

# Energy Efficiency of Buildings with a Solar Space: Two case studies from the Anatolian Plateau

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*ABSTRACT: This paper discusses two case studies on the energy efficiency of buildings with south facing solar spaces. The study was conducted on buildings located on the Anatolian Plateau, a semi-arid upland region of Central Turkey where the harsh climate is characterized by long severe winters and hot, dry summers. One is an experimental hollow-brick building on the edge of Ankara, the capital city, and the other is a mud-brick building at the Kerkenes Eco-Center located in a traditional village in the Yozgat region. Findings of this study have demonstrated that solar spaces added to both structures have a positive influence on the thermal performance of these buildings by reducing the annual heating loads by almost 10%.*

*Keywords: energy efficiency, thermal comfort, mud-brick construction, solar spaces*

## INTRODUCTION

Building occupants seek maximum levels of comfort with minimum input of resources, whether in extreme or mild climates. Populations are moving from villages to cities in search of new opportunities and the prospect of higher living standards. Only a very small percentage of the earth's population shows real concern for the future of the planet and a large majority selfishly disregards long term consequences of its actions. Answering the call of an economy-biased demand, especially within the urban scene, the building industry, does not generally adopt designs with integrated passive solar heating or other principles of bioclimatic architecture although this could significantly reduce the consumption of fossil fuel and other combustibles that contribute to CO<sub>2</sub> emission. Those who can afford the luxury of mechanical and automated control within a building still choose the high energy-consuming modern technology rather than opt for more environmentally friendly approaches involving user participation.

The urban environment unquestionably dominates the scene when discussing global issues related to energy consumptions and carbon emission. Cities of an ecological nature being targets difficult to reach, one can fear disastrous consequences of uncontrolled increase in urban populations. Migration of people from rural areas to urban centres can be blamed for a dramatic increase in pollution and energy consumption. Slowing down, stopping or even reversing the migration from villages to cities could contribute very significantly to an increase in environmentally friendly practices less harmful to the planet.

How can the rural scene be made more attractive in Turkey and other countries with similar circumstances? Perhaps aspects of the city could be brought to the village thus providing the rural areas with the standard of living and level of comfort that one expects from the urban areas. Promoting energy efficient bioclimatic architecture to provide higher standards of living in villages could thus contribute significantly to a low carbon high growth rural economy and provide new opportunities attracting people to rural areas.

Arousing the awareness of people will help reduce the negative impact of our contemporary society on its environment provided that architects and engineers can offer solutions that satisfy the expectation of a more demanding population. Two case studies located on the Anatolian Plateau have been chosen to demonstrate the potential of an environmental friendly approach that could reduce significantly the national energy consumption in Turkey and encourage low carbon high growth economy development in rural areas where essential infrastructure is now provided.

The first one, the experimental solar building at the EIE (Elektrik İşleri Etüt İdaresi Genel Müdürlüğü / Electrical Power Resources Survey and Development Administration) is on the edge of Ankara, the rapidly expanding capital city.

The second, situated in the Yozgat region, is the Kerkenes Solar Building within the Eco-Center [1] built in the Village of Şahmuratlı which possesses a world class cultural heritage site, ancient Pteria, an Iron Age mountain-top city founded on the Kerkenes Dağ. Both

examples have been built as models to be monitored and studied. Results and conclusions are used to propose improved design solutions and visitors gain increased understanding from direct experience.

The EIE Solar Building has a glazed south-facing facade with adjustable openings. Materials have been carefully selected to maximize energy efficiency and thus reduce significantly energy consumption. Data is collected and the environmental performance of the building monitored. Improvements could include a more sophisticated system for temperature control powered by renewable energy so as to satisfy those occupants who demand as little interaction as possible. Similar design principles could be adapted to both urban and rural environments for the production of a stock of energy efficient buildings in the housing, commercial and industrial sector.

The Kerkenes Solar Building is located in the rapidly developing Eco-Center where a number of pilot schemes for renewable energy and appropriate technologies have been initiated against a background of climate change, socio-economic inequality and rapid depopulation of rural areas in favour of urban growth. The ongoing program, which stimulates and creates income generating activities for both men and women, include experiments with appropriate building materials and energy efficient designs, promotion of solar energy for cooking and drying food, drip irrigation for organic gardens and recycling. The Kerkenes Solar Building is designed to use passive solar heating as well as to harness solar energy for food preservation with small-scale village production units.

Ongoing studies at the Eco-Center are many-faceted: Data loggers are used to record temperature and humidity within the building, solar cookers and driers. Virtual models are created and used in analytical simulation programs to assess and compare energy efficiency. Results help with design improvements. The behaviour of users is observed and their comments and suggestions recorded.

This project is a model for similar initiatives to be implemented on a regional and even national scale. Grants from sponsors and support from local authorities have enabled ŞAH-DER, the Kerkenes and Şahmuratlı Village Association, to develop energy efficient building designs, promote the use of solar energy and pioneer small scale environmentally friendly technology for the production of dried fruit and vegetables, jams and marmalades, sauces and seasonings.

Where rural economies on the Anatolian Plateau are underdeveloped and opportunities for young people limited, the development of sustainable, environmental

friendly, rural economies supported by renewable energy will provide a reduced rural population with acceptable levels of comfort and economic security. Besides, the development of bioclimatic designs may even attract those who are ready to give up urban life for a more sustainable one.

### **SOLAR SPACES FOR ENERGY EFFICIENCY**

Findings of previous studies on thermal performance of the various buildings at the Kerkenes Eco-Center have been reported at various international conferences. One study has shown that for rural areas mud-brick is one of the most appropriate building materials. It is an environmentally friendly material that is recyclable and easy to produce locally [2]. Mud-brick buildings are thermally comfortable even in extreme climates because of their high thermal capacity. Due to the success of the first mud-brick building at the Eco-Center (Fig. 1), it was decided to construct another one after having experimented with straw, Autoclaved Aerated Concrete blocks and other materials.



*Figure 1: Mud-brick building at the Kerkenes Eco-Center*

On the other hand, Trombe walls are used in passive solar buildings because they can regulate the temperature within a space by transferring heat absorbed from the sun to the surrounding air. The direction of flow of the convection currents is manipulated so that this system can cool a building during summer and heat it during winter [3].

When mud-brick walls absorb energy from the sun they act as heat sinks and this heat is dissipated into the surrounding space which is at a lower temperature. Due to this behaviour a mud-brick wall can be transformed into a Trombe wall if it is behind a glazed area. Hence, it was decided to convert the balcony of the second mud-brick building constructed at the Eco-Center into a solar

space. In this way it would be possible to study the effects of a solar space on the energy demand of a mud-brick building. A solar space uses passive solar heating to minimize the energy needed to provide the occupants with the desired level of thermal comfort in winter but is, on the other hand, a source of unwanted heat gain during the hot summer season [4]. It is nevertheless possible to control overheating by using ventilation and shading techniques when necessary and thus optimise the energy efficiency of the building all year round [5, 6].

Occupants can regulate the flow of heat generated in the solar space during the day to either cool or heat a connecting space by opening or closing doors or vents. For example, during winter the heat from the solar space was directed inside the building to heat the spaces within, by opening the doors. To stop the trapped heat in the room from being lost through the vast glazing areas of the solar space at night, connecting doors were closed soon after sun-down.

## CASE STUDY BUILDINGS

The Kerkenes Solar building (Fig. 2) consists of a single room that has a traditional fireplace kitchen and a covered balcony facing south that was converted into a solar space. Drying racks for vegetables are built into the solar space. Due to the sloping site, the space beneath the building has been utilized for storage of various articles of use as well as the jams and dried fruit and vegetables produced by the village ladies in this building. The foundation and semi-basement walls are constructed with stone masonry and the walls above with mud-brick rendered with traditional mud plaster on both sides.



Figure 2: Surrounded by solar driers and cookers, the Kerkenes Solar Building with its south facing glazed balcony uses solar energy for heating and food processing.

Floors in this building are of concrete. The flat roof consists of timber beams and rafters covered with timber boards, water-proofing bitumen felt and a thick layer of

mud. Second hand wooden doors and single-glazed window units from demolished buildings were reused.

The EIE Solar Building (Fig. 3) has a reinforced concrete structure, perforated brick walls and 6cm thick thermal insulation (EPS) both outside and inside the external walls. There is a layer of the same insulation on the roof and a layer of glass-wool under the floor of the building. The solar space on the southern façade of the building is also two storeys high.

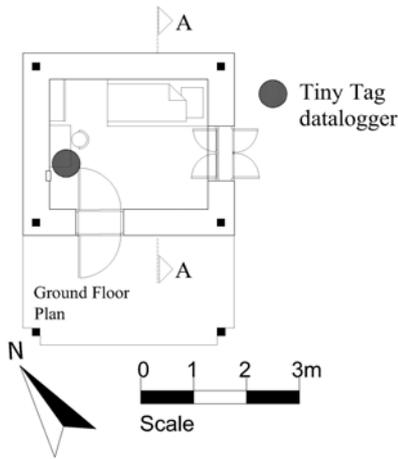


Figure 3: The EIE Solar building in Ankara.

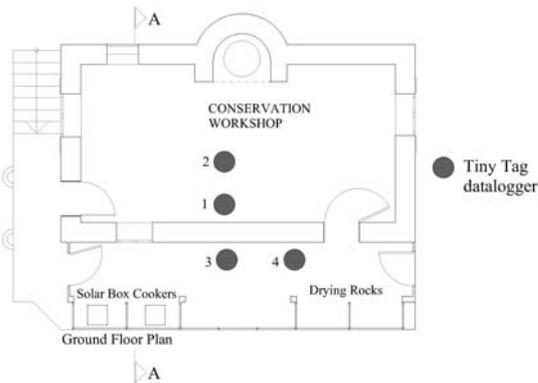
## Data Collection

The thermal behaviour of the three buildings was studied by taking actual measurements on site. “Tinytag-Plus 2” data-loggers were placed in appropriate locations outside and inside the three buildings to record temperature and humidity levels. The plans of the two mud-brick buildings showing the location of the data loggers are presented in Fig. 4 below. Plans of the EIE Solar building were not available; but the data loggers were placed inside the solar space and the room opening into it, as well as outside the building to record exterior temperature and humidity readings.

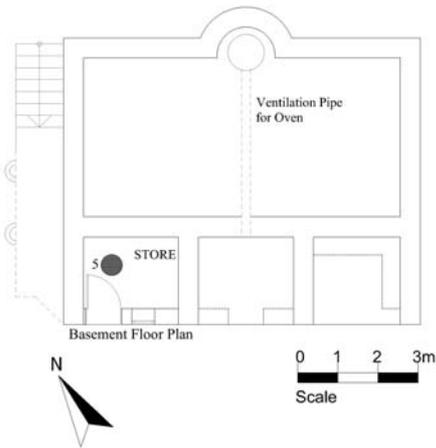
Temperature and humidity data were recorded at 15 minute intervals for a few days at a time, throughout the year. However, in this paper, data belonging to a 7 day period only, from the 21<sup>st</sup> to 28<sup>th</sup> of October 2007 has been evaluated to compare the thermal behaviour of the various spaces in the two mud-brick buildings. Additionally, the effect of the solar space on the thermal behaviour of the adjacent spaces has been evaluated by comparing data recorded with open and closed connecting doors. Data for the EIE Solar Building could be recorded from the 21<sup>st</sup> to the 23<sup>rd</sup> of January 2009 only as previous data could not be saved.



(i) MUD-BRICK BUILDING GROUND FLOOR PLAN



(ii) SOLAR BUILDING GROUND FLOOR PLAN



(iii) SOLAR BUILDING BASEMENT PLAN

There was considerable diurnal fluctuation in external weather conditions but since the buildings were not in use during this period, there were no internal gains due to metabolic energy of occupants or machinery/equipment being operated. For the same reason they were neither heated nor cooled; nor were the doors or windows opened, therefore there was practically no ventilation. The temperature and humidity data that were recorded concurrently inside and outside the buildings are presented graphically in the following section.

### Computer Simulation

The effect of solar spaces on thermal behaviour was also simulated. Annual heating loads were calculated twice for the Mud-brick building by simulating thermal comfort conditions with the help of the energy simulation software Ecotect V5.5 [7]. The first calculation was done for the 'as-built' model and the second one was done after adding a solar space on the southern end of the building. This simulation demonstrates the influence of a solar space on the heating loads, and thus the energy efficiency of a building.

### RESULTS AND DISCUSSION

The thermal behaviour of the two solar buildings was analysed by evaluating the real-time temperature and humidity readings obtained from the data loggers. Results of these evaluations are discussed in the following sections.

The temperature data for the two mud-brick buildings were combined and presented in a single chart in order to compare visually their thermal performance (Fig. 5 below).

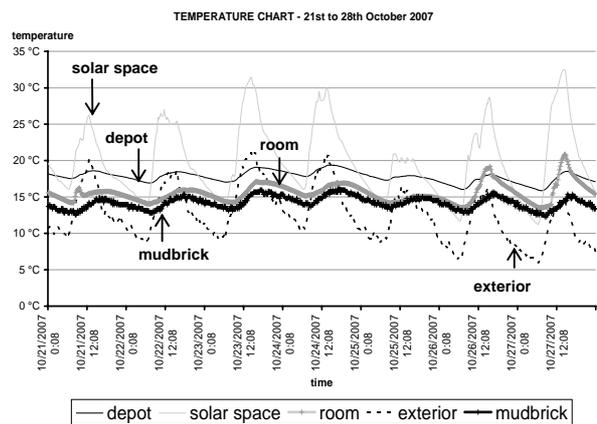


Figure 4: Plans of the Mud-brick Building and Solar Building at the Kerkenes Eco-Center, showing location of the data loggers.

Figure 5: Comparative temperature chart for the Mud-brick Building and Solar Building at the Kerkenes Eco-Center.

From the comparative temperature chart above, it is clear that as the outside temperature fluctuates (approximately 12 °C) so does the temperature within the four spaces in two buildings; namely, solar space, main rooms and storage (depot). The temperatures within the solar space are higher than exterior temperatures. Since both the mud-brick buildings are facing south, passive solar gains would have been high in all three, but the presence of a covered veranda in front of the room in the Mud-brick building prevents direct solar gains from the south. Conversely, the solar space in front of the Kerkenes Solar Building contributes to heat build-up within the main room. On the other hand, the absence of solar protection allows solar gains in the depot below. Again from the comparison chart it can be seen that, generally, internal temperatures for all spaces follow the same trend maintaining the temperature difference between them. The graph that temperature data collected in the main room of the Solar Building shows a decrease in temperature gain on the 25<sup>th</sup> of October, a cloudy day, while on the 26<sup>th</sup> and 27<sup>th</sup> October there is a relative increase in temperature gain when the door between the solar space and the main room was left open.

There is a 5°C difference between the room in the Mud-brick Building and the depot under the Solar Building. The higher temperature in the depot can be attributed to three reasons:

- 1) Solar gains in the depot are higher than the Mud-brick building, which is protected from the south by a covered veranda. The role of solar gains in giving rise to this temperature difference is emphasized when we see the temperature difference between the two buildings drop due to cloud cover on the 25<sup>th</sup> and 26<sup>th</sup> of October.
- 2) The depot is directly under the solar space which is warm while the roof of the Mud-brick building is open to the cold night sky. This situation gives rise to heat loss due to radiation.
- 3) The depot is completely protected from the North as it is dug into the ground and has another storey above it.

The temperature in the main rooms of the two mud-brick buildings is close together when the solar space to the south of the Solar Building is closed off by shutting the doors and windows (that open into the solar space). However, when these doors and windows are left open, the heat generated in the south facing solar space enters the room and raises its temperature even more.

On the other hand when the sky conditions were cloudy, less heat is generated in the solar space and the temperature difference between the two building interiors drops. This phenomenon is noticeable on the 25<sup>th</sup> and 26<sup>th</sup> of October 2007, when the internal temperatures were almost the same due to cloudy skies. Also, during

these two days the doors and windows opening into the solar space were closed.

After the 26<sup>th</sup> of October the building was used by the village ladies who opened the windows and doors into the warm solar space. Hence the temperatures within rose by 3°C even though external temperatures had dropped further; i.e. by 5°C. Yet the minimum internal temperatures did not drop further in any of the mud-brick rooms; this shows that the material has high thermal capacity. Hence, it can be seen from the recorded data that when the days were sunny, the mud-brick structures soaked up the incident solar heat and could store it due to their high thermal mass. This heat was then dissipated within the spaces to keep them warm even after sundown.

Temperature data for the EIE Solar Building could be recorded for two days only and it has been presented in Fig. 6 below. As can be seen from the temperature curves for the solar space and the room, these spaces are warmer than the exterior of the building. Also when the doors leading to the solar space from the room are kept open from 9am to 5:30pm, the temperature in the room rises due to heat gains from the solar space. This behaviour of the EIE Solar Building constructed with perforated bricks is similar to that of the Kerkenes Solar Building constructed with mud-brick walls. This means that regardless of the type of building envelope material, solar spaces are useful in raising the temperatures of these buildings.

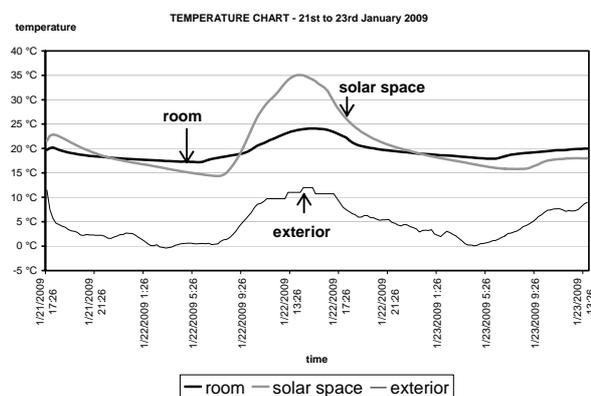


Figure 6: Temperature chart for the EIE Solar Building in Ankara.

### Simulated Heating and Cooling Loads

The total heating and cooling loads for a typical year were obtained for the simulated 'as-built' and 'solar-space add-on' models of the mud-brick building. The models were simulated with HVAC set-points for heating as 18°C and cooling as 26 °C. The results of Ecotect v5.5

simulations under Yozgat weather conditions were then transferred into Microsoft Excel format and then combined as a single data set for the sake of comparison.

These data were then used to prepare a comparative chart for the monthly heating/cooling loads per usable floor area of all the three buildings. This bar-chart is presented in Fig. 7 below. As can be seen from this chart, the monthly heating loads per square meter (kWh/m<sup>2</sup>) are lowered by adding on a solar space to the as-built model. This effect is considerable even when connecting door between the solar space and the building is kept closed; but if it is left open then the effect is further enhanced. Consequently the annual energy consumption of the simulated as-built Mud-brick Building is calculated to be 2160kWh; this load is reduced by 9.69% if a solar space is added to the southern façade of the building and the connecting door to the interior space is kept closed. However, opening the door and allowing the trapped heat in the solar space to enter the building interior reduces the total annual energy consumption by 18.72%. This is a significant decrease in energy consumption which can be further reduced by adding night insulation to reduce the dissipation of heat through the solar space glazing.

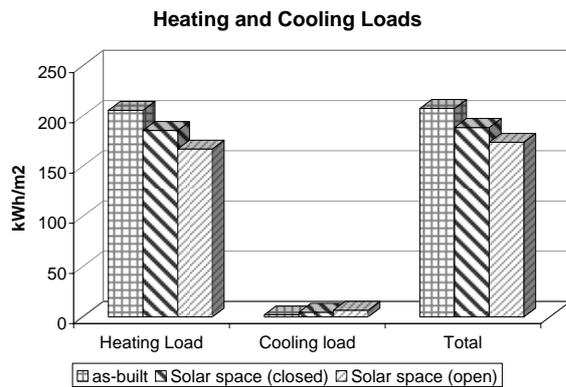


Figure 7: Annual energy loads for the simulated Mud-brick Building; with and without the solar space.

## CONCLUSION

This paper showed how a solar space can be influential in lowering the annual heating loads of buildings. Additionally, a solar space can be used for drying fruits and vegetables under hygienic conditions and for longer periods than in the traditional way of doing it out in the open. The villagers use this dried fruit and vegetable during winter months when it is not possible to grow crops; hence, this function of the solar space is an important contribution to their sustenance.

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