1106

An Energy Efficient House for Under $3,000

J. Strueber, V. Harris, E. Meyer, E. Carter, E. Maweza, M. Matshaya

Tuskegee University/Tuskegee University/University of Fort Hare/
Tuskegee University/University of Fort Hare/University of Fort Hare

Introduction

This paper describes the design and materials development for building small energy efficient housing for the rural areas of the Eastern Cape Province of South Africa, which is experiencing an extreme shortage of suitable housing. This is a student exchange project between Tuskegee University and the University of Fort Hare, Republic of South Africa. With students and faculty visiting both campuses researching materials developing the design and finally assisting in building the demonstration house in Alice. Even though the housing being developed is of modest size the prototype with very little modification could be used for migrant and other seasonal farm worker housing in the United States, and larger versions could be developed for rural low cost housing.

During 2003 Tuskegee University and the University of Fort Hare were awarded a USAID, ALO student exchange partnering grant to provide training in building low cost energy efficient housing to produce healthier living conditions in the rural areas of South Africa, which are suffering a severe shortage of affordable, clean, warm and durable housing. It has been demonstrated that not having clean and vermin-proof housing, as well as safe water are the major contributing factors to the very short life expectancy in developing countries. Typically a 50% or greater increase in life expectancy can be gained through providing clean, warm and vermin-proof housing and water. The intent of the grant is to develop a program, utilizing the approximately $3,000 South African Government housing subsidy, to develop a viable grass roots industry in small scale building and community based manufacturing in depressed rural communities, while concurrently providing appropriate affordable comfortable housing.

This project has several phases, the first of which is to build on the base of existing construction methods and materials and develop building uses for currently unused and underutilized materi-

als *(such as, but not limited to, using coal ash to build lightweight insulated building blocks and more effective and durable application of the indigenous mud construction)* and to design a small energy efficient house that is both acceptable to and usable by the intended user, *(this paper)*. The second phase is to develop and demonstrate the use of transferable skills *(small scale building and community based manufacturing)* to build appropriate affordable and durable housing. The material development in this project should provide affordable advancement for those who might have a chance to improve their substandard and unhealthy housing, while at the same time is acceptable to prospective tenants through simplicity and functionality of design.. *(In this context, an unhealthy-house is a house that is very difficult keep clean and vermin-proof with lack of reasonable temperature moderation, or with unpolluted inside air, water and appropriate sewage disposal).*

BACKGROUND

The Republic of South Africa, located on the extreme southern tip of the African Continent with a diverse and dramatic landscape, which ranges from a mostly semi-arid highlands to subtropical costal areas. The country has a relativity mild climate in the project area East London where the summer temperatures are12-34C (54-93F) and winter 4-24C (38-76F).[i] The population is 42 million, 52% are women and 50% of the population lives in rural area, blacks at 77% are the majority, whites 11%, coloureds 9%, Asians and others makeup the rest.[ii] Even though the country has a literacy rate of 80% some 11.2 million women and 9.8 million men have little or no formal education to the secondary school level. The major languages spoken are English, Afrikaans, Zulu and other tribal languages with most educated persons fluent in two or more. The major religions are Christian 60%, Hindu 20%, and Muslim 20%.[iii]

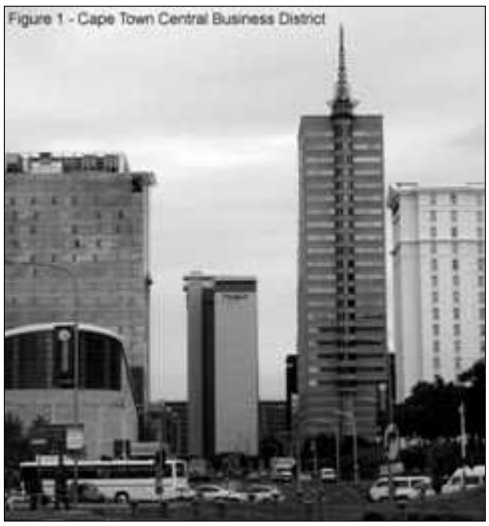


Figure 1 - Cape Town Central Business District

"South Africa is the primary hub of Africa with the region's best transportation linkages, banking facilities, health facilities, communications infrastructure and trained personnel. It has one of Africa's most extensive manufacturing sectors, which includes motor manufactures, food processing, and production of textiles, cement, metal products, paper, and chemicals. Minerals, such as gold, diamonds, and processed aluminum, and various cash crops are South Africa's largest foreign exchange earners with tourism fast catching up as a major income earner. Although South Africa has one of the

most vibrant economies in Africa, unemployment and underemployment are serious problems. Some 63% of all South Africans earn less than R1500 *(US$200)* per month with 45% earning less than R500 *(US$70)* per month."[iv] See Figure One.

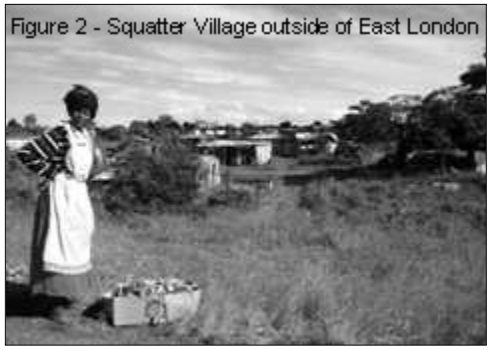


Figure 2 - Squatter Village outside of East London

During apartheid, the blacks the major sector of the population was kept out of the viable economy, provided with little schooling and were not allowed to own land or housing until 1994. Typically in the urban areas the majority in this sector lived in hostels (barrack type worker housing) or in informal towns, which sometimes had one or more water taps for thousands of residents. See Figure 2. Some lived in the black townships; Soweto, basically a suburb of Johannesburg, being the most famous has somewhat more substantial housing. Nelson Mandela's Soweto home, which appeared to be a rather typical Soweto home was a small brick house of about 50sm (525sf).


Figure 3 - An early RDP Housing Project Outside of East London


Figure 4 - Interior RTP House in Bisho

One of the new ANC government's more important promises to the people is to build one million new homes under the Reconstruction and Development Program (RDP). In 2002, South Africa was facing a 2.2 million unit shortfall in low income housing[v]. The RDP houses are built by private industry using a government grant of about R16,000 (US$2,300)—not very much money to build a house and to buy and develop the site including the streets and utilities. Not surprisingly these entry level houses are very small and unfinished by US standards typically 30-35sm (310-370sf), smaller than a double small car garage. The houses typically have two rooms with minimal plumbing—a toilet, a sink, maybe a shower—with no heat or hot water (the climate varies, however, in most locations the houses need some form of home heating.) The houses are built out of 8"x8"16" cinder block with a shed tin roof without energy or sound insulation, and only two or three windows and a single door. The typical government house does not have heat, any insulation nor is any thought given to free heating through pas-


Figure 5 - Room Heater burns coal

sive solar techniques and orientation. Heating when affordable is achieved by burning coal in an open bucket filled with sand. See Figures 3-6.


Figure 6 - Typical Construction - 60 Meter House

About 500,000 houses have been built and are mostly in urban areas. As would be expected with any major program there are good and bad housing projects. In the better ones one can see housing being well taken care of, with improvements and enlargements being made to the original house. RDP houses meet minimum standards; however, most significantly they come with tenureship, and are a quantum improvement over a squatter shacks constructed out of discarded materials.

To qualify for the housing grant, now about R21,000, the house has to be the applicant's first house and the applicant's family needs to have an income between R800-2,500 (US$100-300) per month. The applicant can add other resources to the grant to build a more substantial house. It is beyond the scope of this program to provide housing for those below this base income. Also, experience has shown that since there is a cost for maintaining a house; to provide a house that the owner cannot afford to maintain which then deteriorates to becoming unusable is a waste of the limited resources and is not economically viable for the country. An example of how limited the resources are for some families is the experience of providing household water taps; since 1994, of the three million low income households which had water taps installed, 90% have been cut off because the family could not afford to pay the water bill.[vi]

STUDY AREA HOUSING


Figure 7 - Traditional Housing Near Alice.

The study area is in the Cape Province of South Africa near the town of East London. Traditionally in this region, variations of adobe construction have been used, which, ranges from mud brick construction to building a frame out of branches and infilling with straw and mud with thatch roofs see Figures 7 & 8. The traditional houses are loosely arranged small round structures with minimal openings and a separate building being built for each use rather than connected rooms. The newer structures are mostly small rectangle buildings similar to RDP housing built out of either concrete blocks or mud bricks with corrugated zinc roofing. A small number of octagonal block houses that mimic the traditional house are seen in the villages. Corrugated zinc is the preferred roofing even on the

traditional round structures and it appears that the preferred housing type is a variation of the brick houses built by the Europeans.


Figure 8 - Building Showing a Traditional Form of Adobe Construction

The Eastern Cape Province has an active housing program and is building 40sm versions of the RDP houses. There are various housing developments in the province. The most interesting are "housing associations or cooperates" that are adding to the government subsidy to build larger improved housing, see figures 9 - 11. These associations develop the land; put in streets, utilities and build the houses for their members. Since the intended clients do not have a credit history (typical for most black and colored citizens as a result of apartheid) and cannot obtain a standard mortgage, the houses are typically rented to the client for four years for the same rate as a purchase mortgage would be. After four years the client has a record of payments—that is the same as a mortgage plus utilities would be—to present to the building society to show that they can handle a mortgage. The association then uses the mortgage payout to construct additional housing. In the suburban areas the housing types are simple two-three bedroom, one bath single family houses and in the urban areas town houses and condos are typical. Fifty to sixty-five square meters seems to be the going unit size for these projects.


Figure 9 - A New Housing Development - 60 Meter Houses


Figure 10 - Housing Association Condos - 45-60 Meter Units


Figure 11 - Living Room of House Shown In Figure 9

HOUSING TO IMPROVE SUBSTANDARD AND UNHEALTHY RURAL HOUSING

Since half of the population lives in rural areas and most of the subsidized housing is in the urban areas; this project was conceived to develop a small energy efficient house for the rural and the rural edges of the urbanizing areas. Goals for the house prototype are:

- the house has to be both acceptable to and usable by the intended user,
- needs to make the most use of the small amount of money available,

- use passive solar heating to eliminate the unhealthy indoor environment by the burning of coal in un-vented open containers in the house for heating,
- be built using an modernized version of traditional building techniques and materials,
- minimizes the amount of material needed to be purchased outside of the immediate community-this is to use the government housing subsidy to provide economic development to the community and
- provides local community employment in making the materials and construction of the housing.

This is a lot to ask for and currently the material is being researched and being developed and a 40sm (420sf) three bedroom house design, will be presented to the proposed clients for their input.

THE MATERIALS

Figure 12 - Current Mud Brick Construction

Figure 13 - Making Mud Bricks

It appears from previous research that an air dried stabilized enriched mud brick with straw is the best choice. A non-stabilized mud brick has several problems the major ones are the absorption of moisture leading to eventual failure if not corrected and erosion from rain. The addition of a stabilizer to the mud mixture minimizes these problems and strengthens the brick. The choice between using asphalt emulsion, cement, or fly ash to stabilize the brick is largely a choice of economics—the cost of the material in the specific location. It appears that in the project location asphalt emulsion is the best choice. The amount added depends on the soil used.

There are typically three methods of making the brick. They are:

- a pressed brick using a lever operated simple machine to compress rather dry materials together makes the best brick
- a hand molded brick using materials with a higher moisture content than needed for pressed bricks, and
- a puddled brick, the slowest drying with the most shrinkage and cracking this process typically produces the lowest quality brick.

The pressed brick is the best brick, however because it requires a simple but specialized machine to make the brick it adds to the startup expense, complicates the process and restricts the process. It's the experience of the authors that in rural developing countries when a machine from a distant place breaks down for various reasons it is typically never repaired. The molded, or hand pressed brick seems to offer the most advantages. It is strong enough and dries almost as fast as a pressed brick and most important, it requires only simple hand tools a shovel and hands to mix the materials, simple wooden molds and a wooden tamper to press the mud tight.

The soils can be field tested for suitability in making mud bricks by simple testing techniques; the feeling between the fingers of a wet soil sample for slipperiness—the more slippery the higher the clay content; balling up a small moist sample to see if it holds together, the higher the clay content the better it balls; and a settlement test by shaking a sample of the soil in a clear jar and letting it settle the layers show the amount by volume of the various materials in the sample. Typically the clay content needs to be between 30-70% to make suitable bricks. The higher the clay content the more straw added to control shrinkage.

The rest of the structure will use standard easily available components -low cost single plane window units and door units and the ever present corrugated zinc roofing. However some form of roof insulation would assist in controlling the temperatures in all seasons and will be installed. It is intended to use a borax treated straw in the first house for the roof insulation. The borax is to control insects. Thatch roofs were the traditional roof and are still seen; for climate and sound control thatch is better than the non-insulated tin roof.

Field checks in the area show that there are some problems with structural integrally of existing mud brick houses. The problems most prevalent seem to be cracking and failure at the corners and openings and the ever present erosion from rain. For stability mud bricks should be isolated from the soil and placed on a stable foundation. The footings for the structure are the one place where short cuts cannot be taken. We suspect that a reasonable number of the observed cracking failures are due to failing or missing foundations. The prototype houses will be placed on a concrete foundation which extends above the final ground level by at least 6". Two major ways are used to control rain erosion the best is keeping rain off the structure though roof overhangs and adding a stabilizer in this case asphalt emulsion to the mud brick lessens the rain erosion. Both methods are being used.

ENERGY-HEATING AND COOLING THE STRUCTURE

Mud bricks have almost no insulating properties; the addition of straw perhaps helps a little. Mud bricks best feature is that they moderate the temperature due to wall mass. Heat transfers through the wall at about 2.5cm (1") per hour[vii] so high mass walls tend to even out the temperature changes during the temperature cycles of day and night and serve as a heat storage system. If properly designed they can store the sun energy and radiate it back out at night. Because of the particular social, economic, and climate conditions the normal heavily insulated passive solar house with large windows that allows the sun to heat up a massive floor system which then radiates warmth to the interior is not possible. In this particular house, the windows are smaller the walls are non-insulated and because of the small size and furniture not much floor area will be exposed to direct sunlight. To overcome this limitation, the north wall will be carefully aligned for most solar exposure, the north, east, and west walls will be painted a dark color to assist in solar gain and the thickness will be such as to store and transfer as much warmth to the inside as possible. The north side windows are placed to expose as much of the concrete floor to the north sun as possible without interference from the furniture. For the warm seasons the north wall will be shaded by the roof overhang and other shading devices and operable openings are placed for maximum air flow.

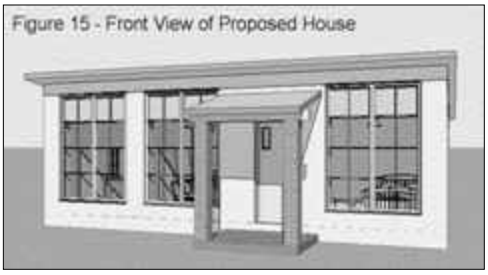
THE HOUSE

The use of the passive solar design of the house and the use of a modified traditional material for construction are the major factors that separates the housing in this project from other housing projects in South Africa. Most projects use block or brick construction. However, currently AusAID (the Australian Agency for International Development) is sponsoring a Self-Help Housing mud brick project in Durban[viii]. These mud brick building techniques are quite similar.

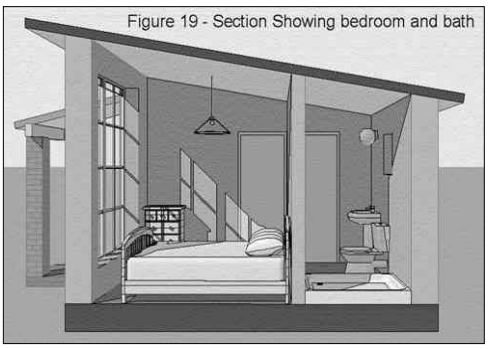

Figure 14 - Improved Unvented Coal Room Heater

In South Africa there is almost no effective passively heated and cooled housing for the low income sector and what we have seen the current attempts are not really successful. In the low cost housing subsidy, there is no budget to provide for properly vented heating stoves; the normal way for the poor to heat their homes is by burning coal in an open unvented sand filled bucket, which is both very unhealthy and a fire hazard. An improved bucket burner has been developed; however, the improved model still produces so many harmful gases that the air quality is so toxic that researchers find it hard to understand how anyone survives the exposure. If the structure is improved to being less drafty burning coal in an unvented stove could be fatal. See Figure 14.

The house is a forty square meter (425sf) variation of the now standard 30 to 40 meter low cost house. The major differences are the changes to make it a passive solar house and a more functional arrangement of the inside. See Figures 15 - 18. The house has all the elements of an efficient, attractive, and acceptable home—it's light filled and feels spacious, while still giving privacy to the occupants, which is not normal in this housing. One of the authors built houses with a similar floor plan in a South Pacific country, which were very popular with the occupants.



The proposed house will be slightly more expensive than a standard design due to the additional glass required by the passive design. Also, there may be at first some resistance to the larger windows on security grounds (improvements potentially conflicting with custom) since traditionally the houses have a few tiny windows at most. There may also be operational problems should the occupants keep the shades closed during the day as the sun must be able to heat the floor during the daytime for the passive design to work. The proposed design is being reviewed by the perspective clients and changes will be made to adapt the house to their needs and perceptions and still make the house work.



THE BUILDING PROCESS

The building of the house has a two fold purpose; the first is to provide suitable, durable affordable housing that is easy and affordable to maintain. The second purpose and maybe the most important, is to develop and demonstrate the use of transferable usable skills in making of the building materials—stabilized mud bricks. The methods used to build a passive solar heated house would also provide economic development in rural communities

through small scale community based manufacturing and as well as the construction of solar houses.

THE COST

The low cost is achieved through the small size, the use of site produced mud bricks, minimal finishing and little paid labor. The expense for the local community are the cost of the concrete for the foundation and floors, the asphalt emulsion for the mud bricks, windows, doors plumbing fixtures, electrical items, 2x4 framing for the roof structure, the corrugated zinc for the roof and dark paint for the north facing walls. Even with the local community cost of making the bricks included the estimated cost is below the proportion of the R21,000 (US$3000) subsidy allocated to the building.

Summary

A very important feature of this house is that it gives control of the construction process to the local community and makes it possible for under financed rural communities and small groups with limited skills to make the major materials and to construct an energy efficient, comfortable, healthy dwelling. The money that would go outside of the immediate community to purchase the building components stays in the community providing jobs for those who have none. However, if it is desired to purchase the wall components-concrete blocks, and fill them for the required mass the solar aspects of the house would work just as well providing a major improvement to the existing low cost housing.

---

[i] South Africa, Encarta, www.encarta.msm./encoyclopedia_761557321/South_Africa.html
[ii] South Africa Facts and Figures, Encarta, http://Encarta.msn.com/fact_631504863/South_Africa.html
[iii] Facts and Figures, Habitat for Humanity, www.habitat.org.za/facts
[iv] About South Africa, Habitat for Humanity, www.habutat.org.za/aboutsa1.html
[v] US Department of State Fact Sheet, South Africa Housing Initiative: US Contribution, www.state.gov/g/oes/rls/fs/2002/17004pf.htm
[vi] South Africa Housing Fiasco, www.socialisterna.org/rs eng/texts/sahousfi.htm
[vii] Important Facts About Stabilized Earth, Rammed Earth Works, www.rammedearthworks,com/facts.html
[viii] The Durban Self-Help Housing Project, The Australian Agency for International Development, , Steve Burroughs www.selfhelphousing.org.za/mubbrick.html