Int. J. of Thermal & Environmental Engineering
Volume 3, No. 1 (2011) 21-25

Design and Construction of a Green, Controlled-Environment Dwelling in Jordan

Abdul Hai Alami*

Mechanical Engineering Department, Higher Colleges of Technology, Al-Ain, UAE, 17155

Abstract

This paper investigates the design and implementation of an enclosure that uses locally developed technologies in terms of insulation and solar thermal heating, as well as exploit the location of Jordan as a recipient of a formidable amount of solar radiation per year to create and maintain a dwelling where the environment is kept at an excellent level of thermal comfort all year round.

Keywords: *Solar energy, green buildings, Thermal solar collectors and photovoltaic cells*

1. Introduction

The past three decades were the dawn of what is now, deservingly, known as the Energy Era [1]. Both the depletion of the once abundant, cheap and convenient fossil fuels, coupled with the adverse effects of large carbon prints of processes and possessions have necessitated an introspective review of all energy-related activities.

Green construction and planning is not a new concept, nor is it a research concept, as many environmentally conscience laws and regulations are in effect globally; where the environmental impact of any project has to be assessed before it commences. One solution that can prove feasible for the future is considered in this paper by examining construction materials and methods used in the past to construct houses in the Hashemite Kingdom of Jordan, and incorporating them appropriately into contemporary construction methods of habitats. For example, the use of mud in Jordan for building goes way back into history. Houses in the Jordan Valley were built of sun-dried mud bricks with roofs made of wood and reeds. Some dwellings were based on stone foundations and many were planned around large courtyards.

2. Setup

The current proposition is to design and construction of a controlled environment dwelling for use in remote areas first, and then wider adoption can occur depending on the economy of scale and production of the manufacturing technique. The proposed design combines an effective insulator extracted from locally abundant masonry materials that have been experimentally proven to provide the desired thermal insulation, cooling during summer months using photovoltaic solar cells, and heating during winter months using a special solar thermal collector made of a combination of copper and aluminum absorber.

2.1. Components

Note the blank line between the heading of this level 1 sub-section and this paragraph. The style is 9-point Times New Roman boldface, flush left and a 12-point spacing before.

2.1.1. Outer structure

The outer structure will be made of I-beams welded together to form a prismatic structure of 3 x 2 m area and 2.5 m height, with walls made of an organic insulator sandwiched between steels sheets.

The roof of this structure will be divided into two sections, one houses the thermal solar collector absorber and pipes, and the other has the photovoltaic solar cells to provide electricity. A bird's-eye view of a solid model is shown in Figure 1.

2.1.2. Insulation

The insulation will be made of a special mixture of locally available materials that was examined by the author [2] and proved to provide both excellent insulation properties, good manufacturability and is completely biodegradable. This material is made of clay, hay and olive husk. The olive husk is a solid waste material that is generated from pressing olives for oil in Jordan. The percentages of the target mixture is 40% husk, 25% hay and the rest is clay (from the Karameh region in Jordan). This mixture is provides surprisingly ductile properties to the clay-hay-husk mixture, that when tested under compression, the specimens have shown a significant elastic region and a spring back characteristic after the load is removed, as seen in Figure 2.

---

[*] Corresponding author. Tel.: +971561605355
Fax: +971537095588; E-mail: Abdul.alami@hct.ac.ae

DOI: 10.5383/ijtee.03.01.004

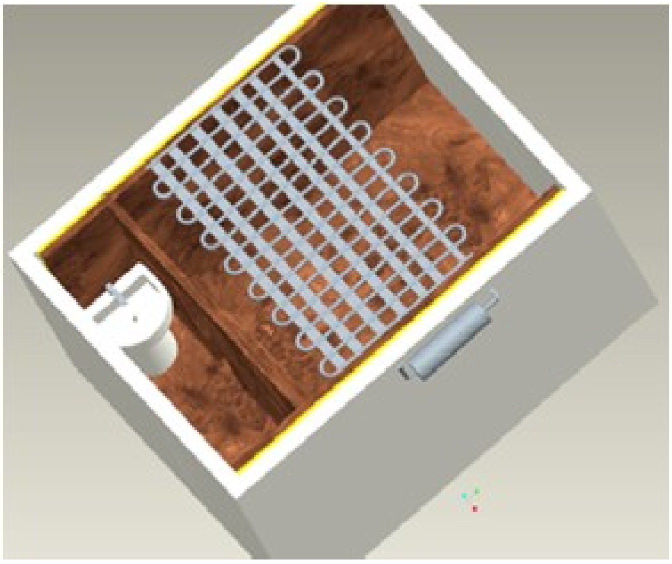
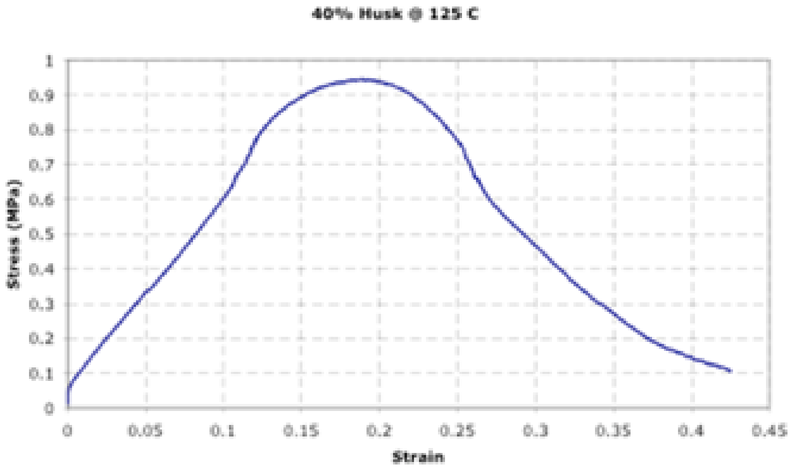
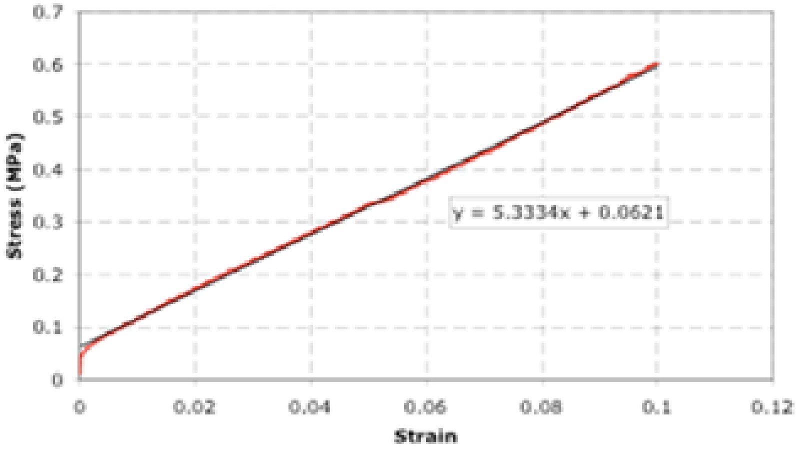


Fig. 1. Solid model of the proposed enclosure



(a)



(b)

Fig. 2. Mechanical Properties with 40% husk (a) stress-strain, (b) linear portion from (a)

These favorable mechanical properties have enabled the production of flat sheets (Figure 3) of controlled thickness and virtually no dimension changes due to contraction that can be successfully used as an insulator with the aforementioned advantages.

Fig. 3. Flat plate of clay, hay and olive husk

2.1.3 Power requirements for cooling load

Jordan has an average of 330 sun-lit days per year, with a maximum number of sun-lit hours in June (14.1 hrs) and a minimum in December (9.95 hrs), with mean maximum temperature that climaxes in July (34.43° C). [3]. The average temperature that will be used for cooling load calculations is going to be the yearly average of 29.4° C.

Jordan also has an average daily peak incidence of 1000 W/m2 of solar radiation during summer months, thus emphasizing the feasibility of using photovoltaic cells for direct electricity generation and storage using batteries. The main load driven by the electricity generated is a suitable compressor for cooling the enclosure as well as any lighting needed for the interior. To select the size and power needed to operate the compressor, a cooling load calculation is required given that the PV cells will be installed on the roof of the enclosure, which is to be oriented so it allows the PV cells to face the southeast, as seen in the Figure 4 with an inclination angle on the roof between 19° (winter value) and 43° (summer value) for Zarqa, Jordan [4] for optimal solar incidence. To minimize cooling loads, the window will be located on the northwest side of the building.

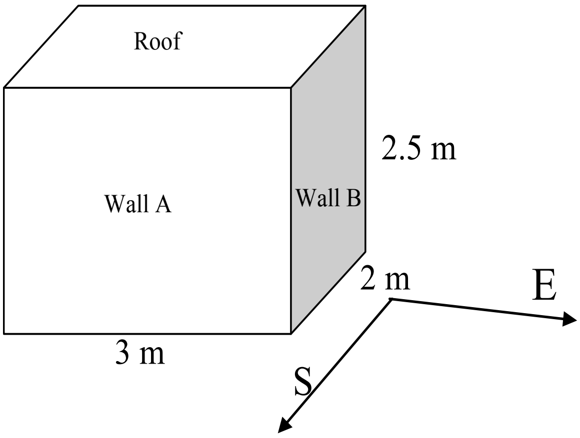


Fig. 4. Orientation and dimension of enclosure

The method used for the cooling load is the Cooling Load Temperature Difference (CLTD) recommended by the ASHRAE (reference to each table/figure will be made accordingly). This method adds up cooling loads for solar radiation, walls, window and lights, with corrections to fit the outside temperature and the materials used. A summary of the heating load for each component is shown in Table 1. Note that for the solar gain, the calculations were based average daily diffused radiation gain of 189 W.h/m^2 based on the work of Etier, et al [5] for the same locality as the current research . The cooling load factor (CLF) was kept at 0.8

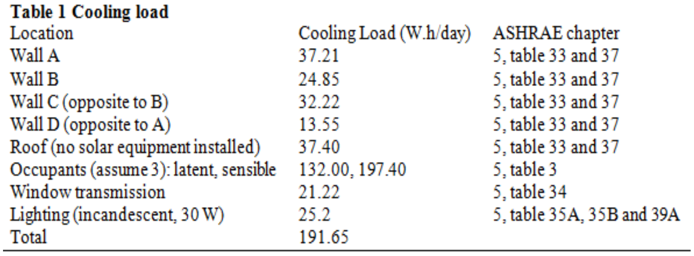


Table 1 Cooling load

Location	Cooling Load (W.h/day)	ASHRAE chapter
Wall A	37.21	5, table 33 and 37
Wall B	24.85	5, table 33 and 37
Wall C (opposite to B)	32.22	5, table 33 and 37
Wall D (opposite to A)	13.55	5, table 33 and 37
Roof (no solar equipment installed)	37.40	5, table 33 and 37
Occupants (assume 3): latent, sensible	132.00, 197.40	5, table 3
Window transmission	21.22	5, table 34
Lighting (incandescent, 30 W)	25.2	5, table 35A, 35B and 39A
Total	191.65	

2.1.4 Heating load and modular thermal solar collectors

During winter time, the heating load is calculated for the enclosure through the conventional method of dividing the heat loss into heat transmission losses, and losses due to infiltration. With the use of the clay-hay-husk insulator that has a coefficient of thermal conductivity of 0.09 W/(m2.K), and since the enclosure is considered to be air-tight, the transmission heat losses are the ones having most significant contribution. A table similar to Table 1 is available, where the total heating load was calculated to be 937.78 W during winter months

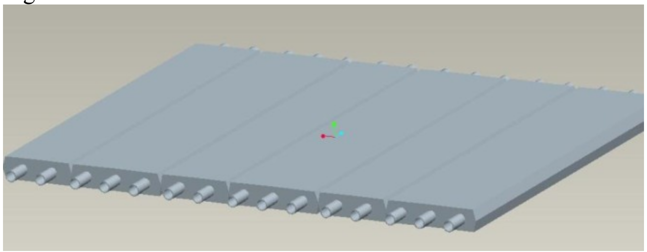
3. Results and Component Selection

3.1 Cooling load

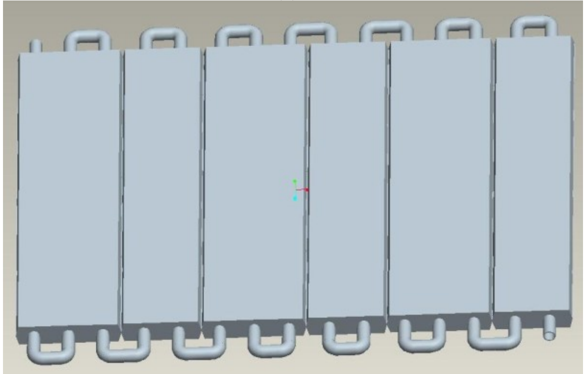
To offset the calculated cooling load of 192 W.h/day calculated, an air conditioning unit must be installed and operated. A selection process needs to take place to choose the appropriate size of the PV cells (since they cannot be produced locally) to provide enough energy to start up and run the air conditioning unit compressor and provide electricity for the lighting. Batteries are also selected to store electricity for times when no solar radiation is available (night/overcast conditions). It should be noted that more electrical appliances can be added as needed, thus the PV grid selection should depend on actual W.h/day needs, multiplied by a reasonable factor of safety. For the current case, we will assume the factor of safety to be 2 (to account for the cooling load plus any other electrical appliance required). This makes the current estimated electrical load 400 W.h/day. The choice of solar panels that can meet this demand is wide since there are many suppliers currently competing in this market. For example, Ecosupplies [6] provide a PV cell arrangement of 1001x1675 mm that produces an average maximum power of 217.4 W. Two such panels are required to meet the projected load of 400 W.h/ day, which will occupy 2002x1675 mm of the roof, leaving 1000x2000mm for the thermal solar collectors. The listed price per watt for units sold in the US is $3.59 (October 2010) [7].

3.2 Heating load

To compensate for this heat loss, a thermal solar collector is to be used, and this one has been developed at the Hashemite University as with a modular design that can expanded as needed. This design is based on experiments on aluminum-copper alloys that were conducted on mixtures of these alloys and then used to manufacture a cast the absorber for a thermal solar collector that has the water pipes passing through the cast and connected using copper bends and fittings as can be seen in Figure 5.



(a)



(b)

Fig. 5.modular absorber design (a) Isometric view and (b) top view

Based on the experiments of the author on copper-aluminum alloys [8] he module was cast from 60-40% cu-al alloy, respectively, as shown in Figure 6.

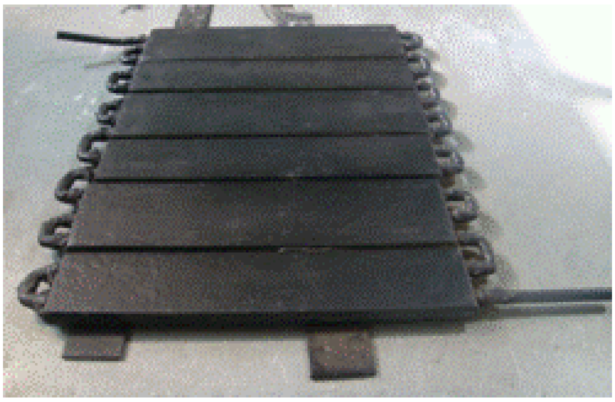


Fig. 6. Casting of solar thermal absorber of 60-40 Cu-Al alloy with copper bends and fittings

The cast absorber was darkened with a matt black spray, and placed within low-emissivity glass and foam insulation to have a final total length of 1000 mm and a width 700mm as seen in Figure 7.

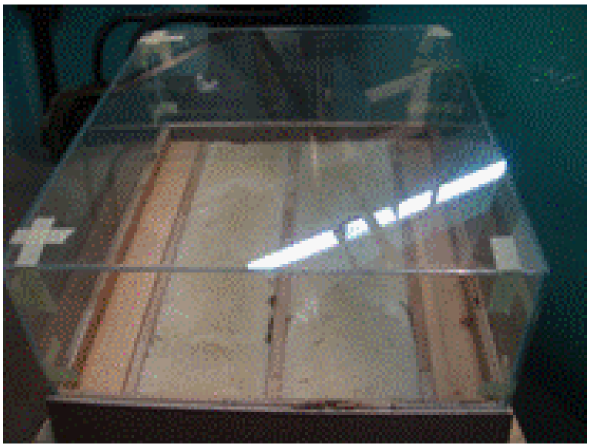


Fig. 7. Glazing and insulation of the thermal solar collector

The device that consists of the absorber, insulation and glazing was then tested during winter months (October through January) with an average temperature of 17.7 ° C, and each of the six modules that make it up generated 32 kJ of energy for the duration of the test (2 hours around the local solar noon occurring at 11:24 am Jordan Standard Time). The test measures the temperature of the absorber material via an attached thermocouple to help calculate the available heat within the material itself. Figure 8 shows the first half of the test before the solar noon (one hour before) and how the temperature of the plate has reached over 60° C, which is a promising result knowing that the mass of the absorber is around 31 Kg (18.6 Kg of which is copper and the rest is aluminum) and that the air temperature is around 17° C.

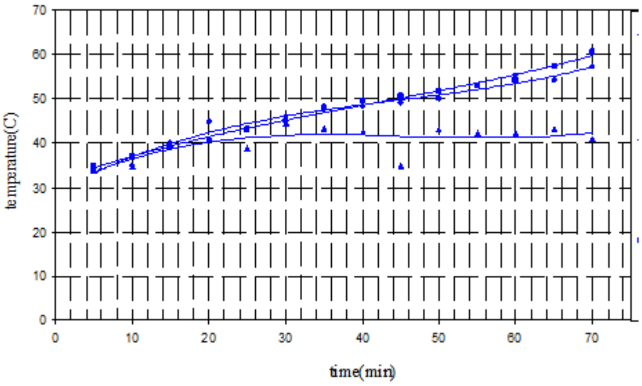


Fig.8 Thermal test of absorber

The thermal solar collector is to be attached with a tank to collect hot water, a distribution network of underfloor heating and an outlet for domestic hot water use. A solid model of the network for heating is shown in Figure 9

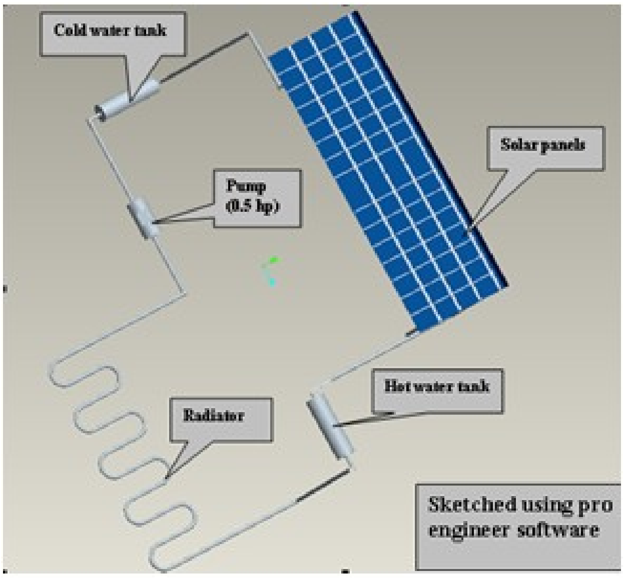


Fig. 9. Heating network

3. Discussion and Conclusion

This paper investigated the design and operation of an enclosure where the environment within is controlled in such a way that it can be isolated from the outside weather elements all year round. The novelty of the approach is that the insulation material and the solar thermal collector were developed locally at the Hashemite University and were placed in operation as a 100% biodegradable, recyclable components that are economically attractive. The dwelling under investigation can operate in complete independence of the utility grid and can provide a well-equipped shelter for remote or military applications.

The power requirements are provided by a photovoltaic solar cell that was selected based on efficiency and economy, as well as being a physical size that is augmentable with the current design.

References

[1] Thomas Friedman, "Hot, Flat, and Crowded: Why We Need a Green Revolution", Farrar, Straus and Giroux, New York, 2008.

[2] Abdul Hai Alami, "Experiments on Olive Husk-Addition to Masonry Clay Bricks on their Mechanical Properties, and their Application and Manufacturability as an Insulating Material", Advanced Materials Research (Volumes 83 - 86), pp 874-880

[3] http://www.climatetemp.info/jordan/

[4] Abdul Hai Alami, "Experiments on solar absorption using a greenhouse-effect gas in a thermal solar collector", Journal of Renewable and Sustainable Energy, American Institute of Physics, Vol 2, Issue 5, 2010

[5] Issa Etier, A. Tarabsheh and M. Ababneh, "Investigation of Solar Energy in the Hashemite University", International Conference and Exhibition on Green Energy & Sustainability for Arid Regions & Mediterranean Countries, Amman, Jordan 2009

[6] www.ecosupplies.eu

[7] www.solarbuzz.com/Moduleprices.htm

[8] [8] Abdul Alami, "Experiments on Aluminum-Copper Alloys Properties as Solar Absorbers", Jordan Journal of Mechanical and Industrial Engineering, Volume 4, December 2010.