AFRICAN JOURNAL OF APPLIED RESEARCH (AJAR)
www.ajaronline.com Vol.2, No.2 (Pages 35-46) ISSN 2408-7920 (October 2016)

BUILDING MATERIALS AND THEIR ENERGY DEMAND: A CASE IN GHANA

[1]Gyimah, K. A., and [2]Oppong, R. A.

[1&2]Department of Architecture, College of Art and Built Environment, Kwame Nkrumah University of Science and Technology –Kumasi, Ghana
[1]kobbygyimah@hotmail.com
[2] roppongassasie.cap@knust.edu.gh

Abstract
Building design and construction have evolved from a lot of theories and styles. The first cities were created when humankind decided to take on farming on a more regular basis. To facilitate their farming, there was the need to settle down to raise permanent homes, shrines, temples and palaces. The development of these cities resulted in the birth of architecture as man needed to settle and improve their new cities. Even though energy conservation was not known until the 1950s, the early theories dwelt on the use of locally available materials. The advent of industrialization brought in its wake a lot of materials which gave birth to architectural movements, including modernism and post modernism. Currently, there is the flexibility of material taste and use in the world and the energy use of a building has become a great concern. The world seeks to reduce energy use in buildings due to the fact that energy-related CO_2 pollution is a contributory factor to climate change. This study, therefore, looks at various construction and material uses in a benchmark building for less energy demand. Autodesk simulation tool Ecotect is used as a case study in Ghana. The benchmark (hypothetical) building in Accra, Ghana is oriented to an optimum position and materials and construction methods are changed for results. The results of this study reveal that the concrete roofing tile is the most optimum for less energy use while block work with cladding is the best for walls and slab with wooden finish is the most appropriate for floor construction. However, with some modifications in construction systems, brick is the best option for wall construction in Ghana.

Keywords: *Architecture, Building materials, Methods, Energy, Climate change, Ghana.*

1.0 INTRODUCTION

1.1 Background

Architecture has advanced for over decades and different improvements over these decades are required when discussing it. Architecture can be described as unpreventable, widespread, perpetual, consistent and rudimentary because it encompasses the crudest types of settlement in caves from the ancient times to the most complex sort of modern environments. In any case, whatever the scale and unpredictability, architecture means shelter which is an essential need of every man (Glancey, 2000). Developmental stages have always been affected by the materials available to the builders. The need for building came into existence as man sought to modify the macro climate into a suitable micro climate. This made it possible for man to live everywhere on the surface of the earth (Hooda et al, 2013). However, these early structures were not durable and lasted sometimes days or weeks. Man engaged mostly in hunting and gathering and was always on the move from one place to another; thus, structures lasting for a few days suited their way of life. Caves that were man's means of abode have survived to date due to their durable nature. (Swenson and Chang, 2008).

During the Neolithic era man begun farming and settled at places for a longer time. This initiated the demand for much more durable buildings. Their farming activities and domestication also brought in the need for storage spaces in their buildings. Functionality became necessary in the spaces provided as well as construction materials to help achieve the various needs (Glancey, 2000). A typical example of a building with functionality is shown in fig.1.

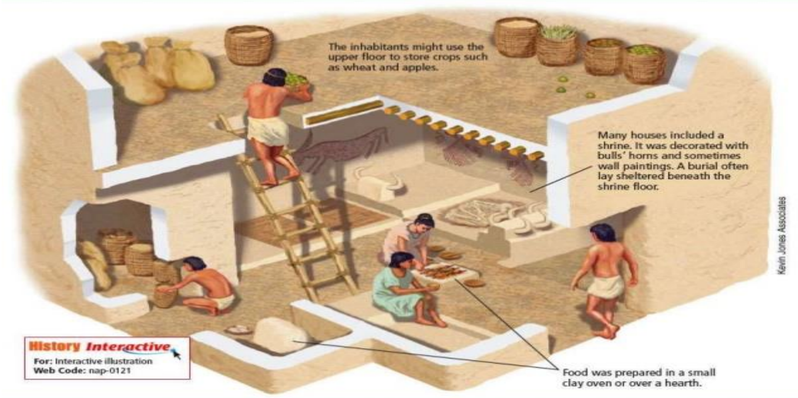

Figure 1: Typical section through a Neolithic home showing functionality
(Source: http://strawnsswha.weebly.com/week-6-nov-3-7.html)

There was a gradual development of building materials and styles to exhibit grandness and prestige during the Roman and Greek eras. This saw the introduction of aesthetics into the built environment. Figure 2 elaborates on this aesthetics and grandness.

Figure 2. Interior view of the Pantheon in Rome designed by Giovanni Paolo Panini (1691 - 1765) showing aesthetics and grandness (Source: http://www.thousandwonders.net/Pantheon+Rome)

These advancements confirm the assertions by the Roman Architect Vitruvius in his *De Architectura c.15 B.C.* Vitruvius named three qualities required of architecture as Firmitas (durability) – Neolithic durable structures, Utilitas (functional) – Functional spaces during neolithic era and Venustas (delight) – Aesthetics and grandness of the Greeks and Romans.

These developments continued until World War II which came with a lot of destruction. After the war, there was a housing boom and people saught to settle in their own homes (Stoloff, 2004). This brought about a lot of demand on oil for heating these homes. Automobile, which had also been developed at the time added to the demand for oil. With demand hike, the cost of oil also became high and thus heating cost went up. This led to the development of energy conservation techniques such as trombe wall and solar in the 1950s (Brohl, 2001).

1.2 Buildings and Energy Use

Buildings utilize nearly 40% of the world's energy, 16% of the fresh water and 25% of the wood timber, while it is in charge of just about 70% of transmitted sulphur oxides and half of the carbon dioxide (CO_2) (Santamouris, 2010). However, in Ghana, residential and industrial demand for power has for quite some time been moderately low, albeit expanding. The population in Ghana has increased throughout the years and monetary development rates have likewise increased consistently; yet, the energy supply base has not caught pace with the development. From the Volta River Authority of Ghana and other public sources, the overall installed capacity and effectual capacity of electricity in Ghana as at December 2013 remained at 2,814 and 2,492 megawatts (MW), correspondingly. A majority of this supply originates from hydro-based sources which are the Akosombo and Bui hydro dams (Acheampong and Ankrah, 2014). In 2006, the energy demand in Ghana totaled about 9,518 GWh as against energy generation of 15,418 GWh. It has been anticipated that Ghana will require more than 7 times its 2006 electricity capacity by 2020 in the event that it ought to succeed in forming its economy into a middle income one (Ofosu-Ahenkorah, 2007). This means there is the need to reduce the energy load on the national grid for sustainability. Thus the building and construction industry need to play a key role in reducing energy demand as they contribute greatly to energy use in the country.

1.3 Problem Statement

To Hooda et el, (2013), these processes of research and development are still ongoing. There is always an evolution of new materials and techniques to suit our needs. Due to this need, there has been a lot of developments and research into construction materials. *U* values which show a material's thermal conductivity are known all over the world. Li et al (2015) show that even though the standard UK wall *U* value has been used for energy certification, it is not the optimum. The study revealed a reduction in space heating demand of 16% when the standard UK wall properties were changed. These developments have also advanced into the construction of composite or complex building envelopes. Phase Change Material (PCM) is amongst the new discoveries and has the potential of reducing thermal influx into buildings, as well as improves energy efficiency (Silva et al, 2015; Han and Taylor, 2016). A composite material is a material produced using two or more constituent materials with fundamentally distinctive physical or substance properties that, when consolidated, produce a material with qualities not the same as the individual parts.

Composite structures make thickness of materials increase. Thus, even though a particular material might not be good thermally, its performance in a composite structure will be different.

For instance, a study by Nematchoua and Orosa (2016) shows that the application of marble over the surface of a wall helped to improve the indoor ambience. The introduction or development of complex materials such as PCM and composite combination of different materials as one unit brings to bear a big question; thus, how appropriate can *U* values of such materials be used to conclude on their energy demand implications? Producers of construction materials will not objectively tell that their product can cost you money on energy use to be comfortable because this will put them out of market. The study seeks to contribute to the body of knowledge of the energy efficiency of building materials in construction industry.

1.4 Aim and Objectives

The aim of this study thus is to identify some key construction systems in Ghana and investigate their impact on energy demand. The objectives to achieve the aim of this research are:

i. Assess the energy performance of some key construction systems or materials in Ghana.
ii. Modify and recommend the best construction systems or materials in Ghana for less energy demand

2.0 METHODOLOGY

This research is mainly quantitative and adopts both the experimental and case study approach. Case study approach is flexible and combines very well with other approaches (Descombe, 2007). Thus its choice makes it possible to add the experimental approach as well. The experiment is done with a benchmark (hypothetical) building as the case and within the climate of Accra, Ghana. Only one building was chosen for this study because the most optimum orientation for the climate of Accra Ghana was chosen for the benchmark building.

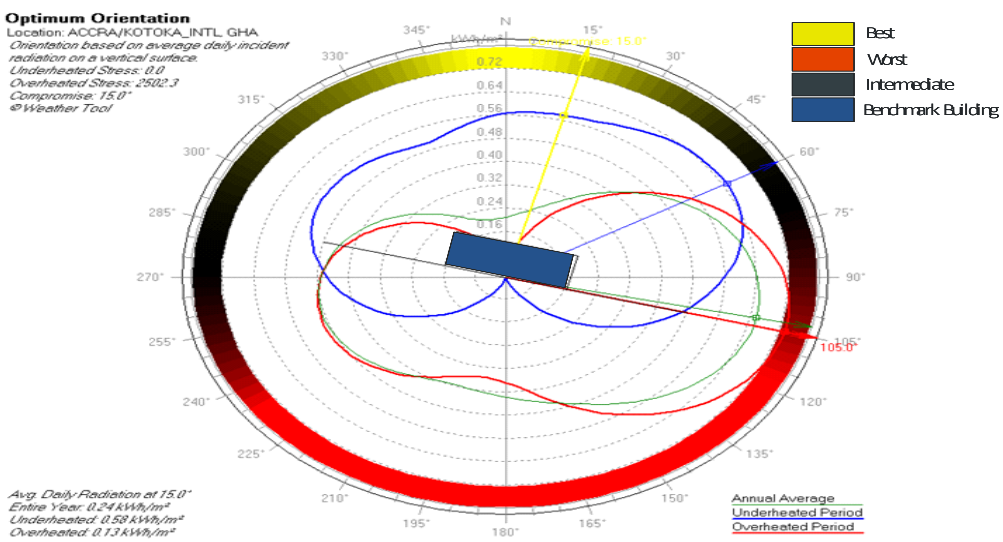

Figure 3. Optimum orientation for Accra, Ghana weather.

Optimum orientation was derived from analysis of weather data in Ecotect and this can be seen in Figure 3. This optimum orientation takes into consideration achieving the best of natural ventilation and less solar radiation into building to reduce heating in spaces. Thus any other orientation with the same building materials and opening sizes would yield worse results. Figure 3 depicts a 15^{o} compromise from the north. This means that even though some schools of thought are for a north-south orientation in the tropical regions, analysis of weather data specific to Ghana changes a little. This orientation was applied to the benchmark and then other modifications followed. To achieve aim of research, selected construction systems were composed into Autodesk Ecotect software for analysis. The results were then interpreted in terms of energy requirement for comfort in such spaces.

Building elements such as roof, wall and floor are the main variables for the study. One variable is taken and manipulated for results while the other variables remain constant. The changes applied are current construction systems existing in the country for various building elements. The results are then analysed and discussed for the best performing construction material in terms of less energy demand for comfort in the benchmark building. Table 1 below shows the various construction systems applied to the various building elements.

Table 1. Construction Systems – Authors Construct

Building Element	Benchmark Material Specification	Modification Option 1	Modification Option 2	Modification Option 3	Modification Option 4
Roof s	Gable roof with aluminium roofing sheets	Gable roof with aluzinc roofing sheets	Gable roof with concrete roofing tiles	Gable roof with stone coating on aluzinc roofing sheets	Gable roof with shingles
Walls	150mm solid block work 10mm sandcrete plaster	150mm hollow block work 10mm sandcrete plaster	150mm solid block work 5mm metal cladding	150mm solid block work With wall tiles	100mm brick work
Floors	150mm floor slab with screed only	150mm floor slab with terrazzo finish	150mm floor slab with wooden finish	150mm floor slab with tile finish	150mm floor slab with carpet finish

These materials were inputted into the building simulation software Ecotect for results. Results were exported into a Spreadsheet and graphs generated for discussions.

3.0 RESULTS AND DISCUSSION

With the study having a focus of identifying some key construction systems in Ghana and investigate their impact on energy demand, key construction systems identified can be seen in Table 1. These construction systems are not the only systems in the country but rather the most widely used in the country. Based on the methodology used varying *U*-values were realised from the various construction systems (Table 2).

Table 2: U values of the various construction systems.

Building Element	Benchmark Material U-value	Modification Option 1 U-value	Modification Option 2 U-value	Modification Option 3 U-value	Modification Option 4 U-value
Roof s	2.520	2.700	2.290	2.630	2.170
Walls	2.770	1.830	1.210	2.880	2.810
Floors	2.490	2.400	1.920	2.400	1.310

Table 2 reveals that option 4 (shingles) of roofs has the lowest *U*-value and thus the best for the climate of Ghana. Option 1 (hollow block) for the walls was the best and option 4 (floor with carpet) for the floors. These *U*-values, however, were not the only factors for the simulated results. Other material properties such as reflectivity and emissivity were considered. Table 3 gives details of the various materials and such properties.

Table 3: Other properties of the various construction systems.

Roof	Benchmark Material	Modification Option 1	Modification Option 2	Modification Option 3	Modification Option 4
Reflectivity	0.837	0.624	0.351	0.571	0.492
Emissivity	0.870	0.890	0.753	0.831	0.852
Walls	**Benchmark Material**	**Modification Option 1**	**Modification Option 2**	**Modification Option 3**	**Modification Option 4**
Reflectivity	0.549	0.679	0.735	0.801	0.590
Emissivity	0.900	0.900	0.681	0.852	0.783

The above emissivity values affected the simulation results. However, the value of the floors was not included due to the fact that they are not exposed to the external environment. Even though the *U* values presented shingles as the best material, emissivity and reflectivity differ. This is because, the higher the reflectivity, the lower the heat influx and the lower the emissivity, the lower the heat influx. Thus, the most appropriate for less energy to cool spaces is high reflectivity and low emissivity. With this argument, the benchmark material (aluminum sheets) is best in terms of reflectivity and concrete tiles, the best for emissivity. This disparity led to a total simulation of all variables to determine the best material for less energy use.

3.1 Roofing

With aluminum being the benchmark roofing material, the other roofing construction systems were applied to see the energy needed for comfort. From the generated results, only cooling loads were realised. This means the climate of Ghana does not require heating. Tabulated figures plotted into bar graphs can be seen in Figure 4.

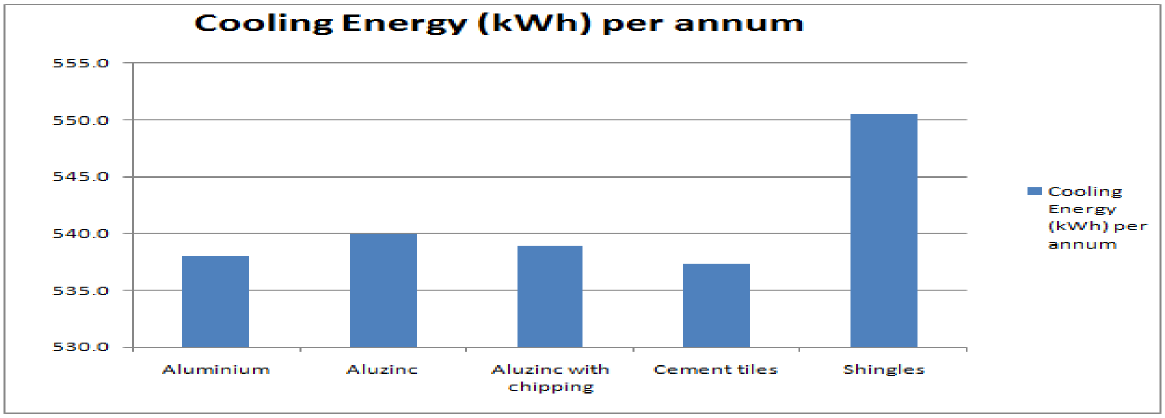

Figure 4. Cooling Energy needed for the various roofing systems.

The cooling loads show that one will need more energy for cooling with shingles than any other roofing construction system. Cement tiles had the lowest with 537.3kWh of energy per annum. Aluminum performed better than both Aluzinc and Aluzinc with chippings. But the energy needed for cooling reduced when stone chippings were added to the Aluzinc. Thus, it means shingles are not very good for a climate such as Ghana. The worst performing roofing systems in relation to energy are the most current types such as shingles, aluzinc and aluzinc with chippings.

3.2 Walls

The benchmark wall which is 150mm solid block simulated against the other construction systems and the results are shown in Figure 5. The solid block has a mixture ratio of 1:8, that is 1 part of cement to 8 parts of sand.

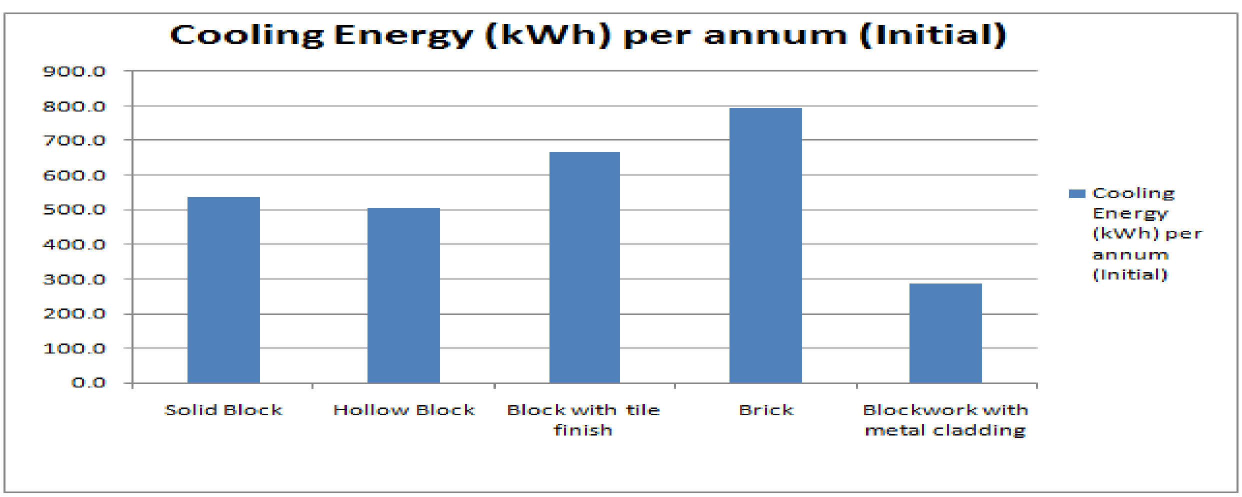

Figure 5. Cooling Energy needed for the various wall systems.

AFRICAN JOURNAL OF APPLIED RESEARCH (AJAR)
www.ajaronline.com Vol.2, No.2 (Pages 35-46) ISSN 2408-7920 (October 2016)

Figure 5 shows that solid block work with metal cladding is the best performing construction system while brick is the worst of them all. This means brick walling system of 100mm is not good for a climate such as Ghana. However, the results present a reflection of the thickness of construction systems with the thicker walls having low cooling energy required. Block work with metal cladding with a thickness of 215mm needs cooling energy of 288.4 kWh and brick with a thickness of 100mm needs 794.3 kWh. In view of this all construction systems had their total thickness increased to 215mm to tally with that of the block work with metal cladding (See Table 4).

Table 4: Wall construction systems with equal thickness

Wall Construction	Initial Thickness	New Thickness
Solid Block	Outside plastering 10mm, Block 150mm and Inside Plastering 10mm ***Total = 170mm***	Outside plastering 10mm, Block 195mm and Inside Plastering 10mm ***Total = 215mm***
Hollow Block	Outside plastering 10mm, Block 150mm and Inside Plastering 10mm ***Total = 170mm***	Outside plastering 10mm, Block 195mm and Inside Plastering 10mm ***Total = 215mm***
Block with tile finish	Tile 5mm, Block 150mm and Inside Plastering 10mm ***Total = 165mm***	Tile 5mm, Block 200mm and Inside Plastering 10mm ***Total = 215mm***
Brick	Brick 100mm and Inside Plastering 10mm ***Total = 110mm***	Brick 205mm and Inside Plastering 10mm ***Total = 215mm***
Block work with metal cladding	Metal cladding 5mm, Air Gap 50mm, Block 150mm and Inside Plastering 10mm ***Total = 215mm***	Metal cladding 5mm, Air Gap 50mm, Block 150mm and Inside Plastering 10mm ***Total = 215mm***

Table 4 details out the wall construction systems having their thicknesses increased to 215mm. The main material components were increased while the surface finish remained the same size. The simulation results can be seen in Figure 6.

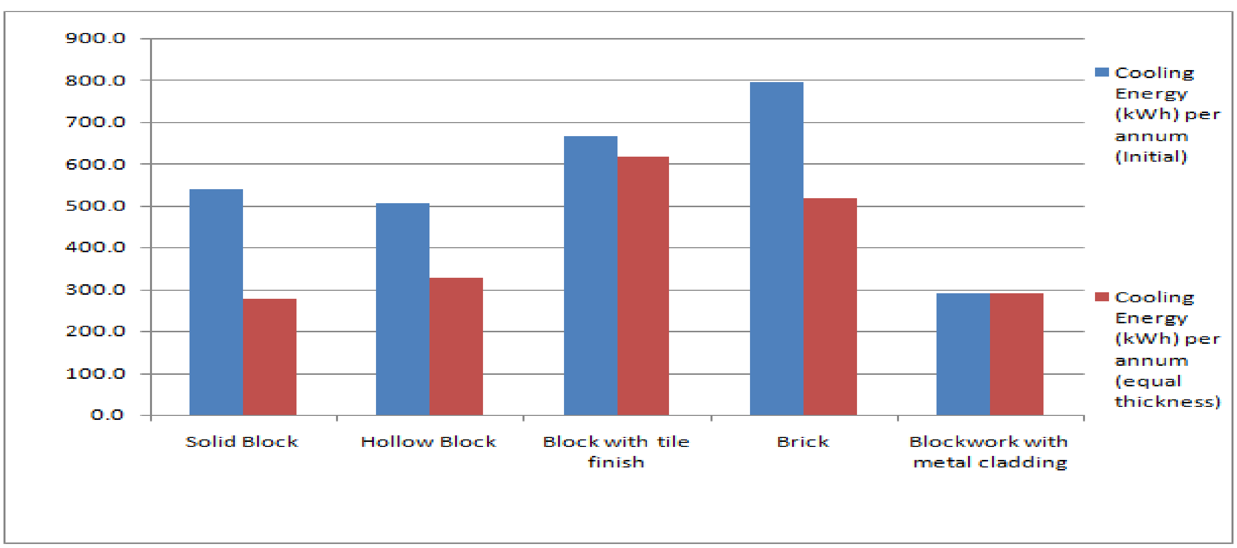

Figure 6. Cooling Energy needed for the various wall systems of equal thickness.

From Figure 6, it is observed that all systems had their energy demand reduced when the thickness is increased. However, the best construction wall system that demands less energy is the solid block work. Such block thickness is rarely used in the Ghanaian construction industry and thus needs attention. Bricks and block work with tile finish are not close to the block work with metal cladding. A further simulation was done to check if the air gaps in the block work with metal cladding construction system contribute to the performance of the wall. Air gaps were then added to the other construction wall systems and simulated for results. The wall construction system of block work with metal cladding is maintained for comparison. Air cavity was then introduced into all the wall construction systems. However, the total thickness of each wall construction system was still maintained at 215mm. Thus, the cavity thickness ranges from 45mm to 55mm. The simulated results can be seen in Figure 7.

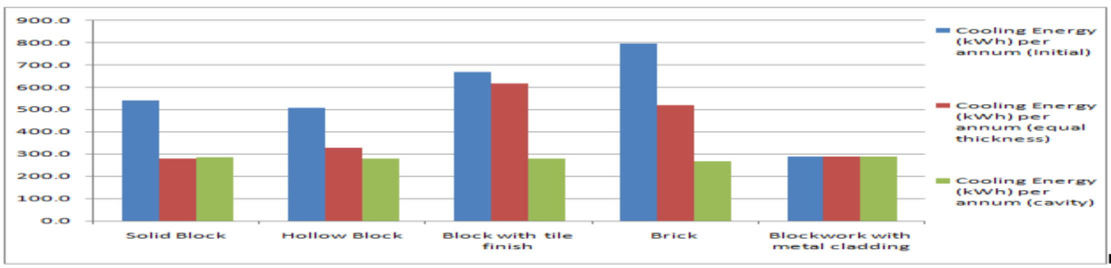

Figure 7. Cooling Energy needed for the various wall systems with cavity of equal thickness.

Though there were no changes in the block work with metal cladding because materials were not changed, all the others had significant changes. Brick recorded the highest with a decrement in cooling energy from 794.3kWh to 265.4kWh. This shows that brick performs better when used in cavity wall constructions. This explains why cavity brick construction is dominant in the temperate regions. Generally, all wall construction systems have lower cooling energy needed for the building with the exception of the solid block. Solid block with cavity when compared with its initial benchmark block had energy loads reduced but it is better when it has a mass thickness of 215mm.

3.3 Floors

The various ground floor slab construction systems as outlined in Table 1 after simulation presented the results in Figure 8.

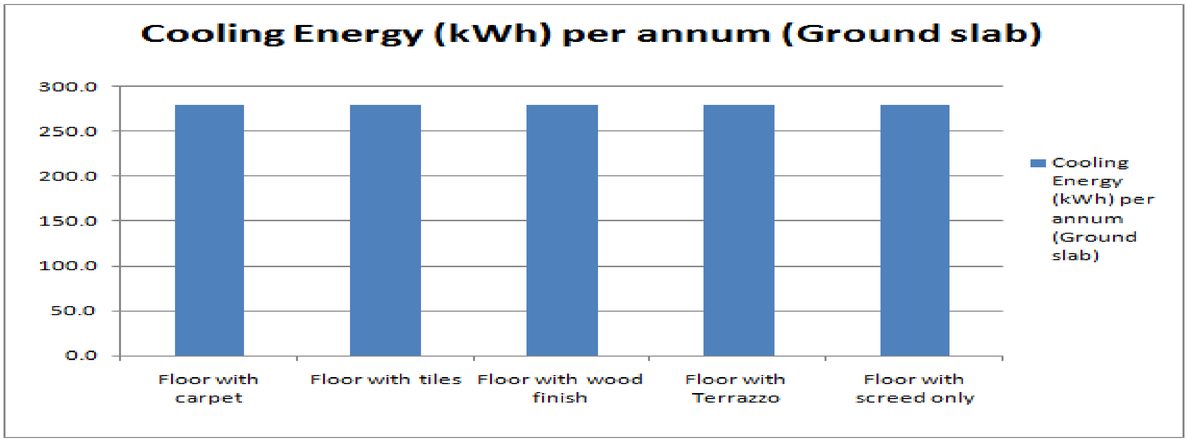

Figure 8. Cooling Energy needed for the various floor systems on ground

The cooling loads needed to cool the various floor constructions systems were found to be equal. This means that the type of floor construction system chosen for a building does not necessarily matter when it is a ground floor slab. All ground floor slabs have hard core filling of 1500mm and thus this has been considered as part of the simulation. The equivalence in cooling loads can be attributed to this thickness of both hard core filling and slab which run through all simulations. The floors above are looked from a suspended floor angle where there is no hardcore filling. The results can be seen in Figure 9.

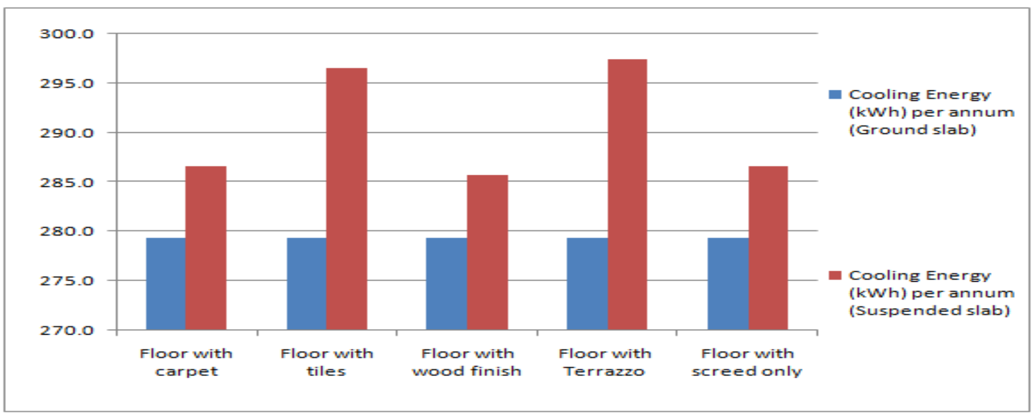

Figure 9: Cooling Energy needed for the various floor systems - suspended floors

4.0 CONCLUSIONS AND RECOMMENDATIONS.

The building fabric and construction systems keep changing and thus there is the need for continuous research and development into the best and most appropriate building material for every peculiar weather or climatic condition. In the temperate regions, producers of building materials normally provide *U* values of the materials and professionals in the industry are tempted to conclude on the materials performance based on the *U* values only. The Ghanaian market also thrives on the thickness of the construction system to market materials resistance to heat influx. However, this research has revealed that reflectivity and emissivity of the material need to be considered to know the actual energy performance of the material. Thus, there is the need to continuously analyse materials and construction systems for effective energy use in buildings.

4.1 Recommendations

Based on the simulation of materials done with the climate of Accra, Ghana, the following recommendations have been made:

- The apparent roofing material that should be used in Ghana to reduce the amount of energy needed for cooling is cement tiles. This is a plus for cement tiles and, therefore, research and development should be done to resolve any issue that discourages end users from patronising this roofing system. The traditional aluminum roofing system, on the other hand, is the next likely choice after cement tiles; it seems better than both the ordinary aluzinc and that with chippings. Thus, the challenge of this roofing system rusting can be dealt with by coating its surfaces with anti rust. Shingles seem to be the worst performing roofing system and should not be encouraged in Ghana.
- Block work with metal cladding seems superlative over all other walls with the lowest energy needed for cooling. However, further research should be done in relation to its cost. Hollow block is the next appropriate wall for construction system while brick is the worst. With thickness of 215mm, solid block, rather, is the most appropriate wall system. Thus thermal mass wall constructions should be done with solid blocks. When air gaps are introduced into the wall systems, brick cavity wall is the most suitable wall system in Ghana for less energy consumption. This study, therefore, recommends cavity brick wall construction for residential buildings and block work with metal work cladding for commercial buildings. The issue of cost can be argued here but the cost reduction in relation to energy use of the building should be duly considered. Thus Life Cycle Analysis (LCA) is needed to ascertain this.
- Ground floor slabs do not have much of an effect on the cooling energy needed for spaces. But the most appropriate floor construction system is a floor slab with wooden finish. The worst performing floor system amongst the lot is a floor slab with terrazzo finish. Thus, the usage of terrazzo finish floor slabs should be discouraged.

Even though these findings and recommendations are very viable, there is the need for a further research on LCA. Apart from cost related issues, some materials' reflectivity and emissivity can change after years of usage. This can affect their performance and, thus, there is a need for further research into these areas.

ACKNOWLEDGEMENTS

The authors appreciate the Editorial Board and Scientific Committee of the 5th Applied Research Conference in Africa (ARCA) for the opportunity given them to present this research at the 5th ARCA conference held in Pempamsie Hotel in Cape Coast, Ghana.

6.0 REFERENCES

Acheampong, T. and Ankrah, F. (2014) Ghana energy situation report: Pricing and deregulation of the energy sector in Ghana: challenges & prospects, Accessed 2nd May, 2016 at http://www.imanighana.com/wordpress/wpcontent/uploads/2014/01/Ghana_Energy_Report_2014-Imani-Report.pdf

Brohl, K. (2001) The 1950s: *Pursuing the American Dream*, BNP Media, Accessed 25th April, 2016 at http://www.achrnews.com/articles/87033-the-1950s-pursuing-the-american-dream

Denscombe, M. (2007) *The Good Research Guide for Small-Scale Social Research Projects*, England; McGraw Hill, Open University Press.

Glancey, J. (2000). The Story of Architecture. D.K. Publishing.

Han, Y. and Taylor, J. E. (2016) *Simulating the Inter-Building Effect on energy consumption from embedding phase change materials in building envelopes*, Sustainable Cities and Society,

Hooda, N., Singh, P., Singh, B., Verma, V. and Dhiman, S. (2013) *Modern Trends in Construction*, International Journal of Innovative Technology and Exploring Engineering, 3,3, pp 80-83

Li, F. G. N., Smith, A. Z. P., Biddulph, P., Hamilton, I. G., Lowe, R., Mavrogianni, A., Oikonomou, E., Raslan, R., Stamp, S., Stone, A., Summerfield, A.J., Veitch, D., Gori, V., Oreszczyn, T. (2015) *Solid-wall U-values: heat flux measurements compared with standard assumptions*, Building Research & Information, 43, 2, pp 238-252

Nematchoua, M. K. and Orosa, J. A. (2016) *Building construction materials effect in tropical wet and cold climates: A case study of office buildings in Cameroon*, Case Studies in Thermal Engineering, 7, 55-65

Ofosu-Ahenkorah , A K. (2007) Potential for Energy Savings in Ghana‖, In: Brew-Hammond, A. & Kemausour, F., eds., Energy Crises in Ghana: Drought, Technology or Policy? College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, pp.16-33

Santamouris, M. (2010) The Role of Buildings on Climatic Change. 9th International (SET 2010). 24 to 27 August 2010, Shanghai, China

Silva, T. , Vicente, R. , Rodrigues, F. , Samagaio, A. , Cardoso, C. (2015) *Development of a window shutter with phase change materials: Full scale outdoor experimental approach*, Energy and Buildings, 88, pp 110–121

Stoloff, J. A. (2004) A Brief History of Public Housing. Paper presented at the annual meeting of the American Sociological Association, Hilton San Francisco & Renaissance, Parc 55 Hotel, San Francisco, CA. http://www.allacademic.com/meta/p108852_index.html Accessed May 13, 2016.

Swenson, A. and Chang, P. - C. (2008) *Building Construction*, Encyclopaedia Britannica. Retrieved 2016-03-25 *at* http://www.britannica.com/technology/building-construction

Szokolay, S. V. (2004) Introduction to architectural science: The basis of sustainable design, Architectural Press, Elsevier Science.