FIELD INVESTIGATION OF INDOOR THERMAL ENVIRONMENTS IN TRADITIONAL AND CONTEMPORARY HOUSES IN HOT–DRY CLIMATES

Abstract

The traditional architecture of Yemen was well known for the use of natural and passive methods for creating a comfortable indoor environment. Over the years, construction methods and materials have changed with lifestyle requirements. This sometimes resulted in buildings without much respect to the climate of the place, such as windows without shading, the disappearance of courtyards, etc. Since the traditional principles were absent in the new architecture, keeping buildings comfortable meant much dependency on air conditioning. Some of the traditional architectural elements in current design are mere copies of the old, without proper environmental applications. Since energy is getting more expensive and sustainable design is becoming a primary factor in many countries, there is a pressing need for using sustainable design practices in hot, dry climates with limited energy sources.

This study investigates indoor thermal conditions in traditional and contemporary houses in Hadramout, Yemen, using field measurements and focuses on the cooling effects of traditional strategies. The main aim of the investigation is to compare thermal performance and identify key factors influencing indoor comfort.

The results indicate that the indoor air temperature was lower than outdoors in all the spaces in the traditional buildings. It was also seen that these temperatures were within the comfort zone's limits. All indoor values of relative humidity in the traditional houses were higher than outdoor values in most spaces. This would have provided comfortable conditions, taking into consideration the very dry outdoor conditions. In contrast, the modern building had much poorer performance (in its non-air-conditioned state) compared to the traditional ones.

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Introduction

The climate is one of the most effective factors in the formation of traditional houses. Sun direction, wind, air pressure, humidity, temperature, cloud cover, and rainfall indicate the climate, which influences the form, material, and orientation of buildings (Mashhadi, 2012). The climatic elements have their negative and positive effects on house design in hot-dry regions. Many traditional passive environmental techniques in buildings were developed because of the effect of the hot-dry climate in this region. Consideration of the effects of these elements leads to the use of massive building materials that attenuate the effect of extremely high temperatures on interior spaces and other methods such as evaporation inside the courtyard or direct water spraying on the roofs (Binthabet, 2007).

The case studies for this research are located in Hadramout, Yemen, situated in the southern part of the Arabian Peninsula. Hadramout falls under the broader umbrella of a hot-dry climate (Noaman, 2004). Three residential buildings have been chosen for the research: Ahmed Buqshan Palace in Khaylah village, Salemin Bajeefer's house in Husan village, and the contemporary building Salem Bajeefer House in Husan village of Wadi Dwa'an. All three buildings are situated in the same valley in Hadramout. Hadramout has a unique architectural heritage. The builders have learned how to suit location, geography, materials, and climate. The traditional buildings in Hadramout were built solely from mud bricks made by builders and baked dry in the sun. The buildings have thick walls, often more than 80cm. The buildings built close together provide shade for one another.

The study aims to investigate both traditional and modern houses from an environmental perspective. Two traditional houses have been selected based on specific criteria: the building should maintain its original plan layout, have natural ventilation, be constructed using local materials, be in the same region and climate, and have the air conditioners in the new building turned off.

Case Studies

CASE STUDY 1: AHMED BUQSHAN PALACE

Ahmed Buqshan Palace is a well-known building in Khaylah, in the valley of Dwa'an. It was constructed during 1955–1956 AD (AH 1375) and has been renovated a few times. Buqshan Palace is an eight-story house that was built around a central courtyard. It is an example of a typical large traditional building in the region. Like most of the houses in Khaylah village, Buqshan House is a west-facing building facing the valley. All spaces are planned around a courtyard measuring 11m x 11m. The building has shaded corridors, or liwans (a word used since ancient times into the present to refer to a long, narrow-fronted hall that is often open to the outside), along the courtyard. The palace has two main circulation staircases located on the north and south. Those stairs are linked to the liwans overlooking the courtyard.

CASE STUDY 2: SALMEIN BAJEEFER HOUSE

Salmein Bajeefer was built in 1970. This is a five-story mud-built house and is an appropriate example of a traditional building in this context. The ground level is allocated for storage. The storage rooms have high windows or ventilators for providing light and ventilation. The house has two entrances, with the main entrance located on the east. The stairs are located in the south, which leads to the first floor. The main entrance is higher than ground level to avoid flooding problems. The rooms in the house have attached bathrooms, built-in closets, and private verandas.

CASE STUDY 3: SALEM BAJEEFER HOUSE

Salem Bajeefer House was built in 1997 and is regarded as an example of modern housing in Husan Village in the valley of Dwa'an due to its representation of the modern style of construction in the region. This three-story house is built of concrete masonry blocks. This is an air-conditioned building. For the research, air conditioners were turned off. The reason for selecting this house was that it was a modern concrete building and was situated in the same valley as the two traditional mud buildings in the case study.

Traditional Passive Cooling Strategies

Table 1 gives an overview of the strategies and elements for cooling in Ahmed Buqshan Palace and Salemin Bajeefer's house, which are common in the buildings in Hadramout.

Environmental Strategies/Elements	Case Studies
Thermal Mass	
A distinctive feature of the case studies is the thick walls and roof. These thick walls and roofs with high thermal mass act as good climate modifiers. The mud wall with a high thermal mass delays the transfer of heat considerably from outside to inside (Hawsawi, 2016). The mud brick walls range from 30 cm to 1m in thickness, providing effective insulation against the hot summer sun.	
Windows	
Windows generally consist of two elements: the screens that allow airflow and privacy, and shutters. Most windows consist of four parts or one part. The palace also has jalousie windows with movable shading devices. Screens made from wood serve the purpose of curtains. On hot summer days, the shutters are closed during the day and open during the cooler nights. In winter, these windows are closed, especially at night, to avoid heat loss.	
Courtyard	
The central courtyard in Ahmed Buqshan Palace provides natural ventilation and light and acts as a multi-functional shaded space. The courtyard is tall and quite narrow compared to the size of the house, and it stays shaded for most of the day. The air is cooled in the shaded courtyard, which then enters the rooms through the lower-level windows.	
Liwan or Shaded Corridor or Gallery	
Buqshan Palace has shaded corridors, or liwans, all around the courtyard on all levels of the house. The liwan is a semi-open space that acts as a thermal regulator by cooling the air to a certain extent before it enters the room. Liwan shades the windows and thus brings in softer light to the rooms. The indirect light also helps in reducing the amount of heat that goes inside.	

Table 1: Traditional passive cooling strategies. (Source: Author.)

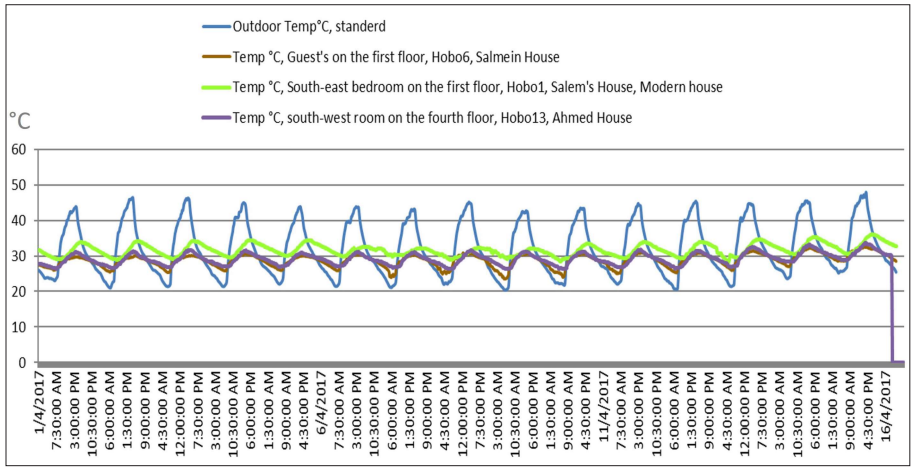

Figure 1: Temperature graph: Comparison of traditional buildings and modern houses. (Source: Author.)

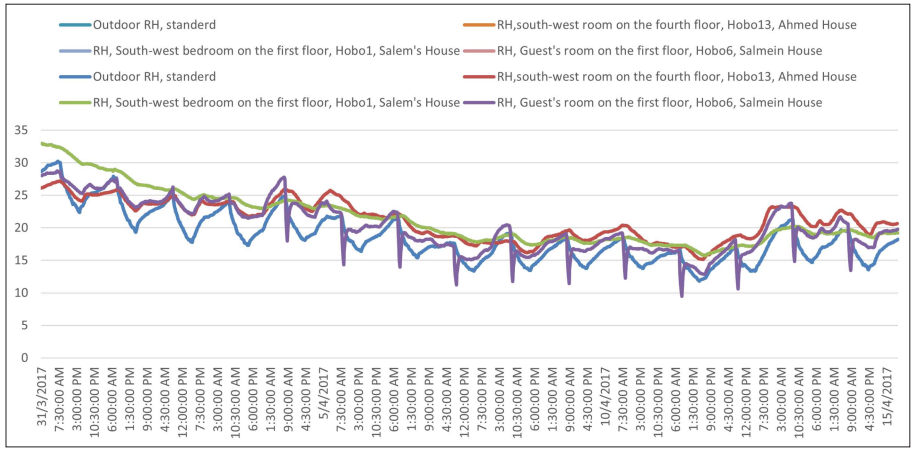

Figure 2: RH graph: Comparison of traditional buildings and modern houses. (Source: Author.)

Results and Discussion

There are many factors that affect a building's environmental performance. For this research, the environmental or thermal performance of the case study buildings in a non-air-conditioned state was studied by collecting continuous and simultaneous thermal data such as the air temperature, relative humidity, and airflow. The collected data was analyzed by comparing thermal performance data between traditional and modern buildings. The equipment used for data collection was an electronic data logger for continuous data recording (a Hobo data logger) for temperature, relative humidity, and airflow.

COMPARISON OF THERMAL PERFORMANCE OF THE THREE CASES STUDY BUILDINGS

To see the effect of traditional passive cooling strategies, the air temperatures of the study buildings were recorded at the same time from April 1 to April 15.

The comparison was made among specific spaces in the three buildings. These were the southeast bedroom of modern Salem house, the guest room of traditional Salmein house, and the southwest room of traditional Ahmed Buqshan palace in one graph.

The graphs show (Figures 1 and 2) the comparisons between the traditional and modern houses. The temperature recorded inside the southwest room of the traditional Ahmed Buqshan palace was between 26.4°C and 33°C, while the southeast room of the modern Salem Bajeefer house had air temperatures between 29°C and 35.5°C. The difference varied from 1°C to 4.2°C between rooms at Salem Bajeefer House and Ahmed Buqshan House. The modern house recorded the highest internal temperature. The better performance of Ahmed Buqshan Palace is due to the use of various traditional passive cooling techniques. The wall in the southwest room of Ahmed Buqshan Palace is 32cm thick, while the wall in the southeast room of Salem House is 20cm thick. Also, the traditional house has deep recessed windows and verandas that provide cool air and prevent direct sun from getting inside.

The graph shows that from 8:30 a.m. to 10:00 p.m., the outdoor temperature was higher than the rooms in Ahmed Buqshan Palace and Salem Bajeefer House, and from 10:15 p.m. to 8:15 a.m., the outdoor temperature was lower than the respective rooms of the respective houses. From 8:30 a.m. to 10:00 p.m., the difference was 16.5°C between the indoors of the traditional Ahmed Buqshan palace and the outdoor, while the difference was 11°C between the indoors of the modern Salem house and the outdoor.

Temperatures indoors were lower than outdoors in all the spaces in the traditional buildings, i.e., Ahmed Buqshan Palace and Salmein Bajeefer House. It was also seen that these temperatures were within the comfort zone's limits.

Conclusion

The conclusions are based on the synthesis of analysis of thermal data, literature review, and detailed observations of the researcher on the environmental consequences of the plan, elevation, section, form, materials, and special passive cooling strategies.

Thermal data on the case study buildings in their free-running or non-air-conditioned state were collected, analyzed, and compared. The traditional ones used passive cooling methods, and the indoor spaces were found to be in much lower temperatures than outdoors, and within comfortable range in summer. The traditional building thus mitigated well the harshness of the hot-dry climate. The effect of its sheer layout, form and special environmental strategies offers the possibilities to reach comfort through passive cooling means. On the other hand, the modern building, with air conditioning turned off, showed much higher indoor temperatures and many of those readings were over the comfortable limits. The modern building did not have the traditional environmental strategies, and thus was not comfortable. It relied on air conditioning for comfort.

If the modern building had a few of those strategies applied such as, thick walls or walls with similar insulation value (effect of similar thermal mass), courtyard, recessed or shaded windows, verandas, earth cooling, etc., conditions would have been improved much in terms of cooler interiors. Research also proved that it is possible to employ these strategies with contemporary materials and methods. Since modern living in the country needs electric fans and/or air-conditioning, using these traditional strategies would lower the use of mechanical means to a considerable degree and thus save energy.

References

Binthabet, M. (2007). *Thermal behavior in the traditional courtyard houses of Yemen.* https://erepo.usm.my/items/0dc2c817-569f-4ef3-aa25-35f34231202f

Hawsawi, H. (2016). *Nature Inspired Interior Design Principles in the Hot Arid Climate of Saudi Arabia.* https://www.semanticscholar.org/paper/Nature-Inspired-Interior-Design-Principles-in-the-Hawsawi/2bf330325329c3ab3748c9711cc0b31c4de4fecf

Land, B. E., Magda Sibley, Mohammad Hakmi, Peter (Ed.) (2005). *Courtyard Housing: Past, Present, and Future. Taylor & Francis.* https://doi.org/10.4324/9780203646724

Mashhadi, M. (2012). *Comparison of Iranian and Turkish TraditionalArchitectures in Hot-Dry Climates.* https://www.semanticscholar.org/paper/Comparison-of-Iranian-and-Turkish-in-Hot-Dry-Mashhadi/7076e785023de3f20a86a4c652dba42534600fe1

Noaman, A. (2004). *Indigenous knowledge for using and managing water harvesting techniques in Yemen.*

Nooraei, M., Littlewood, J., & Evans, N. (2013). Passive Cooling Strategies for Multi-storey Residential Buildings in Tehran, Iran and Swansea, UK. In A. Hakansson, M. Höjer, R. J. Howlett, & L. C. Jain (Eds.), *Sustainability in Energy and Buildings* (pp. 623–636). Springer. https://doi.org/10.1007/978-3-642-36645-1_58

Safarzadeh, H., & Bahadori, M. N. (2005). Passive cooling effects of courtyards. *Building and Environment, 40*(1), 89–104. https://doi.org/10.1016/j.buildenv.2004.04.014

Soflaei, F., Shokouhian, M., & Zhu, W. (2017). Socio-environmental sustainability in traditional courtyard houses of Iran and China. *Renewable and Sustainable Energy Reviews, 69,* 1147–1169. https://doi.org/10.1016/j.rser.2016.09.130