Appropriate Technology for Housing in Sudan: Evaluation of Selected Innovative Building Materials and Technologies

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Abstract

Similar to many developing countries, Sudan is experiencing high and rapid urbanization rates. The urban population of the country, as percentage of total population, increased from 6.8% in 1950 to 40.8% in 2005 and estimated to be 74% by 2050 (UN, 2008b). Wars, conflicts, natural disasters and escaping vulnerability are among the leading forces to the rapid growth in urbanization rates in Sudan. Among many other urban agglomerations problems, the provision of adequate and affordable housing forms the greatest challenge for governments and concerned parties. Housing in the Sudan comprises, on average, of more than 47% of the individuals' income.

The National Fund for Housing and Rehabilitation (NFHR) has been established according to a presidential decision in 2008 in an attempt to solve the problems of Housing in Sudan. In search for adequate and affordable housing based on appropriate local building materials and technologies, the NFHR devoted much of it resources to address the problems of the housing sector in Sudan. Research institutes, professional associations and practitioners were invited to give their suggestions and recommendations. Some demonstration models were developed to show the appropriateness of each technology and the extent of its affordability.

The purpose of this study is to carry out a comparative analysis between some of these different technologies in terms of economical and environmental contexts to fulfill the sustainability development requirements. The level of suitability of these demonstrative models to the Sudan will be addressed and discussed.

***Keywords**: Sudan, Housing, Building Materials, Building Technology, Sustainable Development*

1 Introduction

The world's total population in 1950 was estimated at 2.5 billion, it is expected to triple by the year 2010 reaching 6.9 billion. The last few decades have brought a world that is far more urbanized with a much higher proportion living in large cities and metropolitan areas (UNCHS, 1996). The World Urban population has been estimated to be about 50% in 2010 (UN, 2008b). Between 2007 and 2050, the population living in urban areas is projected to gain 3.1 billion, passing from 3.3 billion in 2007 to 6.4 billion 2050. By midcentury the world urban population will likely be the same size as the world's total population in 2004 (UN, 2008a).

The urban population of the least developed countries (LDCs) has increased from 0.8 billion in 1975 to 2.3 billion in 2005 and expected to be 2.9 billion in 2015. The urban population of the LDCs represents more than two third of the urban population in the world.

Sudan, as one of the least developed countries (LDCs) (UNDP, 2008) , has experienced rapid urbanization rate during the last few decades. The total population of the country increased from 9.1 million in 1950 (UN, 2008b) to 39.1 million in 2008 (CBS, 2008). The urban population of the country- as percentage of total population- increased from 6.8% in 1950 to 40.8% in 2005 and estimated to be 74% by 2050. The inhabitants of Khartoum, the largest city in the country, increased from 0.9 million in 1975 (UN, 2008a) to 5.2 million in 2008 (CBS, 2008) and expected to reach 7.9 million by the year 2025. The share of the city in the total population in the country increased from 2% in 1950to 13.5% in 2008, and the city accommodates more than one fourth of the urban population of the country (UN, 2008b) & (CBS, 2008) . The city has been ranked as the 214th , 53rd , 44th among the world's urban agglomerations having 1 million inhabitants for the years 1975, 2007, and 2025 respectively (UN, 2008a).

The increase of the inhabitant of the globe and its urban population calls for more construction activities especially for housing. In developing countries, in general, the rate of construction is far below the demand for shelter, infrastructure and other amenities.

Many factors such as demographic growth, shifts from rural to urban areas, natural and human-made resource depletion, and significant changes in expectations and life styles, all combine in their various ways to erode the viability of traditional approaches to shelter provision. But many approaches to shelter provision developed over the past 50 years require capital, equipment, or skills that are inaccessible to the majority. Between the declining viability of traditional solutions and the inaccessibility of many modern alternatives, sustainable architecture defines an approach that seeks to bridge this gap (Norton, 1999).

In search for resolving the problems of housing in Sudan, the government launched in March 2008 the national project for housing and rehabilitation "Shelter for all". Under this project came the establishment of the National Fund for Housing and Rehabilitation (NFHR). The search for economically affordable materials and alternative technologies is of the concerns of the NFHR. Different materials and building technologies have been introduced to the NFHR as being convenient for housing in Sudan. These alternative materials and technologies need to be evaluated to assess their appropriateness to Sudan in terms of economical affordability, environmental impact and performance, and applicability.

The purpose of this paper is to evaluate some of these alternatives and put them into comparison. The results of this analysis will help the NFHR in the decision making regarding the most appropriate alternatives to adopt and disseminate.

2 Building materials and Sustainability in Developing Countries

There is a direct link between construction activities and human settlements development. In this context, the supply of building materials is a key factor in the construction sector's response to the needs of human settlements (UNCHS, 1986). Due to the increasing demand for construction activities, the demand for building materials and components increased accordingly. The importance of the building materials stems from the fact that it constitutes the single largest input to construction, accounting for 50 to 80 per cent of its total value (UNCHS, 1986) & (Planning Commission (India), 2002). High costs of construction in developing countries are attributed, among some other factors, to the insufficient production and limited output, low quality, and high costs of building materials beside the employment of inappropriate technologies in construction (UNCHS, 1986).

Sustainable construction can be defined as that which considers the economy and efficiency of resources or even eliminating possible negative impacts caused to the environment and its users. There are several alternative choices of constructive systems, materials, and available technologies. It is of great importance to get to know their real characteristics, their performance and possible impacts. It is through this knowledge that one opts for the best solutions and thus reaches good sustainability levels in the products of building site (Marques & Salgado, 2007).

Turin (1973) categorized the construction industry in developing countries into four levels based on the different levels of technology used, these levels are; the international modern, the national modern, the national conventionally, and the traditional. The traditional sector relies extensively on the locally-produced building materials while the international level relies on the imported materials.

The imports of building materials dominate the list of problems of building materials in developing countries. Besides, many developing countries depend, to a large extent, on imported construction skills and machinery. The reliance on imported materials is attributed to the low competitiveness of the locally-produced materials with imported materials. Insufficient production and limited output, low quality, and high costs are common characteristics of the locally produced materials in developing countries. The employment of inappropriate technologies being used in the production of building materials is responsible for the limited output and range of indigenous materials. Moreover, the limited ability of the traditional sector to make bulk purchases of inputs and limited access to capital and credits justify the small scale production of the sector (UNCHS, 1986).

Norton (1999) provided a list of criteria for the assessment of sustainable architecture. The criteria includes: the use of locally available materials and resources, socio-economic affordability, response to the local climate, durability, and potentials to be locally replicated. Therefore, the development of the locally-produced materials could have a significant impact on the building sector in developing countries. However, and for this purpose, developments in production capacity and technological capabilities are perquisites. Technological development in the production of building materials accompanies the sustainable development of construction methods and techniques.

The dependence on local capabilities has its economical impacts as stated by (Hillebrandt, 1999) that the use of simple technologies, local materials and little capital equipment is appropriate for developing countries. In Sudan, many researches were performed in search for low-cost local building materials for housing. For instance, when taking the history of earth architecture in Sudan as an example, a research was carried out in 1964 by prof. Ahmed Abdel Rahman Elagib (Adam & Alagib, 2001), his research focused on the earth, especially the rammed earth because of its easy fabrication and simplicity. Other important findings were obtained from a PhD research done in the United Kingdom by Dr. Alfadil Ali Adam. His findings were very important, because he classified the Sudan soil into groups; draw a proper map that showed his classification and the proper soil mixture that can be applicable in each part of Sudan. His findings were a base for many and also to future researches in the earth architecture in Sudan. However, these research efforts were limited, isolated, and lack coordination and collaboration between different stakeholders.

3 National Fund for Housing and Rehabilitation in Sudan (NFHR)

3.1 Background

In March 2008, the president of Sudan launched the national project for housing and rehabilitation "Shelter for all". The president adopted the provision of housing for the residents of the entire country within all the income class groups.

The main objective of the project is the implementation of comprehensive renaissance in the urban environment and achievement of sound physical planning fulfilling the best utilization of land. Besides, the project is concerned with the provision of adequate, affordable, and comfortable housing for the middle and low income population. For the purpose of achieving the goals of the project, the National Fund for Housing and Rehabilitation was established. The main objectives of the NFHR are to:

- Contribute to the process of urban planning and the setting of strategies through the cooperation with other authorities at the national and states levels.
- Coordinate and cooperate with funds for housing and rehabilitation on the states levels.
- Contribute in obtaining loans and grants in the area of the Fund's work.
- Encourage financing for housing and rehabilitation on national and states levels.
- Contribute to the development of building research and the application of local materials in construction and building.
- Reduce the construction costs through refunding of taxes and duties imposed on cement and iron.

A committee, headed by the Minister of Finance and National Economy, is formed to manage the Fund, run its affairs, and exercise the powers which enable it to achieve its goals. The Secretary-General of the NFHR is the chief executive officer of the fund, and responsible for running the financial and administrative affairs of the fund beside the implementation of policies decided by the directors of the fund.

3.2 NFHR Projects: A Search for Alternative Building Materials and Technologies

The correct choice of the materials to be used in construction has to happen in a conscious way, considering the distance of its production, its thermal and acoustic performance, its cost, the operation and maintenance easiness. (Marques & Salgado, 2007). Technologies that are appropriate at a national level must also be segregated from those that are appropriate for local consumption. This would distinguish technologies that need to go into macro-industrial production from those suited to micro-enterprise. Appropriate technologies are those that respond to the local environment, resources and economic needs. The development of new materials and technologies needs also to take into account the fact that the majority of the population is poor with very limited investment capacity (du Plessis, 2002).

As part of its objectives to reduce construction costs for housing, the NFHR invited contractors, building materials suppliers, and building technologies providers to build demo houses in the green valley in Khartoum. A couple of different materials and technologies had been presented (table 1). The objective of these demo houses was to help the NFHR adopting a list of alternative materials and technologies which proof to be affordable and adequate for the housing of middle and low income population. The engineers at the NFHR performed the economical comparison between these alternative technologies. The methodology followed in the economical analysis was based on cost information provided by different contractors. The alternative materials and technologies introduced to the NFHR focused on four components of the house building. These components are: walls, roofs, floors, and doors and windows. The subject study will focus on the materials and technologies employed in the walls and roofing since they represent the highest share in the construction cost beside their significance in terms of environmental performance.

Table (1): List of alternative building materials and technologies introduced to the NFHR

Walls	**Roofs**	**Floors**
Red Brick	Concrete (Conventional)	Plain Concrete
Cement Blocks	Pre-Cast Concrete	Cement Tiles
Stabilized Soil Blocks	Jack Arch	Ceramic Tiles
Hollow Red Blocks	Sandwich Panel	
Stone Blocks	Steel Sheet Roofing	**Doors &Windows**
3D Panel	Onduline	Locally Manufactured Steel Ds & Ws
Light Concrete	Corrugated Iron Sheets	Imported Steel Ds & Ws
	PVC Roofing	

4 Evaluation of the Thermal Performance of Selected Building Materials for Housing

Referring to the Köppen climate classification and according to the geographical location of Sudan (between latitudes 3.5°N south and 22°N north) Sudan is classified as an arid hot and dry climate. In Sudan, given its climate characteristics, blocking solar radiation and minimizing solar gains are among the main design criteria to be met for a totally environmental-building. Therefore, from an environmental point of view and energy uses, avoiding heat gains is preferable. Walls and roofs are the important elements of the building envelope that are directly affected by the solar radiation, which is responsible of a big amount of heat gains in buildings. The minimization of heat gains can be obtained through the selecting of appropriate materials for each element of the building envelope. While the maximum amount of heat gains is attributed to the building skin which consists of the materials. Therefore, focusing on building materials selection is of a great importance and should be put into consideration from the early stages of the design process. According to Moon (2007), there are efforts to create buildings that do not require external energy to heat, cool, or power them. Thus materials with low embodied and operating energy are considered environment-friendly and meet the sustainable construction criteria.

The following analysis focuses on the effect of using different materials used in walls and roofs on the internal environment of the building in term of thermal performance. For the wall materials, the most common materials used in buildings are selected. While for the roofing materials, the cost is also considered in the selection by including, into the analysis, the materials that have the highest and lowest costs. The selection of alternative materials is based on cost comparative analysis results carried by the engineers at the NFHR. The analysis results are shown in table (2):

Table (2): Cost comparison and ranking of alternative building materials and technologies for walls and roofs introduced to the NFHR

Walls	**Cost in SDG (Ranking)**	**Roofs**	**Cost in SDG (Ranking)**
Red Brick	16,170 (5)	Concrete	9,590 (8)
Cement Blocks	15,545 (4)	Pre-Cast Concrete	6,440(6)
Stabilized Soil Blocks (SSBs)	17,295 (6)	Jack Arch	7,700 (7)
Hollow Red Blocks	14,445 (2)	Sandwich Panel	6,300 (5)
Stone Blocks	15,195(3)	Steel Sheet Roofing	4,200 (3)
3D Panel	18,645 (7)	Onduline	4,900(4)
Light Concrete	11,725 (1)	Corrugated Iron Sheets (CISs)	3,850 (2)
		PVC Roofing	2,800 (1)

For the purpose of analyzing the appropriateness of the suggested building materials and technologies, sets of alternatives (materials and technologies) have been selected interchangeably. The objective of the underlying analysis is to evaluate the thermal performance of the selected alternatives and their implications on the internal environment.

One of the most effective means of reducing a building's reliance on external grid power is to reduce energy use as a whole. Increasing reliance on natural lighting and passive heating and cooling are some of the most effective ways of reducing energy consumption in a building. Heating and cooling buildings contribute to more energy usage than any other aspect of a buildings use. Consequently, the choice of building materials is one of the most important aspects that determine the performance of a building and thus its level of sustainability (Moon, 2007). This paper adopts the following criteria to compare the performance of different materials recommended to the NFHR. The criteria are based on the amount of energy that the building needs to perform well:

a) **The annual energy Loads:** The amount of annual energy that is needed to cool one square meter of the building (Wh/m^2)to be within the comfort band (18°C to 26 °C)

b) **Passive Comfort:** The total number of hours which the building enjoys in the thermal comfort level from the total number of hours of the year.

c) **Heat gains:** The amount of heat gained by the building in the hottest day in the year (20th of May).

d) **Passive breakdown of heat gains:** Amount, as percentage, of heat gains and losses attributed to different ways of heat gains and losses.

In all cases, the materials for floors, doors and windows are assumed to be similar. The selected materials for the underlying analysis include:

- **Walls:** (a) Red Brick, (b) Cement Blocks, (c) Stabilized Soil Blocks (SSBs)
- **Roof:** (a) Concrete, (b) Jack Arch, (c) Corrugated Iron Sheets (CISs), and (d) PVC

According to the materials and technologies applied, two roof shapes are considered in the analysis; flat roofs for concrete, CISs, and PVC while vaulted roof is applied for the Jack Arch. The total number of alternatives evaluated is 12. Another important aspect to consider for the corrugated iron sheets roof is the possibility of adding ceiling by employing a traditional technology for ceiling (by using timber boards). The ceiling improves the performance of the roof significantly.

The analysis is performed using the Ecotect software which belongs to Autodesk Corporation. Ecotect is a programme that analyzes buildings designs as three dimensional models (3D) to simulate how they will perform and operate. Ecotect gives architects and engineers the opportunity to study their buildings energy performance from the earliest stages of the design to see how their buildings will operate. The Ecotect software has many environmental tools which are used to analyze many environmental design principles such as thermal, solar, shading and lighting. Ecotect is one of the programmes that assist on estimating, managing, and controlling buildings energy. The analysis employs the same house plan for the analysis of the 12 alternatives. The total built area of the house is $70m^2$ consisting of two bedrooms and veranda (figure 1).

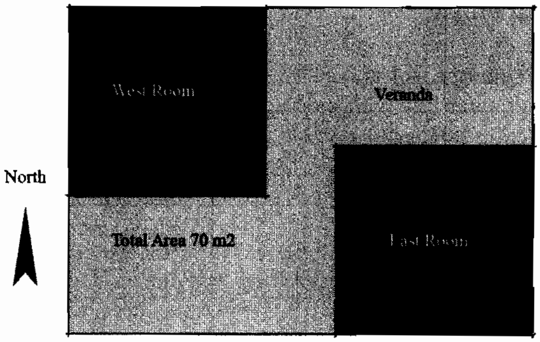

Figure (1): The house plan used in the analysis

The following table gives information regarding the properties of the materials used such as their layers, thermal conductivity, and thermal decrement.

Table (3): Properties of the materials selected for the analysis

Element	Materials	Layers	Section	U-Value W/m^2K	Thermal Decrement (0-1)
Walls	Red Brick	1.Plaster Building (Molded Dry) 2. Brick Masonry Medium 3. Plaster Building (Molded Dry)		2.64	0.70
	Cement Blocks	1.Plaster Building (Molded Dry) 2. Cement Blocks, 3.Plaster Building (Molded Dry)		3.93	0.98
	Stabilized Soil Blocks	1. Soil (Avg. Props) 2. Plaster Building (Molded Dry)		2.00	0.42
Roofs	Conerete	1.Concrete 2.Plaster Building (Molded Dry)		1.09	0.74
	Jaek Arch (Brick Roof)	1. Plaster 2. Brick 3. Iron 4. Plaster		2.98	0.63
	Corrugated Iron Sheets without ceiling	1. Zinc		5.62	0.98
	Corrugated Iron Sheets with ceiling	1. Zinc 2. Air Gap 3. Timber		2.33	0.07
	PVC	1.Polyvinylchloride		2.16	0.99

4.1 The Annual Energy

The total annual energy that is needed to control the internal environment of the building by using mechanical cooling systems to be in the comfort band, gives an indication of which materials combinations (combinations of the roof and the walls materials and also the roof shape), are the best and lead to use the minimum amount of energy to cool the house and raise its performance all over the year.

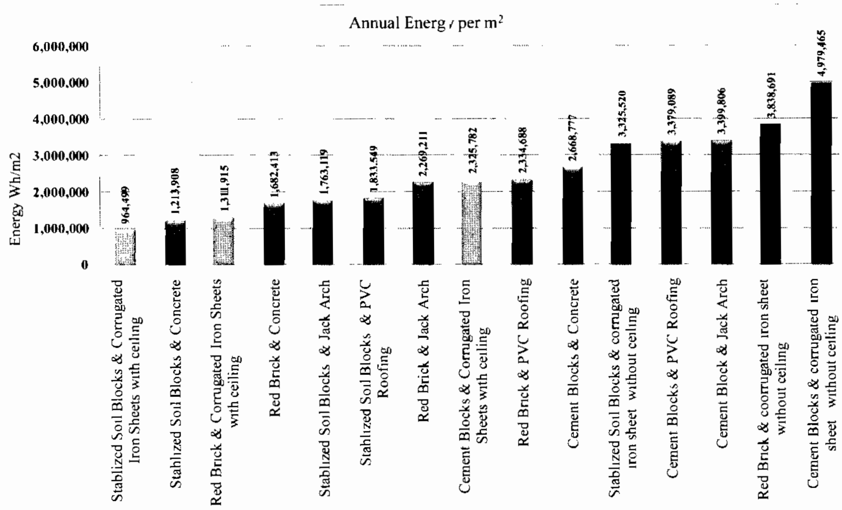

Figure (2): Annual Energy that is needed to cool the house

Figure (2), shows the amount of total energy that the house needs to be within the comfort band all over the year. The graph illustrates that the SSBs in walls, when combined with different materials for roofing, perform well. Meanwhile, cement blocks with any type of roofing system and materials need an amount of total energy more than any other combination. For roofing materials and technologies, on the other hand, the corrugated iron sheets (with a false ceiling) and concrete show the best performance. However, if the corrugated iron sheets roof is used without a false ceiling, it comes at the end of the list with all wall materials. This imply that corrugated iron sheets as roofing system can be successful and give good results if it is used with a false ceiling (yellow bars in fig 2), while if it is used without any kind of false ceiling it will be the worst type of roofing system and it will lead to use more energy in order to raise the performance and the quality of living conditions inside the house. The minimum amount of energy required is associated with using a combination of stabilized soil blocks for walls and corrugated iron sheets with a false ceiling as a roofing system. The maximum amount of energy required is accompanied with the combination of cement blocks and corrugated iron sheets without the false ceiling for walls and roof respectively (red bars in fig 2).

4.2 Passive Comfort

The total number of hours that the building enjoys in the comfort band compared to the total number of hours of the year (8760 hours in one year), gives an indication of how the building is performing passively with the environment and the amount of time that the house will be in need for mechanical cooling.

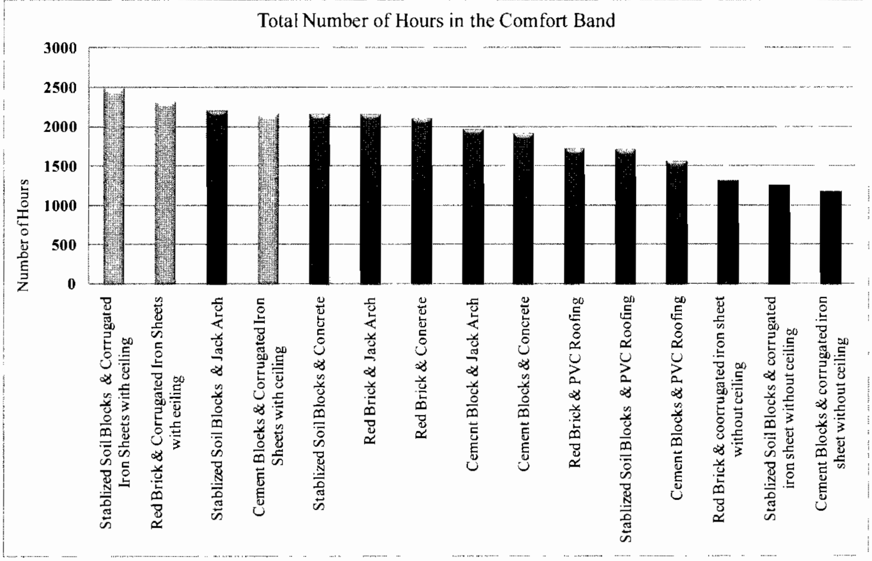

Figure (3): Total number of hours inside the comfort band from the total hours of the year for each alternative

The graph on figure (3) indicates that the building enjoys the highest amount of time in comfort band by combining stabilized soil blocks for walls and corrugated iron sheets (with a false ceiling) in the roof. The total number of hours, inside the comfort band, is estimated to be about 2500 hours, meaning that the building enjoys 28.4 % of the total number of hours all over the year in the comfort band without any mechanical cooling or heating. The minimum number of hours in the comfort band is experienced through the combination of cement blocks in the walls and corrugated iron sheets (without a false ceiling) in the roof. Similarly, the PVC roofing system, with all walls materials, falls at the end of the list with about (17-19%) of time in passive comfort.

4.3 Heat gains:

The amount of heat gains in the hottest day of the year (in May 20th) gives an indication of the performance of different material in terms of gaining heat. The graph in figure (4) shows heat gains and losses in the hottest day of the year (20th of May). Similar to the results of the analysis provided in (section 3.1), the stabilized soil blocks top the list in terms of best performance. While the cement blocks for walls tail the list. The combination of SSBs and corrugated iron sheets (with false ceiling) gives the best results in this regards, meanwhile the combination of cement blocks and jack arch gives the worse results. However, the brick, as a main material in the jack arch, tends to gain and losses heat slowly.

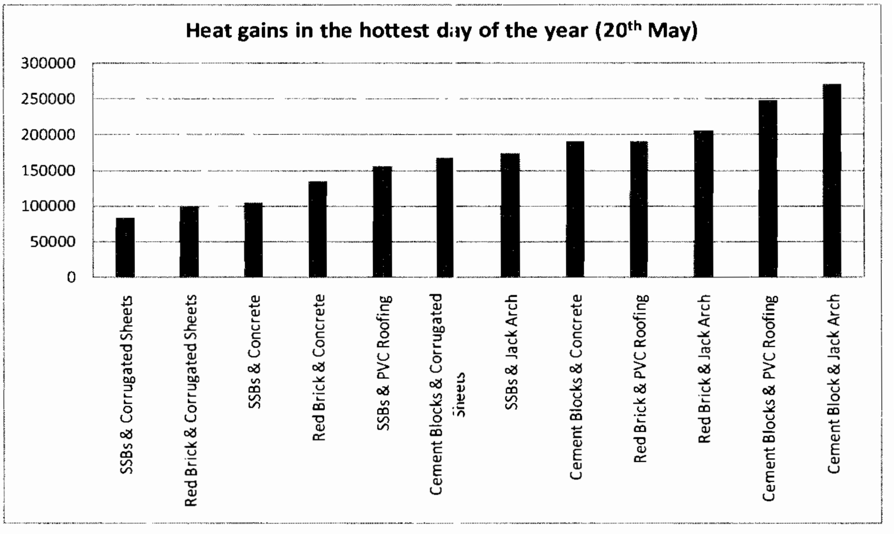

Figure (4): The amount of heat gains (wh) by different materials in the hottest day of the year for each alternative

4.4 Passive Breakdown of Heat Gains and Losses

Passive breakdown of heat gains and losses gives an indication of gains and losses attributed to different ways by which the building interact with the solar heat. The building usually gains and losses heat through its fabric (external building materials), by conduction and solair (gains due to indirect solar exposure), otherwise known as the Sol-Air temperature. These heat gains are caused by the molecular excitation within the building materials when exposed to solar radiation. The total amount of the heat gains or losses by both ways is the role of the materials of the external surface (especially walls and roof), and here comes the main role that the materials selection plays. The building also gains and losses heat by ventilation, occupancy, internal equipments that generate heat, direct solar radiation through glazed surfaces and also from the surrounding buildings. The breakdown of heat gains and losses by different combinations for walls and roofs is shown in figure (5).

Figure (5) shows that the heat gains by all parts of the house and factors (the fabric, solar, ventilation, users, lighting and equipment, and the surroundings). It shows the heat gains associated with different combinations of materials for walls and roofs where the total heat gains by the material is the summation of the heat gains by the fabric and the solair. Accordingly, the minimum amount of heat gains, (about 45%) of the total gains occurs when using the corrugated iron sheets with the false ceiling for the roof and the stabilized soil blocks for walls. Also when the same system of corrugated iron sheets is used with red bricks in walls; it gains about 56% of the total gains. The maximum amount of heat gains is obtained when red brick is used for walls and combined with corrugated iron sheets without ceiling for roofing (about 84.5% of the total gains).

The graph clears that the building, mainly and in most cases, gains heat, through its fabric and the solair. However, the heat gains attributed to ventilation is higher than that to solair when using a combination of SSBs for walls and corrugated iron sheets for roofing. Additionally, and in most cases, the heat gains attributed to the fabric are the highest except when the corrugated iron sheets and PVC are used for roofing without a false ceiling, where the maximum heat gains are attributed to the solair.

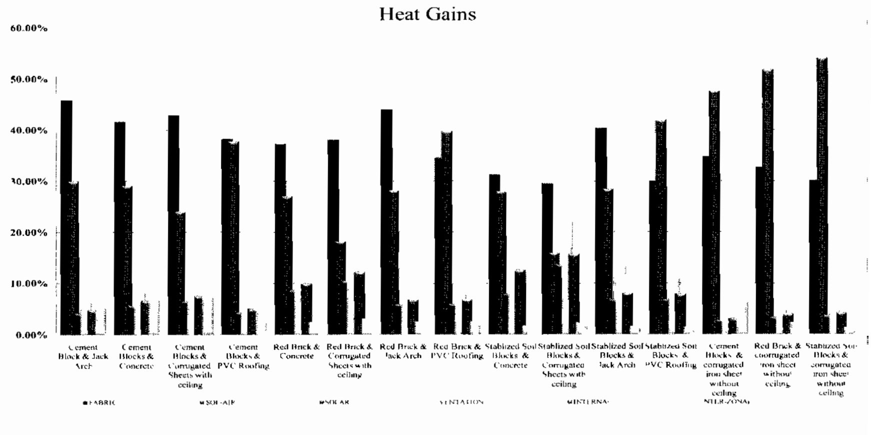

Figure (5): Passive breakdown for heat gains for different alternatives

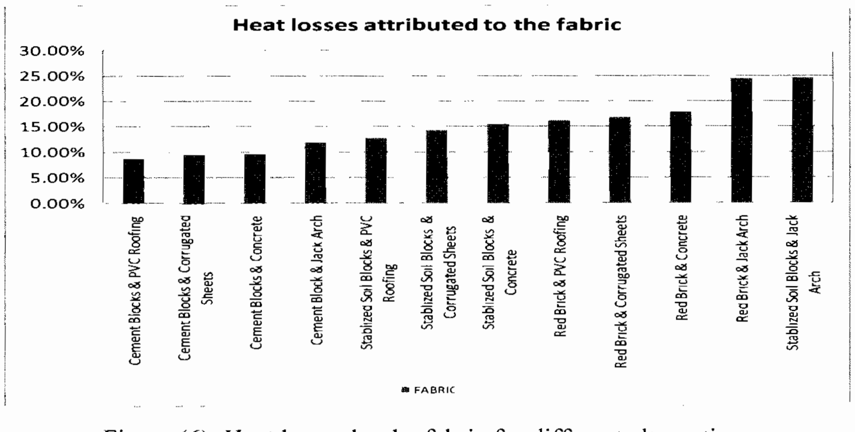

Figure (6): Heat losses by the fabric for different alternatives

Figure (6) above shows the amount of heat losses attributed to different ways through which the building gets rid of heat. In this regard, brick as a material, in all combinations for both walls and roofs, appears to be the best material in terms of loosing heat through the fabric. While the cement blocks tend to have small percentage of heat loss attributed to the fabric. In all combinations options between walls and roofing materials, most of the heat losses are attributed to the inter-zonal factor.

5 Conclusions and Recommendations

The search for adequate and sustainable housing, in general, should include, besides cost, other sustainable construction requirements such as environmental impact, thermal performance, and availability of the building materials. The selection of materials for walls and roofs, which have the highest share in the cost of housing beside their importance to the thermal performance of buildings, is crucial. The selection of materials involves manifold factors such as durability, maintenance, operation, ..etc. These factors are beyond the scope of this analysis.

The authors highlighted the performance of different combinations of selected materials in terms of annual energy required, passive comfort, heat gains, and passive breakdown of heat gains and losses. The analysis results presented in this paper conclude that corrugated iron sheets in roofing perform well with all wall materials if false ceiling is used. On the other hand, cement blocks tend to be inappropriate in terms of thermal performance. Therefore, this conclusion should be considered when selecting cement blocks for walls construction. Alternative design solutions could be presented in this regard (i.e, false ceiling). The analysis approach should be extended to all possible alternatives for walls and roofs in order to get a more comprehensive and in depth sight on the technologies introduced to the NFHR. To recapitulate, the NFHR needs to consider more factors, beside the cost, in the selection of the alternative materials or technologies to adopt. The following recommendations might help the NFHR in developing its own criteria for the selection of materials and building technologies to be employed in its schemes that meet the sustainable construction requirements:

- Establish an assessment tool to analyze the performance of different building materials i.e., Leadership in Energy & Environmental Design (LEED);
- Introduce the application of recycled materials and encourage the use of materials which are recyclable;
- Choose appropriate methods of construction in term of energy and resources efficiency;
- Establish collaborative research projects with research institutes and universities;

- Analyze the application of innovative building materials and technologies to assess their appropriateness to the Sudan and transfer these technologies whenever possible.
- Adoption and dissemination of appropriate building technologies;
- Establish workshops and training programs to share the knowledge of successful and appropriate technologies;
- Open contact channels with similar bodies abroad and nongovernmental organizations (NGOs) to benefit from their experience;
- Invite the private sector, individual architects, and contractors to participate in the NFHR schemes;
- Provide direct and indirect access to finance for the low and middle income population.

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