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A comprehensive survey analysis focusing on the effect of living literacy on residential environment and health recognition under COVID-19 in Japan

Takashi Kawasaki[1] | Koki Kikuta[2] | Motoya Hayashi[2] | Michiko Bando[3] | Kenichi Hasegawa[4] | Takao Sawachi[5]

[1]Graduate School of Engineering, Hokkaido University, Sapporo, Japan
[2]Faculty of Engineering, Hokkaido University, Sapporo, Japan
[3]Department of Environmental Health, National Institute of Public Health, Wako, Japan
[4]Faculty of Systems Science and Technology, Akita Prefectural University, Yurihonjo, Japan
[5]President, Building Research Institute, Tsukuba, Japan

Correspondence
Takashi Kawasaki, Graduate School of Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, Hokkaido, 060-8628, Japan.
Email: sakitaka0826@eis.hokudai.ac.jp

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Abstract

Appropriate knowledge and actions of residents in housing are expected to reduce health effects, defined as "living literacy." With the spread of COVID-19 and the diversification of lifestyles, a quantitative evaluation of a comprehensive model that includes living literacy in the housing environment is required. In this study, the author conducted two web-based surveys of approximately 2000 different households in Japan during the summer of 2020 and winter of 2021, and a statistical analysis based on the survey results. As a result, ventilation by opening windows was observed as a new resident behavior trend under COVID-19. In addition, structural equation modeling using the survey samples confirmed the certain relationship between living literacy and subjective evaluation of the indoor environment and health effects in both periods.

1 | INTRODUCTION

In modern residential life, the role played by occupants in maintaining and improving their health is as significant as that of housing performance and facility performance. To maintain a good indoor environment in a house, it is essential for residents themselves to have appropriate knowledge and to practice effective behaviors. This ability of residents can be interpreted as a kind of literacy and is the area on which this study will focus.

Health literacy is one such capacity of the health parties. Health literacy is defined as "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions."[1] The Institute of Medicine takes the view that the health literacy that people possess is the result of the interaction of social and cultural backgrounds and personal factors.[2] In addition, low levels of health literacy have been shown to be significantly related to prevalence, and its lack has been considered problematic.[3]

While the importance of health literacy is well recognized and applied in a variety of ways, divergent views exist regarding its specific definition and framework. Sørensen et al. discuss the scope and conceptual aspects of health literacy, suggesting the existence of several levels and different dimensions with respect to health literacy and presenting an integrated model of it.[4] Others present a conceptual model with two views that understand health literacy as either a "risk" in clinical care or an "asset" in public health.[5] Some studies have focused on lifestyle as such a health risk or health promotion factor. In particular, the relationship between lifestyle habits such as alcohol consumption, smoking, and physical activity and chronic diseases has been reported.[6,7] It is commonly believed that health literacy or lifestyle is influenced by social context, and studies have shown that people's socioeconomic status (SES) influences health through the mediation of health literacy or lifestyle.[8,9]

In this study, health literacy was applied to residential living, and "living literacy" was defined as "the degree of knowledge of appropriate behavior and residential living of residents within their homes." The hypothesized model in this study is shown in Figure 1. Similar to health effects, living literacy is influenced by internal and external factors. Internal factors refer mainly to psychological characteristics according to individual principles and preferences. External factors include learning through education and social demands. The behavior and perceptions of such subjects may change with life-stage transformations. For example, behavioral changes during a woman's gestational period and the perception of the environment as a major factor for a healthy pregnancy at the level of consciousness have been reported.[10]

The concept of health interventions like living literacy, which is the focus of this study, has already been examined in relation to health problems caused mainly by environmental pollutants.

Joyce et al. in their study of risk factors related to infant allergy and asthma examined mothers' avoidance behavior and level of knowledge of environmental risk factors.[11] Recent studies have also suggested that control of the indoor residential environment may be an effective means of addressing serious health problems related to childhood asthma.[12,13]

Cultivation of living literacy is one of the guidelines for healthy living that residents should aim for under more diverse lifestyles. This study aims to quantitatively evaluate the relationship between living literacy, indoor environment, and health effects through a web survey in Japan.

Kishi et al.[14] conducted a nationwide survey of indoor environmental conditions in Japanese houses from 2003 to 2004. In their survey, Kishi et al. confirmed that indoor humidity, odor, and air stagnation indices were associated with the risk of Sick House Syndrome (SHS) in dwelling units. Hasegawa et al.[15] also conducted a web-based survey of the same scale in 2018, showing associations between housing performance and home occupants' behavior and knowledge of indoor environmental problems (e.g., condensation, mold, and odor).

In this study, based on a large-scale survey conducted by Hasegawa et al.[15] in Japan in the past, a web-based survey was conducted from April to August 2020 (hereinafter referred to as "summer") and from October 2020 to February 2021 (hereinafter referred to as "winter"). The period covered by the survey is the initial stage of the spread of COVID-19 in Japan. It is necessary to focus on the short-term behavioral changes of residents and clarify the details of these changes. Based on the survey results, the author will conduct a statistical analysis of the relationships among the factors involved in the hypothetical model (Figure 1), especially those indicated in orange, and examine the model using structural equation modeling (SEM).

Practical Implications

- This study identified the impact of occupants' knowledge and in-home behaviors on indoor environment and health assessments.
- Under COVID-19 in Japan, opening windows was a measure that many people practiced, suggesting that a certain level of behavioral change occurred in the homes due to social demands.
- The subjective recognition of several health effects that can occur within the housing was found to change depending on the level of knowledge and countermeasure behavior of the occupants. More attention should be paid to the involvement of detailed personal lifestyle habits regarding changes in health status.

2 | METHODS

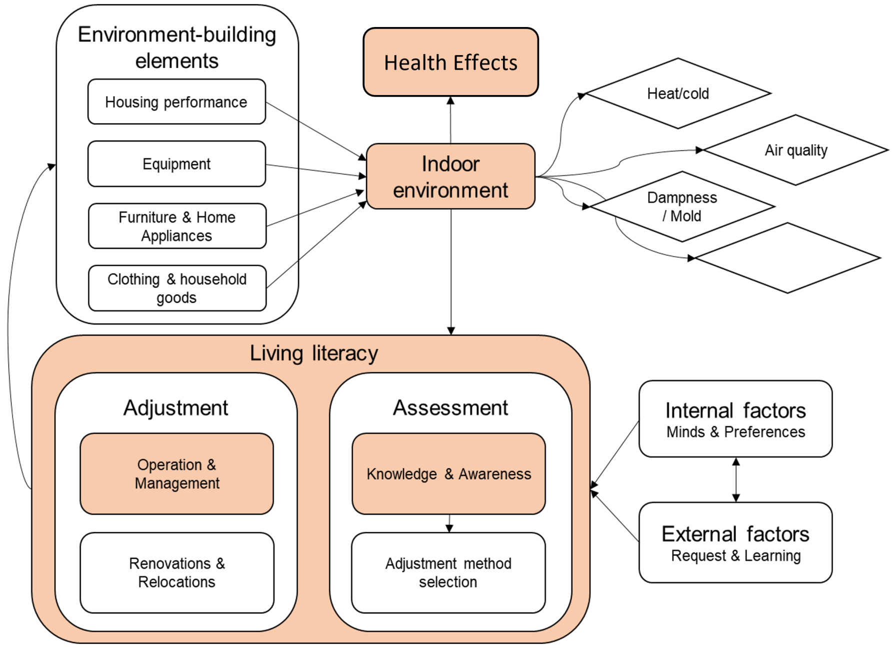
2.1 | Data collection

In this study, two surveys were conducted using the web-based questionnaire method, one in the summer and the other in the winter. Note that the subjects of the summer and winter surveys were not necessarily the same; they were recruited randomly from the survey agency's registrants. The target respondents for both surveys were approximately 2000 persons (aged 20–60 years old). The number of requests from the survey agency was 128 098 s (summer) and 137 123 s (winter), and the collection rate was about 1.5% for both. The target population was families (excluding single-person households) that had lived in the same house for at least 3 years and whose family composition had not changed for at least 2 years. In addition, to determine household energy consumption in the survey, respondents were required to know their electricity rates for a specific period of time. For the summer survey, only households with an air conditioner in the house were included. Survey participants were screened and then equalized by gender, age, and region (Hokkaido, Akita, Miyagi, Tokyo, Osaka, Kochi, Nagasaki, and Okinawa) as much as possible (final sample size: summer $n = 2116$ and winter $n = 2181$).

2.2 | Questionnaires

The questionnaire consisted of approximately 50 questions in total.

FIGURE 1 Research hypothesis model



The questions consisted of seven items: respondent attributes, housing attributes, facilities, knowledge, indoor environment, lifestyle, and COVID-19.

Questions on respondent attributes included questions on gender, age, family structure, smoking, and medical history ("asthma," "atopic dermatitis," "dry eyes," "pollinosis," "hay fever," "allergic rhinitis," "allergic conjunctivitis," "food allergy," "SHS (Sick House Syndrome)," "MCS (Multiple Chemical Sensitivity)," "hypertension," and "diabetes"). Questions regarding housing attributes included housing type, year of construction, history of residence (years), region, and building renovation (Table 1). The questions related to facilities include those related to ventilation and air-conditioning systems. Knowledge questions are about information on environmental indicators, knowledge about SHS, knowledge about heat stroke (in summer), and knowledge about bathing accidents (in winter). Questions related to the indoor environment include questions on condensation, mold, dust mites, odor, cold, and humidity. Lifestyle questions are about equipment usage, cleaning frequency, and preventive measures (condensation, mold, mites, odor, heat stroke, and bathing accidents); COVID-19 questions are about COVID-19 measures, ventilation, changes in time and number of people at home, and changes in electricity rates.

In developing the survey questionnaire, several past surveys on the residential indoor environment in Japan were used as references.[16–19]

2.3 | Statistical analysis

In the statistical analysis, the chi-square test and logistic regression analysis used in Chapters 3 and 4 were performed in BellCurve for Excel (Social Survey Research Information Co., Ltd.). SEM in Chapter 5 was conducted in IBM SPSS AMOS 27 (IBM Japan, Ltd.).

Binomial logistic regression analysis on symptoms associated with heat stroke and bathing employed a variable reduction method (standard p-value = 0.20). Variables to be entered as explanatory variables were examined in advance for their association with the objective variable, and appropriate variables were extracted.

3 | LIVING LITERACY UNDER COVID-19

The widespread use of COVID-19 has significantly changed people's lives, and it can be inferred that the impact of this change has extended to the behavior of individuals in their residences. This chapter focuses on the behavior of Japanese residents and their indoor environment in the COVID-19 environment.

According to the Japanese Ministry of Health, Labor, and Welfare, the first infected person in Japan occurred on January 16, 2020. During the summer survey, the number of cases exceeded 1500 in August 2020. Since then, there have been multiple peaks of infection spread in the country, and during the winter survey, there was a day in January 2021 when the number of cases exceeded 8000. Since the winter survey, the infection has continued to spread further, and the results of this survey report the initial stage of COVID-19 in Japan.

With the spread of COVID-19, people's working and schooling patterns changed significantly. Figure 2 shows the increase in the number of people at home and the time spent at home obtained from the survey results for the summer and winter periods. However, the summer and winter surveys cover different sample groups. Comparisons are made with the same period of the previous year and show the average number of persons in a household whose home time increased, as well as the average increase in home time per person. The survey results show that home time increased by approximately 2–3 h per person. This may have impacted the comprehensive survey and increased the opportunities for residents to look at their indoor environment.

TABLE 1 Characteristics of respondents

Characteristics	Summer n = 2116 n	(%)	Winter n = 2181 n	(%)	Characteristics	Summer n = 2116 n	(%)	Winter n = 2181 n	(%)
Gender					Type of house				
Male	981	(46.4)	1012	(46.4)	Detached house	1147	(54.2)	1169	(53.6)
Female	1135	(53.6)	1169	(53.6)	Apartment/condominium	969	(45.8)	1012	(46.4)
Age					Year of construction				
20–29	177	(8.4)	205	(9.4)	Before 1985	399	(18.9)	446	(20.4)
30–39	487	(23.0)	477	(21.9)	1986–1995	445	(21.0)	459	(21.0)
40–49	526	(24.9)	534	(24.5)	1996–2003	459	(21.7)	455	(20.9)
50–59	468	(22.1)	477	(21.9)	2004–2013	527	(24.9)	505	(23.2)
60–69	458	(21.6)	488	(22.4)	After 2014	286	(13.5)	316	(14.5)
Rising children (year <20)					Years lived in				
Yes	758	(35.8)	1090	(50.0)	3 to <5	322	(15.2)	275	(12.6)
Smoking					5 to <10	494	(23.3)	513	(23.5)
Yes	502	(23.7)	484	(22.2)	>10	1300	(61.4)	1393	(63.9)
Symptoms					Region				
Asthma	79	(3.7)	98	(4.5)	Hokkaido	271	(12.8)	318	(14.6)
Atopic dermatitis	89	(4.2)	87	(4.0)	Akita	245	(11.6)	255	(11.7)
Dry skin	58	(2.7)	46	(2.1)	Miyagi	273	(12.9)	285	(13.1)
Dry eye	116	(5.5)	113	(5.2)	Tokyo	278	(13.1)	286	(13.1)
Pollinosis	235	(11.1)	252	(11.6)	Osaka	272	(12.9)	265	(12.2)
Allergic rhinitis	218	(10.3)	208	(9.5)	Kochi	274	(12.9)	264	(12.1)
Allergic conjunctivitis	38	(1.8)	32	(1.5)	Nagasaki	258	(12.2)	269	(12.3)
Food allergies	31	(1.5)	42	(1.9)	Okinawa	245	(11.6)	239	(11.0)
SBS	3	(0.1)	3	(0.1)	Building remodeling (within 3 years)				
MCS	4	(0.2)	3	(0.1)	Yes	261	(12.3)	238	(10.9)
High blood pressure	295	(13.9)	293	(13.4)					
Diabetes	104	(4.9)	106	(4.9)					

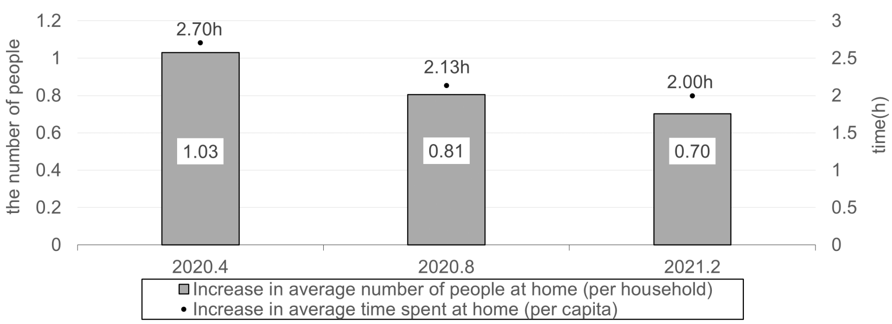


FIGURE 2 Increase in the number of people and hours at home

3.1 | Countermeasures

3.1.1 | Overview and characteristics

The following section presents the overall results (Table 2) and the relationship between the COVID-19 countermeasure level implemented and personal attributes (Table 3) about the infection control measures implemented in the houses. Questions regarding countermeasures were multiple answerable (hereafter referred to as "MA" in the figures and tables), and similar questions were employed in the summer and winter surveys. The COVID-19 measure levels were divided into four tiers, depending on the number of the nine measures implemented. "None" (the number of measures = 0), "Low" (1–3), "Middle" (4–6), and "High" (7–9). In Table 2, more than 90% of the residents indicated that they wash their hands and gargle, suggesting that they are highly conscious of not bringing viruses into

TABLE 2 COVID-19 measures (MA)

Variables	Summer $n = 2116$		Winter $n = 2181$	
	n	(%)	*n*	(%)
Using disinfectant to clean the room	664	(31.4)	687	(31.5)
Washing hands and gargling	1957	(92.5)	1962	(90.0)
Careful to control temperature	388	(18.3)	345	(15.8)
Careful to control humidity	517	(24.4)	344	(15.8)
Increasing ventilation	1012	(47.8)	1006	(46.1)
Decreasing ventilation	29	(1.4)	29	(1.3)
Using an air purifier	562	(26.6)	511	(23.4)
Wearing a mask even indoors	181	(8.6)	150	(6.9)
Careful with food and beverages	480	(22.7)	514	(23.6)
Other	22	(1.0)	25	(1.1)
Nothing	85	(4.0)	128	(5.9)

TABLE 3 Pearson's chi-square test on characteristics and COVID-19 measure level

Attributes	COVID-19 measure level	
	Summer (*p*-value)	Winter (*p*-value)
Gender	$p < 0.001$**	$p < 0.001$**
Age	0.755	0.612
Smoking habits	0.312	0.127
Type of house	0.141	0.457
Year of construction	0.550	0.047*
Years lived in	0.060	0.284
Region	$p < 0.001$**	0.219

Note: **p < 0.01, *p < 0.05.

their residences when they return home. In addition, about half of the residents indicated that they "increase the amount of ventilation," meaning a heightened awareness of ventilation that has not been seen in conventional infection control measures. Regarding Table 3, a comparison by gender revealed that women took more measures than men in both the summer and winter surveys ($p < 0.001$). In addition, the summer survey showed a statistically significant relationship between the number of measures implemented and the area of residence ($p < 0.001$). Details are shown in Figure 3. Tokyo and Hokkaido, where many countermeasures were implemented, were the areas that showed a significant increase in the number of new positive cases during the summer survey, confirming that the difference in crisis awareness associated with the spread of infection affected the behavior of residents. Thus, the influence of social conditions on resident behavior is one of the characteristics of living literacy under COVID-19 conditions.

3.1.2 | Ventilation

For COVID-19 countermeasures in residences, it was important to ensure ventilation volume, and ideally, the operation of normal ventilation systems should be intensified, and doors and windows should be opened when necessary.[20] Therefore, the current survey focused on ventilation, particularly the operation of ventilation systems and the opening of windows, to investigate the actual conditions.

Table 4 shows ways to increase ventilation in homes. Note that only those who responded "increase ventilation" in the above COVID-19 measure (Table 2) were included in the survey. In setting the options, the respondents were asked to consider those that would increase ventilation by intensifying the operation of the ventilation system and those that would open windows. For those that would open windows, they were asked about the frequency and direction of the ventilation. Residents who increased ventilation through the enhanced operation of the ventilation system accounted for about 30% of the total respondents in both surveys. Regarding window opening, the most common pattern was to always open windows from two directions, which accounted for more than 40% of the total respondents in the summer survey. Table 5 shows how windows are opened during cooling (summer) and heating (winter). In both periods, "regularly open windows" was the most common pattern, and even in winter, when the outside temperature drops rapidly, many residents kept their windows open while heating.

The above description of the ventilation situation in the COVID-19 environment shows that the ventilation awareness of the occupants has increased compared to the pre-COVID-19 environment. Although this change may be temporary, this is an example of how the spread of COVID-19 has led to different occupant behavior than in the past.

3.2 | Relevance to the indoor environment

This section of the analysis focuses on the indoor environment and the opening of windows, which was a trend in this COVID-19 measure.

First, the indoor environment of the respondents to this survey is summarized. Figure 4 shows the incidence of problems related to

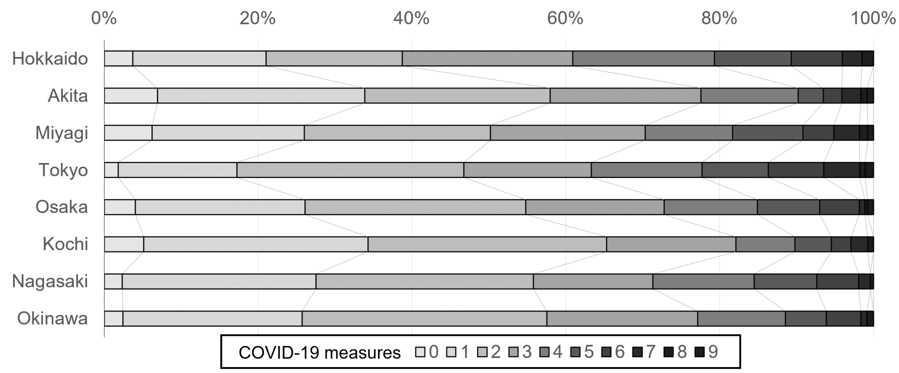


FIGURE 3 COVID-19 measure level and region (summer)

TABLE 4 How to increase ventilation (MA)

	Summer $n = 1012$		Winter $n = 1006$	
Variables	*n*	(%)	*n*	(%)
Enhancing the ventilation system	282	(27.9)	290	(28.8)
Regularly open a window in one direction	161	(15.9)	190	(18.9)
Always try to open a window in one direction	140	(13.8)	125	(12.4)
Regularly open a window in two directions	306	(30.2)	328	(32.6)
Always try to open a window in two directions	441	(43.6)	348	(34.6)
Other	7	(0.7)	7	(0.7)

the indoor environment (for the last year at the time of response). Figure 5 shows the implementation rate of countermeasures for indoor environmental problems. Regarding the implementation of countermeasures, the number of residents who have implemented at least one of the options listed was tabulated.

Regarding Figure 4, compared to the results of the survey by Kishi et al.,[14] the incidence of condensation, mold, and odor in residences nationwide was similar to that before COVID-19. Regarding Figure 5, it was found that more than half of the occupants took some measures to address problems related to the indoor environment in all categories.

Figure 6 shows the relationship between the occurrence of mold and measures taken by ventilation in the COVID-19 environment. According to the analysis results, households experiencing problems related to the indoor environment tend to be more likely to implement measures through ventilation. This tendency was similar in comparison to the occurrence of other indoor environmental problems. Regarding residents' countermeasure behavior and problems related to the indoor environment, Hasegawa et al.[15] explained that the more residents implement countermeasures, the more strongly their awareness of problems related to the indoor environment is expressed, and the same tendency is likely to be observed in the results of the present survey. These detailed causal relationships are dealt with in Chapter 5.

4 | RECOGNITION OF HEALTH EFFECTS

The increased health effects associated with deteriorating indoor environments are a severe issue, and research has been conducted on the relationship between various indoor environmental issues and health. For example, since Strachan et al.[21,22] reported its association with respiratory health problems, with regard to dampness and mold in housing, a link to various health effects (asthma, allergic rhinitis, and respiratory infections) has been implicated.[23,24] Concerning indoor temperatures, conditions that are either too high or too low have been found to lead to poorer health effects.[25,26] In addition, airborne Volatile Organic Compounds (VOCs), especially aromatic and aliphatic compounds, have been reported to be associated with increased asthma symptoms.[27] This chapter discusses the relationship between health problems in housing and the indoor environment and living literacy. The health problems addressed in this study will be physical ailments that occur only inside the house, heat stroke (summer), and physical ailments related to bathing (winter), the incidence of which increases in each study period.

4.1 | Physical conditions in housing

The survey asked about symptoms occurring in the house (headache and dizziness/sore, itchy, flickering eyes/cough, sore throat/hives, skin irritation, itchy skin/runny nose, congestion/feeling tired, and nauseous/hypersensitivity to odors) from seven symptom groups. Multiple answers were allowed for each question. In the analysis, the occurrence of indoor environmental problems (condensation/mold/tick/odor) and the reported data of symptoms were subjected to a chi-square test to confirm statistical significance (Table 6).

TABLE 5 Opening the window while cooling/heating

Variables	Summer $n = 2060$		Winter $n = 1983$	
	n	(%)	n	(%)
Regularly open a window	908	(44.1)	1053	(53.1)
Always try to open a window	448	(21.7)	306	(15.4)
Always close the windows	683	(33.2)	595	(30.0)
Not using air conditioning	21	(1.0)	29	(1.5)

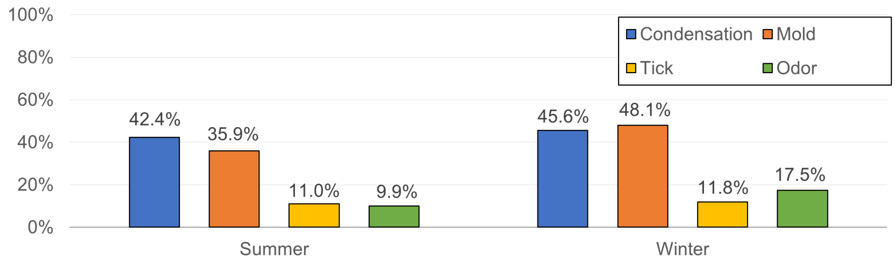


FIGURE 4 Problems related to the indoor environment

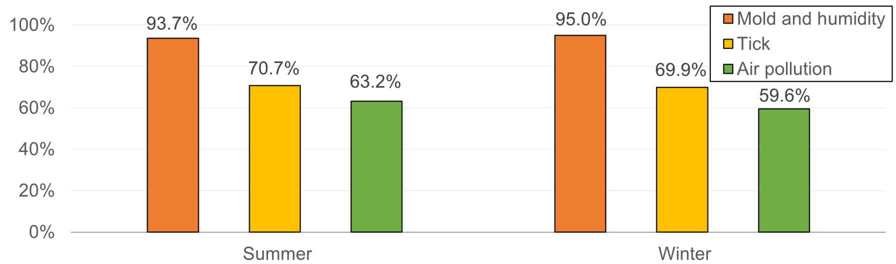


FIGURE 5 Measures for problems related to the indoor environment

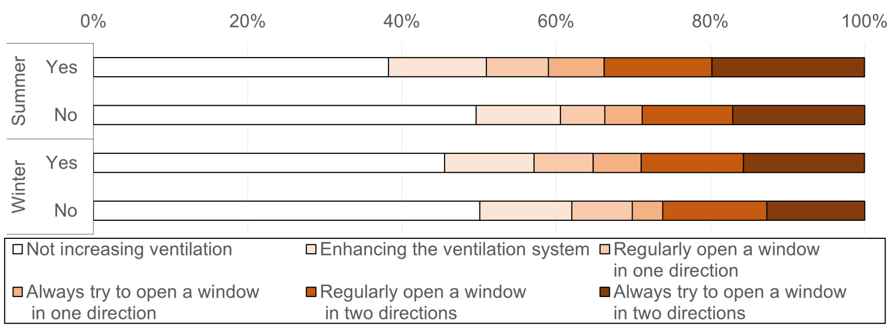


FIGURE 6 Mold occurrence and ventilation for COVID-19 measures

The statistical analysis confirmed an increase in declarations with the deterioration of the indoor environment for many symptoms. These data show a statistically significant relationship, implying that physical discomfort in the housing is strongly influenced by the deterioration of the indoor environment.

4.2 | Risk factors of heat stroke symptoms

Heat stroke caused by raised body temperature is one of the health problems that require attention, especially during the summer season when room temperatures in housing are elevated. In general, it is recommended to keep room temperature below 28°C by actively using air conditioners and fans to prevent heat stroke. In COVID-19 environments, appropriate ventilation is recommended while cooling equipment is in use.[20]

On the other hand, Hatakeyama et al.[28] noted in Japan, COVID-19 preventive measures such as home requests and the use of counseling services may be associated with reduced exposure to heat. This study conducted a statistical analysis of the occurrence of heat stroke in residences in the COVID-19 environment and its contributing factors based on the survey results. For the risk analysis related to heat stroke, the results of the summer survey were referred to.

TABLE 6 Physical condition in housing and indoor environment

Physical condition in housing	Condensation			Mold			Tick			Odor		
	Summer			Summer			Summer			Summer		
	n	(%)	*p*-value	*n*	(%)	*p*-value	*n*	(%)	*p*-value	*n*	(%)	*p*-value
Headache and dizziness	65	(7.2)	**	67	(8.8)	**	32	(13.7)	**	33	(15.7)	**
Sore, itchy, flickering eyes	63	(7.0)	**	56	(7.4)	**	26	(11.2)	**	29	(13.8)	**
Cough, sore throat	23	(2.6)		25	(3.3)	**	15	(6.4)	**	11	(5.2)	**
Hives, skin irritation, itchy skin	58	(6.5)	**	57	(7.5)	**	33	(14.2)	**	36	(17.1)	**
Runny nose, congestion	58	(6.5)	**	55	(7.2)	**	28	(12.0)	**	23	(11.0)	**
Feeling tired, nauseous	36	(4.0)	*	34	(4.5)	**	22	(9.4)	**	22	(10.5)	**
Hypersensitivity to odors	6	(0.7)		6	(0.8)		5	(2.1)	**	6	(2.9)	**
Physical condition in housing	**Winter**			**Winter**			**Winter**			**Winter**		
	n	(%)	*p*-value	*n*	(%)	*p*-value	*n*	(%)	*p*-value	*n*	(%)	*p*-value
Headache and dizziness	70	(7.0)	*	86	(8.2)	**	31	(12.0)	**	45	(11.8)	**
Sore, itchy, flickering eyes	68	(6.8)		77	(7.3)	**	29	(11.2)	**	42	(11.0)	**
Cough, sore throat	54	(5.4)	**	60	(5.7)	**	26	(10.1)	**	38	(10.0)	**
Hives, skin irritation, itchy skin	46	(4.6)	*	56	(5.3)	**	28	(10.9)	**	30	(7.9)	**
Runny nose, congestion	109	(11.0)	**	110	(10.5)	**	43	(16.7)	**	61	(16.0)	**
Feeling tired, nauseous	36	(3.6)	**	35	(3.3)	**	15	(5.8)	**	24	(6.3)	**
Hypersensitivity to odors	33	(3.3)	**	33	(3.1)	*	11	(4.3)	*	26	(6.8)	**

*$p < 0.05$; **$p < 0.01$.

4.2.1 | Severity and personal attributes

For the severity of heat stroke, the author cited the Environmental Health Manual for Heat Stroke[29] of the Ministry of the Environment and classified the eight symptoms asked in the question into three categories (Table 7).

Table 8 shows heat stroke symptoms and respondent characteristics. In determining severity, the severity category was determined by referring to the most severe symptoms reported by the respondents. Significant relationships were found between age, region, and reported heat stroke symptoms. Regarding age, it was confirmed that younger people were more likely to report

TABLE 7 Severity of heat stroke symptom

Symptoms		*n*	(%)
Severity I	Dizziness	116	(5.5)
	Flushed skin	92	(4.3)
	Muscle cramps	42	(2.0)
Severity II	Sluggishness, nausea	94	(4.4)
	Alteration in sweating	96	(4.5)
Severity III	High body temperature	63	(3.0)
	Unconsciousness	9	(0.4)
	Disorientation	11	(0.5)

heat stroke symptoms. However, according to the Fire and Disaster Management Agency, more than half of the emergency medical evacuees in Japan from June to September 2020 due to heat stroke were elderly people (65 years and older). This is thought to be because the elderly are less likely to recognize the onset of heat stroke. In addition, the number of people complaining of heat stroke is higher among households in warmer climates than in colder climates. In particular, the percentage of those complaining of severity III is more than twice as high in warm-weather regions than in cold-weather regions.

4.2.2 | Logistic regression analysis

The results of the binary logistic regression analysis are shown in Table 9. In the model with heat stroke onset as the objective variable, significant associations were observed for five variables. In the crude analysis, building age and medical history were not significantly associated with heat stroke symptoms, so these two factors were not included in the model. In the analysis, adjusted odds ratios (ORs) were calculated with heat stroke symptoms as the dependent variable and risk factors, heat stroke prevention, and knowledge about heat stroke as independent variables. In the extraction of independent variables, a single regression analysis with the dependent variable was conducted in advance to determine the variables. The final model was created by the variable reduction method using the likelihood ratio. Regarding the living environment, households with indoor environmental problems such as mold (OR = 1.62, $p < 0.01$), dust mites (OR = 2.36, $p < 0.01$), and odors (OR = 2.40, $p < 0.01$) were more likely to report heat stroke symptoms. Regarding residents' heat stroke prevention, those who "use air conditioners or fans while sleeping" (AOR = 1.60, $p < 0.01$) were found to be more likely to report heat stroke symptoms. On the other hand, regarding residents' knowledge, those who knew "In addition to hydration, it is important to replenish salt" (AOR = 0.62, $p < 0.01$) tended to be less likely to complain of heat stroke symptoms.

In summary, the results show that deterioration of the indoor environment is one of the factors that most strongly influence the reporting of heat stroke. In addition, residents who took effective heat stroke precautions were more likely to report the onset of heat stroke than other residents. On the other hand, cases were identified in which residents' knowledge reduced the risk of developing heat stroke. This suggests that resident behavior and knowledge may have independent effects on living literacy.

4.3 | Risk factors of bathing accidents

Bathing accidents are a health risk that includes changes in physical condition during and after bathing. According to a report by the Ministry of Health, Labor, and Welfare, there were 5166 deaths in Japan in 2019 due to drowning or drowning in a bathtub, of which over 90% were among the elderly (over 65). Symptoms related to bathing include "heat shock" caused by rapid changes in body temperature during bathing, as well as the development of symptoms considered to be heat stroke. Previous studies in Japan[30] have indicated that blood pressure rises and falls before and after bathing due to temperature changes in the bathroom and changing rooms.

TABLE 8 Characteristics and severity of heat stroke

	None		Severity I		Severity II		Severity III	
Characteristics	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Gender								
Male	864	(88.1)	34	(3.5)	50	(5.1)	33	(3.4)
Female	959	(84.5)	61	(5.4)	71	(6.3)	44	(3.9)
Age**								
20–29	135	(76.3)	10	(5.6)	19	(10.7)	13	(7.3)
30–39	411	(84.4)	25	(5.1)	29	(6.0)	22	(4.5)
40–49	448	(85.2)	26	(4.9)	31	(5.9)	21	(4.0)
50–59	405	(86.5)	21	(4.5)	29	(6.2)	13	(2.8)
60–69	424	(92.6)	13	(2.8)	13	(2.8)	8	(1.7)
Region*								
Cold region	697	(88.3)	35	(4.4)	40	(5.1)	17	(2.2)
Warm region	1126	(84.9)	60	(4.5)	81	(6.1)	60	(4.5)
Type of houses								
Detached house	984	(85.8)	47	(4.1)	65	(5.7)	51	(4.4)
Apartment, condominium	839	(86.6)	48	(5.0)	56	(5.8)	26	(2.7)
Preventive measures								
Do (at least one)	1658	(85.5)	88	(4.5)	119	(6.1)	75	(3.9)
Do not	165	(93.8)	7	(4.0)	7	(4.0)	2	(1.1)

Note: Chi-square test: $^{*}p < 0.05$, $^{**}p < 0.01$.

TABLE 9 Logistic regression for heat stroke onset

Variables	Heatstroke n	(%)	OR (95% CI)		p-value
Mold					
Yes	760	(35.9)	1.62	(1.22–2.15)	**
No	1356	(64.1)	1.00		
Tick					
Yes	233	(11.0)	2.36	(1.68–3.33)	**
No	1883	(89.0)	1.00		
Odor					
Yes	210	(9.9)	2.40	(1.69–3.42)	**
No	1906	(90.1)	1.00		
Drink water frequently					
Do	1850	(87.4)	1.58	(0.92–2.71)	
Do not	266	(12.6)	1.00		
Take salt in moderation					
Do	837	(39.6)	1.29	(0.97–1.70)	
Do not	1279	(60.4)	1.00		
Use air conditioners and fans while sleeping					
Do	1173	(55.4)	1.60	(1.19–2.16)	**
Do not	943	(44.6)	1.00		
Open windows while sleeping					
Do	267	(12.6)	1.28	(0.89–1.85)	
Do not	1849	(87.4)	1.00		
Wear cooling products					
Do	410	(19.4)	1.36	(0.99–1.86)	
Do not	1706	(80.6)	1.00		
Heat stroke occurs in all seasons					
Know	966	(45.7)	1.30	(0.97–1.74)	
Do not know	1150	(54.3)	1.00		
In addition to hydration, it is also important to replenish salt					
Know	1464	(69.2)	0.62	(0.44–0.86)	**
Do not know	652	(30.8)	1.00		

Note: Likelihood ratio test $p < 0.001$; Percentage of correct classifications 86.3%. Confounding factor: sex, age, region; Reduction method Reference value: $p = 0.200$; Significance probability: $^{**}p < 0.01$, $^{*}p < 0.05$. Adjusted odds ratios are presented. Each independent variable is adjusted for all the other independent variables.

In this study, a list of symptoms based on heat stroke symptoms was developed and residents were asked about their actual physical condition during and after bathing. For risk analysis regarding bathing accidents, the results of the winter survey were used as a reference. In addition, respondents were asked about measures and knowledge that they thought would be effective in preventing bathing accidents.

4.3.1 | Severity and personal attributes

The aggregate results by severity are shown in Table 10. In this survey, symptoms related to bathing accidents were added to Severity III from symptoms of heat stroke: "drowning" and "falling over." Table 11 shows the relationship between resident attributes and severity. In determining severity, the severity category was determined by referring to the most severe symptoms reported by the respondents. Significant relationships were identified between gender, age, region, and implementation of countermeasures and the reporting of symptoms of bathing accidents. Statistics related to gender show that a slightly higher percentage of women than men report symptoms. Especially in Severity I, women were more than twice as likely as men to report symptoms. By age, it was observed that younger people were more likely to report symptoms of bathing accidents. This may be because, as in the analysis of heat stroke, the elderly is less likely to recognize the onset of symptoms during and after bathing. No significant relationship was identified with the occurrence of bathing accidents with respect to housing type.

4.3.2 | Logistic regression analysis

A binary logistic analysis was performed for detailed factors of bathing accidents as well as heat stroke (Table 12). The independent variables were measures and knowledge of housing, indoor environment, and survey results regarding bathing accidents. The results of variable selection by the decreasing method showed that seven variables had a significant relationship with the reports of bathing accidents. Confounding factors were gender, age, and region of the respondents. Three levels of acceptance of indoor cold (OR = 1.67, $p < 0.01$) were established. "There are no cold places in the house," "there are cold places in the house, but they are acceptable," and "there are cold places in the house, and they are unacceptable." Regarding the living environment, both mold (OR = 1.32, $p < 0.05$) and odor (OR = 2.09, $p < 0.01$) were found to be more likely to report symptoms. As in the analysis of heat stroke, residents who had implemented countermeasures were more likely to report symptoms. On the other hand, residents who had knowledge that warmer water is safer (OR = 1.51, $p < 0.01$) were more likely to report symptoms. This trend was not seen in the logistic regression analysis of heat stroke.

These findings confirm that, as with heat stroke in summer, deterioration of the indoor environment is a factor in the occurrence of bathing accidents, with mold and odor being common and influential factors. Residents' countermeasure behaviors also had an impact on increased reports of health problems, like the results of the summer survey. On the other hand, regarding the reports of bathing accidents, the tendency for more knowledgeable residents to recognize the occurrence of symptoms was confirmed, which differs from heat stroke in the summer season.

TABLE 10 Severity of bathing accident symptoms

Symptoms		*n*	(%)
Severity I	Dizziness	241	(11.0)
	Flushed skin	170	(7.8)
	Muscle cramps	12	(0.6)
Severity II	Sluggishness, nausea	63	(2.9)
	Alteration in sweating	94	(4.3)
Severity III	High body temperature	69	(3.2)
	Unconsciousness	4	(0.2)
	Drowning	5	(0.2)
	Fall over	59	(2.7)
	Disorientation	6	(0.3)

5 | INTEGRATION OF VARIOUS FACTORS BY SEM

5.1 | Multiple indicator modeling

Structural equation modeling is a flexible linear in-parameter multivariate statistical modeling method. The purpose of this chapter is to integrate the various factors related to residential living into a single systematic model based on the survey results and the findings of Chapters 3 and 4. The model was created using the responses obtained from the summer (n = 2116) and winter (n = 2181) surveys, with one model for each sample group. In the creation process,

TABLE 11 Characteristics and severity of bathing accidents

	None		Severity I		Severity II		Severity III	
Characteristics	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Gender**								
Male	846	(83.6)	67	(6.6)	49	(4.8)	50	(4.9)
Female	884	(75.6)	155	(13.3)	55	(4.7)	75	(6.4)
Age**								
20–29	120	(58.5)	34	(16.6)	19	(9.3)	32	(15.6)
30–39	349	(73.2)	64	(13.4)	26	(5.5)	38	(8.0)
40–49	411	(77.0)	60	(11.2)	29	(5.4)	34	(6.4)
50–59	406	(85.1)	34	(7.1)	18	(3.8)	19	(4.0)
60–69	444	(91.0)	30	(6.1)	12	(2.5)	2	(0.4)
Region**								
Cold region	694	(80.9)	94	(11.0)	38	(4.4)	32	(3.7)
Warm region	1036	(78.3)	128	(9.7)	66	(5.0)	93	(7.0)
Type of houses								
Detached house	931	(79.6)	125	(10.7)	52	(4.4)	61	(5.2)
Apartment, condominium	799	(79.0)	97	(9.6)	52	(5.1)	64	(6.3)
Preventive measures**								
Do (at least one)	1145	(74.5)	184	(12.0)	95	(6.2)	112	(7.3)
Do not	585	(90.7)	38	(5.9)	9	(1.4)	13	(2.0)

Note: Chi-square test: *$p < 0.05$, **$p < 0.01$.

TABLE 12 Logistic regression for bathing accidents

Variables	Bathing accident n	(%)	OR (95% CI)		p-value
Acceptance level of indoor cold					
Unacceptable	384	(17.6)	3.06	(1.91–4.89)	**
Acceptable	1505	(69.0)	2.23	(1.49–3.33)	**
No cold place	292	(13.4)	1.00		
Mold					
Yes	1048	(48.1)	1.32	(1.04–1.68)	*
None	1133	(51.9)	1.00		
Odor					
Yes	381	(17.5)	2.08	(1.59–2.72)	**
None	1800	(82.5)	1.00		
Drink water before bathing					
Do	597	(27.4)	1.50	(1.17–1.91)	**
Do not	1584	(72.6)	1.00		
Warm up the bathroom before bathing					
Do	316	(14.5)	1.35	(1.00–1.83)	*
Do not	1865	(85.5)	1.00		
Call out to your family before bathing					
Do	277	(12.7)	1.45	(1.06–1.98)	*
Do not	1904	(87.3)	1.00		
It is safer to take a bath at a lukewarm temperature					
Know	601	(27.6)	1.57	(1.23–2.02)	**
Do not know	1580	(72.4)	1.00		

Note: Likelihood ratio test $p < 0.001$; percentage of correct classifications 81.1%. Confounding factor: gender, age, region; reduction method reference value: $p = 0.200$; Significance probability: **$p < 0.01$, *$p < 0.05$. Adjusted odds ratios are presented. Each independent variable is adjusted for all the other independent variables.

the authors first determined the observables (shown as ovals in the figure) linked to the four constructs "Poor Indoor Environment," "Recognition of Health Effects," "Countermeasure Actions," and "Knowledge" about the hypothetical model described in Chapter 1. The constructs, also called latent variables, are hypothetical concepts that emerge using the observed variables as indicators.

The author conducted an exploratory model specification among the four latent variables to determine the paths among the constructs. In specifying the model, the author assumed, based on prior research and the analysis in Chapter 4, that deterioration of the indoor environment would have a direct impact on increased perceptions of health problems. A covariance relationship was also assumed between "Countermeasure Actions" and "Knowledge" because they are components of each other's living literacy and are expected to influence each other. The model was determined from the fitted values of each.

5.2 | Path analysis

Figures 7 and 8 show the results of the analysis (path diagrams) of the summer and winter surveys obtained through model identification. The path diagram consists of 4 constructs and 15 observed variables for both models. The arrows connecting each construct and observed variable indicate the direction of causality, and the nearby path coefficients (−1.00 to 1.00) indicate the strength of the causal relationship. The gray circles indicate the error variables (e), which are variables that exist outside the model and explain the variables connected by paths. The numbers in the upper left corner of the figure indicate the fitted values of the model. Both models created in this study meet certain criteria in Goodness of Fit Index (GFI), Adjusted GFI (AGFI), Comparative Fit Index (CFI), and Root Mean Square Error of Approximation (RMSEA), and the models are judged to be valid.

As an observed variable defining "Countermeasure Actions" for resident behavior associated with COVID-19, the common COVID-19 measure (standardized path coefficients = 0.60, 0.61) functions as an indicator on par with the other measure behaviors. However, ventilation behavior by opening windows (=0.42, 41) is somewhat less strong as an indicator than the others.

Focusing on the relationship between the constructs, the "Countermeasure Actions" component of living literacy has a positive and significant effect (0.42, 0.28) on the "Recognition of Health Effects" in both models. This trend was confirmed in Chapter 4. On the other hand, "Knowledge" has a negative and significant effect

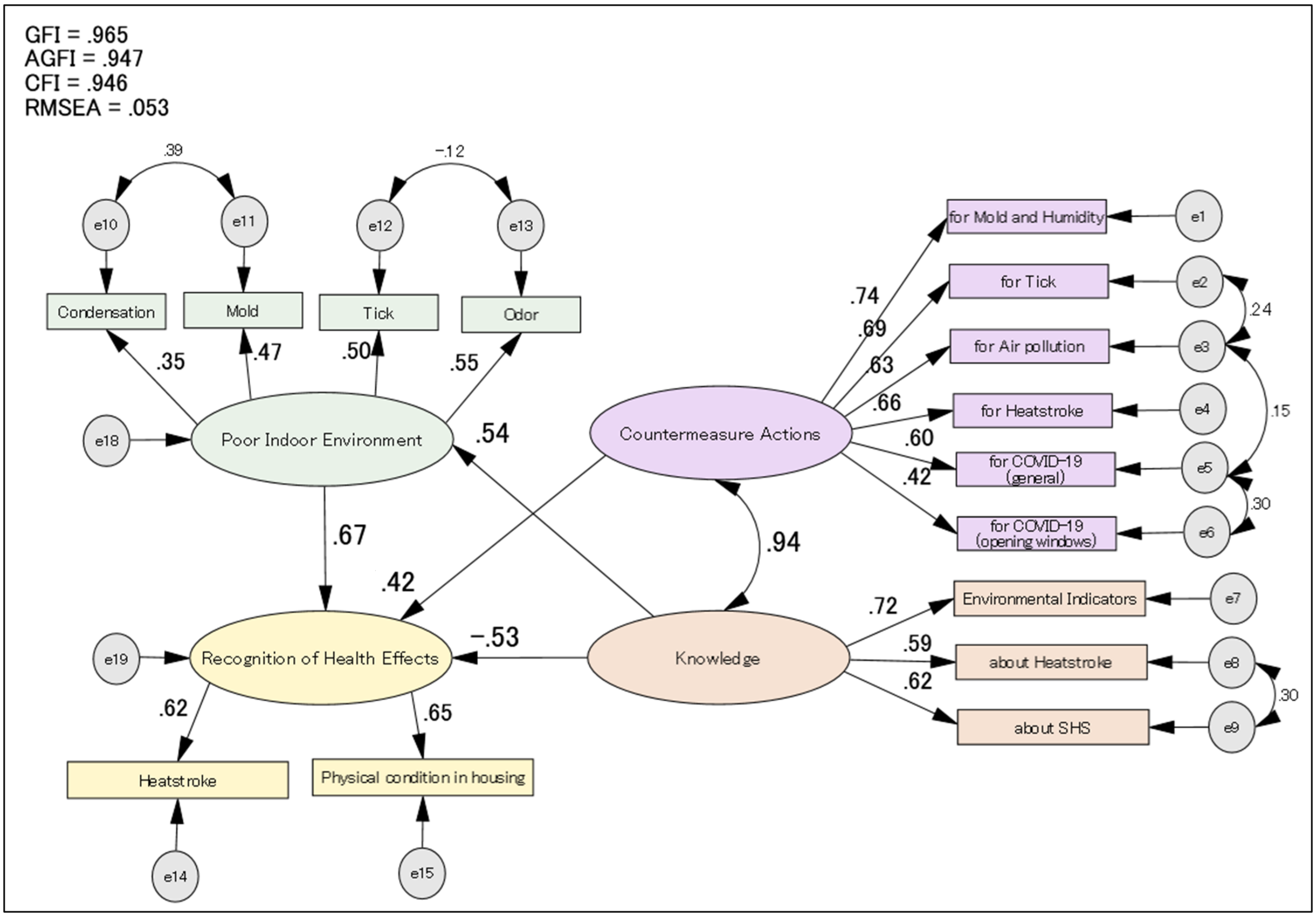


FIGURE 7 Path diagram (summer)

(−0.53, −0.23) on “Recognition of Health Effects”. At the same time, “Knowledge” is confirmed to have a positive indirect effect on “Recognition of Health Effects” through other constructs. In the model, the overall effect from “Knowledge” to “Recognition of Health Effects” is negative (−0.254) in the summer model and positive (0.151) in the winter model. Therefore, it is not possible to assert from the present results that the acquisition of knowledge is a factor that reduces health effects in actual living conditions. However, if other parameters are fixed and only the direct effect of knowledge acquisition on health effects is considered, it can be confirmed that it reduces residents' declarations of health effects.

Model identification results confirm that living literacy, such as resident behavior and knowledge, has a significant effect on the indoor environment and health (subjective ratings). Most of the results showed that the relative improvement in living literacy was associated with a greater tendency to identify new problems. The results also suggest that the evaluation of the indoor environment has a mediating effect on the impact of living literacy on health effects.

5.3 | Latent variable score

While the path diagram in summer and winter had a similar structure to the hypothetical model described in Chapter 1, it provided new insights into living literacy and other constructs. Therefore, the relationships between the constructs defined by the observed variables were evaluated in more detail based on latent variable scores.

For the four constructs in the model obtained in the previous section (“Poor Indoor Environment,” “Recognition of Health Effects,” “Countermeasure Actions,” and “Knowledge”), the latent variable scores were calculated based on the factor score weights obtained for the outputs and the mean deviation of each observed variable. Note that latent variable scores are relative values that each respondent has individually for the assumed constructs.

Figure 9 shows a correlation chart of latent variable scores for “Countermeasure Actions” and “Knowledge.” These two constructs assumed a covariance relationship (0.94/0.76) in the path diagram, and a strong positive correlation was also found when scored (summer: R2 = 0.979, winter: R2 = 0.722). This confirms that residents' behavior and knowledge regarding living literacy are strengthened in an integrated manner.

Figure 10 shows a correlation chart of the latent variable scores for “Recognition of Health Effects” and “Poor Indoor Environment.” The correlation chart shows that residents who strongly perceive health effects are more likely to recognize the deterioration of the indoor environment. The reason why multiple linear correlations are identified in the lower part of the figure, especially in the summer analysis results, is that many residents answered “no symptoms” in the observation

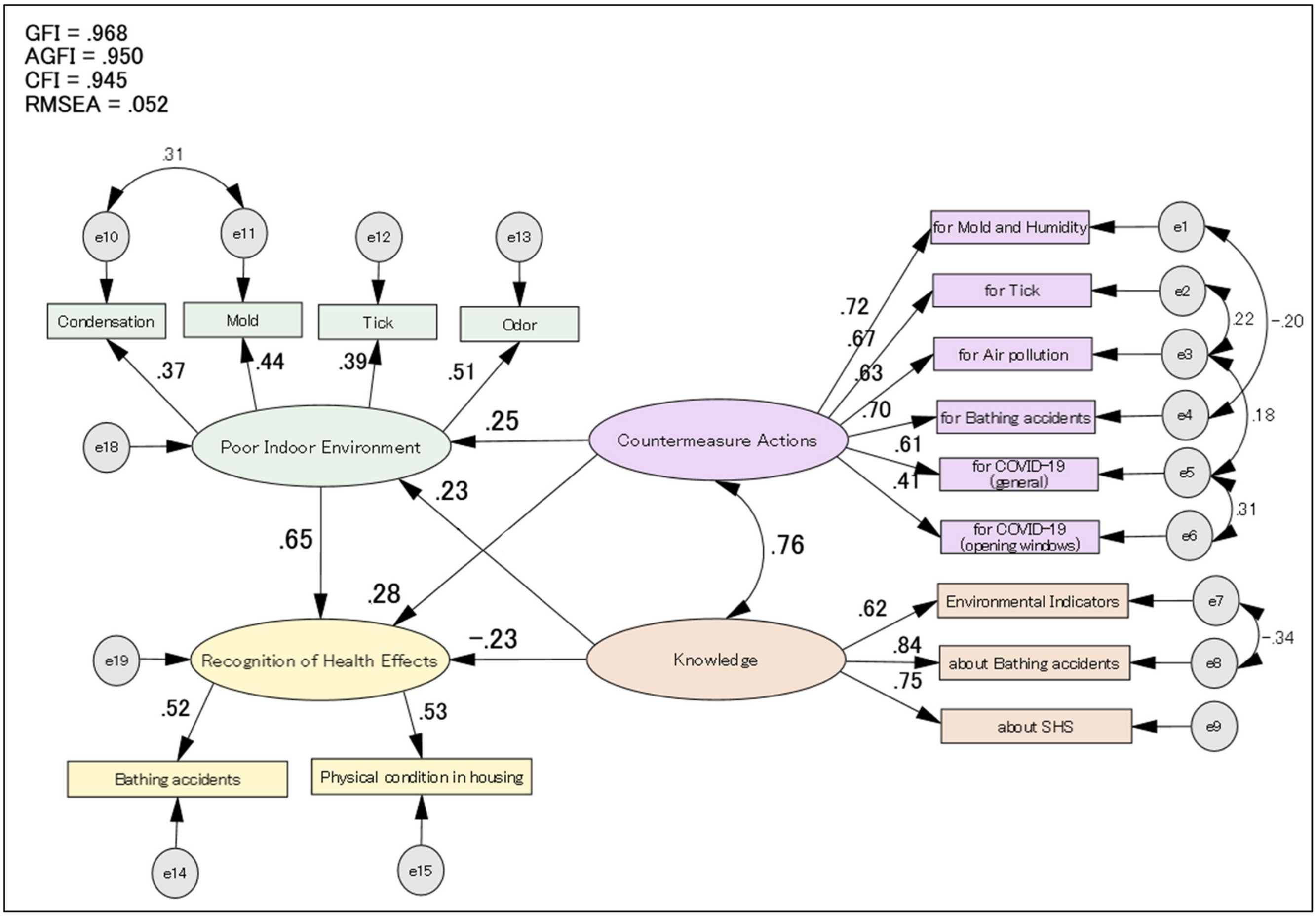


FIGURE 8 Path diagram (winter)

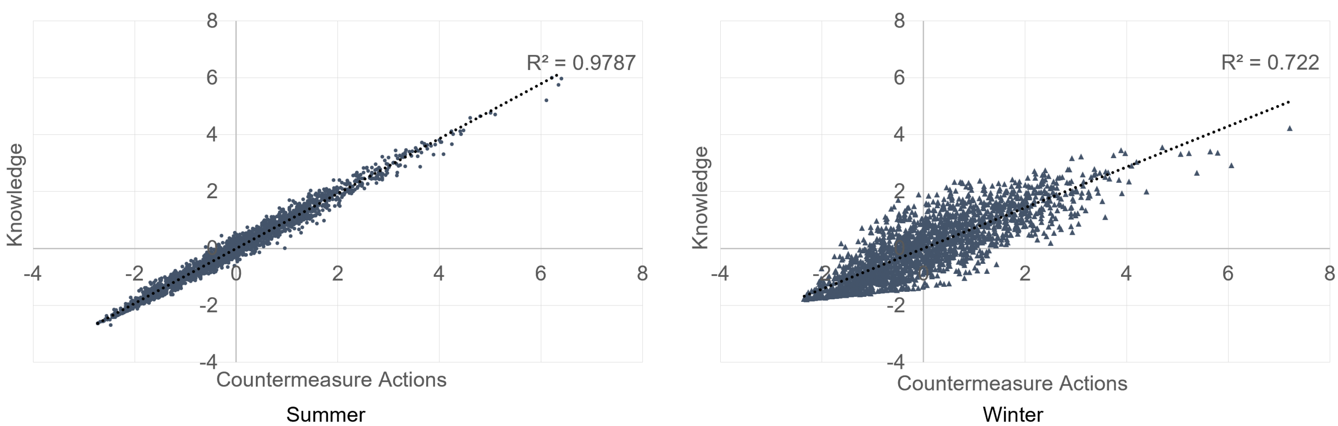


FIGURE 9 Latent variable scores (countermeasure actions and knowledge)

variable question that constitutes the Recognition of Health Effects, which simplifies the trend of latent variable scores. The group of residents with higher scores on the Recognition of Health Effects has a weaker correlation with the "Poor Indoor Environment" latent variable score than those with lower scores. This may be because factors other than poor indoor environment become more influential as predictor variables when health risk increases to an extreme level.

5.4 | Summary of SEM estimates

Structural equation modeling was used to create different models from the results of the two surveys. In both models, the COVID-19 measure was strong enough to indicate residents' countermeasure behavior. On the other hand, ventilation behavior by opening

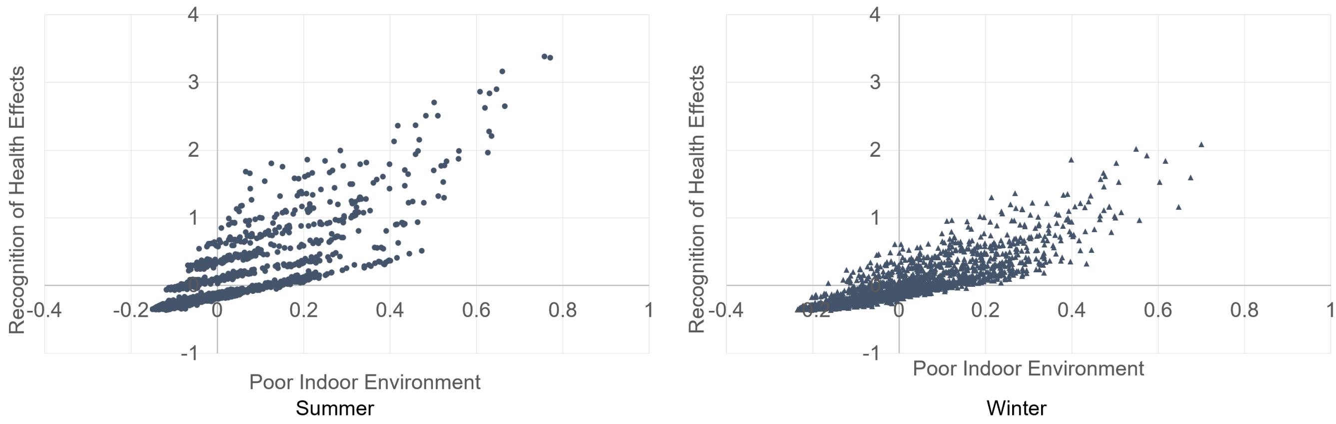


FIGURE 10 Latent variable scores (poor indoor environment and recognition of health effects)

windows was found to be weaker as an indicator than the other observed variables, perhaps because it is a short-term behavior change.

Living literacy (behavior and knowledge) was found to significantly impact occupants' subjective evaluations of the indoor environment and health effects. In other words, the effect of living literacy on the assessment of health effects can be direct or indirect, through the assessment of the indoor environment. In addition, while behaviors that promote the improvement of the indoor environment and the acquisition of appropriate knowledge about the living environment are highly correlated, they may have different effects on the assessment of health effects.

Deterioration of the indoor environment is likely to increase health problems, but the correlation varies with the level of deterioration.

6 | LIMITATION

First, although the sample groups for the summer and winter surveys had similar sampling conditions, the author did not track individual respondents. This makes it particularly difficult to compare the impact of COVID-19 (e.g., increased home time, changes in the home environment, etc.) along a complete time series.

Second, there were parts in the questionnaire where it was not possible to separate and organize the subject of the living conditions into only the respondent himself/herself and the household as a whole. This allowed for ambiguity in the implementation of measures at the individual level, etc. In other words, with regard to living literacy, the survey results may include a mixture of both the household and individual levels.

Third, the survey covered the occurrence of problems related to the indoor environment for a valid period of 1 year before the time of the survey response, so some problems may have already been resolved by the time of the response (problems resolved by moving out of the house are not included). It should be noted that in this survey, indoor environment and health effects were assessed only through simplified responses, and more detailed assessments may be needed to improve the accuracy of the model.[31]

7 | CONCLUSION

In this study, the author conducted a statistical analysis of the relationship between the indoor environment and health effects, focusing on living literacy under COVID-19 in Japan, based on two web-based surveys. The following are the findings obtained from the analysis.

1. Various COVID-19 countermeasures were implemented in residences due to the increase in time spent at home under COVID-19 and social demands for such countermeasures. Among them, ventilation by opening windows was implemented in more than half of the households even when air conditioning systems were in operation. This new trend tended to be implemented more often in households that acknowledged indoor environmental problems.
2. The study found that indoor environmental degradation contributed to health problems related to heat stroke and bathing in housing under COVID-19. It was also found that residents who had implemented countermeasures were more likely to perceive health problems subjectively.
3. SEM provided a multiple indicator model showing the causal structure of subjective ratings of indoor environment and health effects and living literacy. The model explained some of the relationships in the traditional hypothetical model and provided multiple indications of its effect values. Evaluation by latent variable scores confirmed high correlations in residents' actions and knowledge. In addition, certain correlations were identified in the residents' subjective evaluation of the indoor environment and health effects.

AUTHOR CONTRIBUTIONS

Takashi Kawasaki: Conceptualization-Equal, Data curation-Lead, Formal analysis-Lead, Investigation-Lead, Methodology-Lead, Validation-Lead, Visualization-Lead, Writing-original draft-Lead. **Koki Kikuta**: Conceptualization-Equal, Investigation-Supporting, Methodology-Supporting, Validation-Supporting, Writing-review & editing-Lead. **Motoya Hayashi**: Conceptualization-Lead, Project administration-Lead, Resources-Lead, Supervision-Lead, Writing-review &

editing-Supporting. **Michiko Bando**: Writing-review & editing-Supporting. **Kenichi Hasegawa**: Writing-review & editing-Supporting. **Takao Sawachi**: Funding acquisition-Lead, Project Administration-Supporting, Supervision-Supporting, Writing-review & editing-Supporting.

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CONFLICT OF INTEREST

No conflict of interest has been declared by the authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ORCID

Koki Kikuta https://orcid.org/0000-0002-4407-4154

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