Research Article

Stock Housing and Utilities Under Hot and Cold Weather

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In Japan, extensive consideration is given to utilising ageing housing complexes as part of the housing stock. However, when renovating old buildings, some prioritise costs but neglect energy consumption. While insulation retrofitting is a highly effective measure, it often becomes unaffordable due to competing priorities, such as design improvements and ensuring airtightness. To date, there has been little academic analysis of the costs and energy conservation benefits of retrofitting existing housing stock. This study aims to analyse the cost and energy efficiency of ageing housing complexes, such as apartment buildings. The evaluation focuses on the cost and energy consumption of an old apartment building, with findings showing that ceiling insulation has a significant impact. The collected data is presented in numerical form, providing practical results for designers to utilise in their projects. This project is a valuable resource because it is a database for preventing heat shock in vintage and ageing homes. Furthermore, since heat load is energy, it is important to improve insulation capacity to reduce energy consumption. However, this is difficult due to the cost. Although cost evaluation is important, we must focus on the importance of insulation retrofitting to ensure the prosperity of school buildings and the well-being of children, the elderly, and young people under national policy. Therefore, I hope the conclusions of this paper will serve as a reference for design practitioners and that other researchers will pay attention to this type of steady research.

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Introduction

The quantity of housing in Japan is sufficient, and the report Institutional Framework for New Housing Policy, compiled by the Housing and Building Lots Subcommittee of the Social Infrastructure Development Council of the Ministry of Land, Infrastructure, Transport and Tourism, recommends the

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effective utilization of existing housing stock, the formation of high-quality housing stock, the appropriate maintenance and management of that stock, and the promotion of the formation of a circulating market for the smooth distribution of housing. The report also recommends the effective use of existing housing stock and the formation of a recycling-oriented market in which high-quality housing stock is formed, properly maintained, managed, and distributed. (Note 1).

However, in terms of housing performance, some housing stocks do not meet earthquake-resistance, barrier-free, or energy-conservation standards. As the number of elderly households, including single-person households, continues to grow, the need for housing with a good thermal environment becomes more urgent.

According to the 2021 Housing Market Trends Survey conducted by the Housing Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (Note2), the most common reason given by households that purchased custom-built homes for selecting a new home was "because it is a highly airtight and insulated home," indicating a high level of interest in indoor environments. Conversely, 30% of respondents cited "low quality in terms of earthquake resistance and thermal insulation (Note 3)" as the reason for not choosing an existing (second-hand) house, indicating low expectations for the indoor thermal environment of existing houses. However, in a home remodeling survey, "insulation work, anti-dew condensation work, etc." was the most common answer for "specific improvements/changes to the structure of the house" at 50.0%, along with "reinforcement of the foundation/structure," indicating that improving the indoor environment is an important part of utilizing existing stock (Note 4). According to the Japan Housing Reform Promotion Council, the average budget for home remodelling was 2.79 million yen, while the actual cost averaged 3.56 million yen. (Note 5)

Regarding remodelling in rental housing, Keiichi Iso and his colleagues conducted a survey and analysis of owner-paid, customised rentals. They found that the average renovation cost was 2 million yen.

In the private rental housing targeted by this study, current owners[1] have been "aggressively allocating budgets for renovations" since 2016 to increase property values after tenants move out. However, in the Kurume City rental market, it was difficult to link renovation investments to rent increases and recover construction costs (NOTE 6).

In 2006, the company invited applicants with DIY experience, and the owner covered some finishing costs. In 2009, the company shifted its policy to renovations at the owner's expense, inviting people who wanted to experience DIY work. This lowered renovation costs significantly. This made it possible to set rents at about the same level as market rents in Kurume City (Note 7). Insulation retrofitting is rarely done as a DIY project. Because its contribution to space composition and interior design is small, we believe that it does not have the effect that would lead to higher rents.

However, in this age of carbon neutrality, activities to promote energy-efficient housing design are essential, and energy-saving standards such as Net Zero Energy House (ZEH)[2] for new buildings and the Investigation Committee of Hyper Enhanced insulation and Advanced Technique for 2020 houses (G20) [3] are being developed[4]). The development of energy conservation standards, such as the Net Zero Energy House (ZEH) [2] for new houses and the Investigation Committee of Hyper Enhanced insulation and Advanced Technique for 2020 houses (G20) [3], is being promoted [4]. For example, to cite an overseas example, in Mexico, where insulation is not used in houses, the amount of electricity consumed by the air conditioning systems of general buildings other than houses is estimated to be 4.5 times that of the entire residential sector, so insulation performance is essentially an important factor in housing [5]. As for older houses, they are designed based on old energy-saving standards, so their insulation performance is not good. Therefore, the CO2 emission reduction effect of urethane injection + aperture retrofitting, which predicts the current situation, has been dramatically effective for older buildings [6].

Partial insulation retrofitting is an effective means of insulation retrofitting. When the effects of partial insulation retrofits were verified, insulated fittings were introduced, and the thermal performance of the insulated compartment was improved [7]. It was also confirmed that it is important to consider the way of living, and that it is necessary to raise the awareness of residents regarding the use of insulated fittings. Studies have been conducted on the installation of the latest equipment, such as air conditioning and floor heating, in traditional houses, such as old private homes, while retrofitting them with thermal insulation[8].

Although insulation retrofitting is effective in relatively old buildings, such as elementary schools, the total cost is high because it includes structural modifications. However, simulations that take life cycle cost (LCC) into account have shown that annual cost reductions of approximately 1.7 million yen can be achieved, depending on the scenario [9]. The increased cost of external insulation retrofitting can be recovered in approximately 40 years.

The renovation of multi-unit residential buildings has also been studied. The results of a 2011 study showed that the payback period for CO_2 was relatively fast and significant at 0.7 to 22.6 years. However, the payback period for costs was less significant at 42.6 to 898.2 years [10].

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These results could be analysed in more detail by adding an analysis of heat. In other words, a study on the correlation between heat and cost is worth considering.

Therefore, this study will focus on the correlation between heat and cost and conduct a case study in an actual apartment building to generalise the results.

Terminological Clarifications in the Japanese Residential Context

Below are concise, academically styled definitions of key Japanese housing terms, designed for readers unfamiliar with domestic conventions. DK (Dining–Kitchen): DK is a housing layout classification indicating a combined dining and kitchen area, represented by the letters "D" and "K." In Japan's floor-plan terminology, the number before "DK" specifies additional private rooms (e.g., "2DK" describes two separate rooms plus a dining–kitchen space). This term conveys both functional zoning and approximate scale, shaping spatial expectations in residential design. UA Value (Unit Heat Transmittance): The UA value indicates the average thermal transmittance of a building's envelope per unit area, measured in watts per square metre–Kelvin ($W/m^2 \cdot K$). It is calculated as the total heat loss coefficient (U multiplied by surface area), divided by the envelope's area, which quantifies overall insulation performance. Lower UA values mean better thermal resistance and are a key metric in Japan's energy-efficiency standards. Renovation (kaishu): Refers to the process of upgrading or retrofitting an existing building to improve structural integrity, environmental performance, or usability. This includes thermal insulation improvements, seismic reinforcement, system replacements, and spatial reconfigurations. In academic and policy contexts, "renovation" signifies a holistic approach to extending a building's lifespan while meeting current performance standards.

Methods for verifying the effectiveness of insulation retrofits for housing stock

Overview of the target building

The target building for this study is a rental vintage housing complex built in Kurume City, Fukuoka Prefecture, which is over 40 years old. It consists of a four-story, staircase-type housing complex (16 units).

Overview of the study

In this study, as STEP 1, the thermal sensitivity due to the vacancy of the adjacent rooms is considered for each season. In STEP 2, the variation of the thermal load by the insulation repair site is considered seasonally. In STEP 3, the correlation between heat and cost will be discussed. The purpose of this study is to obtain useful data for renovations. Therefore, it should be noted that this study is intended for buildings without solar shading or insulation, which has been widely pointed out in the past.

TRNSYS Analysis Model. TRNSYS Analysis Conditions.

This study used TRNSYS Ver. 18 [11], a general-purpose heat load calculation tool. Figure 1 shows the floor plan of an apartment building, and Table 1 provides an overview of the target building. TRNSYS modelling was performed based on this information. Table 2 shows the TRNSYS analysis conditions. The recommended range for the set temperature for heating and cooling was used, and the ventilation frequency was set to 0.5 times per hour, as required by law. The calculation results were determined using mean absolute error (MAE) relative to the outdoor air temperature for comparative purposes.

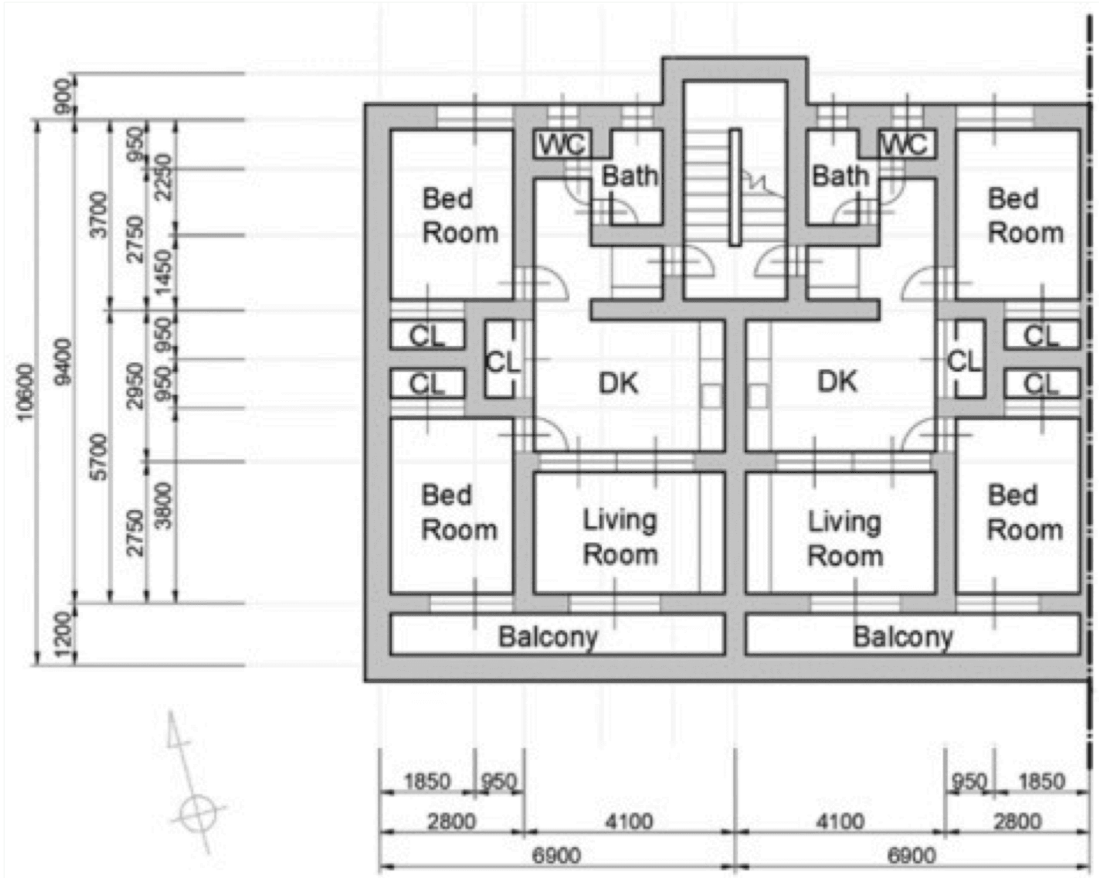

Figure 1. Detailed drawing of the building to be analyzed (four units exist, inverted.)

Item	Value
Location	Kurume City, Fukuoka Prefecture
Total Floor Area	1059.84 m²
Building Footprint	264.96 m²
Purpose	Apartment Building (Multifamily Residential)
Floors	4 stories
Number of Units	16 units

Table 1. Summary of Subject Building

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Item	Condition
Weather Data	Extended Standard Year AMEDAS Weather Data (2001-2010Edition)
HVAC Set Temperature	Heating: 21°C
	Cooling: 26°C
Air Exchange Rate	0.5 times/hour
Calculation Interval	15-minute intervals
Calculation Period	Warm-up period: 12/1–12/31
	Main calculation period: 1/1–8/1

Table 2. TRNSYS calculation conditions

Figure 2 shows the enrollment schedule. Since the interview survey revealed that most managers lived in one- or two-person households, the room occupancy schedule was created for those households. Schedule Ver2.0 was used to create the schedule, assuming the bedrooms would be used as such and that the usage pattern would be the same for two-person households. Living schedules vary greatly depending on the era. To reproduce modern lifestyles, it would be necessary to ask residents to respond to questionnaires. However, this study does not go into that level of detail.

We derived the assumptions for thermal insulation performance from the drawings in terms of realistic living conditions. However, ZEH standards are unique to Japan. Some indicators align with the climate standards of various countries worldwide. This study focuses on Kurume City in Fukuoka, Japan, so please keep this in mind. Additionally, although microclimate-related meteorological data has been developed in recent years, the building in this study has only a small number of shaded areas around it. This has been confirmed, so the settings are precise in that regard.

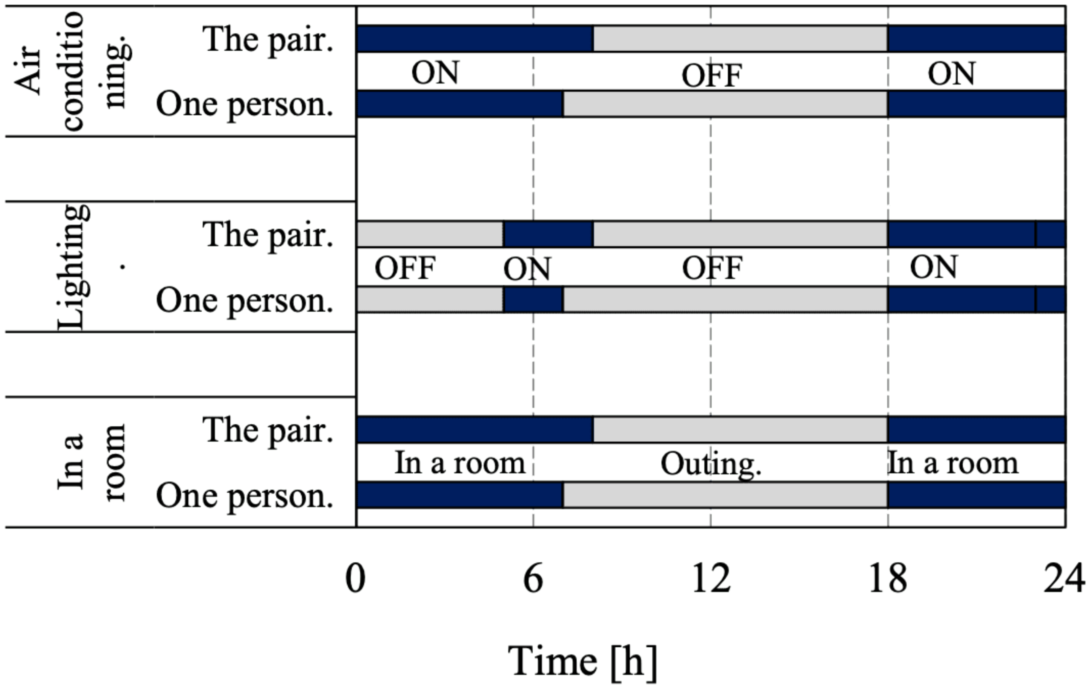

Figure 2. Presence schedule used in the numerical analysis

The UA value of 0.91 [W/m²K] indicates the building's poor insulation performance due to its age. Figure 3 shows temperature fluctuations and solar radiation on representative days in Kurume City. The representative day was selected based on the maximum and minimum temperatures. Representative waveforms of solar radiation were also selected.

Item	Material	Thickness [m]	Thermal Conductivity [W/(m·K)]
External Wall	Mortar	0.015	0.7
External Wall	Montan Wax	0.175	0.99
External Wall	Glass Wool	0.167	0.048
External Wall	Wood Wool Cement Board	0.02	0.13
Internal Wall	Gypsum	0.013	0.21
Internal Wall	Rigid Polyurethane Foam Insulation Type 2 No.1	0.07	0.083
Internal Wall	Residential Glass Wool Insulation 32K	0.1	0.04
Internal Wall	Gypsum	0.013	0.21
Floor	Tatami	0.005	0.08
Floor	Concrete	0.05	1.4
Floor	Rigid Polyurethane Foam Insulation Type 2 No.1	0.04	0.083
Floor	Residential Glass Wool Insulation 32K	0.06	0.13
Floor	Cement	0.16	2.1
Floor	Mortar	0.015	0.7
Ceiling	Mortar	0.015	0.7
Ceiling	Cement	0.16	2.1
Ceiling	Residential Glass Wool Insulation 32K	0.06	0.13
Ceiling	Rigid Polyurethane Foam Insulation Type 2 No.1	0.04	0.083
Ceiling	Concrete	0.05	1.4

Table 3. Wall configuration for analysis

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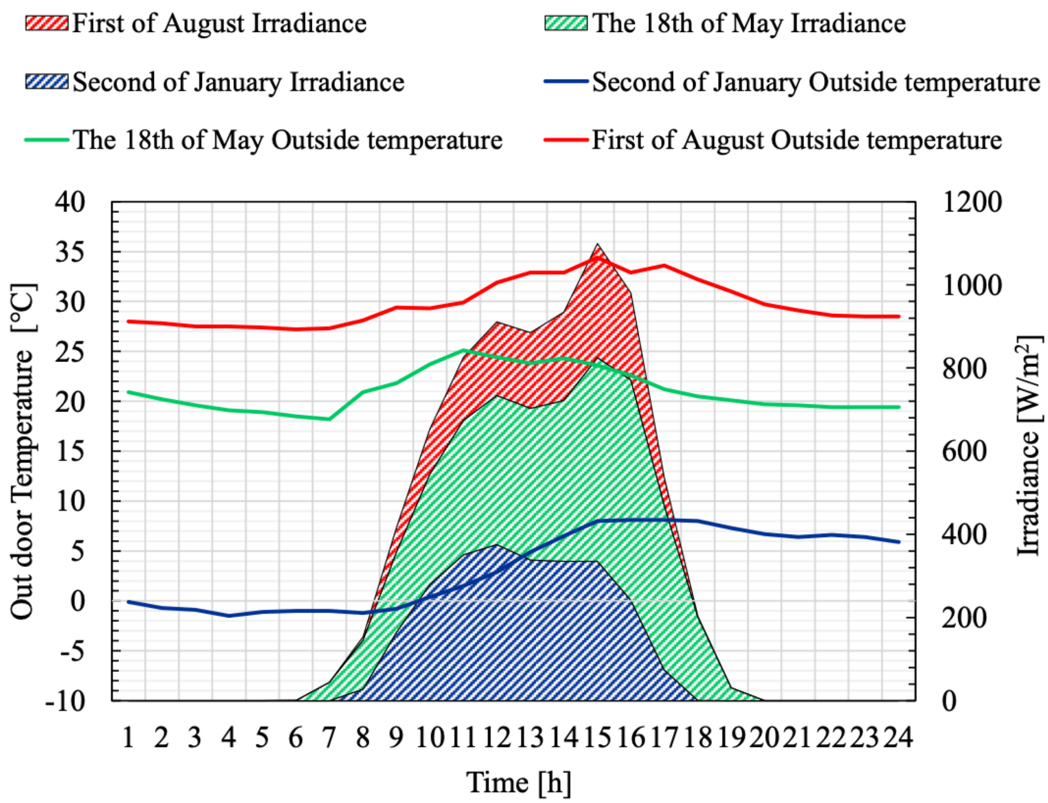

Figure 3. Typical Daily Temperature Variation and Solar Radiation in Kurume City

Thermal environment analysis of the vacancy status of adjacent rooms

Calculation contents and conditions

In addition, the calculation conditions are following the verification method, and the occupancy schedule is calculated and compared relative to the housing stock using the same means as the verification method for insulation retrofitting. Table 4 categorises cases based on vacant location and number of household members. The purpose of categorising vacant rooms is to acknowledge the importance of considering the impact of vacancies when discussing the thermal environment. Table 5 shows the mean absolute error (MAE) calculation results for each room on representative days. In all seasons, differences of 0.1 to 0.4 °C were observed. In general, vacancies do not significantly impact the thermal environment in its natural state. As a trend, the difference from no vacancy is larger in January when the lower part of

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the room is vacant. Conversely, in August, the difference from no vacancy tends to be larger when the upper part of the building is vacant. The following items were examined. A case study was conducted in which the number of vacant rooms was varied. The objective was to confirm the degree to which the thermal environment of adjacent rooms influences the space. The insulation retrofit's effect will be evaluated using heating and cooling loads. Heating and cooling load is a useful quantitative indicator of insulation performance, which is why it is used here. The evaluation was made by dividing the cases into the following categories: "ceiling, floor, wall, window, and all," with or without heating/cooling in adjacent rooms. This evaluation method can be used to roughly estimate the potential of the thermal environment in each area.

Case		The Number of Persons [People]	Empty Room	Empty Room Number [Room]
Case0	Case0-1	1	No	0
	Case0-2	2		
Case1	Case1-1-1	1	Outside	1
	Case1-1-2	2		
	Case1-2-1	1	Inside	
	Case1-2-2	2		
	Case1-3-1	1	Top part	
	Case1-3-2	2		
	Case1-4-1	1	lower part	
	Case1-4-2	2		
Case2	Case2-1-1	1	Both sides	2
	Case2-1-2	2		
	Case2-2-1	1	high and low	
	Case2-2-2	2		
	Case2-3-1	1	Outside up	
	Case2-3-2	2		
	Case2-4-1	1	Outside down	
	Case2-4-2	2		
	Case2-5-1	1	Inside up	
	Case2-5-2	2		
	Case2-6-1	1	Inside down	
	Case2-6-2	2		
Case3	Case3-1-1	1	Above and to the right	3
	Case3-1-2	2		

Case		The Number of Persons [People]	Empty Room	Empty Room Number [Room]
	Case3-2-1	1	Both sides below	
	Case3-2-2	2		
	Case3-3-1	1	outside top and bottom	
	Case3-3-2	2		
	Case3-4-1	1	Inside top and bottom	
	Case3-4-2	2		
Case4	Case4-1	1	Above and below present	4
	Case4-2	2		

Table 4. Study cases with vacant locations and number of household members as variables

Case		The Number of Persons [People]	Empty Room	January 2nd [℃]		May 18 [℃]		August 1st [℃]	
				BED	DK	BED	DK	BED	DK
Case0	Case0-1	1	No	17.64	18.10	3.23	4.59	3.46	3.20
	Case0-2	2		17.65	18.09	3.37	4.60	3.45	3.20
Case1	Case1-1-1	1	Outside	17.62	18.10	3.23	4.58	3.44	3.20
	Case1-1-2	2		17.63	18.90	3.37	4.60	3.43	3.20
	Case1-2-1	1	Inside	17.64	18.08	3.23	4.57	3.46	3.17
	Case1-2-2	2		17.65	18.08	3.63	4.58	3.45	3.17
	Case1-3-1	1	above	17.55	18.05	3.28	4.57	3.35	3.08
	Case1-3-2	2		17.56	18.05	3.42	4.59	3.34	3.08
	Case1-4-1	1	below	17.45	17.97	3.00	4.23	3.48	3.19
	Case1-4-2	2		17.46	17.97	3.06	4.25	3.47	3.19
Case2	Case2-1-1	1	both sides	17.62	18.08	3.23	4.57	3.44	3.17
	Case2-1-2	2		17.63	18.08	3.37	4.58	3.43	3.17
	Case2-2-1	1	high and low	17.36	17.93	3.02	4.21	3.37	3.07
	Case2-2-2	2		17.37	17.93	3.08	4.22	3.36	3.07
	Case2-3-1	1	Outside up	17.35	17.96	3.04	4.43	3.34	3.03
	Case2-3-2	2		17.36	17.96	3.07	4.44	3.33	3.03
	Case2-4-1	1	Outside down	17.35	17.95	3.04	4.40	3.34	3.04
	Case2-4-2	2		17.36	17.95	3.06	4.41	3.33	3.04
	Case2-5-1	1	inner and above	17.37	17.94	3.04	4.41	3.36	3.00
	Case2-5-2	2		17.38	17.95	3.07	4.42	3.35	3.00
	Case2-6-1	1	Inside down	17.37	17.94	3.04	4.38	3.36	3.00
	Case2-6-2	2		17.38	17.94	3.06	4.40	3.35	3.00
Case3	Case3-1-1	1	Above and to the right	17.53	18.04	3.28	4.55	3.33	3.04

Case		The Number of Persons [People]	Empty Room	January 2nd [℃]		May 18 [℃]		August 1st[℃]	
				BED	DK	BED	DK	BED	DK
	Case3-1-2	2		17.54	18.03	3.42	4.57	3.32	3.05
	Case3-2-1	1	Both sides below	17.43	17.96	3.00	4.21	3.46	3.15
	Case3-2-2	2		17.44	17.96	3.06	4.22	3.45	3.16
	Case3-3-1	1	outside top and bottom	17.34	17.93	3.02	4.21	3.35	3.07
	Case3-3-2	2		17.35	17.93	3.08	4.22	3.34	3.07
	Case3-4-1	1	Inside top and bottom	17.36	17.91	3.02	4.19	3.37	3.03
	Case3-4-2	2		17.37	17.91	3.08	4.20	3.36	3.03
Case4	Case4-1	1	Above and below	17.34	17.91	3.02	4.19	3.35	3.03
	Case4-2	2		17.35	17.91	3.08	4.20	3.34	3.03

Table 5 MAE calculation for each room on representative days

Table 6 shows the areas of insulation retrofitting. About the retrofit sites, we have limited ourselves to the most common areas. The reason for this is to reduce the difficulty of relative comparisons due to the increase in the number of cases. Rigid polyurethane foam and glass wool, which are generally used for retrofitting, are used for insulation.

Window surfaces were made with LowE double-glazing, which can be used in both summer and winter. The UA value after the renovation was 0.56 [W/m2K], which meets the standard equivalent to ZEH.

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Component	Material	Thickness [m]	Thermal Conductivity [W/(m·K)]
Exterior Wall	Mortar	0.015	0.7
Exterior Wall	Rigid polyurethane foam insulation board	0.07	0.08
Exterior Wall	Residential glass wool insulation (32K)	0.1	0.04
Exterior Wall	Gypsum	0.013	0.21
Interior Wall	Gypsum	0.013	0.21
Interior Wall	Rigid polyurethane foam insulation board	0.07	0.08
Interior Wall	Residential glass wool insulation (32K)	0.1	0.04
Interior Wall	Gypsum	0.013	0.21
Floor	Tatami	0.005	0.08
Floor	Concrete	0.05	1.4
Floor	Rigid polyurethane foam insulation board	0.04	0.08
Floor	Residential glass wool insulation (32K)	0.06	0.13
Floor	Cement	0.16	2.1
Floor	Mortar	0.015	0.7
Ceiling	Mortar	0.015	0.7
Ceiling	Cement	0.16	2.1
Ceiling	Residential glass wool insulation (32K)	0.06	0.13
Ceiling	Rigid polyurethane foam insulation board	0.04	0.08
Ceiling	Concrete	0.05	1.4
Window	Low-E double glazing	0.02	1.4

Table 6. Parts/Areas of Insulation Renovation

Table 7 shows the case study with heating and cooling of adjacent rooms as the variables. Assuming four patterns of heating and cooling for adjacent rooms makes it possible to consider the degree to which rooms adjacent to outside air influence the system.

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case		Repairs	Heating and cooling of adjoining rooms
case0		No repair	Left and right present
case1	case1-1	Ceiling	Left and right present
	case1-2		Left absent
	case1-3		Right absent
	case1-4		Left and right absent
case2	case2-1	Floor	Left and right present
	case2-2		Left absent
	case2-3		Right absent
	case2-4		Left and right absent
case3	case3-1	Wall	Left and right present
	case3-2		Left absent
	case3-3		Right absent
	case3-4		Left and right absent
case4	case4-1	Window	Left and right present
	case4-2		Left absent
	case4-3		Right absent
	case4-4		Left and right absent
case5	case5-1	All in (all houses)	Left and right present
	case5-2		Left absent
	case5-3		Right absent
	case5-4		Left and right absent

Table 7. Cases with heating and cooling of adjacent rooms as variables

Calculation Results and Discussion

Table 8 shows the sensible heat load in each main room during heating and cooling. By comparing the values with and without insulation retrofitting, it can be seen that the values differ by about 500 kW during the winter. The improvement in insulation performance significantly reduces the heating load. Generally, heat load increases in the summer when insulation improves. This is expected to be due to the flow of heat through window surfaces, which keeps the room warm. The large difference in heat load between the bedroom and the dining room (DK) is assumed to be because the bedroom is in contact with outside air and is strongly influenced by the window surface.

As for the ceiling, it appears that the heat load increased during the winter. One possible reason for this is that modelling the ceiling affected heat transport in adjacent rooms. During the intermediate period, different trends were observed in the bedrooms and dining rooms. This is expected because of the window surfaces facing outside. No insulation effect was observed during the summer.

Regarding the floor, the insulation renovation was found to have had an effect during the winter. However, the heat load increased in the dining room in the middle of winter and in the bedrooms in the summer. This suggests that insulating the floor may not always have a positive effect. It is assumed that, by insulating the floor, heat is transported to the next room. The increase in cooling load in the summer is thought to be due to floor insulation making the room more susceptible to solar radiation. In this case, radiation is expected to be effective.

The wall insulation retrofit has been very effective, especially in the winter, resulting in a noticeable reduction in the heating load. However, in the middle of the year, the heating load in DK increased. Although the increase is not significant, the insulation retrofit has had a negative effect. This is expected to be due to the effect of solar radiation following the insulation improvement.

As for window surfaces, there was no significant effect on the heating load during the winter months. In the middle of the year and during the summer months, however, the heating and cooling loads were found to increase. However, since the difference is small, the impact of window insulation retrofits on multi-family housing stock is minimal.

As with floors and walls, the same phenomenon occurs concerning all renovations when focusing on the intermediate period. Additionally, the cooling load increased by about 200 kW during the summer season. The results show that conducting renovations during the summer has a negative impact. This finding is very important when planning renovations.

Although the differences are relatively small, they may be due to an insufficient heat supply caused by the Sekirei air conditioning system settings. Considering only the thermal perspective of the natural state, insulating the ceilings and floors is desirable. However, it is difficult to infer property values solely from a temperature perspective. In the next section, we will discuss the correlation between "thermal environment" and cost by combining cost and heat load considerations.

case		Repairs	Adjacent HVAC	winter (1/2) [kW]		midcycle (5/18) [kW]		summer (8/1日) [kW]	
				Bed	DK	Bed	DK	Bed	DK
case0		No repair	None	2710.03	752.24	389.71	167.96	1104.00	1070.78
case1	case1-1	Ceiling	Left and Right Present	2790.99	771.20	428.92	156.59	1067.64	1050.47
	case1-2		Left Absent	2893.97	769.68	441.92	156.82	1122.64	1049.49
	case1-3		Right Absent	2793.84	824.56	429.18	166.95	1070.38	1127.20
	case1-4		Left and Right Absent	2907.78	826.42	442.35	167.19	1125.39	1126.03
case2	case2-1	Floor	Left and Right Present	2638.13	701.28	363.72	203.03	1248.79	1155.45
	case2-2		Left Absent	2751.51	703.04	377.89	203.16	1303.06	1156.54
	case2-3		Right Absent	2641.11	753.11	364.09	213.57	1251.47	1232.27
	case2-4		Left and Right Absent	2754.50	754.90	378.27	213.70	1305.75	1233.36
case3	case3-1	Wall	Left and Right Present	2382.31	664.00	347.30	200.58	1154.76	1076.75
	case3-2		Left and Right Absent	2263.01	564.20	309.97	298.73	1335.81	1247.30
	case3-3		Left Absent	2207.25	588.71	303.37	304.47	1307.73	1282.77
	case3-4		Left and right absent	2264.05	589.16	308.78	304.50	1336.01	1283.05
case4	case4-1	Window	Left and right present	2658.69	713.02	373.28	206.33	1191.23	1154.17
	case4-2		Left absent	2765.91	714.59	388.28	206.52	1243.94	1157.14
	case4-3		Right absent	2661.38	761.73	375.18	216.66	1193.76	1227.85
	case4-4		Left and right absent	2768.61	763.32	388.58	216.82	1246.44	1228.92

case		Repairs	Adjacent HVAC	winter (1/2) [kW]		midcycle (5/18) [kW]		summer (8/1日) [kW]	
				Bed	DK	Bed	DK	Bed	DK
case5	case5-1	All in (all houses)	Left and right present	2206.21	563.76	303.19	298.64	1306.84	1242.91
	case5-2		Left absent	2263.01	564.20	309.95	298.66	1335.12	1243.23
	case5-3		Right absent	2207.25	588.71	303.37	304.54	1308.38	1285.55
	case5-4		Left and right absent	2264.05	589.16	310.13	304.56	1336.70	1286.22

Table 8. Sensible heat load in each main living room during heating and cooling

Bidirectional Evaluation of Heat and Cost from Renovation

Calculations and Conditions

Figure 4 shows the correlation between heat load per unit area and cost. The calculation results refer to the heat load in Section 4. The correlation between cost and heat load per unit area is used for generalization purposes. Therefore, the calculation conditions are in accordance with previous calculations. The cost data comes from books [12] and is realistic, serving as a reference for designers.

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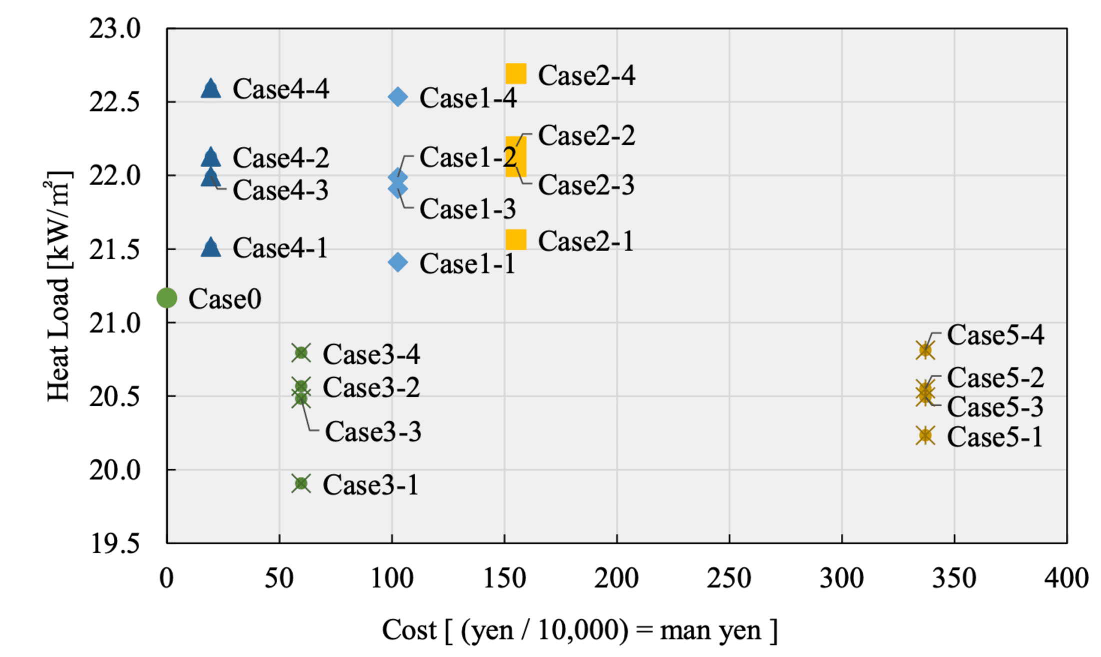

Figure 4. Bidirectional evaluation of heat load and cost per unit area

Calculation Results and Discussion

First, the cost of the whole house retrofit is by far the highest. However, relatively speaking, the heat load per unit area is 20–25 kW/m², which is a small value. In terms of cost alone, window surfaces are the cheapest. Notably, the cost of ceiling and floor insulation retrofitting differs, though the heat load does not differ greatly.

However, the cost of retrofitting walls is lower, yet the retrofit value is the same as that of a whole house retrofit. The results of Case 3-1 were more effective than the whole-house retrofit results, and other suggestive results were obtained. In all cases, the heat load was higher on the left than on the right. This is because the room is second from the left and more susceptible to outside air.

The calculation results show that the heat load throughout the year is lower than in the case of no renovation, and the areas where insulation renovation is most effective are clear from a cost standpoint. We hope that everyone at Space R Design, Inc., will consider retrofitting their insulation as well.

Asked whether carbon emissions throughout the life cycle and thermal insulation performance are closely related, the answer is no. In the SI unit system, heat and power consumption are converted using a

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formula. From a physical perspective, it is difficult to confirm the correlation between them. Therefore, please understand that this study will not engage in such uncertain discussions.

Conclusion

1. This study analyzed the correlation between heat and cost in DIY in detail. Rather than being a case study, it is a realistic analysis that can be used as a reference for actual implementation. The following highly suggestive findings and perspectives were obtained from the study:
2. First, from a thermal point of view, it was concluded that ceilings and floors should be insulated when the adjacent room is vacant. However, when considering the correlation between thermal load and cost, ceilings are more effective than floors.
3. The conclusions did not change when comparing the verification results of heating and cooling heat loads, whether or not the adjacent room was unoccupied. Looking at the correlation with cost allowed us to obtain more practical, generalised data.
4. In conclusion, the wall insulation retrofit is more effective and less expensive. However, increasing the thickness of the wall surface can create a sense of oppression in the space, which offsets the benefits of the retrofit. This concern is based on the building's composition and the client's preferences. While this study did not address this issue, we would like to emphasise that we consider the effect on spatial composition an important factor for the future.
5. In the future, it would be desirable to review older housing complexes not only from a thermal perspective, but also from an energy perspective. This could be done step by step or by compiling a database of valuable data for effective utilization promptly. Special mention should be made of the management of Corpo EDOYASHIKI, which is managed by Space R Design, Inc.
6. In this study, we analysed data based on relative comparisons from a thermal perspective only. The results of this study are based on a "thermal" point of view. When unravelled, it is a step-by-step study. As a conclusion, we must not forget that cost-based considerations are limited.

Future Prospect

Although meeting ZEH standards would be a positive development for the rental market, thermal insulation retrofits have drawbacks, such as cost, that make implementation difficult. The government should bear the cost of thermal insulation materials to promote the "revival" of ageing buildings.

Looking ahead, it would be beneficial to include pilot programs and regional comparisons. However, it is important to carefully consider the age of the buildings, the durability of their structures, the age and income levels of their users, and how these factors interact with each other.

Notes

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3. The most common multiple responses were "New construction is more comfortable" (60.1%) and "Remodelling costs are more expensive" (33.0%).
4. For the five years from FY2009 to FY2021, the highest percentages were 67.7%, 63.2%, 54.8%, 46.7%, and 50.0%.
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7. From interviews with current owners.

Statements and Declarations

Conflicts of interest

No potential competing interests to declare.

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Declarations

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