SUSTAINABLE HOUSE FOR BOTSWANA

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ABSTRACT
Botswana's weather conditions are characterised by high insolation, with an average of 320 clear, sunny days per year. Such weather conditions considerably increase the costs of keeping building at comfortable conditions particularly due to the high cooling loads. Despite all these high solar energy, its use to produce electricity is minimal. However it appears that designing of buildings particularly residential homes do not take weather conditions into considerations.

This paper investigates effect of building construction on the cooling loads profiles for several different wall constructions including one prevalently used for single-family housing. Analysis clearly indicates advantages of modern construction with embedded insulation. Installation of both, thermal – to heat water and photovoltaic solar collectors allow the housing to be sustainable.

KEY WORDS
Energy efficiency measures in building

1. Introduction

Recent huge increase in crude oil price, together with the expected decline in production of energy from fossil fuels, mainly oil and natural gas, is expected to stimulate energy efficiency in buildings in many countries. It is also envisaged that this situation will encourage the revision of buildings codes of practice in many states, Botswana included. Codes currently used in several countries appear not to consider energy efficiency in buildings. This is particularly true in developing nations. Available evidence indicates that investments to improve energy efficiency in buildings coupled with tax incentives provided by the government often give attractive rates of return. However, a study by World Energy Efficiency Association (1999), have indicated that many profitable investment opportunities are being lost due to broad national, economic and institutional factors which restrict investments in energy efficiency. The study further noted that problem of financing appears to be the major factor causing the slow rate of progress in achieving modern standards of energy efficiency.

It is noted that in Botswana, the government is currently looking into incorporation of energy efficiency and conservation measures in building control guidelines. This is exemplified in Botswana government 5 years National Development Plan 9 (NDP 9). The policy measures mentioned in NDP 9 are energy audits, training, better standards, incentives and information campaigns. According to the policy documents, energy efficiency will focus on the residential, commercial and industrial sectors through the above-mentioned concerted efforts. Considering the need to conserve energy as well as its efficient use in buildings, it is obvious that investigation of the effect of building construction on the cooling loads profiles for several different wall constructions must be of considerable practical interest. This paper seeks to demonstrate possible means to improve energy efficiency in buildings. Residential type H 130 house in Botswana was selected as an example.

2. Description of the house

It is pertinent to mention that Botswana Housing Corporation (BHC) a government owned company provide residential accommodation for the majority of work force in cities and towns in Botswana. In order to provide accommodation for large spectrum of the work force in cities and towns, BHC design various types of residential houses, which are classified into three groups, namely, the low, medium and high cost houses. The major difference among these three types of buildings is their floor areas and finish. For example, a high cost house has a floor area of approximately 130 m^2 while the low cost house has about 60 m^2. The construction phase is carried out by private companies and follow national standards which appears to restrict investments in energy efficiency as earlier mentioned.

In the present study, a high cost residential house type H 130 was selected to facilitate the investigation. This selection was based on its relatively high-energy requirements. The house has three bedrooms, living/dining room, kitchen and an attached garage. The highest point of the roof is 5.075 m from the ground level. Roof has 22.5º pitch and is covered with concrete tiles laid on 38 by 38 soft wood purlins at 0.320 m centres. To ensure that any water leaking from the concrete tiles will not cause damage to the ceiling insulation and plasterboard a 250-micron plastic sheet is nailed between the roof timbers below the concrete roof tiles. It also provides incident solar radiation reflecting surface. In order to reduce heat transfer a 0.050 m thick fibreglass insulation blanket is spread loosely on top of the ceiling plasterboard.

The walls are constructed from double layers of bricks of 0.10 m thickness, with approximately 0.01m gaps between bricks. The gap is then filled with mortar. The walls are plastered internally and externally with approximately 0.01 m thick mortar. A water-based paint is then applied internally and externally. Floor is 0.100 m concrete slab on 0.150 m well compacted laterate and is covered with the vinyl tiles except for kitchen and bathrooms which are covered with the ceramic tiles. Windows are typical for Botswana steel frame glazed with 4 mm glass. Doors are 0.044m solid core hanged to steel frames. To have clear picture of the influence of house construction and materials used, it was decided not to include load due to house occupancy, lighting and appliances.

The authors content that the absence of some important design features required for efficient use of energy in buildings has bearing on the total energy running costs in type H 130 house as currently constructed. The challenge for engineers therefore is to show the available savings potential for the same residential house, by carrying out thermal analysis.

On the bases of the above observations, this paper present data on cooling load profiles for type H 130 house using Radiant Time Series (RTS) method. The results are compared with those obtained after incorporating some design changes like an insulation between two layers of bricks, the use of single brick walls with an insulation and gypsum board on the inside.

There was no need to include load due to inhabitants, lighting and appliances, since these factors did not change with the building construction.

3. Design details

Detailed descriptions and thermal properties of the roof – ceiling combination, current and the proposed wall and windows will be given. It should be noted that in the present investigation the current roof configuration, as well as the types of windows and doors used remind unchanged since their effect on the overall cooling load was small. The house, H 130 type has a 22.5° pitched roof, to avoid rainwater being delayed on the roof section, which may cause leaking from the roof.
The roof-ceiling arrangement together with thermal properties of all layers is presented schematically in Fig 1. All data are from the ASHRE Handbook Fundamentals (2001). The total thermal resistance R = 2.35 $m^2 \cdot K/W$, thermal capacity of the roof-ceiling α = 16.25 $W \cdot h/ m^2 \cdot K$, and the total mass per square meter ρ = 34.6 kg/m^2. Structure is similar to ASHRAE Roof #4.

#	Layer description	Layer ID	R	ρ	α
1	**Outside surface resistance**	**F01**	**0.04**	**0**	**0**
2	**Roof tile**	**F14**	**0.01**	**24.4**	**8.52**
3	**Air space resistance**	**F05**	**0.18**	**0**	**0**
4	**250μm waterproof sheeting**	**-**	**-**	**-**	**-**
5	**50 mm insulation batt**	**I02**	**1.76**	**2.2**	**0.74**
6	**Horizontal surface resistance**	**F04**	**0.15**	**0**	**0**
7	**16 mm gypsum board**	**G01**	**0.05**	**7.0**	**7.00**
8	**Inside surface resistance**	**F03**	**0.16**	**0**	**0**
	TOTAL		**2.35**	**34.6**	**16.25**

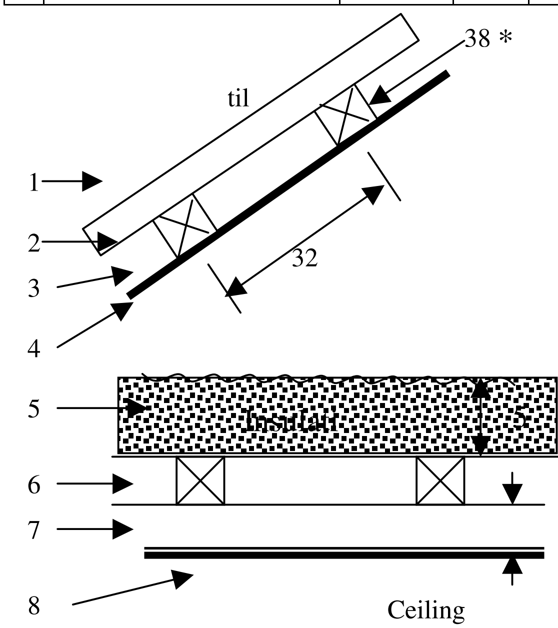

Fig1. Roof / ceiling combination for an H 130 type house in Botswana.

#	Layer description	Layer ID	R	ρ	α
1	**Outside surface resistance**	**F01**	**0.04**	**0**	**0**
2	**EIFS finish**	**F06**	**0.01**	**17.7**	**4.12**
3	**100 mm brick**	**M01**	**0.11**	**195.2**	**43.16**
4	**10 mm mortar**	**F06**	**0.01**	**17.7**	**4.12**
5	**100 mm brick**	**M01**	**0.11**	**195.2**	**43.16**
6	**EIFS finish**	**F06**	**0.01**	**17.7**	**4.12**
7	**Inside surface resistance**	**F02**	**0.12**	**0**	**0**
	TOTAL		**0.41**	**443.5**	**98.68**

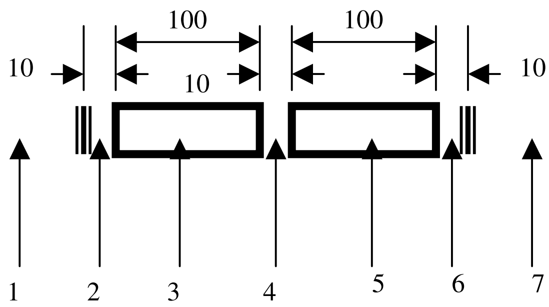

Fig 2. Cross section of a wall construction currently used in Botswana (all dimensions in mm)

Fig 2 shows the current wall arrangement, with double bricks as earlier mentioned in Section 2. The total wall thermal resistance R = 0.41 m^2·K/W, thermal capacity α = 98.68 W·h/ m^2·K and the total mass per square meter ρ = 443.5 kg/m^2. Structure is similar to ASHRAE Wall #18.

House has standard for Botswana single glass steel framed windows with the total area of 22.31 m^2 and 44 mm thick solid doors with the area of 6.61 m^2.

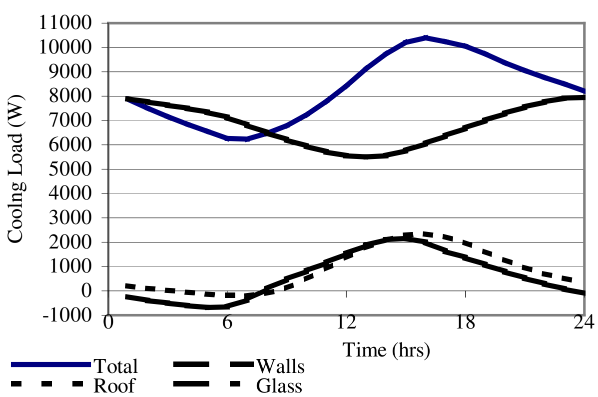

Fig 3. Cooling load for a typical wall construction in Botswana (from Fig 2.)

For the described above wall and roof construction calculations of cooling load were made using approved by ASHRAE Radiant Time Series (RTS) method. As it can be seen on Fig.3 the effect of windows and roof was relatively small comparing with walls. Therefore for further investigations only changes in the wall construction were included.

Two modifications were incorporated. First one involved spacing two layers of bricks by 90 mm and filling the space with the 89 mm batt insulation (layer I04) hanged between standard studs spaced 0.40 m apart (Fig. 4), which resulted in the increase of the overall thermal resistance to R = 2.03 m^2·K/W with the minimal changes in both, thermal capacity, and the total mass per square meter. Structure is similar to ASHRAE Wall #17.

#	Layer description	Layer ID	R	ρ	α
1	**Outside surface resistance**	**F01**	**0.04**	**0**	**0**
2	**EIFS finish**	**F06**	**0.01**	**17.7**	**4.12**
3	**100 mm brick**	**M01**	**0.11**	**195.2**	**43.16**
4	**90 mm insulation (or stud)**	**I04**	**1.63**	**7.71**	**3.22**
5	**100 mm brick**	**M01**	**0.11**	**195.2**	**43.16**
6	**EIFS finish**	**F06**	**0.01**	**17.7**	**4.12**
7	**Inside surface resistance**	**F02**	**0.12**	**0**	**0**
	TOTAL		**2.03**	**433.5**	**97.78**

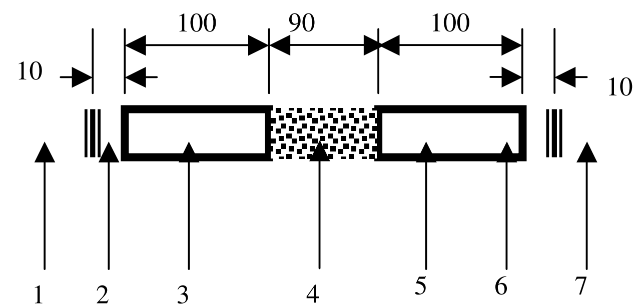

Fig 4. Cross section of a wall construction #2 with added insulation. (all dimensions in mm)

The other modification replaced internal brick and finish with the 89 mm batt insulation (layer I04) hanged between standard studs spaced 0.40 m apart covered on the inside with the 16 mm gypsum board (layer G01) (Fig. 5). This modification resulted in the change of the overall thermal resistance to R = 2.01 m^2·K/W, so pretty close to the value for the second modification. Both thermal capacity and mass per unit area were reduced to almost half of the original. Structure is similar to ASHRAE Wall #14.

#	Layer description	Layer ID	R	ρ	α
1	**Outside surface resistance**	**F01**	**0.04**	**0**	**0**
2	**EIFS finish**	**F06**	**0.01**	**17.7**	**4.12**
3	**100 mm brick**	**M01**	**0.11**	**195.2**	**43.16**
4	**90 mm insulation (or stud)**	**I04**	**1.63**	**7.71**	**3.22**
5	**16 mm gypsum board**	**G01**	**0.10**	**12.7**	**3.85**
7	**Inside surface resistance**	**F02**	**0.12**	**0**	**0**
	TOTAL		**2.01**	**233.3**	**54.35**

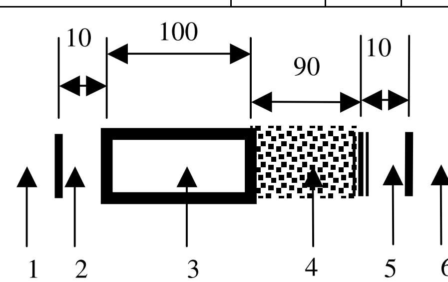

Fig 5. Cross section of a wall construction #3 without the second layer of bricks (all dimensions in mm)

Thermal analysis for the present design and the remaining two types of modifications was then carried out and the results are presented in Fig. 6 for wall construction #2 which included 90 mm insulation between bricks and on Fig. 7 for construction #3.

4. Discussions of results

The results in Fig 3 should be viewed in parallel with Figs 6 and 7 which shows the cooling load profiles for modified wall constructions. For simplicity only a sample of cooling load profiles for walls and roof are presented and discussed in this Section. First, the results in Fig 3 reveal that the wall design used in the standard construction house results in the significant cooling load. It can be seen that the maximum and minimum cooling loads only due to wall construction varies from 5,500 to 8,000 Watts respectively. The results show that the peak total (includes only structure) cooling load for type H 130 BHC house is around 10,500 Watts, and occurred around 16 hours. This value can be compared with the peak-cooling load of 6,100 Watts for wall construction #2 which incorporates 90 mm insulation between bricks (Fig. 6). Walls portion is reduced to 4,100 Watts so almost to half of the previous value. The load for the wall construction #2 varies from 0 at 6 am to 6,100 Watts at 16:00 hours. It should be noted that relatively low mean cooling load demonstrated for standard wall construction with 90 mm insulation between bricks suggest that investment opportunity for the standard construction type H 130 BHC house looks increasingly attractive.

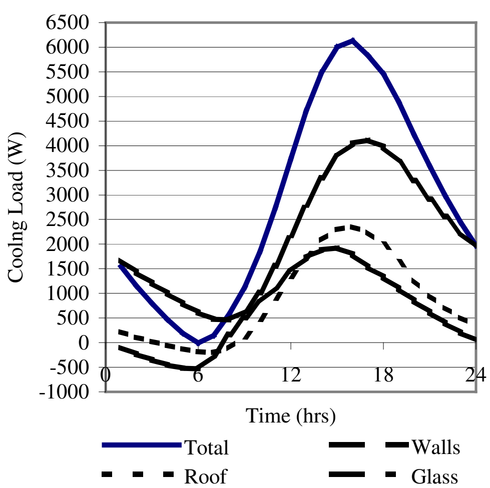

Fig 6. Cooling load for a house with the wall construction #2 (from **Fig 4.** 90 mm insulation between tow layers of bricks)

Comparing the cooling load profiles for standard wall construction in Fig 3 and for construction #3 (Fig. 7) without internal layer of bricks also visible is significant decrease in cooling load. The maximum cooling load observed in Fig 7 is close to 7,000 Watts and occurs at 16:00 hour with the minimum being 0 Watts between 4 and 7 a.m. This will result in smaller energy use and therefore the cost of operating the building. When comparing wall constructions #2 and #3, visible is slight advantage of the former and it is due to the smaller peak

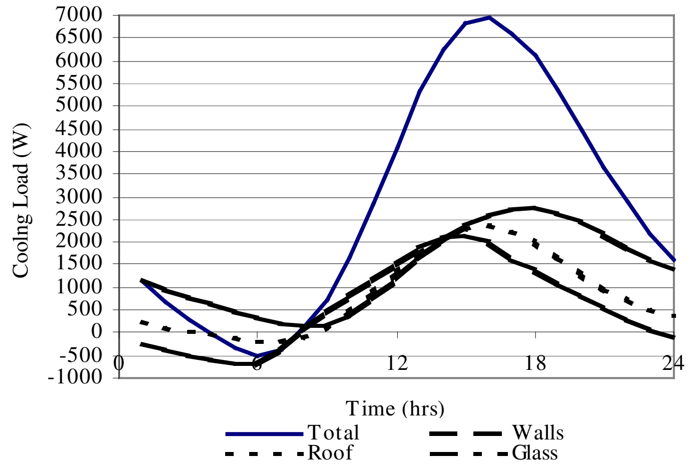

Fig 7. Cooling load for a wall construction #3 (from Fig 5 – single layer of bricks plus 90mm insulation.

Total energy consumptions for three discussed wall constructions show threefold decrease for both, construction #2 and #3 when compared with the consumption for the standard wall construction. On the bases of the above observations, the authors believe that issues related to energy efficiency in building in Botswana needs serious policy direction to ensure that building design incorporates basic design features aimed to improve energy efficiency in building with minimal costs.

The data in Fig 8 shows total daily power consumption for three wall constructions. Considering this data, it can be seen that power consumption for standard wall construction (BHC Type H 130) house would use 65% more cooling energy than construction #2 and #3.

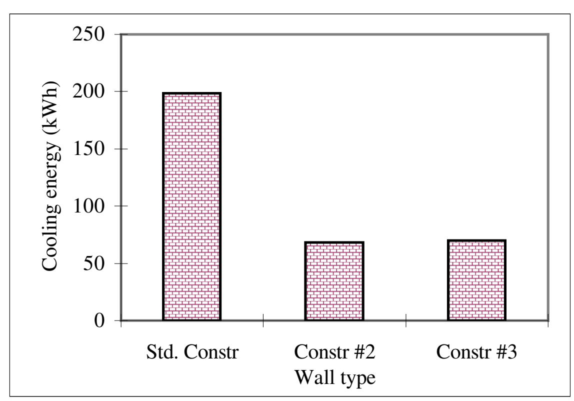

Fig 8. Total daily power consumption for three wall constructions.

It is pertinent to mention that data recorded by Botswana Technology Centre (BOTEC) on Solar Chimney indicate