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ARTICLE

Housing Stock Optimisations

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ABSTRACT

In Japan, aging housing complexes are considered a key component of the national housing stock. However, renovation projects often prioritize initial costs over long-term energy performance. Although retrofitting insulation effectively reduces energy consumption, budget constraints and competing priorities, such as architectural improvements and airtightness measures, limit its adoption. Few academic studies have quantified the economic and energy-saving impacts of retrofitting existing apartment buildings. This study uses TRNSYS simulations to evaluate retrofitting scenarios for a typical aging apartment complex. The analysis focuses on lifecycle costs and annual heating and cooling loads. Results indicate that ceiling insulation yields the largest reduction in heat load. The numerical data generated by this research offer practical guidelines for design practitioners evaluating retrofit options. A cost breakdown based on material and labor estimates is provided to demonstrate the trade-off between investment and energy savings. Sensitivity analyses assess the robustness of the findings when insulation thickness and energy prices vary. This study provides a database of thermal performance metrics for existing buildings to support decision-making in renovation projects. The implications include optimized retrofit strategies that balance initial costs and energy efficiency, thereby promoting the sustainable management of aging housing stock. The results serve as a reference for architects, engineers, and policymakers involved in building energy retrofits. By quantifying the relationship between insulation measures and thermal load, the database helps planners mitigate risks such as indoor thermal discomfort and cold-related health hazards in older residences.

Keywords: Energy; Heat Load; Simulation

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1. 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 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 (Note 2), 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 remodeling was 2.79 million yen, while the actual cost averaged 3.56 million yen. (Note 5) Regarding remodeling in rental housing, Keiichi Iso and his colleagues conducted a survey and analysis of owner-paid, customized 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 CO_2 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].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 generalize the results. As a contribution to the study, the results are beneficial to design practitioners because retrofitting insulation in ageing buildings is very beneficial. Therefore, we obtained data that will help reduce heating and cooling loads, such as for future insulation retrofits (DIY). Space R Design, Inc. has highly appreciated the results of this research, and we have been informed that we can utilise them in our design practice.

2. Materials and Methods

Overview of the Target Building

This study focuses on a rental vintage housing complex in Kurume City, Fukuoka Prefecture. The complex is over 40 years old. The complex consists of 16 units in a four-story, staircase-type building.

Overview of the Study

This study considers the thermal sensitivity due to vacancy in adjacent rooms for each season (STEP 1). In STEP 2, the seasonal variation of the thermal load due to insulation repairs is considered. STEP 3 will discuss the correlation between heat and cost. The purpose of this study is to obtain useful renovation data. It should be noted that this study is intended for buildings without solar shading or insulation, a fact that has been widely acknowledged 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 modeling 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. For comparative purposes, the calculation results were determined using mean absolute error (MAE) relative to the outdoor air temperature.

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 based on those results. Schedule Ver2.0 was used to create the schedule under the assumption that the bedrooms would be used as intended and that the usage pattern would be the same for two-person households. **Table 3** shows the wall thickness and thermal insulation performance. This valuable information was extracted from old drawings. **Figure 3** illustrates the temperature and solar radiation levels on an average day in Kurume City. Data from months and days that clearly show trends are extracted and used in research.

Table 1. Summary of subject building.

Item	Value
Location	Kurume City, Fukuoka Prefecture
Total Floor Area	1059.84 m^2
Building Footprint	264.96 m^2
Purpose	Apartment Building (Multifamily Residential)
Floors	4 stories
Number of Units	16 units

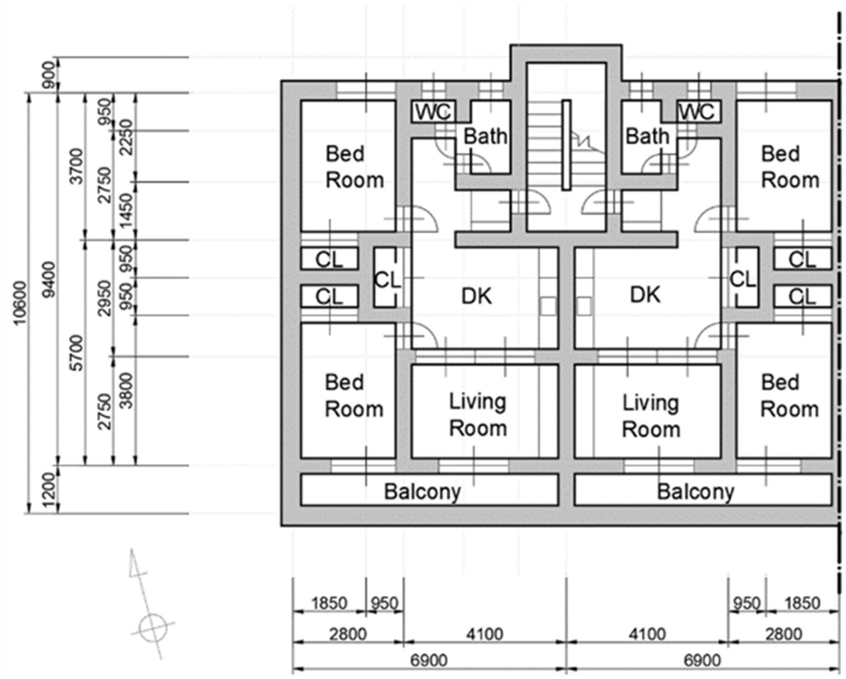

Figure 1. Detailed drawing of the building to be analyzed (four units exist, inverted).

Table 2. TRNSYS calculation conditions.

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

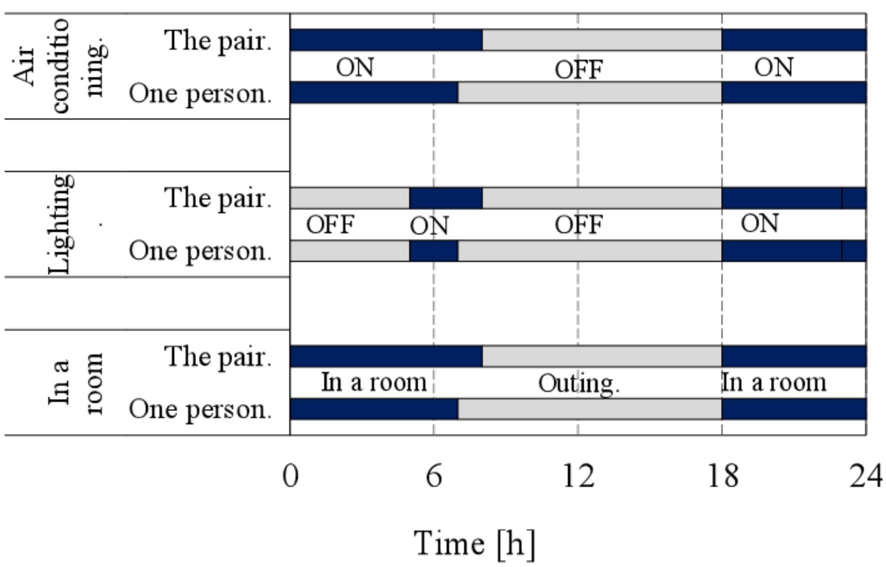

Figure 2. Presence schedule used in the numerical analysis.

Table 3. Wall configuration for analysis.

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

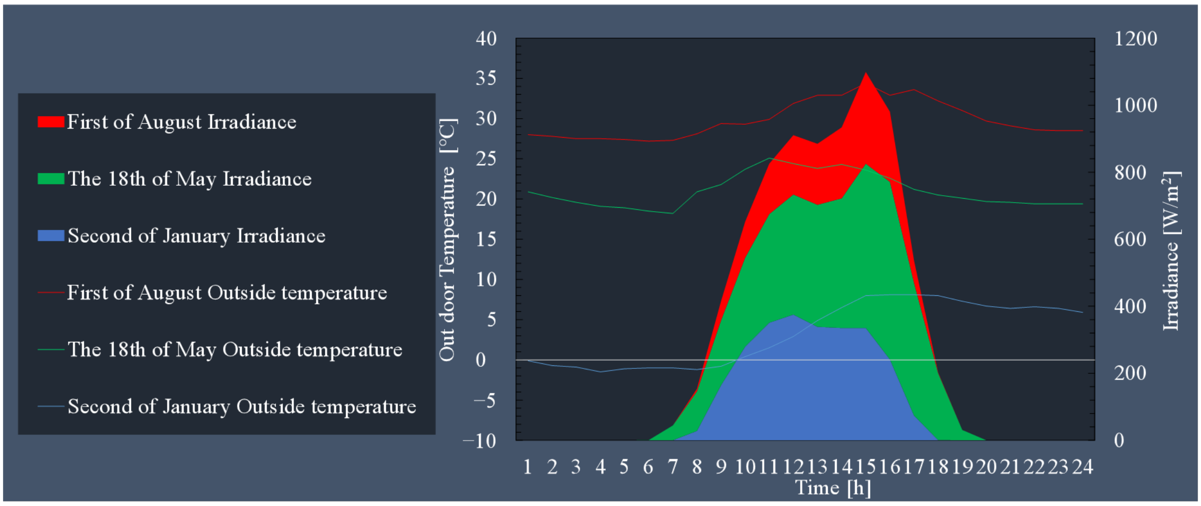

Figure 3. Typical daily temperature variation and solar radiation in Kurume city.

3. Results

In this section, we present a thermal environment analysis of the vacancy status of adjacent rooms, along with a description of the calculation contents and conditions applied. The calculation conditions follow the verification method. The occupancy schedule is calculated and compared to the housing stock using the same method as the insulation retrofitting verification method. **Table 4** categorizes cases based on vacant location and number of household members. Categorizing vacant rooms acknowledges 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. Generally, vacancies do not significantly impact the thermal environment in its natural state. However, the difference from no vacancy tends to be larger in January when the lower part of 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 effect of the insulation retrofit 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 or cooling in adjacent rooms. This evaluation method can be used to estimate the thermal environment's potential in each area.

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

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		
	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 5. MAE calculation for each room on representative days.

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

Table 5. *Cont.*

Case		The Number of Persons [People]	Empty Room	January 2nd [°C]		May 18 [°C]		August 1st [°C]	
				BED	DK	BED	DK	BED	DK
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
	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 6 shows the areas where insulation retrofitting occurred. Regarding the retrofit sites, we limited ourselves to the most common areas. This reduces the difficulty of making relative comparisons due to an increased number of cases. The insulation uses rigid polyurethane foam and glass wool, which are generally used for retrofitting.

The window surfaces were made with Low-E double glazing, which can be used in both summer and winter. After the renovation, the UA value was 0.56 [W/m²K], meeting the ZEH standard.

Table 6. Areas of insulation retrofit.

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 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.

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

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

4. Discussion

Table 8 shows the sensible heat load in each main room during heating and cooling periods. Comparing the values with and without insulation retrofitting shows that the difference is about 500 kW during the winter. Improved insulation performance significantly reduces the heating load. Typically, heat load increases in the summer as insulation improves. This is expected to be due to the flow of heat through window surfaces, which keeps the room warm. The significant difference in heat load between the bedroom and dining room (DK) is likely due to the bedroom's exposure to outside air and its proximity to the window surface.

As for the ceiling, it appears that the heat load increased during the winter. One possible reason for this increase is that modeling 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 due to the windows facing outside. No insulation effect was observed during the summer.

The insulation renovation was found to have had an effect on the floor 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 insulating the floor transports heat to the next room. The increase in cooling load during the summer is thought to be due to the 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 winter, resulting in a noticeable reduction in heating load. However, the heating load in DK increased in the middle of the year. Although the increase is not significant, the retrofit has had a negative effect on insulation. This is expected to be due to solar radiation following the insulation improvement.

There was no significant effect on the heating load during the winter months for window surfaces. However, the heating and cooling loads were found to increase in the middle of the year and during the summer months. Since the difference is small, though, the impact of window insulation retrofits on multifamily housing is minimal.

As with floors and walls, the same phenomenon occurs with all renovations during the intermediate period. Additionally, the cooling load increased by about 200 kW during the summer. The results show that renovating during the summer has a negative impact. This finding is important for 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. From a thermal perspective, insulating the ceilings and floors is desirable. However, property values are difficult to infer solely from a temperature perspective. In the next section, we will discuss the correlation between "thermal environment" and cost, taking into account both cost and heat load.

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

Case		Repairs	Adjacent HVAC	Winter (1/2) [kW]		Midcycle (5/18) [kW]		Summer (8/1) [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
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

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.

Calculation Results and Discussion:

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

However, retrofitting walls is less expensive, yet the retrofit value is the same as a whole-house retrofit. Case 3-1 produced more effective results than a whole-house retrofit, and other suggestive results were obtained. In all cases, the heat load was higher on the left side than on the right side. 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. The areas where insulation renovation is most cost-effective are clear. We hope that everyone at Space R Design, Inc., will consider retrofitting their insulation as well.

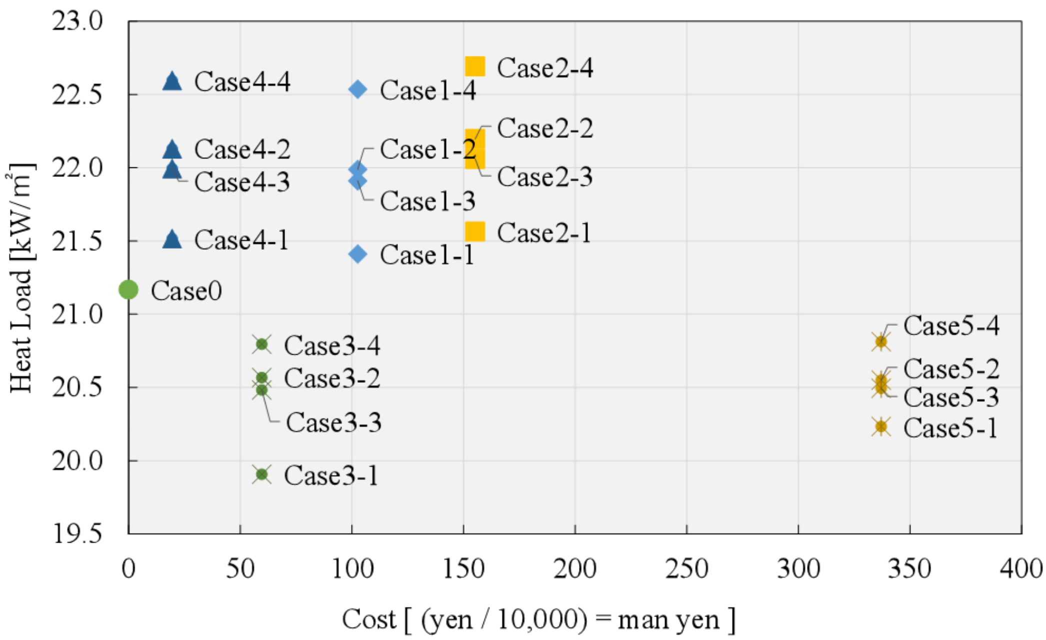

Figure 4. Bidirectional evaluation of heat load and cost per unit area.

5. Conclusions

This study thoroughly analysed the correlation between heat and cost in DIY. Rather than being a case study, it is a realistic analysis that can be used as a reference for implementation. The following highly suggestive findings and perspectives were obtained from the study:

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.

The conclusions did not change when comparing the verification results of heating and cooling loads, regardless of whether the adjacent room was unoccupied. Examining the correlation with cost provided more practical, generalised data.

In conclusion, the wall insulation retrofit is more effective and less expensive. However, increasing the wall surface thickness can make the space feel oppressive, which offsets the retrofit's benefits. This concern is based on the building's composition and the client's preferences. Although this study did not address this issue, we would like to emphasise that we consider the effect on spatial composition an important future factor.

In the future, it would be desirable to review older housing complexes from both a thermal and an energy perspective. This could be done step by step or by compiling a database of valuable data for prompt utilisation. Special mention should be made of the management of the Edoyashiki Corporation, managed by Space R Design, Inc.

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. In conclusion, we must not forget that cost-based considerations are limited.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data is available upon request.

Conflicts of Interest

The author declares no conflict of interest.

Note

1) Report of the Council for Social Infrastructure Development (Housing and Lots Subcommittee): "On the Institutional Framework for a New Housing Policy, September 26, 2005.
2) Ministry of Land, Infrastructure, Transport and Tourism, Housing Bureau. "Report on Housing Market Trends in FY2021." March 2022.
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%.
5) Japan Housing Reform Promotion Council, "Report on the Results of the FY2020 Consumer Survey on Housing Reform," February 2021, p. 16.
6) Katsumi Yoshihara and Naho Yoshihara, "Aged Real Estate Management Revitalization Starting with a College in the Apartment Complex 'Corpo EDOYASHIKI' (Kurume City, Fukuoka Prefecture) in a Private Rental Apartment Complex, and Subsequent Area Revitalization: Synchronous Method of DIY Design, Community Design, and Market Design," 2019 Annual Conference of the Architectural Institute of Japan (Hokuriku) Building and Social Systems Division Research Council Materials, Architectural Institute of Japan, September 2019, p. 34.
7) From interviews with current owners.

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