An Adaptive Thermal Comfort Model for Residential Buildings in Iraq

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Abstract: In Iraq, the temperature reaches around 0 °C in winter and 50 °C in summer. Aiming at providing thermal comfort for people, studies have been advocating developing innovative thermally responsive designs or adopting traditional architecture's passive design strategies. However, to develop appropriate solutions for the country, it is critical to determine the thermal comfort limits to define the targeted thermal performance of buildings. This research worked on defining Iraqis' thermal comfort limits in residential buildings for two reasons. First, they are the dominant building type in the country. Second, to inform the design of large housing developments Iraq is planning to have to satisfy large housing needs. Exploring previous literature in Iraq or regional countries shows that residential thermal comfort limits for people have not been defined properly. To achieve this aim, the research conducted thermal comfort survey in four Iraqi cities for a year. Nearly 4800 thermal comfort votes were recorded by 90 participants. The results show that the lower thermal comfort Globe temperature in winter is 17 °C and the highest acceptable Globe temperature in summer is 33 °C.

Keywords: Adaptive thermal comfort model, Iraq, Residential buildings.

1. Introduction

Iraq has an extremely long and hot summer and cold winter. The temperature range in Baghdad is between 0 °C in winter and 50 °C in summer (Iraqi Meteorological organization, 2016). 60% to 70% of the total energy consumption in the country is used for air-conditioning purposes (Hasan, 2016). These factors, in addition to the fact of having frequent interruptions in the electricity supply since 1990 (Al-juboori, 2015), makes it of high importance to develop options to provide thermally comfortable environments for people. Among the main possible options is to develop innovative thermally responsive buildings or to use traditional passive design strategies to have less energy consuming and more thermally comfortable buildings (Holmes and Hacker, 2007; Al-Jawadi, 2011). However, before developing any solution, Iraqis' thermal comfort threshold needs to be defined. This will help to define the targeted performance for designers and to judge possible alternatives' thermal efficiency. Otherwise, buildings' thermal efficiency might be not correctly determined which might lead to adopting inappropriate solutions for the country.

This research aims to explore and define Iraqis' thermal comfort limits in residential buildings. This building type was selected for two reasons. First, it is the dominant building type in the country. Second, Iraq has a housing shortage of around 1.5 million housing units. To solve this challenge, the country is planning to have massive housing development in the future (Iraqi Ministry of Construction and Housing, 2017). Having thermal comfort limits for people properly defined might help to inform future residential developments' design.

To achieve this aim, the research explored the subject of thermal comfort, previous thermal comfort studies in Iraq and regional countries, then conducted a thermal comfort survey in Iraq.

2. Thermal comfort

Thermal comfort is defined as '*that condition of mind that expresses satisfaction with the thermal environment*' (ASHRAE, 2005; Enescu, 2017; Höppe, 2002). It affects people comfort in their buildings (Al horr et al., 2016; Frontczak and Wargocki, 2011), in addition to their health (Nicol et al., 2012) and productivity (Freire et al., 2008). It also affects buildings' energy consumption as a large amount of the consumed energy in buildings is directed towards achieving thermal comfort (Yang et al., 2014), which leads to increasing the CO^2 emissions (Elaiab, 2014). Because of these reasons, it has been investigated by researchers since the beginning of the 20th century, when the air-conditioning systems were first introduced (Fabbri, 2015; Nicol and Roaf, 2017). Since that time many studies have been conducted to determine thermal comfort limits around the world. National and international thermal comfort standards have been established and developed, such as ISO Standard (7730), ASHRAE Standard 55 and CEN Standard EN15251 (Rupp et al., 2015; Nicol et al., 2012; Humphreys et al., 2015b).

To assess and predict people's thermal sensation, studies, first, have worked on defining the factors that affect people's thermal sensation. They have found that they are of two groups: quantitative factors and qualitative factors. The former includes air temperature; air velocity; humidity; Mean Radiant Temperature (radiation); people activity level and people clothes (Reiter and De Herde, 2003; Nikolopoulou, 2011; Setaih et al., 2013). The latter includes not measurable factors such as people previous experience, thermal expectations, the time of exposure to climatic conditions, psychology, and their culture and social backgrounds (Reiter and De Herde, 2003; Nikolopoulou, 2011; Aljawabra, 2014).

Depending on these factors, two thermal comfort models have been developed to assess and predict thermal comfort models: the Static Model and the Adaptive Model (Yao et al., 2009; de Dear and Brager, 2002a). The former was developed by Fanger during the 1970s. It assumes that thermal comfort can be universally defined by determining the impact of the six quantitative factors on the human body's thermal balance. It has been developed by doing thermal comfort experiments in special thermal comfort chambers (de Dear and Brager, 1998; Fanger, 1970). The latter was developed and introduced later by researchers, including Humphreys, Nicole, and de Dear. It states that there are qualitative factors that affect people thermal sensation other than the factors of the human body's thermal balance. It argues that people from different places and cultures have different thermal comfort limits and that people adapt themselves to their surrounding climatic conditions (de Dear and Brager, 2002a; Nicol, 2004; Nicol and Humphreys, 2002). This model has been developed through doing thermal comfort surveys in people's actual contexts doing their normal activities (Nicol et al., 2012). It predicts people's thermal sensation through making correlations with outdoor running temperature (Humphreys et al., 2010). Both of these two models have been used to determine people's thermal sensation and comfort limits. However, studies have found that the static model overestimates the discomfort of occupants in the buildings that depend on natural ventilation (Nicol et al., 2012; Brager and de Dear, 2001). It is also not able to tackle and consider the psychological, social and cultural factors that affect people perception of thermal comfort (Nicol et al., 2012; De Dear and Brager, 2002b).

According to this exploration, this research used the Adaptive model to determine Iraqis' thermal comfort limits. It offers to explore thermal comfort in a wider range of space types in addition to making a better correlation with countries' local conditions.

3. Thermal comfort limits in Iraq

There are a number of international comfort standards that have developed adaptive models, such as ASHRAE 55 and EN 15251 standards (Rupp et al., 2015; Nicol et al., 2012). However, they cannot be used for Iraq's climates because they have been developed depending on experiments, in most cases, in moderate climate zones (Nicol et al., 2012). This makes them inaccurate when they are applied to hot regions. The considered mean temperature limits in the ASHRAE 55 standard's model, for instance, is between 10 °C and 33 °C, which different from hot regions' temperature (Farghal and Wagner, 2010; Eltrapolsi, 2016; Indraganti et al., 2014).

Exploring previous studies that have worked on developing an adaptive thermal comfort model for hot regions shows that there has been two comfort studies in Iraq and a number of studies in regional hot countries (Table 1). Although these studies give useful indications about thermal comfort limits for people in hot regions, they do not conclude a complete adaptive thermal comfort model that can be used to determine Iraqis' thermal comfort limits in residential buildings. They are either in non-residential buildings, which makes them not accurate for residential buildings, or in residential buildings but of small sample size and limited time frame. A representative sample size, as it is determined by (Nicol et al., 2012), is twenty participants giving around 2000 thermal comfort votes. This study aims to address this research gap through conducting a thorough thermal comfort survey in Iraq to develop an inclusive thermal comfort model for residential buildings in the country.

Table 1. Previous thermal comfort studies in hot regions

The study	Country	Outdoor temperature range (°C)	Buildin g type	Study period	No. of comfort votes	Results (thermal comfort limits)	
						W. (°C)	S. (°C)
(Rashid et al., 2018)	Baghdad, Iraq	0 - 50	Class-rooms	Dec., Jan., Aug.	530	Ta: 19.0	Ta: 29.0
(Alshaikh, 2016)	Dammam, KSA	5 – 40	Houses	Jan., Aug.	561	Ta: 18.0-29.0	Ta: 22.7-29.7
(Indraganti and Boussaa, 2016)	Doha, Qatar	18 - 37	Offices	13 months	3742	Tg: 24	Tg: 25
(Farghal and Wagner, 2010)	Cairo, Egypt	10 – 35	Class-rooms	Feb. – Dec.	2689	Ta: 17.0	Ta: 35.0
(Heidari, 2008)	Tehran, Iran	- 2 – 37	Offices	July	631	---	Ta: 24.6-26.2
(Heidari and Sharples, 2002)	Ilam, Iran	1 – 53	Offices	One year	3819	Ta:21.7	Ta:26.7
			Houses	Aug., Dec.	891	Ta:20.8	Ta:28.4
(Webb, 1964)	Baghdad, Iraq	0 - 50		Jun., Jul.	1284	---	Tg:32

Ta: Air temperature – Tg: Globe temperature – W.: winter – S.: summer

4. Research methodology

This research worked on developing an adaptive thermal comfort model for Iraq to be used to determine Iraqis' thermal comfort limits. To achieve this objective, the research conducted a thermal comfort survey that lasted for a year from October 2017 to October 2018. The survey was conducted following exploring a number of similar thermal comfort studies and with considering (Nicol et al., 2012) guide to conduct thermal comfort surveys.

- The study sample: As the survey's objective is to develop an adaptive thermal comfort model for the whole country, the research considered having participants from all of the country's regions. But, due to not having participants ready to participate in the study from the whole country, this was not possible to be achieved. However, eight households from four cities accepted to participate. Three households were in Erbil, three in Mosul, two in Baghdad and one in Ramadi. They all constitute around 70 participants, which made it possible to exceed the 2000 votes threshold defined by (Nicol et al., 2012). Although they might not represent the whole country, the participated cities are still from different regions and can give useful results about the overall thermal comfort limits in the country. All of the participating households' houses were mix mode ventilation buildings.

  It is important to state here that it was not possible to select participants randomly due to the nature and conditions of the survey which required having committed and motivated participants.
- The survey form: A survey form was developed following exploring previous literature and a thermal comfort survey guide (Nicol et al., 2012). In preparing the survey forms, it was considered to make it as easy and simple as possible to encourage participants to record as many readings as possible. The survey form included asking participants to record thermal conditions measurements, define used approaches to control the spaces' environments, define the nature of spaces and record their thermal sensation on a seven-point scale from very cold to very hot (Figure 1)
- Assessing people' thermal sensation: This research used the Globe Temperature to assess Iraqis' thermal sensation. It combines the impact of air temperature, air velocity and radiation in its value, which makes it of an inclusive measurement. Studies have found that it represents an appropriate index to represent people's thermal sensation (Humphreys et al., 2015).
- Instrument: The measuring instrument was selected to be able to measure the Tg directly. For this reason, Calibrated Extech HT30 Heat Stress WBGT (Wet Bulb Globe Temperature) meters were purchased and delivered to the participants in Iraq (Figure 2). This instrument is manufacturer calibrated, easy to use, with acceptable accuracy and measures all the required factors. Participants were asked to take the measurements and record their thermal comfort votes on the survey form simultaneously. They were informed to fill the survey while doing their normal daily activities.

ENVIRONMENTAL BUILDING WITH PLYMOUTH UNIVERSITY

استبيان تعريف حدود الراحة الحرارية في العراق

Thermal comfort limits survey in Iraq

وصف الاستبيان

يهدف هذا الاستبيان الى تحديد حدود الراحة الحرارية في العراق وتغيرها على مدار السنة.
يرجى من حضرتكم مليء المعلومات في الجدول ادنها بالاستعانة بجهاز قياس الظروف الحرارية المرسل اليكم.
يرجى من كل مشارك مليء المعلومات الخاصة به ثلاث مرات على الاقل في الاسبوع في اي وقت واي فضاء سكني.
للحصول على نتائج صحيحة, يرجى من حضرتكم قراءات تعليمات الجهاز و الملاحظات التالية:

- يتوجب تسجيل الظروف الحرارية والاحساس الحراري سوية في نفس الوقت.
- يتوجب ان لا تزيد المسافة الافقية بين جهاز القياس والمشارك عن 3م و بارتفاع 1.5 – 1.1م, بحيث يتم تعريض الجهاز لنفس الظروف الحرارية للمشارك.
- في حال تغير مكان الجهاز او الظروف الحرارية, يتوجب مراعاه ان الجهاز يحتاج فتره 15 دقيقة للوصول الى حالة الاستقرار واعطاء قراءات صحيحة.
- يتوجب من كل مشارك ان يكون قد وصل الى حالة استقرار من حيث الفعالية السكنية والتوزان مع الظروف الحرارية المحيطة قبل تسجيل الاحساس الحراري.
- في حال تغير الظروف الحرارية بسبب تغير نظام التكييف, و بحسب مساحة الفضاء ونظام التكييف المعتمد, يتوجب اعطاء وقت كافي لتستقر ظروف الفضاء الحرارية قبل تسجيل الاحساس الحراري.
- يتوجب اعطاء كل مشارك رمز تعريفي يتضمن اول حرفين من اسمه وسنة تولده (مثل MO86). في حال كون المشارك ضيف, فانه يرجى اضافة حرف (G) الى رمزه التعريفي.
- يتوجب ان لا تقل الفتره بين تسجيل قياس واحساس حراري واخر لنفس المشارك عن ساعة واحده.

	المشارك The participant	الوقت و التاريخ Date & time		الظروف الحرارية Thermal conditions				نظام التكييف / التهوية (في حالة الفضاء الداخلي) Air-conditioning / ventilation system (Indoor spaces)					وصف الفضاء Space description		الاحساس الحراري Thermal sensation						
		التاريخ Date	الوقت Time	الاجهاد الحراري WBGT Heat stress (WBGT) (C°)	درجة حرارة مركبة TG Tg(C°)	درجة حرارة الهواء TA Ta (C°)	الرطوبة النسبية Humidity (%)	جهاز تكييف Air-condition	مبردة Evaporative cooler	مروحة Fan	مدفئة Heater	تهوية طبيعية Natural ventilation	فضاء داخلي Indoor space	فضاء خارجي Outdoor space	حار جدا Very Hot	حار Hot	حار قليلا Slightly hot	مريح Comfortable	بارد قليلا Slightly cold	بارد Cold	بارد جدا Very cold
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لارسال القياسات والتواصل مع الباحث, يرجى استخدام عناوين الاتصال التالية:

Figure 1. The survey form

Specification s	Range	Accuracy
Black Globe Temperature (Tg)	0 °C -80°C	2°C
Air Temperature (Ta)	0 °C -50°C	1°C
Relative humidity	0 to 100%	3%
The ball size	40mm diameter, 35mm high	

Figure2. The used instrument to measure the Globe Temperature

5. Results analysis and discussion

More than 90 people participants in the survey. 73 of them recorded their votes on a regular basis. The rest were irregular participants who participated in the survey a few times while visiting the survey hosting households. The total number of the properly recorded thermal comfort votes were 4797: 2643 in naturally ventilated spaces, 2154 in air-conditioned spaces.

The results show that the monthly average indoor Globe Temperature ranges between 20 °C and 30 °C (Figure 3). The outdoor monthly average air temperature is between 9 °C and 36°C. The heating period is five months: during the months of January to March and November to December. The cooling period is nine months: between March and November. Within the cold period, people sometimes do not use heating systems and satisfy with closing their windows. The peak use of heating systems is in January, and the peak use of cooling systems is between July and August. The period in which they mostly use neither cooling nor heating systems is in March and November.

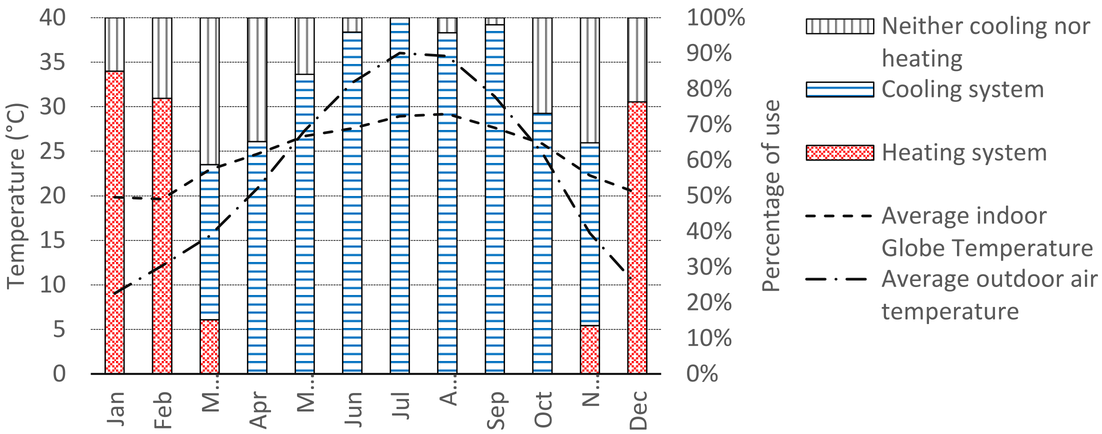

Figure3. The measured Globe Temperature (°C) and use of heat and cooling systems (%)

Analysing the correlation between indoor Globe Temperature and participants' thermal sensation shows that the thermal comfort limits is similar in both of the air-conditioned (AC) spaces and naturally ventilated (NV) spaces (Figure 4). The upper comfort limit is 32 °C and the comfort limit is 12 °C. This might be contradicting the results of thermal comfort studies that have shown differences in comfort temperature between air-conditioned and naturally ventilated buildings (Brager and de Dear, 2001). But, in the case of the current study, it is reasonable to have them similar for two reasons. First, they are in mixed mode ventilation buildings. Second, which might not be applicable to some countries, is the electricity supply interruptions that obstruct using air-conditioning systems.

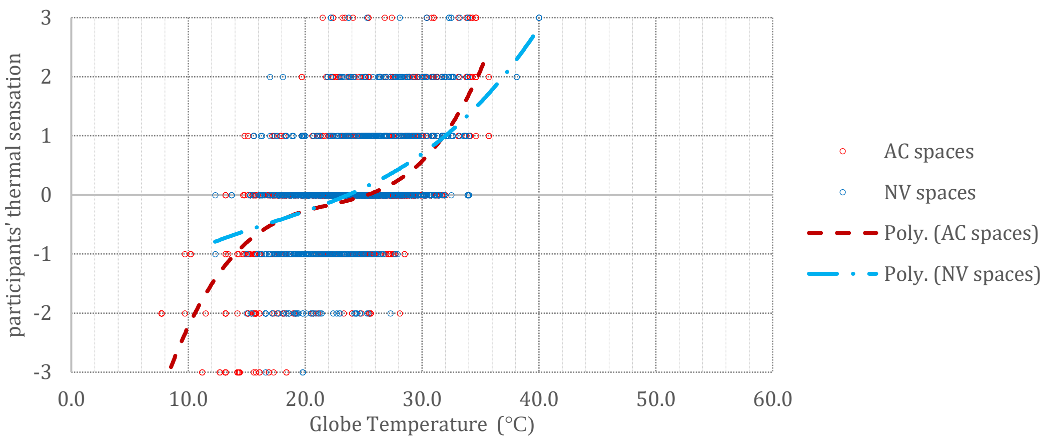

Figure4. The correlation between the measured Globe Temperature and participants' thermal sensation in AC and NV spaces

To develop an adaptive model to define Iraqis' thermal comfort limits, this research conducted a regression analysis to correlate the running mean outdoor air temperature and indoor Globe temperature and participants' thermal sensation (Figure 5). The average running main outdoor air temperature was calculated for a year for the four cities depending on temperature data from the Iraqi Meteorological Organization and online temperature records (www.accuweather.com, 2019). The analysis shows that the lowest comfortable Globe temperature for Iraqis is 17 °C when the running mean outdoor air temperature is 8 °C. The highest acceptable Globe temperature is 33 °C when the running mean outdoor air temperature is 38 °C. The perfect comfortable Globe temperature is 19 °C and 30 °C when then running mean outdoor air temperature is 8°C and 38°C, respectively.

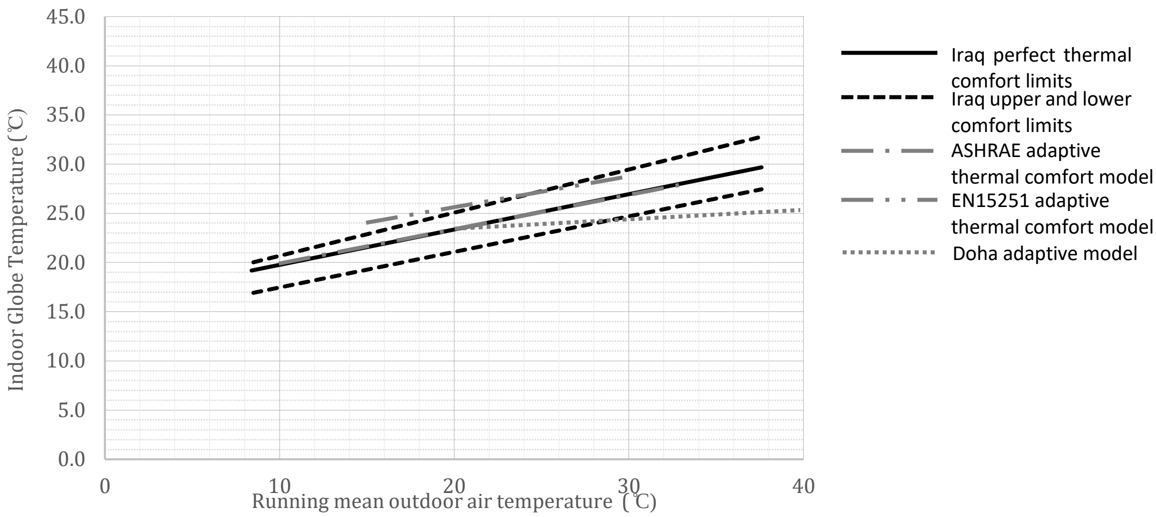

Figure4. The proposed adaptive thermal comfort model for Iraq

Comparing these comfort limits with the comfort limits defined by other studies shows some similarities and differences (Figure 4). On the first hand, the upper comfort limit in summer is similar to the one defined by (Webb, 1964) fifty years ago. However, it is highly different from the one defined by the (Indraganti and Boussaa, 2016) study in Doha, even though Doha's summer temperature is close to Iraqi summer temperature. The reason behind this difference is that the conducted study in Doha was in air-conditioned offices during the whole year. Three out of ten buildings surveyed in this study were without operable windows. This gives them high dependence on air-conditioning systems and a high level of control over the environment, which is not the case in the present study's surveyed buildings and participants. Studies have shown that people in naturally ventilated buildings accept a wider range of temperature than people in totally air-conditioned buildings (Brager and de Dear, 2001). Comparing the results with ASHRAE and EN15251 standards' adaptive models shows that the lower comfort temperature in the present study is less than the lower comfort temperature defined by both of these two standards. The upper comfort temperature for Iraqis defined by this study is above the temperature defined by both of them as well. This difference is reasonable as it results from the difference between the Iraqi climate and the climate of the countries where the two international standards have been developed.

6. Conclusions

This study conducted a thermal comfort survey to develop an adaptive thermal comfort model to determine Iraqis' thermal comfort limits in residential buildings. The results show that the upper comfortable Globe temperature in summer is 33 °C and the lower Globe temperature in winter is 17 °C. These are the overall thermal comfort limits for Iraq and they are applicable to mixed mode ventilation residential buildings. The results discussion shows that they are different to the comfort limits defined by international standards' adaptive models. They are also different to thermal comfort limits in air-conditioned buildings in a hot country. This means that designers can still develop thermally comfortable buildings without having to totally depend on energy consuming air-conditioning system. It also implies that buildings' design and thermal efficiency need to be determined in hot regions in a different way than in regions of a different climate. The defined comfort limits in this study can be used by designers and developers to consider having as much as possible thermally comfortable and energy efficient residential buildings in Iraq or countries of similar climate and culture.

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