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Measurement of Indoor Thermal Environment and Analysis of Heating Energy Saving in Residential Buildings in Ulaanbaatar, Mongolia

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Abstract: Owing to the unique climate of Mongolia, the heat supply of residential buildings is a pressing social and economic problem. In Mongolia, the heat loss indicators for numerous residential buildings still exceed the standard. There is an urgent need to update and improve the architectural structure of residential buildings for energy saving. Few studies focused on energy consumption and the indoor environment in residential buildings in Mongolia. To provide effective and practical energy-saving measures, we conducted field surveys and measurements to clarify the energy consumption and indoor environment in residential buildings. A questionnaire was used to collect data from 100 households in Ulaanbaatar (the capital city of Mongolia), and five representative buildings were selected as the study objects to investigate the indoor thermal environment. The measurement result shows that the average indoor air temperature and relative humidity in the living rooms and bedrooms were 25.4 °C and 26.3%, 24.0 °C and 33.2%, respectively. The indoor air temperature was higher, and the air humidity was lower than the national standards. The average ventilation rate lies between a maximum of 71 m^3/h and a minimum of 46 m^3/h. The breakdown of the total heat loss shows that the ventilation heat loss of two objects is high. The total heat loss for the study objects was between 1.202–1.694 $W/(m^2K)$. The analysis result reveals that there exist great potential and effective measures to save heating energy.

Keywords: apartment building; heat loss; indoor thermal environment; field measurement

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1. Introduction

1.1. Background

Mongolia, a landlocked country in north-central Asia, has a population of 3.46 million. Ulaanbaatar, the capital city, is surrounded by four mountains. As the country experiences economic development, the population of Ulaanbaatar is increasing, leading to a centralized trend in population growth. In 2000, the population of Ulaanbaatar was 794.6 thousand; it had risen to 1596.3 thousand by 2022 [1]. On average, approximately 16,000 household apartments are constructed each year [2]. With the growth in population and housing, there is a significant increase in energy demands from the residents and related services. Three co-generation power plants and one heating plant distribute heating energy for space heating and hot water supply to buildings [3].

According to the data from 2023, the total heating energy produced amounted to 6532.6 gigacal [4]. With all plants operating at their maximum capacity, there is a risk of shortages if energy consumption continues to rise [3]. Therefore, energy conservation in residential buildings has become urgent and requires immediate attention.

With the progress of economic development, people's living standards have been on the rise, leading to an increase in the size of residential spaces in newly constructed buildings (built after 2000). Post-2018 statistics indicate a significant shift in the distribution of apartment sizes. The percentage of apartments with a floor area ranging from 21 to

40 m^2 and over 41 m^2 has increased by 41% and 3%, respectively, while that below 20 m^2 has decreased by 3.9% over a span of five years [5].

By the end of 2021, the total area of Ulaanbaatar's housing fund had reached 19.47 million square meters. However, the thermal specifications of the building envelopes in most buildings do not meet the relevant standards. Only 6% of residential buildings in Ulaanbaatar city satisfy the building thermal protection criteria. Although the thermal protection of recently constructed buildings has shown improvement, a considerable number of buildings still require major repairs and maintenance. In 2018, the percentage of buildings with more than 30% of wear was 37.7%, while those with 30–60% accounted for 47.7%. Furthermore, buildings with wear exceeding 60% made up 14.9% of the total. As a result, the energy consumption of older buildings is 2.5–3 times higher compared to newer buildings. Figure 1 illustrates the proportion of heat loss flow in residential buildings [6].

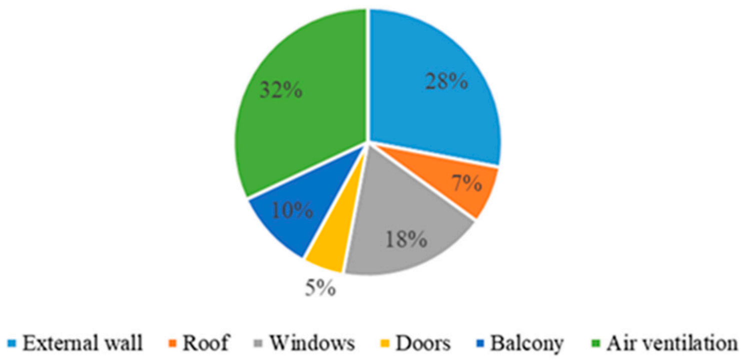

Figure 1. Heat loss flow of residential buildings, Ulaanbaatar city.

1.2. Issue Statement

The heating supply for buildings in Mongolia faces several challenges due to the arid and harsh continental climate. These challenges emphasize the need for energy savings and efficiency [7]. Some of the critical issues are as follows:

- The heating season in Mongolia spans eight months, lasting from 15 September to 15 May next year. During this period, the country experiences more than 6200 heating degree days on average.
- The most common type of apartment buildings in Mongolia were constructed during the 1970s and the 1980s using ore-cast panels (426 in the capital city). However, these buildings have a high rate of heat loss and increased energy consumption, reaching 600 kWh/m^2 during the heating season.
- The heating consumption in other reinforced concrete, brick and block buildings reached 400 kWh/m^2.
- The heat distribution network has low efficiency.
- The government does not subsidize energy costs or payments based on the heating demand. Consequently, sectors that are considered high-risk are likely to experience a significant increase in heating costs.
- The primary heating sources are from coal-fired power plants with low heat efficiency.

1.3. Research Purpose

In light of the challenges mentioned above and concerns, this study aims to examine the issues of energy consumption and energy efficiency in building construction in Mongolia, focusing on densely populated areas like Ulaanbaatar. Within the scope of this objective, this paper sets out the following specific goals: (1) to investigate the current heat loss conditions and indoor environment in residential buildings through empirical observations; (2) to identify factors affecting building heat loss and (3) to explore and propose potential solutions for reducing heat loss in buildings.

The novelty of the study is to scientifically identify the minimum allowable heat loss in residential buildings. The study has practical implications as its outcomes can be utilized to enhance the decision-making process in Ulaanbaatar city planning, with a specific focus on reducing heat loss. Additionally, the model developed in this study can serve as a valuable tool for planning energy-efficient heating systems, providing recommendations for optimal energy usage. Furthermore, it can assess the economic efficiency of the proposed measures in planning housing construction and the energy sector.

2. Literature Review of Related Works

The terms “energy efficiency” and “energy savings” were introduced in Mongolia in the late 1990s. Following this, in 2009, energy audit and energy efficiency concepts were incorporated into building norms and standards [8]. Moreover, in 2017, the government of Mongolia formulated a national energy-saving program and set the following goals [9]:

1. Save energy by enhancing energy efficiency;
2. Establish and expand a national electronic information system for consumers to provide information that promotes energy savings and efficient use;
3. Identify the allowable limits for heat loss coefficients in buildings based on weather conditions;
4. Conduct energy audits of commissioned apartment buildings;
5. Improve construction standards and normative documents regarding energy saving and align them with international standards;
6. Identify buildings in need of insulation and gradually reduce heat loss by 20%.

In Mongolia, research on heat loss and the indoor environment of residential buildings has received less attention compared to other energy-related topics. Most old apartment buildings in Ulaanbaatar were built following outdated Russian technology and standards. Consequently, the heat loss characteristics of these buildings have been assumed to be similar to those built in Russia since 1975.

In 2013, Satu et al. (2013), who estimated the heat consumption of prefabricated clay-concrete buildings in Moscow, found that reducing heat precast of exterior walls by 65%, roof heat loss by 77%, and window heat transfer by 36% could result in a decrease of 37% in total heat loss in apartments [10].

In 2014, Mandakh Sukhnaran conducted an in-depth analysis and research focused on the indoor thermal environment of buildings in typical small towns located in cold areas. This previous study also examined the adaptability of residents to the thermal environment in these towns. As a result of the research, Sukhnaran proposed thermal environment evaluation standards suitable for residents in small towns. Another finding is that the adaptable air temperature range for the residents in the small towns was between 11.5 °C and 18.9 °C; the fluctuation range was 4.1 °C; the temperature change rate was 0.6 °C/h; the effect temperature range was between 12.6 °C and 17.6 °C [11].

In 2018, Khandjamts Baatarsukh conducted a questionnaire survey focusing on the summer indoor environment of 10 residential buildings in Bayan-Ulgii Aimag. The study systematically analyzed the characteristics of the summer thermal environment of residential buildings in cold regions and explored potential strategies for enhancing the thermal environment. The results showed that the implementation of measures to improve the indoor thermal environment significantly improved the comfort of the living environment and energy saving [12].

According to a study conducted by Endo et al. in 2014, it was estimated that by adding an additional 14 cm of insulation materials to the walls and roof of an apartment building with an initial energy consumption of 48.28 GJ, the energy consumption could be reduced to 21.16 GJ [13]. This highlights the potential energy-saving benefits of improving insulation in buildings.

In 2018, Bilguun and Qingyuan Zhang studied energy consumption and the indoor environment in residential buildings. The study involved surveying, measurement and simulation to assess the current condition and recommended energy-saving measures. The heat loss coefficient ranged between 0.74 W/m^{2}K and 1.53 W/m^{2}K for apartment buildings [14].

A study conducted by Ozarisoy and Altan (2022a) presents the results of a questionnaire-based survey undertaken in August 2018 with 118 households in base-case representative residential tower blocks in South-Eastern Europe. The survey revealed that weekday cooling consumption patterns were significantly and strongly related to weekend heating consumption patterns (χ^2 = 54.590, $p < 0.001$, Cramer's V = 0.522) [15].

In Ozarisoy and Altan (2022b)'s study, they introduced a building energy performance framework developed based on the in-situ measurements of the building fabric thermal structure. The framework assesses robust energy performance evaluation and certification schemes in the residential sector [16].

In a study conducted by Japanese researchers in 2007, it was found that a Mongolian yurt, a traditional dwelling type in the yurt area of Ulaanbaatar, was deemed the most unsuitable for economical and comfortable living [17].

Furthermore, numerous international studies have focused on energy consumption and exploring possibilities for energy reduction in many types of buildings. These studies have assessed the economic benefits associated with energy-saving measures.

The heating energy consumption of the building is highly dependent on the architectural and structural solutions. Research conducted by Russian academics Gorshkov, Vatin, and Nemova has indicated that the methods and solutions used in planning new energy-efficient buildings can also be applied to renovating older buildings [18]. Several articles published in the REHVA (Federation of European Heating, Ventilation, and Air Conditioning Association) journal have discussed fundamental principles concerning engineering systems and exterior railings. These studies have developed models to simulate indoor environments, ventilation, and air conditioning based on the specific requirements of each building. These models consider energy-efficient building planning, renovation of older buildings, and heat transfer assessment [19].

Although research in this field has increased, there is still a lack of research on the indoor thermal environment and energy consumption of residential buildings in Mongolia. The present study fills the gap by investigating the indoor thermal environment and heating energy consumption in residential buildings in Ulaanbaatar, Mongolia.

3. Methodology

3.1. Questionnaire Survey

This study used a questionnaire to obtain general information and indoor thermal comfort of the apartment buildings since the existing statistical data was insufficient. A total of 100 responses were collected through the questionnaire. The questionnaire used in the study consisted of several components, including demographic information, architectural characteristics, residents' lifestyles, knowledge about energy-saving, and information on electrical equipment and tools. The questionnaire results were collected by using Google Forms. The reliability of the survey questionnaire was also analyzed.

3.2. Field Measurement

Based on the questionnaire results from the 100 households, five of all surveyed apartments were selected as representative objects for measuring the indoor environment. The data monitoring in the selected households took place from January to February 2019. During this monitoring period, measurements were conducted at a frequency of every 1 min. Air temperatures and relative humidity were measured using the sensor (HIOKI-LR5001). The sensor was placed at a height of 1.2 m in the center of the room as possible, where was almost not affected by human activities during the measurement. Table 1 indicates the specifications of the measurement sensor.

Table 1. Specifications of measurement sensors.

Sensor Model	Measurement Parameter	Accuracy
HIOKI-LR5001	Temperature (°C) Relative humidity (%)	±0.5 °C ±5%

3.3. Calculation of the Ventilation Rate

The air change rate (V) can be calculated by Equation (1).

$$V = \frac{m}{(\rho - \rho_0) * 10^{-6}} \quad (1)$$

Here: m—amount of carbon dioxide exhaled, m^3/h
ρ—indoor carbon dioxide concentration, ppm
ρ_0—outdoor carbon dioxide concentration, ppm

3.4. Calculation of the Heat Loss Coefficient

The heat loss coefficient of an apartment is calculated by Equation (2).

$$Q = \frac{\sum(k_i * A_i)}{A_f} + \frac{c_p * V * \rho}{3600 * A_f} \quad (2)$$

Here: k_i—thermal conductivity coefficient, W/m^2K
A_i—area of heat loss, m^2
c_p—apartment area, m^2
V—ventilation coefficient, m^3/h
p—air density, kg/m^3

4. Results

4.1. Outline of Investigated Apartments

In the 100 households surveyed, 19% of the respondents live in buildings with reinforced concrete frames and block and brick filling, while 35% reside in apartments with fully cast reinforced concrete structures. Five different apartments were selected in the study (see Table 2).

Figure 2 illustrates the measurement points in the five selected apartments when Table 2 provides building information for these apartments. All apartments have natural exhaust ventilation shafts in the kitchens and bathrooms. Fresh air is typically supplied by opening windows, which can be challenging to control. Heating in most apartment buildings is provided by a small number of residential boilers connected to central-heating systems. The five apartments included in the study were connected to central heating systems, as shown in Figure 2.

Among the 100 households surveyed, 97% reside in the capital city's central districts, 3% in remote districts such as Bagakhangai and Nalaikh, 24% in Bayangol District, and 27% in Bayanzurkh District, as shown in Figure 3.

Figure 4 provides an overview of the economic status of the participants. It indicates that a small portion, only 3% of the households, had a monthly income of 150 USD. In contrast, 17% of the households reported high income, while 55% had a medium income level. The remaining 25% had low incomes.

Figure 5 illustrates that more than half of the participants resided in apartments with an area of up to 50 m^2, while 33% lived in apartments with an area of 60–70 m^2. It implies that a significant majority, 86% of the participants, inhabited 3–4 room apartments with an area of up to 70 m^2.

Table 2. Information of the measured buildings.

Object	Floor Area (m^2)	Location Floor/Total Story	Orientation of the Main Windows	Built Year	Building View	Structure Type
1	68.9	6/10	E	2012		Block-filled and insulated
2	53.5	8/9	W	2013		Fully cast reinforced concreteand insulated
3	49.9	6/10	N	2016		Reinforced concrete, insulated
4	58.5	4/6	S	2012		Brick-filling and insulated
5	35	3/10	W	2012		Brick-filled and insulated

Figure 2. Locations of measurement points in the study apartments.

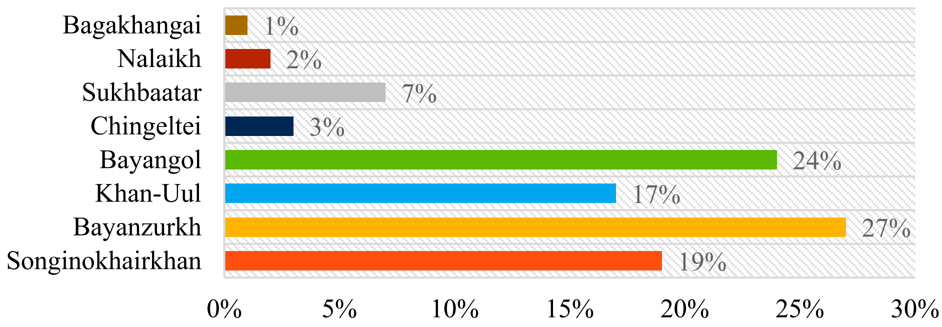

Figure 3. Locations of the surveyed apartments by districts.

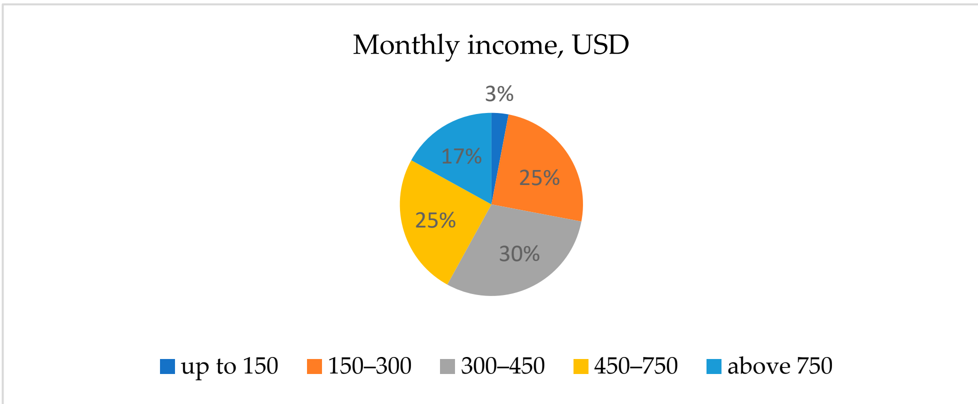

Figure 4. Monthly income of households.

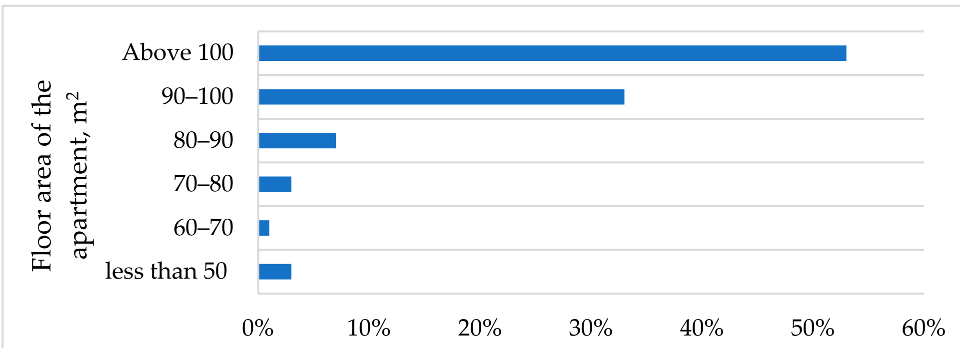

Figure 5. The floor area of the apartment.

4.2. Meteorological Data in Ulaanbaatar

The ambient air temperature and humidity data were obtained from the Meteorological and Environmental Research Agency. Figure 6 displays the hourly variation of the ambient air temperature and relative humidity in Ulaanbaatar for 2019–2020 [20]. The graph highlights that the coldest seasons occur in December, January, and February, with air temperatures dropping below −30 °C. Conversely, the hottest months are from June to September, with maximum temperatures nearing 30 °C. The relative humidity reaches its maximum at 90% and decreases to 10% during the hot season. Notably, there is a strong negative correlation between air temperature and relative humidity in Ulaanbaatar.

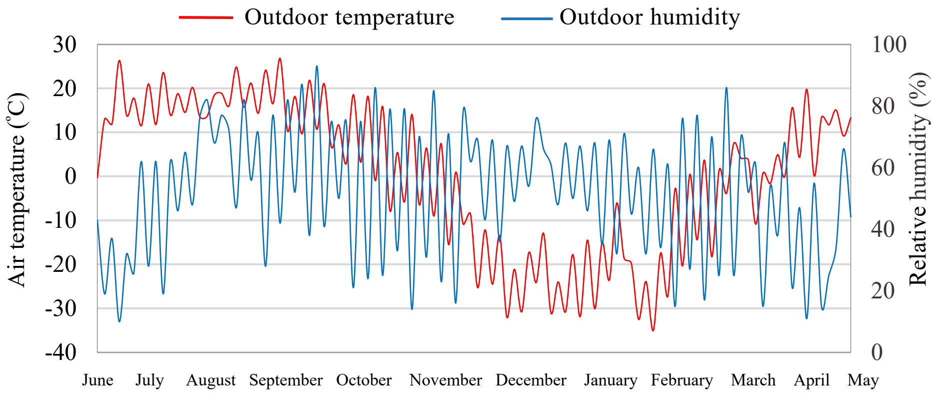

Figure 6. Outdoor air temperature and relative humidity for a year in Ulaanbaatar.

4.3. Measurement Results

4.3.1. Indoor Air Temperature

During the measurement period, continuous measurements were conducted, providing valuable data on indoor air temperature and relative humidity. The average indoor air temperature was 25.4 °C in living rooms and 24.0 °C in bedrooms. As for relative humidity, the average values were 26.3% in living rooms and 33.2% in bedrooms (see Figures 7–10). According to the national standards of Mongolia, the maximum and minimum air temperatures in an apartment should be 22 °C and 18 °C, respectively [21]. In addition, it can be noted that the indoor air temperature varied across apartments with different building structures.

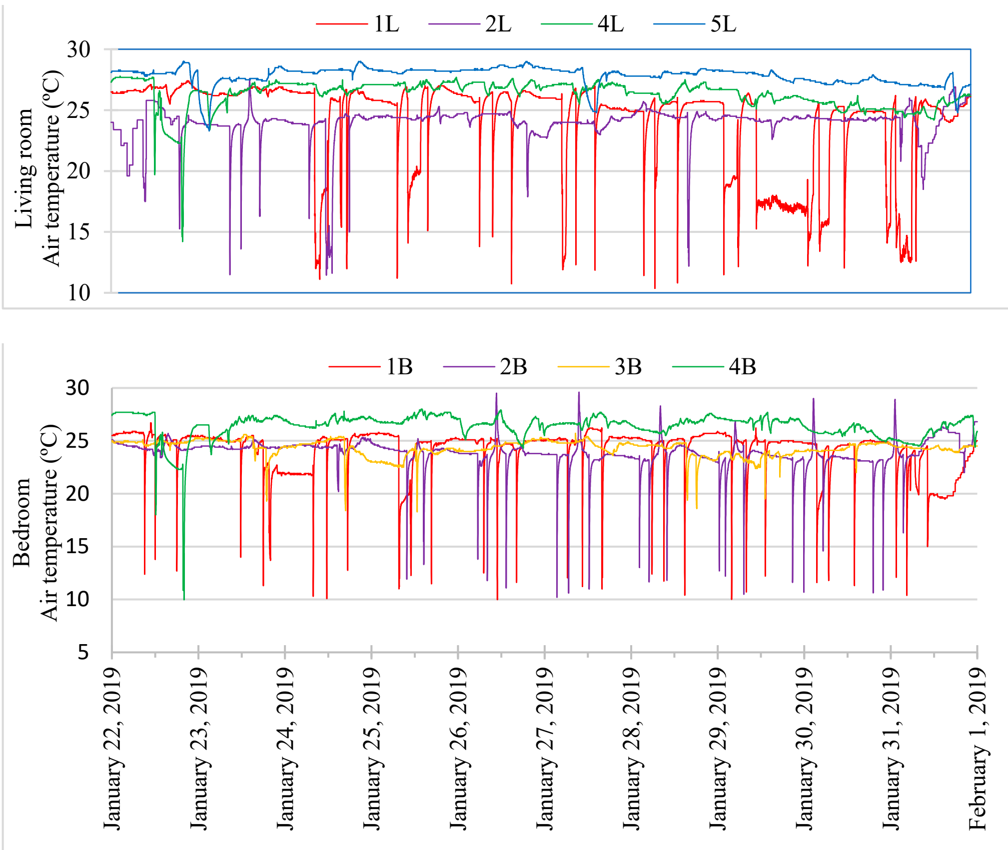

Figure 7. Indoor air temperatures from 22 to 31 January 2019.

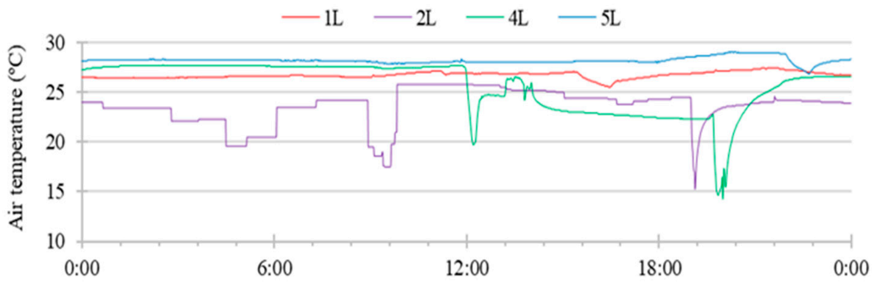

Figure 8. Indoor air temperatures on 22 January 2019.

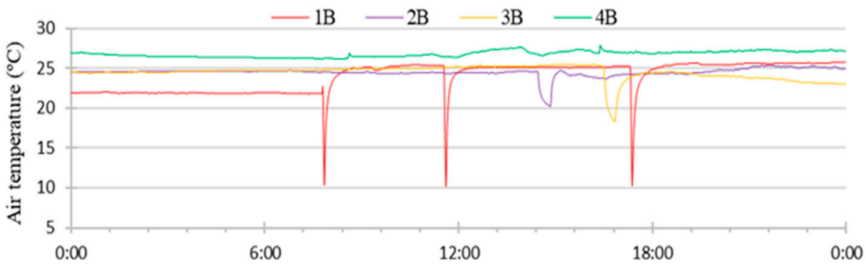

Figure 9. Indoor air temperatures values on 24 January 2019.

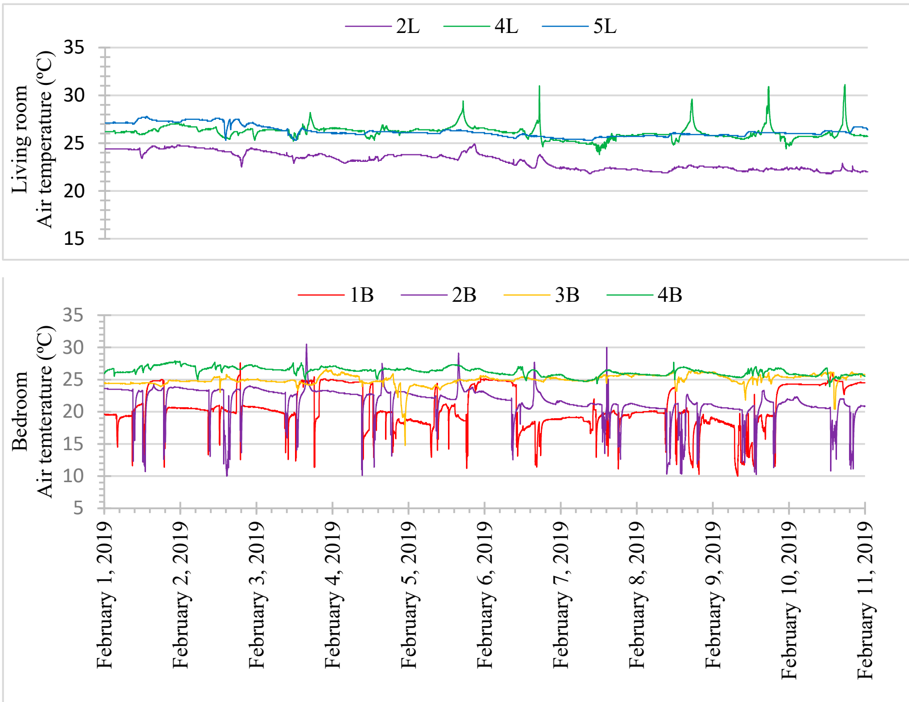

Figure 10. Indoor air temperatures from 1 to 11 February 2019.

Figure 7 highlights the significant fluctuations in air temperature observed in the living rooms and bedrooms of objects 1 and 2. For object 1, the air temperature dropped sharply during certain nights, indicating considerable heat loss due to the low outside temperature on those particular days. In contrast, the average air temperature in the living rooms of objects 4 and 5 was 27 °C, and the average air temperature in the bedroom was 25.3 °C.

In Figure 7, it is evident that objects 3, 4, and 5 had the warmest indoor temperatures, while objects 1 and 2 were the coldest. Some household members leave for work and school in the morning and return home in the evening. During the day, when residents are at home, they tend to spend most of their time in the living rooms, using them as the primary living and activity space. However, at night, the living rooms are often used as bedrooms. Therefore, living rooms and bedrooms were chosen for the measurements. The study observed that the households in the apartments practiced ventilation by opening windows occasionally, especially when the indoor air temperature became uncomfortably high or when the residents wanted to let in the fresh air. During these ventilation periods, the room temperatures dropped significantly. The biggest temperature difference was observed in the living room during the day.

Figure 8 presents the air temperatures in the living rooms on 22 July 2019. The average air temperature in the living rooms from 08:00 to 20:00 during the daytime ranged from 19.9 to 28.9 °C. During the nighttime period from 20:00 to 07:00, the average air temperature in the living rooms ranged from 24.9 to 26.2 °C. These temperatures were 2.9 to 6.9 °C higher than the national residential standards.

Figure 9 shows the air temperatures in the bedrooms on 24 July 2019. The average air temperature in the bedrooms during the daytime ranged from 14.2 to 29 °C. In object 1, the air temperature dropped sharply due to the opening of windows in the morning, midday and evening.

As seen in Figure 10, the air temperatures in the bedrooms were slightly lower than the living room temperatures, and the bedroom temperatures tended to decrease during the test period, ranging from 23 to 25 °C. Additionally, the air temperatures of the bedrooms and the rooms in objects 1 and 2 dropped sharply due to the absence of a ventilation system, leading to air exchange through open windows. However, the air temperatures in the living rooms remained relatively stable.

4.3.2. Indoor Relative Humidity

Figure 11 illustrates that the relative humidity levels in the living rooms in objects 1 and 2 fluctuated from 5% to 76%. The room temperatures in objects 4 and 5 were relatively stable, and their relative humidity in the living rooms was between 8% and 31%, indicating low value. The relative humidity in the bedrooms of objects 1–3 varied greatly, spanning from 10% to 68%. Object 5 maintained a relatively low range of relative humidity between 8% and 28%.

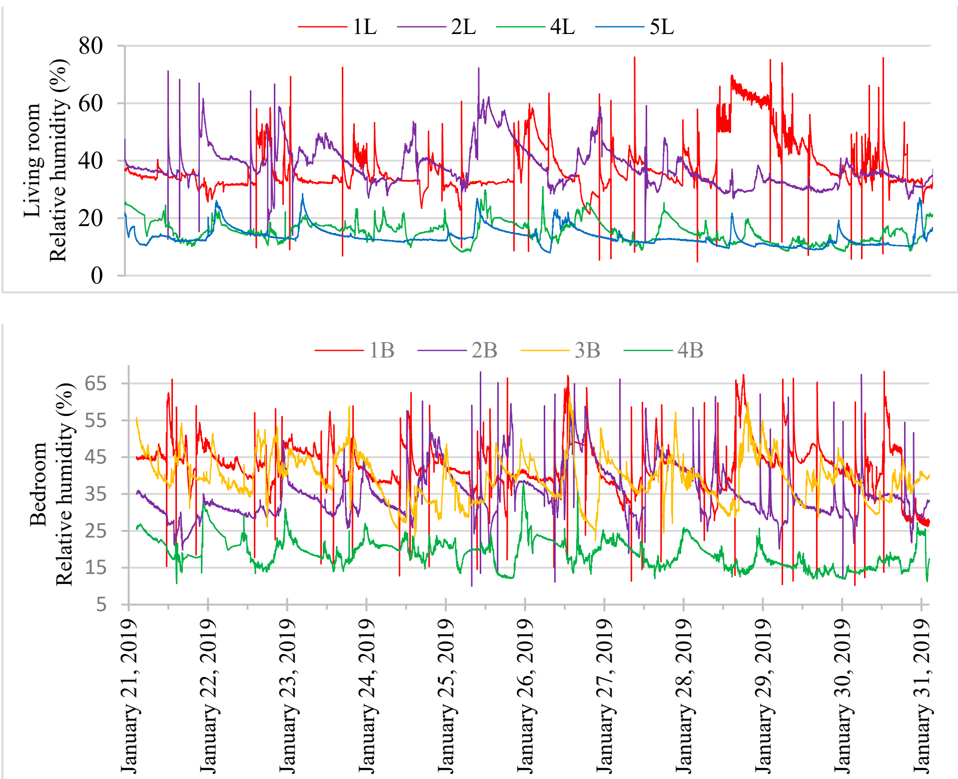

Figure 11. Indoor air relative humidity from 22 to 31 January 2019.

In Figure 12, the relative humidity in the living rooms of objects 2, 4 and 5 varied from 6% to 70%. Similarly, the relative humidity in the bedrooms of these objects also showed considerable fluctuations spanning from 5% to 74%. Objects 1, 2 and 3 displayed fluctuating relative humidity levels. Low humidity values indicate that the objects' indoor environments tend to be dry. In-house activities primarily influenced the humidity levels in these objects.

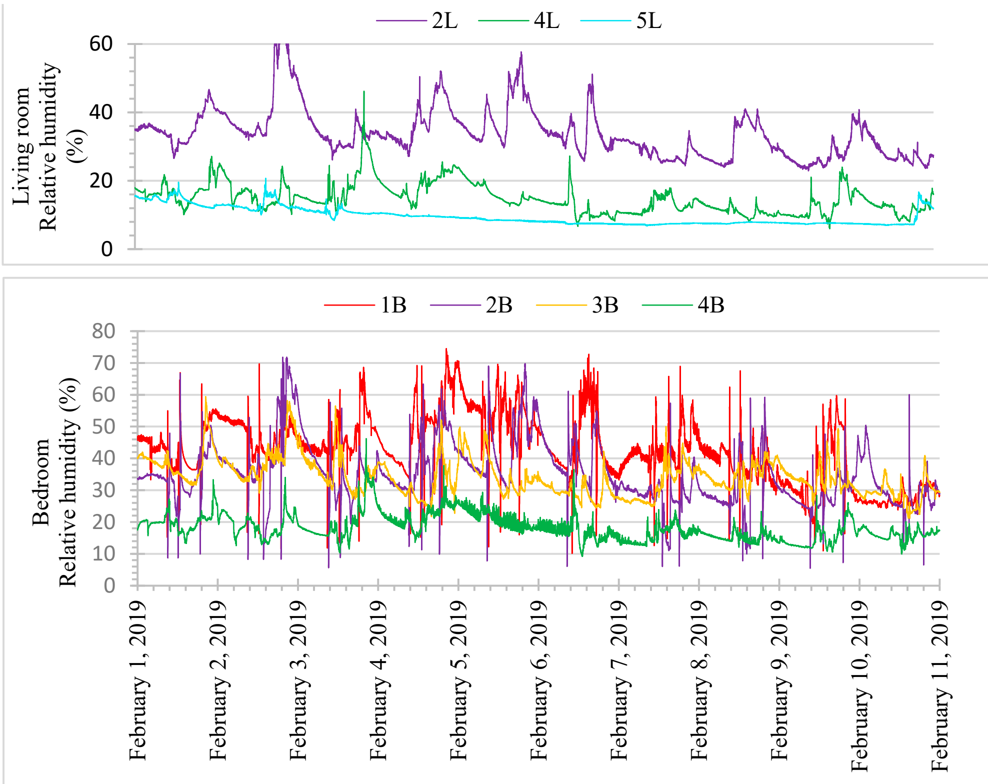

Figure 12. Indoor air relative humidity from 1 to 11 February 2019.

4.4. Air Change Rate

The number of household members influences the level of indoor carbon dioxide concentration. A larger number of household members require more regular ventilation to maintain air quality, resulting in increased heat loss. The main pollutants are carbon monoxide and carbon dioxide.

In Figure 13, object 2 had the highest carbon dioxide concentration, while object 3 had the lowest. The average CO_2 concentration across all objects was 972 ppm, which meets the Mongolian standard. The average carbon content measured by No Yafa, JMS12C carbon dioxide detector was 920 ppm, also meeting the relevant standards [22]. The carbon dioxide levels did not show significant variations between daytime and nighttime. However, some objects had slightly higher levels of carbon dioxide during the night.

Ventilation is essential for homes, ensuring fresh air exchange and regulating room temperatures. In winter, it allows fresh air in, expels excess carbon dioxide, and regulates the room temperature. Ventilation is explained by a sharp decrease in carbon dioxide. According to hygiene requirements, 30 m^3/h of outside air per person is required. In residential buildings, the air intake system is in the bedroom, and the exhaust system is in the fireplace and bathroom.

As seen in Figure 14, the ventilation ratio was highest for object 2 and lowest for object 5. The average ventilation ratio within the sample varied between 46 m^3 /h and 71 m^3/h.

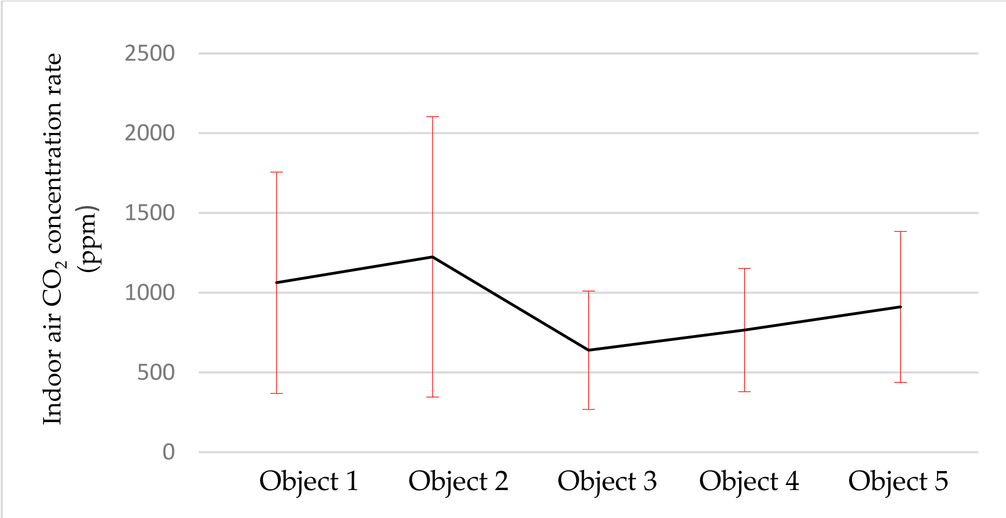

Figure 13. Carbon dioxide concentration average in the five study apartments.

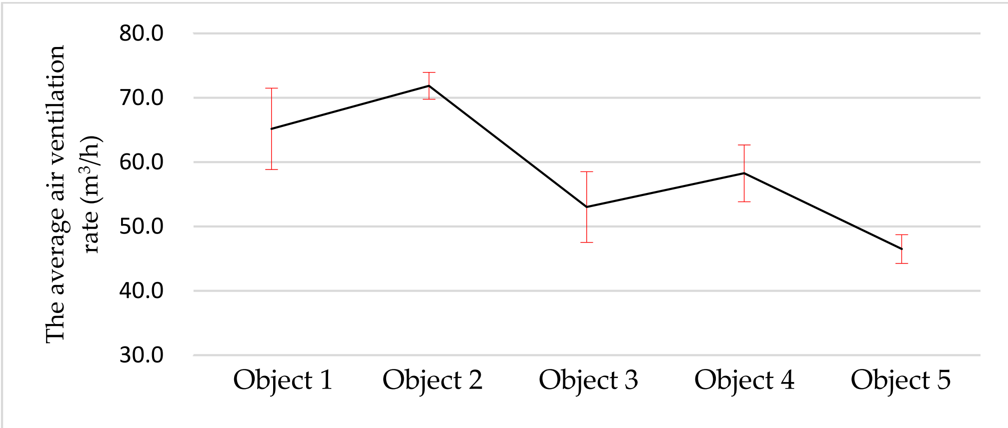

Figure 14. The average ventilation rate in the five study apartments.

4.5. Estimation of the Heat Loss Coefficient

The heat loss coefficients for each object were estimated by Equation (2). As indicated in Table 3, the heat loss of objects 2 and 5 is relatively high, and the heat loss through ventilation is high.

Table 3. Building information and specific heat loss for the study buildings.

Object	Area m^2	Exterior Wall Area m^2	Heat Conduction Coefficient $W/(m^2K)$	Leakage Heat Loss Coefficient $W/(m^2K)$	Air Ventilation Rate m^3/h	Ventilation Heat Loss Coefficient $W/(m^2K)$
Object 1	68.9	12.2	0.195	0.039	65.2	1.167
Object 2	43.5	9.3	0.178	0.036	71.8	1.656
Object 3	49.9	8.5	0.199	0.040	53.0	1.310
Object 4	58.5	14.5	0.202	0.040	58.3	1.229
Object 5	35.0	6.3	0.137	0.027	46.5	1.639

Table 4 provides the calculation results of heat loss for the five objects, revealing that heat loss coefficients range from 0.025 to 0.050 $W/(m^2K)$ with minimal variation. Ventilation-related heat loss is between 1.229 $W/(m^2K)$ and 1.656 $W/(m^2K)$. Objects 2 and 5 have a higher value of ventilation heat loss. As shown in Figure 15, the ventilation heat loss coefficient surpasses the transmission heat loss, indicating a high potential for energy saving through the reduction in ventilation heat loss.

Table 4. Calculation of total heat loss breakdown.

Object	Area m^2	Heat Loss Coefficient $W/(m^2K)$	Ventilation Heat Loss Coefficient $W/(m^2K)$	Empiric Heat Loss Coefficient $W/(m^2K)$
Object 1	68.9	0.035	1.167	1.202
Object 2	43.5	0.038	1.656	1.694
Object 3	49.9	0.034	1.310	1.344
Object 4	58.5	0.050	1.229	1.280
Object 5	35.0	0.025	1.639	1.663

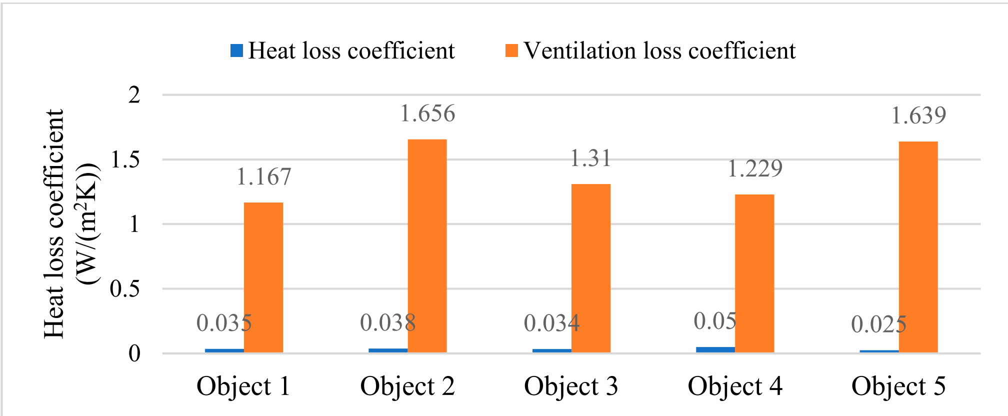

Figure 15. Total heat loss breakdown in the five study apartments.

In Table 4, the ventilation heat loss coefficient is calculated by multiplying the specific heat loss of air (1.007 J/Kg-K) by the air density (1.225 kg/m^3) and the average air circulation, divided by the apartment area.

4.6. Analysis of Building Individual Heat Load Modeling

This section explores the potential for improving the energy efficiency of apartment buildings through the application of mathematical and statistical modeling methods. Given the limited availability of such studies, an analytical approach was proposed, incorporating regression analysis, dynamic simulation, and component breakdown techniques. The proposed method includes energy-saving modeling, considering ventilation, insulation and temperature parameters. Regression analysis was performed using the least-squares method to determine the interpretability of these parameters. The simulation was conducted using the E Views 10 software, and statistical tests were performed using SPSS 26 software.

Analysis of Statistical Results

The variables were inputted into SPSS 26 software, and the relationship between the building heat loss and the related variables was displayed in the correlation matrix. The correlation analysis results in Table 5 revealed a strong and statistically significant correlation between heat loss and the explanatory variables. The correlation relationship value is below 0.05.

Table 5. Result of correlation analysis.

Correlation Matrix						
	Object	1	2	3	4	5
Correlation	Air ventilation	1.000				
	Insulation	0.024	1.000			
	Indoor temperature	0.135	0.062	1.000		
	Windows type	0.078	0.054	0.099	1.000	
	Windows direction	0.096	0.113	0.114	−0.013	1.000
	Heat loss	0.561	0.217	0.396	0.348	0.368
Sig. (1-tailed)	Air ventilation					
	Insulation	0.027				
	Indoor temperature	0.028	0.000			
	Windows type	0.020	0.046	0.049		
	Windows direction	0.001	0.003	0.014	0.765	
	Heat loss	0.044	0.000	0.000	0.000	0.000

Factor analysis shows how much the variation of a dependent variable can be explained by explanatory variables. As depicted in Table 6, the results indicate that ventilation has the highest share in explaining the variability of the heat loss coefficient. The coefficient of thermal conductivity is mostly explained by air circulation, with a variation of 30.1%. Insulation has a 26.7% variation, while room temperature is 25.7%. Surprisingly, the window type has a lower-than-expected impact, explaining only 8.2% of the variation. Furthermore, window orientation has a minimal effect on heat loss.

Table 6. Factor analysis results.

Total Variance Explained						
Component	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Air ventilation	2.766	30.097	30.097	2.766	30.097	2.766
Insulation	1.045	26.699	56.796	1.045	56.796	1.045
Indoor temperature	0.867	25.728	82.524			
Windows type	0.575	8.252	90.777			
Windows direction	0.482	2.913	93.689			
Other	0.264	6.311	100.000			

Extraction method: Principal component analysis.

5. Discussion

5.1. Comparison with Previous Studies

A study by B. Bilguun and Z. Qingyuan [14] surveyed 374 apartments with different structure types and 18 selected apartments for measuring indoor thermal environment and found that the total heat loss coefficient for apartment buildings ranged from 0.74 W/m^{2}K to 1.53 W/m^{2}K. The results indicated that the indoor air temperature in the apartment building was generally higher. At the same time, the relative humidity was lower compared to the Mongolian standard and the ISO 7730 standard for the majority of the hours. Additionally, the study demonstrated that implementing thermal retrofits in certain buildings could result in substantial energy savings.

Most old apartment buildings in Ulaanbaatar were built with outdated Russian technology and standards. Among different types of buildings, residential buildings are evaluated to have the highest potential for energy savings. The largest part (67%) of potential energy savings in these buildings can be achieved by improving the efficiency of district heating systems for space and water heating. Around 60% of the districts utilizing Russian heating network technology are estimated to require extensive repairs or replacements [10].

A previous study [16] examined the thermal performance of 118 apartments in 36 representative archetype buildings in a post-war social-housing estate in Famagusta, Cyprus. The region experiences a subtropical climate (Csa), with some areas classified as semi-arid (Bsh). The research investigated various factors related to the multi-domain factors of households' socio-demographic characteristics, occupancy patterns, and home energy performance. In-situ measurements of the indoor air environment were conducted to assess the influence of the building's thermal properties on the risk of overheating and occupants' thermal comfort.

The conclusions of the present study align with the previous studies conducted in the field [10,14,16]. Similar to other previous studies, this study explored the potential for increasing the energy efficiency of apartment buildings by employing mathematical and statistical modeling methods. Due to the scarcity of such studies, an analytical approach was proposed using regression analysis, dynamic simulation and component breakdown techniques. The proposed method developed energy-saving models considering important parameters such as ventilation, insulation and temperature.

5.2. Limitations of the Study

There are a few limitations to this study in the field investigation and simulation process. This study mainly analyzed the indoor thermal environment without calculating building energy consumption. In subsequent research, energy consumption should be taken account into.

6. Conclusions

In Mongolia, the heating of apartment buildings relies solely on the central heat distribution network [23]. However, this energy source adversely affects the environment and human health. The present study aimed to investigate heat loss in the five objects of residential buildings in Ulaanbaatar and thoroughly examined the variability of selected parameters related to the internal temperature and their dependence.

A total of 100 households were selected as participants for the questionnaire, and data were collected through the questionnaire. The collected data were then analyzed using SPSS 26 software. The majority of respondents resided in block and brick infill apartments, primarily constructed in the 2000s. Out of 100 respondents, five households were selected randomly for a more detailed analysis. The indoor air temperatures and relative humidity were monitored between January and February 2019. The data analysis yielded the following results:

The indoor temperature for the apartments built by the latest standards was relatively high. The average indoor air temperature and relative humidity in the living rooms and bedrooms were 25.4 °C/26.3% and 24.0 °C/33.2%, respectively. Compared with the ISO 7730:2005 standard [24], the study buildings somewhat matched the standards but had many cases of dryness due to high temperatures.

Decreasing the number of overheated indoor apartments is crucial to enhance energy efficiency. The average indoor temperatures in the apartments were above 20 °C, which aligns with Mongolian standards. However, there were instances where the indoor air temperatures were too high.

The average ventilation rate ranged from 43 m^3/h to 78 m^3/h. The breakdown of total heat loss shows that the ventilation heat loss of objects 2 and 5 was high.

The total heat loss of the apartments varied between 1.202 and 1.694 $W/(m^2K)$. It is recommended to employ quality thermal insulation for the buildings and their enclosures to minimize heat loss to the external environment.

It was found that ventilation had the highest impact on the variability of the heat transfer coefficient. Air circulation influenced the coefficient of thermal conductivity, with a significant variation of 30.1%. Insulation showed a variation of 26.7%, while the room temperature was 25.7%. The window type explained only 8.2%, which is lower than expected. Every apartment has an air conditioning system, but there is not enough air circulation; households rely on window ventilation, resulting in heat loss.

Major maintenance work is necessary based on the building's energy consumption. This kind of inspection should categorize buildings according to their energy efficiency and take immediate measures for buildings requiring significant maintenance.

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