Folk Memory and Temperature Measurements for Thermal Comfort in Vernacular Courtyard Houses of Saudi Arabia's Hot Arid Climate

Residents' memories of living in Al-Khabra vernacular mud brick houses

MOHAMMED ALGHAFIS [1,2] MAGDA SIBLEY [1] ESHRAR LATIF [1]

[1] Welsh School of Architecture, Cardiff University, United Kingdom, CF10 3NB
[2] Department of Architecture, College of Architecture and Planning, Qassim University, Saudi Arabia, 52571

ABSTRACT: This paper presents the results of the first study of its kind as it investigates the memories of space use and thermal comfort of the previous inhabitants of eight vernacular mud brick courtyard houses of Al-Khabra in Al-Qassim hot-arid region in the centre of KSA. This paper fills a knowledge gap about recording the memories of previous residents' behavioural and cultural aspects of their space use of courtyard houses and their perception of thermal comfort while recording the temperatures inside and outside their abandoned houses. The paper presents first the architecture of eight vernacular houses and analyses their embedded environmental passive strategies and associated social and cultural practices. It then presents the results of measurements and interviews conducted during the summer of 2020. The outside air temperature varied between 25.5°C and 44°C, while indoor rooms' temperatures ranged between 33 to 37°C. The indoor temperatures observed on the west-facing rooms were higher than the other sides of buildings up to 2.0 °C. Interviewees mentioned that the west side of their houses was the most thermally uncomfortable during summer. Information gathered from interviewees provides a better understanding of the behavioural adaptations strategies which include horizontal and vertical mobility inside the house.
KEYWORDS: Hot-arid, Thermal comfort, Behavioural adaptations, Perception, Vernacular houses

1. INTRODUCTION

Indoor environmental quality has become an increasingly important aspect of building design in recent decades, with most people spending the majority of their leisure and working hours in indoor environments, particularly during the COVID-19 "lockdown" situation. Demands for more energy-efficient structures have set the parameters for studies of thermal comfort. Behavioural adaptations and thermal comfort in extreme temperatures is a growing research field, particularly in the context of climate change and the COVID-19 pandemic. Residents in hot arid regions in the Kingdom of Saudi Arabia (KSA) have lived for many years with extreme temperatures and have adapted their vernacular architecture and behaviour to cope with such an extreme climate.

It has been widely acknowledged that the contemporary and excessive use of air conditioning units has led to a number of health issues such as respiratory problems and a lack of Vitamin D due to household members staying indoors most of the time. Previous research on thermal comfort in housing in KSA has been increasing in the last two decades [2,3,4,11], in addition to studies conducted in other countries of the Gulf region [7,8,9,10].

Most of these studies are focused on contemporary housing using measurements and behavioural aspects to investigate thermal performance of buildings and the behavioural and cultural aspects of the residents. However, research which combines perceptual and measurements data collected in vernacular houses in KSA are inexistent. Only one research was found that investigates the thermal performance of vernacular houses in Al-Derriah settlement with a focus on measurements to assess the role of evaporative cooling in courtyards in hot arid climates in enhancing thermal comfort in KSA [2].

This could be explained by the fact that most vernacular settlements are abandoned / or not occupied by their residents as is the case of the settlement of Al-Khabra in Al-Qassim region, Saudi Arabia.

Vernacular houses' thermal comfort has never been investigated from the point of view of their previous original inhabitants. Previous studies on vernacular houses involving occupants have taken place in KSA. However, the occupants involved in these studies consist mainly of low-income migrants who have moved to these houses because of low rent [5]. These houses have been changed to adapt to multi-occupancy use of residents who are not the original local population.

This study is based on interviews with older generations who lived in the vernacular houses with no air conditioning and moved into air conditioned houses. They are the last generation who has lived in the vernacular houses. This generation had a different comfort expectation than the current generations. Their memories of comfort are therefore important to record.

This study is the first one of its kind as it traces some of the original inhabitants of the courtyard houses of Al-Khabra, who left the settlement thirty years ago and investigate their memories of thermal comfort as occupants of the houses. A sample of eight previous residents from the now older generation of Al-Khabra settlement (who moved out 1991 to newly built concrete frame and block infill villas. These eight previous residents of Al-Khabra were contacted in August-September 2020 to take part in online or face to face interviews about their lifestyle in their old houses. Interviews were conducted in the summer of 2020, during the most thermally stressing time. These interviews took place at the same time when data loggers for measuring indoor and outdoor temperatures were installed in eight vernacular mud brick houses that had been rehabilitated but not occupied.

The proposed paper aims to fill the knowledge gap about investigating residents' perception, behavioural, and cultural aspects of thermal comfort and their relationship to objective measurements of temperature in vernacular single-family houses in Al-Khabra.

The vernacular architecture of the selected sample of eight vernacular houses is analysed alongside its associated social, cultural, and spatial practices as revealed through the oral history of their previous inhabitants. In addition to this, the occupants were also asked about their memories of perception of thermal comfort inside the houses during the extreme summer heat, and compare them with the objective measurements of temperature inside the houses.

2. METHODOLOGY AND CASE STUDIES

2.1 Methodology and equipment

The research employs mixed methods calibrated to address the research objectives, comprising both quantitative and qualitative methods. The four selected methods of data collection and analysis linked to the research objectives are as follows:

1. Semi-structured interviews with the residents of the selected case study houses, using recorded telephone and online interviews with both male and female the adult residents. The subjects are Saudi citizens, aged between 40 and over 75 years old.
2. Site visits and direct observation of the housing units and their environment.
3. On-site measurements of outdoor and indoor temperatures and evaluation (quantitative).
4. Analyses of data collected through interviews and from data loggers.

The study relies on the oral memory of previous residents. It combines in-situ scientific measurements of temperature and former residents' perceptions of the thermal comfort of the studied vernacular houses where measurements are taken. The themes in the study include investigating the thermal comfort of the studied vernacular houses and understanding how were the spaces used and organized.

The current study used one main tool, HOBO Pendant 8K Data Loggers with supporting tools (e.g. HOBO Optic USB Base Station and software), applied due to their small size and ease of installation. HOBO pendant data loggers for temperature measurement are cost-efficient and small, making it easy to deploy them almost anywhere, facilitated by their high portability, and their long life batteries. These operate in indoor and outdoor environments, logging temperatures ranging from -20° to +70°C (-4° to 158°F). Fig.1 shows the tool installed in some rooms at height of 1.5 meters. It should be noted that all doors and windows were kept closed as much as possible during the data collection, to minimise air infiltration into the spaces.

Figure 1: HOBO loggers installed in vernacular houses

2.2 The case study houses and their context

The eight case study houses are located in Al-Khabra village in the west of Al-Qassim region in central KSA. It is located at 26.33 latitude and 43.97 longitude, situated 606 m above sea level. Buraidah is the capital of Al-Qassim. This region has been significant due to its agriculture value to KSA.

The houses were selected on the basis of their current condition and the availability of their previous occupants who could be found after they had left the site in the early 1990s. It was possible to connect five houses to their previous occupants, for the remaining three case study houses were familiar to the previous occupants interviewed in this research. Seven of the case houses have been rehabilitated between 2013 and 2016 by Al-Khabra Municipality but not occupied, one house (B8) has not been rehabilitated but are still standing in relatively.

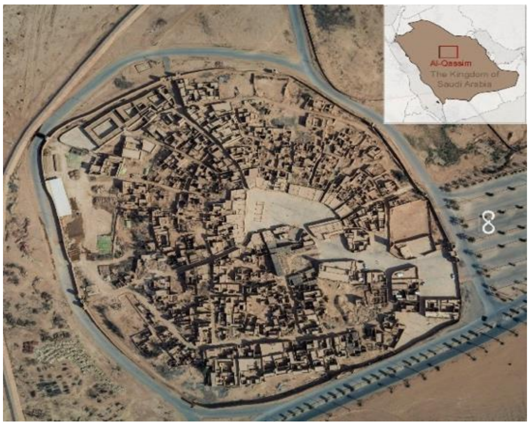

Figure 2: Top view of Al-Khabra by Saleh Ahmed Alhuthlul

Many aspects should be considered in determining housing typologies; but the most important are climate and culture. Through history, the availability of building materials, lifestyle, and climate have had major impacts on local architectural built forms. Vernacular buildings were well-adapted to climatic aspects and contexts in their design, planning and construction, as well as to the low rise high density urban scale of the heritage settlements.

The basic construction materials are limestone, adobe and wood and the structural system used in Al-Khabra village is a load-bearing structure. Limestone was used for foundations of walls, adobe for walls and roofs; wood was used for structure of roofs, doors and window, and it is known as athel (tamarix tree) [1]. All materials were brought from surrounding areas and integrated in the construction of the houses and the settlement.

Wall thickness in Al-Khabra buildings is 400 mm adobe sun-dried brick and 40 mm mud plaster. Adobe material properties were collected from different resources due to the available data limitation to model thermal properties values like specific heat, and thermal conductivity etc. [3, 6].

Table 1: Thermal properties of the adobe construction

Material	Thickness	Thermal Conductivity (W m-1 K-1)	Density (Kg/m3)	Specific Heat (J/kg K)
Adobe wall	0.5	0.730	1650	1000
Adobe roof	0.3	0.730	1650	1000
Adobe with straw	0.025	0.180	440	900
Palm tree fronds	0.015	0.166	600	1200

The combination of narrow streets and houses arranged around courtyards to achieve the balance between environmental comfort (through increased shaded spaces) and privacy through inward looking courtyard buildings. Houses had secure access to the inside, controlled via long blocks of housing with few outside openings, whereas the large openings were directed to the inside courtyards of houses. Cool air circulation was improved via narrow openings as illustrated in the following participant's observation:

''Windows in some places were at a high level of the external wall, whereas large openings were located in low level of the walls towards central courtyards for smoke extraction in winter and air circulation in summer'' (Al-Hudaythi 2020)

The twisting narrow streets reduce exposure of the buildings and urban spaces to sand storms, which are common in the region. The spaces provided amidst the houses of vitality and suitable for social interactions, while the street system and neighbourhood cul-se-sacs preserved the privacy, security, and physical and mental rest of local residents.

The climate of the Central Region is mainly a desert one, with minimal, rainfall, and an intense hot-arid summer. This climate makes living more complicated and challenging for residents due to the harsh summer conditions. In Al-Qassim, summer temperatures often reach above 40°C, with very low humidity (Table2).

Table 2: Average maximum temperature and relative humidity, January-December 2020 (Source: NCM 2020).

Month	T max	RH max
JAN	22°C	54%
FEB	26°C	43%
MAR	30°C	37%
APR	36°C	33%
MAY	41°C	20%
JUN	43°C	13%
JUL	42°C	13%
AUG	44°C	14%
SEP	43°C	14%
OCT	38°C	23%
NOV	31°C	43%
DEC	24°C	55%

Due to generally low yearly rainfall, vernacular houses in the Middle East have flat roofs, which traditionally served multiple functions as living areas, where people couple prepare food, dry clothes, and sleep in hot weather. A modern roof, conversely, would serve to radiate heat throughout the night. This was reflected in the following participant's observation:

"*Sleeping on the roofs of vernacular houses is like having a fridge under you, while sleeping on roofs of modern homes like having an oven under you*"

(Ali Al-Salamh 2020)

2.2.1 Case studies results

This section illustrates the analysis of all 8 vernacular houses (Fig.6) and one example of the 8 houses to explain in details the local vernacular architecture of Al-Khabra mud brick houses and their integration in the urban context of the settlement, as illustrated in (Fig.3).

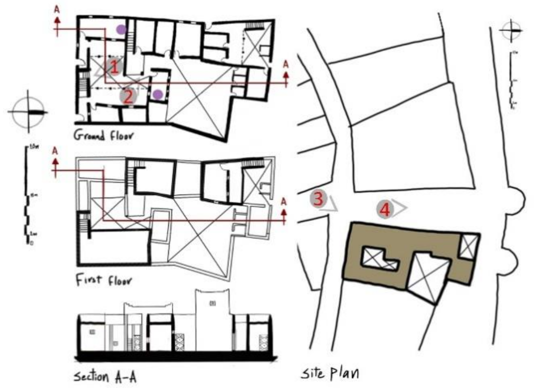

Figure 3: Architectural plans, site location, section for B1, and the purple circle means the loggers that were installed.

Figure 4: Internal and external pictures for B1.

Building 1 (B1) has two floors and three internal courtyards. It has seven rooms on the ground floor and four rooms on the first. The dimensions of the house are 26 by 15 metres. The building is rectangular in plan and shares its wall with neighbours in the east side. It has short distances to other buildings on the south and west sides (4 and 7 metres respectively). The house has three entrances; two for family (private) on the north and west side, and the other for guests (semi-private) on the south side. The house is very close to the northern village entrance. It was built after 1800 and was refurbished in 2016 by Al-Khabra Municipality, using the same local building materials. (Fig.3) shows the floor plans, section, and site location of the house. (Fig.4) illustrates the internal courtyard, external façade, and northern village entrance. North-south (NS) and South-west (SW) facing rooms on the ground floor were selected to measure the air temperature, with room floor area of 14.50 m^2 and 27.25 m^2 for NS and SW rooms, respectively. The graph (Fig.5) shows the measurement of air temperature for NS and SW facing rooms. The collected data in the NS facing room presented that the average indoor temperature ranged between 33.3 to 34.7°C, while the SW room illustrated higher indoor air temperature ranging from 35 to 36.5°C.

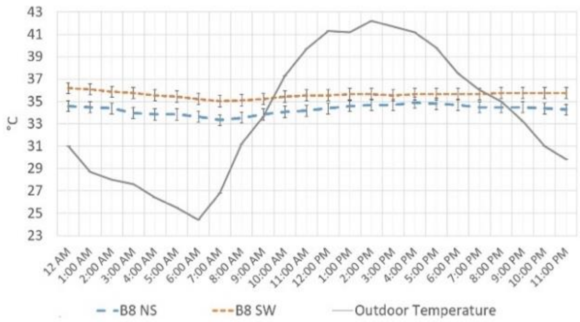

Figure 5: Air temperature in B8 during a 24-hour

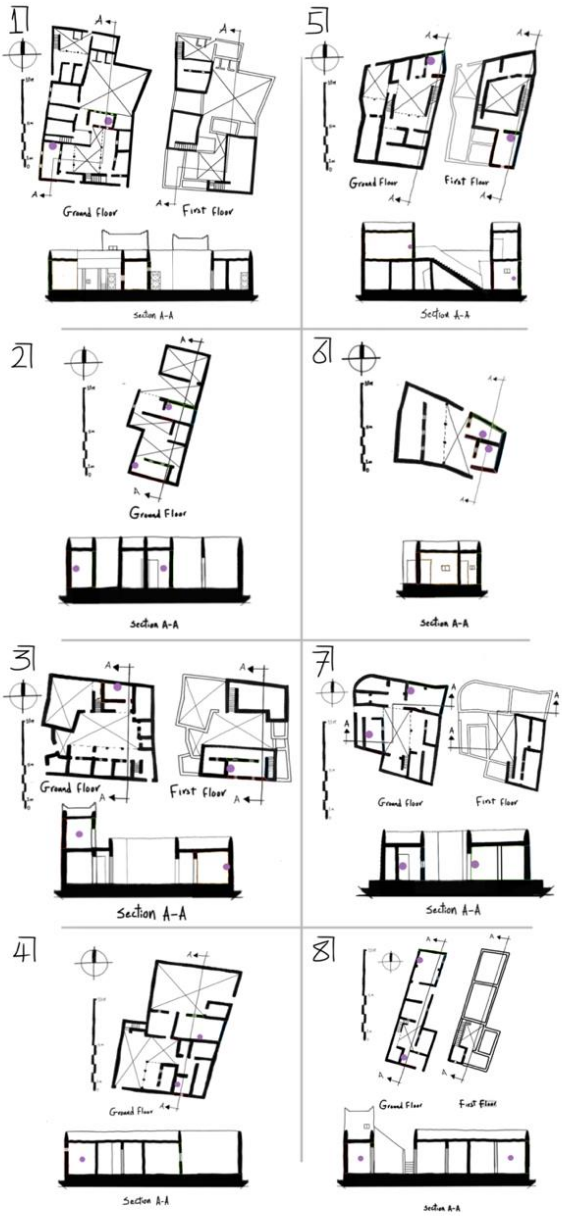

Figure 6: Plans, and sections of all houses

Figure 7: The location of the houses that have been rehabilitated, except B8 in yellow colour

3. RESULTS AND DISCUSSION

The collected data indicates that outside air temperature has a diurnal temperature range (DTR) of 18.5°C, with a minimum of 25.5°C during the night and a maximum of 44°C during the day.

On the other hand, indoor rooms' average temperatures varied between 33 to 36°C exhibited almost no noticeable DTR change, except in one single space: south-west (SW) room in B8 which has not been rehabilitated. The following Table 3 summarises all chosen rooms.

Table 3: Summarizing all chosen rooms in the hot season over a 24-hour (SD means standard deviation).

	Room location	Mean	SD	Min	Max	Room area m²
B1	GF NS	34.2	0.42	33.3	34.7	14.78
B1	GF SW	35.6	0.27	35.0	36.5	27.01
B2	GF NSE	36.3	0.37	35.8	36.9	20.88
B2	GF SN	36.0	0.57	35.0	36.7	21.76
B3	GF SW	36.7	0.42	36.0	37.2	15.51
B3	FF NSE	36.4	0.59	35.5	37.1	18.88
B4	GF NE	35.1	0.45	34.4	35.8	39.84
B4	GF S	36.0	0.21	35.5	36.2	20.68
B5	GF NSE	35.0	0.36	34.2	35.5	18.86
B5	FF NSE	35.3	0.19	35.1	35.7	31.62
B6	GF NE	35.3	0.60	34.4	36.2	19.08
B6	GF SEW	36.0	0.12	35.8	36.3	13.30
B7	GF NSE	35.4	0.57	34.4	36.0	25.84
B7	GF SE	35.6	0.27	35.0	36.1	21.84
B8	GF NE	36.2	0.48	35.1	36.9	35.36
B8	GF SW	36.6	1.70	33.7	38.6	18.36

The other studied rooms exhibited the effect of the high exposed thermal mass of mud building materials and delayed heat absorption and release compared to concrete materials, in addition to the heat island effect. The reason there was no obvious diurnal change in the indoor spaces was the absence natural ventilation. Closed doors and windows prevent air circulation inside rooms, and consequently low infiltration allows warm air to stay inside, which contributed to keep temperatures high, but reasonably steady.

The majority of interviewees mentioned that the west side of their houses was the most thermally uncomfortable during summer (See West facing rooms in B1, B3, B6, and B8). They tend to avoid using the rooms with external walls exposed to the west. Most respondents also explained their preference for using the North side of the house because it is cooler and tends to catch cool breezes, while in winter they prefer the eastern side in the morning to get the warm sunshine of Al-Qassim short winter.

An interesting spatial practice revealed by the interviewees is the tendency of men to gather outside the houses in the morning and sit on benches along the east facing walls to enjoy the heat coming from the sun and catch up on the latest of the neighbourhood. These types of sitting areas in public spaces for men are referred as ''Al-Mishraq'' which means the morning rising sun. It is also designed to make the most of the sun rise during winter after the dawn prayer. Al-Mishraq is therefore an important adaptive environmental strategy allowing the residents to enjoy a public space that thermally comfortable in winter because of its orientation. Furthermore, Al-Mishraq was used next to the souq, the open market, as described by one of the respondents:

''*people used to sit outside in a place called the ''warm Mishraq'' ... Al-Mishraq time is a place where the sunshine shines, until it rises (perpendicular) at noon''* (Abdullah Al-Tasan 2020)

The interviewees recalled that people slept upstairs in summer and inside in winter. This relates to the thermal mass of construction materials. Mud bricks radiate heat from the exterior to interior spaces relatively slowly, due to their thickness (40-60 cm) and thermal properties. When the sun is hitting the exterior surfaces, it takes until late afternoon for the heat to transfer to the internal face of the wall and begin heating the internal space. Consequently, internal spaces are relatively cooler during the day, and warmer at night, thus people traditionally escaped hotter internal temperatures at night by sleeping on the vernacular houses' roof, benefitting from the time lag thermal mass impact of vernacular construction. This was reflected in the following participant's observation:

''In the summer, we sleep in an open place, such as courtyards or roofs ... we do not sleep in rooms at all and its advantage if dawn comes people are awake and we hear the call of prayer, but now the air conditioning is over your head and your feet are numb and there is no one who will wake you up except for the alarm and you wake up lazy this is the differences''. (Abdullah Al-Oremah 2020)

Information gathered from interviewees provides a better understanding of the adaptive strategies that the residents of the vernacular houses of Al-Khabra have adopted to mitigate the extreme temperatures of the summer. These are behavioural adaptations which include horizontal and vertical mobility inside the house, bearing in mind that all the spaces are multifunctional with the exception of the Majlis and the kitchen.

4. CONCLUSION

Identifying structures suitable for use in testing representative vernacular housing was very difficult, due to the dearth of inhabited houses and sites in a state of good repair particularly in terms of the presence of doors and windows in their fittings.

The chosen case study buildings were under the supervision of Al-Khabra Municipality, which preserved them by applying the same building materials and methods of vernacular construction, which made them appropriate examples of a vernacular building to understand thermal performance and to conduct thermal tests.

The paper presents first the architecture of eight vernacular houses and analyses their embedded environmental passive strategies and associated social and cultural practices. It then presents the results of measurements and interviews conducted during the summer of 2020, when temperatures are at their extreme. The collected data indicates that outside air temperature has a diurnal temperature range (DTR) of 18.5°C, with a minimum of 25.5°C during the night and a maximum of 44°C during the day while the indoor rooms' average temperatures varied between 33 to 36°C exhibited almost no noticeable DTR change, except in one single space.

The indoor temperature of west facing rooms were relatively high, therefore people generally try to avoid this side to the building as stated by the majority of participants. In summer people preferred the north side because the north breeze in cooler, while they preferred eastern sides to get sunlight in Al-Qassim short winter. In B1, for instance, the difference between the recorded indoor temperature of north-south (NS) and south-west (SW) rooms is about 2°C, with a maximum temperature of 34.7°C and 36.5°C for NS and SW rooms, respectively.

The recorded indoor temperature of all eight vernacular dwellings in selected rooms ranged from a low of 33.3°C to a high of 38.6°C (reported in a single case), with a mean of about 35.4°C. There was a high fluctuation in one room (SW room in B8), with standard deviation of 1.70. This is likely anomalies due to B8 has not been rehabilitated or doors and windows were not being tightly closed, and there were cracks in the walls, in addition of being on the western side.

The fieldwork measurements in summer 2020 provided a deeper understanding of the various temperatures in the vernacular case study houses. The results of the fieldwork provide the foundation to understand how vernacular houses performed and how the residents of the vernacular houses of Al-Khabra have adopted to mitigate the extreme temperatures of the summer. These are behavioural adaptations which include horizontal and vertical mobility inside the house.

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