

# A Comparative Study of the Thermal Performance of Building Materials

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**ABSTRACT:** This study focuses on the environmental performance of a selection of buildings in the typical Central Anatolian village of Şahmuratlı in Turkey. The objective was to search for affordable and energy-efficient construction techniques suitable for rural settlements and incorporating traditional cultural values in a semi-arid upland region characterised by long severe winters and hot, dry summers. This was pursued by analysing temperature and humidity measurements within buildings constructed from a variety of traditional and modern materials. The thermal behaviour and comfort, the patterns of energy use and the appropriateness of the different building techniques and materials are analysed, compared and discussed. Aspects of this ongoing study, initiated by a British Council Partnership Programme, are presented in this paper which focuses on a traditional mudbrick structure, a straw bale house and an aerated concrete building. 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: energy, comfort, straw bales

## 1. INTRODUCTION

Due to their inherent properties, different building materials respond differently to climatic conditions. The thermal properties of building components such as walls, ceiling and floors together determine the energy consumption patterns and comfort conditions in an enclosed space.

In order to test their thermal properties certain building materials have been used to construct a group of buildings that house various activities at the Kerkenes Eco-Center. This Center is located in the central Anatolian village of Şahmuratlı in the Turkish province of Yozgat (latitude 40° N). Figure 1 displays the climatic characteristics of the study area.

The dominant climate in Yozgat is the semi-arid upland climate, which is characterised by cold winters and warm summers. Winter outdoor air temperatures are near or below freezing in December and January, and stay well below thermal comfort values for much of the period between October and April.

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 the Eco-Center. In addition to these conventional building materials, other material such as straw bales, papercrete and recyclable waste (like bottles, cans and tires) are also being experimented with and tested for their environmental performance as building material.

## 2. EVALUATING THERMAL PERFORMANCE

This study focuses mainly on the thermal performance of a traditional mud brick structure, a straw bale house and an under-construction aerated concrete building (Figures 2, 3 and 5). In order to compare their environmental performance, temperature and humidity measurements were taken in the hollow brick, mud-brick and straw bale buildings as well as the prefabricated structure on site (Figure 4). However, performance of the incomplete aerated concrete structure was evaluated on the basis of computer simulations only.

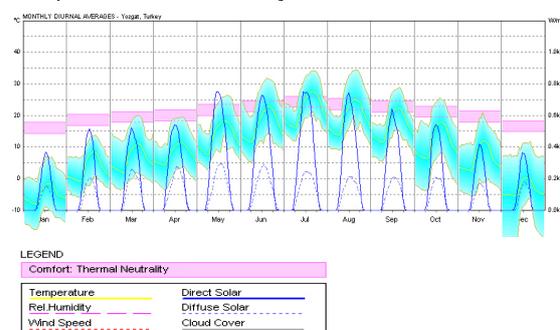


Figure 1: Diurnal averages of outdoor air temperature and solar radiation, for Yozgat, plotted against thermal neutrality bands.



**Figure 2:** Building with straw bales.



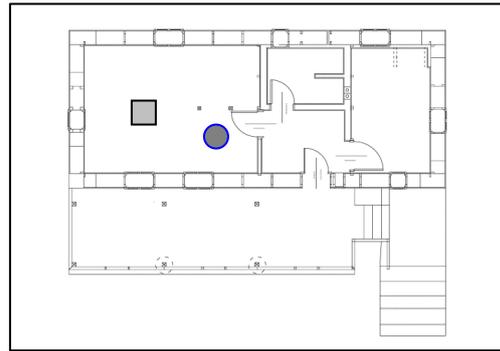
**Figure 3:** Building with mudbrick



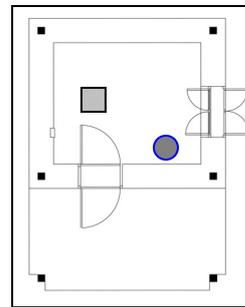
**Figure 4:** Prefabricated building



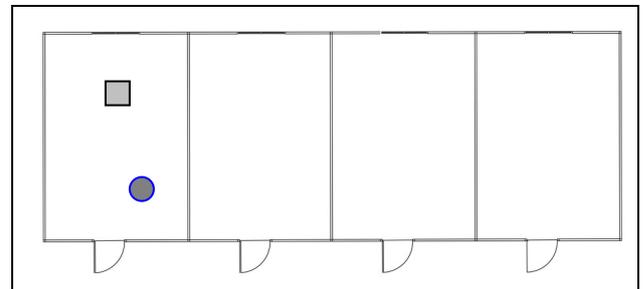
**Figure 5:** Building with Aerated Concrete and reinforced concrete frame



**A:** Plan of straw bale building



**B:** Plan of mudbrick building



**C:** Plan of prefabricated building

**KEY:**



Stove



Tiny Tag dataloggers

**N**



(North direction for all the three building plans above)

**Figure 6:** Plans of the buildings under study, at the Kerkenes Eco-Center, showing placement of stoves and data-loggers.

## 2.1 Research Material

Of the two indigenous materials, mud brick has been used widely in rural areas of Central Anatolia. It is environmentally appropriate since it not only possesses high thermal capacity, which is desirable for creating heat sinks in extreme weather conditions, 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 this season (2006) is autoclaved aerated concrete (AAC), which is a contemporary building material that, in spite of its high cost, is becoming increasingly popular due to its highly desirable properties of fire-proofing and thermal insulation. AAC building blocks and panels are light weight, modular and facilitate speedy construction.

## 2.2 Data collection

The thermal behaviour 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 5.2.

For the first part of the study, temperature and humidity measurements were taken with the help of Tinytag data loggers, in both unheated as well as heated spaces. For each set of data, one data logger was placed outside in a shaded area protected from direct sunlight and rain, while the others were placed inside the buildings to record external and internal temperatures concurrently.

At first, the data loggers were placed in the buildings without any auxiliary heating. Data thus collected could help demonstrate how the building envelope performed in terms of its insulation and thermal inertia properties, under natural conditions.

For the second round of measurements, the hollow brick, mud brick, straw bale, and prefabricated buildings were heated with a fixed amount of coal and wood, which is the conventional fuel in rural areas, for a certain period of time. The aim was to observe and compare the thermal behaviour of these buildings under natural weather conditions, with that exhibited during auxiliary heating periods. The location of data-loggers and the stoves used for heating the spaces is shown in Figure 6 above. It should be noted here that the amount of fuel burnt was not in direct proportion to the volume of the spaces to be heated but a constant predetermined amount; hence, further adjustments would be necessary to eliminate this indiscrepancy.

The second part of the study comprised of computer modelling, 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. The simulations were performed with recorded weather data for a typical year in Yozgat. For this purpose the test unit, the mud brick building, was first modelled 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, wall thickness was kept constant for all materials.

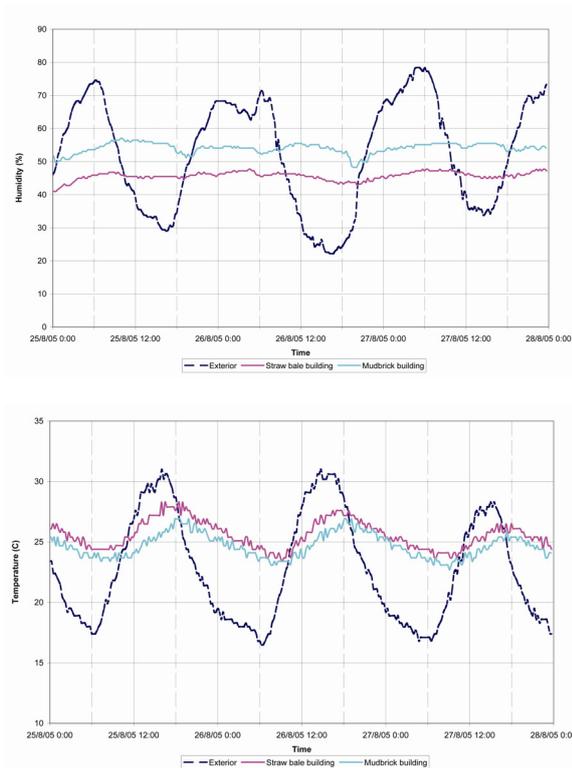
## 3. DATA ANALYSIS

Data were collected under un-heated conditions for a 40 day period from the 30<sup>th</sup> of July until the 9<sup>th</sup> of September, 2005; and for heated conditions, for a 21 day period from the 5<sup>th</sup> to the 26<sup>th</sup> of March 2006.

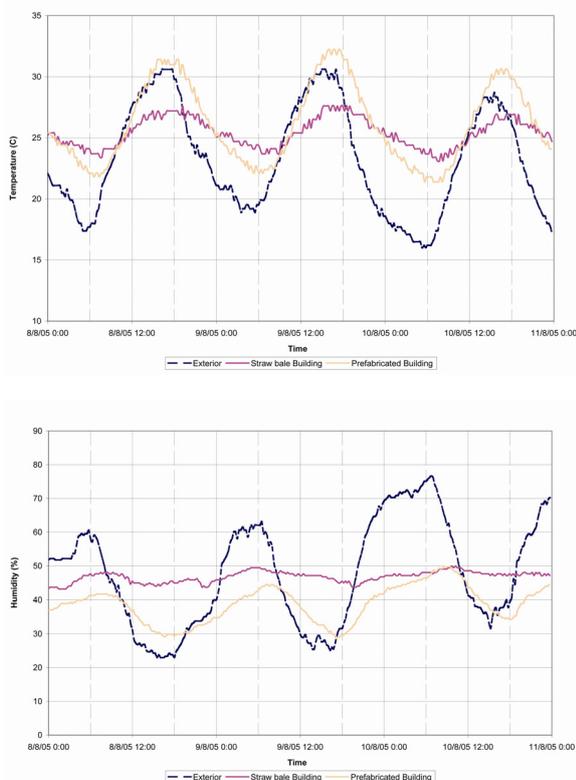
### 3.1 Behaviour of un-heated spaces

For the sake of clarity, temperature and humidity measurements for only three days are presented graphically i.e. from 25<sup>th</sup> to 28<sup>th</sup> August 2005 for Straw bale and Mud-brick, and from 8<sup>th</sup> to 11<sup>th</sup> August 2005 for Straw bale and Prefabricated buildings. The reason why data for the three buildings, along with the external conditions, could not be recorded concurrently was that during this period only three data loggers were available for the research. The charts in Figures 7 and 8 demonstrate the typical behaviour of mud-brick, straw bale and prefabricated buildings under un-heated conditions. It is known from previous studies that due to their thermal insulation and/or thermal mass properties, straw bale and mud brick structures require comparatively less energy to sustain thermal comfort conditions. Furthermore, temperature fluctuations within buildings made of these material are also kept at a minimum; hence, it was observed that internal temperatures in the mud-brick and straw bale buildings remained fairly stable despite external diurnal fluctuations.

In addition to temperature, humidity data was also collected simultaneously, which in turn showed that fluctuations in external humidity levels do not affect humidity levels within the mud-brick and straw bale structures significantly; since these levels also remained quite stable throughout. On the other hand, the prefabricated structure responded more to external fluctuations in temperature and humidity. Moreover, humidity levels in the mud-brick building were the least, followed by those in the straw bale house; while the prefabricated structure had the highest level of humidity.



**Figure 7 a & b:** Three-day temperature and humidity charts for straw bale and mud brick under un-heated conditions



**Figure 8a & b:** Three-day temperature and humidity charts for straw bale and prefabricated buildings under un-heated conditions

It follows that even without providing any air conditioning it is possible to keep internal air temperatures of a building close to thermal comfort levels by preventing extreme temperature conditions and also by avoiding temperature and humidity fluctuations, which cause discomfort to their occupants. This can be done by taking into consideration the thermal properties of wall materials during the design stages.

### 3.2 Behaviour of heated spaces

Figure 9a and 9b show the results of an experiment in which the hollow-brick, mud brick, straw bale and prefabricated buildings were heated with the same amount of coal and wood for two days at a time; i.e. on the 6<sup>th</sup> and 7<sup>th</sup>; and 15<sup>th</sup> and 16<sup>th</sup> of March 2006. In between these days the buildings were left to respond to the external weather conditions without supplemental heating, in order to observe the heat retention ability of each material.

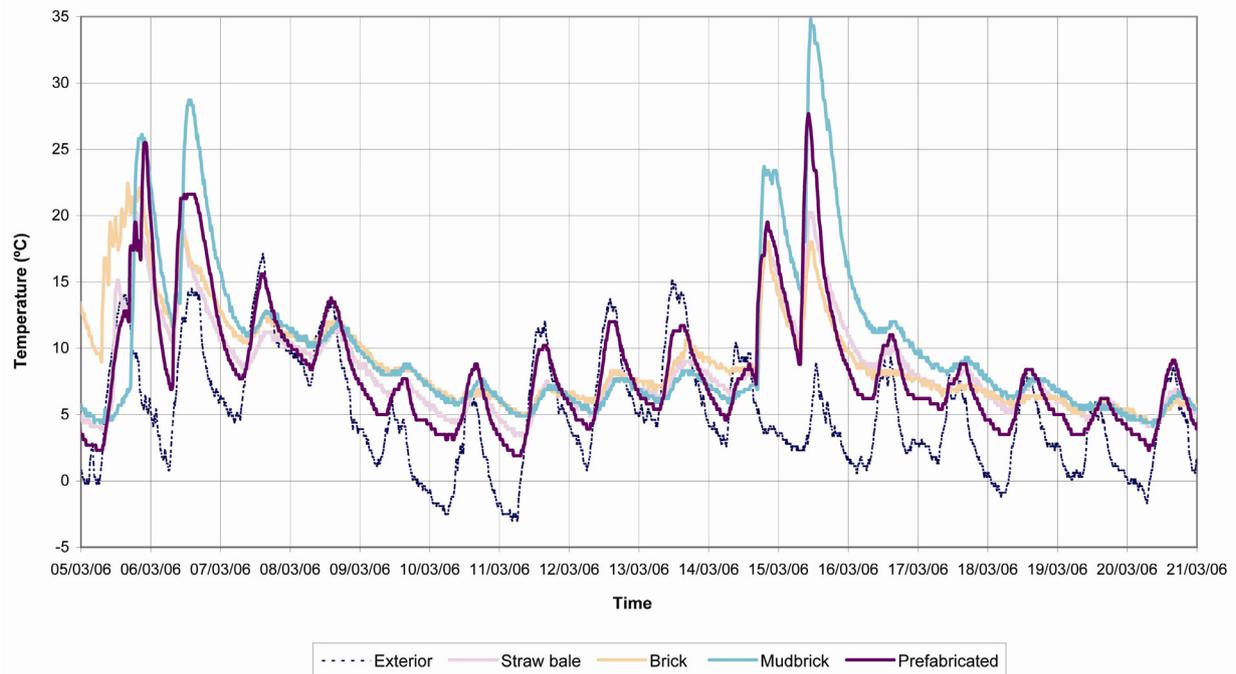
It is important to note that the amount of coal was not in direct proportion to the volume of the spaces being heated; but a constant value for all four buildings. The figures below show the behaviour of the four buildings from the 5<sup>th</sup> to the 21<sup>st</sup> of March, 2006, with respect to their responses to external variations in temperature and humidity levels when they are heated intermittently for a certain length of time.

Mud brick is not considered to be a good thermal insulator since it possesses a high unit-mass and very low porosity. However, its high thermal capacity is conducive to storing the absorbed heat for a longer period of time and releasing it back into the surrounding space more slowly than the other materials being investigated in this study. On the other hand, straw bale has better thermal insulation property.

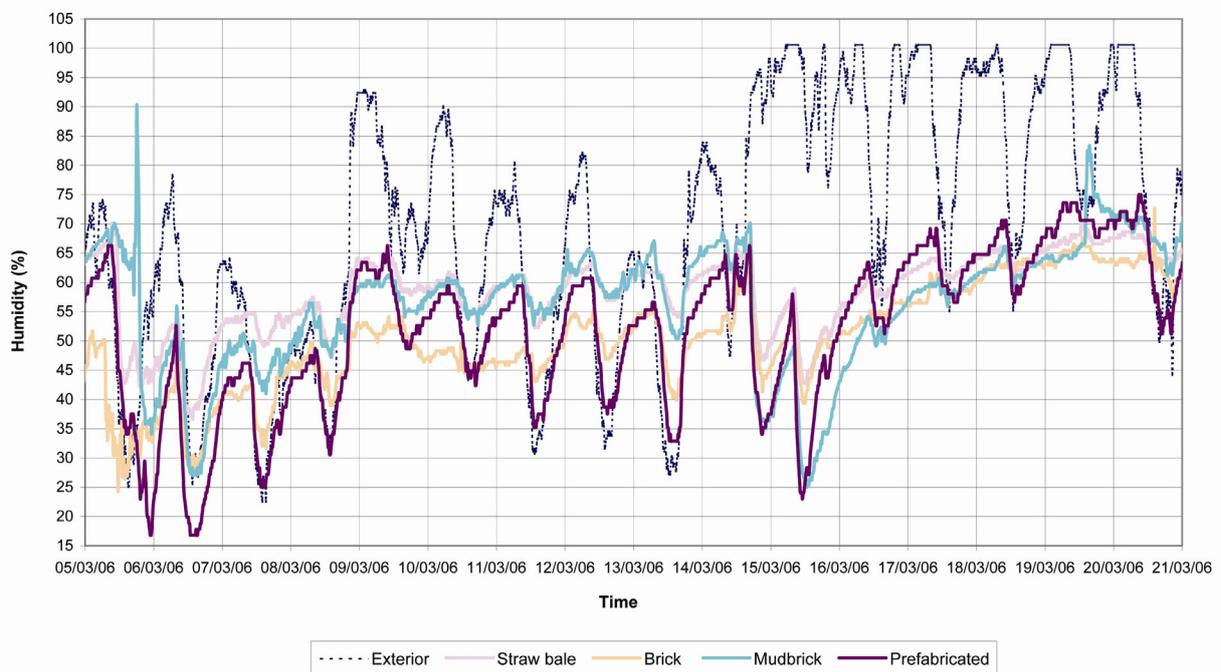
The difference in behaviour, of mud-brick and straw-bale, can be seen clearly on the 13<sup>th</sup>, 14<sup>th</sup> and the 21<sup>st</sup> of March 2006. On these dates the effect of heating diminishes, yet, the mud brick structure maintains a higher internal temperature, since it re-radiates the heat it had stored back into the room. After this point the straw bale structure starts to be more advantageous; this space maintains higher internal temperatures because, although it cannot store the absorbed heat, it can minimize or delay the passage of heat from the warmer internal space to the colder external one.

The prefabricated building is made with sandwich panels of thin concrete and insulation (EPS) boards. Despite this insulation, the thickness of the panels does not provide enough thermal mass to store the heat for longer periods of time; consequently, the prefabricated building cools down very quickly. Hollow brick is similar in behaviour to mud-brick but does not perform as well as straw bale.

Mud-brick and straw bale (due to its mud plaster) are also conducive to balancing humidity levels within the space, therefore, when the heating is stopped the humidity levels within these buildings remain quite stable. On the other hand, humidity levels within the hollow brick and prefabricated buildings rise and fluctuate with changes in external humidity levels.



**Figure 9a:** Temperature chart showing the comparative behaviour of buildings constructed with four different wall materials, when heated intermittently with a (coal & wood) room heater.



**Figure 9b:** Humidity chart to compare the behaviour of buildings constructed with four different wall materials, when heated intermittently with a room heater.

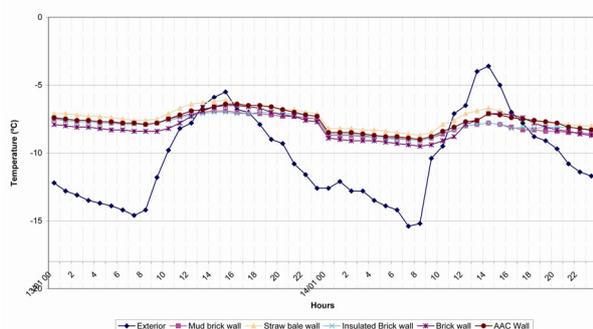
### 3.3 Simulation

Computer simulations help to analyse 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 5.01 were carried out for different months of the year, results of the simulations for only two days, i.e. the 13<sup>th</sup> and 14<sup>th</sup> of January, are presented here for brevity. In order to compare the behaviour of the

different materials, simulation data for all of the five wall materials, namely; aerated concrete, factory produced clay brick, insulated brick, mud brick and straw bale, are presented together in Figure 10.

The simulations were run on a computer model of the mud brick building, which actually exists at the Kerkenes Eco-centre and has an area of 10.5 m<sup>2</sup> (Figure 3). In order to ascertain the direct effect of wall materials on the thermal behaviour of the building, only the material properties of the walls of the unit building were altered for each run. In other words, the wall thicknesses as well as the materials and dimensions of the roof and floor constructions were retained as they were. For each different wall type the U-values were calculated by assigning relevant wall components, in the programme.



**Figure 10:** Hourly temperature profile for the five types of walls, on the 13<sup>th</sup> and 14<sup>th</sup> of January.

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 for equal wall thicknesses the behaviour of the straw bale walls are closely followed by walls made of AAC blocks; while a mud brick wall has nearly the same properties as an insulated brick wall. On the other hand, a factory produced brick, with or without insulation, costs considerably more than locally produced mud-brick of equal size; while AAC is the most expensive wall material available in the market.

#### 4. CONCLUSION

Compared to contemporary building materials with high embodied energy, the energy required to produce mud brick and straw bale buildings is minimal. In addition to their energy efficient behaviour during use, these two materials are completely biodegradable. 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.

#### ACKNOWLEDGEMENTS

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#### REFERENCES

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