ishiwata, Toshiharu Ikaga, Junichiro Hirata, Maki Ito, Chika Ohashi, Eri Honda, Yusuke Nakajima, and Yukie Hayashi, Experiment on effect of insulation performance and floor material on indoor thermal environment and blood pressure (Part 2): Relationship between psychological, physiological factor and blood pressure, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4042, No.86, pp.165-168, 2016.3 (in Japanese)

(44) *Toyohiro Kurabe, Toshiharu Ikaga, Tanji Hoshi, Maki Ito, Chika Ohashi, Eri Honda, Yusuke Nakajima, and Yukie Hayashi, Summer field survey on effect of housing envelope and living behaviour on body temperature of elderly, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4044, No.86, pp.173-176, 2016.3 (in Japanese)

(45) *Moeka Ubukata, Toshiharu Ikaga, Junichiro Hirata, Satoko Omi, and Yukie Hayashi, Field survey on indoor thermal environment, interior material, and influenza infection in kindergarten, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4045, No.86, pp.177-180, 2016.3 (in Japanese)

(46) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, Chika Ohashi, and Eri Honda, Field survey on indoor thermal environment and blood pressure of nursing home residents, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4046, No.86, pp.181-184, 2016.3 (in Japanese)

(47) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, Shintaro Ando, Wataru Umishio, Chika Ohashi, and Eri Honda, Field survey on indoor environment and falls of frail elderly, *Proceedings of SHASEJ annual conference*, Osaka University, C-48, pp.181-184, 2015.9 (in Japanese)

(48) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, Shintaro Ando, Wataru Umishio, Chika Ohashi, and Eri Honda, Survival analysis of indoor thermal environment and the care-requiring condition of frail elderly, *Proceedings of AIJ annual conference*, Tokai University, Kanagawa, 40463, pp.973-974, 2015.9 (in Japanese)

(49) *Yukie Hayashi, Toshiharu Ikaga, Tanji Hoshi, Shintaro Ando, Wataru Umishio, Naoto Takayama, Chika Ohashi, and Eri Honda, Field survey on the influence of the indoor thermal environment in summer on the number of steps of frail elderly, *AIJ Kanto Branch research report collection*, Nihon University, Tokyo, 4035, No.85, pp.137-140, 2015.3 (in Japanese)

Total 49 papers

6. Awards

(1) Yukie Hayashi, Excellent research report, AIJ Kanto Branch, Retrospective study on indoor thermal environment in winter and age at care certification of community-dwelling elderly, 2018.3

(2) Yukie Hayashi, Excellent Presentation Award for young researchers, AIJ Kanto Branch, Retrospective study on indoor thermal environment in winter and age at care certification of community-dwelling elderly, 2018.3

(3) Yukie Hayashi, Excellent Presentation Award for young researchers, Environmental engineering committee of AIJ, Effect of indoor temperature and humidity in pay nursing home on deterioration of care level of residents, 2017.9

(4) Yukie Hayashi, Excellent research report, AIJ Kanto Branch, Study on changes in blood pressure of nursing home residents by partial insulation retrofit, 2017.3

(5) Yukie Hayashi, Excellent Presentation Award, SHASEJ, Relationship of a cold indoor environment with change in nursing care level of residents in special nursing homes: a multiple logistic regression analysis, 2016.10

(6) Yukie Hayashi, Excellent research report, AIJ Kanto Branch, Field survey on indoor thermal environment and blood pressure of nursing home residents, 2016.3

(7) Yukie Hayashi, Excellent Presentation Award for young researchers, AIJ Kanto Branch, Field survey on indoor thermal environment and blood pressure of nursing home residents, 2016.3

(8) Yukie Hayashi, Excellent Presentation Award for young researchers, Environmental engineering committee of AIJ, Survival analysis of indoor thermal environment and the care-requiring condition of frail elderly, 2015.11

(9) Yukie Hayashi, Award for excellent graduation thesis of Department of System Design Engineering, Department of System Design Engineering, Faculty of Science and Technology, Keio University, Field survey on the effect of indoor thermal environment on care needing condition of frail elderly (Graduation thesis of Keio University), 2015.3

(10) Yukie Hayashi, Award for promotion of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan (for university students), SHASEJ, Field survey on the effect of indoor thermal environment on care needing condition of frail elderly (Graduation thesis of Keio University), 2015.3

Total 10 awards