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The Impact of Traditional Architectonic Characters on the Environmental and Thermal Condition of Houses: A Case Study of Erbil, Kurdistan, Iraq

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ABSTRACT

Traditional houses in Erbil City, with their time-honored designs and materials, offer a compelling study of sustainable living, especially when juxtaposed with their modern counterparts. correspondingly, thermal comfort is the overarching concept of creating a physical environment that is the most comfortable for its occupants. This study examines the differences in thermal performance between the modern traditional homes in Erbil, Northern Iraq. Thermal comfort was measured in the field as part of the study. Four case studies of current modern houses common in Erbil have been selected and one traditional case from Erbil Citadel contains all the architectural and traditional details. Temperature and humidity were among the environmental factors examined for the summer months of June and July. While the most recent thermal equipment had been used to monitor and record the indoor and outdoor temperatures for the homes under study, The most collected data, recorded during June and July 2023, can be considered as a representative of a typical summer period. The weather conditions during those weeks were sunny, clear, and hot. Maximum outside temperature, 39-41℃, was the typical value during this period of the year. The adaptive thermal comfort model for Iraq was used as a reference for validation, according to the result, the indoor air temperature of a traditional house is maintained at 21.2℃ and 26.3℃ throughout the summer with a relative humidity of 9% to 11%, which is within the ASHRAE-recommended comfort zone. Modern houses maintain an indoor temperature between 28℃ to 37℃ with a relative humidity of 12% to 16%, which is outside of the comfort range. The findings demonstrate that because traditional houses employ passive and natural building techniques, about thermal comfort, they are superior to the current ones. This research offers information about the possible strategies for raising indoor thermal condition levels in modern houses.

1. INTRODUCTION

The environment significantly affects the thermal performance and energy consumption of homes in hot, dry countries such as the Kurdistan Region Government, where the residents deal with a variety of climate-related concerns, especially in modern housing [1]. This provides an opportunity to explore how traditional architectural features influence the types of buildings and how best to preserve thermal comfort in hot, dry climates [2]. Thus, to comprehend the thermal efficiency of traditional dwellings, several criteria are needed, including architectural design, occupancy patterns, planning, and constructional procedures and materials [3]. Examining the effects of traditional architectural elements on the surroundings and thermal comfort of traditional residences in the Erbil Citadel is the purpose of the current study [4]. As Gamero-Salinas et al. [5] illuminate, Erbil's modern homes use more energy and perform worse thermally because they disregard important climate-responsive principles. Additionally, courtyards that served as natural ventilators were built into historical architecture to encourage airflow and lessen dependency on mechanical equipment [5]. The modern drive for uniformity and speedy development, on the other hand, has led to poor insulation methods that disregard the city's natural climate resources, increasing reliance on energy-intensive solutions. In addition to being inefficient, the result is a corresponding environmental burden that is evident through increased carbon emissions, demonstrating the high cost of ignorance of conventional approaches. Thus, it is crucial to take use of these historic insights and incorporate them into contemporary architectural paradigms to create homes that are both energy-efficient and climate-resilient as we stand on the brink of urbanization and environmental responsibility. In addition to improving living circumstances, such integration offers Erbil's urban growth a sustainable course for the future. It is clear from continuing to analyze Erbil's architectural development that contemporary housing developments suffer thermally from poor insulation, a reliance on artificial climate control, and a disregard for traditional techniques that were once prevalent in local architecture [6].

Erbil's traditional homes expertly used thick earthy materials for their walls, including stone or adobe, which naturally controlled inside temperatures by using thermal mass to counteract the harshness of the outside climate. Compared to the current strategy, which places less emphasis on building envelope performance and results in greater energy inefficiency, this method reduced energy use and offered natural insulation [6]. Additionally, several studies on these subjects have been conducted in other nations. Few studies have compared the thermal comfort and indoor environmental characteristics of traditional and modern homes to date.

The study aims to investigate the potential of applying traditional architectonic characteristics to modern residential in Erbil City, to enhance indoor thermal conditions the unit of analysis will be spaces and plans from traditional houses and residential modern low-rise buildings; in addition, to determine the most important elements that must be achieved in residential buildings in Erbil to achieve sustainability and to identify the potential traditional architectonic characteristics in Erbil City that can be adapted to modern residential buildings to enhance the thermal condition. Therefore, this work is going to serve as the basis for additional studies on the subject. The purpose of the research is to measure and analyze the environmental factors temperature, and relative humidity to compare and assess the thermal comfort in Erbil's traditional and modern homes. After studying several traditional houses, a traditional house that combines a lot of traditional architectonic characteristics was selected in the Erbil historical citadel as a case study, including four modern low-rise houses near the center of Erbil. Accordingly, using data from both indoor and outdoor climates, thermal comfort prediction technology was used to assess the thermal performance of both types of homes. Conclusively, the housing type that provides the greatest outcomes in terms of thermal performance throughout the summer is identified using the study's result. Ideas for attaining thermal comfort in modern houses were put out considering these findings. The research was divided into three main parts. The first part includes environmental and thermal conditions in Erbil City and traditional architectonic in Erbil City The second part deals with the practical study (Field measurement) of traditional houses in Erbil Citadel and four modern houses near Erbil Citadel. The third part dealt with the results and conclusions drawn from the theoretical framework and the practical study.

1.1 Environmental and thermal condition in Erbil City

The condition of the environment around us, which includes natural phenomena such as the climate, weather, air and water quality, and ecological factors, is referred to as 'environmental conditions' [7]. It contains a wide range of elements that could affect ecosystems, living creatures, and human conduct [8]. The elements of the environment can significantly affect the quality of life for humans and other living creatures, and they are essential in determining the overall health and well-being of ecosystems. Examining the thermal comfort and thermal behaviour characteristics of historically significant buildings should be one of the most important phases in the implementation of a new construction [9]. Thermal comfort is a design characteristic that must be kept within the recommended normal values. This covers the comfort of humans, animals, and even volume-using machinery [10]. As is well known, thermal comfort is more than just temperature, it is also considered as air temperature, humidity, radiant heat, air circulation rate, and metabolic temperature, as well as the heat that is generated by persons or objects utilizing the volume control unit (UNESCO, 2021). The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 1992 criteria define an individual's thermal comfort as, "The mental state elucidating contentment with thermal conditions". Regardless of the environment, the human body must maintain a steady temperature based on comfort levels [11].

In the courtyard of a house, the two primary elements influencing room arrangement and placement are the sun and the wind [12]. The most significant variables for analysis are the weather, which is influenced by the sun, wind, temperature, humidity, and other external factors, as well as the physical characteristics of the limit elements, which include walls, roofs, doors, and windows that demarcate both inside and outside spaces. Thermal comfort in traditional buildings refers to the ideal indoor temperature, humidity, and levels of light based on their intended uses [13]. Energy consumption is employed in the new, modern building designs using the thermal comfort data from the historical areas' traditional structures [14]. Furthermore, during the heat and water vapour transfer between the indoor microclimate and outdoor requirements, the temperature and water vapour partial pressure circulation in the building sections are closely monitored, and the presence of visible condensation on the surfaces is critical in determining the distorting effects on traditional building substance [15]. Additionally, choosing materials based on their type, color, and size, recognizing the thermal mass effect of thick masonry, learning about passive architectural climate solutions such as ventilation from the outdoors or thermal chimneys, and designing environmentally friendly modern structures that balance location and climate can all be important sources of design information. Moreover, older buildings should also be oriented towards the sun, wind, and other environmental factors [16].

1.2 Traditional architectonic in Erbil City

Traditions in architecture relate to architectural designs, styles, and techniques that have their roots in the historical and cultural background of a specific region or community. It involves traditions, materials, and design ideas that have been sustained over time in construction techniques [17]. Traditional architecture typically reflects the local environment, accessible resources, social norms, and cultural values. The distinctive characteristics and features of traditional architectural styles vary greatly among diverse cultures and geographical areas. It could have characteristics such as unusual roof designs, various details, traditional construction methods, and room arrangements that follow the customs and traditions of culture, there may also be specific usage of building materials, including adobe, stone, or wood. By conserving and using ancient architectural concepts, cities can maintain a connection to their past, promote sustainable building practices, and create architecture that complements its natural and cultural environment. Additionally, creating comfortable living areas, improving energy efficiency, and adapting to local environmental circumstances all benefit greatly from traditional architectural knowledge and abilities [18]. Erbil, given its physical and cultural relationship to Iran and Turkey [19], has witnessed notable developments in its architectural design which includes vernacular buildings. The buildings are reminiscent of Turkish and Iranian architecture due to the environment. There are two categories of traditional buildings in Erbil. The first category consists of regional structures that were created using the principle of experimenting and failing; these structures did not rely on the design phase [20]. Using scientific planning and design, the architectural style is the second category of vernacular construction. Almost all traditional buildings were designed with the shape of the courtyards in mind as a starting point, irrespective of the type [21]. The courtyards, which are placed in a variety of shapes depending on the geometry of the property, are the focal point of the traditional homes in Erbil [22].

1.3 The climate in Erbil City

Erbil is the capital of the Kurdistan Region in northern Iraq. With hot, dry summers and chilly, rainy winters, it has a semi-arid climate. This is a summary of the weather in Erbil.

Erbil experiences hot, dry summers from June to September. Daytime highs typically range from 95° to 113°F, with occasional heatwaves pushing those figures even higher. The lows in the evenings are significantly lower, at around 20℃ (68°F). This time of year brings beautiful sky and sunny days to the city, with minimal rain [23] The greatest average high temperature is 42.1℃ in July, while the lowest average high temperature is 38.4℃ in June, and the month with the highest temperatures is July. The lowest average high temperature is recorded in January (11.9℃). The average low temperature in June is 25.5℃, while July has the greatest average low temperature of 27.8℃. January has the lowest average low temperature (5.2℃), making it the lowest month overall. July is the windiest month since it has the maximum mean wind speed (10.3 km/h) [24]. With an average wind speed of 6.9 km/h, November is the calmest and least windy month. January has the highest relative humidity of any month (57%). July and August (15%) have the lowest relative humidity [25]. The most hours of daylight a day are in July (14 hours, 35 minutes on average). The least amount of daylight hours per day occurs in December (9 hours, 45 minutes on average). The average amount of sunshine in June is 12 hours and 18 minutes, and the average amount in August is 12 hours and 30 minutes [26]. January and December get the least quantity of sunshine (6 hours and 0 minutes on average) as illustrated in Figure 1.

There are many ways that classic architectural character principles and elements might be used in modern building design. Traditional architecture uses an integrated approach and incorporates several factors into the decisions that are made [27]. A few recent studies have suggested strategies for enhancing building thermal comfort that make use of traditional architectural features as the climate-responsive design elements [28].

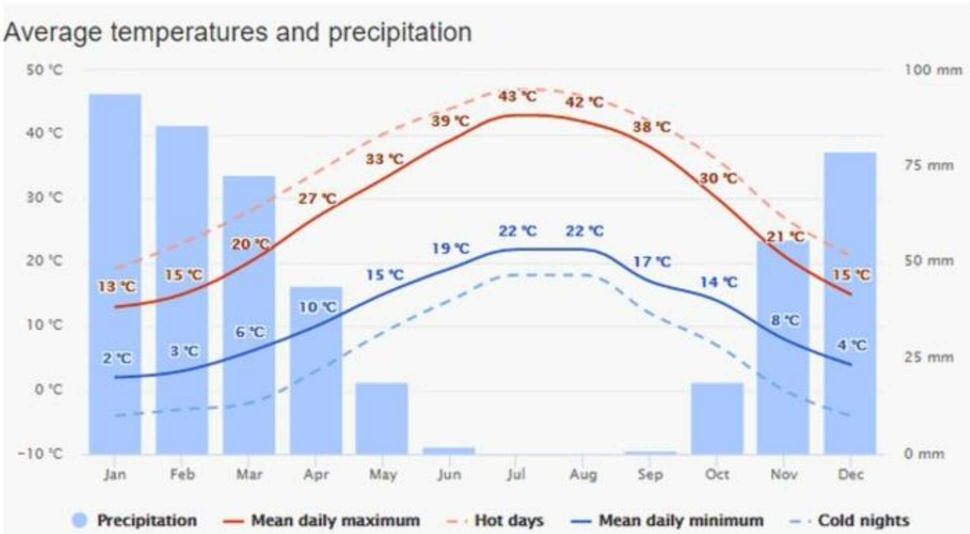


Figure 1. Erbil monthly average temperature and precipitation

2. METHODOLOGY

The study's methodology was determined to be field measurement: four case studies of modern houses that are currently common in Erbil have been chosen to measure the homes' thermal condition, and an ideal case study has been selected from a group of homes that are situated, and can be reached, in the Erbil Citadel which contains all the architectural and traditional details. Given that one of the most crucial factors in determining human comfort is air temperature [29], this study primarily focuses on measuring the inside and outside air temperatures, and relative humidity to determine the house's interior thermal condition.

This research was conducted in one of Erbil City's traditional homes; Erbil is situated between latitudes 45, 35–37, and longitudes 43 and 45. With extremely hot and dry summers and cold and rainy winters, Erbil enjoys a semi-arid continental climate. The Castle is the city's highest point, rising to a height of around 414 meters above sea level [30].

Through the monitoring of variables that are related to the interior's thermal comfort, such as relative humidity, and air temperature, and the comparison of the results with industry standards such as ASHRAE 55 and others, the field measurement approach depends upon the assessment of the indoor environment. This study has employed methods to evaluate the indoor thermal comfort of both traditional and modern houses.

2.1 Description of selected case study buildings

In the northern part of Iraq, traditional homes are built using baked bricks and several stories [31]. Typically, mud wall which is adequate for the region's potential is used for the construction of the walls. The explanation behind this is that alternative building materials are more difficult to find in the area and are long-lasting and climate compatible. Although some are brickwork, most of the homes are constructed from mudbrick. These stones have a well-established role in heat insulation. The light and air cause the white color of the bricks that are retrieved from the quarry to darken. Ventilation is crucial to preserving the microclimate in a courtyard home, where several techniques are used to safeguard the cold air entering the dwelling [32]. Hence, the buildings are naturally ventilated, and airflow is provided within the gaps and wooden portions near the roof.

The main winds that blow in a northerly direction during the winter and a westward direction during the summer are the primary components of the residential areas. These winds are created to take advantage of the widespread habitation [33]. Furthermore, the positioning of windows or remittance holes in interior rooms facilitates easy entry and exit for winds coming from the west or northwest.

This study's primary focus is on the general examinations of the homes in the ancient city of Erbil, and the observations about the modern houses are based on public interviews and literature reviews. The primary focus of the general investigation was examined, namely, the thermal comfort of the typical Erbil House. Choosing a suitable dwelling is a prerequisite for looking at whether planning exists in these homes. The sample buildings that possess the general layout of a traditional Erbil house, such as a courtyard, portico, Iwana, terrace, and rooms on different levels, have been chosen and their original structure has been preserved.

The study includes four case studies of modern houses and one case study of a traditional house, showcasing the architectural features of the two types of buildings that have been chosen for investigation.

From the ground level, the Jamil Afandi residence is accessible to the road. The entire downstairs area has a courtyard view, as do semi-open areas such as porticoes and courtyards, as well as inside spaces such as rooms, cellars, and kitchens. The exterior (patio), internal (room), and semi-open (Iwan) areas are located on the upper story. South orientation (open view) characterizes every room on the upper floor.

2.1.1 Case study 1: Inside the Jamil Afandi House of the citadel of Erbil

Figure 2 depicts Jamil Afandi house, which was historically built located in the old citadel of Erbil City, north of Iraq, in the ancient neighborhood of Saraie, is the mediaeval courtyard villa known as the Sheikh Jamil Afandi home. Due to the towns hot and arid climates, many residences were built with courtyards and other architectural characteristics until the middle of the 20th century. The architect Osta Ismail, a Kurdish architect from Iran, and a team of Sena architects who created the major entrance to the Erbil Citadel. designed the home. Four sides make up the lowest part of the design, which is built around a courtyard. According to Figure 2, the northern side of the structure faces the courtyard beside the front door of the house. They used wood beams to build the roofs and brick vaults to cover the semi-basements. Gypsum ‘Spikari’ was used to cover the interior wall surfaces, which featured several shelves and recesses adorned with colorful patterns and features [34].

Constructed between 1899 and 1909, the mansion is almost 110 years old. The structure was constructed with masonry bricks and designed in the Ottoman style. The residence consists of two-story apartments encircling a 14.80×8.80 m rectangular central courtyard presented in Tables 1 and 2.

(a) (b)

Figure 2. Traditional houses in Erbil City (a) Jamil Afandi House; (b) Courtyard of Jamil Afandi House

Table 1. The description for the traditional case studies

Case No.	House Name	Type	Location	Date of Construction
1	Jamil Afandi House	Traditional House	located in center of Erbil Citadel in Erbil City	2010

Table 2. The analysis for the traditional case study (Jamil Afandi House)

Case No.	House Name	Plot Area (m^2)	Built- up Area (Gr) (m^2)	Plot Coverage %	Open Space Area (m^2)	Total Built-up Area (m^2)
1	Jamil Afandi House	438	371	84%	67	371

2.1.2 Contemporary (Modern) Houses in Erbil City

In recent decades, the housing construction sector in Erbil, Kurdistan, Iraq, has experienced considerable changes. According to a study [35], modern houses in Erbil are distinguished from traditional residences by a few key features. One such feature is the employment of contemporary building materials and methods, such as steel frames and concrete, which enable the creation of larger and more intricate forms. Furthermore, Western-style elements such as balconies, terraces, and big windows that let in natural light and ventilation are frequently included in modern homes. While these homes may seem opulent and contemporary, they frequently lack the practical and sustainable design features inherent in conventional homes, such as effective use of space and passive heating and cooling systems [36]. Additionally, the study points out that modern Erbil homes frequently put aesthetics ahead of functionality, which causes problems such as inadequate insulation and high energy use. In the final analysis, although Erbil's contemporary homes may exhibit cutting-edge architectural and building methods, as illustrated in Figure 3, this study has selected four case studies from contemporary homes to contrast with traditional homes presented in Table 3 and Table 4. It is crucial to take sustainability and aesthetics into account when planning and developing new projects in the years to come, Table 3 provides the details of the case studies.

2.1.3 Calculate U-value in the selected cases

The first step in calculating the (U-value) is to determine the thermal conductivity k (W/m K) of each individual material utilized in the envelope construction, as indicated by the following equation [37]. The next action is to figure out each material's thermal resistance R (m^2K/W), as shown depicted in Figure 4.

$$R = \frac{t}{k}(m^2K/W) \quad (1)$$

Each material's thickness in the building envelope is represented by the variable (t) in this equation. The reversal of the R-value is used to compute the U-value in the following equation.

Table 3. The description for the modern case studies

Case No.	House Name	Type	Location	Date of Construction
2	Ashti City House	Modern House	located near Kasnazan town in Erbil City	2010
3	Italian 1 city	Modern House	Located between 100m road and 40 m road and near Sami Abdurrahman park	2012
4	Ganjan City	Modern House	Kurdistan Region – Erbil – Road Resort Salah al-Din – Bahrka	2015
5	English Village	Modern House	located between 100m and 40m roads south of Erbil international airport	2007

Table 4. The analysis for the modern case studies

Case No.	House Name	Plot Area (m^2)	Built- up Area (Gr) (m^2)	Plot Coverage %	Open Space Area (m^2)	Total Built-up Area (m^2)
2	Ashti City House	350	320	85%	30	320
3	Italian 1 city	320	290	85%	30	290
4	Ganjan City	250	230	88%	20	230
5	English Village	324	300	89%	24	300

(a) (b) (c) (d)

Figure 3. Modern low-rise houses (case study) (a) Ashti City House; (b) Italian 1 city; (c) Ganjan City; (d) English Village

$$U = \frac{1}{R}(W/m^2K) \quad (2)$$

and

$$U = \frac{1}{Rsi + R1 + R2 + \cdots Rx + Rse} \quad (3)$$

where,

Rsi = temperature transmission resistance for the internal face's surface (m^2K/W)

Rse = heat transmission resistance (m^2K/W) for the exterior face's surface .

The case studies envelope the building materials' thermo-physical characteristics. The U-value of the external walls, roofs, floors, and windows of the various styles of traditional and modern low-rise houses at 'Erbil' was calculated to assess the exterior wall components and to determine whether the buildings could potentially gain or lose heat. This allowed for the prediction of the buildings' energy comfort levels. The comparison between the results and international norms and regulations for the best U-value in houses is shown in Figure 4.

According to international guidelines, only the traditional house was typically able to meet the sustainability objectives. The examination of the U-value of the different external components for the five different types of chosen case studies, which are regarded as illustrations for multiple years of age, makes this clear. The results of the analysis of the building envelope's constituent parts' construction materials were applied. The study's findings demonstrated that the U-value of the conventional buildings' external walls are highly sensitive to sustainability requirements in terms of heat acquisition and heat loss and follow the global laws. The typical residences outside the walls' U-value for Jamal Afendi House met the standards and reported 0.70 (W/m^2 K), although the required U-value was 0.8 (W/m^2 K).

This resulted from the usage of 'Adobe bricks' as a masonry unit in the walls outside. Even though the needed U-value was not higher than 1.5 (W/m^2 K), the average building's roof (slab) demonstrated compliance with environmental regulations in the same setting about the performance of thermal gain and thermal loss, with the U-value determined at 1.11 (W/m^2 K). The floor of a typical home responded to heat gain and loss a little less well than was required, according to international standards, which assessed the U-value at 0.6 (W/m^2 K) - 0.99 (W/m^2 K) and was the acceptable optimal U-value). Even though the materials that have been used in the Traditional Building are outdated, their thermo-physical qualities indicate that they have responded quite well to heat acquisition and loss.

2.2 Field measurement

The measurement period for this study was from June to the end of July 2023. The temperature and humidity therein were measured using the HTC-2 Digital Hygrometer and Infrared Thermometers. Data gathered from the modern and historical houses were noted in both cases, regardless of the presence or lack of mechanical ventilation, heating, and cooling systems. Sixty days were allocated for recording data from measurements in both traditional and modern houses, thirty days in June and thirty days in July. Because summer has the highest temperatures of the four seasons in the research area, it is the most uncomfortable.

For this reason, it is crucial to evaluate the interior thermal comfort during this season. The HTC-2 Digital Hygrometer and Infrared Thermometers were installed in five residences between June and July 2023, to monitor temperature, humidity, in each apartment's living room. The instruments were placed between 1m and 1.5 meters above the ground in a stable area shielded from the sun and air currents. The goal was to assess the home's entire indoor thermal environment quality and compare it to the industry norms such as ASHRAE 55 and other thermal comfort standards. Every month, the homeowners were questioned about their practices, and the energy consumption (electricity) was tracked. A measurement was also conducted five times of day in traditional houses, and modern low-rise houses (9 a.m., 12 p.m., 3 p.m., 6 p.m., 9 p.m.). In the living room of both the modern house and the traditional house, the air temperature and relative humidity were measured with an orientation towards the north. The living room was found to be the most utilized room out of the five samples, based on the selection process which considered the frequency and duration of usage.

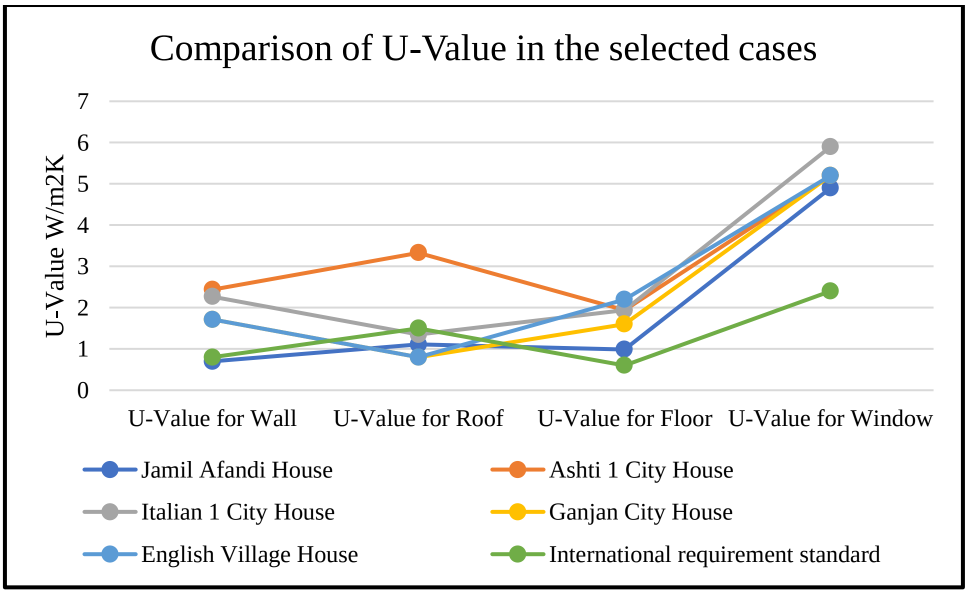


Figure 4. U-value for traditional house and contemporary houses

2.2.1 Field measurement equipment

In the experiment, the indoor air temperature, relative humidity, and outside temperature were measured and recorded using two different types of equipment are detailed in Table 5. Digital Temperature Humidity Meter Model UT332+ and a hygrometer was used to measure the air temperature and humidity, are presented in Figure 5.

The equipment was set in the living rooms of the houses. Digital Temperature Humidity Meter Model UT332+, HTC-2 Digital Hygrometer, set in the living room is shown in Table 5.

(a)

(b)

Figure 5. Instruments setup for measuring environment condition (a) Hygrometer (b) Infrared Thermometer

Table 5. Accuracy, range, and measurement frequency

Model	A	B
	HTC-2 Digital Hygrometer	Digital Temperature Humidity Meter Model UT332+
Accuracy	T: (+, -) 10C H: (+, -) 10%	T: (+, -) 0.30C H: (+, -) 10%

Table 6. Details of the measuring equipment used in the field measurement

Instruments	Location	Parameters
Digital Temperature Humidity Meter Model UT332+	Living room	Air temperature Relative Humidity
Meteorological stations in Erbil	Outdoor	Outdoor temperature

The instruments were placed between 1.5 meters above the ground in a stable area shielded from the sun and air currents, as stated in Figure 5. The goal was to assess the home's entire indoor thermal environment quality and compare it to industry norms like ASHRAE 55 and other thermal comfort standards. Every month, homeowners were questioned about their practices and energy consumption (electricity) was tracked. The list of the instruments used for the field measurement has been listed out in Table 6.

The living room was found to be the most used room out of the five samples, based on the selection process which considered the frequency and duration of usage, so sunshine and heating/cooling equipment did not affect them, illustrated in Figure 6.

Figure 6. The equipment position inside the living room in casas study

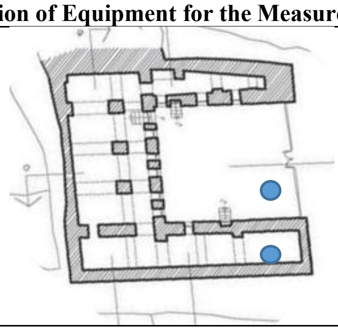
2.2.2 Measurement time and procedure

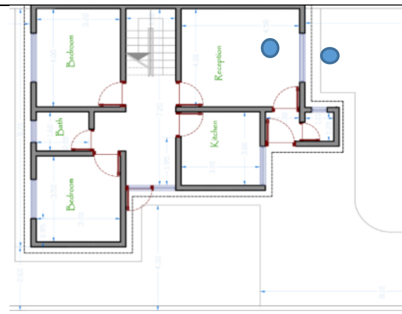
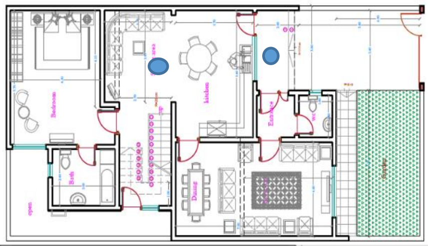
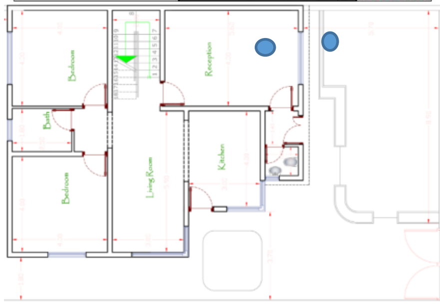
The measurement days were selected based on the owner's availability of the house. Moreover, climatic factors are also considered as the measurement has been done under actual environmental conditions. Building upon the previous study, it is vital to scrutinize the temporal scope of indoor air temperature measurements from 0900 hrs. to 2100 hrs. As it provides critical insights into Erbil City's thermal dynamics, this period is not only capturing pivotal occupancy phases but also aligns with the peak diurnal variations impacting indoor air comfort levels. Therefore, the measurement was conducted from morning 0900 hrs. to 2100 hrs. under conditions (without fan and closed window and door). Two months (June and July) of data were collected in 2023.

2.2.3 Position of equipment for the measurement in traditional and Modern houses

In a traditional home, the main room that was next to the courtyard and the exterior of the house included instruments for measuring the air temperature, and relative humidity. The types of equipment that are used in modern homes are fixed, both on the outdoors and within the main area presented in Table 7. The field measurements were conducted in both homes in July 2023, from June to July, during the hot and dry summer season. During field measurements, the use of any type of mechanical ventilation is prohibited.

Table 7. Position of equipment inside and outside houses

No. Cases	Name of Cases	Direction with Sun	Type of Building	Position of Equipment for the Measurement
1	Jamil Afandi House		Traditional (Case study 1)	

2	Ashti City House		Modern low-rise (Case study 2)	
3	Italian 1 City House		Modern low-rise (Case study 3)	
4	Ganjan City House		Modern low-rise (Case study 4)	
5	English Village House		Modern low-rise (Case study 5)	

3. FINDINGS AND DISCUSSION

The analysis and presentation are shown in this part of the data that are measured through a comparison of the traditional houses and modern low-rise houses with environmental conditions (temperature inside and outside, and relative humidity) in Erbil City.

3.1 Environmental condition comparative analyses

3.1.1 Air temperature

Curves were created using the measured outdoor temperatures of the observed houses and the living room's interior air temperature for each of the time periods that were taken into consideration in the field study, as shown in Figure 7. Average indoor air temperature in summer months June and July, the average outdoor temperature is between 36.5℃ and 45℃. In this case, TH1 stands for Traditional House 1, MH1 for Modern Low-Rise House 1, MH2 for Modern Low-Rise House 2, MH3 for Modern Low-Rise House 3, and MH4 for Modern Low-Rise House 4. The graphs show that, in all the situations that are studied, the mean summertime indoor temperature is lower in traditional dwellings and modern low-rise buildings than it is outside June and July, the indoor temperature of traditional houses was significantly lower than that of modern houses due to this temperature difference, which made the interiors colder than the outside. This increased the optimal thermal comfort. Additionally, as June and July came to an end, the interior temperatures in (four cases -modern houses) were significantly higher than the interior temperatures in traditional house. As a result, the interiors of these buildings were significantly hotter than those of traditional house, and the residents' utilised fans and air conditioners to achieve the best possible thermal comfort, as illustrated in Figure 7.

The summer season in Erbil, which runs from June to July 2023, is when the field measurements were collected. Based on the observation, it was discovered that the inside room temperature ranges from 21℃ to 27℃, showing an approximate daily variation of 6℃ only in the conventional house, whereas the outdoor temperature swings between 36.5℃ and 45℃. Modern low-rise dwellings have a daytime variation of around 8℃ in the internal room temperature, which varies between 30.5℃ and 38℃, as illustrated in Figure 7.

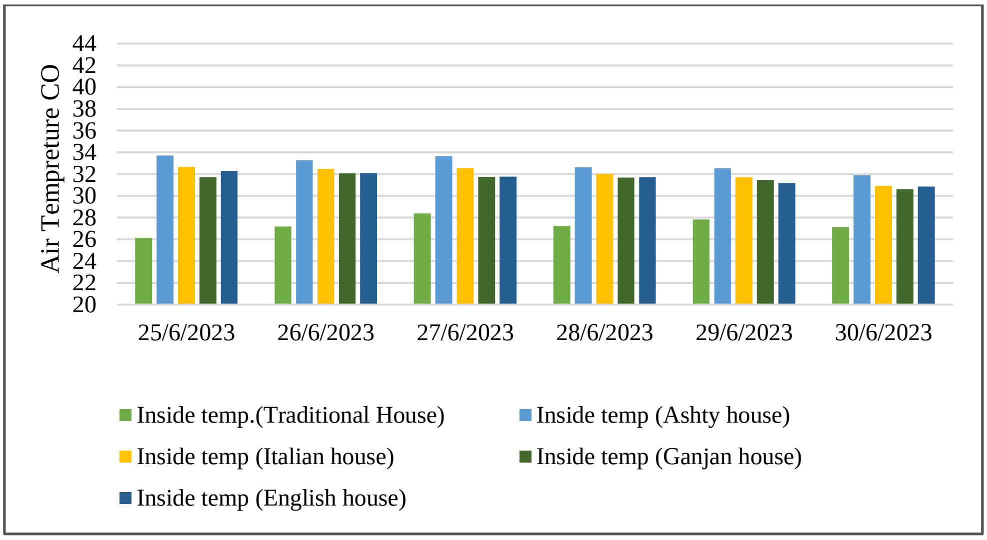


Figure 7. Average temperature degree in traditional and modern houses in June month

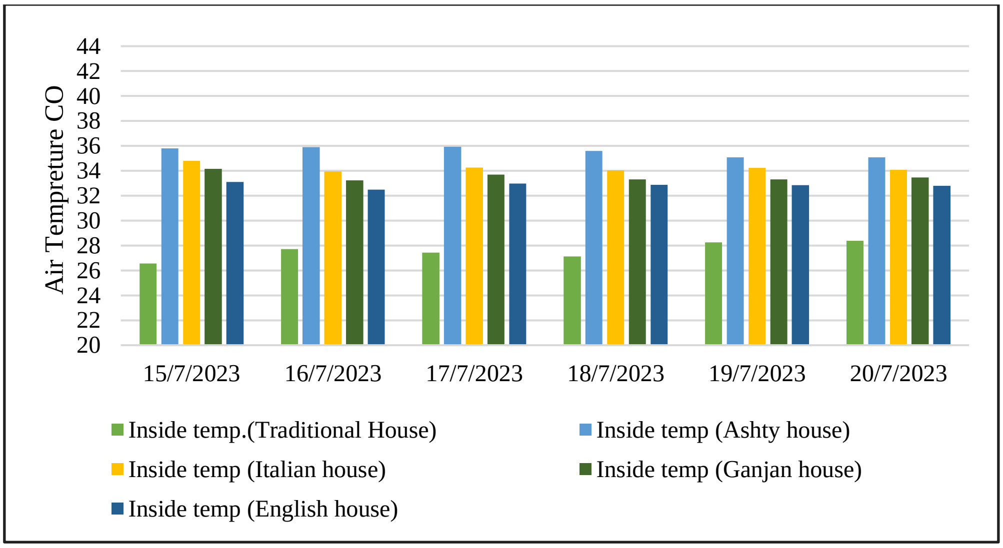


Figure 8. Average temperature degree in traditional and modern houses in July month

In traditional buildings, the main room's lowest recorded temperature is 21.5°C, whereas the modern homes' main rooms report a minimum temperature of 27.5°C, according to the comparison of air temperatures in traditional and modern houses (Figure 8). It has been noted that, modern homes have the higher lowest temperatures, by 6°C than traditional residences. A modern building's living room can reach a maximum temperature of 6°C higher than a traditional living room. This is since a traditional house features windbreaks above the courtyards to provide natural ventilation, sturdy walls, a large veranda, and curving terracotta roof tiles. However, the modern structure features large gaps, thin walls, a concrete roof, and tiny sunshades. The rising temperature in Erbil City's modern structures is the cause of the discomfort caused by heat.

3.1.2 Relative humidity

Figure 9 illustrates the relative humidity inside and outside of both traditional and modern low-rise dwelling types for each survey time during the field investigation in June month.

It indicates that for a traditional home, the humidity levels at room temperature and outside temperature are nearly identical. However, during the months of June and July, the relative humidity inside the modern low-rise dwellings was higher than that of the inside of traditional buildings at a given outdoor and indoor temperature. The inside rooms of these historical houses saw a drop in relative humidity to 10%, which made them significantly colder than necessary. As a result, interior temperatures dropped throughout June and July, when the summer's lowest winds occurred.

In a similar vein, for the month of July, the relative humidity within modern houses was higher than the interior of traditional houses for the given outdoor and indoor temperatures. The relative humidity of inside spaces rose to 7%, making them significantly hotter than necessary.

Consequently, interior temperatures rose during July, which was the hottest month. This indicates that regardless of changes in the outside temperature, the interior constructed environment of traditional houses is at a very pleasant level. On the other hand, the interior temperatures and humidity levels in modern houses are prone to drastic variations. As such, it is impossible for modern low-rise homes to keep a comfortable interior climate, as shown in Figure 10.

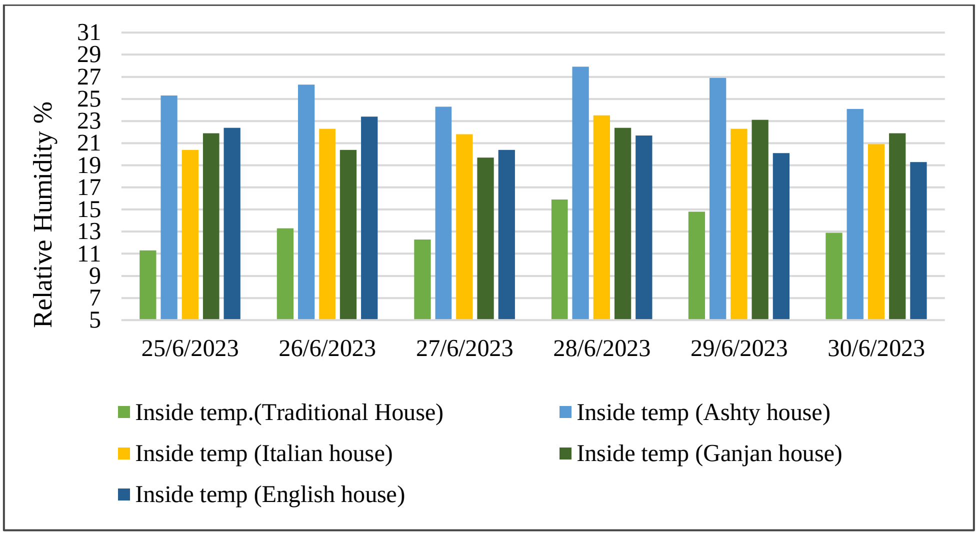


Figure 9. Average relative humidity degree in traditional and modern houses in June month

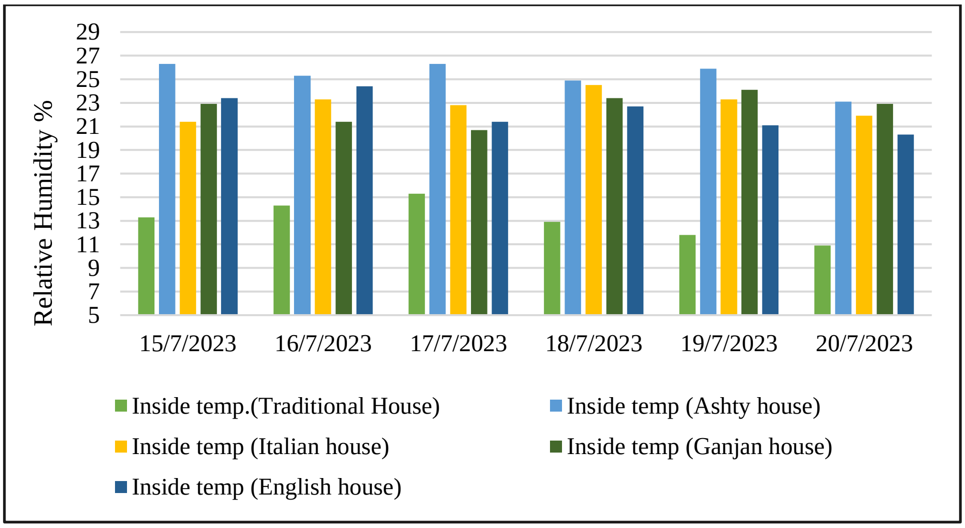


Figure 10. Average relative humidity degree in traditional and modern houses in July month

3.2 Thermal comfort comparative analyses

Based on Al-Hafith et al. [38], this study created an adaptive model to evaluate Iraqis' thermal comfort restrictions by doing a regression analysis to link the running mean external air temperature and inside Globe temperature with the respondents' thermal perception. Using online temperature records and temperature data from the Erbil Meteorological Organization, the average running outside air temperature for Erbil City was determined over the course of a year (www.accuweather.com, 2019). Ultimately, the survey respondents' thermal votes and the recorded globe temperature were correlated with the overall running mean outdoor air temperature by a regression analysis performed with the IBM SPSS Statistics 24 programme. As illustrated in Figure 2 shows the modified thermal comfort model that was produced. With a 90% confidence level, the graph shows that in the winter, when the running mean outdoor air temperature is 8.0°C, the optimal globe temperature falls between 14.0 and 24.0°C. The comfortable globe temperature range in the summer is 25.0-35.0°C, when the running mean outdoor air temperature is 38.0°C. The optimal lower and upper comfort limits are 19°C and 30°C, respectively, while the outside mean air temperature is 8°C and 38°C, respectively. The maximum suitable global temperature in the hottest part of summer is 33.0°C, and the lowest comfortable global temperature in the coldest part of winter is 17.0°C, according to this comfort range (Figure 11). This adaptive thermal comfort model will be applied to the evaluation of the indoor and outdoor living areas in Iraq. This research has employed the global temperature (Tg) as a thermal comfort index to predict the degree of heat that people will experience in courtyards. Hence, Tg was chosen for two factors. Firstly, the model of adaptive thermal comfort under discussion uses the thermal value [39]; accurate assessments of the degree of thermal comfort require the use of the same index. Second, prior research has shown that Tg readings accurately represent the people's true thermal perception. However, the option to determine Tg directly is not available in the version of Envi-met that is utilised in this work. Rather, the study has employed an equation that is created by earlier research for this reason [39]. The three microclimatic elements that make up Tg and have a major impact on people's perception of heat is included in the equation: Mean radiant temperature (MRT), *Ta* and *Va* [40]. The Envi-met 4.2 simulation tool was utilized to ascertain these three microclimatic parameters (Used equation to determine Tg).

$$Tg = (MRT + 2.35 \times Ta \times (Av)\,0.5)/\,(1 + 2.35 \times (Av)\,0.5) \quad (4)$$

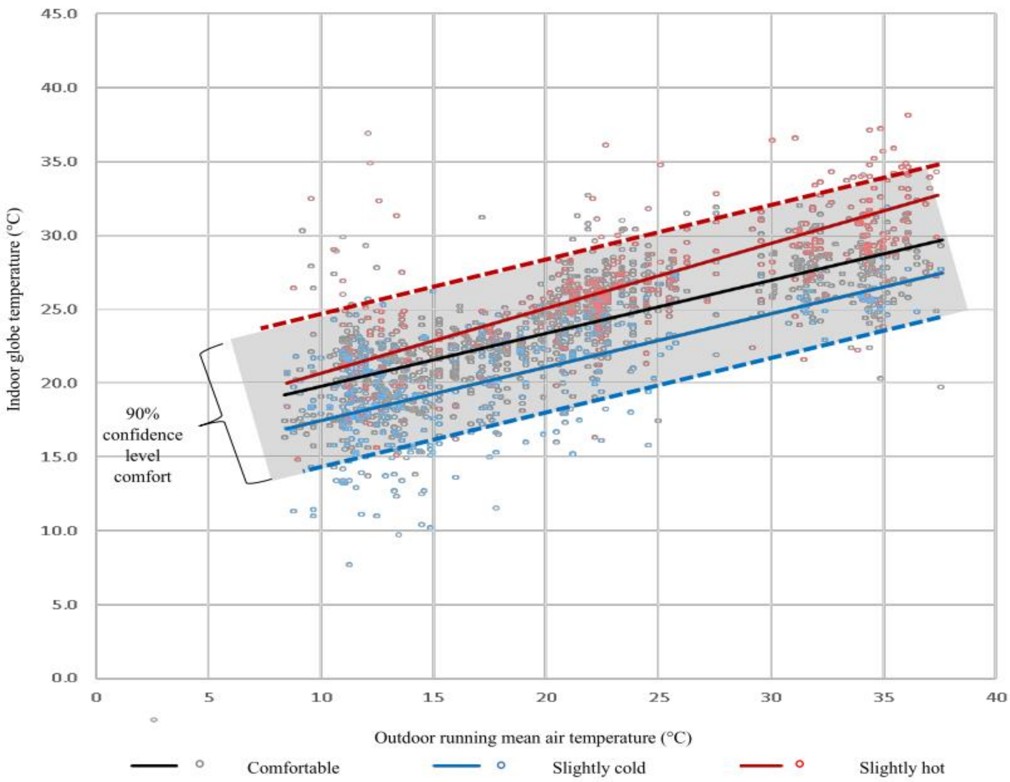


Figure 11. The adaptive thermal comfort model for Iraq [41]

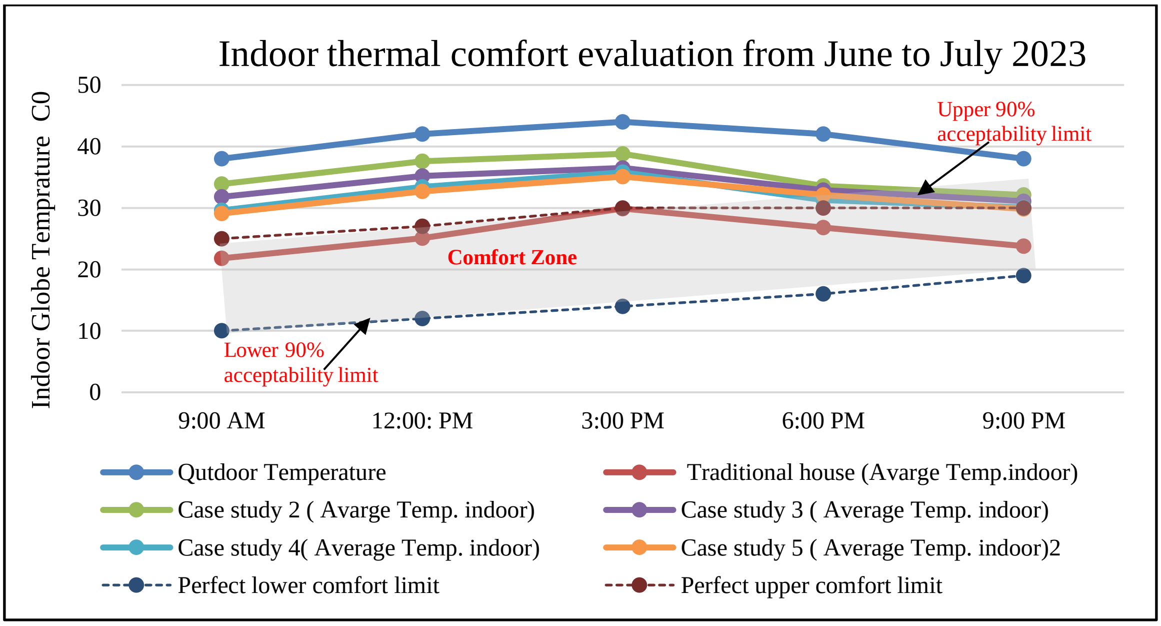


Figure 12. Indoor thermal comfort evaluation from June to July 2023

The consistent inside temperature of traditional homes was attributed to several factors, including high internal ceiling heights, lime plaster, shade, and local building materials including wood, mud, bricks, and stone. Research indicates that the use of materials with poor thermal conductivity, such as sand, bricks, straw, and mud, significantly reduces the flow of heat [38]. This lessens the impact of heat stress and promotes the creation of an environment that is sustainable. In a study by Hailu et al. [42], their research has demonstrated that the incorporation of clay and straw into a building can lower the interior's temperatures by 5℃ on sweltering summer days, minimise the number of hours that warmth causes discomfort by 25%, and cut the building's overall energy consumption by 65% [38].

As illustrated in Figure 12, It was found that the interior temperature of conventional homes falls within the comfort zone when compared to ASHRAE guidelines. A modern building's main room typically reaches a maximum air temperature of 37.4℃ and a low air temperature of 28.1℃. The indoor temperature was found to be outside of the comfort zone when compared to the ASHRAE norms. According to Figure 9, the inside air temperature of a typical building is maintained at 21.2℃ and 26.3℃ throughout the summer with a relative humidity of 9% to 11%, which is within the ASHRAE-recommended comfort zone. Modern houses (Figure 9) maintain an indoor temperature between 28℃ to

37°C with a relative humidity of 12% to 16%. In accordance with ASHRAE regulations, this occurs when the outside temperature fluctuates between 19°C and 30°C, which is outside of the comfortable range. Therefore, in the absence of a fan or air conditioning, the exterior of an older structure stays more pleasant for a longer period than the newer building. The presence of windows, wind catchers, and courtyards in traditional buildings shields the interior living area from direct solar radiation, which is likely the cause of its increased cross-ventilation rate phenomenon. The measurement's outcome indicates that the traditional home is pleasant between the hours of 9:00 a.m. and 12:00 p.m. and between 12:00 p.m. and 9:00 p.m., and its temperature falls within that range. New buildings provide comfortable indoor temperatures between the hours of 8:00 p.m. and 6:00 a.m. (19°C to 30°C), thus, it is thermally unfriendly in modern structures after 6:00 a.m. Relative humidity and temperatures of the traditional and modern homes were recorded throughout the months of June and July. In the assessment of interior temperature comfort in June and July 2023, the allowed limit for interior air temperatures between 19°C and 30°C is comfortable. Therefore, modern residences fulfilled the dreaded 90% requirement. Even though the data from the traditional house suggests that these residences conform with the 90% acceptance band of the adaptive comfort standard model, this research will demonstrate that the temperatures in these homes are typically outside of the comfort range.

Morad Aldoski and Sevinc's [43] comparative analysis makes it clear that traditional homes in Erbil City are inside the ASHRAE-recommended comfort zone, building on the disparity between traditional and modern homes. Their study illustrates that traditional house, designed with a deep understanding of local climatic inherently align with ASHRAE-recommended comfort zones due to passive design features such as strategic orientation, thermal mass from thick walls, and natural ventilation systems, recent findings by Alzoubi and Almalkawi [44] further elucidate the thermal comfort disparities between traditional and contemporary houses. According to their thorough analysis, traditional dwellings successfully match ASHRAE-recommended thermal comfort zones with their passive design techniques based on local knowledge, fostering an indoor atmosphere that is organically regulated and free from undue energy dependence. Mangeli et al. [45] illustrate how traditional houses inherently achieve a balanced indoor climate without reliance on mechanical systems due to passive design elements tailored to their environmental context. These include elements like natural ventilation channels, optimal orientation, and the use of locally available materials that offer better thermal insulation. In contrast, contemporary homes in Erbil City exhibit glaring inconsistencies with respect to the comfort zones advised by ASHRAE.

4. CONCLUSIONS

To determine the average temperature, and relative humidity in each case study, metrological data were obtained from the city of Erbil's Meteorological Department. For the interiors of the traditional and modern homes outdoor temperatures were measured at specific times during the summer using the (Measurement Tools). Notably, traditional structures exhibit a better potential to lower interior temperatures at different times of the day, starting at nine in the morning and ending at nine at night during the hot and dry summer months. According to the result, the indoor air temperature of a traditional house is maintained at 21.2°C and 26.3°C throughout the summer with a relative humidity of 9% to 11%, which is within the ASHRAE-recommended comfort zone. Modern houses maintain an indoor temperature between 28°C to 37°C with a relative humidity of 12% to 16%, which is outside of the comfort range.

It has been found that traditional houses are more calming than modern ones in the same settings. With the same outside temperature prevailing in both buildings, the interior temperature of modern buildings is significantly greater than the interior temperature of traditional buildings. This is because traditional houses are made of mud bricks and thus experience evaporative cooling in the summer; there is a noticeable temperature differential between the inside and outside of these buildings. Modern concrete structures have thinner walls and roofs due to their lack of thermal conductivity, which illustrates how their temperatures fluctuate more than those of traditional houses. Consequently, it follows that solar passive elements that are employed in older structures can be applied to newer construction in the future. It was found that historic homes were more in line with the acceptance limit of 90%, which was the acceptable range, compared to modern homes.

In the presented study, traditional houses were included since they showed a considerable drop in air temperature when compared with modern homes. This is due to the loss of traditional architectural character that is brought on by contemporary society and the public transportation systems. Courtyards, shades, and the proportion of windows to walls are some significant climatic elements of traditional houses, and these are not taken into consideration in modern buildings.

Key findings from our field measurements in Erbil City, there are numerous climate-responsive design strategies that guarantee people's thermal comfort without the use of power. Utilizing passive design strategies such as underground spaces serdab and self-shading, traditional architecture made efficient use of natural resources and achieved thermal comfort.

Future fields of this study might concentrate on: (1) Applying these design principles to modern homes make them comfortable and sustainable. (2) In Erbil City, a variety of elements are required to support environmentally friendly housing development for the interior's thermal comfort. These elements include suitable design orientation, location of openings, consideration of the local microclimate when choosing building materials, encouragement of environmentally friendly behaviour, sufficient natural ventilation, and the use of specific design elements that can produce passive cooling. (3) These elements are essential to achieving thermal comfort and energy-efficient building outcomes. Therefore, incorporating elements from ancient buildings into modern structures separately does provide positive results.

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REFERENCES

[1] Martin-Caro, J.A., Paniagua, I. (2015). Erbil Citadel restoration: Some thoughts on earth-built constructions exposed to seismic action. WIT Transactions on the Built Environment, 168: 583-593. https://doi.org/10.2495/SD150511

[2] Sami, H. (2021). Sustainability analysis of climate responsive elements in Erbil vernacular architecture. Eurasian Journal of Science and Engineering, 7(1): 217-227. https://doi.org/10.23918/eajse.v7i1p217

[3] Besbas, Y., Mezerdi, T., Belakehal, A. (2022). Glazed facades buildings in the different climatic regions in Algeria: The architects' viewpoint. International Journal of Innovation Studies in Sociology and Humanities, 7(8): 108-117. https://doi.org/10.20431/2456-4931.070810

[4] Baper, S.Y., Khayat, M., Hasan, L. (2020). Towards regenerative architecture: Material effectiveness. International Journal of Technology, 11(4): 722-731. https://doi.org/10.14716/ijtech.v11i4.2631

[5] Gamero-Salinas, J., López-Hernández, D., González-Martínez, P., Arriazu-Ramos, A., Monge-Barrio, A., Sánchez-Ostiz, A. (2024). Exploring indoor thermal comfort and its causes and consequences amid heatwaves in a Southern European city—An unsupervised learning approach. Building and Environment, 265: 111986. https://doi.org/10.1016/j.buildenv.2024.111986

[6] Al Jaff, A.A.M. (2022). Thermal comfort in traditional Erbil Houses. American Journal of Civil Engineering and Architecture, 10(1): 45-56. https://doi.org/10.12691/ajcea-10-1-6

[7] Philokyprou, M., Michael, A. (2021). Environmental sustainability in the conservation of vernacular architecture. The case of rural and urban traditional settlements in Cyprus. International Journal of Architectural Heritage, 15(11): 1741-1763. https://doi.org/10.1080/15583058.2020.1719235

[8] Larrain de Andraca, I., Rodwell, D. (2021). Environmental value for heritage conservation and urban sustainability: Adaptation in widely divergent climatic conditions. The Historic Environment: Policy & Practice, 12(3-4): 478-512. https://doi.org/10.1080/17567505.2021.1991104

[9] Mustafa, F.A., Ali, L.A. (2024). Common architectural characteristics of traditional courtyard houses in Erbil City. Ain Shams Engineering Journal, 15: 103003. https://doi.org/10.1016/j.asej.2024.103003

[10] Abba, H.Y., Majid, R.A., Ahmed, M.H., Gbenga, O. (2022). Validation of designbuilder simulation accuracy using field measured data of indoor air temperature in a classroom building. Management, 7(27): 171-178. https://doi.org/10.35631/JTHEM.727014

[11] Peeters, L., De Dear, R., Hensen, J., D'haeseleer, W. (2009). Thermal comfort in residential buildings: Comfort values and scales for building energy simulation. Applied Energy, 86(5): 772-780. https://doi.org/10.1016/j.apenergy.2008.07.011

[12] Khayat, M.A.B., Khaznadar, B. (2010). Formal characteristics of vernacular architecture in Erbil City and other Iraqi cities. The Iraqi Journal of Architectural Engineering, 19: 50-71. https://doi.org/10.36041/iqjap.v9i1.205

[13] Hamad, T.A., Oğuz, H. (2020). Determining thermal comfort zones for outdoor recreation planning: A case study of Erbil–Iraq. Turkish Journal of Forest Science, 4(1): 133-145. https://doi.org/10.32328/turkjforsci.705926

[14] Ali, H.S., Khayat, M.A.B. (2024). Erbil Citadel as a Brand for the City, the Role of Residents Awareness and Perceptions. Architecture, Building and Construction, 16(19): 1-17. https://doi.org/10.20944/preprints202407.2569.v1

[15] Hussein, Z.A., Uzunoğlu, K. (2020). Evaluation of the residents' satisfaction with high rise housing in new Eskan/Erbil–Iraq as a gated community. International Journal of Advanced and Applied Science, 7(11): 25-36. https://doi.org/10.21833/ijaas.2020.11.003

[16] González, J., Da Costa, B.B.F., Tam, V.W., Haddad, A. (2024). Effects of latitude and building orientation in indoor-illuminance levels towards energy efficiency. International Journal of Construction Management, 24(7): 784-798. https://doi.org/10.1080/15623599.2023.2215087

[17] Ibrahim, A.J., Zangana, D.D., Dehghanifarsani, L. (2024). Effectiveness of building envelope parameters and adopting PV panels to reduce reliance on local generators in hot-dry climate. International Journal of Renewable Energy Development, 13(3): 466-479. https://doi.org/10.61435/ijred.2024.60111

[18] Seddik Hassan, A.M., Abd El Aal, R.F.A., Fahmi, A.A.E., Ali, S.M.A., Abdelhady, M.I. (2024). Courtyard geometry's effect on energy consumption of AlKharga city residential buildings, Egypt. Scientific Reports, 14(1): 11149. https://doi.org/10.1038/s41598-024-60487-8

[19] Abuhussain, M.A., Al-Tamimi, N., Alotaibi, B.S., Singh, M.K., Kumar, S., Elnaklah, R. (2022). Impact of courtyard concept on energy efficiency and home privacy in Saudi Arabia. Energies, 15(15): 5637. https://doi.org/10.3390/en15155637

[20] Asadpour, A. (2020). Defining the concepts & approaches in vernacular architecture studies. Nature: National Academic Journal of Architecture, 7(2): 241-255. https://doi.org/10.24252/nature.v7i2a8

[21] Khoshnaw, R., Kissfazekas, K. (2019). Urban form and sustainability in historic cities: A case study of two neighbourhoods in Erbil City, Iraq. Építés-Építészettudomány, 47(1-2): 189-215. https://doi.org/10.1556/096.2018.014

[22] Aram, R., Zafer Alibaba, H. (2018). Investigating sustainability of the traditional buildings in Kermanshah, Iran. International Journal of Humanities, Arts & Social Sciences, 4(6): 235-244. https://doi.org/10.20469/ijhss.4.10002-6

[23] Sami, H. (2021). Sustainability analysis of climate responsive elements in Erbil vernacular architecture. Eurasian Journal of Science and Engineering, 7(1): 217-227. https://doi.org/10.23918/eajse.v7i1p217

[24] Amin, R.M., Al-Din, S.S.M. (2018). Evaluation of the sustainable aspects in housing sector to overcome housing stress in Northern Iraq. Contemporary Urban Affairs, 3(1): 67-81. https://doi.org/10.25034/ijcua.2018.4684

[25] Aziz, F.H., Rasheed, R.O., Ahmed, A.Q. (2022). Historical overview of air temperature of Kurdistan Region-Iraq from 1973 to 2017. Journal of Garmian University, 9(1): 263-271. https://doi.org/10.24271/jgu.2022.149171

[26] Hamad, T.A., Oğuz, H. (2020). Determining thermal comfort zones for outdoor recreation planning: A case study of Erbil–Iraq. Turkish Journal of Forest Science, 4(1): 133-145. https://doi.org/10.32328/turkjforsci.705926
[27] Ordóñez-Castañón, D., Cunha Ferreira, T. (2024). Toward the adaptive reuse of vernacular architecture: Practices from the school of Porto. Heritage, 7(3): 1826-1849. https://doi.org/10.3390/heritage7030087
[28] Hamad, A.A., Husein, H.A. (2023). The types of spatial adaptability based on user preferences of low-income apartments in Erbil City. Al-Qadisiyah Journal for Engineering Sciences, 16(2): 133-144. https://doi.org/10.30772/qjes.v16i2.932
[29] Alghamdi, S., Tang, W., Kanjanabootra, S., Alterman, D. (2022). Effect of architectural building design parameters on thermal comfort and energy consumption in higher education buildings. Buildings, 12(3): 329. https://doi.org/10.3390/buildings12030329
[30] Mankuri, D.P.A., Dönmez, Y. (2022). Assessment of urban identity and its components: A case study of Erbil. Bartın Orman Fakültesi Dergisi, 24(1): 157-176. https://doi.org/10.24011/barofd.955905
[31] Alhilo, I.A., Ismael Kamoona, G.M. (2024). Parametric analysis of the influence of climatic factors on the formation of traditional buildings in the city of Al Najaf. Open Engineering, 14(1): 20220525. https://doi.org/10.1515/eng-2022-0525
[32] Al-Omary, A.Y., Sabah, O.A. (2022). Architectural systems integration in traditional houses of the Mosul city of Iraq. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13(4): 1-15. http://doi.org/10.14456/ITJEMAST.2022.77
[33] Vatan Kaptan, M. (2020). Climate-responsive design strategy for Erbil City. Archnet-IJAR: International Journal of Architectural Research, 14(1): 90-111. https://doi.org/10.1108/ARCH-04-2019-0089
[34] Vinet, L., Zhedanov, A. (2011). A 'missing' family of classical orthogonal polynomials. Journal of Physics A: Mathematical and Theoretical, 44(8): 085201. https://doi.org/10.1088/1751-8113/44/8/085201
[35] Mankuri, D.P.A., Dönmez, Y. (2022). Assessment of urban identity and its components: A case study of Erbil. Bartın Orman Fakültesi Dergisi, 24(1): 157-176. https://doi.org/10.24011/barofd.955905
[36] Alhilo, I.A., Ismael Kamoona, G.M. (2024). Parametric analysis of the influence of climatic factors on the formation of traditional buildings in the city of Al Najaf. Open Engineering, 14(1): 1-16. https://doi.org/10.1515/eng-2022-0525
[37] Caruso, L., Buhagiar, V., Larcher, M., Borg, S.P., Bottino-Leone, D. (2024). Validation of 3D thermal simulations of the Double C Block, a novel composite masonry unit, using in-situ U-value measurements. Energy and Buildings, 325: 114956. https://doi.org/10.1016/j.enbuild.2024.114956
[38] Al-Hafith, O., BK, S., Bradbury, S., De Wilde, P. (2018). Thermally comfortable housing in Iraq—prospects of the courtyard pattern in achieving energy efficiency. In Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017), Iraq, pp. 904-917. https://doi.org/10.1007/978-3-319-63709-9_69
[39] Diz-Mellado, E., López-Cabeza, V.P., Roa-Fernández, J., Rivera-Gómez, C., Galán-Marín, C. (2023). Energy-saving and thermal comfort potential of vernacular urban block porosity shading. Sustainable Cities and Society, 89: 104325. https://doi.org/10.1016/j.scs.2022.104325
[40] Muhy Al-Din, S.S., Ahmad Nia, H., Rahbarianyazd, R. (2023). Enhancing sustainability in building design: Hybrid approaches for evaluating the impact of building orientation on thermal comfort in semi-arid climates. Sustainability, 15(20): 15180. https://doi.org/10.3390/su152015180
[41] Gao, Y., Meng, L., Li, C., Ge, L., Meng, X. (2023). An experimental study of thermal comfort zone extension in the semi-open spray space. Developments in the Built Environment, 15: 100217. https://doi.org/10.1016/j.dibe.2023.100217
[42] Hailu, H., Gelan, E., Girma, Y. (2021). Indoor thermal comfort analysis: A case study of modern and traditional buildings in hot-arid climatic region of Ethiopia. Urban Science, 5(3): 53. https://doi.org/10.3390/urbansci5030053
[43] Morad Aldoski, D.H., Sevinc, H. (2024). A sustainable residential building model in north Iraq by considering occupant behaviour, sociocultural needs, and the impact on energy use. Sustainability, 16(9): 3651. http://doi.org/10.3390/su16093651
[44] Alzoubi, H.H., Almalkawi, A.T. (2019). A comparative study for the traditional and modern houses in terms of thermal comfort and energy consumption in Umm Qais city, Jordan. Journal of Ecological Engineering, 20(5): 14-22. https://doi.org/10.12911/22998993/105324
[45] Mangeli, M., Aram, F., Abouei, R. (2024). Energy consumption and thermal comfort of rock-cut and modern buildings. Heliyon, 10(14): 14-22. https://doi.org/10.1016/j.heliyon.2024.e34217