Affordable Energy Efficient Housing

The Proposed TEMA COMMUNITY 23, Greater Accra Region

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ABSTRACT

Globally, affordable energy efficient housing has become a better option for providing adequate housing for urban dwellers. Most developed countries have considered the option passionately and have been enjoying the benefits of allocating resource towards developments of such nature. Some of the benefits include low energy use, low operational cost and increased rate of development of housing units.

However, this has not been given adequate attention in developing countries like Ghana where the adverse effect of rapid population growth on housing delivery for urban dwellers and energy use in housing is prominent. The adverse effect includes the accumulation of housing deficit and energy crisis. The housing deficit was 250,000 units in 1985, 300,000 units in 2002 and in 2006 it was 500,000 units.

To help solve the problem, this thesis investigates the benefits of tropical architecture design principles such as the use of passive ventilation techniques, use of courtyards, building orientation, appropriate window sizing and placement. The use of compressed earth as walling material, design standardization, efficient land use planning and measures put in place to reduce energy use in the buildings were also considered. The advantages of encouraging the use of energy saving technologies such as light-emitting diodes (LED), air conditioning exchangers (HVAC) and biogas in the Proposed Affordable Energy Efficient Housing for Tema Community 23were highlighted.

The proposed affordable energy efficient housing for Tema community 23 may serve as a good model to help government and private developers to increase the supply of adequate housing units. It also serves as case to encourage policy makers to develop and enforce measures for ensuring that energy is efficiently used in buildings to prevent energy crisis.

DECLARATION

I hereby declare that this submission is my own work towards the Master of Architecture and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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Head of Department Name Signature Date

DEDICATION

This thesis is dedicated to:

My Uncle- Mr. Ben Atsu Agbomanyi, My Mum-Mad. Agnes Alornyo, My Late Dad-Mr. Lawrence Agbomanyi.

My Late Brother- Mr. Devine Kwame Denoo, My Mentor- Architect Philip Amuzu, and My Wife and Son- Ms. Olivia Gbekle and Sedui Kwormigah Agbomanyi respectively

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My greatest gratitude goes to GOD without whom I would not even be alive to carry out such a research; He is the source of all my ideas and inspiration. My sincere gratitude goes to Architect Samuel Amos-Abanyie for his help and guidance during the research period. My warm appreciation also goes to the following personalities who helped in making this research work a reality:

Architect Segbedzi of Architects Co Partners.

Architect Abraquah –Tema Development Corporation.

Architect Philip Amuzu, General Manager of New England Estate.

I am very much thankful to my Uncle Mr. Ben Atsu Agbomanyi, Director of Top Oil for his financial assistance. May the Creator grant him long life and prosperity. I am also grateful to My late brother Mr. Devine Kwame Denoo (former Principal Technical Engineer, DVLA-Wa) for his financial support from the beginning of to the end of the course. However I know he is in his creator’s bosom enjoying the fruits of his labour.

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CHAPTER ONE

1.1 Introduction

"The provision of decent, adequate, affordable and quality shelter for the urban poor constitutes a significant source of concern for several developing countries, especially, in Africa and Asia" (Yormesor, 2007**)** Generally, one of the critical problems facing developing countries is housing. The phenomenon has been attributed to rapid population growth and urbanization. The situation is not different in Ghana. The tragedy of the housing sector in Ghana can never be over emphasized and available data show that the situation is becoming worse as the rate of population growth increases over the years. In 1985 housing delivery deficit was estimated to be 250,000 units, in 2002 it was 300,000 and in 2006 it was 500,000 units (Ghana Review International, 2002).

It can be concluded that all attempt made in the past through policy formulation did not in any way aid in the reduction of the delivery deficit let alone, meet the effective demand for shelter. It is rather unfortunate to have current housing stock estimated at 2.2 million in a country of a population of approximately 22 million (*TAYSEC*, 2007*).* The obvious adverse effect of the ever-growing deficit in the housing sector is slum development around city centers and examples include those in Nima and Sodom and Gomorra. "Various data on housing in the country disclose a backlog of about 500,000 housing units while supply figures are between 25,000 and 40,000 units per annum, as against annual requirement of 100,000 units". (National Agenda, 2007)

High cost of housing in urban areas is the order of the day and this has created financial stress for home buyers and renters as they spend over 50% of their income on housing alone. The consideration for affordable housing is of great concern to government, urban planners, architects, estate developers and professionals in the building industry due to the rising cost of rents and prices of properties. (Ghana Review International, 2002)

However, a building may be affordable in terms of its production but not necessarily cost efficient in relation to its use over a period of time, hence the need to consider its energy efficiency. The housing project needs a design intervention that will not render the building only affordable to the developer but also affordable and cost efficient (energy use and cost of maintenance) in terms of its use to the buyer or the renter. Hence it is a laudable intervention to carry out a research into a development that is structured to provide an immense benefit to all parties involved in the building development and construction process.

1.2 Problem Statement

Rapid population growth coupled with its adverse effect has resulted in the increasing demand for accommodation. However the supply to meet this demand for housing is inadequate and therefore leading to the accumulation of housing delivery deficit. Ghana as a developing country is also faced with the problem of energy crisis. These challenges have necessitated the need to carry out a research into affordable energy efficient housing as a lasting solution for the situation.

1.2.1 Accumulation on housing deficit

Attempts made to meet the estimated annual supply requirement of 100,000 housing units in 2007 were not encouraging. Rapid population growth, increasing rural-urban migration and the unplanned nature of our city centers have virtually led to increasing housing deficit and urban sprawl with its attendant problems such as pressure on social amenities and infrastructure, and increasing socio-economic challenges. (Ghana Review International, 2002)

The increasing housing delivery deficit is due to the high rate population growth, urbanization and less supply of housing units to meet the growing demand for housing. As long as population never stops growing, housing delivery deficit would be increasing at an exponential rate. Tema, being the largest industrial City and satellite town to Accra is attracting 40% of the migrants from all over the country. These migrants are adding to the pressure on the already limited number of the housing stock in Tema and its surrounding towns. (Ghana Review International, 2002)

1.2.2 Energy Crisis

Ghana, for some time now is faced with energy crisis. This is evident in the energy crisis that hit the country in 2007. This is due to the fact that greater percentage of the populace depends on one source of energy for all domestic and industrial use, which is hydro-electric power, generated mainly by the Akosombo Dam. The Bui Dam is being built to supplement the energy needs of the country. The energy crisis has not only put unnecessary financial stress on government but also families that use large portion of their income to pay for other means of power supply.

1.3 Objectives

i. To identify and investigate the importance of reducing material waste through the use of standard material sizes for generating room sizes. This leads to the elimination of dead spaces and increase functional spaces. When this is done, the need to build more units to solve the problem of the housing deficit is encouraged as the construction cost and time spent per unit is reduced.

ii. To evaluate and improve the measures put in place to help in the attainment of efficient energy with respect to energy use in housing facilities without increasing the life cycle cost.
iii. To investigate the importance of employing the principles of tropical architecture in the attainment energy efficient through passive thermal control, orientation of buildings and choice of materials.

1.4 Scope

The research examines the tropical design principles and measures employed to help achieve an energy efficient use in the proposed affordable housing for Tema Community 23. The research also gives a vivid account of the state of housing in Ghana, design considerations for planning strategies employed to attain efficient land use planning. Cases studies on some local and foreign projects with the aim of attaining objectives such as reducing the rate housing deficit and improving the energy use in housing projects were considered in this research. The research laid much emphasis on measures put in place to reduce the life cycle cost of using the building over a period of time rather than short term affordability.

1.5 Contributions

The proposed design of the affordable energy efficient housing at Tema Community 23 Project and the outline of measures needed to achieve energy efficiency and affordability in housing projects found in the research are the contributions.

CHAPTER TWO

2.1 Introduction

This chapter considers available literature which is relevant to the study of affordable energy efficient in a housing project. First, it gives an account of the state of housing from 1986 to 2011. Efforts made by both public and private sector over the years have not totally solved the problem of accumulating housing deficit according to Ghana Review International et al, (2002). Various design considerations that have been proven to be successful when used in the design and development of affordable and energy efficient housing projects are also discussed.

Principles of Tropical architecture were considered as they have direct impact on the attainment of energy efficiency in housing project. Comparative studies of terrace and tessella principles of land planning were considered under efficient land planning. Selected local and foreign cases were studied base on their successes or failures with respect to affordability and energy efficiency.

2.2 Overview of Housing in Ghana

Rapid population growth and its attendant urbanization have made the provision of housing one of the most critical problems facing Ghana as a nation in recent times. This phenomenon can be traced back into history- from the period of 1986 to 2002. (Ghana Review International, 2002)

The inability of the housing delivery system to meet demand over the years has put pressure on the existing housing stock and infrastructure in urban areas. Some of the constraints of housing delivery include land allocation, institutional capabilities, finance, infrastructure, material and skills. There is therefore the need to develop a strategy for the provision of adequate housing for urban dwellers in particular.

Housing and its attendant problems has not been easy to solve both by government and the private sector since 1954. The attempts to solve the housing issue by government have not yielded the desired results. During the period 1954-1986, the housing policy only gave a broad aims of the need to provide adequate housing. There were no indications of projected outputs. So from the pre-independence era through 1986, the programme objectives of the various public housing delivery agents, for instance, the State Housing Corporation, Tema Development Corporation, Public Works Department (PWD) and Ghana National Chamber of Commerce (GNCC) /SCC became synonymous with the housing policy at the time. (Ghana Review International, 2002)

During this period other public schemes were introduced for the improvement of the old dwellings that were fast deteriorating; they came as wall protection loan schemes and roof loan schemes. The year 1985 marked the peak of the period and was still characterized with delivery deficits of 250,000 units. It can therefore be summed, that the aforementioned schemes did not meet the national objectives (Ghana Review International, 2002).

In 1986, the Government of Ghana became conscious of the need to improve its approach to finding sustainable solutions to the problems facing the housing sector by appointing a committee on 2nd June, 1986 to examine the national housing situation and advice the then Ministry of Works and Housing accordingly. As a result the National Housing policy and Action Plan 1987-1990 emerged. (Ghana Review International, 2002) A new programme was developed so that the public sector can play a facilitating role of providing relief to the private sector from the difficulties associated with land acquisition and housing development. This was to compliment the private sector's already leading delivery role. Below were some of the initiatives taken during the plan period of 1987-1990:

- Increased investments by the Social Security and National Insurance Trust (SSNIT) in housing. Examples are housing estates at Sakumono and Adenta in Greater Accra and other regional capitals.
- The establishment of the Home Finance Company (HFC) by the Government of Ghana, the SSNIT and the World Bank as an alternative to the proposed National Fund.
- The founding of the Ghana Real Estate Developers Association (GREDA) (Ghana Review International, 2002)

However, with all above stated improvement during the period 1987-1990 the programme ended due to inadequate attention given by the government to the strategies and policy initiatives required to support the action plan and the programme. The period between 1993-1997 was the period of National Shelter Strategy; the plan specified goals that Government would seek to achieve the production of improved housing solutions and renovation of the existing housing stock. The budget allocation for the implementation of the plan at the time was approximately ¢580,000 million. According to Ghana Review International *et al*, (2002) the funds were to be used to provide 66,000 new units; 21,000 units would be improved and 30,000 lots developed.

Government then increased rate of developing housing units and cleared most bureaucratic process for land acquisition and ownership, encouraged maintenance of existing units, promoted the construction of more affordable housing, improved government programmes and encouraged an expanded role of the private sector. All these were done in a bid to achieve the targets set in the National Shelter Strategy Action Plan. Government's efforts during the period were targeted on the housing needs of the lower income families.

From 2001 to 2008, though there have been a lot of attempts at solving the housing problems of the country, there is still more room for improvement till the average Ghanaian can be provided with affordable and decent housing around all the regional capitals. Government's policy during this period is to create land bank to give private developers an access to these land banks at reasonably price and free from encumbrance. This has been one of the major barriers to land ownership in Ghana. Under the current programme, thousands of acres were acquired in Accra and all the regional capitals. All lands acquired under the programmed would be serviced with basic facilities and be made available to private and individual developers. This strategy is to aid in reducing the 70% of the overall construction fund which goes into the provision of access roads, and servicing a site before even the buildings are constructed. (GREDA, 2007 as in National Agenda, 2007)

The amount spent in providing services such as water, electricity and providing access road to these lands accounts for the high cost of houses in Ghana. So the aim of government for this programme is to reduce the unit cost of a house in the country. Some of the sites in Accra where the land bank were created are; Berekuso A&B, Odarteman-Nkakina (Odumasi-Amanfrom Amasaman), Machi/Owulman, Oyarifa, Opeiman-Kasoa, Danchir, Kasoa Farl Farms, New Adenta, Odupon-Kpehe, Ashalaja, Adamrobe, Okupeman (Pantang), New Bortianor, Eglesi Amanfro. (National Agenda, 2007)

According to National Agenda (2007), the current administration is undertaking affordable housing project in the nation capital to provide housing for the urban dwellers so as to reduce the housing delivery deficit which is currently pegged at 500,000 units. The aim of the programme is to build 100,000 housing units for the middle and low income groups through public-private partnership (P.P.P). The affordable housing project is ongoing at the following areas; Borteyman and Kpone in the Greater Accra Region, Asokore- Manpong in Ashanti Region, Koforidua in the Eastern Region, Tamale in the Northern Region and finally Wa in the Upper West Region. The projects are being undertaken by Tema Development Corporation (T.D.C) and the State Housing Company (SHC).

The proposed affordable housing to be situated at Borteyman near Tema consists of 1,138 units. The various units comprise 192 one-bedroom flats, 88 one bedroom flats with shops, 608 two bedroom flats, 200 type C one bedroom cluster of blocks and 50 type C three bedroom cluster of blocks. Amenities such as police stations, churches, primary and Junior High Schools, playgrounds, and public parking, recreational and commercial centers are also to be provided to serve the neighbourhood. (National Agenda, 2007)

Ghana has a long way to go with regards to the provision of affordable housing because prices of houses are still high. This situation has led to the development of slums around the central business district (CBD) for e.g. Sodom and Gomorrah, Nima settlement. (CHF International, 2004)

2.2.1 Causes of the Housing delivery deficit

The housing delivery deficit which the country is facing from decades is caused by a number of factors most of which are of socio-economic origin. The ever increasing housing delivery deficit is caused mainly by the following; the price of Land and the high cost of servicing the land which includes the construction of access road network and the provision of water, electricity and telecommunication. It has been confirmed that “70% of the capital allocation for housing development goes into the provision of utilities for the properties” (Ghana Review International, 2002)

The process of land acquisition is very difficult. A sale of land to two or more individuals or private developers has over the years led to land litigations with its attendant expenditure. This phenomenon has led to high cost of land. There is therefore high demand over supply for housing which is also accounting for the high cost of renting and buying of houses in Ghana. The situation is such that the average Ghanaian worker now has to spend disproportionately large amount of their income on housing alone. After the years of rapid increase in rental fee, affordable housing has become corrective measure to reducing the ever increasing housing delivery deficits.

In short the tedious process of land acquisition and its servicing, population growth and migration are the major causes of the ever increasing housing deficit. (CHF International, 2004)

2.3 Design and construction consideration for Affordable and Energy Efficient Housing

Although many developers consider "good design - large functional spaces with minimized death spaces" as an unnecessary frill, it can contribute to affordability. The cornerstone of affordable housing design is containing and even reducing construction costs and cost of using the building over a period of time (life-cycle costs) – those associated with building operations long term maintenance, and refurbishment –while maintaining livability. (Feldman and Chowdlury, 2002) Below are five areas where significant savings can be realized:

2.3.1 Construction efficiencies

Construction efficiency is among the most effective strategies for decreasing the cost of housing construction without reducing its livability. Construction details that use standard material dimensions and equipment modules limit waste and labor, reducing cost by at least 10 percent. Using locally available and easy to repair materials, equipment, and finishes also contains construction and life-cycle cost. (Feldman and Chowdlury, 2002)

Modular housing is considered the strongest among frame housing and conforms to the same standards and codes as site-built. Pre-manufactured components, such as roof and floor trusses and wall panels, allows builder to enclose a structure, quickly saving both time and labor costs. The ability to place and secure a finished unit quickly can be especially advantageous in urban areas where a site-built home faces prolonged exposure to theft and vandalism. (Feldman and Chowdlury, 2002)

Rehabilitation of existing housing and the adaptive reuse of other building types, if the structures are in good condition, can also offer cost-effective construction practices. Recycling an entire building to extend its useful life is environmentally sound and preserves cultural and historic structure (Feldman and Chowdlury, 2002).

2.3.2 Space efficiencies

Space efficiencies can be achieved without reducing livable spaces, by minimizing circulation spaces in housing design. For example, the arrangement of circulation space in a central node or short hallway with surrounding rooms can significantly decrease the unit square footage without changing the size of the rooms. The ratio of a room’s width and length also determine how well conventional furnishing will fit without wasting space. Rooms that are very long proportionally often do not offer the most efficient use of space (Feldman and Chowdlury, 2002).

Compact building forms minimize the building‘s “envelop, “and thus decrease costly building components, such as the foundation, roof, and exterior walls. A one story single family dwelling is more expensive to build than a two-story structure with the same square footage, quality of construction, and amenities. Compact building forms also reduce life-cycle costs because they are less expensive to heat, cool, and maintain. (Feldman and Chowdlury, 2002).

2.3.3 Greater housing densities

Greater housing densities can also save money, especially in areas where there is a high land cost, although in the U.S low density housing, predominantly single-family dwellings are favored. Higher density multi-family housing has environmental benefits, as well in preserving agricultural land and open space and facilitating mass transit. One of the challenges of higher density housing is maintaining norms for privacy and valued, useable outdoor space; for example, in small backyards that about dwelling yards. Apartments and townhouses, in fact, can have the same or similar layouts. (Feldman and Chowdlury, 2002)

2.3.4 Energy-efficient design

According to Wikipedia definition, energy efficiency in design is any design intervention with a goal to reduce the amount of energy required to provide products and services. For example, in the temperate zones, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature whereas in the tropical climate providing large openings especially on the windward side of the building also helps to achieve thermal comfort and energy that would have been used for air conditioning such space would have been saved. Installing fluorescent lights or natural skylights reduces the amount of energy required to attain the same level of illumination compared to using traditional incandescent. Compact fluorescent lights use two-thirds less energy and may last 6 to 10 times longer than incandescent lights. Improvements in energy efficiency are most often achieved by adopting a more efficient technology or production process. (Wikipedia, 2008)

Energy-efficient design contributes to environmental sustainability and reduced life cycle costs. Unfortunately it is all too often excluded from affordable housing projects because it is perceived as “too expensive”. In fact, it is possible to attain energy efficiency without incurring additional costs. The study carried out by Feldman and Chowdlury, (2002) revealed that use of compact forms and appropriate construction assemblies can reduce heat losses in home by up to half. For example, just by simplifying a floor plan from an L-shape to rectangle approximately 15 percent can be saved in heat losses in the temperate climate. Stacking floors and combing dwelling in the form of duplexes and row houses also provides significant energy saving through major reductions in exposed wall area. (Feldman and Chowdlury, 2002)

Energy costs can also be reduced by using energy-efficient equipment and materials. For example, residential energy consumption can be cut by about 75% by using Energy Star-rated equipment and appliances. The higher costs of energy-efficient materials and equipment, such as super insulation and double-glazed low-e windows can be offset by the cost saving incurred in the decreased, necessary capacity of the HVAC equipment. (Feldman and Chowdlury, 2002)

2.3.5 Passive solar design

Passive solar design is the use of the building envelops, orientation and other design windows and opening placement to modify the internal climate or micro climate for comfort without the use of any mechanical methods. It also reduces the energy requirements of the building by meeting either part or all of its daily cooling, heating, and lighting needs through the solar energy. Simply orienting and shaping a building and its windows to maximize passive solar gain can save 10 to 20 percent of heating energy. In sunny climates, such as Arizona, house orientation alone can make a difference of 50 percent or more in heating and cooling costs. (Feldman and Chowdlury, 2002)

2.3.6 Design for durability

Design for durability saves on costly maintenance and future building renovations.

Spending on durable materials, finishes, furnishing and equipment may entail higher initial construction costs, but is compensated by substantially decreased life-cycle maintenance. (Feldman and Chowdlury, 2002).

2.3.7 Adaptability of design

The type of housing and its ease of adaptability are very important to its useful life. Families grow or may require more space than they can afford at the time they purchase their home. Major alterations, such as room additions, can be simplified and made cost-effective by planning for them in the initial design or by providing unfinished space. For example, the Villas in Jingle town, Oakland, were built small to hold down mortgage payments, and designed to accommodate growing families. The homes include an expandable attic to add two bedrooms and one bath when the owners' incomes permit. In some cases, space was added adjacent to bedroom above it. (Feldman and Chowdlury, 2002)

Designing for changes in residents' age's needs and abilities accommodate "aging –in-place "without incurring the emotional and economic costs of moving or expensive remodeling. Accommodations as simple as blocking reinforcement in bathroom walls to attach grab bars when needed, or kitchen cabinets and counters that can be adjusted to allow wheelchair access, can be achieved at very modest cost: in the hundreds of dollars. (Feldman and Chowdlury, 2002)

2.4 Efficient way of planning to save land- Tessellation Planning

Planning of land for building development must be done carefully due to the high cost of its acquisition, tedious process of acquisition with its attendant litigations. This section of the research seek to bring to the fore the strategy of tessellation planning as a proven planning strategy for achieving efficient land allocation. According to Ghazali *et* *al (*2008), colours used in a typical tessellation are not just decorative art but signify functional spaces when applied in town planning.

2.4.1 Background of Tessellation Planning

In geometry, to tessellate means to cover a plane with a pattern without having any gap or overlap. It has been used by artist and craftsmen since ancient time (over six hundred year ago) to create visual effect on surfaces. One of the commonest ways of tessellation is in tilling. (Ghazali *et al (*2008)

In Latin, a small cubical piece of clay, stone or glass used to make mosaics is called tessella. The word "tessella" means "small square" (which is from the Greek word (tessera) for "four"). They were used to make up 'tessellata' - the mosaic pictures for floors and tiling in Roman buildings. (Ghazali, *et al* 2008)

There are two parts to Tessellation Planning: the first is the use of tessellation geometry to create a layout plan as shown in Figure 2.1below. The second has to do with the design of housing layout to create neighbourhoods.

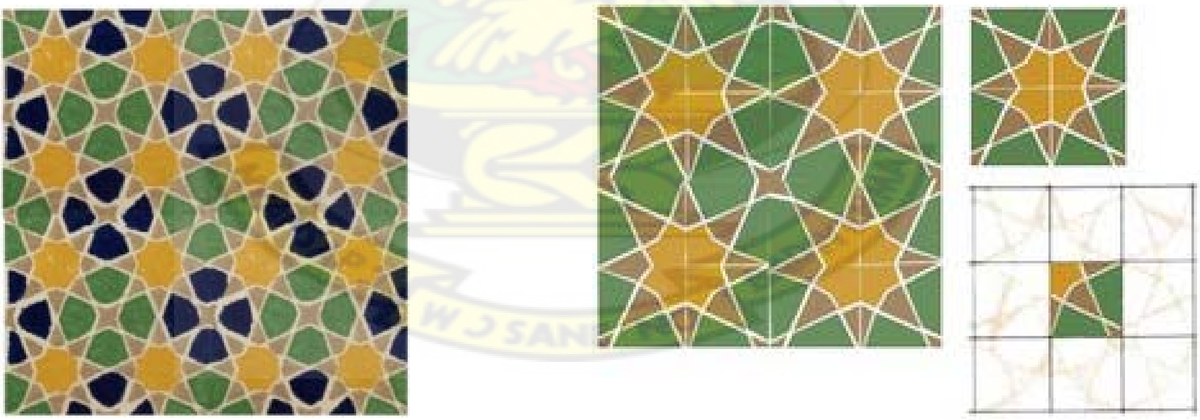


Figure 2.1 Typical tessellation patterns. (Source: Ghazali *et al*, 2008)

According to Ghazali *et al* (2008), the creative power associated with tessellation can be applied in Town Planning where the colours found in a typical tessellation are not mere decorative art but represent functional spaces. A small triangular tile, the mother-tile is the basic building block that creates the honeycomb layout. It contains three requisite elements of a township layout: road (yellow), house and garden (red/blue), public green area (green) as shown in Figure 2.1 above. Below is an illustration of how multi houses could be created using tessellation planning techniques; a triangular shape with a house unit was tessellated to form equilateral triangle with six (6) houses with private backyard garden. The triangle is further tessellated to form hexagon with 26 house units arranged around a cul-de-sac and a common court. This process is repeated for larger land area to form neighbourhood. A typical example is the Honeycomb housing layout as illustrated in Figure 2.2 below.

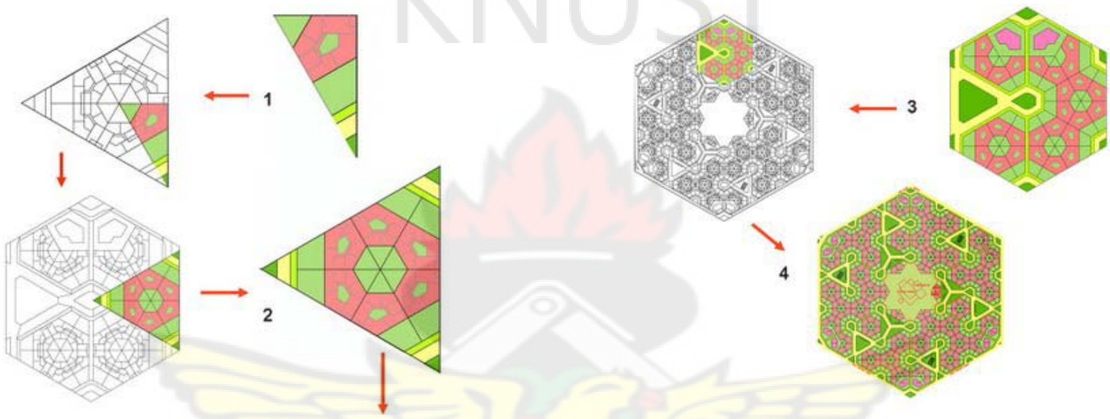


Figure 2.2 Tessellation process (Source: Ghazali *et al* 2008)

Tessellation has led to the formation of new house types. Linked honeycomb houses ideally join back to back and are accessed from different cul-de-sacs. This is the case of the duplex and triplex. But they can also link side to side at the same time, as in the case of the quadruplex and sextuplex as shown in Figure 2.3 below.

Figure 2.3 House types in tessellation planning (Source: Ghazali *et al* 2008)

2.4.2 Comparison between Honeycomb and Terrace layout

The honeycomb layout is a form of tessellation patterned layout and this section explains the how arrangement of housing units in the honeycomb layout is efficient in terms of land used compared with terrace layout. Honeycomb housing comprising 5 units of quadriplexes and duplexes is compared with a terrace house arrangement of an equivalent 5 units. Although the land size of the houses is the same, when it was analyzed based on land use, it was found that the area used up for roads (yellow) in the honeycomb layout is much less than that in the terrace house layout. Because the green areas are the same size, there is more saleable land. Table 2.1 below shows a comparison between a honeycomb neighbourhood of 16 units of quadriplexes and duplexes against a terrace house arrangement of equivalent units.

Table: 2.1 comparisons of Honeycomb neighbourhood and Terrace housing.

HONEYCOMB VS. TERRACE (SM)* Square Meter				
5 UNITS				
	HONEYCOMB HOUSE		TERRACE HOUSE	
	(SM)*	(%)	(SM)	(%)
ROAD	334	26%	611	41%
GREEN	93	7%	103	7%
HOUSE	861	67%	761	52%
TOTAL	1288	100%	1475	100%
16 UNITS				
	HONEYCOMB HOUSE		TERRACE HOUSE	
	(SM)*	(%)	(SM)	(%)
ROAD	879	23%	1323	35%
GREEN	264	7%	269	7%
HOUSE	2721	70%	2190	58%
TOTAL	3864	100%	3782	100%

(Source: Ghazali *et al* 2008)

Layouts created with the honeycomb concept have a propensity to increase land use efficiencies. These advantages are summarized in the mathematical Table 2.1 comparing the terrace housing against quadruplex /sextuplex honeycomb housing. The density is the same but the amount of road for the 'honeycomb' is only 33% against 47% for the terrace. Consequently, the average size of each lot is 30% larger. (Ghazali *et al* 2008)

2.4.3 Advantages of honeycomb layout

1. The back-lane in the terrace house situation is wasteful; this feature is totally eliminated in honeycomb housing.

2. The amount of circulation space in a through road by cutting it off at the end is reduced. The final length is replaced by paved area designed for turning as shown in Figure 2.4 (Ghazali *et al* 2008)

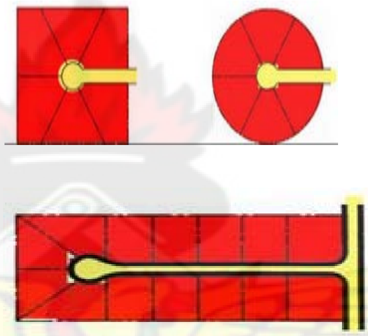


Figure 2.4 Cul-de-sac, road type use in tessellation. (Source: Ghazali *et al* 2008)

Given a fixed area and number of houses to access, the shorter the cul-de-sac, the less the area taken up by the road. A square cul-de-sac neighbourhood has less road area than a long rectangular one. A circular one by itself would be the most efficient. However, as shown in Figure 2.5 below the circle does not tessellate. However, hexagonal neighbourhoods interlock without gap or overlap.

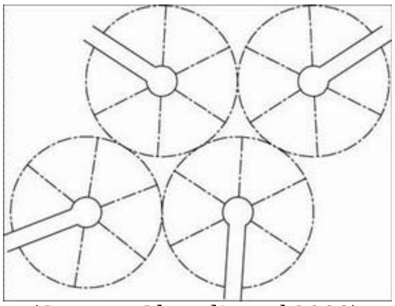


Figure 2.5 Tessellation of circles (Source: Ghazali *et al* 2008)

3. The perimeter of a hexagonal precinct is 7% shorter than the perimeter of a square one of the same area.

4. In the example shown in Figure 2.6, the truncated triangle shape of 6000 square feet yields a higher plinth area compared to a typical 60’ x 100’ site; as show in Figure 2.6 below

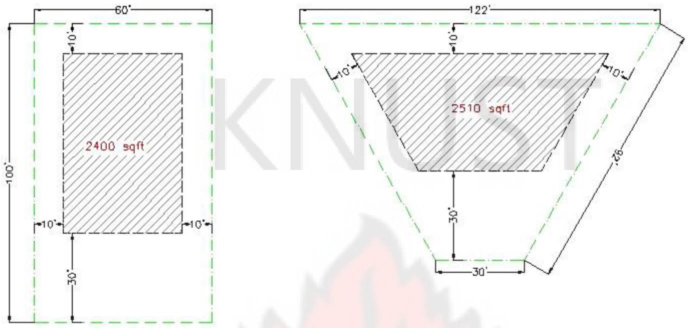


Figure 2.6 Rectangular and truncated triangular shapes, 6000 square feet. (Source: Ghazali *et al* 2008)

Terrace housing can be seen as a row of houses surrounded by roads. In contrast, honeycomb houses surround the road. It is easy to understand intuitively that roads accessing internally are more efficient than roads accessing houses from the external boundary. This accounts for the efficiency of cul-de-sacs in general, and partly explains the efficiency of ‘honeycomb housing. (Ghazali, *et al* 2008)

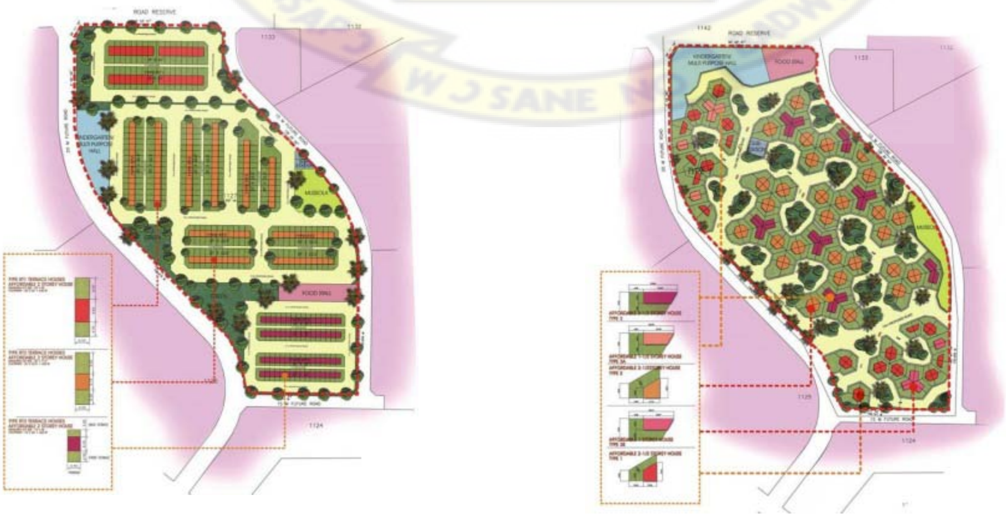


Figure 2.7 Typical Terrace and Honey comb layout (Source: Ghazali *et al* 2008)

2.5 Tropical Architecture

In this section, details of various principles of Tropical architecture are examined. It also exposes the impact of building orientation, window size, window type, location and placement of windows on the energy use of the building and affordability. Over the years good design practices and research have shown that proper orientation of building can for example reduce the energy use of the building significantly and improve thermal comfort in the spaces created. (Salmon, 1999)

According to Square One, an Environmental Design Website, compiled by Dr. Andrew Marsh and Caroline Raines of Square One Research and the Welsh School of Architecture at Cardiff University, tropical climates have year round average temperatures in excess of 18 degrees Celsius, and generally extend northward and southward from the equator to about 15 to 25 degrees of latitude". Most of these areas are in Central Africa, Southeast Asia and Central America. (Ericynot-ga, 2008)

According to Sam C. M. Hui at the University of Hong Kong, because of the almost constant heat and frequent high humidity, cross ventilation is far more important in the tropics than in other climatic zones. This architectural emphasis differs somewhat from other climatic zones in that cross ventilation always should be maximized in the tropics, whereas in other zones, it needs either to be minimized during some high velocity wind events, or blocked altogether in colder seasons. (Ericynot-ga, 2008)

The objective of achieving best cross ventilation achieved is vital in the achievement of thermal comfort in interior spaces in hotter climates. Cross ventilation is done through (1) building design and by (2) appropriately orientation the building to make maximum use of natural air movement. Cross ventilation design is driven by the understanding what Australian architect, Ann Roche said, "air will not enter the building unless there is a passage of exit." In other words, simply having an opening (door and window) facing the direction of the prevailing wind will not create cross ventilation because without an exit point, the air will not flow through the building.

Below are some design considerations that are very important in tropical architecture design.

2.5.1 Site Planning

The type of ground cover found around the immediate surroundings of a building tends to have an immerse effect on the local climate around the building. This is due to the fact that radiation reflected from the ground into the building can add to the cooling requirements of the structure. The solar heat load can be minimized by selecting exterior surface material of low reflectivity. (Salmon, 1999)

The greatest concern to the architect, therefore, is the area immediately outside the building. For example, although locating asphalt driveway outside a wall will keep reflected radiation at minimum, the air temperature outside the wall would be made higher by the heat absorbed by the paving element than that over lawn and most other surfaces. Therefore, ground covers make effective sun absorbers and cool the air by evaporation. (Salmon, 1999)

Issues concerning orientation of building can never be left out when discussing site planning under tropical architecture; in tropical region it is highly recommended that buildings are arranged such that their longer parts faces the North- South direction. This is due to movement of the sun and the prevalent wind direction which is NE-SW. When buildings are arranged in this way, the area exposed to the sun is reduced thereby reducing the heat load on the building and its attendant cost implication. (Salmon, 1999)

2.5.2 Natural Ventilation

Air movement replaces stuffy used air, odor, and evacuates unwanted warm air. Vents are sized and located to allow every space within a building to promote passive ventilation. The direction and speed of air flow determines the cooling effect of natural ventilation. Air can be adjusted for comfort by opening or closing a variety of properly placed windows. There must be inlet and outlet on opposite or adjacent sides of a space or building so as to promote natural ventilation. Air flow into an opening on the windward side of space is most effective when the wind direction is within 30° of the normal opening. Also on the openings on the leeward side should be larger than on the windward side so that a maximum suction effect would be created to facilitate free air movement through a space.

2.5.3 Locating openings for natural ventilation

Doors and windows are the natural means of ventilating houses. The placement, size, and type of openings affect the effectiveness of the elevation. Windows can be oriented to catch or slow down prevailing breeze. A particular type of window can also be selected based on the intended purpose, for example awning may be selected to only allow air and prevent rain from entering the space, basement windows can also be opened to capture or buffer the wind, louver openings permit uninhibited air flow and hopper windows allow free upward motion of air since warm air rises and expands, fresh air from outside the space normally blows in low and leaves the space in the upward direction. (Salmon, 1999)

Therefore operable skylights are very effective ventilators and allow very good illumination. They have the advantage of always being exposed to the wind regardless of where it comes from. They are recommended for ventilating bathrooms and kitchens. In areas of driving rain and heavy wind it is advisable to orient the opening away from the direction of the storms as shown in Figure 2.10. (Salmon, 1999).

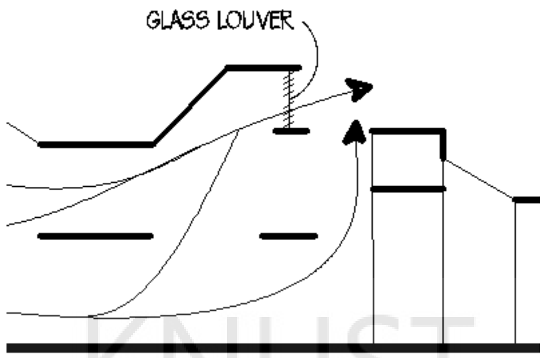


Figure 2.8 Operable elements provide natural ventilation.

2.5.4 Ventilation strategies

The two primary strategies that can be used for ventilating buildings include continual venting and nighttime venting. Naturally air moves from high pressure zones to low pressure zones. This makes it very ideal to locate a building's breeze inlet adjacent to the higher pressure zone and its breeze outlet adjacent to the lower-pressure zone. (Salmon, 1999)

It is very important therefore, to have some ideas where the high or low pressure zone occurs on the building so as to determine best place for inlets and outlets. Generally, air moves by pressure difference that is hot air rises and cold air falls. The pressure differences cause the air to flow towards the lower- pressure usually higher up. (Salmon, 1999)

These stack-effect air currents are useful for exhausting unwanted air that might collect under a skylight or next to the ceiling. They are particularly effective at night, when the cooler night air can be brought in to carry to the outside the heat absorbed by the building during the day. But, they provide little evaporation because they do not move fast enough and usually do not pass through the living zone where people are found.

Stack-effect ventilation usually allows prevailing breezes to overcome the effect of air movement caused by thermal differences. Even in areas where considerable process heat is emitted in the interior, mild cross –ventilation will overcome the stack-effect and carry the heat out via the breeze. The venting tower is a vertical channel created on top of the roof of a building where the rising hot air from habitable spaces is directed to the atmosphere. (Salmon, 1999) Figure 2.9 shows the pattern of air flow from higher pressure zone to lower pressure zones.

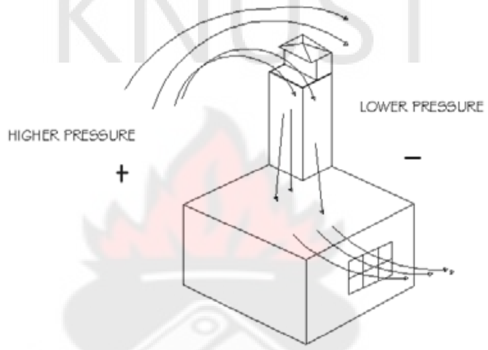


Figure 2.9 Isometric view and section of venting tower.

2.5.5 Courtyards

The use of courtyards is a common feature for buildings designed especially for tropical climate. Courtyard is employed to aid in cooling the hot interior spaces. This open, shaded space can be covered with light shading lattice during the heat of the day to prevent sun intrusion and heat buildup in the interior walls. Vegetation and fountains or ponds add evaporation to the cooling effect of the breezes passing in one side of building and out the other. Air and evaporative cooling continually remove heat from the walls as well as the interior spaces at night, by opening all doors and windows and removing the day shade. (Salmon, 1999). Figure 2.10 shows the outline of a typical courtyard. The hatch area shows the uncovered space around which the main building is built.

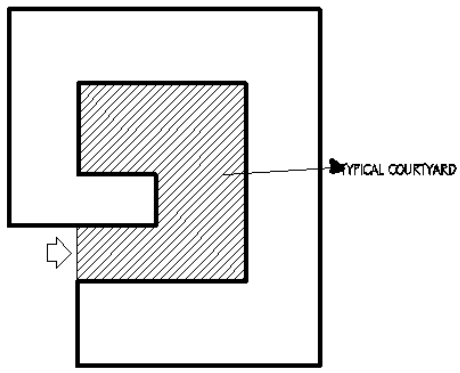


Figure 2.10 Typical courtyard

2.5.6 Aids for Cooling

Wind catchers are very important in hot areas. The basic principle of catching unobstructed higher-level breezes remains the same although the form and detail vary from region to region. In some places the catchers are unidirectional and oriented to catch the favorable breezes, while in other places, pivoted scoops and multidirectional towers utilize winds from any direction. For example in the courtyard houses in Iraq, a series of wind catchers on the roof provide natural ventilation for a basement room where the resident normally take their summer afternoon nap. Each catcher is connected to the basement by a ducts located between two skins of an internal party wall that is cooled during the night by natural ventilation, because the party wall receive no direct solar radiation and because of its thickness, its surface remains at a lower temperature than the rest of the interior throughout the day. The incoming air is cooled by conduction when it comes into contact with the cold inner surface of the duct walls, and its relative humidity is increased into the basement. After passing through the basement, the air flows into the courtyard, aiding in this area during the daytime. (Salmon, 1999)

To move the air through the window from one of the building to the other, there is the need to create a new high pressure area at the outlet. Low pressure will further be reduce by attaching a windbreak that will create a high pressure area in front of the building at one end and one at the opposite end towards the leeward side. Air is drawn from one end of the building to the other or crossways to the prevailing breezes.

The principle that air flows from high pressure to low pressure helps us to analyze air flow around the building. For example Figure 2.11 shows the relationship between pressure zone and location of windows. Air will only circulate around the perimeters of the opening and the interior space is left without air flow as seen in diagram 1 under Figure 2.11. However in diagram 2 under Figure 2.11 openings are not directly opposite to each other so the air is forced to go through the interior spaces.

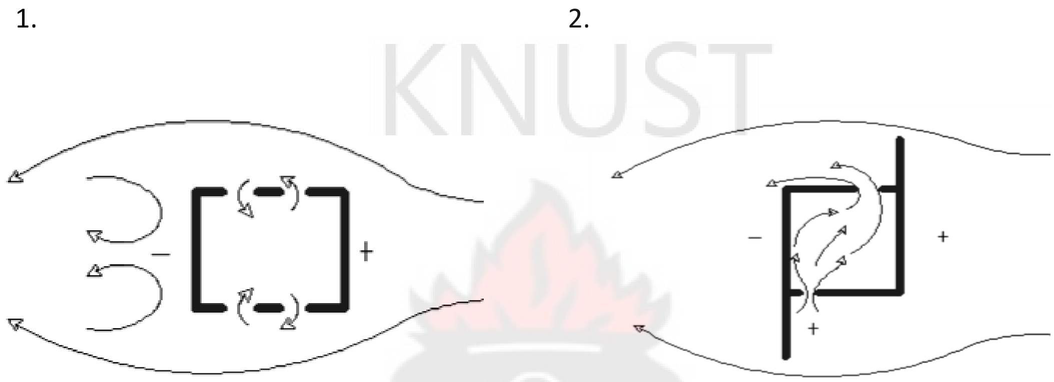
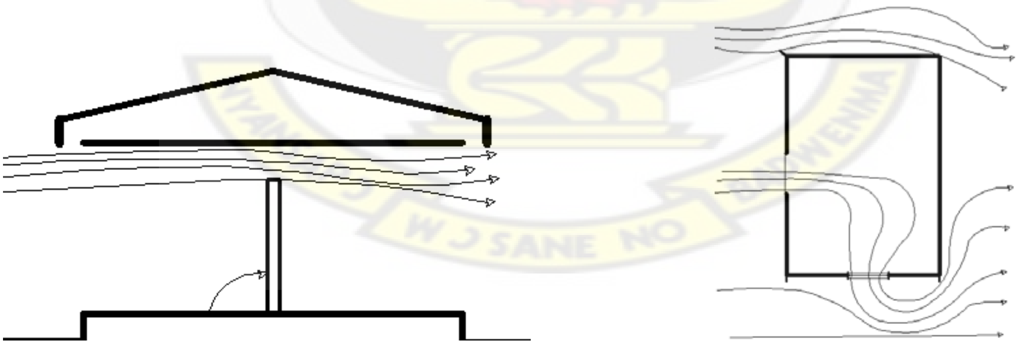


Figure 2.11 Cross ventilation



(a) Partition (b) Air speed reduced by the “dog-leg” effect

Figure 2.12 Effect of Openings on air current.

2.5.7 Evaporative Cooling

Evaporative Cooling can be achieved through both roof sprays and ponding or by extracting heat from the building through an evaporative treatment. Warm air passing over water evaporates the water, and as significant amount of heat is absorbed in the process, the air is cooled. The evaporated water is retained in the air, increasing its humidity, thereby making this method ideal for relatively dry areas. The simplest system is wooden frame across which open-weave matting of vegetable fiber is stretched. The matting humidifies and cools the air as well as filtering dust, when hung in front of windows in the path of natural air flow. (Salmon, 1999)

2.6 Utilization of Renewable Energy

It is an established fact that there are number of alternative energy sources for domestic and industrial use. Notable among them are the Solar Energy, Wind mill, thermal energy, hydro-electric energy and biogas. However, this section concentrates on the Biogas Energy. The study into biogas as an alternative energy for domestic and industrial use was carried out due its advantages over normal hydro-electric power and fossil fuel.

2.6.1 Biogas

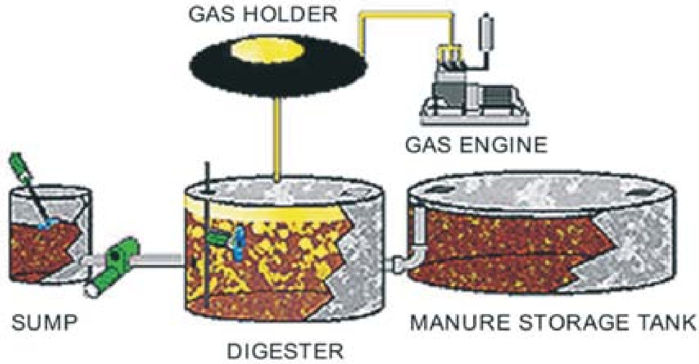
Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of biofuel. Biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material and energy crops. This type of biogas comprises primarily methane and carbon dioxide. Other types of gas generated by use of biomass are wood gas, which is created by gasification of wood or other biomass. This type of gas consists primarily of nitrogen, hydrogen, and carbon monoxide, with trace amounts of methane. The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. (Wikipedia, 2008)

Air contains 21% oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. It can also be used in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power. Biogas can be compressed, much like natural gas, and used to power motor vehicles and in the United Kingdom for example, it is estimated to have the potential to replace 17% of vehicle fuel. Biogas is a renewable fuel, so it qualifies for renewable energy subsidies in some parts of the world. (Wikipedia, 2008)

Biogas is a renewable energy source; it contributes to reducing greenhouse gas emission as its replacement of fossil fuels results in the reduction of CO_2. In addition, CH_4 emission from anaerobic lagoons of agro-industrial waste treatment can be reduced. CH_4 are much stronger greenhouse gas than CO_2. Further, methane is a potent greenhouse gas (GHG): according to authorities, the 100-years Global Warming Potential (GWP) of methane is estimated to be 21. (Mlive, 2000)

2.6.2 Basic Layout of a Biogas plant

A biogas plant consists of the following principal components; a digester, a gas holder, a gas engine, tubes, and mixers. Figure 2.13 below is schematic layout of a typical biogas plant.



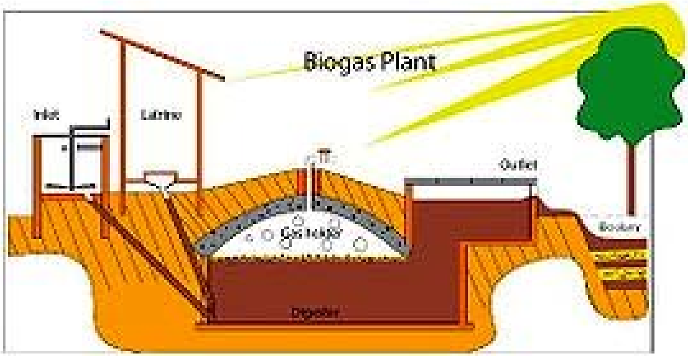


Figure 2.13 Typical layout of biogas plant (Source: Wikipedia, 2008)

2.6.3 Advantages of using biogas technology.

Electricity generated from Biogas is cheaper compared to other energy source.

In North America, utilization of biogas generates enough electricity to meet up to three percent of the continent's electricity expenditure. Normally, manure that is left to decompose releases two main gases that cause global warming: nitrous dioxide and methane. Nitrous oxide warms the atmosphere 310 times more than carbon dioxide and methane 21 times more than carbon dioxide. It is estimated that one cow can produce enough manure in one day to generate 3 kilowatt hours of electricity; only 2.4 kilowatt hours of electricity are needed to power a single one hundred watt light bulb for one day (Wikipedia, 2008).

Biogas helps reduce the Greenhouse effect.

Conversion of waste from cow manure into biogas can reduce emission of greenhouse gases by nine-nine million metric tons or 4%. The 30 million rural households in China that have biogas digesters enjoy 12 benefits: saving fossil fuels, saving time collecting firewood, protecting forests, using crop residues for animal fodder instead of fuel, saving money, saving cooking time, improving hygienic conditions, producing high-quality fertilizer, enabling local mechanization and electricity production, improving the rural standard of living, and reducing air and water pollution. (Wikipedia, 2008)

The advantages of biogas have not been tapped to the benefit Ghanaians. The potential for the development biogas plant on both large and small scale for commercial and domestic use respectively is very high in developing countries such as Ghana due to the need for alternative energy sources.

2.7 Review of Building materials in Ghana

Building materials are readily available in Ghana. However the cost of cement is relatively high due to the cost of imported clinker. It is however surprising about the general lack of use of locally produced building materials, especially wood. Ghana is a net exporter of timber.

In general, building materials have gone through a process of evolution and this has resulted in all kinds of improved building materials used from foundation to roofing. This section of the thesis seeks to bring to the fore some of the building materials that have been used over the years and their impact on affordability and energy efficiency. Some of these building materials include rammed earth, adobe brick and compressed earth block (CED) and interlocking stabilized soil block (ISSB).

2.7.1 Rammed earth

According to the Penguin Dictionary of Architecture, Rammed earth is known as Taipa in Portuguese, Tapial in Spanish and Pisé de Terre in French. It is a technique used in the building of walls using the raw materials of earth, chalk, lime and gravel. It is an ancient building method that has seen a revival in recent times as people seek more sustainable building materials and natural building methods. Rammed earth walls are simple to construct, fireproof, thermally massive, very strong and durable. Conversely they can be labour-intensive to construct without machinery (powered rammers), and if improperly protected or maintained they are susceptible to water damage. It is highly recommended for tropical regions due to its ability to keep room temperatures low. The availability of useful soil and a building design appropriate for local climatic conditions are the factors which favour its use (Wikipedia, 2008).

a. Construction technology for rammed earth

According to Willie Scott, rammed earth building technology is centuries old. It includes mixing soil with appropriate percentages of gravel, clay, sand and water into a damp workable mixture. Walls are formed by pouring the mix into a preformed framework where it is rammed down by hand or a machine using a tamper.

Building a rammed earth wall involves a process of compressing a damp mixture of earth that has suitable proportions of sand, gravel and clay into an externally supported frame, creating a solid wall of earth. Stabilizers are added. The ratio percentages of the various components are as follows; sand-30%, clay-65%, Gravel-1% and a stabilizer in the form of lime forming the remaining 4%.

Some modern builders add coloured oxides or other items such as bottles or pieces of timber to add variety to the structure. A temporary formwork is first built, usually from wood or plywood, to act as a mold for desired shape and dimensions of each wall section. The frames must be firm and well braced, and the two opposing wall faces clamped together, to prevent bulging or deformation from the high compressive forces. Damp material is poured in to a depth of between 100 to 250 mm (4 to 10 in), and compressed to around 50%. The compression of material is done iteratively in batches, to gradually build up the wall to the required height dictated by the top of the frame (Wikipedia, 2008).

Once the wall is completed after casting the framework can be immediately removed. This is necessary if a surface texture (e.g. by wire brushing) is desired, since walls become too hard to work on after about an hour. The walls are best constructed in warm weather (tropical region) so that they can dry and harden. Walls take some time to dry out completely, and may take up to two years to completely cure. Compressive strength increases with increased curing time, and exposed walls should be sealed to prevent water seepage. In recent times, rammed earth walls are constructed on top of conventional footings or a reinforced concrete slab base (Wikipedia, 2008).

b. Characteristics and benefits of rammed earth.

Rammed earths typically have low embodied energy and generate very little waste because locally available materials are used. The soils used are typically subsoil which is low in clay, between 5% and 15% typically with the topsoil retained for agricultural use. Rammed earth buildings reduce the quantity of timber needed as the formwork used is removable and can be continually reused.

Rammed earth can effectively control humidity where unclad walls containing clay are exposed to an internal space. Humidity is held between 40% and 60% which is the ideal humidity range for asthma sufferers and the storage of susceptible items, such as books. When cement is used in the earth mixture, sustainable benefits such as low embodied energy and humidity control will not be realized. Rammed earth can contribute to the overall energy-efficiency of buildings. The density, thickness and thermal conductivity of rammed earth makes it a particularly suitable material for passive solar cooling. Warmth takes almost 12 hours to work its way through a 350-millimetre (14 in) thick wall. The material mass and clay content of rammed earth allows the building to "breathe" more than concrete structures, significant heat gain. Rammed earth housing has been shown to resolve problems with homelessness caused by otherwise high building costs, as well as to help address the ecological dilemma of deforestation and toxic building materials associated with conventional construction methods. (Wikipedia, 2008)

2.7.2 Adobe brick

Adobe is a natural building material made from sand, clay, water, and some kind of fibrous or organic material (sticks, straw, and/or manure), which the builders shape into bricks using frames and dry in the sun. Adobe buildings are similar to cob and mud brick buildings. Adobe structures are extremely durable and account for some of the oldest existing buildings in the world. In hot climates, compared with wooden buildings, adobe buildings offer significant advantages due to their greater thermal mass, but they are known to be particularly vulnerable to earthquake damage. (Wikipedia, 2008)

a. Thermal property

An adobe wall can serve as a significant heat reservoir due to the thermal properties inherent in the massive walls typical in adobe construction. In desert and other climates typified by hot days and cool nights, the high thermal mass of adobe levels out the heat transfer through the wall to the living space. The massive walls require a large and relatively long input of heat from the sun (radiation) and from the surrounding air (convection) before they warm through to the interior and begin to transfer heat to the living space. After the sun sets and the temperature drops, the warm wall will then continue to transfer heat to the interior for several hours due to the time lag effect. Thus a well-planned adobe wall of the appropriate thickness is very effective at controlling inside temperature through the wide daily fluctuations typical of desert climates, a factor which has contributed to its longevity as a building material (Wikipedia, 2008).

2.7.3 Compressed earth block- CEB

Compressed Earth Blocks (CEB) are construction blocks made from a mixture of soil and a stabilizing agent and compressed by different types of manual or motor-driven press machines. The Interlocking Stabilised Soil Blocks (ISSB) is a variation on this as shown in Figure 2.14 The compressed earth Cement Block technology compresses soil mixed with cement (OPC, as a stabilizer) into a Soil Cement Block; and dry stacking, where the shape of the blocks achieves block interlocking.

Figure 2.14 Laid interlocking stabilized soil block (Source: UN-HABITAT/Adrian Perez, 2008)

ISSB technology is an affordable way of construction. The bricks are weatherproof hence; there is no need to plaster the building exterior. Also, due to its interlocking mechanism, little cement is needed between block joints and wall construction goes up quickly allowing for labor savings. (UN-HABITAT/Adrian Perez, 2008)

2.8 Standardization of measurements within homes.

Standardization of measurements within residential construction is very important because it enables easier replacement of technology in houses and more rapid implementation of emerging systems. Standardization also may improve construction quality which is often poor due in part to a low skilled, high turnover labour force by simplifying the construction process and decreasing the necessary labour skills thereby leading to the overall affordability of the building project (Path Concept Home, 2005).

Standardization is certainly not a new concept to the building industry. In fact, it is an essential element in an industry where thousands of separate parts and systems are manufactured, specified, installed, and inspected by a large cast of participants. Examples of standardization within the building industry include: timber sizes, spacing of structural members, dimensions for plumbing and gas lines, electrical capacities of components, duct sizes, doorway widths, countertop heights, trim widths, sheathing thicknesses (Path Concept Home, 2005).

Manufacturers, suppliers, designers, builders, contractors, and the building code community all rely upon these standards to integrate commonality, predictability, and efficiency into the building process. The focus of this study is to identify those areas within the building industry where standardization and compatibility enhancements will support buildings that are easier to construct, adaptable over time, and produced in a manner that is both efficient and easier to construct. In essence, standardized measurements is a concept of designing buildings with standardized dimensions and components that can yield improved quality, production efficiencies within a stipulated time (Path Concept Home, 2005).

2.8.1 Standardization of design dimension

Standardization of dimensions in the design phase is a powerful tool that can promote subsequent efficiencies during building construction. Standardization of dimensions employs a degree of modularity that enhances production efficiency, but it also allows for various degrees of customization by facilitating design alternatives within a structure. In a design approach using standardized dimensions, a standard grid (e.g., 2’x2’or 600x600mm) is used to lay out the structure of a building. Some builders might use one increment along gable walls (e.g., 4' or 1200mm and another increment along eave walls (possibly a half-increment). This approach leads to a floor plan in which most rooms end up with common dimensions example 12', 14', and 16'or 3600, 4200 and 4800mm respectively). The design of the interior floor plan will involve a much smaller grid, often in increments of 3" or 75mm to accommodate standard cabinet dimensions. Combining the structure's grid with the interior grid can then result in a collection of standardized design solutions in which rooms of standard dimensions can be fitted with an interior floor plan known to work within the space. (Path Concept Home, 2005)

Design standardization efforts yield more efficient production, yet they must also be viewed in the context of what building codes will allow. In some instances, design standardization efforts, such as using 2'or 50mm room increments, could actually conflict with code requirements, which often have a minimum room dimension that is not on a 2 feet increment (Path Concept Home, 2005).

2.8.2 Standardized Measurements for Modular and Whole House Systems

Standard measurements for whole-house designs rely on modules or components that individually or collectively make up the entire dwelling. Standardization at this level can provide significant onsite production efficiencies for a variety of housing applications. One example system is Spacebox, a self-contained studio residence made of high-quality composites. Units come with their own kitchen, shower, and toilet facilities, and each unit is equipped with a boiler, mechanical ventilation, and electric heating. The Spacebox unit complies with the requirements of the Building Act of Netherlands (Path Concept Home, 2005).

2.8.3 Production Process Standardization

Standardization of the building production process is a frequently cited limitation in the home building industry, especially when it is compared with highly standardized and automated industries such as the automobile industry. While houses may be built with many standardized components, the collection of these components and the manner in which they are assembled often results in a non-standard unit that can impede efficiency of production and result in material waste high cost of the product. (Path Concept Home, 2005)

Discussions of production process standardization often lead to the topic of factory building. Factory building may involve building entire house modules within a factory (e.g., modular and manufactured housing), constructing components like trusses or wall panels, or even bringing factory production processes on site to construction developments. Factory building can bring a strong measure of standardization to the production process, as many identical units can be manufactured on automated lines driven by software. Or taking this concept a step further into actual business and production issues – many individual units can be manufactured on lines driven by CAD and CAM software, which enables unique components to be efficiently produced within a standardized and automated process. Two challenges of standardization within factory building are 1) Allowing some measure of design flexibility, and 2) Integrating design, engineering, and production software such that customized component packages can be developed within a standardized production approach (Path Concept Home, 2005).

2.8.4 Component Standardization

Standardizing components within home building is a means to improve product compatibility, interchangeability, and production efficiency. And while it may seem counterintuitive, standardizing building components also serves to increase design flexibility. For instance, consider typical interior doors with standard dimensions of 2’ 6” or 750mm by 6’ 8” or 2000mm. Given this size standard, manufacturers are able to offer a huge spectrum of possibilities, with thousands of options ranging from less than $100 to several thousand dollars. If a door with non-standard dimensions is needed, however, the number of options is reduced to a few custom door manufacturers with limited styles and a much higher price premium (Path Concept Home, 2005).

In this example, standardizing the dimension of the door component has driven an enormous array of available products at a range of prices. Similar issues arise with the components used in residential mechanical systems like plumbing, where standardized components can lead to great flexibility for builders, contractors, and homeowners to repair, expand, and upgrade services. When systems like plumbing are comprised of standardized components and connections, the addition or replacement of components is a predictable task with many production options available and affordable. Beyond standardizing components, the use of simplified connectors and designing systems to be accessible further enhances the ability to modify services such as plumbing (Path Concept Home, 2005).

According to Path Concept Home (2005) standardization of components focuses on standardization needs that will support adaptable, flexible, and easily integrated building systems in a home. Since many technologies for flexible and adaptive homes are still evolving or yet to be developed, the discussions below highlight potential standardization needs that will emerge. Standardization can accelerate the adoption of new components. However lack of standardization may hamper implementation of new products.

2.8 Lessons learnt from the literature review

i. There is a real need for not just mass housing but a housing project that consider affordability and energy efficiency.
ii. Affordability does not mean cutting cost of construction by using inferior materials; it only attains affordability only in the short term. Hence reduction of

this cost by a significant margin is what makes any building project affordable and energy efficiency.

iii. The design must handle all the basic design characteristics of the tropics since it helps in reducing cost of energy use in the utilisation of the building. And that the use of material such as compressed earth blocks with high tendency to promote thermal comfort in interior space is a step to achieving energy efficiency in the use of the buildings at no extra cost.

iv. The use of standardization in design help to reduce waste in the building process thereby cutting down the overall cost of material used hence affordability of the project.

2.10 Case studies

This section reviews a precedence study that gives a detail account of an energy efficient project and an affordable but not energy efficient projects. Analyses of similar situations are used as basis to draw conclusions for the designing of the Affordable Energy Efficient Housing. The following projects were studied:

- Echlin-west End Street Terrace Apartments, Australia
- Beddington Zero Energy Development (BedZED), London
- Sakumono Estate, Accra.

2.10.1 Echlin-west End Street Terrace Apartments, Australia

The objective for the study of Echlin-west End Street Terrace Apartments project is to investigate how the entire planning and design was done to attain the following: Good Climatic response, Resource Efficiency and Affordability.

The Project is located in West End (Townsville) which falls within Australia tropical climate. Australia is located between latitude 19^o 13' S and longitude 146^o 48' E with greater portion falling within the tropical climate and its south-eastern and south-western corner falling within the temperate climate. The prevailing wind directions are North westerly during summer and south easterly during winter (Townville Port Authority, 1997).

The project was designed by David Stefanovic, of Architects North and developed by Brendon Douglas. It is a refurbishment of a warehouse site in Echlin St. West End. The prime objectives for carrying out this project were to achieve good climate responsive design, resource efficiency and affordability. The result of the project were three and two bedroom terrace apartments that are naturally cool and better to live in socially, economically and environmentally (Townville Port Authority, 1997).

According to Townville Port Authority (1997), a unit of the apartment comprise a lounge, dining, kitchen and laundry areas on the ground floor with two or three bedrooms and a study corner. A large deck at the front of the second level provides great outdoor living space and can easily accommodate 8-10 people and a small private balcony at the back. The apartments are also divided by a six metre deep paved courtyard entrance and secured covered car parks are located at the front of the homes. This allows enough ventilation and daylight to enter individual homes. Figure 2.20 shows the exterior view of the apartment.

Figure 2.15 Exterior views of Echlin Street Terrace Apartments. (Source: Townsville City Council Planning and Development Services 2007)

2.10.1.1 Resource Efficiency

The aim of the project was to make maximum use of resources available so as to reduce waste in the construction process. Part of the refurbishment involved retention of the concrete floor and section of the walls and the roof from the existing warehouse. The life span of the structural elements in the warehouse were extended by reinforcing weaker columns and walls and this resulted in merits including reduced quantity of demolition waste, avoidance of used and new construction materials and decrease in labour required for the construction process (Townsville City Council Planning and Development Services, 2007).

2.10.1.2 Affordability

More people are accommodated as a typical unit occupies only $84m^2$ of land area. The proximity of shops, schools, and public transport makes daily living convenient and relative cost of living moderate. The ability to refurbish an existing building has reduced construction cost leading to affordable housing option for buyers. As at the time (2005) the project was completed it valued $270,000 (Townville Port Authority, 1997).

2.10.1.3 Climate Responsive Design

The climatic responsiveness of building is investigated base on the ability of the building through its envelope to modify internal climate to achieve thermal comfort without excessive use of mechanical means such as the use of air conditioners and fans.

i. **Keeping out the heat through the use of Orientation and shading.**

   The terrace style housing was oriented to face north or south and this is ideal for the tropics. Majority of windows were facing north or south and are shaded by eaves and overhangs.

The west and east sun has less impact on the end walls and windows located there were kept small, tinted and high up under the eaves to reduce heat gain. Figure 2.16 and 2.17 show the plan and section of the apartment and an indication of air flow.

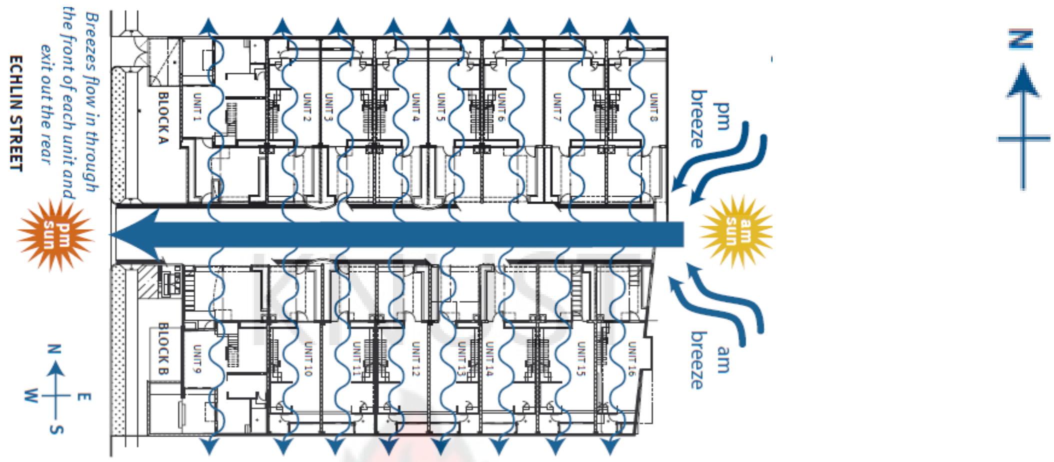


Figure 2.16 Plan showing air flow. (Source: Townsville City Council Planning and Development Services 2007)

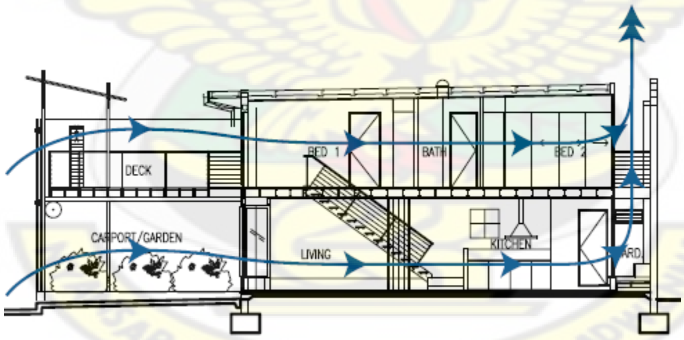


Figure 2.17 Typical section showing air flow. (Source: Townsville City Council Planning and Development Services 2007)

Gray tinted glass was used throughout mainly for privacy and also to reduce glare and its thermal resistance. The polycarbonate sheeting, shade sails and the main deck were used to shade outdoor spaces as shown in Figure 2.23 (Townsville City Council Planning and Development Services, 2007).

Figure 2.18 High level windows shaded outdoor space. (Source: Townsville City Council Planning and Development Services 2007)

ii. The Roof

The roof is colour bond and it is a good choice as it cools down quickly after dark. On top of the roof are roof ventilators which remove warm air from the roof space. A reflective solar paint (insulpro) was applied to the roof; this is very good in reducing the roof temperature and increasing thermal comfort in the upstairs rooms. (Townsville City Council Planning and Development Services, 2007)

iii. Capturing the breeze.

The prevailing breeze from the north-westerly and south-easterly are funnelled into the complex along an east-west aligned breeze corridor. Mesh screens were used along the east fence line to increase airflow through the centre of the complex. Figure 2.24 shows the perforated doors and mesh screen employed to reduce barriers to breezes

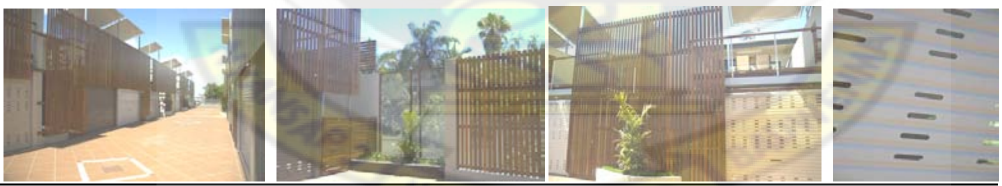


Figure 2.19 Methods used to reduce barriers to breezes. (Source: Townsville City Council Planning and Development Services 2007)

<u>Merits</u>

i. The design is sensitive to the tropical climate through the use of materials, orientation of the building structure.

ii. The design exhibits high quality of energy efficiency in design through appropriate window location, size and placement.

iii. The design also answers clearly, the question of affordability with the use of available material within the confines of the site hence reduction in the cost of transportation.

Demerit

i. Bath and toilet at the top floors are not exposed to the sun. This will aid the growth of bacterial in the wet areas.

ii. The use of sliding windows reduced ventilation into the spaces by 50% as only halve of the sliding panels can be opened to allow air into the space. (Townville Port Authority, 1997)

2.10.2 Beddington Zero Energy Development (BedZED), London.

The objective for the choice of this project as a case study is to find out modern and simple systems employed in building which aids in attaining energy efficiency and affordability.

The project is located in London, United Kingdom. It was designed by Bill Dunster. BedZED, a new collection of houses and flats in Beddington just like that of Holy Grail: a sustainable, high-density residential development which manages to reduce reliance on the car and protects the dwindling green belt from the bulldozers. It is a collection of 82 live/work terraces built on the site of a former sewage plant. This in effect, means that the project will use no more energy than it produces a target it achieves through the use of heavily-insulated buildings, photovoltaic solar panels and a range of energy-saving technologies such as light - emitting diodes (LED) and heating, ventilating and air conditioning exchangers (HVAC) and appliances. These combined will cut the total energy demand of a typical suburban home by 60% and the total heat demand by a staggering 90% (BedZED Eco-Village, 2008).

The project was designed to cut residents' reliance on the car and reduce the need for the dread commute through the provision of working spaces and a pool of electric cars powered by the electricity generated on site. Private car use is not restricted but parking space is limited and residents were encouraged to take advantage of the car pool and use local public transport wherever possible. There were on-site facilities such as a shop, a café, a healthy living centre and childcare unit which will also reduce the need to travel and an internet shopping link which allowed for a regular, co-ordinate community delivery service (BedZED Eco-Village 2008).

The buildings themselves have been developed to make the maximum and most efficient use of the available land but there was a concerted effort to provide a degree of diversity and ensure that the accommodation is aesthetically pleasing, light and bright, and responsive to a variety of needs. For example the use of the roof ventilators employed as shown in Figure 2.20 gives the development its unique character (BedZED Eco-Village, 2008).

Figure2.20 Aerial View of BedZED (Source: BedZED Eco-Village 2008)

Billed as a "mixed development urban village" the 82 dwellings range from flats and marionettes to town houses and mews. The backyard which one will normally find in a traditional terrace is used for workspace, but all the homes either have regular gardens or 'sky gardens' located on the roofs. Local materials were used wherever possible for the construction of the buildings. They include timber boarding and reclaimed steel joists. (BedZED Eco-Village, 2008). An isometric section through a typical building exposes all levels of building as shown in Figure 2.21 and the use of solar panel became a dominant feature on the roofscape as shown in Figure 2.22 below.

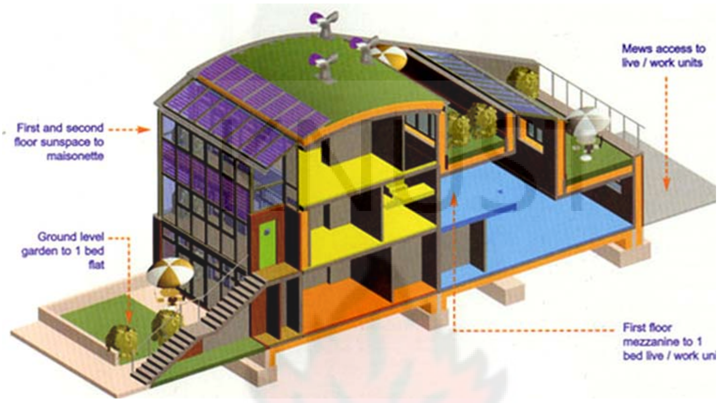


Figure 2.21 Isometric section through a typical BedZED building. (Source: diagram adopted from BedZED Eco-Village 2008)

Figure 2.22 PV panels on the roof and the roof ventilators (Source BedZED Eco-Village 2008)

2.10.2.1 Lesson learnt

i. The attainment of energy efficiency design is highly possible. The project is designed to use only energy from renewable sources generated on site. There are 777m² of solar panels. Tree waste fuels the development's cogeneration (the use of a heat engine or a power station to simultaneously generate both electricity and useful heat) plant (downdraft gasifier) to provide district heating and electricity. The houses also face south to take advantage of solar gain, are triple glazed, and have high thermal insulation to prevent excessive heat lose (BedZED Eco-Village, 2008).

ii. The use of photovoltaic modules is not cost effective in the short term but pays back in the long term (reduced Life Cycle Cost using energy) because the initial cost of installing the panels are higher compared to cost of accessing power from the national grid. According to Chris Twinn (2003) and a winner of the building service engineer 2002, designing the building concept around these principles allows the most cost-effective use of renewable energy. Covering a building in photovoltaic (PV) solar electric collectors may show environmental awareness and highlight new energy technologies, but in energy grading terms, PV's modest output and current high cost suggest there may be more pragmatic ways to provide renewable energy.

2.10.3 Sakumono Estate, Accra.

The main objective for selecting Sakumono Estate as a project for a precedence study is to investigate the cause of high utility bills as complained by user and to know how its layout meet the following; facilitation of activity, modification of climate and utilization of resource.

In undertaking the case studies, the following were given prime significance:

i. Location, modification of climate, and planning of the settlement.

ii. Utilization of resources to achieve affordability and energy efficiency.

Figure 2.23 The Sakumono Estate.

Sakumono Estate is one of the investments of SSNIT (Social Security and National insurance Trust). It was designed by architect B.S.L Sam of Design Associate, Accra. The target group include individuals and organisations; National Lotteries and the other corporate bodies. According to architect B.S.L Sam it was aimed at providing affordable housing for workers. The study of the estate is grouped under the following headings; Facilitation of Activities (flexibility of spaces), Climatic Responsiveness and Resource Utilisation.

2.10.3.1 Facilitation of Activities (convertible use of space)

The layout is well zoned; it has open space, civic area, educational zone, the main residential area, a commercial centre, a Temporal Health Post near a football park. The entire road network is of the grid iron with a parking ratio of 1:1; this ratio is inadequate so dwellers even go to the extent of parking on the lawns provided. The main residential area consists of one and two bedrooms two storey flats. Due to culture and economic reason the dining areas have been converted into study area or an extra bedroom, the store room into a kitchen, and the balcony into a shop. Figure 2.24 is Schematic Layout of the Sakumono Estate and Figure 2.25 and Figure 2.26 give a view of various uses in the apartment spaces provided, balcony changed into a shop, dining to a bedroom and store to a kitchenette.

Figure 2.24 Schematic Layout of the Sakumono Estate

Figure 2.25 Typical Balconies converted into shops.

(a) Dining hall partitioned to get added bedroom (b). Store into a kitchenette

Figure 2.26 Convertible use of space in the Police Flat.

2.10.3.2 Climatic Responsiveness

Orientation of buildings in SW-NE direction has resulted in internal temperatures being uncomfortable, so inhabitants resort to the use of extensive mechanical means of ventilation such as funs and air conditioners. Daylight in the spaces provided is very poor as thicker curtains are used to shade the interior space from the solar radiation. Invariably, the problem of poor daylight accounts for the high monthly electricity bills. The use of the balcony for shop reduces the air flow into the living space drastically.

However, flats that are close to the landscape areas (greens) have a much comfortable micro climate.

2.10.3.3 Resource Utilisation

The structural system is post and beam made of reinforce concrete. Sancrete blocks were used for the building envelope. Brick and Tyrolean finish were used alternatively at the stair well areas for aesthetic and orientation purpose as shown in Figure 2.31.

Figure 2.27 The alternative use of brick and Tyrolean finish at stair areas

2.10.4 Conclusions of Case Studies

- Roof ventilation is very vital in the design of energy efficient housing especially in the tropics.

- The use of energy-saving technologies such as light - emitting diodes (LED) and heating, ventilating and air conditioning exchangers (HVAC) and appliances is part of measures towards the attainment of energy efficiency in the use of the building

- Design of affordable housing should be flexible so that it can be able to accommodate change in use. For example the design for a dining hall should be flexible enough so that it can be converted to a bedroom if the occupants feel the need for an additional space. The same should be true for converting a balcony on a lower floor into a shop without compromising day lighting and natural ventilation. This can be done by providing separate openings into the living room without any obstruction from the balconies.
- Provision of adequate parking is essential so as to prevent parking of cars in the lawn which is designated for outdoor activities which is typical of the situation in Sakumono Estate. Figure 2.28 shows the parking situation in the Estate.

Figure 2.28 Cars parked on lawns and car park provided.

CHAPTER THREE

3.1 Methods used

The methods employed in the research include the following: Interviews, photography, literature review, personal observation, sketches and data analysis.

3.1.1 Interviews

Views were gathered from users of domestic spaces mainly on the factors which compel them to convert spaces into other uses. The interviews carried out established the fact that poor residential design has an adverse effect on energy use for domestic purpose.

3.1.2 Photography

Pictures were also taken to give a pictorial impression on the situation on the ground.

3.1.3 Personal observation.

General impression about the entire situation was analyzed and conclusions were drawn based on personal experience.

3.1.4 Case studies and precedence studies

Both local and foreign case studies were also considered together a broader knowledge base to help achieve the set objectives for the proposed Tema Community 23. These goals were discussed at the beginning of every case study.

3.1.5 Litterateur Review

Various literatures on the subject area of affordability and energy efficiency were reviewed. This is to help establish the need to further carry out a research into the subject of affordable energy efficient housing. The electronic media was also used for gathering international and local view point on the research topic. Some books of prime relevance on affordable energy efficiency housing were also consulted so as to have clear understanding towards the achievement of set goals.

3.1.6 Sketches

Sketches also became one of the methods employed in this research to make it a successful one. Sketches were also used as method of conveying the various options and concepts for the proposed design. Sketches were use to capturing functional layout and modified spaces due to the need for extra spaces for habitation and storage.

3.1.7 Data Analysis

Data gathered were critically analyzed using the following as guiding principles:

- Facilitation of activities; analysis of the room sizes and activities that go on in such space to arrive at the minimum floor areas required to comfortably carry out such activities.
- Climatic responsiveness. The various methods for providing thermal comfort in rooms were examined based on their energy efficiency.
- Resource utilization; the methods and material component were critically analyzed to ascertain the impact of choice of material to the attainment of affordability and energy efficiency.
- Affordability; daily expenses on utility bills against the initial cost the building over a period of time were considered to establish the fact of attaining affordability through the measures put in place to reduce life-cycle cost of using the building.
- Comparison with the ideal situation to draw a fair conclusion.

CHAPTER FOUR

4.1 Introductions

In this chapter, the discusses the findings from the proposed affordable energy efficient housing for Tema Tema Community 23.

4.2 Findings and Discussion

Below is the salient information about the process of designing the proposed affordable energy efficient housing for Tema Community 23. The proposal targets within the middle income class. From the general brief for the development, an accommodation schedule was developed.

4.2.1 Project Details

The Client for the proposed affordable energy efficient housing project is Tema Development Corporation –TDC- Tema. The funding of the project is through Public-Private Participation (PPP) strategy. This is to help reduce the cost of servicing the site as the Government of Ghana takes the responsibility of providing access road and other services such as portable water and electricity. The brief for the project includes the following: educational area (nursery, primary and junior high school), health centre, residential area (single bedroom flats, two bedrooms flats, three bedroom flats and mixed residential flats (Resi-Com), commercial area, recreational areas and worship area.

4.2.2 Accommodation Schedule

Based on the studies conducted, and the conclusions drawn, the brief was further expanded with the approximate floor areas. The Tables 4.1 to 4.4 below show the various areas of rooms for the different house types. They are based on the analysis of spatial requirement as per the activities that are likely to take place in the rooms. Refer to Table 2 in appendix for details on the zoning and recommended planning standard.

Table 4.1 Type A- one bedroom flat- 4 floors

Space	Area (m^2)
Bedroom/Living room	21.5
Kitchen	6.1
Utility area	3.4
Sanitary	2.6
Lobby	2.0
Storage	3.2
Circulation	53/4=13.25
Total unit Area	**52.05**
There for the Area per floor of four units	52.05* 4= **208m²**
Total area of four floors	208*4= **832 m²**

Table 4.2 Type B- Two bedrooms flat – 4 floors

Space	Area (m^2)
Bedroom 1	12
Bedroom 2	14
Kitchen	12
Utility area	7.4
Sanitary	2.6
Lobby	2.0
Storage	2.6
Yard	5.2
Living/dining/ working area	31
Balcony/laundry	2.2
Terrace	5.5
Circulation	17/2=8.5
Total unit Area	**96.5**
Area per floor	96.5* 2= **193**
Total area of 4 floors	193*4= **772**

Table 4.3 Type C- Three bedrooms flat – 3 floors

Space	Area (m^2)
Bedroom 1	12.3
Bedroom 2	12.5
Master Bedroom/sanitary	14+2.6=16.6
Kitchen	10
Utility area	5
Sanitary	3.2
Lobby	2.0
Storage	9.4
Yard	6.2
Living/dining/ working area	28
Balcony/laundry	5
Terrace	9
Circulation	12/2=6
Total unit Area	**125.2**
Area per floor	125.2* 2= **250.4**
Total Area of 3 floors	250.4*3= **751.2**

Table 4.4 Type D- one bedroom with shop - 2 floors (RESI-COM)

Space	**Area (m^2)**
Bedroom	20
Kitchen	7.3
Utility area/yard	2.0
Sanitary	3.0
Lobby	1.7
Storage	5.7
Terrace	4.7
Circulation	12/2=6
Total area per unit	**50.4**
Area per floor	50.4* 2= **100.8m^2**
Total area of 2 floors	100.8*2= **202m^2**

4.2.3 Functional Relationship Diagram

Figure 4.1 below is the resultant of the various activity flow pattern usually characterized with housing and planning schemes. It indicates the flow of drainage system, direction of waste collection and relationship between the residential, open space, educational, commercial, civic and waste management zones.

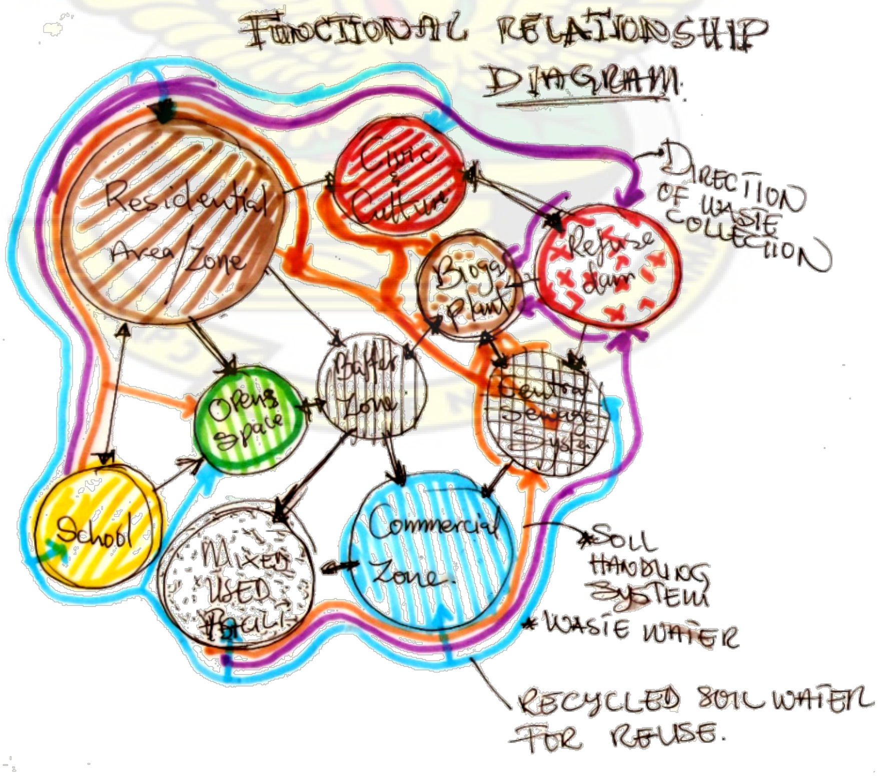


Figure 4.1 Functional Relationship Diagram

4.3 The Site- Proposed Tema Community 23.

4.3.1 Site description

The site is located about 2.077km away from the Accra-Tema motorway in the Greater Accra Region of Ghana and it is to North-West of Adjei Kojo and Kanewu Village. It is bounded on the north-west by the proposed site for Accra International Hospital, the Nungua Farms are to its extreme South-West and the proposed site for Trassacco Valley is at its the immediate South-West. The site is also bounded on the extreme North by Santo village and Tema Community 24.

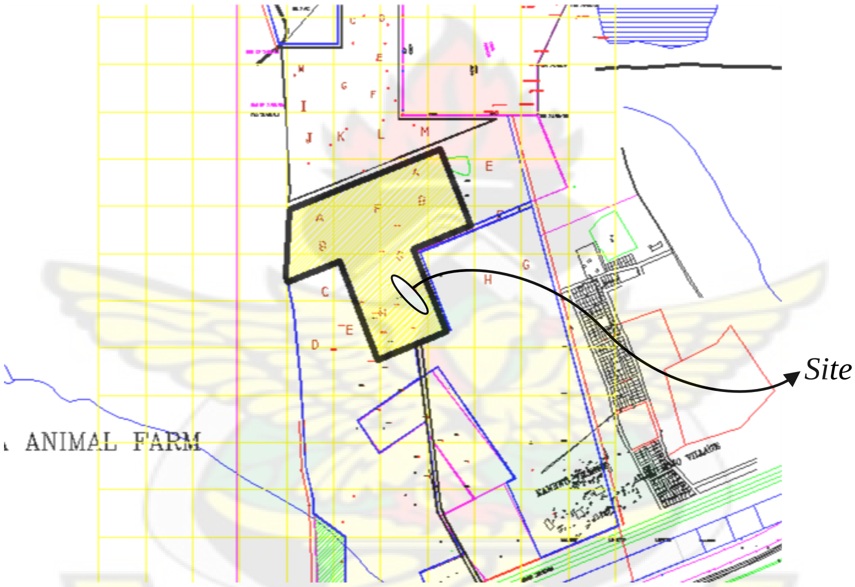


Figure 4.2 Site plan for the Proposed Affordable Energy Efficient Housing

The site is T-shaped and at an angle of about 30 degrees in relation to the true north. It measures 1041m on the longest side and 526m, 397m, 569m, 468m, 670m, 358m, and 416m as indicated in Figure 4.3 below. The area of the site is approximately 86.24 hectares.

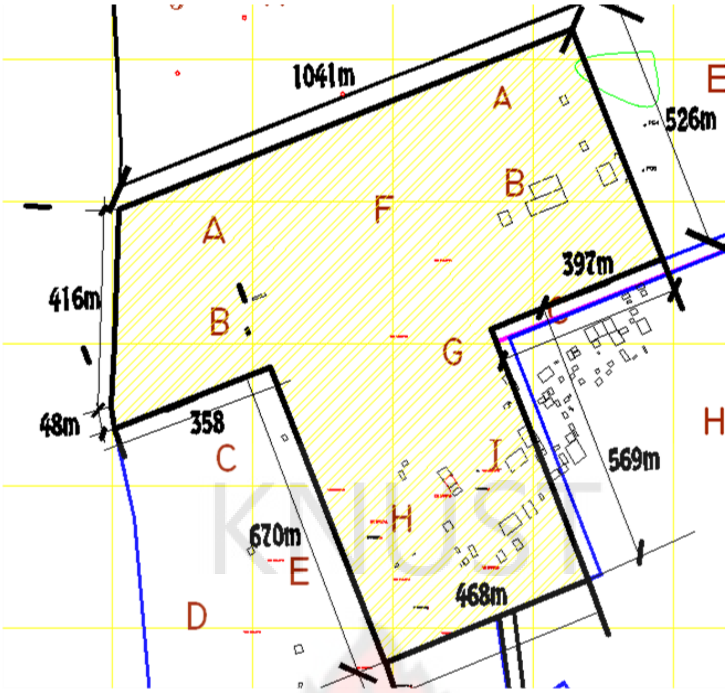


Figure 4.3 Site plan (Source: TDC, 2006)

4.3.2 Site Criteria and Justification

Two sites were allocated for the housing project. These are Obosomase New Town in the Eastern Region and Tema community 23. Obosomase New Town site stretches from Bawaleshie in the Greater Accra to Obosomase in the Eastern Region. One major determinant was the topography. The topography of the Tema Community 23 site is a gentle sloping compared with steep slopping Obosomase site. Tema Community 23 site was selected due to its gentle slopping topography.

The Tema site is also originally designated for the development of Housing, under the HOS (House Ownership Scheme) by the Tema Development Cooperation which makes it highly devoid of any land litigation and other limiting issues associated with land acquisition in Ghana. Its location is very good due to its proximity to the CBD and the Accra Mall at the Spintex Road compare to that of Obosomase almost in the Eastern Region.

The Tema site is easily accessible from the neighbouring communities in the north through Santo village and Tema Community 24. It has available basic utilities in the form of water and electricity. The Lake at its extreme North-East can be harnessed to the benefit of the users of the proposed housing scheme.

4.3.3 Site Inventory

4.3.3.1 Access

The main access to the site is from Kanewu village, Adjei Kwodjo village and the Nungua Farms through the proposed site for the Accra International Hospital. There is a minor access from community 19 from the south of the motorway (Over-head one-way).

4.3.3.2 Topography

The site is generally gentle sloping. The lowest and the highest points on the site are 45ft. (27m) and 97ft. (58.2m) above sea level respectively. This resulted in a change in height of 31.2m with a gradient of 1: 0.042 or a gradient percentage of 4.16%. (Source: TDC, 2006)

4.3.3.3 Drainage

Due to the slightly undulating nature of the site and the valley at its south-west, surface water is collected at the lowest point during the raining season. However, there are no constructed drainage systems.

4.3.3.4 Geology and Vegetation

The site is dominated by lateritic soil with clay base and some metamorphic rock out crops. The vegetation on the site is sparsely populated with savannah shrubs.

4.3.3.5 Microclimate

The site is of NNE-SSW orientation from the true north traversed by SW Monsoon winds from the Atlantic Ocean and NE Trade winds from the Sahara. Temperatures range from 23-30 degrees with one rainy season of 800-1200mm annually (Source: Meteorological department, 2006).

4.3.4 Site Analysis

4.3.4.1 Strengths

The site is just appropriate for such a scheme with respect to its location within the Tema metropolis.

i. The topography is also good as it makes it easier for locating some ancillary facilities for the smooth running of the community.
ii. Its central location between the proposed Trassacco Valley and neighbouring villages including Borteyman (site for the Affordable Housing Scheme) makes the site highly marketable.
iii. The project will act as a platform for the implementation of measures for attaining affordability and energy efficiency when it takes off.

4.3.4.2 Weaknesses

i. The lowest part of the site may be prone to flood during heavy downpour. Cost for design and construction of drainage system to prevent flooding of the site in the future would go a long way to affect the affordability of the project.
ii. The site is also not serviced with electricity, portable water, ICT or even telecommunication. The cost such services to site will adversely affect the entire cost of the project.
iii. The absence of tarred roads on the site makes it difficult to transport construction materials to and from the site and thereby increase the construction cost of the development by about 70% (GREDA, 2007 as in National Agenda,2007).

4.3.4.3 Opportunity

The site is a virgin land to develop with fewer limitations.

i. The topography and the level of the water table is good as ball hole can be created to supply water to the community to supplement that from the Lake and the Ghana Water and Sewage Company.

ii. Its proximity to the Nungua Farm is just good; it would supply raw material needed to run the proposed Biogas Plant.

iii. Its proximity to the lake is also advantageous because water could be channelled from the lake to the site for construction and other use.

4.3.4.4 Threat

The neighbouring village are likely to put pressure on the few social amenities to be provided for the community. The prepossessed Trassacco settlement will also increase the standard of living compared to the living standard of the target group.

4.4 Design Philosophy and Concept

4.4.1 Design Philosophy

The morphological development of any settlement in Africa and Ghana in particular is based on individual households coming together around an open space or along a major road as seen in typical Ashanti settlements. The challenge has been, keeping an enabling environment to grow this beautiful culture of togetherness. (Hannah Schreckenback, 1983)Therefore, the design philosophy for the Affordable energy efficient housing is "United in Comfort"

4.4.2 Design Concept

The design concept is taken from the attributes of the umbrella**.** Figure 4.4 (a) demonstrates how an umbrella provides shade for users against the vagaries of the weather. This attribute of the umbrella was adopted and interpreted architecturally to provide shelter for the urban dwellers. Figure 4.4(b) also shows the flexibility of the umbrella in terms of directing it to provide cover from wind led rains.

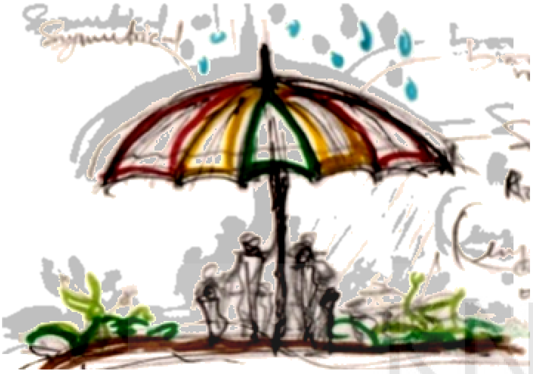


Figure 4.4 a .Provision of shade from sun and cover from rain

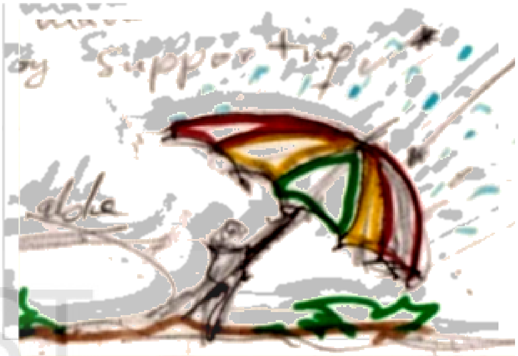


Figure 4.4b adjusted against wind led rains.

4.4.2.1 Attributes of the umbrella

i. It provides shade and allows cross ventilation.

ii. It is affordable and energy efficient. The price of Umbrella is affordable compared to building a roof over one’s head and allows free air circulation under it. It also provides shade for its users.

iii. It is adjustable or flexible; it can be reduced in size for easy handling in times when it is not being used.

iv. It creates environment for sharing during raining season.

v. It is also the symbol of prestige when used by chiefs and kings.

Therefore, the concept is translated in the following architectural language to achieve the philosophy.

i. Creation of an open courtyard which is the outcome of the configuration of individual building blocks. This open court would be the meeting place for individuals and families in the community.

ii. Creating a design that is affordable and energy efficient; (tropical architecture) to the target group.

iii. Creation of design that is flexible to the needs of the user.

4.5 Conceptual Site planning

The site is planned in accordance to planning standards in mind. The site is divided into eight (8) zones namely educational zone, health facility zone, residential zone, commercial, industrial zone, recreational and open space zone, civic and cultural zone and institutional zone. Colours were used to differentiate the various zones for easy understanding of the thought process. Residential zone is the predominant and it is represented with brown in accordance with the Ghana Planning Standards.

4.5.1 Option 1

Figure 4.5, is characterised with patches of cul-de-sac and open spaces. It is dominated with a residential zone (brown colour) with core zone accommodating commercial hub, civic and culture centre, open space with industrial zone to its north-west of the core which is referred to as the heart of the entire layout. However this option lacks consideration for a transport terminus, a buffer zone such as a green belt to act as a buffer between the residential and the industrial where the biogas plant for the project is located.

4.5.2 Option 2

Unlike option 1 as shown in Figure 4.5, option 2 has a broad consideration for making such a housing project serve as a source reference for similar development. It combines the concept of locating the commercial zone close to the major road that links the north to the south of the settlement. It adopts the honeycomb road network with planted open spaces. The commercial centres are fairly distributed among the residential zone to prevent congestion at the heart of the settlement. There is a buffer zone (green belt) between the industrial area and the residential zone.

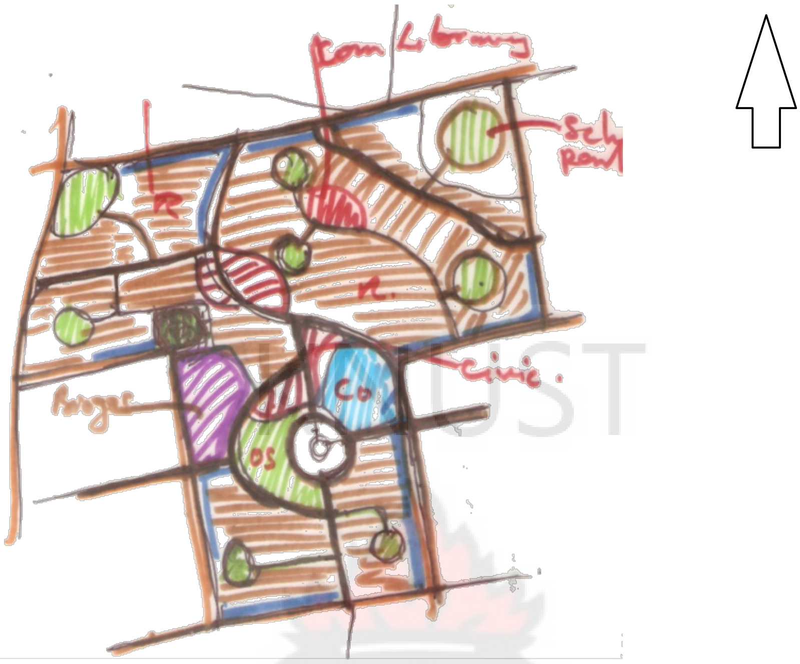


Figure 4.5 Conceptual site planning, option 1

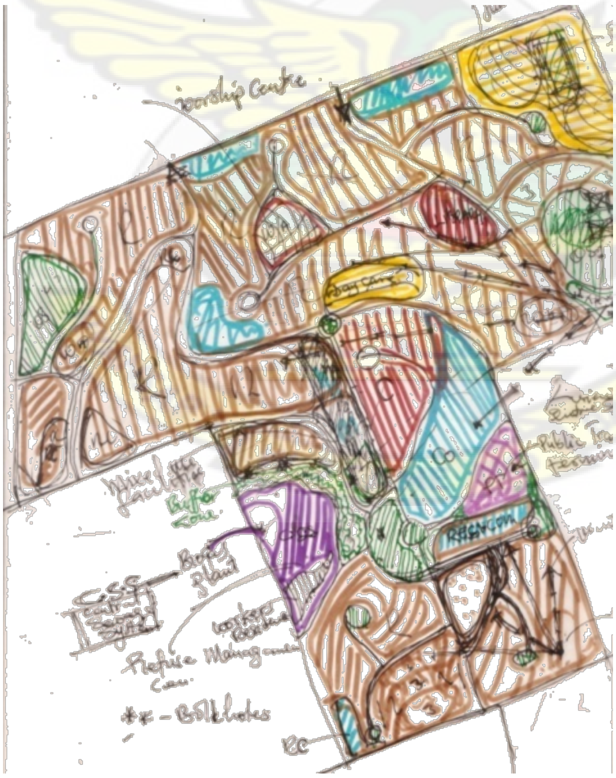


Figure 4.6 Conceptual Site Planning- option 2.

4.5.3 Merits of Option 2 over Option 1

i. Option 2 takes advantage of the various views at the various aspect of the site to locate civic and commercial zones.

ii. Option 2 provides an access from the educational area into the central core. There was no such provision in the option 1.

4.6 The Design

The Affordable Energy Efficient Housing for Tema Community 23 has gone through a number of considerable design processes. Efficient spatial configuration, building orientation and land use planning techniques were all considered during the design process. The design philosophy and concept were used to guide design decisions.

4.6.1 Block Plan

There are four major accesses to the site; the major access leads one from the southern part of the site through the residential zone to the round-about which is philosophically regarded as the heart of an organism; from where blood (vehicular and pedestrian traffic) is pumped to the other part of the community. A by-pass is strategically created so as to prevent the possibility of heart-attack at the core. The nature of the road network was determined by the topography; it is a way of reducing a lot of levelling work needed to be done before the roads would be constructed thereby reducing the cost of developing the layout by considerable margin. Research has shown that out of the total cost of construction, 70% of the cost goes into the servicing of the site and the provision of access road. So targeting a reduction in this direction is a step to attaining affordability of the project (GREDA, 2007). The entire block plan is oriented (north-south) for maximum performance and achievement of great level of comfort in the interior spaces provided so as to attain the energy efficiency of the individual units.

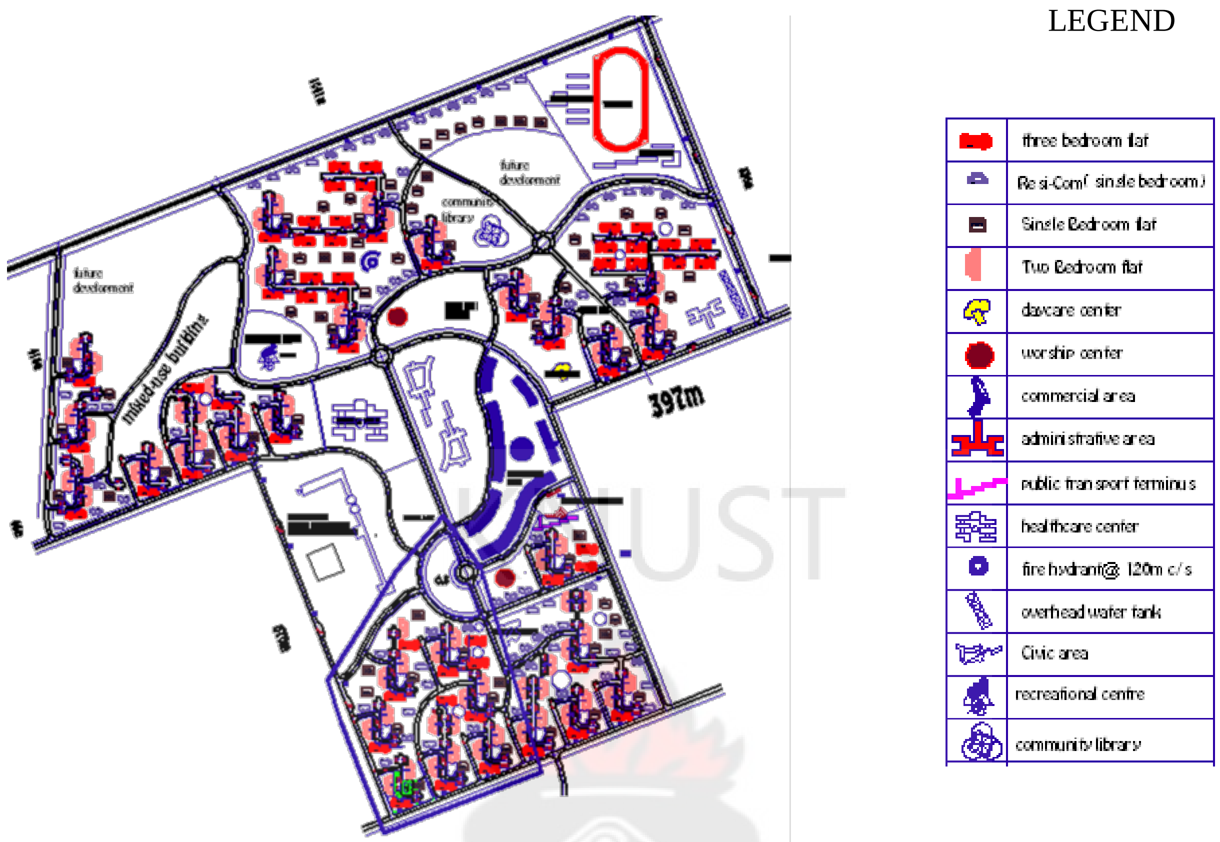


Figure 4.7 General Layout of the proposed Community 23

The core of the layout houses the following; commercial zone, public transport terminus, civic zone, health centre, open space, and buffer zone, light industrial zone including the biogas plant, central sewage system and refuse management area. The school is also located at extreme NNE of the site and it is at the periphery so that users can also have access through the community to reduce vehicular congestion. Members can also drive easily to the periphery of the site and access the school easily without much constraint.

The layout is also dominated by open spaces to depict the importance of open spaces in our culture as shown in Figure 4.8 below and they are also philosophically regarded as nucleus (providing energy) of a living cell (community) fostering unity among members (plasma membrane of an animal cell).

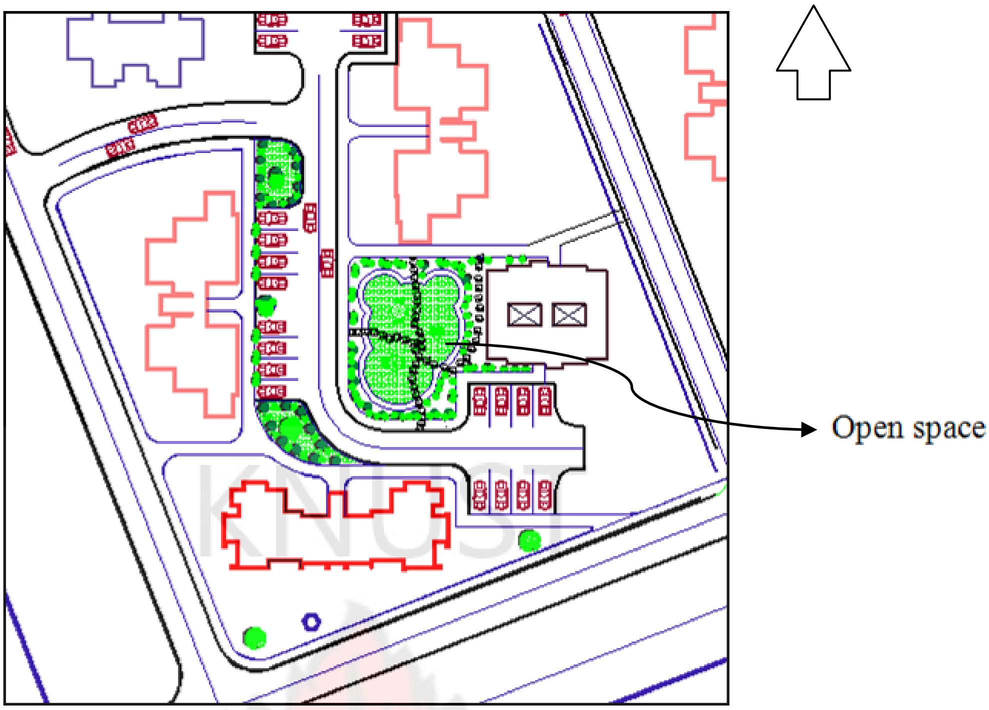


Figure 4.8 A typical layout for sub-sector

4.6.2 Plans

The plan utilises a 300mm, 50mm and 25mm as the basic module for generating room sizes. The standard bedroom sizes were kept between 3.6m x 3.6m and 3.6 x 4.2m. This is to makes easier for standard fitting and fixtures to fit perfectly without dead area since most of these fittings were manufactured in accordance with modular sizes of 50mm or 25mm.

From the stairwell one can easily have access to the two units on either side of the staircase. This is a way of attaining affordability of the each of the blocks compared with the situation at the Sakumono Estate, where two staircases serve one block and the landing ends abruptly on the entrance of the a unit. So in the development of the design, an opened transitional zone was created to allow room for free movement from and to the stair well. 95% of all openings and fenestrations are to the North-South orientation

The kitchen being the busiest part in each unit, is located such that parents can have unobstructed views to the court where children would play. Also the configuration of the various spaces is functional as clear lines are drawn to separate semi-public, public and private areas within each house unit. Figure 4.9 shows a typical two bedroom plan.

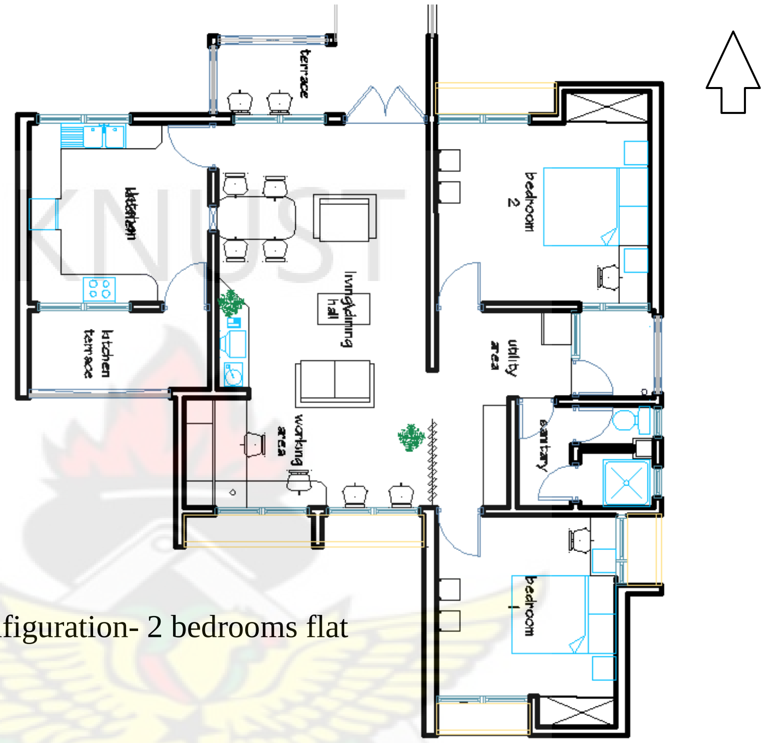


Figure 4.9 Typical spatial configuration- 2 bedrooms flat

Rooms created can be used for different purposes at different times. For example a typical one bedroom could be used as a living and dining space in the day time by simply adjusting bed to fit into the adjacent wall.

Instead of providing separate store rooms, storage spaces were provided under windows so that dual benefits can be derived; the recess nature shade the windows from the solar radiation thereby improving thermal comfort in the rooms and providing space for storage. Affordability is attained as the cost of constructing separate storerooms is saved to reduce the overall cost of construction.

4.6.3 Structure/Form

The two bedroom flats are four levels, three bedroom flat and adjustable one bedroom are in three levels with the residential commercial unit (RESI-COM) being two levels. The frame system of construction was employed as an appropriate construction method for rapid and constructive results. The use of the compressed stabilized earth is motivated by the fact that, for this particular type no mortar joints are needed thereby reducing cost and time needed to erect a structure.

4.6.4 Elevations

The entire site elevation is characterized with the inter play of volumes of two, three and four floors separated by open space to prevent monotony. The roofscape also creates a very unique view as it is dominated by the roof ventilators mounted on the barrel roof.

4.6.5 Materials

Stabilized compressed earth is the main walling material use for the project due to its cost-saving properties. Figure 4.10 is an image showing the interlocking stabilized compressed earth blocks used for the construction of a building.

Figure 4.10 Stabilized compressed earth blocks

Building element	**Materials**
Walls--	Compressed, stabilised earth blocks
Columns and beams--------------------------	reinforced concrete
Doors---	Furnished timber frames with timber Panelling
Windows--------------------------------------	Furnished timber frames with tinted glass.

Floors --	Wrought terrazzo for sanitary spaces Polished terrazzo for main spaces
Balustrades-------------------------------------	Aluminium base metal balusters and Railings
Shading devices-------------------------------	Aluminium base metal
Roofs---	Green mixed with insulpro as finish for aluzinc long spans cut to specification with timber fascias fixed to timber sprockets

4.7 Services

The main service considerations are the use of vertical and horizontal ducts distribution system. The following are the main services provided:

i. Electricity- from the Biogas Plant
ii. Telecommunication
iii. Water supply-cold
iv. Fire-fighting equipment
v. Gas from the Biogas to various unit for cooking
vi. Storm water drainage/ rain water harvesting
vii. Refuse disposal and Soil and waste water drainage

4.7.1 Electricity / Biogas Plant

A sub-station will be created at a vantage point. Supply of electricity will therefore be tapped by using underground armoured cables (three phase supply) and it will only be used as a supplementary power source. The biogas will supply the community with 75% of the needed energy to run the community effectively. The entire block will be connected to the control panel from where faults would be detected and rectified. Pre-paid system of billing would be employed.

4.7.2 Telecommunication

Telephones and intercom facilities will be installed in every block to facilitate communication in and around the community and to connect the community to the rest of the world. Alarm systems will be installed at the stairwell so that visitors can easily have access to responds from the floor they are visiting without going up the stairs.

4.7.3 Water supply

Fresh water would be tapped from the Lake at the extreme North-East of the site. This water will be supplied to sanitary areas and the landscape will be watered with water from the Lake. This is a way to reduce utility bill from the use of water from Ghana Water Company. Overhead tanks will also be erected at the highest part of the site so that water could be supplied to the various blocks under gravitational force. Water from the boreholes created will be connected to the overhead tank through PVC pipe of 100mm diameter. A pump of 35 head meter will be installed to aid in conveying water from the lowest point of the site to the highest part of the site. The specification of the pump with such a head meter is due to the change in level of 31.2m able sea level.

Individual installation of poly tank will not be encouraged by the design; this is due to unsightly roofscape due to the use of overhead poly tanks. As part of control measure, a stand- by overhead tank would be installed to ensure the constant supply of water to the community.

4.8 Passive Cooling.

Wider openings have been provided to allow free flow of fresh air in and around the buildings to prevent internal heat load and to improve thermal comfort in the interior spaces. The buildings were also oriented in the north-south direction so that only a small percentage of the wall areas were exposed to the solar radiation.

4.8.1 Fire fighting provision

There is the provision of fire safety equipment and fire hydrants are located at intervals of 120 metres along the main roads.

4.8.2 Cooking gas supply

Methane gas produced from the operation of the biogas plant is channelled through copper pipes into the various kitchens to be used for cooking. An automated billing system would be connected to the control panel. Gas from the plant is supplied at an affordable price through a prepaid meter system.

4.8.3 Storm water drainage

Storm water will be collected from roofs through P.V.C pipes to water surface drains.

4.8.4 Refuse Disposal

Refuse shute is installed from upper floors at the stairwell area to collect refuse that are already separated into organic, plastic or polythene and breakables such as glass from the kitchen. The shute has a bigger base and separate chambers to collect the various type of refuse. This is to facilitate faster and cheaper handling and recycling of the refuse so collection can be done promptly and effectively so as to keep the environment clean at all times. Bins will be located at appropriate points in the community.

4.8.5 Soil and waste drainage

All waste from sanitary areas will be channelled to the Central processing unit for the biogas plant. Treatment is also carried out at the central processing plan.

4.9 Landscaping

Landscaping has been employed as an integral part of the entire community planning. The various courts in the centre of a cluster of block would be neatly landscaped with variety of plants with sweet scent and lawns regularly kept neat. The courts would be furnished with street furniture so that meeting of members within the community can take place there easily so the philosophy of unity would be attained.

The residential areas would be 80% pedestrianized zone with paved walkway made of compressed stabilized earth with pronounced concrete kerbs. The choice of the paving material was due to its eco-friendliness and cost effectiveness. More of soft landscape element would be encouraged over the hard one; the use of hard landscape will be highly minimized compared to the use of the soft landscape due to its significant ability to increase the local temperature. The soft landscape element has the inherent quality of helping passive thermal control in the environment created.

Below are other areas of focus

- All the parking areas are going to receive designed pavement blocks of compressed stabilized earth in different coloured shade to prevent monotony in the community with pronounced kerbs.
- The water from the lake would be channelled to the open spaces so that the plant material would be kept fresh irrespective of the season.
- Courtyards will receive special soft landscaping with sand, stone and water features.
- Creeping plants would also be planted especially at the eastern and western facades of the individual blocks. This is to help in shading exposed walls thereby preventing excessive solar radiation into rooms.

4.10 Costing

This costing is an estimate to give the client an idea of the financial investment the project will need. The cost per square meter of construction is, **GH¢474.71** and this figure is used for the cost of the entire project.

In order to arrive at a realistic cost per unit area as indicated above, current rates must be use in preparing a Bill of Quantities from which the cost per unit area can be generated. The proposed two bedrooms were used as the basis for generating the cost per unit area.

4.10.1 Cost per Unit Floor Area Analysis

Total cost of building of the 4 units two bedrooms flat.	GH¢354,968
Total Internal Floor Area (96.5m^2 x 8)	772.0m^2
Therefore the cost per unit area	GH¢459.8

Refer to appendix 3 for the summary of the bill of quantities for two bedrooms flat.

4.10.2 Costing of project per Sub Sector.

Refer to appendix 5-.Summary of cost for the entire project. With accurate project management skill and material use the above figure can drastically be reduced by 20-40%

CHAPTER FIVE

5.1 Introduction

This chapter brings to the fore the general conclusions and recommendation arrived at of the design for the proposed affordable energy efficient housing project for Tema Community 23.

5.2 Conclusion

Ghana needs to be liberated from the accumulation of housing deficit. Without a second thought about the viability of the project, it must be accepted with both hands and implemented.

Affordability of the buildings and their energy efficiency are attainable through the use of standardization in design (utilization of 300mm, 50mm, and 25mm as basic module for generating room sizes). Standardization helps to reduce waste during construction as the dimensions of space are harmonized with dimensions of finishes, fitting and fixtures through the reduction of construction waste.

It is also evident through this thesis that affordability is attained not through the reduction of sizes of the spaces required by users but it has more to do with the elimination of dead space such as long corridors and large terraces that end up abandoned in the long run. If such dead spaces are designed to be multi functional, there would not be the need to reduce the livable space with the aim of reducing the per square meter cost.

It was evident that design principles such as passive solar design, appropriate orientation and use of courtyards are vital in planning affordable and energy efficient projects in the tropics. Again, avoiding the use of quality materials would increase cost of using the building in the long term. In the design of affordable housing project, efficient land use planning is basic in making the design a success.

The use of energy-saving technologies such as light emitting diodes (LED) and heating, ventilating and air conditioning exchangers (HVAC) and appliances plays a vital role when considering energy efficient measures in housing. Hence, with the ever-growing demand for housing for urban dwellers in Ghana points to the fact that the consideration for development of the affordable energy efficient project for the proposed Tema community 23 does not call for a second opinion.

5.3 Recommendation

The following are the recommendations that would be of immense benefit to the country in the area of developing affordable housing if it could be given the needed attention in the near future.

First, the use of local material and improved procedures of using them in building should be given intensified publicity and relieve should be given to citizens, private developers who decide to build with local material such as lancrete blocks and bricks. Also most public buildings should be built with local building materials so as to instill confidence in the use of the local building materials.

Second, all land banks acquired by government must be serviced and given out to private developers who are ready to conform to the affordable energy efficient design guide mentioned in this research, at a reduce cost so as to encourage them to help reduce the housing delivery deficit through the Public- Private Partnership.

All the above recommendations when implemented would go a long way to reduce the housing delivery deficit that the country is facing in recent times. Finally, policies should be developed to encourage the building of more affordable and energy efficient housing project. This can be done by setting up a council to examine housing projects on the criteria of energy efficiency and affordability and giving credit facilities with relatively lower interest margin for development of such nature.

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APPENDICES

APPENDICES

Interior Perspectives

Interior perspective of the proposed 2-bedrooms flat

Interior Perspective showing the work area in the living/dining area

Exterior Perspectives

Showing the 2-bedrooms flat and the 3-bedrooms flat.

Perspective of the proposed affordable energy efficeint housing showing the common court

Layout of Sub-Sector A

Aerial view of Sub-sector A

Appendix 1 Prices of building materials in Ghana, 2007

Typical Building Materials	GH ¢ Retail Price
Cement Bag 50kg	92
Sand (15 cubic meter)	240
Stone (15 cubic meter)	320
Water (2,500 gal)	35
6" Block	0 .80
5" Block	0 .70
2 by 4 Wood (soft wood)	4.50
2 by 4 Wood (hard wood)	7 .00

2 by 6 Wood (hard wood)	9.00
Wawa Boards 1 x 14 ft (1 inch)	8.00
Binding Wire (full coil)	75.00
30ft Iron Rod (.25 inch)	4
30ft Iron Rod (.5 inch)	10
4 Inch Nails (1 box)	30
2.5 Inch Nails (1 box)	30
Roofing Nails (per square meter)	5
Ridge Cap	5
Aluminium Roofing Sheet 3 x 6 ft (.5mm)	17

Appendix 2 Zoning and Recommended Planning Standards

ZONE	BRIEF	AREA sq metre	REMARKS
EDUCATIONAL	1.Nursery	55.74	Should be located in close proximity to residential areas
	2.Primary	12140.6	Should be located within neighborhood of up to 5000 people
	3. Junior High School	16187.4	Could be sited between two neighbourhoods up to 10000 people
		0	
HEALTH FACILITY	Health Centre	10117.14	Site must be easily accessible by road,
		0	
RESIDENTIAL	Single bedroom Apartments	703564.11	The area is the total land area, to be use to determine the density
	Two bedrooms apartments	0	Using 150 people per hectare, target population is 12,936
	Three bedrooms apartment	0	
	Mixed rexidential - RESI-COM	0	
		0	
COMMERCIAL	Large depatment stores	10000	The whole settlement area and its peripheral influence
	General merchandise	0	close proximity to a public transport terminal post office
	Hardware stores	0	Location should have good access to major roads
	Restaurants	0	
	Small shops and stores	0	
	Services enterprises	0	
		0	
INDUSTRIAL	Land for light industry	8093.71	Location of industrial site must ensure protection of
	Regular supply of pipe water	0	near by residents from industrial pollution.
	Fire fighting facilities	0	
	Adequate access to site	0	
		0	
PARKING	Residential (one family) house and apartment	0	Class III and IV- 1 for each building block
		0	
RECREATION AND OPEN SPACE	Active Recreation	8093.71	5000 to 35000 people
	Football field ,tennis courts	0	Generally located and within easy reach to
	Large hall for table tennis, badminton	0	catchment area should not exceed 45 min
		0	must be supplied with Water and electricity
		0	
	Passive Recreation	0	
	public open spaces	86,198	Minimum of 2500person per 0.5ha
		0	not less than 10% of development
		0	
		0	
CIVIC AND CULTURE:	worship center	7000	A neighbourhood or a small settlement.
		0	Up to 15,000 people
		0	0.35ha to 0.7ha.
		0	Central location with good vehicular access
		0	Within 15minutes walking time from most houses
		0	
INSTITUTIONS	Fire fighting facility	200	Settlement up to 35,000 persons
		0	A minimum area of 200m2 to afford ample
		0	space on site for parking and maneuvering
		0	of at least three 400 gallons capacity water tender truck
	neighbourhood post office	30	Up to 15,000 people
		0	
		0	
	Telephone Exchange	300	Minimum of 1 telephone to 25 persons
	TOTAL	**861980.41**	
	TOTAL LAND AREA	86190.4	

Appendix 3 Summary of the bill of quantities for the two bedrooms flat.

	Description	Qty	Unit	Rate	Amount
	GENERAL SUMMARY				
	BILL No. 1				
A	GENERAL CONDITIONS AND PRELIMINARIES AND SCHEDULES OF DAYWORKS RATES(17%)				45,053
	BILL No. 2				
B	SUB-STRUCTURE				29,978
	SUPERSTRUCTURE				
C	GROUND FLOOR				43,439
D	FIRST FLOOR				51,778
E	SECOND FLOOR				51,918
F	THIRD FLOOR				71,404
G	STAIRCASE				8,500
H	ROOF VENTILATOR				8,000
	SUB-TOTAL				265,017
	TOTAL (1)				310,070
I	EXTERNAL WORKS (8%)				24,806
	TOTAL (2)				334,875
J	CONTINGENCY (6%)				20,093
	GRAND TOTAL				354,968

Item	Description	Qty	Unit	Rate	Amount ¢
	SUMMARY				
A	CONCRETE WORKS				22,069
B	BLOCKWORK				3,315
C	JOINERY				3,300
D	ELECTRICAL INSTALLATIONS				5,600
E	CARPENTRY AND ROOFING				11,147
F	FINISHES				11,364
G	METAL WORK				1,837
H	GLAZING				575
J	PAINTING AND DECORATIONS				12,197
	THIRD FLOOR TO GENERAL SUMMARY				71,404

STAIRCASE

Item	Description	Qty	Unit	Rate	Amount GH¢
A	Provide a P. C. sum of GH¢ 8500 for the supply of and construction of R.C.cranked slab staircase in 1:2:4/20mm agg. between floors and finished fair faced				8,500
	STAIRCASE To Summary				8,500

Appendix 4 Summary of cost for the entire project.

Block	Total Floor Area (m2)	Cost per unit area GH¢	Cost - GH¢
Type A- 4 floors	832.0	459.8	382,553.6
Type B- 4 floors *2 in Number	772.0	459.8	709,931.2
Type C- 3 floors	751.2	459.8	345,401.76
Type D- 2 floors	201.6	459.8	92,695.68
Grand Total Per Sub- Sector			1,530,582.24