MALAYSIA ARCHITECTURAL JOURNAL

Malaysia Architectural Journal

Journal homepage: https://majournal.my/index.php/maj
e-ISSN : 2716-6139

Do Renovation of Kominka Offer an Efficient Path to Town Revitalization and Energy Efficiency?

Aakriti Shrestha[1]*, Takafumi Shimizu[2]

[1] Architectural Design Course, Major in Science and Engineering for Innovation, Graduate School of Natural Science and Technology, Shimane University
[2] Architectural Design Course, Institute of Environmental Systems Science, Academic Assembly, Shimane University

ARTICLE INFO

Article history:
Received: 30 April 2024
Received in revised form
Accepted: 15 October 2024
Available online: 23 June 2025

Keywords:
Kominka (old house) renovation; Community-oriented space; Thermal studies; Town revitalization; Circular economy

ABSTRACT

In Japan, collaborative public-private efforts are being made to renovate and reutilize the older buildings with the aim of preserving historic townscape and adapting them for commercial and communal needs. Subsidies are granted for maintenance and renovations of these buildings, which have attracted local businesses (cafes, shops, and offices) and have become venues for cultural activities, and gatherings. Renovations are done with no external wall insulation as it alters building physical characteristics and conservation principles, whereas internal walls are avoided as they are designed to facilitate the community. However, the energy cost of such buildings is generally high that can discourage people using them in the long-term thus, affecting town revitalization approaches. Therefore, it is important to understand the actual thermal environment of renovated old houses for sustainable and economically viable town development. With this aim, we surveyed a newly renovated kominka, now used as multipurpose library to understand the temperature distribution in shared and private spaces with and without use of air conditioning systems during the winter month. Similarly, the thermal characteristics of building elements were studied using a thermal camera, which shows uneven thermal distribution and leakages through the wall, floor, and roof after using AC. The surveyed building was renovated with the approximate cost of 150 million yen, with this study we can assume, there will be additional burden of annual energy cost due to the poor thermal insulation. Thus, there is a need for energy efficient renovation approaches.

1. Introduction

The rural part of Japan is a home to a diverse array of traditional wooden buildings including farmhouse (minka), temples, shrines, tea house, merchant house with distinctive architectural features

* *Corresponding author.*
E-mail address: aakritishrestha057@gmail.com, shimizu@riko.shimane-u.ac.jp

characterized by local climate, available building materials, and culture.

These rich architectural characteristics contribute significantly to the historic landscape of the town. However, most parts of rural and old urban areas of Japan have lost its historical streetscape due to ageing population, relocation of younger generation and demolition or reconstruction of abandoned houses [1]. In the last two decades, local governments have been formulating several model projects for reviving and preserving the historic streetscape to enhance awareness among residents. These projects are designed not only to protect old houses, but also to be used by local people. There are many examples where kominka (old town houses) have been redeveloped and used as a public venue for cultural activities and guesthouses, public facilities for events, concerts, and exhibitions in the town [1]. As these buildings maintain the original façade in their new construction, there are no or very less studies regarding actual thermal environment of renovated kominka after being used in the context of Japan. Therefore, in this study, we have surveyed the indoor thermal condition of renovated kominka, which is recently transformed into multipurpose library for Omori residents and tourists.

In order to maintain physical characteristics and conservation principles, historic and traditional buildings lack exterior wall insulation following their vernacular construction method [2]. The United States [3, 4], the European Union [5] and the United Kingdom [6] have exempted historic building from energy regulation to protect the potential risk of retrofit. However, several past researches on energy retrofit highlighted historic buildings responsible for 20-40 % of total energy consumption [7] and approximately one-third of global energy related CO_2 emissions [8]. This has attracted the attention of policy maker and preservationists to consider energy regulatory exemption, since upgrading the historic building to current needs will ensure their continuous use rather than being neglected and demolished [9, 10]. From this perspective, it is important to understand the actual thermal environment of existing and renovated historic buildings to keep using it without bearing additional cost of energy consumption in the future.

For this study, newly renovated kominka now used as multipurpose library has been investigated during the wintertime with and without use of air conditioning systems (AC). The surveyed building is in Omori area in Oda city, Shimane prefecture, once home to a silver mine whose production reached one-third of the world's silver nearly four centuries ago (between 1526–1923) [11]. During that time, the population of the town was approximately 200,000, which declined sharply after the mine was closed in 1923. Following the closure of the mine, the town became deserted as residents moved away and abandoned wooden houses disintegrated, eventually reclaimed by dense forest labelling into a ghost town [12]. With the combined efforts of local government, business, and the community, Omori ginzan area was established as UNESCO world heritage site in 2007, transforming from a ghost town to a vibrant community. To maintain the historic landscape of the town, these buildings are renovated with no external wall insulation that can lead to an increase in energy cost, thus discouraging people using them in the long term. This can affect town revitalization efforts being made by the people to rejuvenate the town. It is important to address this issue as the town could once again face the possibility of decline. Shrestha and Shimizu [13] studied the actual thermal environment of well-preserved samurai residence at Omori town during the summer and wintertime and revealed severe indoor temperatures of below 1.5 °C in winter. This clearly demonstrates the inevitable rise in energy cost. Therefore, in this study, we have focused on understanding the actual indoor thermal environment of newly renovated kominka with and without heating during the extreme winter.

The winter measurement was conducted for 5 consecutive days with and without using AC. The thermohygrometers were kept in different places (public and private) to understand temperature distribution within spaces and with respect to the outside temperature under both setting AC and non-AC. Similarly, when AC was turned on, thermal characteristics of building elements were studied using a thermal camera to understand the temperature distribution and leakages through floor, roof, and walls. Finally, conclusions were made based on the on-site thermal measurements. The study's findings are expected to reveal the issues regarding inefficient thermal performance after the construction.

2. Methodology

2.1 Overview of measurement site

As shown in **Fig. 1**, the colored portion on map indicates the location of surveyed building, which is in globally recognized place specifically within the UNESCO World Heritage Site in Omori town at Shimane prefecture. This surveyed building was believed to have been built after the Great Kansei fire of 1800, which destroyed the entire town [14]. This two-story wooden house known as Matsubara family residence was one of the influential merchant families in the 18th century that brewed and sold vinegar in the Omori town. Historically, this house holds significant importance as it was the birthplace of Junichi Matsubara (1884 –1952) who served as the president of the Bank of Korea [15]. Besides, this residence is located on the main street of the Iwami Ginzan Silver mine, which was registered as a UNESCO World Heritage site in 2007. In 1969, the silver mine and surrounding villages have been designated as Special Preservation District for groups of historic buildings therefore, renovations were done preserving the historic characteristics of the town. This residence was in dilapidated condition until 2016, when it was acquired by the Nakamura Brace company. Between 2021 and 2023, the company collaborated with Shimane prefectural university to undergo major renovations of the residence, preserving the building's distinctive exterior while redesigning the interior to meet the needs of children, citizens, and tourists. In 2023, the building was opened as a multipurpose library.

Fig. 2-3 presents the exterior and interior views, while the architectural planning is illustrated in **Fig. 4**. On the first floor there are two library spaces, one with lantern style bookshelves and another with Iwami Ginzan mine shaft bookshelves (see **Fig. 2 (b-c)**). For this measurement, these two library spaces are named as open book space (resembling lantern style bookshelves) and closed book space (resembling mine shaft bookshelves) (see **Fig. 4 (a)**). The red dot seen in the architectural planning represents the thermal measurement points on the first and the second floor (see **Fig. 4**).

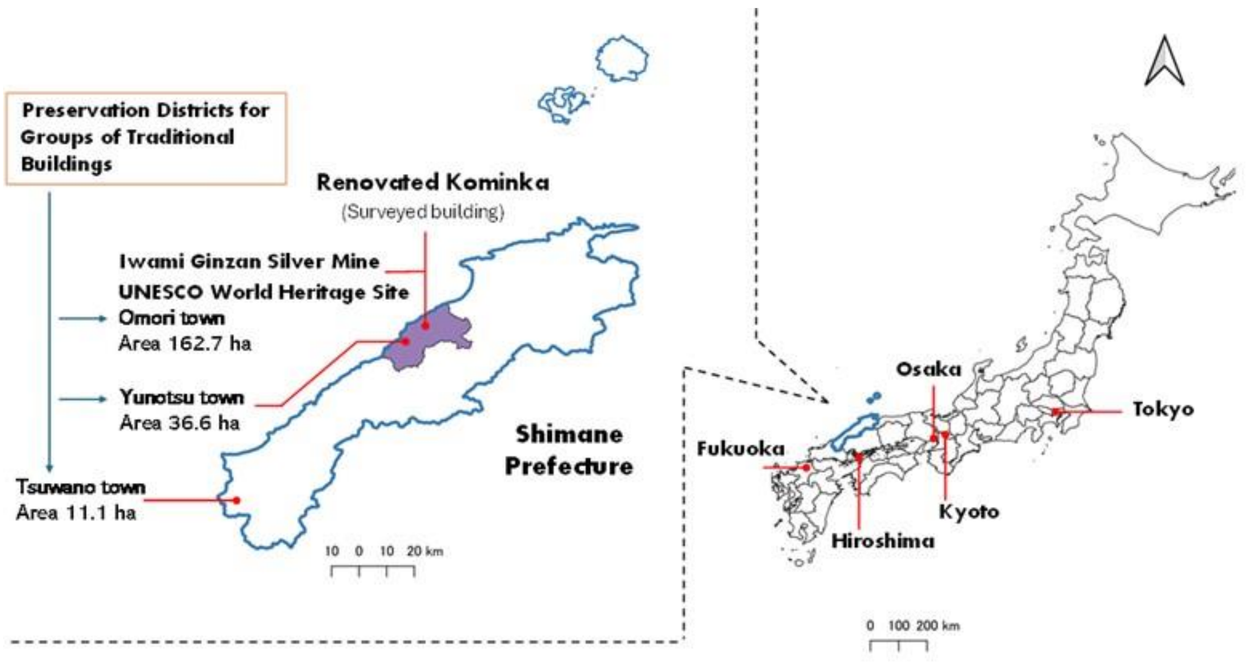
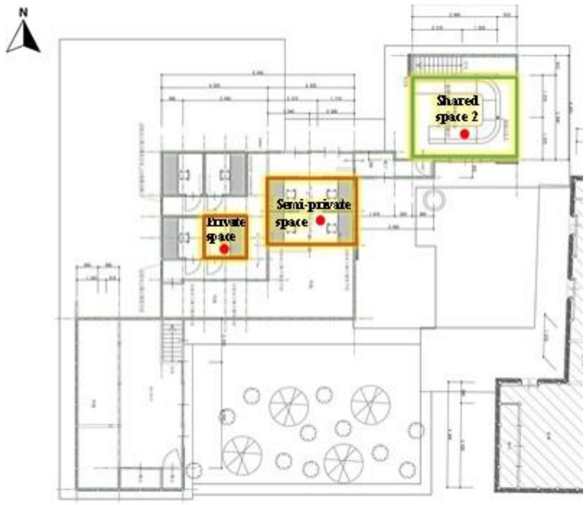


Fig.1. Map showing location of measurement at Omori town in Shimane prefecture

Fig. 2. Interior view of first floor showing (a) Omori Ginzan settlement (b) Open book space (c) Closed book space (d) Passage (e) Shared space 1

Fig. 3. Interior view of second floor showing (a) Shared space 2 (b) Semi-private space (c) Private space

(a) First floor



(b) Second floor

Fig. 4. Architectural planning of the surveyed building with red dot showing measured spaces (a) First floor planning (b) Second floor planning (Architectural drawing: source reproduced with permission by Nakamura Brace Co. Ltd.)

2.2 Measurement setup

Fig. 2-3 shows the interior view of surveyed building with the thermohygrometers placed 1,100 mm height from the base in the center of each room. The thermohygrometers used for indoor measurement was an A&D AD-5695DL with the measurement accuracy of ±0.6 °C and range of 0-50 °C. Similarly, the thermohygrometers used for outdoor and foundation was a T&D TR72A with the accuracy of ±0.5 °C and range of 0-55 °C. Additionally, an Eko MS-40 pyranometer with a sensitivity of approximately 10 µV/W/m² was set on the south side in the patio to measure the solar irradiance of the day during the measurement time.

As seen in Table 1, the winter measurement was conducted for 99 h with and without using AC. Initially, the first 4 h, the measurement was carried out using AC while the next 66 h, the measurement was taken without using AC. On the fourth and fifth day, measurement was performed using AC for 24 h. On the last day, the AC was turned off again for 5 h between 11:00 am to 16:00 pm. In this study, the temperature of AC was set 25 °C in all the rooms. Similarly, we turned the AC on and off for intermittent hours to capture the thermal condition of rooms with respect to the outside temperature under both settings. Even though Omori Ginzan area received heavy snowfall in the wintertime [16], during the measurement period, the weather conditions were sunny, rainy, and cloudy.

Table 1 Winter measurement period

Date (Year/month/day)	Days of the week	Measurement time	
		With AC	With no AC
2023/02/24	Friday (Sunny)	13:00 pm–17:00 pm (4 h)	17:00 pm–00:00 am (7 h)
2023/02/25	Saturday (Rainy)		00:00 am–0:00 am (24 h)
2023/02/26	Sunday (Cloudy)		00:00 am–0:00 am (24 h)
2023/02/27	Monday (Sunny)	11:00 am–00:00 am (13 h)	00:00 am–11:00 am (11 h)

2023/02/28	Tuesday (Sunny)	00:00 am–11:00 am (11 h)	11:00 am–16:00 pm (5 h)

3. Results

3.1 Data overview

Fig. 5 (a) compare the indoor-outdoor temperature and solar irradiance distribution for the whole measurement time. On the first day, when AC was turned on for 4 h, the indoor temperature of semiprivate space reached 31°C followed by private space 29 °C within 2 hours of heating. While the shared space on the second and first floor elevated to 25 °C and open and closed book space rose to 21 °C. Similarly, the entrance and passage remained between 16-18 °C during the time, the outside temperature was found to be approx. 10 °C. Next AC was turned off for 66 h, the indoor temperature of all measured places ranges between 5-10 °C while the outdoor temperature was fluctuating throughout the day and nighttime (minimum -2 °C and maximum 14 °C). Afterward, AC was turned on for 24 h, the indoor temperature at semi-private and private space tended to stabilize between 28-30 °C while shared spaces in the second and first floor remained between 25-26 °C and open and closed book space between 21-22 °C throughout the AC time. The indoor temperature at entrance and passage ranges between 15-18 °C whereas outdoor remained between 11-15 °C during daytime and below 5 °C during nighttime. In contrast, temperature at foundation remained steady between 5-9 °C during the measurement period. Similarly, increase in solar irradiance during daytime shows little effect in the indoor temperature of the measured places.

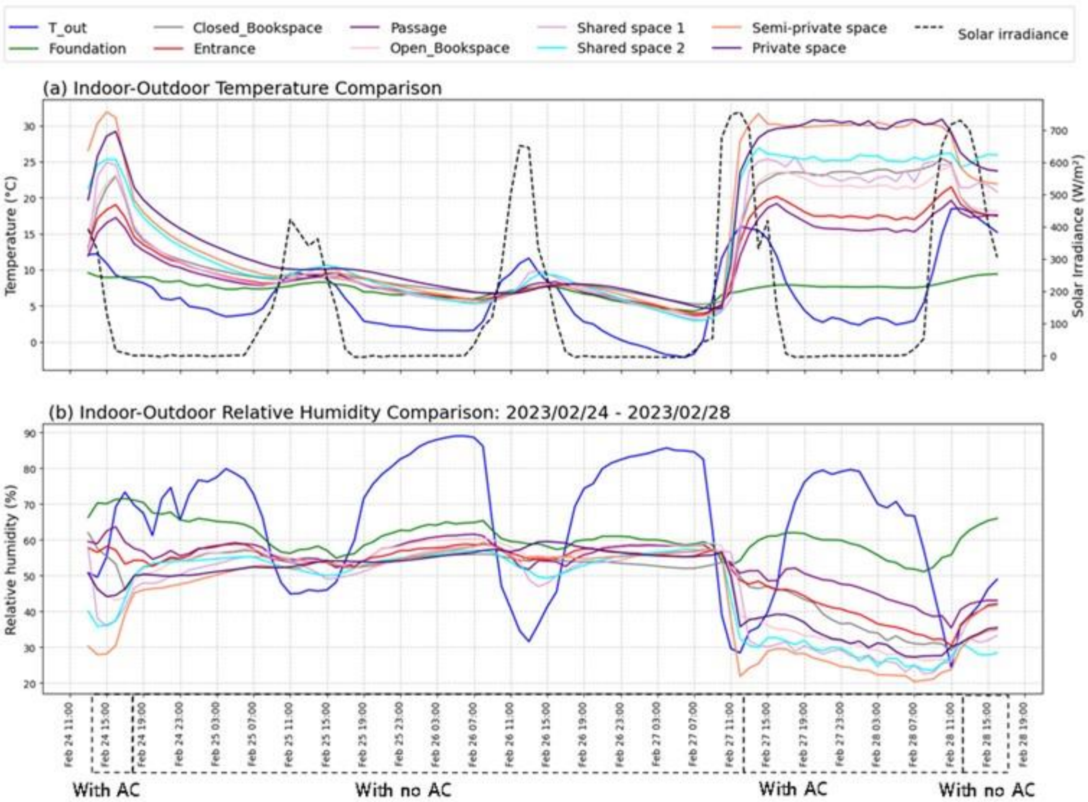


Fig. 5. Winter measurement for four days (a) Indoor-outdoor temperature comparison (b) Indoor-outdoor relative humidity comparison

Fig. 5 (b) compare the indoor-outdoor relative humidity (RH) for the whole measurement time. During the daytime, the outside relative humidity ranges between 40-50% while at nighttime increase to 70-80%. Without using AC, relative humidity for all measured indoor spaces remained between 50-60% during day and night-time. After using AC, the relative humidity reduced to 35-45% at all measured indoor spaces. In contrast, only slight changes (55-60%) were recorded in the relative humidity in foundation during both day and night.

3.2 Operative temperature and relative humidity distribution: With and without AC

Fig. 6 evaluate the comfort condition of the measured rooms with and without AC. **Fig. 6 (a)** compare the operative temperature and RH trends and variability in the indoor measured spaces without using AC. During the time, all measured rooms exhibit smaller interquartile range of operative temperature 6-9 °C and RH 50-60%, indicating lower variability during the day and night. Due to the use of AC on the first day (13:00–17:00 pm), shared space 2, semiprivate and private space's average operative temperature and RH remained relatively high 15-17 °C and 45-50% respectively during the night. Therefore, there are outliers on the higher end in the operative temperature of these spaces.

Fig. 6 (b) compare the changes in the operative temperature and RH in the indoor measured spaces after using AC. During the time, interquartile range of private and semiprivate space's operative temperature was notably small, indicating very narrow range of temperature variation (29-31 °C) within the period. In the case of other rooms, shared space 1 and 2, open and closed book space's operative temperature tended to stabilize between 22-25 °C, suggesting that all the room temperature remains relatively constant and stable when AC was used. While RH decreased sharply, with the minimum (below 30%) observed in semiprivate space, shared space 1 and 2. In contrast, closed book space exhibited wider interquartile range, with the RH ranging from 30-45% during the day and night. During the period, RH of closed book space and private space was found between 26-36% and 30-40% respectively.

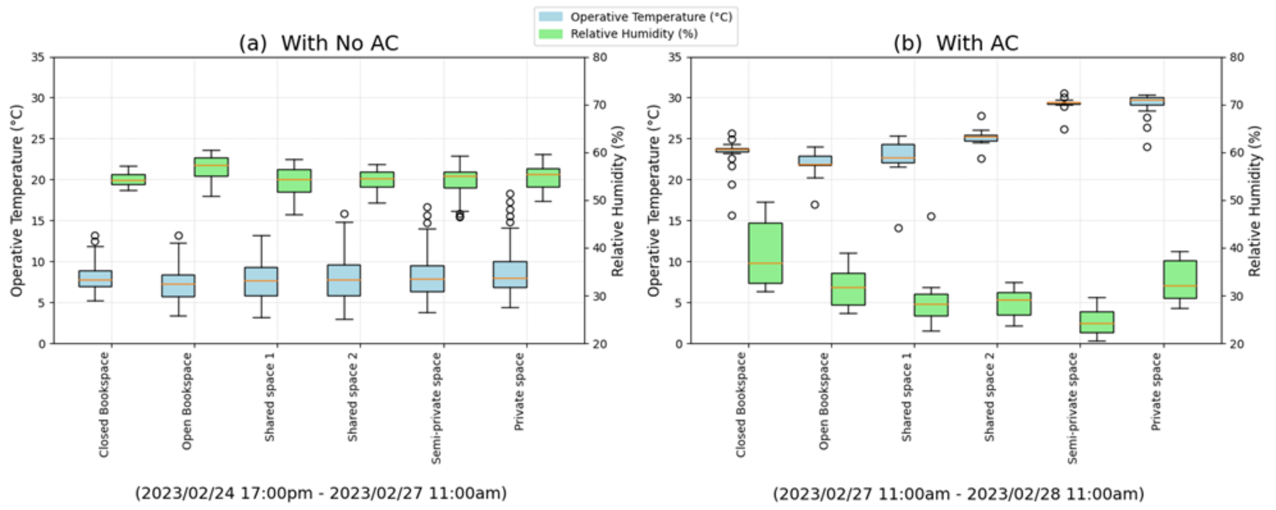


Fig. 6. Comparison of operative temperature and relative humidity within the measured rooms with and without AC

3.3 Comparison of indoor-outdoor temperature differences: With and without AC

Fig. 7 compare the thermal performance of the surveyed building based on the indoor-outdoor temperature differences with and without AC. **Fig. 7 (a)** shows the differences between indoor-outdoor measured places without using AC during 66 h of measurement time. The indoor temperature of all measured places was found to be 5-7 °C warmer than outside temperature during the nighttime, while minimum temperature difference (0.5-1 °C) was found during the daytime. On the first day when AC was turned off after 4 h, shared space 2, semiprivate and private space remained warmer (8.5-11 °C) than the outside temperature at night without AC while the other rooms exhibited similar tendency, being 6 °C warmer.

Fig. 7. (b) shows the temperature differences between indoor-outdoor when AC was turned on for 24 h. During the nighttime, closed and open book space and shared spaces 1 and 2 were found to be 18-21°C warmer, while semi-private and private spaces were found to be 27-28 °C warmer than outside temperature. Whereas in the daytime, maximum temperature differences were found to be approx. 10 °C between measured places.

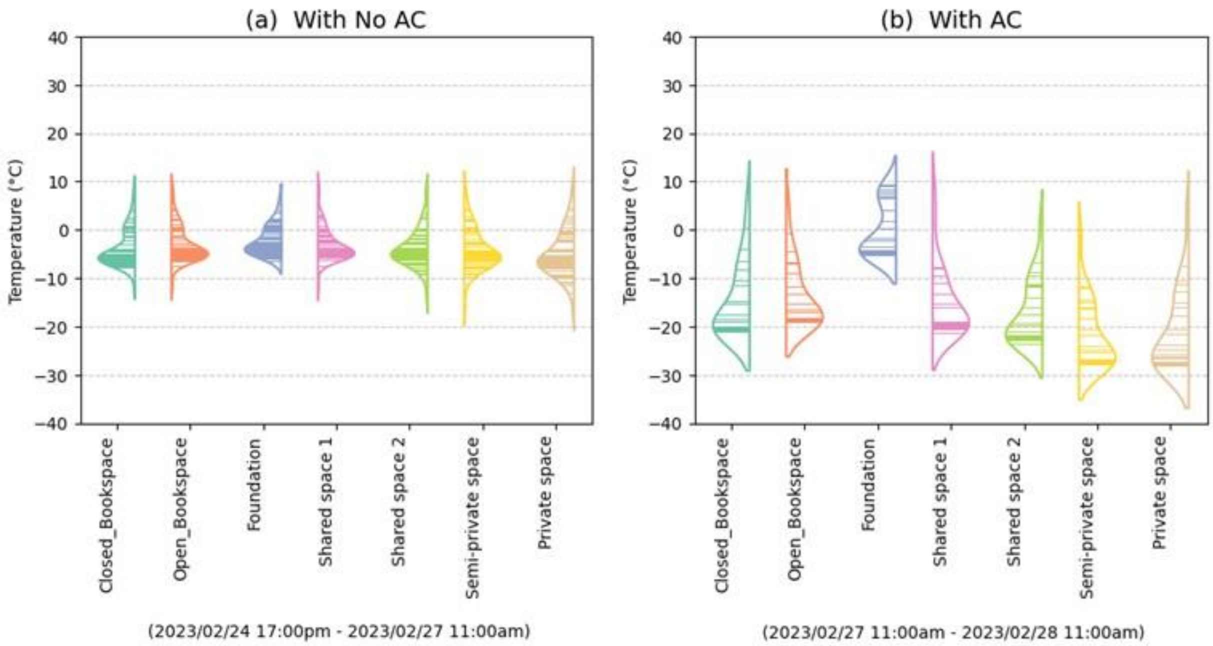


Fig. 7. Temperature differences within the spaces with and without use of AC

3.4 Thermal distribution with AC using Thermal Camera

Fig. 8 shows the thermal distribution in the closed book space after using AC. As shown in **Fig. 8. (b, c)**, the temperature difference of heat source and area below it was found to be more than 20 °C. This significant drop in temperature, suggesting heat being not efficiently spread throughout the room. Consequently, maintaining a consistent room temperature require more effort from AC, affecting overall efficiency and comfort.

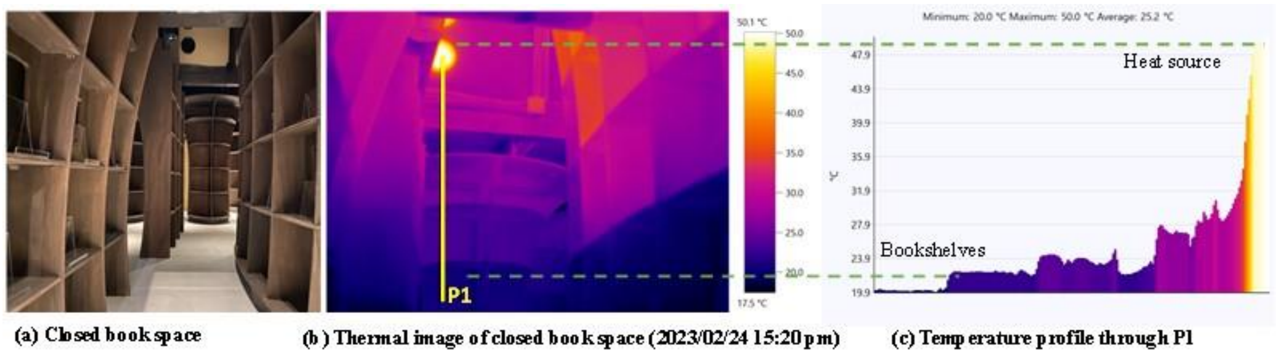


Fig. 8. Thermal distribution in closed book space when AC was turned on

Fig. 9 shows the thermal distribution of entrance when AC was turned on. The thermal image and temperature profile through P1 depict significant temperature gradient between wooden door at head level and stone floor. This temperature stratification within the spaces can affect change in indoor temperature and thermal comfort in the room.

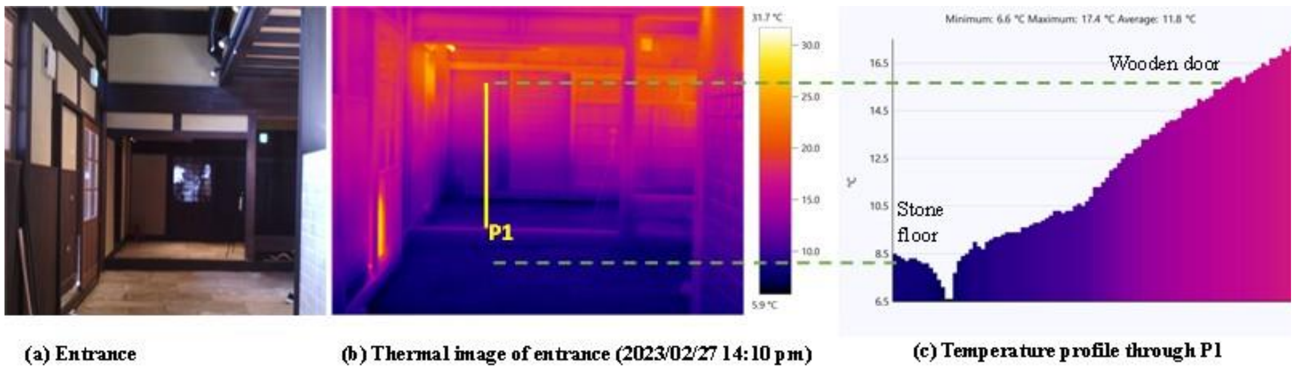


Fig. 9. Thermal distribution in entrance when AC was turned on

Fig. 10 shows the thermal distribution in bookshelves when AC was used. As shown in **Fig. 10. (b, c),** the vertical temperature distribution was found to be more than 10 °C. Similarly, there is significant temperature difference between AC setting temperature (25 °C) and the surface temperature of tatami flooring (rice straw mat), which was found to be approx. 12 °C. This shows during the wintertime, it is uncomfortable to walk and do other activities in this space due to coldness even after using AC.

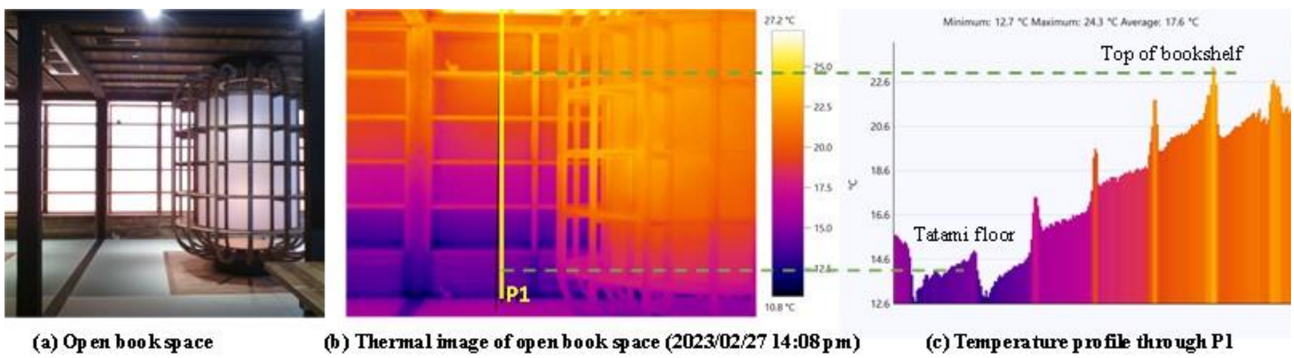


Fig. 10. Thermal distribution in open book space when AC was turned on

Fig. 11 shows the thermal distribution on carpet floor in the shared space 1 after using AC. As shown in (**Fig. 11. (b, c)**), the area of carpet floor directly exposed to AC was found to have maximum temperature approx. 27 °C, whereas the carpet area not directly reached by AC exhibit 17 °C. This shows temperature differences of 10 °C within the space while using AC.

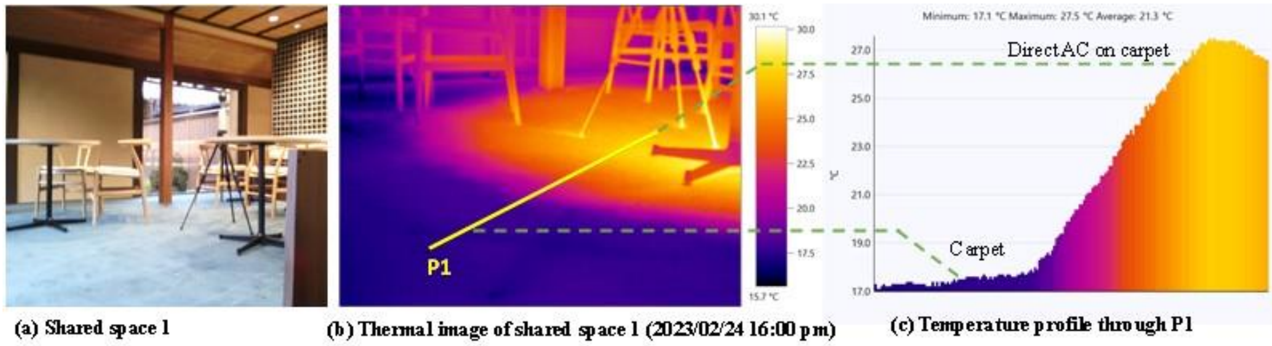


Fig.11. Thermal distribution on carpet floor in shared space 1 when AC was turned on

Fig. 12 shows the thermal distribution of ceiling and shikkui wall in the shared space 2 when AC was used. As shown in **Fig. 12 (b),** the thermal image of shikkui wall reveals the interior structure of the timber frame, suggesting a lack of sufficient insulation on the wall. Similarly, in **Fig. 12. (c)**, the thermal image reveals uneven surface temperature or cold spot in the ceiling, indicating poor insulation that can result energy loss from the wall and roof during winter.

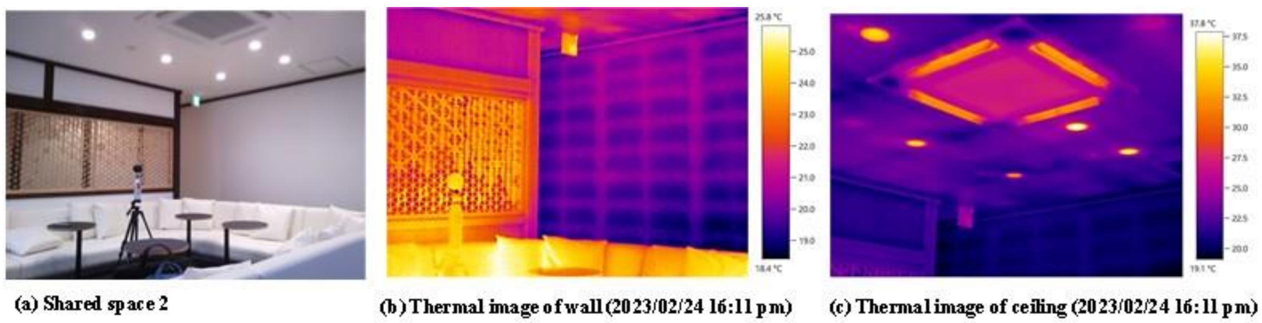


Fig.12. Thermal distribution of wall and ceiling in shared space 2 when air conditioner was turned on

4. Discussion

In this paper, we studied the actual thermal condition of newly renovated kominka (old house) used as multi-purpose library during the wintertime with and without AC. Without the AC, the indoor temperature of all measured places shows a smaller temperature difference of 5-7 °C (nighttime) and 0.5-1 °C (daytime) than the outside temperature. This suggests poor insulation of rooms, which is not sufficient to maintain a significant warmer indoor environment without active heating. Note: on the first day when AC was used for 4 h and turn off during night, shared space 2, semiprivate and private space remained warmer (8.5-11 °C) than the outside temperature while the other rooms exhibited similar tendency, being 6 °C warmer. This suggest compared to other rooms second floor rooms store heat for longer periods making the room comparatively warmer. Similarly, all measured rooms show the operative temperature of 6-9 °C and RH 50-60%, indicating lower comfort condition during the day and nighttime.

When AC was used with setting temperature 25 °C, the indoor temperature at semi-private and private spaces stabilizes between 28-30 °C while shared spaces in the second and first floor remained between 25-26 °C and open and closed book space between 21-22 °C throughout the AC time. The indoor temperature at entrance and passage ranges between 15-18 °C whereas outdoor remained between 11-15 °C during daytime and below 5 °C during nighttime. This shows all rooms except entrance and passage was found to be more than 20 °C warmer than outside temperature during nighttime. Similarly, the operative temperature of private and semiprivate space was found to be 29-31 °C, while other rooms, shared space 1 and 2, open and closed book space was found between 22-25 °C with minimum RH below 30-45%. Based on the thermal comfort set by ASHRAE standard 55 [17], 96.5% of the complaints occurred at temperatures less than 21 °C and RH 30% or greater than 24 °C and RH above 60%. This indicate semi-private and private spaces is likely to be too warm due to excessive heated, which lead to discomfort for occupants. Shared spaces in the second and first floor located in south is likely to be slightly warm, while open and closed book space remained between 21-22 °C within the ASHRAE standard indicating comfortable condition.

Following the result obtained from the thermal camera, the temperature gradient within the rooms was significantly higher indicating inefficient heat distribution throughout the room. Consequently, AC may need to work harder to maintain a consistent room temperature, affecting the overall efficiency and comfort. Similarly, the ASHRAE standard 55 [17], ISO 7730 [18] and several other researchers set an acceptable limit of 3 °C/m, 4 °C/m, 5 °C/m and 8 °C/m between head and feet to reduce local thermal discomfort [19-24]. However, our result shows the vertical temperature differences in the measured spaces more than 10 °C, which could lead immense discomfort in the feet while standing, walking in the rooms during winter months.

Therefore, with these results, it is important to understand whether the renovation of old houses can offer an efficient path to town revitalization and energy efficiency.

5. Conclusions

This paper presents the actual indoor conditions of renovated kominka (old house) located in Omori town during the wintertime with and without using AC. The indoor conditions of the measured rooms without AC ranges between 5-10 °C, while after using AC, rooms were more than 20 °C warmer than outside temperature during the nighttime. Based on the ASHRAE standard 55, the surveyed building shows lower comfort condition during the day and nighttime without AC. After using AC, semi-private and private spaces is likely to be too warm due to excessive heated while shared spaces in the second and first floor located in south is likely to be slightly warm. Whereas open and closed book space remained between 21-22 °C within the ASHRAE standard indicating the comfortable condition. Similarly, vertical temperature differences indicate inefficient heat distribution throughout the room. Their result shows temperature gradient of more than 10 °C at different height with the surface temperature of tatami flooring being approx. 12 °C. This can lead to discomfort in the feet while walking or doing other activities due to coldness even after using AC.

The surveyed building was renovated with the approximate cost of 150 million yen, with this study we can assume, there will be additional burden of annual energy cost due to the poor thermal insulation. **Fig. 1** shows Shimane prefecture consist of three important towns (Omori town, Yunotsu town and Tsuwano town) recognized as preservation districts for groups of traditional buildings. To preserve and continue using the traditional wooden houses, Japan government provides financial support up to 1.2 million yen for renovations. If these buildings are renovated understanding the indoor thermal condition and comfort for occupant, financial supports can be efficiently utilized. Therefore, the understanding of actual indoor conditions is crucial in town revitalization and the circular economy. By accessing the actual indoor condition of the renovated building allows for the implementation of sustainable building practices. This can reduce the carbon footprint of buildings, contributing to the broader goals of a circular economy and sustainable town revitalization.

Acknowledgement

We are grateful to Mr. Tetsuro Nakamura, executive director of Nakamura Brace Co. Ltd., Mr. Takashi Yoshiya, Shimane Prefectural Center for Climate Change Action, Mr. Esumi Toshiaki, Shimane Prefectural Institute of Public Health and Environment Science for their continuous support and contribution. Additionally, this research has received funding from Matsui Kakuhei Memorial Foundation.

References

[1] Utazu Town. Reviving Traditional Japanese Kominka to Revitalise Fading Urban Areas. Available: https://www.clair.or.jp/e/5-2Utazu.pdf

[2] Webb A. L. (2017). "Energy retrofits in historic and traditional buildings: A review of problems and methods," Renewable and Sustainable Energy Reviews, vol. 77, pp. 748–759. Available: http://dx.doi.org/10.1016/j.rser.2017.01.145

[3] ASHRAE, S. (2013). Standard 90.1-2013. energy standard for buildings except low-rise residential buildings. Am. Soc. Heating, Refrig. Air-Conditioning Eng. Inc, 278.

[4] Council, I. C. (2006). International energy conservation code.

[5] European Parliament. (2010). Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings (recast). Off J Eur Union. [L153].

[6] HM Government. (2010). The Building Regulations 2010 Conservation of Fuel and Power Approved Document L1B: Conservation of Fuel and Power in Existing Buildings other than Dwellings.

[7] Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and buildings, 40(3), 394-398. Available: http://dx.doi.org/10.1016/j.enbuild.2007.03.007.

[8] Ürge-Vorsatz, D., Danny Harvey, L. D., Mirasgedis, S., & Levine, M. D. (2007). Mitigating CO2 emissions from energy use in the world's buildings. Building Research & Information, 35(4), 379-398. Available: http://dx.doi.org/10.1080/09613210701325883.

[9] Carbonara, G. (2015). Energy efficiency as a protection tool. Energy and Buildings, 95, 9-12. Available: https://doi.org/10.1016/j.enbuild.2014.12.052

[10] Crockford, D. (2014). Sustaining our heritage: The way forward for energy-efficient historic housing stock. The Historic Environment: Policy & Practice, 5(2), 196-209. Available: https://doi.org/10.1179/1756750514Z.00000000051

[11] Ohda City Board of Education Nomination of THE IWAMI GINZAN SILVER MINE AND ITS CULTURAL LANDSCAPE for Inscription on the World Heritage List. Available at: https://whc.unesco.org/uploads/nominations/1246bis.pdf Accessed 08 March 2024.

[12] Onishi, N. (2008) From Ghost Town to Boom Town. The New York Times. Available: https://www.nytimes.com/2008/09/05/world/asia/05japan.html

[13] Shrestha, A., & Shimizu, T. (2023, July). A Field Investigation on the Thermal Environment of Traditional Japanese Houses at UNESCO World Heritage Site: A Case Study of Former Oka House at Iwami Ginzan Silver Mine in the Omori Area in Oda City. In World Congress of Architects (pp. 59-78). Cham: Springer International Publishing.

[14] Oda City Board of Education. (2011). Iwami Ginzan World Heritage Center. Available at: https://ginzan.city.oda.lg.jp/wp-content/uploads/2022/03/2011_nenpo.pdf Accessed 10 April 2024.

[15] San'in Chuo Shimpo. (2022). Local companies and prefectural university students turn a former merchant house in Iwami Ginzan into a library. Available at: https://www.sanin-chuo.co.jp/articles/-/199873 Accessed 01 April 2024.

[16] Japan Meteorological website . Available at: https://www.data.jma.go.jp/obd/stats/etrn/view/monthly_s3_en.php?block_no=47741&view=14 Accessed 08 January 2024.

[17] ANSI/ASHRAE Standard 55-2017. (2017). Thermal Environmental Conditions For Human Occupancy, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA.

[18] ISO 7730. 2005. Ergonomics of the thermal environment - analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, Geneva, Switzerland.

[19] Olesen, B. W., Scholer, M., & Fanger, P. O. (1979). Discomfort caused by vertical air temperature differences. Indoor climate, 36, 561-578.

[20] Wvon, D. P., & Sandberg, M. (1996). Discomfort due to vertical thermal gradients. Indoor Air, 6(1), 48-54. doi: 10.1111/j.1600-0668.1996.t01- 3- 0 0 0 06.x .

[21] TANAKA, M., YAMAZAKI, S., OHNAKA, T., TOCHIHARA, Y., & YOSHIDA, K. (1986). Physiological reactions to different vertical (head-foot) air temperature differences. Ergonomics, 29(1), 131-143. doi: 10.1080/00140138608968246 .

[22] Yu, W. J., Cheong, K. W. D., Tham, K. W., Sekhar, S. C., & Kosonen, R. (2007). Thermal effect of temperature gradient in a field environment chamber served by displacement ventilation system in the tropics. Building and environment, 42(1), 516-524.

[23] Liu, S., Schiavon, S., Kabanshi, A., & Nazaroff, W. W. (2017). Predicted percentage dissatisfied with ankle draft. Indoor air, 27(4), 852-862. doi: 10.1111/ina.12364 .

[24] Möhlenkamp, M., Schmidt, M., Wesseling, M., Wick, A., Gores, I., & Müller, D. (2019). Thermal comfort in environments with different vertical air temperature gradients. Indoor air, 29(1), 101-111. doi: 10.1111/ina.12512 .