Managing Thermal Comfort within the Residential Context of a Developing Region. A Field Investigation Based on Two Socioeconomically Distinct Households.

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Abstract: Paying particular attention to the relationship between the inhabitants and the physical performance of the environment they occupy and the factors shaping that relationship is believed to be fundamental when conducting building performance researches. This paper follows that approach in examining the management and control of the indoor thermal environment within a sample of socioeconomically distinct households based in Iraqi Kurdistan (KRI). This is undertaken through a close coupling of qualitative and quantitative investigations employing a combination of in situ measurements, observations, and in-depth interviews capturing inhabitant's behavioural control actions with respect to the performance of their dwellings. The paper tends to develop a type of tentative hypothesis which can help structuring a framework to explore what the questions of thermal comfort and environmental control mean within the residential context of KRI. The investigations reveal how occupants' engagement in adjusting indoor conditions is shaped by non-thermal factors, mainly socio-economic ones, and so environmental design in such context requires a stronger focus on that.

Keywords: Socio-technical approach, Adaptive behaviour, Thermal comfort, Environmental control, Fuel poverty

1. Introduction

As key determinants in the functionality of buildings and the way inhabitants interact with the built environment, the questions of thermal comfort and environmental control within the residential context have gained increased attention across the building performance literature over years. The typical approach in undertaking such investigations has based on physiology and engineering-based methods and evaluations. This has been through monitoring the physical parameters, e.g. temperature and air quality, assessing how buildings actually perform in terms of providing and maintaining thermal comfort. This is besides the application of post-occupancy surveys that take occupant's viewpoint in such assessment, identify their expectations and needs, and rate their degree of satisfaction. With such an approach which has been relatively limited to the technical dimensions of environmental control and physical aspects of thermal comfort, however, one cannot rigorously understand the relationship between the inhabitants and the physical performance of the environment they occupy and the factors shaping that relationship (Leaman et al., 2010). One needs to go beyond that conventional approach and think in a wider sense with increased attention to the nature of that relationship (Cole et al., 2008).

There is a widespread belief that what people consider as a satisfactory thermal environment largely varies from one culture, place, climate or time to another (Chappells & Shove, 2005; Nicol & Roaf, 2017). And with no doubt, the human body's physiological and physical state is no longer seen as the only determinant driving the perception and management of comfort in buildings. It is according to (Chappells & Shove, 2005; Shove et al., 2008) only one element among others, such as socio-cultural context, ways of life, the building attributes, and the available measures by which comfort can be provided.

This belief can be supported by a number of field-based researches showing how influential those underlying components can be. For instance, Leaman & Bordass (2007) show that the expectations, tolerance thresholds, and thermal behavioural patterns of those living in a mechanically controlled environment undoubtedly differ from those of who live in a free-running building. Also, a study conducted by Wilhite et al. (1996) compares the way households manage and control the indoor environment of their buildings in Japan and Norway. It indicates the notable impact of cultural differences and available controls which resulted in clear differences in their comfort preferences and practices. Such impact is well analysed and described by Kempton & Lutzenhiser (1992). Another research conducted in a suburb of Copenhagen by Gram-Hanssen (2010) found that even families living in the same type of dwellings could have considerably different heat consumption and behavioural patterns for different reasons, such as thermal preferences and unfamiliarity with the environmental control systems. The study examined the issue from a socio-technical angle employing a combination of quantitative and in-depth qualitative investigations and pointed up the importance of incorporating occupants-centred approach in conducting building performance researches. Indeed, occupants' engagement in adjusting indoor conditions and its significant impact on performance outcomes is proven (Rijal et al., 2007; Hoes et al., 2009). Such engagement according to Cole et al. (2008) is shaped by a set of contextual, behavioural, cultural, psychological and physiological factors. These are alongside religious and economic ones (Humphreys, M., 1997). However, their degree of influence varies according to different conditions and circumstances.

In areas such as those of the developing world where the affordability of comfort is a common issue, human behaviour in controlling the environment becomes quite essential. And so considering the inhabitants as an integral part of the overall performance of the environment they occupy underlines the importance of valuing and engaging questions of human agency when studying thermal comfort and environmental control. And this is according to (Gupta & Chandiwala, 2010; Stevenson & Rijal, 2010) can be undertaken through social qualitative analysis offering intimate insights. Bringing this and methods concerning technical aspects together will form a socio-technical regime (Cole et al., 2008).

Drawing on such a regime, this paper tends to examine the management and control of the indoor thermal environment and factors leading to the behaviour and provide an empirical understanding of performance within the residential context of Iraqi Kurdistan (KRI). It employs the case study method (CSM), bottom-up approach, to develop a type of tentative hypothesis which can help structuring a framework to explore what the questions of thermal comfort and environmental control mean in KRI. The paper is based on data collected from two case studies where both selected from the opposite end of the socioeconomic spectrum. This was based on a framework set by a Joint Report by the Kurdistan Regional Statistics Office (KRSO) and the International Organization for Migration (IOM). The investigations reveal how thermal behavioural patterns of users are essentially shaped by non-thermal factors, mainly socio-economic ones. The paper underlines that human behaviour becomes quite essential in controlling the environment when the affordability of comfort is an issue. Accordingly, environmental design in such context requires a stronger focus on that.

2. The study area

The paper is based on field investigations conducted in the Kurdistan region, a region that is located in the northern part of Iraq (36.41° N, 44.38° E) bordering Turkey, Syria, and Iran and comprising the country's four northernmost governorates: Sulaymaniyah, Halabja, Erbil, and Duhok. The region has a semi-arid climate, with hot dry summers and cold, wet winters. The mean daily temperatures range from 32 °C to 36 °C and 4 °C to 11 °C during summertime and wintertime respectively.

The vast majority of residential units in the region rely on two sources of electricity supply: the national grid and a shared generator (or a small station) operating at a neighbourhood level. The first is considered as the main electricity source and is highly dependent on governmental support. However, owing to extreme strain on its capacities as a result of increased demand, mismanagement, and some other major barriers explained in (IEA, 2012), households often experience power failure throughout the day. In 2018, for instance, the average electricity supply through national grid in the city of Duhok was limited to nearly 13 hours per day (General Directorate of Duhok Electricity, 2018). This creates difficulties for the majority of households to keep their homes at right temperatures during both cooling and heating seasons. The second, which is privately owned by an Independent Power Producer (IPP), is used to fill some of the electricity supply gap that is experienced. However, it supplies electricity at considerably higher prices (1 USD per 4 kWh) creating a major barrier to many households across the region in operating heating and cooling technologies when necessary.

3. Methods

The approach followed in this study lies in a close coupling of qualitative and quantitative investigations employing a combination of in situ measurements, observations, and in-depth interviews capturing inhabitant's behavioural control actions with respect to the performance of their dwellings.

Starting with in situ measurements, data collection of the outdoor and indoor thermal environment, mainly in the occupied spaces in each dwelling, was carried out over the period of four weeks starting from July 25 to August 22, 2018. Similar to other monitoring researches [e.g. Oreszczyn et al., 2006; Hong et al., 2009; Cantin et al., 2010; Bozonnet et al. 2011; Kavgic et al., 2012; Soebarto and Bennetts, 2014], out of six thermal comfort variables that established in ISO 7730 (2006), relative humidity and dry-bulb temperature were measured continuously at 5-min intervals by employing data loggers, called Tinytag. The place in which each logger was hung was carefully chosen aiming for ideal locations taking into account ANSI/ASHRAE Standard 55 guidelines. Householders' guidance was also considered especially in terms of their identification of the main occupied spaces and also the places where they operate portable heaters and/or air coolers within each space. Sensors were positioned away from any source of coolth or heat, e.g. air conditioner, heater, sunlight, cooker, and etc. Alongside that, a smart meter was installed to measure energy consumption.

The monitoring process was accompanied by qualitative data collection through semi-structured interviews with the families and tours inside their houses. This stage aimed to provide a thorough understanding of the occupants' personal knowledge about the contribution of the building itself and the available measures in maintaining thermal comfort. This is in addition to establishing a clear picture about their behavioural control actions and strategies in coping with extreme thermal conditions throughout the cooling season in the light of the constant electricity blackouts that they experience with the

National Grid. The interviews were carried out during August 2018 at their residences. Not only personal thermal comfort preferences, reactions and experiences that are common in post-occupancy evaluations were addressed but also the historical, technical, cultural and social influences in achieving thermal comfort were discussed.

4. Case studies

Taking into account the socio-economic context which cannot be excluded from any in-depth analysis, the two case studies (see Fig. 1) were selected from the opposite end of the socioeconomic spectrum where one has a monthly income of 250,000 – 500,000 Iraqi Dinars (IQD) whilst the other earns over 5,000,000 IQD. This allowed higher degrees of comparability owing to differences in their lifestyles, their strategies of adjusting the indoor thermal conditions, their consumption patterns, and the quality of their buildings. The selection was based on a framework set by a Joint Report by the Kurdistan Regional Statistics Office (KRSO) and the International Organization for Migration (IOM).

Case study 1 **Case study 2**

Figure 1 The front views of the examined houses (author)

The first case study is occupied by a family of two (a 62 year old housewife with her adult son) in which their average monthly income is around 300-350 USD, and thus adapting to conditions below the level of what might people consider as a normal lifestyle. The building incorporates two bedrooms in which one is used as a storage space, besides a kitchen, living room, bathroom, toilet, and staircase leading to rooftop. At the very outset, the house was naturally ventilated, but afterward, both living room and primary bedroom were fitted with three mechanical controls which are a split-type air conditioner, provided by a charity in recent years, an air-cooler and a ceiling fan.

The other case study is a double-storey unit occupied by an upper-class family of three, a man who is in his 50s with his two wives. The ground floor incorporates an open plan living area with dining, staircase, semi-open kitchen, en suite bedroom and toilet alongside an entrance which is connected to the garage, while the top floor consists of four bedrooms, two balconies, a storage, and a bathroom. The ground floor is used primarily and since the house is oversized for such a small family, only one bedroom is used on the first floor, and the rest are unoccupied. To modify the indoor environment, furthermore, the house is fitted with a combination of cooling and ventilation technologies, such as A/C units, air coolers, portable fans. Further characteristics of both case studies are shown in Table 1.

Table 1 The characteristics of both case studies

	Case study 1	Case study 2
Completion	1974	2008
Location	Duhok	Erbil
House Type	One-storey, detached	Double-storey, detached
Floor area	98 m^2	253 m^2
Utilised floor area	76 m^2	169 m^2
ceiling height	2.8 m	2.9 m
Roof type	Concrete flat roof	double-roof system: flat reinforced concrete roof coupled with a pitched lightweight metal tile roof
External wall materials	Cement plaster, solid concrete blocks, cement plaster	Limestone, hollow bricks, gypsum plaster
Roof's U-value	3.8 W/m2K	1.3 W/m2 K
External walls' U-value	2.8 W/m2K	1.43 W/m2K
Window type	All window openings are old, steel framed and single glazed	Sliding windows, aluminium framed and double glazed

5. Findings

Both numerical and qualitative data are presented in the following subsections.

5.1. Physical measurements

Indoor environment data showed an apparent difference between the measurements taken in the first case study and those taken in the second one. Overall, indoor thermal discomfort is evident across the first case, i.e. low-income household, where temperatures being high reaching 35 °C and 39 °C in the living room and bedroom respectively, particularly when A/C was not running. In the living room, which was occupied 24/7, the mean daily temperature ranged from 25.9 °C to 31.2 °C, and for 61% of the monitoring period, temperatures exceeded 28 °C. The bedroom experienced even higher indoor temperatures; its mean daily temperature had been between 29.9 °C and 34.9 °C. It has approximately 99% of occupied hours with records in excess of 26 °C. Readings show that the upper-income household had also experienced relatively warm indoor thermal conditions despite having access to air-conditioning round-the-clock, together with the better building thermal characteristic, i.e. lower U-value, compared with the previous case study. The mean daily temperature ranged from 29.1 °C to 31.2 °C and 27.9 °C to 29.7 °C in the living area and en suite bedroom respectively. The former had the lowest record of 26.4 °C despite the fact that the A/C units there were set to 24 °C. One could argue that the units' inadequacy to accomplish the set temperature is attributed to the fact that air conditioners are normally prone to lose their efficiency and power over time especially if there is a lack of maintenance. However, one should not deny: the impact of the room's layout and size being spacious (around 54 m^2) accommodating both the living and dining area. This is in addition to being attached to a staircase and a non-conditioned semi-open kitchen, where cooking takes place, allowing heat transfer to occur among those spaces through convection.

5.2. Adaptive behaviour and attitude

The qualitative interviews revealed that a range of thermal adaptation habits were being practised by the inhabitants to cope with the summer heat. These practices varied from personal adjustments, i.e. those associated with human body, to building adjustments (see table 2). The level of human intervention in adjusting indoor thermal conditions was found to be high within the low-income household as the occupants exploited many possible adaptive measures, mainly passive ones, to stay thermally comfortable. Meanwhile, the extremely low level of human intervention in overcoming thermal discomfort within the upper-income household was beyond question.

Table 2 Thermal practices of the two households

Thermal adjustments	Low-income household	Upper-income household
Personal adjustments	Staying away from any source of heat Sitting or lying on the screed floor Dampening and adjusting clothes Taking cold showers Drinking cold water Using hand fans	Adjusting clothes
Building adjustments	Sprinkling the roof and vegetation around the house Removing carpets before summer starts Washing the screed floor Opening/closing doors Turning on ceiling fans Switching on A/C	Turning on cooling technologies (i.e. fans, air conditioners, and evaporative air-coolers) Opening/closing windows Adjusting blinds

Their choice of practising a certain adaptive behaviour was not only driven by thermal factors. The cost implications of using cooling technologies, for instance, were found to have a potent role in configuring the thermal behavioural patterns of the low-income household. The operation hours of air conditioners were correlated to the availability of power from the national grid owing to the low electricity prices that it has offered over many years. The household used to close the doors and leave the air conditioners on at the lowest possible temperature setting whenever power was supplied from the public network. In this regard, the housewife stated: "*Nobody is using the bedroom over the day, but the reason why I leave it* [the air conditioner] *on is that I store some food there, and energy from public network is cheap; it does not cost me a lot, so I leave it on."* Nevertheless, frequent power breakdowns that are experienced with the public network hinder the continuous running of air conditioners in spite of having an alternative energy source, i.e. private generator at the neighbourhood level. High electricity prices that this supplier offers, i.e. 1 USD per 4 kWh, prevent the household to mechanically keep their home at right temperatures. Data recorded by the installed smart meters show that the energy consumption over the monitoring period via the generator is about one tenth (i.e. 1.7 kWh/m^2) of the amount consumed with the public network. This is despite the fact that the neighbourhood generator was supplying electricity for nearly 11-12 hours per day. In this regard, she stated: "*We cannot switch on A/C to adjust the thermal environment while we have electricity from the neighbourhood generator because it costs a lot and we cannot spend most of our income on that even though we want it*." This could be a clear indication of how ease-of-use is prevented by economy. Accordingly, the occupants resort to other personal and environmental adjustments (see Table 1) to overcome thermal discomfort when that is a restriction. Particularly, the chance of operating ceiling fans to create a downdraft accompanied by some humidification techniques, e.g. taking cold showers, dampening cloths or washing the floor, is very high and their role is believed to be important in alleviating discomfort from the heat. Alongside that, a platter full of plastic cups of frozen water was observed in the living room indicating the continual drink of cold water.

As a consequence of being on the higher rungs of the economic ladder, on the other hand, the upper-income household was predominantly relying on active cooling technologies to adjust the thermal conditions. In this respect, the householder explained by saying: "*With the extreme prevailing summer temperatures, it is almost impossible to avoid thermal distress with no cooling technologies in hand."* In fact, A/C units were noted to be the most practised environmental control in the house. Associated cost implications were not desperately limiting their operation, and the operation hours (especially during night-time hours when occupants fall asleep) were not exclusively correlated to the supply of electricity through the National Grid. This can be noted through data recorded by the installed smart meter showing that the household had nearly four times more consumed electricity via IPP supplier than the low-income family. Despite the notably higher socioeconomic status the household has, the inhabitants were generally very keen to reduce their consumption of energy no matter from which source the power was supplied. Whatever the electrical appliance was, it was only in use when needed. Before moving from one space to another, for example, they switch off all the appliances; the operation of bedrooms' air conditioners was exclusively limited to the sleeping hours. The householder was asked if such an attitude was encouraged by cost concerns, but he asserted that it is not so; rather it is based on their moral principles being central in their energy-related behaviours. In this regard, he commented by saying:

> *It is definitely a non-economic factor. We morally feel uncomfortable to overspend or consume something in an extravagant way, and even religiously, we are not allowed to be wasteful as the Almighty Allah 'likes not those who commit excess' as it is stated in the Holy Qur'an. So it is not just about energy but I mean in general. Even when we prepare food, we cook only as much as we need and avoid food waste.*

The behavioural adjustments and indoor thermal conditions of both case studies were also influenced by the physical attributes of their buildings. Owing to the poor quality of the building fabric, for instance, the low-income household was practising certain techniques to reduce its impact on the indoor thermal environment. By virtue of the severe indoor conditions that caused by heat flux through the fabric, the family decided to use the least uncomfortable spaces, thus converting the south-facing bedroom into a storage area. Furthermore, since indoor thermal conditions were further exacerbated by heat gains through the non-insulated exposed roof, the hose was being taken to the housetop in the late morning with leaving the faucet running for few hours to reduce that. This was, in fact, a longstanding cultural practice in the region (Abdulkareem, H., 2016). This behaviour also promoted evaporative cooling to occur around the house while water was flowing into the land. While the researcher was filming this behaviour, the housewife, who had been living in a stone house at the village before moving to this house, commented on this action by saying: "*My mom used to do the same at the time* [….] *when I don't do that, we feel excessive heat coming down through the roof*." In addition, a thick cloth was used as a door bottom seal for cool retention in the occupied rooms, especially when A/C was running. Despite the existence of openable windows in the examined rooms, adhesive tape was used around the frames to seal gaps and avoid leaks, and this impeded the occupants from opening them when they need to. The researcher also noticed a few cracked window panes which were covered by a packing tape without being replaced. Resorting to such least expensive means of dealing with the building envelope's conditions again highlights the role of cost in driving decision making.

Building attributes like the internal layout, floor area, and the quality of the building envelope, were found to be affecting the thermal interactions of the upper-income household with the environment too. The way they dealt with, however, was notably different compared with the low-income household. The extra square meters of the living zone alongside its layout, which is semi-open, resulted in increased demand for cooling. Accordingly, the area was fitted with four cooling gadgets as described earlier where two of them, i.e. both A/C units, an air conditioner with the window-mounted evaporative air cooler, or the pedestal fan with air cooler, were often in function throughout the day depending on how extreme the internal conditions were. Furthermore, heat gains associated with the extreme trapped heat in the attic as a result of the corrugated roof being non-insulated causes an unfortunate impact on indoor thermal conditions particularly in the first-floor rooms. All occupants, in fact, voiced that the upper floor is indisputably warmer than the ground floor. For this, the household installed an evaporative air cooler in the attic to constantly supply cool air to the space and the corridor during the daytime to mitigate such impact. In this regard, the householder commented by saying: *Without having the air cooler there, believe me, it is very difficult to tolerate the heat coming down, and all the raw food like uncooked rice, flour, and etc. that we have in the storage area* [on the first floor] *will be spoiled.* All that made the achievement of a pleasant level of thermal comfort within this case study an expensive task.

Conclusion

Inspired by socio-technical theories, this paper sought to address thermal comfort and environmental control within a sample of households being socially in a completely different position. The paper employs the case study method (CSM) presenting an empirical analysis with increased attention to the behaviour of human agency in relation to the physical performance. It has demonstrated that the way people control the environment in their buildings might not necessarily be driven by the human body's physiological and physical state. The paper has also shown that bringing qualitative and quantitative investigations together is of great importance. It generates a rigorous evaluation of the performance and a comprehensive understanding of the inhabitants' thermal behavioural patterns, and the physical attributes of the building. Furthermore, the study has provided supportive evidence of how human behaviour becomes quite essential in controlling the environment when the affordability of comfort is an issue.

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