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ARTICLE

Impact of Energy-Consuming Air Conditioning Systems on People's Thermal Comfort and Preferences: Comparative Study of Iraq and Gulf Cooperation Council Countries

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ABSTRACT

This study investigates the impact of the intense usage of air-conditioning systems on the thermal comfort requirements of building occupants. It compares the thermal comfort requirements of building occupants in Iraq and Gulf Cooperation Council (GCC) countries. Iraqis have limited usage of air-conditioning units, whilst people in GCC countries intensely operate these systems. Research work underpinning this article involved undertaking a year-long thermal comfort survey in Iraq, and an intensive analysis of thermal comfort studies conducted in GCC countries. Results show that, in Iraq, people experience a 2–50 °C annual indoor temperature range, and their annual comfort range is 14–35 °C. In GCC countries, due to the intense usage of air-conditioning systems, the widest recorded annual indoor temperature range is 17.2–31.0 °C, and the widest annual comfort range is 20.0–27.8 °C. These results demonstrate the significant impact of air-conditioning systems on narrowing the thermal comfort limits of building occupants leading to high energy consumption. This study presents a novel comparison between two cases highlighting the impact of air-conditioning systems on the thermal comfort requirements of building occupants. The results of this study can be used to inform the development of thermal comfort standards that better consider people's adaptation capabilities to help reduce energy consumption for heating and cooling purposes.

Keywords: Thermal comfort; Iraq; GCC countries; Energy saving; HVAC systems

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ARTICLE INFO

Received: 1 January 2024 | Revised: 15 February 2024 | Accepted: 22 February 2024 | Published Online: 25 March 2024

DOI: https://doi.org/10.30564/jaeser.v7i1.6220

CITATION

Al-Hafith, O., Satish, B.K., Wilde, P.D., et al., 2024. Impact of Energy-consuming Air Conditioning Systems on People's Thermal Comfort and Preferences: Comparative Study of Iraq and Gulf Cooperation Council Countries. Journal of Architectural Environment & Structural Engineering Research. 7(1): 1–19. DOI: https://doi.org/10.30564/jaeser.v7i1.6220

1. Introduction

Thermal comfort is one of the main requirements of building occupants as it could significantly affect their overall comfort level, health and productivity [1,2]. To ensure satisfying the thermal requirements of occupants, building codes and standards have been developed around the world to define required indoor thermal conditions. In parallel, Heating, Ventilation, and Air-Conditioning (HVAC) systems have been introduced and widely used to meet the set thermal conditions by standards and to provide a high level of thermal comfort to building occupants [3,4]. However, achieving thermal comfort and the widespread usage of HVAC systems have been associated with growing levels of energy consumption [5–7]. Globally, on average, 50% of consumed energy in buildings is directed toward running HVAC systems [8]. In the Gulf Cooperation Council (GCC) countries, in the Middle East, 70–80% of the energy used in buildings is for operating air-conditioning systems [9]. In the European Union, 64% of consumed energy is for heating purposes [8].

Accordingly, whilst the focus on maintaining thermally comfortable indoor environments is still present in building standards, there have been intensive efforts aiming at reducing the high energy consumption associated with achieving thermal comfort. Studies and building codes have investigated and recommended a range of design and construction strategies that have helped with improving the thermal performance of buildings leading to substantial reductions in energy consumption [3,10,11]. In parallel, studies have been investigating occupants' behaviours related to achieving thermal comfort in order to better understand occupants' impact on energy consumption, and to develop behaviour-driven strategies to reduce energy usage in buildings [12,13]. However, targets have not been achieved yet, and energy consumption for heating and cooling purposes has been steadily increasing [14,15].

Whilst research work is still in progress in these two areas to achieve further improvements, a number of recently conducted studies argue that one of the reasons behind the high energy consumption in buildings is related to the thermal comfort requirements as defined by thermal comfort standards [16–18]. The development of thermal comfort standards and the definition of required indoor thermal conditions have been accompanied by the development of HVAC systems [19,20]. Hence, satisfying thermal comfort standards is highly associated with the availability and usage of HVAC systems. Therefore, studies suggest that the determined thermal comfort ranges in standards do not necessarily correspond with the true thermal preferences and adaptation capabilities of building occupants. Scholars show that significant reductions in energy consumption can be achieved by revisiting the defined thermal comfort thresholds to better reflect people's thermal requirements. For example, whilst the recommended setpoint temperature by the Kuwaiti code is 24 °C in summer, Al-ajmi and Loveday (2010) found that the neutral temperature for occupants in AC residential buildings is 25.2 °C. It suggests that over 10% reduction in energy consumption can be achieved if the setpoint temperature is raised by 1.2 °C. Taib et al. (2022) and Fukawa et al. (2021) recommend extending the setpoint temperature range by 1–5 °C, depending on the place, to reduce energy consumption.

Previous studies have provided useful insights into the impact of determined thermal comfort ranges in standards and setpoint temperatures by building occupants on energy consumption for heating and cooling purposes. However, their underpinning fieldwork did not allow them to determine the full tolerance of building occupants with their thermal conditions and the impact of HVAC systems on the thermal comfort requirements of people. The reason is that the majority of these studies were conducted in air-conditioned (AC) buildings in which occupants enjoyed highly controlled indoor environments. These studies did not determine the widest possible range of thermal conditions that building occupants may accept. This study suggests that higher reductions in energy consumption can be achieved if building occupants' comfort limits are determined as if energy consuming HVAC systems are not to be used, which has not been investigated in previous studies. This study aimed to address this research gap. The investigation presented in this study compares and contrasts the thermal comfort limits of two populations that experience similar climatic conditions but have different opportunities to run energy consuming HVAC systems. In its investigation, this study focuses on the impact of cooling AC systems on building occupants' comfort range. Studies stress that, due to the climate change resulting from global warming, energy consumed in buildings for cooling purposes has been increasing and it is expected to increase further in the future [21–23].

2. Aims and objectives

This research aims to examine the impact of the intense usage of AC systems on building occupants' thermal comfort limits and to determine their thermal adaptation capabilities in the absence or limited usage of these systems. It focuses on hot-climate regions, and it takes Iraq and GCC countries as case studies to be compared. Iraq presents a case where people are exposed to extreme climatic conditions with limited access to energy-consuming AC systems. GCC countries present a case where building occupants intensely use AC systems to maintain specific thermal comfort limits. To achieve the aim of this study, the research had to address two objectives:

- Determine the thermal comfort limits of Iraqis.
- Explore the thermal comfort limits of building occupants in GCC countries.

3. Materials and methods

This research employed a quantitative research methodology to achieve its aim and objectives. It involved undertaking a thermal comfort survey and meta-data analysis to determine the thermal comfort limits of two groups of the population that show different levels of depending on running AC systems to satisfy their thermal comfort requirements. Iraq and GCC countries were used as case studies.

3.1 Case studies

This study determines and compares the thermal comfort limits of building occupants in Iraq and GCC countries. These countries experience a harsh hot climate, where, in summer, the temperature reaches 50 °C [24–26]. However, they present different scenarios in the way building occupants face the harsh hot weather. In Iraq, since the Desert Storm War in 1991, due to war damages and decades of low maintenance, the country has suffered from major defects in national electricity production [27,28]. The average daily electricity outage is six hours, and it reaches higher levels during the hot season. The unavailability of electrical power has limited building occupants' opportunities to operate energy-consuming AC systems [24,29]. On the contrary, in the GCC countries, the availability and highly subsidised prices of energy have led to an intense usage of AC systems [9,30]. Comparing Iraqis and GCC residents' thermal comfort limits, thus, allowed to present a novel examination of the long-term impact of AC systems on building occupants' thermal comfort requirements. An important factor that makes the comparison between Iraq and GCC countries of particular relevance, and further justifies investigating these two cases, is that communities in these countries share similar social and cultural values [31], which neutralises the impact of such factors on the comparison presented by this study. Social and cultural factors, such as clothing and the perception of privacy, affect people's thermal preferences and thermal comfort-related behaviours [12,32].

3.2 Adopted methods

Previous literature includes several studies determining the thermal comfort limits of building occupants in GCC countries, whilst there are limited studies on the Iraqi context. Accordingly, two independent lines of investigation were undertaken in this research (**Figure 1**). The first line of investigation included undertaking a thermal comfort survey to determine Iraqis' thermal comfort limits and their level of dependence on AC systems. The second line of investigation included undertaking a meta-data analysis of available literature and it aimed to determine the thermal comfort thresholds of building occupants in GCC countries. The impact of AC systems on building occupants' thermal preferences and comfort limits was determined by comparing and contrasting the thermal comfort limits of building occupants in Iraq and GCC countries.

3.3 Deployment of methodology

Thermal comfort limits in Iraq

To determine the thermal comfort limits of Iraqis, the first objective of this research, the study worked on developing an adaptive thermal comfort model for Iraq. In comparison to the other thermal comfort model, the static model, the adaptive model offers better assessment and predictions of people's thermal sensation and comfort level, in particular, in mixed-mode and naturally ventilated spaces [33,34]. Mixed mode (MM) ventilation refers to the approach where both natural ventilation and mechanical systems are used for ventilation, heating, and cooling purposes. Exploring previous literature shows that there is no national Iraqi thermal comfort standard that can be used to determine Iraqis' thermal comfort limits, but two thermal comfort studies were conducted in Baghdad [24,35]. However, they do not serve the aim of this research of determining Iraqis' comfort limits. The first study was conducted by Webb (1964) in homes, and the second study was conducted by Rashid et al. (2018) in classrooms. These two studies do not propose an adaptive thermal comfort model for the country. International thermal comfort standards, such as ASHRAE 55 and EN 16798, are not useful for determining the true comfort limits of Iraqis. These standards have been developed from experiments, in most cases, in moderate climate zones [33], which makes them inaccurate when applied to hot-climate regions [36–38].

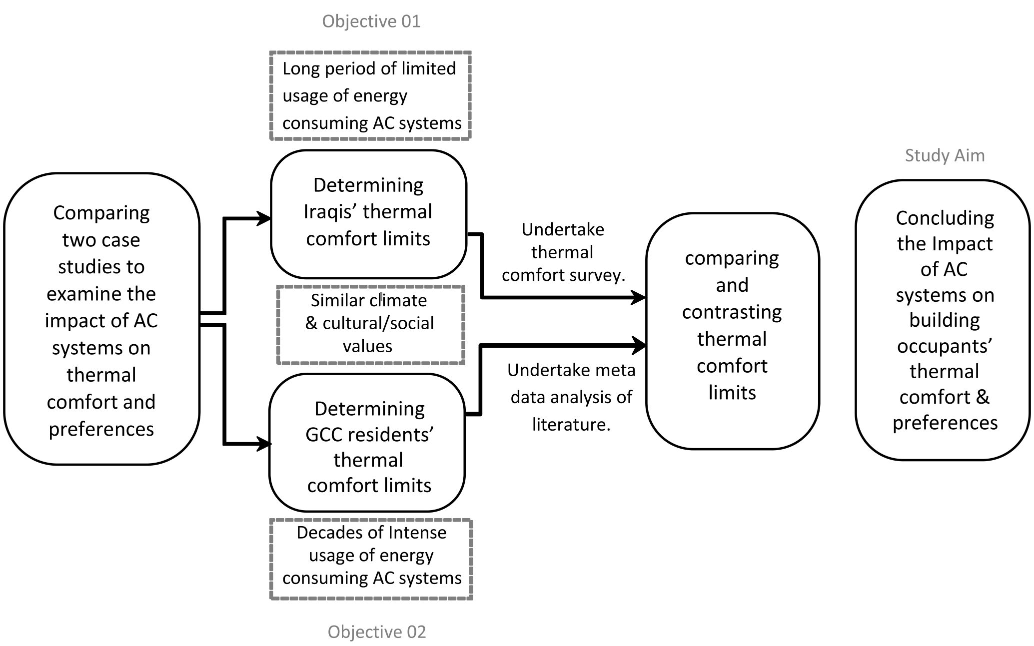


Figure 1. Employed research methodology.

To develop the needed adaptive thermal comfort model for Iraq, a thermal comfort survey was conducted in the country from October 2017 to October 2018. The survey was carried out in residential buildings and grounded on a set of thermal comfort studies. In particular, the survey considered the guide *Adaptive Thermal Comfort: Principles and Practice* by Nicole et al. (2012). Three criteria were considered to develop a representative sample to obtain reliable and generalisable results. The first one was to select participants from different cities in the country. The second one was to ensure that participating households did not have alternative sources of energy production that could enable them to overcome the common electricity shortage challenge in the country and make intense usage of AC units. The third criterion was to use a sample size of, at least, twenty participants giving, at least, 2000 thermal comfort votes, which is the threshold suggested by Nicol et al. (2012) to obtain reliable results. Participants were selected and recruited using the convenience sampling technique. The research required recruiting committed participants willing to record their comfort votes and provide the needed data for the whole twelve-month duration of the study. The convenience sampling technique allowed the research to achieve this objective. Potential participants were first contacted by telephone, and they were briefed about the study including its aims and the participation requirements. Eight households from four Iraqi cities accepted to participate, which were Mosul, Erbil, Baghdad and El-Ramadi. These households included more than seventy participants, which met the targeted sample size. All participating households were living in terrace and semi-detached houses. All the surveyed indoor spaces were of mixed-mode ventilation type.

The survey form was developed by considering similar survey forms used in previous studies and based on insights from a pilot study conducted in Iraq for this purpose. Preparing survey forms based on successful previous surveys and specialised guides guarantees the reliability and validity of the survey [39,40]. The survey sheet was designed as a table with four main columns and twenty rows. Each row was dedicated to recording the thermal conditions and thermal sensation of a participant at a specific point in time. With regard to columns, the first column was for participants to put their identification codes and the time and date of their participation. Participants were asked to give themselves unique identification codes to facilitate data analysis. The second column was for the participants to record the thermal conditions of their residential spaces. The third column was for participants to define the used system(s) to control the microclimatic conditions of their residential spaces. These included AC units, heaters, fans, evaporative coolers, and whether windows are opened or closed. The final column was for the participants to record their thermal sensations on a seven-point scale from very cold to very hot (**Figure 2**). The survey sheet included instructions about how to record thermal sensations and indoor spaces' thermal conditions. Participants were asked to conduct the survey at least three times a week, and each participating household was expected to complete multiple sheets during the study period.

This research used the Globe Temperature (Tg) to assess Iraqis' thermal sensation. Tg combines the impact of air temperature, air velocity and radiation in its value, which makes it an inclusive measurement [41]. Tg is recommended by Nicol et al. (2012), and it has been confirmed by other studies as an appropriate index to determine people's actual thermal sensation [42–44]. Eight Calibrated Extech HT30 Heat Stress meters were purchased and delivered to participants in Iraq. This instrument measures Tg, it is manufacturer calibrated, easy to use, and with acceptable accuracy. The Tg measurement range of the Extech HT30 Heat Stress meter is 0–80 °C and its accuracy level is ± 2 °C. This instrument has been used in thermal comfort studies published in peer-reviewed journals [45–47]. To ensure true recordings of thermal conditions, participants were taught how to use the device by the researcher when it was first delivered to them. Key instructions were included on the survey sheet, and participants were also provided with a user manual in Arabic.

Data were arranged and analysed using Microsoft

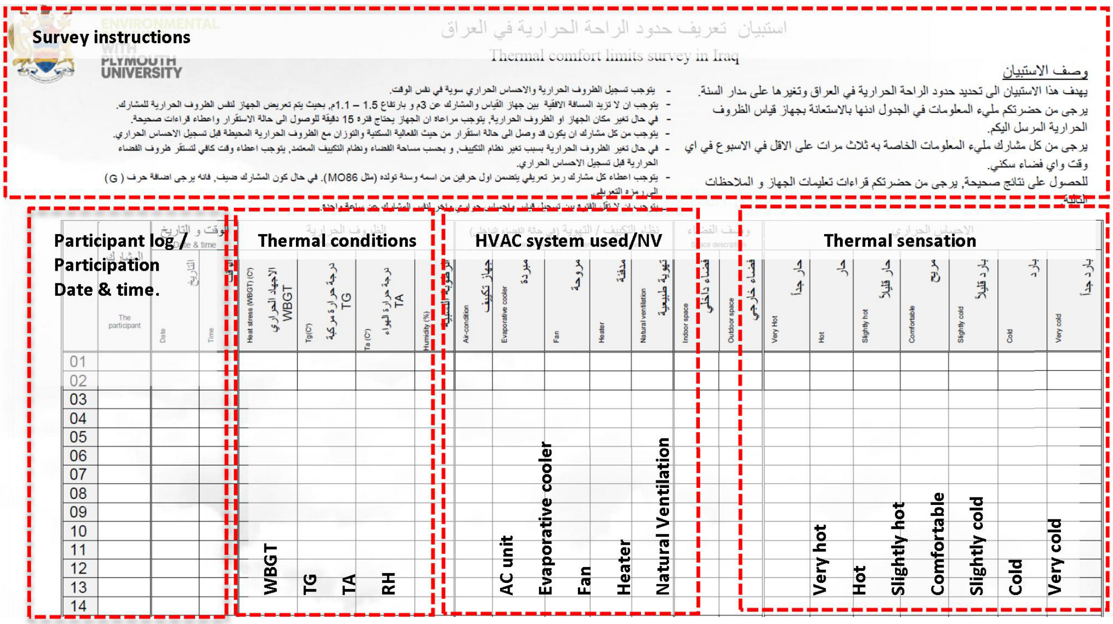


Figure 2. Iraq survey form.

Excel and IBM SPSS Statistics 24. The aim of the analysis was to develop an adaptive thermal comfort model for Iraq. As per Nicole et al. (2012), the analysis included undertaking a regression analysis to define the comfortable temperature range as recorded by participants for the annual range of outside temperature. The analysis of the collected data from Iraq also focused on exploring the usage of heating and cooling systems by participants. The percentages of using these systems over the twelve-month period of the conducted fieldwork were determined to define the heating and cooling periods, the peak points of using these systems, and the most used systems for cooling and heating purposes. In particular, the research focused on determining the level of using energy consuming AC systems by Iraqis to control their residential spaces. The determined usage of AC systems in Iraq was compared with the usage pattern in GCC countries to help with concluding the impact of these systems on building occupants' thermal comfort limits and requirements in the two contexts.

Thermal comfort limits in GCC countries

There are no national thermal comfort standards developed by GCC countries, and the national formal compliance procedures across these countries adopt the international ASHRAE 55 and ISO 7730 standards [8,9,48,49]. However, unlike the case of Iraq, exploring previous literature showed that there is a wide range of studies that have determined thermal comfort limits in GCC countries. The results of these studies were found to be satisfactory to address the second objective of this article. Accordingly, this research conducted a meta-data analysis of the available literature instead of undertaking thermal comfort studies in GCC countries. This research method has been used in previous literature for similar purposes [8].

The search for thermal comfort studies in GCC countries was conducted using online search engines [50–52]. The research focused on articles presenting actual thermal comfort studies conducted in buildings in one or more of the GCC countries and published in peer-reviewed journals or presented in peer-reviewed conferences. Available relevant doctoral studies were also considered in this study. The investigation was done using the saturation approach, in which the investigation continued until no new results were found [53,54]. This search found twelve research studies on occupants' thermal comfort limits in residential, office, educational and religious buildings (**Table 1**). These studies present data from five countries: the Kingdom of Saudi Arabia (KSA), the United Arab Emirates (UAE), Qatar, Kuwait and the Sultanate of Oman. Reflecting the widespread usage of AC systems, ten of these examined studies were conducted in AC buildings, and only two studies reported on MM buildings. The analysis focused on determining occupants' thermal comfort limits, recorded indoor thermal conditions, and the usage of AC systems.

In analysing the data of these studies, the research determined the average upper and lower thermal comfort thresholds in GCC countries to be compared with Iraqis' thermal comfort limits. The research also determined the highest and the lowest recorded temperatures experienced by building occupants in GCC countries to be compared with the thermal conditions experienced by Iraqis. As this study aims to determine the impact of AC systems on occupants' thermal comfort ranges, data from MM buildings was excluded from analysing thermal comfort limits and AC systems usage in GCC countries. These comparisons allowed the research to conclude the impact of AC systems on the thermal comfort requirements of building occupants. It was noted that, in some cases, the same datasets are presented and analysed in multiple articles to serve several objectives and draw different conclusions. To avoid counting these datasets multiple times and distorting the findings of this research, studies reporting similar datasets were excluded from the data analysis. Having the examined studies conducted in a range of building types was seen not to be affecting the results of comparing their conditions with the examined residential buildings in Iraq. Due to the high level of similarities, it has been reported in previous literature that results from thermal comfort studies in GCC countries are highly similar regardless of the building type or location [8]. Also, EN 16798 suggests that results from office buildings are still applicable to residential buildings and any other building type with mainly sedentary activities [55].

Table 1. Descriptive summary of the found thermal comfort studies in GCC countries.

Study	Country	Ventilation mode	Study period	No. of votes/participants
Indraganti et al., 2021 [56]	Doha, Qatar	5 AC residential units 1 MM residential unit	Dec 20–Mar21	9 participants
Indraganti and Humphreys, 2021 [48]	Doha, Qatar	10 AC offices	Jan 16–Jan 17	3742 votes
Elnaklah et al., 2021 [8]	Doha, Qatar	2 AC Schools 9 AC Offices	May–Sep 19	377 participants
	Dubai, UAE	2 AC Mosques 4 AC Offices	Dec 17–Jan 18, June 19	52 participants
Al-ajmi, 2020 [57]	Kuwait, Kuwait	7 AC educational buildings	Summer	136 participants
Al-Khatri et al., 2020 [30]	Muscat, Oman	5 AC schools	Cold season	567 participants
	Jeddah, KSA	3 AC schools		
Indraganti and Boussaa, 2018 [9]	Doha, Qatar	10 AC offices	Jan 16–Jan 17	3742 votes
Indraganti and Boussaa, 2017 [49]	Doha, Qatar	9 AC office buildings	May–Sep 16	1926 votes
Alshaikh, 2016 [58]	Dammam, KSA	20 MM residential buildings	Jan 14, Aug 13.	561 votes
Indraganti and Boussaa, 2016 [59]	Doha, Qatar	10 AC. Offices	Jan 16–Jan 17	1174 participants
Indraganti et al., 2016 [60]	Doha, Qatar	8 AC offices	Jan–Apr 2016	1362 votes
Al-ajmi, 2010 [61]	Kuwait, Kuwait	6 AC mosques	Summer	140 participants
Al-ajmi and Loveday, 2010 [18]	5 cities, Kuwait	25 AC residential buildings	May–Oct 06 May–Oct 07	111 participants

Notes:

- Indraganti and Humphreys, 2021; Indraganti and Boussaa, 2018; Indraganti and Boussaa, 2017 and Indraganti et al., 2016 present similar datasets to Indraganti and Boussaa, 2016. These four studies presenting similar datasets were excluded from the conducted analysis by this study.
- Data from MM buildings presented by Alshaikh, 2016 and Indraganti et al., 2021 were excluded from the undertaken analysis to determine average thermal comfort limits in GCC countries.

4. Results and discussion

4.1 Thermal comfort in Iraq

Ninety people participated in the comfort survey in Iraq. They were eight households consisting of 73 people who recorded their votes on a regular basis over the year-long duration of the survey (**Figure 3**). The rest were irregular participants who participated in the survey when visiting the survey-hosting households. Participants were adults between 18–60 years old. There were 32 participants from Mosul, 30 from Erbil, 18 from Baghdad and 10 from El-Ramadi. The total number of properly recorded thermal comfort votes was 4797.

Collected data show that the monthly average indoor global temperature ranges between 19–30 °C. However, global temperature as low as 2 °C was recorded indoors in winter, and as high as 50 °C was recorded in summer. The heating period is five months long, from November to April. The cooling period is nine months long and it is from March to December. The lowest recorded outdoor air temperature was –1 °C in January. The highest recorded outdoor air temperature was 48 °C in July. The peak usage of heating systems was in January, and the peak usage of cooling systems was in July. Data also shows periods where participants did not use heating and cooling systems. The month with the highest level of using these systems was July, and the month that shows the lowest level of using these systems was March.

Gas/kerosene/electric heaters and AC units were used for heating purposes. Fans, evaporative coolers, and AC units were used for cooling purposes (**Figure 4**). The system with the strongest impact on indoor thermal conditions was the AC units. As an example, on the 19th of July, an AC unit was used by one of the participating households to maintain indoor thermal conditions at 16.9 °C below the outdoor temperature. **Figure 4** demonstrates the distribution of the used cooling and heating systems over the survey period. For heating purposes, the most used heating system was heaters (kerosene, gas, electric), and AC units were marginally used. In January, the peak heating period, heaters were used in 63% of the instances recorded by participants in the survey, and AC units were used in 18% of the recorded instances. For cooling purposes, fans were the most used system to mitigate the harsh climatic conditions in summer, followed by AC units, then evaporative coolers. In July, the peak cooling period, fans were used in 63% of the instances recorded by participants, while AC units were used in 49% of the recorded instances.

To develop an adaptive thermal comfort model for Iraq, first, the annual running mean outdoor air temperature was calculated based on data from the Iraqi Meteorological Organisation and online temperature records [62]. Then, a regression analysis was conducted using the IBM SPSS Statistics 24 package to demonstrate the calculated running mean outdoor air temperature against the recorded globe temperatures by the survey participants for their different thermal votes. **Figure 5** shows the suggested adaptive thermal comfort model of this study for Iraq based on collected data. With a 90% confidence level, the graph shows that during winter, when the running mean outdoor air temperature is 8 °C, the comfortable global temperature is 14–24 °C. In summer, when the running mean outdoor air temperature is 38.0 °C, the thermal comfort range is 25–35 °C.

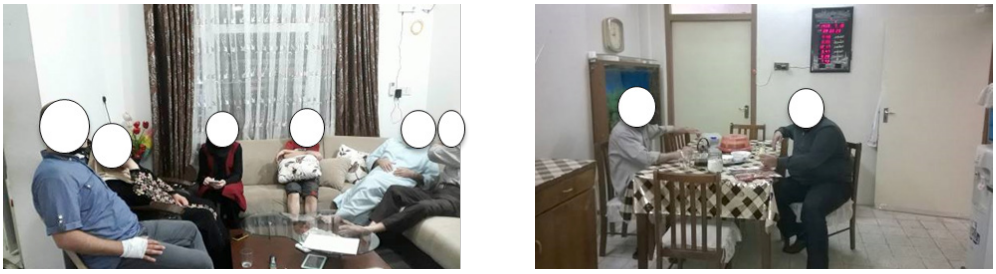


Figure 3. Examples of the contexts where participants filled out the survey forms in Iraq.

Kerosene Heaters

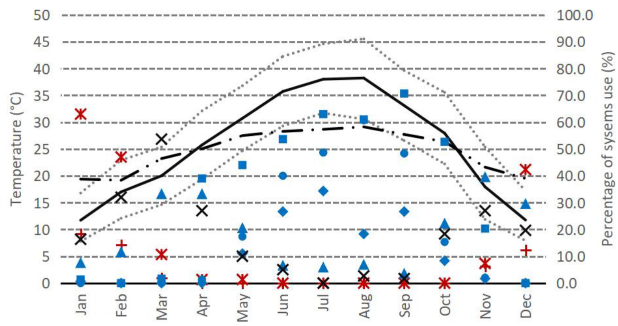
Ceiling Fans

Evaporative coolers

Air-conditioning units (for cooling/heating)

Percentage of using heating and cooling systems (%)

	AC-H	H	AC-C	Eco	F	W	N
Jan	18	63	0	1	1	8	16
Feb	14	47	0	0	0	12	32
Mar	2	11	0	0	2	33	54
Apr	0	1	1	0	39	33	27
May	0	1	17	11	44	21	10
Jun	0	0	40	27	54	7	5
Jul	0	0	49	34	63	6	0
Aug	0	0	61	18	61	7	3
Sep	0	0	48	27	71	4	2
Oct	0	0	15	8	53	22	18
Nov	6	7	2	2	20	40	27
Dec	12	42	0	0	0	30	20



Key

Max. outside Ta
Min. outside Ta
Mean outside Ta
Mean inside Tg
Air conditioning -Heating
Heater
Air conditioning -Cooling
Evaporative Cooler
Fan
Natural ventilation (open window)
No heating/cooling used

AC-H: Air Conditioning – Heating; **H:**Heater; **AC-C:**Air Conditioning – Cooling; **Eco**:Evaporative Cooler; **F**: Fan; **W**: open window; **N:**No heating/cooling used; **Ta**: Air temp.; **Tg**:Globe temp.

Figure 4. Heating and cooling systems usage (%) in association with average indoor and outdoor temperatures (October 2017–October 2018).

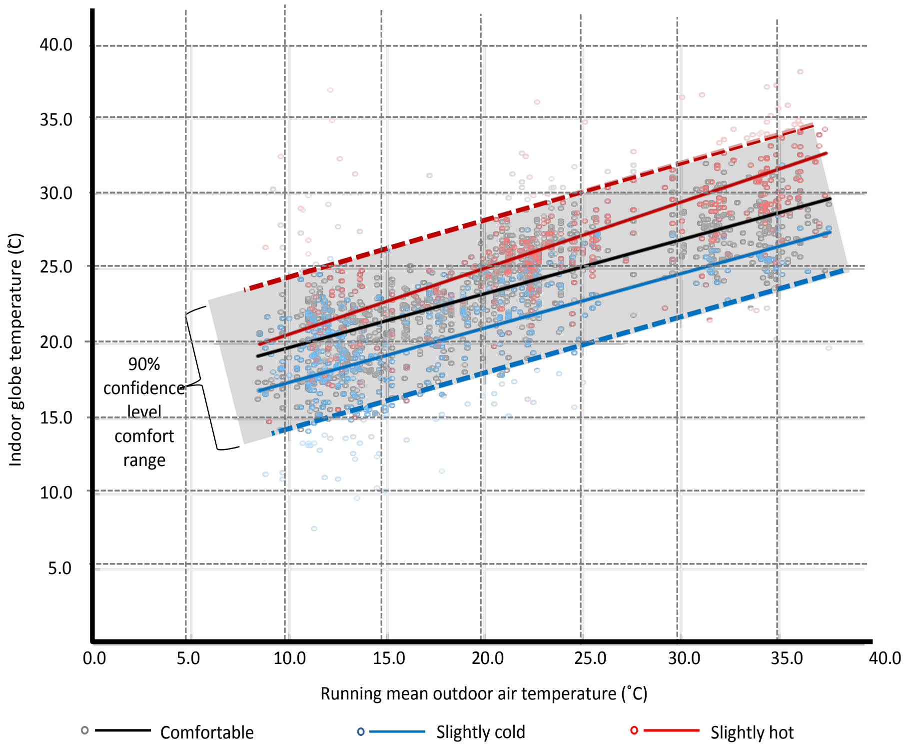


Figure 5. Proposed adaptive thermal comfort model for Iraq.

4.2 Thermal comfort in GCC countries

Analysed datasets from previous literature covered 2566 subjects and 78 AC Buildings. These included 23 offices, 17 educational buildings, 8 mosques, and 30 residential units. **Table 2** presents the ranges of indoor thermal conditions and thermal comfort limits for GCC countries as determined by the examined studies. Whilst the outside temperature in these countries reaches 50 °C [8], the average minimum comfortable temperature is 22.5 °C, and the average maximum comfortable temperature is 24.8 °C. The widest range of thermal comfort is 21.0–26.5 °C, as determined by Al-ajmi and Loveday (2010) in residential buildings in Kuwait. The narrowest thermal comfort range is 24–25 °C, which was determined by Indraganti and Boussaa (2016) in offices in Doha. The minimum reported comfortable temperature is 20.0 °C, and the maximum comfortable temperature is 27.8 °C. The minimum recorded indoor temperature is 17.2 °C, and the maximum recorded indoor temperature is 31.0 °C [8,30].

Regarding the usage of AC systems, analysed studies highlight that AC units are intensely used in GCC countries to the extent that, in summer, there are cases where occupants experience overcooled indoor spaces. Examined studies do not show that heating and cooling systems other than AC units are commonly used in GCC countries. Indraganti and Boussaa (2017a) reported that, in nine examined office buildings, 54% of the cases were with operable windows, but only 1.5% of these windows were operated during the survey period. Indraganti et al. (2021), showed that out of six residential buildings examined, five were dependent on AC units to achieve thermal comfort.

4.3 Comparative study

Results demonstrate that building occupants in Iraq and GCC countries, who share similar cultural and social backgrounds and similar climatic conditions, experience different indoor thermal conditions and have different comfort ranges (**Figure 6**). On the first hand, in Iraq, in residential buildings, the recorded annual indoor temperature range is 2.0–50.0 °C. The lower comfort limit in winter is 14.0 °C, and the upper comfort limit in summer is 35.0 °C. On the other hand, in GCC countries, the minimum and maximum recorded indoor temperatures are, respectively, 17.2 °C and 31.0 °C. The minimum and maximum recorded thermal comfort temperatures

Table 2. Thermal comfort limits in GCC countries.

City	Study	Indoor temperature (Tg/Ta/To) (°C)		Thermal comfort range Ta/Tg/To	
		Min	**Max**	**Min**	**Max**
Jeddah, KSA	Elnaklah et al., 2021 [8]	17.2	26.1	20.0	23.0
	Al-Khatri et al., 2020 [30]	23.0	31.0	23.3	27.8
Doha, Qatar	Indraganti and Boussaa, 2016 [59]	22.0	25.0	24.0	25.0
	Elnaklah et al., 2021 [8]	17.2	26.1	23.0	25.0
	Indraganti et al., 2021 [56]	17.6	22.0	Average 20.2	
Dubai, UAE	Elnaklah et al., 2021 [8]	17.2	26.1	22.0	25.0
Muscat, Oman	Al-Khatri et al., 2020 [30]	20	29	22.6	26.1
Kuwait, Kuwait	Al-ajmi and Loveday, 2010 [18]	19.5	28.1	21.0	26.5
	Al-ajmi, 2010 [61]	18.5	28.6	Average 26.1	
	Al-ajmi, 2020 [57]	19.7	26.5	Average 22.9	
Average thermal comfort range in GCC countries based on previous literature		Min comfortable temperature 22.5		Max comfortable temperature 24.8	

Note: Studies used three indices in assessing and determining indoor thermal conditions and occupants' thermal comfort. These included air temperature (T_a), operative temperature (T_o) and globe temperature (T_g). In the present study, to facilitate the comparison, it was assumed that the three used indices present equivalent assessments. Studies show no or marginal differences between these three indices in surveyed indoor spaces.

are, respectively, 20.0 and 27.8 °C. These differences in the thermal comfort ranges of occupants between Iraq and GCC countries result from the differences in the thermal conditions of their surrounding environments, which can be primarily traced back to the different usage of energy-consuming AC units. Unlike Iraqis, building occupants in GCC countries enjoy running AC units to maintain narrow ranges of indoor temperatures, which can be 20.0–30.0 °C lower than the outside temperature. This impact of AC systems can also be seen when comparing the results of Alshaikh (2016) with the results of other studies on GCC countries. Alshaikh (2016) shows that building occupants in MM ventilation residential buildings in KSA are happy to accept up to 29 °C temperature in summer and as low as 18 °C in winter. Although this comfort range is still narrower than the comfort range of Iraqis, it presents a relatively wider comfort range than the found ranges in AC buildings in GCC countries.

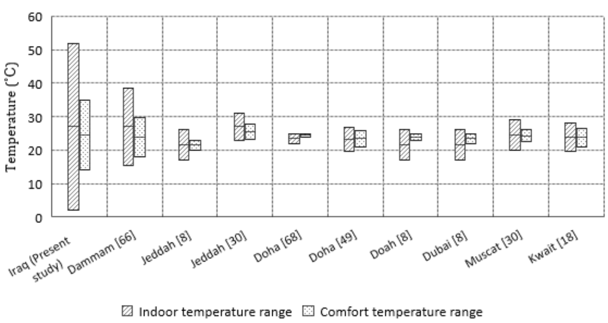
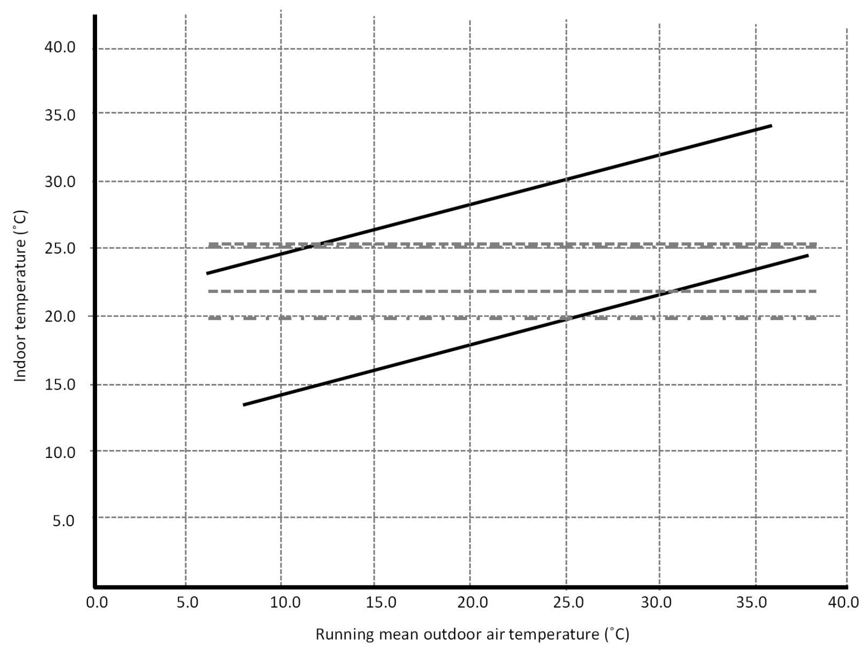


Figure 6. Thermal comfort and indoor temperature ranges in Iraq and GCC countries.

The comfort limits of Iraqis in summer, as determined by the present study, are similar to the comfort limits determined by Webb (1964) around sixty years ago. In other words, Iraqis' thermal comfort limits have not changed over the past decades. Due to the electricity shortage problem, Iraqis have not been able to deploy and use AC units to the same extent used by their neighbouring GCC countries. As a result, no or limited changes have developed in their thermal adaptation and preferences. Agreeing with the results of Rashid et al. (2018), this study found that, in residential buildings, the most used heating and cooling systems in Iraq are the ones with limited impact on indoor thermal conditions, such as fans in summer and kerosene/gas/electric heaters in winter. In peak summer and winter, energy-consuming AC units were used in less the 50% of the recorded instances by participants in the conducted survey, despite that AC units are more effective in providing thermal comfort than other systems. On the contrary, in GCC countries, since the development of their oil industry in the 1970s, wealth and quick urbanisation have been accompanied by escalated energy consumption aimed, primarily, to achieve a high level of thermal comfort. The usage of AC systems has been steadily growing putting energy consumption in these countries at the highest levels worldwide [18,48].

Literature analysis suggests two main reasons behind the intense air-conditioning usage and narrow comfort range in GCC countries, apart from the harsh climatic conditions. The first reason is related to the low energy prices in these countries, which, for decades, have encouraged building occupants to maintain intense usage of AC units [48,49]. Elnaklah et al. (2021) presents a case study from Jordan in which energy consumption was reduced by around 50% following a governmental decision to increase energy tariffs. The second reason, which might have led indoor spaces to be overcooled, is the formal adoption of international thermal comfort standards, such as the American ASHRAE 55 standard, in GCC countries' national building codes [49]. International standards have been originally developed for regions of different climatic conditions than GCC countries. There is no evidence showing that needed adjustments have been made by GCC countries so that local requirements and needs are considered [8,9,18].

Figure 7 presents a comparison between the adaptive thermal comfort model proposed by this study for Iraq and the recommended indoor temperature ranges in the building codes of UAE and KSA. There is a high difference between the determined comfort limits of Iraqis and the set comfort conditions by these building codes. Given the fact Iraq and GCC countries share similar climatic and cultural factors, this comparison demonstrates how far these building codes are from the possible actual needs and potential tolerance of people in GCC countries. Also, in the presented examples, building codes set fixed annual indoor temperature ranges, based on international standards, and with no consideration for the changes in the outside climatic conditions around the year. Dubai building code states that *HVAC systems shall be capable of providing the range of internal conditions in for 95% of the year*. The recommended indoor temperature range is 22–25 °C [63]. Accordingly, these building codes have made the intense usage of AC systems as one of the legal requirements in buildings, which has led to the development of indoor environments where building occupants experience fixed and narrow temperature ranges. As a result, people have developed narrow comfort ranges and limited tolerance to changes in thermal conditions. If the proposed adaptive thermal comfort model for Iraq is to be taken as a prospectus comfort standard for GCC countries, the maximum comfort temperature for summer could be raised by 9 °C, and the minimum comfort temperature for winter could be reduced by 6 °C. Revisiting these standards as per these suggested thresholds could help to achieve significant energy savings [18,64].



Iraq adaptive comfort model (present study)
Dubai's standard (building code) [63]
Saudi Arabia's standard (building code) [65]

Figure 7. Thermal comfort in Iraq in comparison to two standards in GCC countries.

Figure 8 compares the Iraqi adaptive thermal comfort model with a model suggested for Qatar, and the international thermal comfort models of ASHRAE and EN 16798. This figure shows that the lower comfort temperature for Iraq, as proposed by this study, is below the lower comfort temperature as defined by these two international standards. Similarly, the upper comfort temperature from this study is above the ones defined by both standards. As per the Adaptive Model's assumption that the comfort range of building occupants is a function of the outdoor climate, this difference in the thermal comfort limits between Iraqis, Europeans and Americans can be traced back, primarily, to the climatic differences between the three contexts. However, the Qatari Adaptive thermal comfort model performs against this assumption of the adaptive model. Whilst the Qataris live in a region where the temperature is at higher levels in summer than in Europe, their upper thermal comfort threshold is around 4 °C lower than the Europeans' upper comfort range. The upper thermal comfort range for Qataris is 25 °C when the running mean outdoor air temperature is 39 °C, whilst it is 29 °C for the Europeans when the running mean outdoor temperature is 30 °C. In comparison with the Iraqi model, whilst the Qataris experience similar outdoor climatic conditions of Iraq, their upper thermal comfort threshold is around 5 °C lower than the upper thermal comfort of Iraqis. This comparison between the Qataris, on the first hand, and the Europeans and the Iraqis, on the other hand, shows that the thermal comfort range of building occupants is not necessarily a function of outdoor temperature, but it could be indoor temperature. In other words, indoor microclimatic conditions could have a larger impact on forming building occupant's thermal preferences and comfort limits than outdoor conditions (**Figure 6**). As argued by Cena and de Dear (2001), this thermal comfort model for Qatar, which does not follow the adaptive model's theory, has resulted from the intense usage of AC units in Qatar which has led building occupants to be more affected by the indoor temperature than the outdoor climatic conditions [66].

Studies recommend re-introducing vernacular architecture as a research-evidenced approach to reduce energy consumption in buildings [67–69]. For example, for more than three decades, studies have been recommending re-using the traditional courtyard building pattern in hot-climate regions for its proven environmental efficiency [70–72]. The question that can be raised based on the results of this study is: if it is recommended to re-use the energy-efficient architecture of the pre-HVAC era, will it be possible to reduce energy consumption by bringing the thermal comfort limits and preferences of building occupants closer to their levels before the HVAC era? Is it possible to increase the tolerance level of building occupants without major interventions such as a war or price shock?

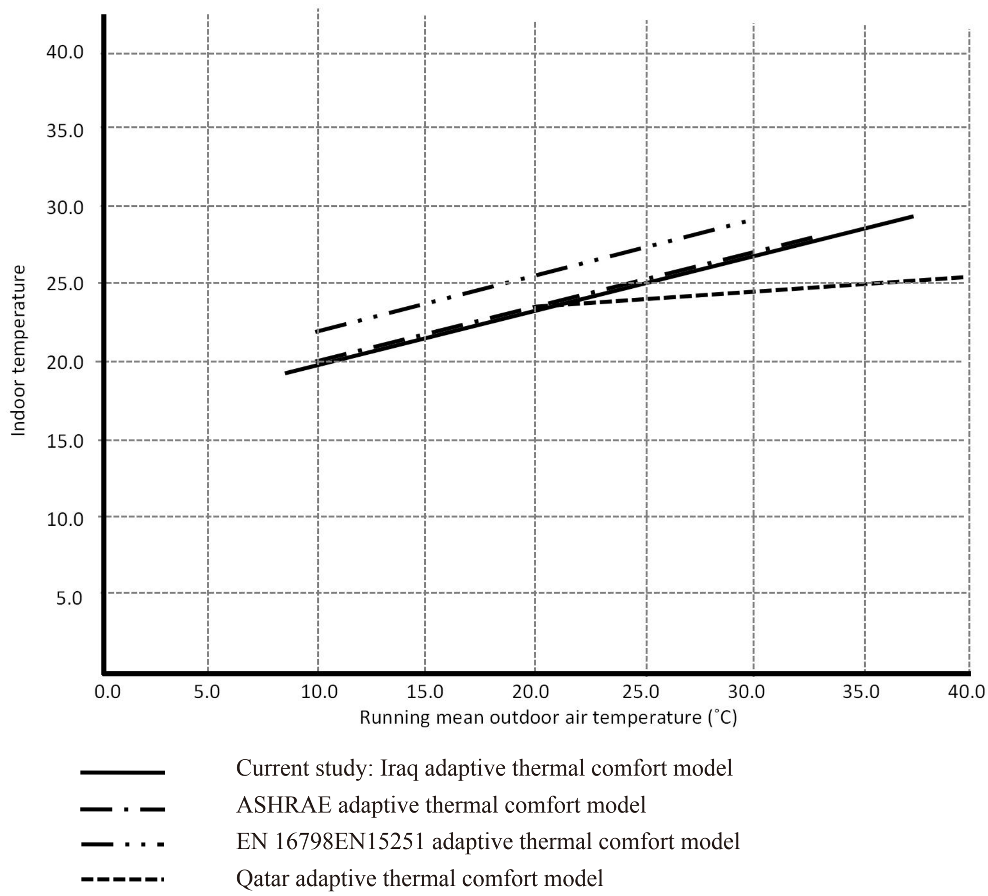


Figure 8. Comparison between the adaptive thermal comfort models of Iraq, ASHRAE, EN 16798 and Qatar.

5. Conclusions and recommendations

This study investigated the impact of the intense usage of energy-consuming AC systems on the thermal comfort requirements of building occupants. The study compared the thermal comfort limits of building occupants in Iraq and GCC countries, which represent two groups of the population that share similar climatic challenges and social factors but have different access to the operation of energy-consuming AC systems. A year-long thermal comfort survey was conducted in eight houses in Iraq, which was concluded by developing an adaptive thermal comfort model and determining the usage of heating and cooling systems in the country. In parallel, twelve thermal comfort studies conducted in GCC countries were analysed to determine the thermal comfort limits of building occupants in these countries and their usage of AC systems.

As a result of three decades of electricity shortage, Iraqis have adapted to accept their climatic conditions with limited dependence on energy-consuming AC units. On the contrary, GCC countries' residents, for decades, have used to intensely operate AC units to achieve thermal comfort. This has resulted in separating them from the outside climatic conditions and developing narrow comfort ranges and limited tolerance to changing thermal conditions. Iraqis experience an annual indoor temperature range of 2–50 °C, whilst building occupants in GCC countries experience no more than 10 °C annual difference in indoor temperature. As a result, in summer, when the outside temperature could reach 50 °C, Iraqis' upper and lower comfortable temperatures are, respectively, 25 °C and 35 °C, while the average annual comfort range in GCC counties is 22.5–24.8 °C. Iraqis, in the majority of cases, depend on relatively low-energy-consuming heating and cooling systems, such as heaters and fans. Building occupants in GCC countries depend, almost solely, on energy-consuming AC units. These results evidence that the decades of intense usage of energy-consuming HVAC systems have significantly affected building occupants' thermal comfort requirements.

Although the case of Iraqis might show extreme conditions of discomfort on occasions of electricity cuts, results illustrate that considering building occupants' adaptation abilities when setting thermal comfort standards can help with achieving significant reductions in energy consumption. One of the reasons behind the intense usage of AC systems in GCC countries is related to the adoption of inappropriate thermal comfort standards in the building codes of these countries, which could be the case in other countries as well. The comparison presented by this study suggests that revisiting GCC countries' building codes to better reflect the climatic conditions of this region and the actual adaptation capabilities of people can help achieve significant energy savings. Hence, it is essential for countries to develop national building codes and thermal comfort standards that reflect local challenges and needs and avoid imposing inappropriate or irrelevant measures and conditions.

Author Contributions

Omar Al-Hafith: Designed the study, undertook data collection work, and produced the article.

Satish B.K.: Supervised the design and the undertaking of the fieldwork and contributed to the production of the article.

Pieter de Wilde: Supervised the design and the undertaking of the fieldwork and contributed to the production of the article.

Sepideh Sadat Korsavi: Contributed to the production of the article.

Conflict of Interest

There is no conflict of interest.

Data Availability Statement

Data will be available upon request, and by contacting the corresponding author at omar.al-hafith@plymouth.ac.uk.

Funding

This research was partially funded by The Higher Committee for Education Development in Iraq

(HCED), grant number D1201858.

Acknowledgments

Fieldwork in Iraq was undertaken as a part of a Ph.D. study conducted at the University of Plymouth (2015–2020).

References

[1] Kawakubo, S., Sugiuchi, M., Arata, S., 2023. Office thermal environment that maximizes workers' thermal comfort and productivity. Building and Environment. 233, 110092. DOI: https://doi.org/10.1016/j.buildenv.2023.110092

[2] Clair, A., Baker, E., 2022. Cold homes and mental health harm: Evidence from the UK Household Longitudinal Study. Social Science & Medicine. 314, 115461. DOI: https://doi.org/10.1016/j.socscimed.2022.115461

[3] Homod, R.Z., Almusaed, A., Almssad, A., et al., 2021. Effect of different building envelope materials on thermal comfort and air-conditioning energy savings: A case study in Basra city, Iraq. Journal of Energy Storage. 34, 101975. DOI: https://doi.org/10.1016/j.est.2020.101975

[4] Dowson, M., Poole, A., Harrison, D., et al., 2012. Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. Energy Policy. 50, 294–305. DOI: https://doi.org/10.1016/j.enpol.2012.07.019

[5] Yang, L., Yan, H., Lam, J.C., 2014. Thermal comfort and building energy consumption implications—a review. Applied Energy. 115, 164–173. DOI: https://doi.org/10.1016/j.apenergy.2013.10.062

[6] Elaiab, F.M., 2014. Thermal comfort investigation of multi-storey residential buildings in Mediterranean climate with reference to Darnah, Libya [Ph.D. thesis]. Nottingham: University of Nottingham.

[7] González-Torres, M., Pérez-Lombard, L., Coronel, J.F., et al., 2022. A review on buildings energy information: Trends, end-uses, fuels and drivers. Energy Reports. 8, 626–637. DOI: https://doi.org/10.1016/j.egyr.2021.11.280

[8] Elnaklah, R., Alnuaimi, A., Alotaibi, B.S., et al., 2021. Thermal comfort standards in the Middle East: Current and future challenges. Building and Environment. 200, 107899. DOI: https://doi.org/10.1016/j.buildenv.2021.107899

[9] Indraganti, M., Boussaa, D., 2018. An adaptive relationship of thermal comfort for the Gulf Cooperation Council (GCC) Countries: The case of offices in Qatar. Energy and Buildings. 159, 201–212. DOI: https://doi.org/10.1016/j.enbuild.2017.10.087

[10] Satola, D., Wiberg, A.H., Singh, M., et al., 2022. Comparative review of international approaches to net-zero buildings: Knowledge-sharing initiative to develop design strategies for greenhouse gas emissions reduction. Energy for Sustainable Development. 71, 291–306. DOI: https://doi.org/10.1016/j.esd.2022.10.005

[11] Wuni, I.Y., Shen, G.Q., Osei-Kyei, R., 2019. Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. Energy and Buildings. 190, 69–85. DOI: https://doi.org/10.1016/j.enbuild.2019.02.010

[12] Satish, B.K., Brennan, J., 2019. Understanding the energy use behaviour of British Indian households to shape optimised sustainable housing strategies in existing housing stock. Sustainable Cities and Society. 48, 101542. DOI: https://doi.org/10.1016/j.scs.2019.101542

[13] Chen, S., Zhang, G., Xia, X., et al., 2021. The impacts of occupant behavior on building energy consumption: A review. Sustainable Energy Technologies and Assessments. 45, 101212.

DOI: https://doi.org/10.1016/j.seta.2021.101212
[14] Jian, Y., Liu, J., Pei, Z., et al., 2022. Occupants' tolerance of thermal discomfort before turning on air conditioning in summer and the effects of age and gender. Journal of Building Engineering. 50, 104099.
DOI: https://doi.org/10.1016/j.jobe.2022.104099
[15] International Energy Agency, 2018. The future of cooling: Opportunities for energy-efficient air conditioning. International Energy Agency: Paris.
DOI: https://doi.org/10.1787/9789264301993-en
[16] Taib, N.S.M., Zaki, S.A., Rijal, H.B., et al., 2022. Associating thermal comfort and preference in Malaysian universities' air-conditioned office rooms under various set-point temperatures. Journal of Building Engineering. 54, 104575.
DOI: https://doi.org/10.1016/j.jobe.2022.104575
[17] Fukawa, Y., Murakami, R., Ichinose, M., 2021. Field study on occupants' subjective symptoms attributed to overcooled environments in air-conditioned offices in hot and humid climates of Asia. Building and Environment. 195, 107741.
DOI: https://doi.org/10.1016/j.buildenv.2021.107741
[18] Al-ajmi, F.F., Loveday, D.L., 2010. Indoor thermal conditions and thermal comfort in air-conditioned domestic buildings in the dry-desert climate of Kuwait. Building and Environment. 45(3), 704–710.
DOI: https://doi.org/10.1016/j.buildenv.2009.08.018
[19] Fabbri, K., 2015. Indoor thermal comfort perception. A Questionnaire approach focusing on children. Springer: New York.
DOI: https://doi.org/10.1007/978-3-319-18651-1
[20] Nicol, J.F., Roaf, S., 2017. Rethinking thermal comfort. Building Research & Information. 45(7), 711–716.
DOI: https://doi.org/10.1080/09613218.2017.1301698
[21] Reveshti, A.M., Ebrahimpour, A., Razmara, J., 2023. Investigating the effect of new and old weather data on the energy consumption of buildings affected by global warming in different climates. International Journal of Thermofluids. 19, 100377.
DOI: https://doi.org/10.1016/j.ijft.2023.100377
[22] Ramon, D., Allacker, K., De Troyer, F., et al., 2020. Future heating and cooling degree days for Belgium under a high-end climate change scenario. Energy and Buildings. 216, 109935.
DOI: https://doi.org/10.1016/j.enbuild.2020.109935
[23] Guarino, F., Tumminia, G., Longo, S., et al., 2022. An integrated building energy simulation early—Design tool for future heating and cooling demand assessment. Energy Reports. 8, 10881–10894.
DOI: https://doi.org/10.1016/j.egyr.2022.08.224
[24] Rashid, S., Kornadt, O., Voelker, C. (editors), 2018. Defining thermal comfort in desert (hot-arid) climates: A thermal comfort field survey in Baghdad, Iraq. 10th Windsor Conference: Rethinking Comfort; 2018 Apr 12–15; London.
[25] Almansour, M., Krarti, M., 2022. Value engineering optimal design approach of high-performance residential buildings: Case study of Kuwait. Energy and Buildings. 258, 111833.
DOI: https://doi.org/10.1016/j.enbuild.2022.111833
[26] Almasri, R.A., Alshitawi, M.S., 2022. Electricity consumption indicators and energy efficiency in residential buildings in GCC countries: Extensive review. Energy and Buildings. 255, 111664.
DOI: https://doi.org/10.1016/j.enbuild.2021.111664
[27] Iraqi Electricity Sector Overview [Internet]. Available from: https://kapita.iq/storage/app/media/Research/Iraqi%20Electricity%20sector%20overview%20final%20March.pdf

[28] Mahdi, A.H., Aljubury, I.M.A., 2021. Experimental investigation of two-stage evaporative cooler powered by photovoltaic panels using underground water. Journal of Building Engineering. 44, 102679.
DOI: https://doi.org/10.1016/j.jobe.2021.102679

[29] Al-juboori, O.A., 2015. Conditions for Applying Public Private Partnership (PPP) in Iraq infrastructure projects successfully [Ph.D. thesis]. Munchen: Technische Universitat Munchen.

[30] Al-Khatri, H., Alwetaishi, M., Gadi, M.B., 2020. Exploring thermal comfort experience and adaptive opportunities of female and male high school students. Journal of Building Engineering. 31, 101365.
DOI: https://doi.org/10.1016/j.jobe.2020.101365

[31] Buda, R., Elsayed-Elkhouly, S.M., 1998. Cultural differences between Arabs and Americans: Individualism-collectivism revisited. Journal of Cross-cultural Psychology. 29(3), 487–492.
DOI: https://doi.org/10.1177/0022022198293006

[32] Aljawabra, F., Nikolopoulou, M. (editors), 2009. Outdoor thermal comfort in the hot arid climate: The effect of socio-economic background and cultural differences. 26th International Conference on Passive and Low Energy Architecture; 2009 Jun 22–24; Quebec.

[33] Nicol, F., Humphreys, M., Roaf, S., 2012. Adaptive thermal comfort: Principles and practice. Routledge: London.

[34] De Dear, R.J., Brager, G.S., 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings. 34(6), 549–561.
DOI: https://doi.org/10.1016/S0378-7788(02)00005-1

[35] Webb, C.G., 1964. Thermal discomfort in a tropical environment. Nature. 202, 1193–1194.
DOI: https://doi.org/10.1038/2021193a0

[36] Farghal, A., Wagner, A. (editors), 2010. Studying the adaptive comfort model a case study in a hot dry climate, Cairo, Egypt. Proceedings of Conference, Adapting to Change: New Thinking on Comfort; 2010 Apr 9–11; Windsor.

[37] Eltrapolsi, A., 2016. The efficient strategy of passive cooling design in desert housing: A case study in Ghadames, Libya [Ph.D. thesis]. Sheffield: University of Sheffield.

[38] Indraganti, M., Ooka, R., Rijal, H.B., et al., 2014. Adaptive model of thermal comfort for offices in hot and humid climates of India. Building and Environment. 74, 39–53.
DOI: https://doi.org/10.1016/j.buildenv.2014.01.002

[39] Thyer, B.A., 2010. The handbook of social work research methods. Sage Publications, Inc.: Thousand Oaks, CA.
DOI: https://doi.org/10.4135/9781544364902

[40] Fink, A., 2006. How to conduct surveys: A step-by-step guide. Sage Publications, Inc.: Thousand Oaks, CA.

[41] Song, G., 2011. Improving comfort in clothing. Elsevier: Amsterdam.

[42] Toe, D.H.C., Kubotam T. (editors), 2011. A review of thermal comfort criteria for naturally ventilated buildings in hot-humid climate with reference to the adaptive model. Conference Proceedings of the 27th International Conference on Passive and Low Energy Architecture; 2011 Jul 13-15; Louvain-la-Neuve.

[43] Rijal, H.B., Humphreys, M.A., Nicol, J.F., 2017. Towards an adaptive model for thermal comfort in Japanese offices. Building Research & Information. 45, 717–729.
DOI: https://doi.org/10.1080/09613218.2017.1288450

[44] Humphreys, M., Nicol, F., Roaf, S., 2015. Adaptive thermal comfort: Foundations and analysis. Routledge: London.
DOI: https://doi.org/10.4324/9781315765815

[45] Dhaka, S., Mathur, J., Wagner, A., et al., 2013. Evaluation of thermal environmental conditions and thermal perception at naturally ventilated hostels of undergraduate students in composite climate. Building and Environment. 66, 42–53.

DOI: https://doi.org/10.1016/j.buildenv.2013.04.015

[46] Kumar, P., Sharma, A., 2022. Assessing the outdoor thermal comfort conditions of exercising people in the semi-arid region of India. Sustainable Cities and Society. 76, 103366. DOI: https://doi.org/10.1016/j.scs.2021.103366

[47] Manu, S., Brager, G., Rawal, R., et al., 2019. Performance evaluation of climate responsive buildings in India-Case studies from cooling dominated climate zones. Building and Environment. 148, 136–156. DOI: https://doi.org/10.1016/j.buildenv.2018.10.063

[48] Indraganti, M., Humphreys, M.A., 2021. A comparative study of gender differences in thermal comfort and environmental satisfaction in air-conditioned offices in Qatar, India, and Japan. Building and Environment. 206, 108297. DOI: https://doi.org/10.1016/j.buildenv.2021.108297

[49] Indraganti, M., Boussaa, D., 2017. Comfort temperature and occupant adaptive behavior in offices in Qatar during summer. Energy and Buildings. 150, 23–36. DOI: https://doi.org/10.1016/j.enbuild.2017.05.063

[50] Google-Scholar [Internet]. Available from: https://scholar.google.com/

[51] Primo [Internet]. Available from: primo.plymouth.ac.uk

[52] ScienceDirect [Internet]. Available from: https://www.sciencedirect.com/

[53] Hennink, M., Kaiser, B.N., 2022. Sample sizes for saturation in qualitative research: A systematic review of empirical tests. Social Science & Medicine. 292, 114523. DOI: https://doi.org/10.1016/j.socscimed.2021.114523

[54] Al-Hafith, O., Satish, B.K., de Wilde, P., 2019. Assessing housing approaches for Iraq: Learning from the world experience. Habitat International. 89, 102001. DOI: https://doi.org/10.1016/j.habitatint.2019.102001

[55] British-Standard-Institution, 2019. BS EN 16798-1: 2019—Energy Performance of Buildings—Ventilation for Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics—Module M1-6. BSI: London.

[56] Indraganti, M., Kutty, F., Ali, R., et al., 2021. Occupant perception of thermal comfort in sleep environments in Qatar. The Journal of Engineering Research [TJER]. 18(2), 137–145. DOI: https://doi.org/10.53540/tjer.vol18iss2pp137-145

[57] Al-ajmi, F.F., 2020. Thermal Comfort in air-conditioned Campus Buildings in Kuwait. American Journal of Civil Engineering and Architecture. 8(1), 12–18.

[58] Alshaikh, A.M.A., 2016. Design principles for thermally comfortable and low energy homes in the extreme hot-humid climatic Gulf region, with reference to Dammam, Saudi Arabia [Ph.D. thesis]. Edinburgh: Heriot-Watt University.

[59] Indraganti, M., Boussaa, D., 2016. Occupant's thermal comfort in Qatari offices–Need for the new adaptive standard. QScience Proceedings. 23. DOI: https://doi.org/10.5339/qproc.2016.qgbc.23

[60] Thermal Comfort and Adaptation in Qatari and Japanese Offices: A Comparative Overview [Internet]. Available from: https://doi.org/10.18948/shasetaikai.2016.6.0_1

[61] Al-ajmi, F.F., 2010. Thermal comfort in air-conditioned mosques in the dry desert climate. Building and Environment. 45(11), 2407–2413. DOI: https://doi.org/10.1016/j.buildenv.2010.05.003

[62] AccuWeather [Internet]. Available from: www.accuweather.com

[63] Dubai Building Code [Internet]. Government of Dubai. Available from: https://dm.gov.ae/wp-content/uploads/2021/12/Dubai%20Build-

ing%20Code_English_2021%20Edition_compressed.pdf

[64] Bassoud, A., Khelafi, H., Mokhtari, A.M., et al., 2021. Evaluation of summer thermal comfort in arid desert areas. Case study: Old adobe building in Adrar (South of Algeria). Building and Environment. 205, 108140.
DOI: https://doi.org/10.1016/j.buildenv.2021.108140

[65] Saudi Building Code Energy Conservation Requirements: 601 [Internet]. SBCNC. Available from: https://fkec.com.sa/website/uploads/Energy_Conservation_Requirements.pdf

[66] Cena, K., De Dear, R., 2001. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. Journal of Thermal Biology. 26(4–5), 409–414.
DOI: https://doi.org/10.1016/S0306-4565(01)00052-3

[67] Sahebzadeh, S., Dalvand, Z., Sadeghfar, M., et al., 2020. Vernacular architecture of Iran's hot regions; elements and strategies for a comfortable living environment. Smart and Sustainable Built Environment. 9(4), 573–593.
DOI: https://doi.org/10.1108/SASBE-11- 2017-0065

[68] Kaoula, D., Rahmani, S., Lemita, I., et al., 2022. Life cycle assessment of traditional Saharan houses: Towards a sustainable building?. Journal of Building Engineering. 57, 104782.
DOI: https://doi.org/10.1016/j.jobe.2022.104782

[69] Chandel, S.S., Sharma, V., Marwah, B.M., 2016. Review of energy efficient features in vernacular architecture for improving indoor thermal comfort conditions. Renewable and Sustainable Energy Reviews. 65, 459–477.
DOI: https://doi.org/10.1016/j.rser.2016.07.038

[70] Almumar, M.M.S., 2019. Understanding the environmental performance of the Iraqi traditional courtyard house, is there an order of façades orientation in randomly oriented land plots?. Journal of Building Engineering. 22, 140–146.
DOI: https://doi.org/10.1016/j.jobe.2018.12.004

[71] Edwards, B., 2006. Courtyard housing: Past, present and future. Taylor & Francis: Abingdon.
DOI: https://doi.org/10.4324/9780203646724

[72] Al-Azzawi, S.H.A., 1984. A descriptive, analytical and comparative study of traditional courtyard houses and modern non-courtyard houses in Baghdad: in the context of urban design in the hot-dry climates of the sub-tropics [Ph.D. thesis]. London: University of London.