TECHNICAL NOTE: IMPROVEMENTS TO THE ENERGY EFFICIENCY OF SHACKS

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Abstract

The majority of very poor people in urban areas live in shacks. These shacks give shelter to inhabitants but are energy inefficient. The owner has to spend excessive amounts on biofuel, which is not only converted into heat but also into greenhouse-forming gases. Detailed thermal efficiency studies for this kind of house are therefore important but unfortunately completely lacking in the open literature. It is the aim of this paper to investigate the influence of different thermal control mechanisms on the energy efficiency of these shacks. Different thermal options were evaluated with a thermal simulation program, QUICK, ***developed by CENT.[1] Orientation, the exterior colour, ventilation, and insulation were inter alia investigated. Of these, insulation showed the most potential. The installation of 25 mm glass wool decreases the energy consumption in winter by approximately 78%.***

Introduction

Pollution, health problems and the depletion of natural resources in the Third World can be addressed simultaneously by enhancing the energy efficiency of informal low-cost houses. In South Africa, 20% of the population currently live in informal settlements.[1] They are housed in shacks which are primarily of corrugated iron construction. This type of construction is popular because of the reusability and ease of transportation of building material, as well as fast construction time.

Although shacks provide the basic need for protection against the elements, the indoor climate and energy efficiency are unsatisfactory. Up to 25% of the poorest households' income (those with an average monthly income of less than R400 (in 1994 terms) is spent on fuel for heating and food preparation purposes.[2] The energy efficiency of corrugated iron shacks is therefore important and is investigated in this paper.

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The simulation software

The thermal analysis program QUICK[3] was used for all the simulations. All the relevant thermal interactions including ground contact, and natural ventilation are accounted for by the thermal model.[4,5] The predictions of the program were validated in more than 60 naturally ventilated buildings.[4] It is not the purpose of this paper to discuss the detail of the method as it has been described elsewhere.[6,7,8]

All the computer simulations performed for this study are based on typical conditions e.g. typical construction, the usual time of occupancy and the number of occupants, as well as the typical time when food is prepared. Field work[9] was conducted to establish these conditions (See Table 1).

Previous studies[10] have indicated an abrupt increase in energy demand when outdoor air temperatures drop to approximately 16°C and below. This finding corresponds with other studies which set the lower limit for acceptable indoor thermal environmental conditions at 16°C.[11] For this study it was therefore assumed that occupants will try to keep the indoor air temperature of their shacks above 16°C.

The energy calculations for these shacks are based on typical winter conditions in Pretoria. Pretoria is dry and sunny in winter with the temperature varying between 0.8°C and 18.7°C from sunset to sunrise. The detailed weather data[3] are given in Figure 1.

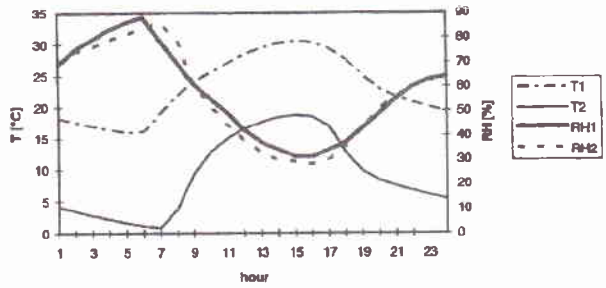


Figure 1 Temperature and relative humidity for a hot and a cold day in Pretoria

A building can be designed to have high indoor air temperatures in winter. However, it would then also be warmer in summer. The effect on the maximum summer temperature is therefore also investigated in this study.

Energy efficiency of different thermal design options

Building materials

The majority of shacks are either built from corrugated iron, wood or fibre cement or a combination of these materials. Simulations were therefore performed to determine the energy efficiency of shacks built from these materials. The thermal properties of these materials are given in Table 2.

Table 1 Typical conditions for informal houses

walls:	corrugated iron (0.8 mm)
windows:	glass (3mm):south (1.6^{2}m), west (1.6m^2)
ventilation:	6 air changes per hour
door:	mild steel (0.8mm), south
floor:	concrete (40mm, 41 m^2)
outside surface absorptance	40%
hourly temperature and relative humidity values:	Figure 1
exposed perimeter:	26 m
roof:	corrugated iron (0.8mm)
orientation	north (0°)
volume:	100 m^3
emissivity:	30%
occupants:	2 from 07:00 to 17:00 6 from 18:00 to 06:00
cooking:	17:00 to 22:00

In Figure 2 the energy consumption of buildings from the different materials is compared. Although corrugated iron is the most popular due to its durability and availability its energy performance is the worst. Improvement to the corrugated iron concept should therefore be the first to receive attention, as the potential for energy saving would be the highest. In the rest of this paper only the corrugated iron option will therefore be investigated.

Table 2 Thermal properties of materials used for informal houses

	Thermal conductivity [W/m °C]	Emissivity [%]	Absorption [%]	Thickness [mm]
corrugated iron	53	30	40	0.8
wood	0.15	30	30	10
fibre cement	0.62	90	60	6(roof) 9(walls)

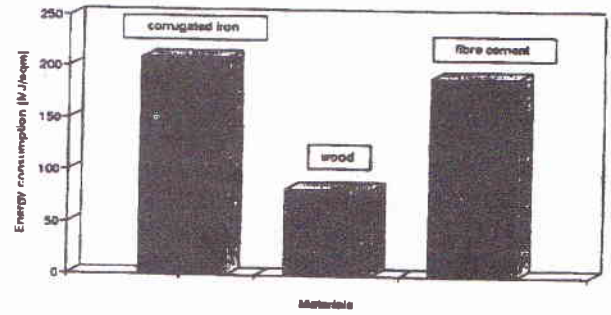


Figure 2 Energy consumption of different materials

Building orientation

The ideal orientation in winter for a house should be such that it utilizes the solar radiation energy to its full extent. This can be achieved by direct solar penetration through windows and ensuring that the largest possible portion of the building receives direct solar radiation. Obviously the ideal winter orientation is not necessarily the same as the ideal summer orientation.

Energy simulations were performed for the typical shack for different orientations. The least amount of indoor heating was required when the largest frontal area faced north. The building thus makes ample use of solar radiation during the day. Results in Table 3 show that the temperatures differ by 0.3°C and that the energy requirements for the best and worst cases differed by only 2% when the orientation of the shack is optimized. It is clear that this is not an important energy savings option.

A reason why the orientation of the shack does not influence the thermal performance significantly is that the different wall areas are all of the same magnitude.

In conclusion to this section: the small improvement in energy efficiency does not justify the need for planning

Table 3 Winter energy consumption for different orientations

	N (0°)	E (90°)	S (180°)	W (270°)
E [MJ/m^2]	203	206	205	205
T_{min} [°C]	1.5	1.5	1.5	1.5
T_{max} [°C]	35.6	35.9	35,7	36.1

low-cost building sites in very dull north/south grids.

Window position and size

The effect that size and position of the two windows has on the energy consumption and indoor temperature of the building were also investigated. Two conventional windows with areas of 1.6 m^2 each were used in the simulations. Table 4 shows that the least energy is required when the two windows are placed in the northem and eastem walls. However, the difference in energy use for different window position is small as expected. A 100% increase in the window area resulted only in a 1.5% decrease in energy consumption. Although the maximum summer temperature variation for the different options showed an acceptable variation of only 0.2°C, the amount of energy saved during the winter does not warrant the effort to optimize window design.

Table 4 The effect of window position and area on the winter energy consumption

Window position	Window area [m^2]							
North	-	1.6	-	-	1.6	1.6	-	3.2
East	-	1.6	1.6	-	-	-	1.6	3.2
South	-	-	1.6	1.6	1.6	-	-	-
West	-	-	-	1.6	-	1.6	1.6	-
Energy [MJ/m^2]	205	203	204	205	204	203	204	200
T_{min} [°C]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
T_{max} [°C]	35.5	35.6	35.5	35.6	35.6	35.7	35.7	35.6

Exterior colour

The exterior colour of a building can play an important role in its thermal performance. The influence of different exterior colours was therefore investigated. Simulations were performed for outdoor absorption coefficients ranging from 30% to 75%. Corrugated iron painted a silver colour would typically have an absorption coefficient of around 30% and corrugated iron with a dark rusty appearance an absorption coefficient of approximately 75%. Both painted surfaces were assumed to have an emissivity of 90%. (The simulation programme takes absorption, emissivity, transmittance, and reflective surfaces into account.[6,7,8])

Shacks with a darker exterior colour require less indoor heating to achieve acceptable indoor temperatures in winter. During the day the darker exterior colour absorbs more energy from the sun than the lighter colour.

Although the light weight structure has a very limited heat storing capacity, the difference in required heating between a light and a dark exterior amounted to 24%. The maximum summer temperatures for the light and dark colour were 34°C and 41°C, respectively. However, a survey[9] among inhabitants of shacks showed a preference for light colours, a silver colour being the most popular. This energy control option is thus not really viable as the inhabitants will not use it. The advantage of course is that summer temperatures are lower with a light exterior colour.

Ventilation control

A recent study showed that the natural infiltration into a 'leaky' building is in the order of 0.9 air changes per hour (ach).[12] By using a coal stove this infiltration rate can be increased dramatically. A maximum possible ventilation rate of 9.54 ach was assumed. This is based on a maximum outlet air speed of 15 m/s[13] for a 150 mm diameter chimney.

For the simulations, ventilation rates of between 0 and 9 air changes per hour were investigated for the typical shack. For this range it was found that a reduction of 28% in heating requirements is possible when the infiltration of cold outdoor air is reduced from 9 to 0 changes per hour.

Although resulting in significant energy savings, drastically limiting natural ventilation in a shack in winter is not practical. The primary energy source in these shacks is braziers and coal stoves which generate significant amounts of smoke and poisonous gases. Adequate ventilation is therefore essential for health reasons. Limiting ventilation is not recommended as an energy efficiency option.

Insulation

Thermal insulation on the walls and roof of a building increases the thermal resistance and hence decreases the energy transferred. In winter, losses through the structure, and in summer, energy gain from the outside, are reduced with the use of insulation.

The energy conservation effect of glass wool insulation was therefore investigated and is shown in Figure

3. Glass wool insulation with a thickness of 50 mm in a corrugated iron shack reduces the winter energy consumption by 81 %. If 25 mm glass wool is used the energy consumption is reduced by 78%. This amounts to approximately R400 per heating season.(Combustion efficiency 37%[14] and the cost of coal 3.2 c/MJ.[15])

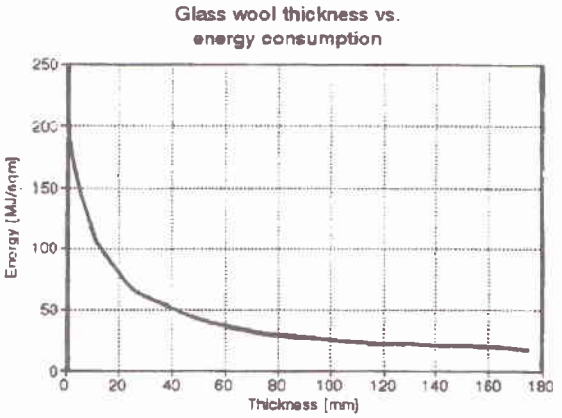


Figure 3 The energy consumption does not decrease significantly with an increase in thickness for thicknesses higher than 25 mm

Figure 3 shows that the energy efficiency effect of insulation does not increase significantly with an increase in thickness above 25 mm. (The maximum summer inside temperature for 50 mm insulation is 29°C while it is only 1°C higher for 25 mm.) It is therefore suggested that the minimum thickness available, which is 25 mm, should be used.

Summary

Figure 4 shows the potential saving for the individual factors investigated in the study, namely:

- The optimum orientation saves 2% of the energy consumption. The effort of trying to orientate the houses correctly is therefore not worthwhile.
- Exterior colour can save 24% of the energy consumption. Although significant savings can be accomplished the preference of colour stays a choice of the owner.
- If no fresh air enters the building, 28% of the energy consumption can be saved. This is however not realistic or advisable since significant amounts of smoke and poisonous gases are generated in these houses. Adequate ventilation is therefore essential for health reasons.
- If the shack is only insulated (without any of the above implemented) 78% of the energy consumption could be saved.

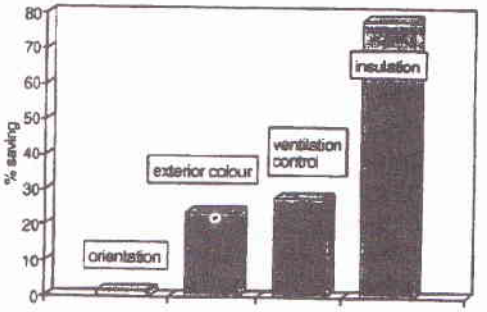


Figure 4 The effect of different improvements on the corrugated iron shack

From the above discussions it is clear that insulation is by far the most important factor influencing the energy efficiency of shacks. However, insulation has a cost implication for the shack owner. Commercial insulation materials are too expensive for this market. Future work will therefore have to concentrate on the development of inexpensive insulation material for this low-cost market.

Conclusion

The corrugated iron shack is the most common house in low-cost urban areas. This is unfortunately one of the most energy-inefficient houses in use. Improving the energy efficiency of these shacks would benefit the inhabitants as well as the environment.

The following energy saving modifications were investigated: building orientation, exterior colour, windows, ventilation control and insulation. Insulation was found to be the most effective way to improve the energy efficiency of these shacks.

This study has shown that perhaps 25 mm of insulation is an adequate thickness to use. It affords a 78% decrease in energy consumption! It is suggested that future research in this field be focused on the development of less expensive insulation materials.

Acknowledgements

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