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A Comparative Study of the Thermal Comfort of Different Building Materials in Sana'a

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ABSTRACT

This study describes the impact of alternative building material envelope systems on the overall thermal performance of four selected materials used in Sana'a, Yemen. These systems included adobe, brick, stone and concrete block. After thorough on-site investigation and data collection, the information, along with regional weather data were input into the Ecotect energy simulation software for thermal performance evaluation. The objective was to search for affordable and energy-efficient construction techniques suitable for settlements and incorporating traditional cultural values in a arid upland region characterized by cold winters and warm, dry summers. This was pursued by analyzing temperature and measurements within buildings constructed from a variety of traditional and modern materials. The thermal behavior and comfort, the patterns of energy use and the appropriateness of the different building techniques and materials are analyzed, compared and discussed. We demonstrate how a building envelope reacts to outdoor conditions through graphic illustration and show ways in which the research can be extended by the creation of simulations using Ecotect software. This research contributes to the promotion of passive and low energy architecture towards a sustainable future.

Keywords: Sana'a, Building Materials, Environmental Conditions, Thermal Performance, Temperatures

1. INTRODUCTION

Building materials play an important role in buildings from the energy efficiency and thermal comfort points of view (Givoni, 1998). The buildings should modify the natural environment to offer livable and comfortable conditions to the occupants. The envelope plays a particularly important role in fulfilling the task of keeping the indoor environmental conditions at a desirable level.

In order to test their thermal properties certain building materials have been used to construct a group of buildings that house various activities at Sana'a. **Figure 1** displays the climatic characteristics of the study area.

The dominant climate in Sana'a is the arid climate, which is characterized by cold winters and warm summers. Winter outdoor air temperatures are near or below freezing in December and January.

Various building materials, such as factory produced extruded hollow brick, concrete blocks, sun dried mud-brick and aerated concrete blocks have been used for construction works in Sana'a. In addition to these conventional building materials, other material such as adobe, are also being experimented with and tested for their environmental performance as building material.

1.1. Evaluating Thermal Performance

This study focuses mainly on the thermal performance of a traditional red brick structure, a stone house and block concrete building. In order to compare their environmental performance, temperature measurements and people questioner were taken in the concrete block, red-brick and adobe and stone buildings on site. Thermal performance of the selective material structure was evaluated on the basis of computer simulations only.

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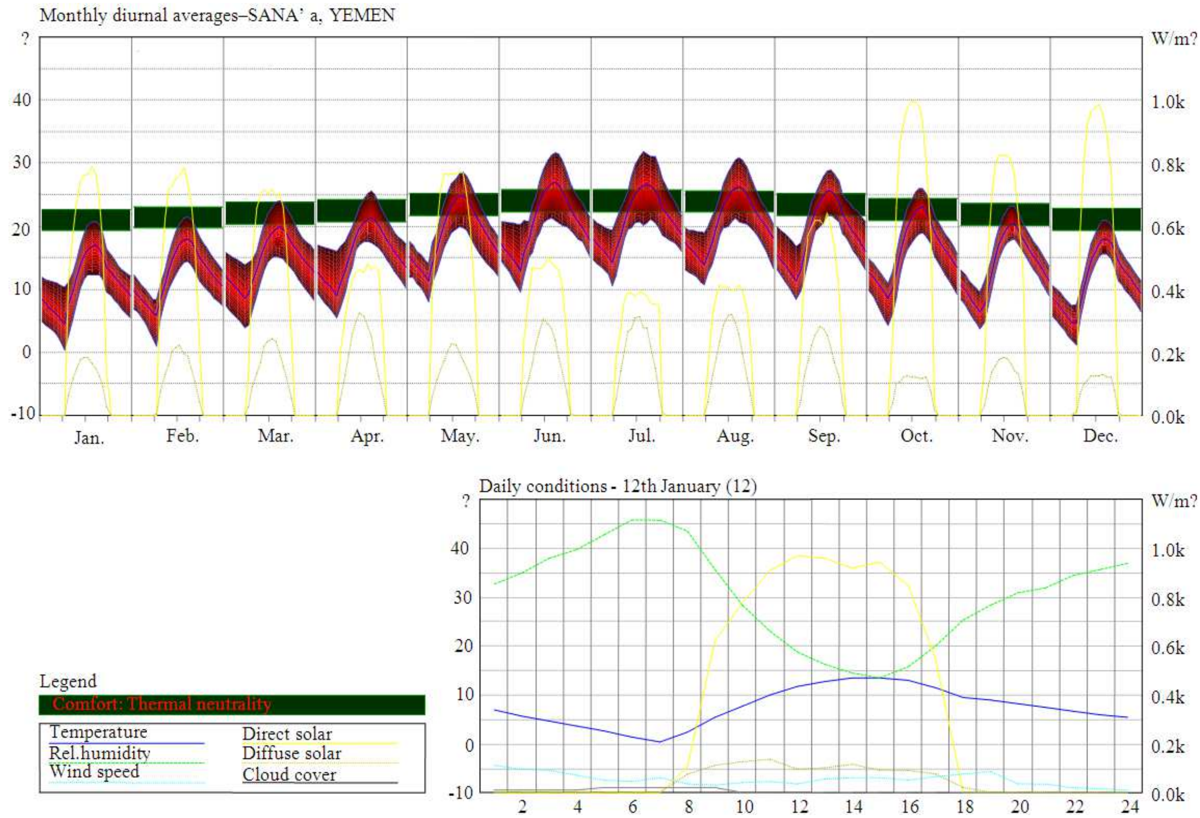

Fig. 1. Diurnal averages of outdoor air temperature and solar radiation, for Sana'a

1.2. Research Material

Of the two indigenous materials, mud brick has been used widely in rural areas of Sana'a. It is environmentally appropriate since it not only possesses high thermal capacity, which is desirable for creating heat sinks in extreme weather conditions (Lechner, 2001), but is also recyclable. Yet, factory produced extruded hollow brick and concrete blocks are gaining more popularity as they are readily available, easy to build with and easy to maintain.

Straw, which is an agricultural waste, can also be used as a building material. Traditionally, it is mixed with clay or soil to produce mud brick. However, since the past few years, it is being considered as a primary building material, since it is easy to obtain, easy to build with, suitable for earthquake zones and possesses good insulation properties. On the other hand, it is not dense enough to store heat in the building fabric, nor is it suitable for higher structures.

The third material being studied is concrete block, which is a contemporary building material that, in spite of its low mass, is becoming increasingly popular due to its highly desirable properties of less space and light weight, modular and facilitate speedy construction.

1.3. Data Collection

The thermal behavior of the aforementioned building materials was studied in two ways: First by taking actual measurements on site and then, by simulating the conditions with the help of the energy simulation software ECOTECT.

For the first part of the study, temperature measurements were taken, in both unheated as well as heated spaces and Interview with people to deeply understand their perception of thermal comfort.

The second part of the study comprised of computer modeling, which simply used known thermal resistance values of the various layers of building materials, to calculate the overall thermal resistance of the system. Hourly values of incident and diffused solar radiation and outdoor temperature were used to simulate indoor temperatures and heating and cooling loads of the building. These loads took into account heat gains due to solar energy, occupancy rates, heat storage in the building fabric and convective coupling between adjacent rooms, as well as heat transferred through the external envelope (ASH, 2004). The simulations were performed with recorded weather data for a typical year in Sana'a. For this purpose the test unit, the mud brick building, was first modeled in ECOTECT and then thermal properties of the constructional elements were varied in order to measure the effect of these changes on the thermal comfort of the occupants. It should be noted here that for this simulation study, building floor plan and room size was kept constant for all materials.

1.4. Data Analysis

Data were collected from the weather station in Sana'a and from the selective building of different material. For the sake of clarity, temperature measurements for only average coldest days and average hottest day presented graphically.

Concrete block and stone buildings. It is known from previous studies that due to their thermal insulation and/or thermal mass properties (Moss, 2007), adobe and red brick structures require comparatively less energy to sustain thermal comfort conditions. Furthermore, temperature fluctuations within buildings made of these materials are also kept at a minimum; hence, it was observed that internal temperatures in the red-brick and adobe buildings remained fairly stable despite external diurnal fluctuations.

In addition to temperature, On the other hand, the concrete block structure responded more to external fluctuations in temperature.

1.5. Simulation

The simulations were run on a computer model of the concrete block building, which actually exists at the Sana'a and has an area of 134m² with total area of 266 m² (**Fig. 2**). In order to ascertain the direct effect of wall materials on the thermal behavior of the building, only the material properties of the walls of the unit building were altered for each run. In other words, the materials and dimensions of the roof and floor constructions were retained as they were and for more clear result the simulation was analyzed just the living room which has south windows with no exposed area to east or west either north. For each different wall type the U-values were calculated by assigning relevant wall components in the programme.

Computer simulations help to analyze conditions that are not yet tested in reality and to draw conclusions based on comparisons of different building systems, prior to beginning the construction works. Although, simulation studies with Ecotect were carried out for different months of the year, results of the simulations for only average temperature are presented here for brevity. In order to compare the behavior of the different materials, simulation data for all of the four wall materials, namely; Concrete block, Red fired brick, Mud brick and Stone, are presented together in **Fig. 3-6**.

An analysis of the simulation studies revealed that indigenous materials have significantly better thermal properties as compared to contemporary building materials.

A closer look at the simulation graphs shows that the behavior of the fired brick walls are closely followed by walls made adobe blocks; while a stone wall has nearly the same properties as an insulated brick wall. On the other hand, a concrete block, costs considerably more than locally produced adobe brick of equal size; while stone is the most expensive wall material available in the market.

Also noted that although fired brick was the best in total thermal comfort that stone rock has the best thermal comfort in summer and the fired brick has the worst thermal comfort in summer which is not a problem in Sana'a because of its mild summer and cold summer wind, so this problem will be easily solve by ventilation.

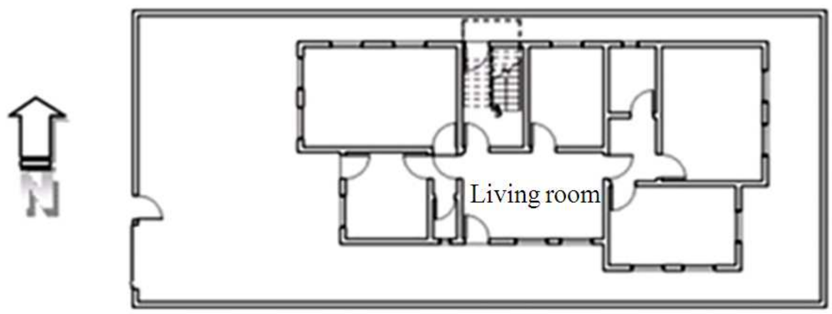

Fig. 2. Analyzed building plan

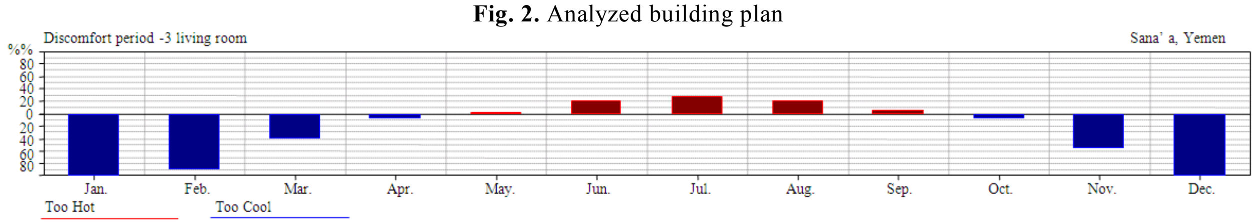

Fig. 3. Concrete block Monthly load discomfort; Discomfort Degree Hours too hot = 72.7 too cool = 399.4; total discomfort = 472.1; Annual Comfort Distribution 5840 h 66.7%

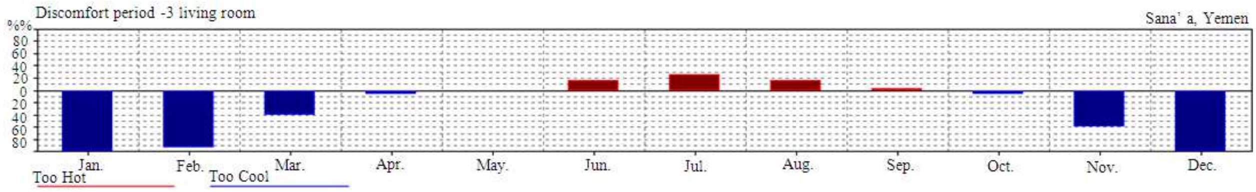

Fig. 4. Rock stone Monthly load discomfort; Discomfort Degree Hours too hot = 60.0 too cool = 406.5; total discomfort = 466.5; Annual Comfort Distribution 5808 h 66.3%

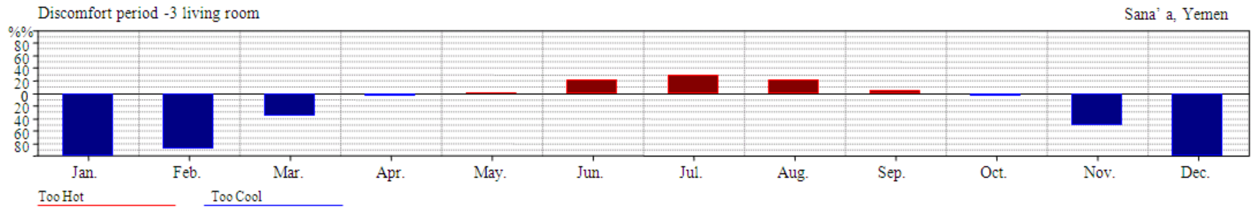

Fig. 5. Mud brick Monthly load discomfort; Discomfort Degree Hours too hot = 79.1 too cool = 385.8; total discomfort = 464.9; Annual Comfort Distribution 5936 h 67.8%

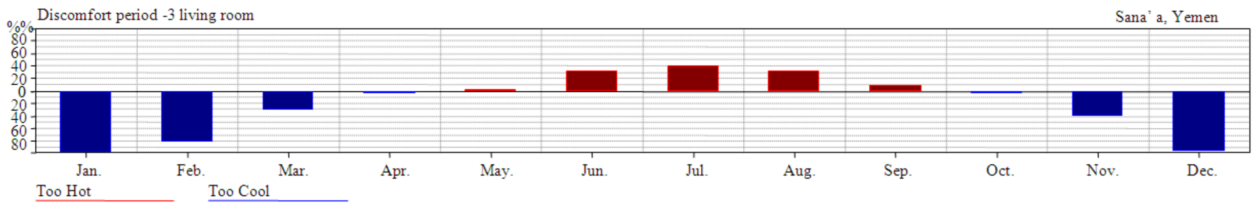

Fig. 6. Fired brick Monthly load discomfort; Discomfort Degree Hours too hot = 112.6 too cool = 345.5 total discomfort = 458.0; Annual Comfort Distribution 6145 h 70.1%

2. CONCLUSION

Compared to contemporary building materials with high embodied energy, the energy required to produce mud brick and mud brick buildings is minimal (Kordjamshidi, 2010). In addition to their energy efficient behavior during use, these two materials are completely bio-degradable. They are also more appropriate and affordable; while the main disadvantage lies in their higher maintenance requirements.

Although there is a large and growing body of empirical evidence that indigenous building materials prove to be more advantageous, there are very few scientific studies to support this claim. Tests on full wall assemblies will prove to be more valuable in this regard rather than those related to the properties of single blocks/units.

Also noted that although fired brick was the best in total thermal comfort that stone rock has the best thermal comfort in summer and the fired brick has the worst thermal comfort in summer which is not a problem in Sana'a because of its mild summer and cold summer wind, so this problem will be easily solve by ventilation. Beside the main concern of people in Sana'a is the cold winter.

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