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# ASSESSING THE RELATIONSHIP BETWEEN ENERGY EFFICIENT DESIGN DECISIONS AND ENERGY PERFORMANCE OF PUBLIC BUILDINGS IN GHANA: ARCHITECT PERSPECTIVE

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**ABSTRACT:** *As energy is a locomotive sector of the national economy, energy efficient decisions in the construction industry cannot be underestimated. The purpose of the study is to assess the perceptions of Architect on relationship between energy efficient design decisions and energy performance on public buildings in Ghana. Questionnaire was the main data collection tool. The questionnaires were distributed to a randomly selected sample of one hundred and thirty-five (135) registered architects. The data was analysed using inferential statistics such as Pearson product moment correlation coefficient and multiple regression analysis. The study established that there was a significant, positive correlation between building envelope/orientation, site condition related decision and energy performance of public buildings and these has explain 81.7 percent of the variation in energy performance. It was again reveal that factors that contributed significantly to this relationship were Passive solar technique, Natural ventilation, Temperature of the building site, Day lighting technique and Site shading strategy. The study indicates that the most critical constrain to energy efficient design were lack of public awareness followed by client budget and lack of skilled labour. It is recommended that Architects should adopt the EED framework designed as an appropriate strategy in the design of public buildings to improve the energy performance of public buildings.*

**KEYWORDS**: Energy Efficient Design, Public Building, Ghana, Energy Performance, Architect

## INTRODUCTION

Improving the energy efficiency of buildings is a growing priority on the policy agenda of many countries as well as the international community such as the International Energy Agency (IEA), the Intergovernmental panel on climate change (IPCC) and the United Nations Environment Program (UNEP). This fact emphasized on the need for energy efficient buildings. As a result some recommendations have been made; some of these recommendations include encouraging energy-saving behavior by home owners, stimulating innovation of energy-efficient technologies, controlling the quality and maintenance of existing buildings and energy standard for new buildings. In the European Union, much attention has also been given in recent years to energy efficiency in buildings, with three directives: directive of 16 December 2002 on the energy performance of buildings; directive of 6 July 2005 establishing a framework for the setting of eco-design requirements for energy-using products; and directive of 5 April 2006 on energy end-use efficiency and energy services (Kanagaraj, and Mahalingam, 2011).


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Moreover, in Ghana according to the energy commission, the total energy consumption for the year 2000 was 6,368 Gigawatt-hours (Gwh), in 2006 it went up to 6,656 (Gwh), representing 4.5percent increase. It further went up to 8,552 (Gwh), in 2012. With this statistics, building sector consumed about 30-40 percent of the total consumption (Energy commission of Ghana, 2013). Saving energy through energy efficient design of buildings can cost less than generating, transmitting and distributing energy from power plants, and hydro and provides multiple economic and environmental benefits to the country (Sadineni, Madala and Boehm (2011).

As energy is a locomotive sector of the national economy, energy efficient decisions in the construction industry cannot be underestimated. US environmental protection agency (EPA) (2008) emphasized that the aspirations of developing countries for higher living standards can only be satisfied through sustainable use of energy. According to Perreira and Assis (2013), significant portion of the energy is consumed by today's buildings in both developed and developing countries. In recent years, energy has become a major concern in Africa of which Ghana is no exception (CEPA, 2007, Doku, 2015). Though, the Ghana Building Regulations (1996) Li 1630 provides regulations and practices in buildings, no section(s) in the act strictly spell out the enforcement of energy efficiency in housings. As a result, there is no legal enforcement of energy efficient regulations of buildings in Ghana. While there have been considerable studies focusing on behavioral change in inefficient utilization of energy. Hence the study, which aim to assess the perceptions of Architect on relationship between energy efficient design decisions and energy performance on public buildings in Ghana. The objective of the study is to determine the association between building envelope/orientation related decisions, site condition related decisions and energy performance in Ghanaian building industry. This study is part of the larger study that assesses the effects of energy-efficient decisions on energy performance of public buildings: the perspectives of architects.

**Hypothesis of the study**

The following hypotheses will be tested

H1-there is relationship between building envelope/orientation related decisions and energy performance of public buildings.

H2- there is relationship between site condition decisions and energy performance of public building

**Sustainable Development and Energy Consumption**

Human beings are remarkable in that we can adopt understandings that are relevant to use and filter out the rest (Plessis, 2007). Human beings have places inside us that can hold values and feelings alongside rational thought. The concept of sustainable development can be interpreted in many different ways. The Brundtl and Commission's defined sustainable development as the "the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"; the use of this definition has led many to see sustainable development as having major focus on intergenerational equity (Kates, Parris and Leiserowwitz, 2005).

Plessis (2007) argued that the purpose of sustainable development of energy is to avoid environmental and / or social meltdown, thus "sustaining" the existence of not only modern society, but the future of the human species. The concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology



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and social organization on environmental resources and the ability of the biosphere to absorb the effects of human activities (Kates, Parris and Leiserowwitz, 2005). Leiserowitz, Kates and Parris (2004) argued that the relationship between humans and their environment is determined by a number of factors. The first is the interpretation of quality of life held by a particular society. This is the main determinant of the need that has to be met.

The second is the choice made in terms of the technological, economic and other systems adopted by the mainstream society. Leiserowitz, Kates and Parris (2004) further argued that these two factors are informed by the particular values system a society subscribes to. This value system not only determines the relationship between people within that society, but also how a society responds to its biophysical environment.

The biophysical, in turn, influences these choices through the limitations of its source and capacities (Plessis, 2007). Bourdeau (1999) also added that with this complex relationship a number of responses are possible that we allow the continued existence of the community of the best possible quality of life. Dalal - Clayton (2003) also found that another way to define sustainable development is how it is measured – practice. But at its core is an approach to development that looks to balance different and often competing needs against an awareness of the environmental, social and economic limitations we face as a society. The World Commission on Environment and Development (WCED, 1987) defined sustainable development "as the development that meets the needs of present without compromising the ability of future generations to meet their own needs". Sustainable development is about the needs of human and environmental in such a way that critical environmental limits are not exceeded and social equity and basic human rights are not obstructed either.

The concept of sustainability is a broad global issue comprising various interrelated studies about people, the environment and society (Chaffarian, Ibrahim, and Baharuddin, 2011). The significance of sustainable buildings could be elucidated by identifying the role of sustainability. Indeed, sustainability is a rethinking process designed to link the environment, technology, the economy, society and people. Ultimately, it can be concluded that sustainability encompasses three fundamental constituents as environmental, socio-cultural and economic sustainability while the respectively mentioned components are substantially bound up with the circumstances of the enhancement of well-being for the inhabitants as represented in fig 1.


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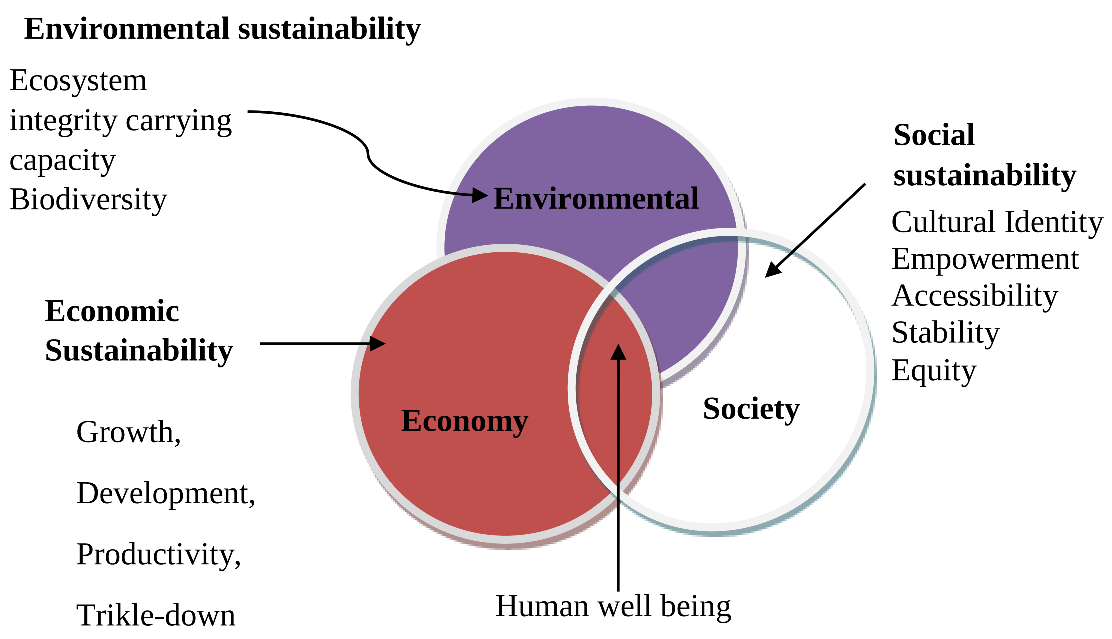


**Figure 1: The Basis of Sustainability Developments** (Alnaser, Flanagan and Alnaser, 2008)

Emphasizing the substantial negative impacts of buildings on the environment, Levin (1997) carried out a comprehensive analysis representing the respective impacts in US as shown in fig. 2 which is claimed to be very similar in other developed countries. The energy consumption and the gas emissions are therefore the most considerable negative consequences which require innovation.


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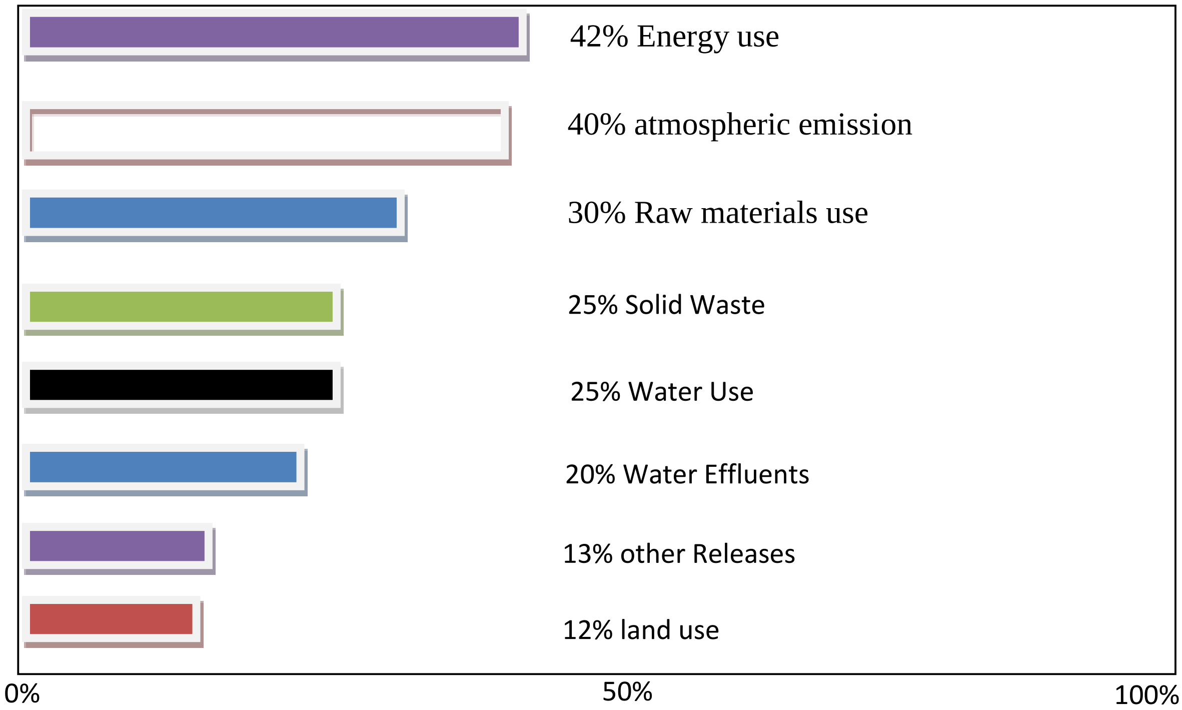


**Figure 2: Negative impacts of buildings on the environment**

In essence, sustainability to build environment is recognized as a holistic approach to the adaptation of socio-cultural concerns in the design and built evolution of architecture. Yilanci, Dicer and Ozturk (2009) observed that sustainability trends encompass economic competiveness specifically while considering hybrid energy systems. Meanwhile, a critical task is to educate the users towards the importance of sustainable design for reducing the energy consumption level of buildings and their harmful influence on the natural environments. Ultimately, the sustainable buildings must be developed based on a clear understanding of the main target of sustainable developments for efficiency as well as low-carbon emission.

## Challenges Facing the Energy Sector in Ghana

The issues of energy security constantly threaten the economy of Ghana. These issues stem from challenges facing the energy sector of Ghana. The energy challenges in Ghana are mainly on the supply of energy. It consists of accessibility, affordability and reliability of energy supply. To meet the local demand of fuel alone is now over dependent on the importation of crude oil. Armah, (2002) found that crude oil importation accounted for about 80% of Ghana's trade deficit in 2001. Seriously, the volatile prices of crude oil essentially affect the economy of Ghana. The energy losses as a result of inefficient conversion, distribution and use of energy resources are huge challenges in Ghana.

According to Energy Commission of Ghana (2006) energy losses totaled around 26% of the total primary supply in 2000 and increased to about 30% in 2004. The use of inefficient equipment for lighting, heating and cooling purposes is the major contributors of energy loss on the demand side of the economy. The growing concern regarding energy efficiency on loss


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supply and demand side has necessitated action by the government of Ghana to reduce these inefficiencies. One of such actions is the promotion of energy efficient lamps (CFL) in households. Additionally the energy commission of Ghana has also introduced an appliance standards and labels to control the importation of inefficient second hand appliances into the country.

Ghana's electricity is generated from three hydro-electric dams and thermal power plants. Approximately 70% of actual electricity is generated from hydro-electric dams, as a result the Ghanaian economy faces severe electricity crisis when there is low-water inflow into the hydro-electric dams. Notably, Ghana has experienced three drought-related electricity crises in 1998, 2002 and 2006 and all result in an expensive load shedding program to cut down and manage the demand load to the country. Again, in 2012 total natural gas required to run all the dual-fuelled thermal plants in optimum was about 180 million standard cubic feet per day mmscfd. However, only an average of 65 mmscfd was available.

The West Africa Gas Pipeline (WAGP) gas flow was truncated in August 2012 due to an accident on the undersea-pipeline. This resulted in a load-shedding. Currently, the nation is experiencing another power rationing programme due to lack of inflow of gas.

**Direct-Gain Passive Solar Techniques**

According to Littlefield, Moore, and Kennedy, (2009) in building planning and design, passive solar techniques are those that take advantage of solar heat and light to offset the need for gas or electric heating, air conditioning, and lighting. They are different from active solar systems, such as photovoltaic solar panels, which transform solar rays into electricity for home use. Common passive solar tactics include south-facing building orientations that absorb and store solar heat during the winter and deflect solar heat during the summer, and "day lighting," or maximizing the use of windows and full-glass exterior walls, often covered in a heat-deflecting glaze, to allow natural lighting into the building's interior work spaces, while minimizing the heat gain that might normally result.

According to the U.S. Department of Energy's Building Technologies Program (2004) new construction offers the greatest opportunity for incorporating passive solar design features. New construction and retrofit projects may also incorporate day lighting strategies that include skylights and light-sensing controls that reduce artificial lighting in response to changing levels of daylight, heat control techniques such as exterior shades or overhangs, and passive solar heating strategies to allow for reduced use of HVAC systems. Passive solar design provides the opportunity to integrate various building components such as exterior walls, windows, and building materials to collect, store, and distribute solar energy (U.S Department of Energy Building Technologies Program 2004).

**Shading Devices**

Fixed or movable devices located inside or outside the glazing are used to control direct or indirect solar gain. Littlefair (2001) argued that devices without moving parts are generally preferable. Littlefair (2001) further added that, movable devices on the exterior are typically difficult to maintain in corrosive environments or in climates with freezing temperatures. In shading, other building elements, such as overhanging roofs, can also serve as shading devices (FEMP, 2001). Sozer (2010) also found that reflective shading devices can further also control



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solar heat gain and glaze. FEMP (2001) further claimed that, shading is used to provide cost-effective, aesthetically acceptable, and functionally effective solar control.

**Day Lighting through Windows**

Day lighting is a central component of the vast majority of energy-efficient buildings and should meet significant time and attention (Kanagaraj and Mahalingam, 2011).

According to Littlefield et al. (2009) day lighting techniques involve the incorporation of natural daylight into the mix of a building's interior illumination. When properly designed, day lighting can offer significant energy savings by offsetting a portion of the electric lighting needed. A side benefit of day lighting is that it also reduces the internal heat gain from electric lighting, thereby reducing required cooling capacity. Littlefield further revealed that results of recent studies imply improved productivity and health in day lighted schools and offices. Windows—the principal source of daylight—also provide visual relief, a visual portal on the world outside the building, time orientation, and a possible source of ventilation and emergency egress (U.S. Department of Energy- efficient building design, 2014). Other sources of daylight include light pipes with mirrored inner surfaces that bring natural light deep into a building interior, skylights, sky domes, and reflective devices and surfaces that spread daylight more evenly in occupied interior spaces.

**Natural Ventilation through Windows**

A user-control operation of windows provides outdoor air for ventilation and cooling. A well-considered control strategy is required to prevent air condition from operating in a space with open windows. A balance approach involves taking advantages of users' desire for environmental control without interfering with efficient HVAC operation. FEMP, (2004), and Sam-Amobi, (2011) also asserted that adequate provision of natural ventilation reduces energy use for cooling and improved comfort

**Improvement of Building Envelope**

A building envelope is what separates the indoor and outdoor environments of a building (Sadineni, Mahalingam, and Boehm 2011). It is the factor that determines the quality and controls the indoor conditions irrespective of transient out-door conditions. Components such as foundation, walls, roof, fenestration, thermal insulation, and thermal mass, external shading devices are essential part of any building. Manioglu and Yilmaz (2000) added that building envelope and the operation period of the heating system are the factors that have the greatest impact on the total energy consumption of the building. The following review the most important building envelope components.

**Walls**

Walls are a predominant fraction of a building envelope and are expected to provide thermal and acoustic comfort within a building without compromising the aesthetics of the building (Sadineni, et al 2011), Christian and Kosny (2006) also found that the thermal resistance (R-Value) of the wall is essential as it has impact on the building energy consumption especially in a situation where the ratio between wall and total envelope area is high such as high rise buildings. Cheung, Fuller and Luther (2005) found that there are types of building wall designs that are applied to improve the energy efficiency in building. The following section describes such advance wall technologies.



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## Passive Solar Walls

Sadineni, et al (2011) argued that passive solar walls are walls designed to trap and transmit the solar energy efficiency into the buildings. Capeluto (2003) also found that Trombe wall is an example of passive solar walls. A novel concept of fluidized trombe wall system (as shown in fig. 4) where the gap between the trombe wall and the glass cover is fluidized with highly absorbing low-density particalsis introduce (Tunc, and Uysal, 1991). It is a wall that separates the outdoor by glazing the air cavity. In this wall, a 12-inch thick concrete wall is used as a soars for geographical northern to absorb solar radiation. It has vents at the top and bottom to the interior wall to control airflow. Solar energy is stored in the wall and subsequently conveyed to the inside of the building by conduction. Hot air is released through upper air vents. Cold air enters the space between the wall and the glazing through the lower air vents and comes in contact with the wall, which makes its temperature rise. After wards the cycle begins again.

There are four (4) different kinds of solar wall configurations. They are unventilated solar wall, Trombe wall, insulated Trombe wall, and composite solar wall. Trombe wall, insulated Trombe wall and composite solar wall transfer heat to the indoors both by conduction through wall and convection through circulating air. A more convection-based type of solar wall such as composite solar wall or insulated Trombe wall is preferable in regions with shorter heating season in order to avoid overheating in cooling season. Whereas, a more conduction-based type of solar wall such as Trombe wall or unventilated solar wall is preferable in region with higher heating season (Sadineni, et al, 2011).

Ventilation wall is also known as cavity walls. It consists of air gap between two layers of masonry wall braced with metal ties. There are two main types, the artificial and natural ventilation. Ventilation walls are used to enhance the passive cooling of buildings (Ciampi, Leccese and Tuoni, 2003).

## Lightweight Concrete (LWC) Walls

It refers to any concrete produced with a density of less than 2000kg/$m^3$ (Al-Jabri, Hago, Al-Nuaimi, and Al-Saidl, 2005). It has a strength grade of 15mpa and for the purpose of thermal insulation, the density is often less than 1450kg/ $m^3$ along with strength grade of 0.5mpa. The thermal resistance of light weight concrete can be strengthened by mixing with pumice, diatomite, expanded clay or shale. Another type of LWC is autoclaved aerated concrete (AAC). It is produced by introducing aluminum powder to generate miniscule air bubbles. AAC has superior thermal resistance than other types of LWC. The density of AAC ranges between 600 and 800kg/$m^3$.

# METHODOLOGY

## Research Design

According to Creswell (2009), research designs are plans and procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis. This study employed quantitative research approach using survey questionnaires developed and administered to the targeted respondents. Walker, Wilson and Sherman (1998) also found that quantitative research design enables the researcher to decide what to study; ask specific, narrow



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questions; collect quantifiable data from participants; analysed these numbers using statistics; and conduct the inquiry in an unbiased, objective manner.

**Population**

The population of the study comprised registered architects and architectural firms in the Greater Accra, Ashanti and Western regions of Ghana. These regions were selected because they are the major regions in Ghana where construction activities are highly concentrated (Akomah, Boakye, and Fugar, 2010). Sampling frame is an objective list of the population from which the researcher can make his or her selection (Davis, 2010). The study sampling frame consisted of all one hundred and sixty-two (162) architects and architectural firms registered with Ghana Institute of Architects and Architects Registration Council of Ghana as of January, 2014 located in the Greater Accra, Ashanti and Western Regions of Ghana. The sample size was determined using the formula (Kish, 1965).

$$n = \frac{n^1}{1 + \left(\frac{n^1}{N}\right)}$$

Where n = sample size

$n^1 = \frac{S^2}{V^2}$ , $S^2 = p\,(1 - p)$

N = total population = 162

S = maximum standard deviation in the population element

P = proportion to the population elements that belong to the defined category

i.e. p = 0.5 (95%) confidence level

V = standard error of the sampling distribution i.e. V = 0.05

Hence solving for $n^1$

$S^2 = p\,(1 - p) = 0.5\,(0.5) = 0.25$

$V^2 = 0.05^2 = 0.0025$

$n^1 = \frac{S^2}{V^2}$, $n^1 = \frac{0.25}{0.0025} = 100$

$$n = \frac{n^1}{1 + \frac{n^1}{N}}$$

n = 100/ (1 + 100 / 162)

= 62 Architects

This formula provides the minimum number of survey participants to be obtained. Although only 62 architects were required to participate in the survey, similar research conducted in Ghana have indicated non response rates ranging from 38% to 87% (Agyekum, Ayarkwa and Adinyira, 2012). Based on the non-response rates recorded in the aforementioned studies and taking into consideration the study setting, 135 architects (all those with valid email addresses on the ARCG list in the three regions) were contacted with the questionnaires to cater for low response rates. Purposive sampling technique were used to select the respondents because architect are knowledgeable in their field and also because the distributions of Architects in Ghana are largely based towards these major city capitals (Oladapo, 2005).

### Administration of the Questionnaires

The questionnaires were delivered to the respondents personally and via email. Out of 135 questionnaires administered; 75 responses were received and out of this, 72 were acceptable, representing a usable response rate of 53 percent. This response rate is considered adequate as, according to Idrus and Newman (2002), Ogbonna, and Harris (2000) a response rate of 30 percent is good enough in construction studies. T-Test was used to find out about the problem of non- response bias, no major differences were found between early and late respondents suggesting that non-response bias may not be a problem ( Ogbonna, and Harris, 2000)

### Method of Data Analysis

Completed questionnaires from the field were edited and coded appropriately to make effective meaning out of the data. The data was analyzed and interpreted by using Statistical Package for Social Science (SPSS) version 16

### Validity

According to Conca, Llopis and Tari (2004) validity is the extent to which the instrument measures what it purports to measure. To ensure face or content validity, items can be generated from a number of sources including consultation with experts in the field (Hair, Anderson, Tatham, and Black, 2006). Hence the validity was checked using "face validity" by the experts in the design profession. The identified design decisions were scrutinized and verified through a series of face-to-face interviews with four selected senior Architects possessing sufficient experience in public construction projects, in Kumasi (the second largest city in Ghana).

### Pilot Study

The researcher conducted a pilot study to ensure the reliability of the questionnaire and to identify items that should be revised. The pilot study was done in the Kumasi Metropolis and it involved the administration of the questionnaire to a sample of eight (8) randomly selected Architects from the population. Because no major adverse comments were received from the respondents, the pilot study questionnaire after slight modifications was taken as the final empirical questionnaire for the investigation.

## RESULT AND DISCUSSION

### The Results of Correlation test between EEDs and EP.

The results of correlation test between the EED variables and energy performance is presented in Table 1. Using correlation analysis, the results indicated that Energy efficient decisions (EEDs) variables are strongly, positively correlated with the energy performance (EP) variable.

There was a significant, positive correlation between building envelope/orientation related decisions and energy performance of public buildings (**r = 0.855, p < 0.01**). This supports the hypothesis that there is a significant, positive correlation between building envelope/orientation related decisions and energy performance of public buildings. Similarly, there was also a significant, positive correlation between site condition related decisions and energy performance of public buildings (**r = 0.849, p < 0.01**).

In order to explore the data further, each energy efficient item loading onto factor 1 (Building envelope/orientation related decisions) and factor 2 (Site condition related decisions) was correlated with the energy performance construct. The results of the Pearson correlation coefficients are shown in table 1. All the items in factor1demostrated significant correlations, some highly significant between the energy performance; there was a highly significant, positive correlation between energy performance and passive solar technique(**r = 0.851, p < 0.01**); adequate natural ventilation (**r = 0.835, p < 0.01**);day lighting (**r = 0.768, p< 0.01**); thermal storage (**r = 0.754, p< 0.01**); provision high performance insulation materials (**r = 0.731,p < 0.01**); and a significant positive correlation between energy performance and air tightness (**r = 0.691, p < 0.01**), incorporation of differential facade (**r = 0.587, p < 0.01**), and integration of roof monitors (**r = 0.580, p < 0.01**).

Similarly, all the items in factor 2 also demonstrated significant correlations, some highly significant between the Energy performance; there was a highly significant, positive correlation between energy performance and temperature of the building site(**r = 0.820, p < 0.01**), and site shading (**r = 0.762, p < 0.01**),and a significant, positive correlation between energy performance and site topography (**r = 0.705, p< 0.01**), wind velocity of the building site (**r = 0.676, p< 0.01**), and humidity and site water bodies (**r = 0.640, p<0.01**).

There was a strong criterion-related validity since the bivariate correlations of the energy efficiency decisions with energy performance measures were statistically significant. The correlation coefficient values were below the cut off threshold of 0.90 (see Table 1.) for the collinearity problem (Jaafreh, and Al-abedallat, 2012).

The findings of this result indicate that all the thirteen elements have significant influence on energy performance of public buildings. The output also implies that the higher Architects in Ghana interested in maximizing their energy efficiency decisions (EED), the higher the opportunity to: achieve reduction in the amount of energy consumed, lower energy cost, improve the comfort of occupants, and improve the health/ safety of the occupants, and the productivity of their occupants.


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**Table 1: Association between EEDs variables and EP variable**

| EEDs | CSP (Pearson Correlation) | Sig |
|---|---|---|
| **Factor 1** | | |
| BE/O | **0.855** | 0.000 |
| Passive solar technique | 0.851 | 0.000 |
| Adequate natural ventilation | 0.835 | 0.000 |
| Day lighting | 0.768 | 0.000 |
| Thermal storage | 0.754 | 0.000 |
| High performance insulation material | 0.731 | 0.000 |
| Air tightness | 0.691 | 0.000 |
| Incorporation of differential facade | 0.587 | 0.000 |
| Integration of roof monitors | 0.580 | 0.000 |
| **Factor 2** | | |
| **SLC** | **0.849** | **0.000** |
| Temperature of the building site | 0.820 | 0.000 |
| Site shading | 0.762 | 0.000 |
| Site topography | 0.705 | 0.000 |
| Wind velocity of the building site | 0.676 | 0.000 |
| Humidity & site water bodies | 0.640 | 0.000 |

**Correlation is significant at the 0.01 level (2 – tailed).

**EP:**Energy Performance; BE/O: Building Envelope/Orientation related decisions; SLC: Site Condition related decisions.

**Multiple regression analysis**

The results of the correlations indicated the existence of a relationship between the energy efficient decisions variables and the energy performance variable but did not identify the most crucial contributory variable for this relationship. To achieve this objective, Stepwise Multiple Regression technique was used to determine the importance of each independent variable and



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its contribution to the energy performance of public buildings. The multiple regression was conducted between EEDs variables namely (Building envelope/orientation related decisions (Passive solar technique, Adequate natural ventilation, Day lighting, Thermal storage, Provision of adequate heat insulation, Air tightness, Incorporation of differential facade, Integration of roof monitors) and Site condition related decisions (Temperature of the building site, Site shading, Site topography, Wind velocity of the building site and Humidity & site water bodies) as they were the independent variables, and the Energy performance variable (dependent variable). The summary of the result of the multiple regression analysis is shown in Table 2.

**Table 2: Model: Summary of Multiple Regression Analysis between EEDs variables and EP variable.**

| **Dependent Variable** | **R** | **R-Square** | **Adjusted R Square** | **Standard Error** |
|---|---|---|---|---|
| Energy Performance | 0.907 | 0.822 | **0.817** | 1.09416 |

**Analysis of Variance**

| | **Sum of squares** | **Df** | **Mean square** | **F** | **Significance** |
|---|---|---|---|---|---|
| Regression | 381.048 | 5 | 190.524 | **159.144** | **0.000** |
| Residual | 82.605 | 66 | 1.197 | | |
| **Total** | 463.653 | 71 | | | |

**Standard Coefficients**

| | Beta | T | Significance | **Collinearity Statistics** | |
|---|---|---|---|---|---|
| | | | | Tolerance | VIF |
| **PST** | **0.510** | | **0.000** | 0.294 | 3.401 |
| **ANV&DL** | **0.373** | 7.128 | **0.000** | 0.488 | 2.409 |
| **TBS** | **0.315** | | **0.000** | 0.281 | 3.554 |
| **DL** | **0.284** | 6.595 | **0.000** | 0.271 | 3.688 |
| **SH** | **0.175** | | **0.000** | 0.271 | 2.622 |
| | | 4.521 | | | |
| | | 3.885 | | | |
| | | 3.572 | | | |

**PST:** Passive solar technique; **ANV & DL:** Adequate natural ventilation**; TBS:** Temperature of the site; **DL**: Day lighting; **SH:** Site Shading


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Table 2 revealed that the $R^2$ adjusted value was 0.817. This indicates that the variables proposed in the framework (building envelope/orientation related decisions and site condition related decisions) together can explain 81.7 percent of the variation in energy performance as a dependent variable. The F- ratio of 159.144 ($p < 0.01$) indicates that the regression of energy performance on the energy efficient decisions assessed, expressed through the adjusted R-squared is statistically significant. The independent factors that contributed significantly to this relationship (a greater effect on the dependent variable) were Passive solar technique, Natural ventilation, Temperature of the building site, Day lighting technique and Site shading strategy. The beta coefficient, which is the standardized regression coefficient, is used as a direct comparison between coefficients as to their relative explanatory power of the dependent variable (Hair et al. 1998).

This assertion is consistent with the findings of Littlefield, et al. (2009), Kanagaraj and Mahalingam (2011), Sadineni et al (2011), Mellon (2005), U.S. EPA (2008). After running a regression analysis (Table 2), the study found that the Energy efficiency decisions of the respondents' designers had significant effects on energy performance of public buildings. Thus, 81.7 percent of changes in the energy performance of public buildings are explained by the EED identified. The results further revealed that passive solar technique, adequate natural ventilation, temperature of the building site, day lighting strategy as well as site shading by vegetation were the EED elements that contributed significantly to this relationship (a greater effect on the dependent variable). Impliedly, these five EED elements have a high explanatory power on public building energy performance.

Passive solar technique made the strongest unique contribution (Beta **= 0.510, $p < 0.05$)** to explaining variations in energy performance of public buildings, when the variance explained by all other variables in the model is controlled for. Impliedly, passive solar technique had significant impact on the energy performance of public buildings. This finding corroborate with Sadineni, et al (2011), and Littlefield et al (2009) assertion that passive solar technique is one of the key elements of energy efficient building designs that take advantages of solar heat and light through south-facing orientation of the building to offset the need for air conditioning and lighting. It also includes "day lighting," or maximizing the use of windows and full-glass exterior walls, often covered in a heat-deflecting glaze, to allow natural lighting into the building's interior work spaces, while minimizing the heat gain that might normally result

Adequate natural ventilation made the second significant contribution (Beta = **0.373, $p < 0.05$**) to explaining variations in energy performance, when the variance explained by all other variables in the model is controlled for. This implies that provision of adequate natural ventilation had significant impact on energy performance of public buildings. This finding is in agreement with FEMP (2008) and Sam-Amobi (2011) assertion that adequate provision of natural ventilation through the use of windows reduces energy use for cooling and also improved the comfort ability of the users.

According to FEMP (2008) a user-control operation of windows provides outdoor air for ventilation and cooling. A well-considered control strategy is required to prevent air condition from operating in a space with open windows. Temperature of the building site made the third significant contribution (Beta = **0.315, $p > 0.05$**) to explaining variations in energy performance, when the variance explained by all other variables in the model is controlled for. This means that energy efficiency decisions incorporating temperature of the building site had significant impact on energy performance of public buildings. Therefore, $H_2$ is supported. This finding corroborate with Kanagaraj and Mahalingam (2011) assertion that analysis of the



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temperature of the building site can enhance the sustainability, energy efficiency, and passive design features of buildings, resulting in cost saving.

The implication of this finding is that designers (Architects) should include temperature analysis of the site when conducting site investigation prior to the design. This will help to know the structural materials (energy efficient materials) that would be incorporated in the design and construction of the energy efficient building. The temperature analysis of the site will also enable the designer to know other strategies to be integrated in the design and construction of the energy efficient building to achieve optimal results.

The values of VIF and Tolerance showed no multi collinearity between the variables as their values less than 10 for VIF and more than 0.10 for tolerance level as suggested by Hair et al. (1998). The variables account for 81.7 percent of the variance in energy performance. This implies that other unexplored variables could account for the 18.3 percent of other variance in energy performance.

The Fig. 3 shows the integrity of the residual plot indicated less dispersed. This implies that the model is credible and can be used to measure energy efficient performance of public buildings within the data range.

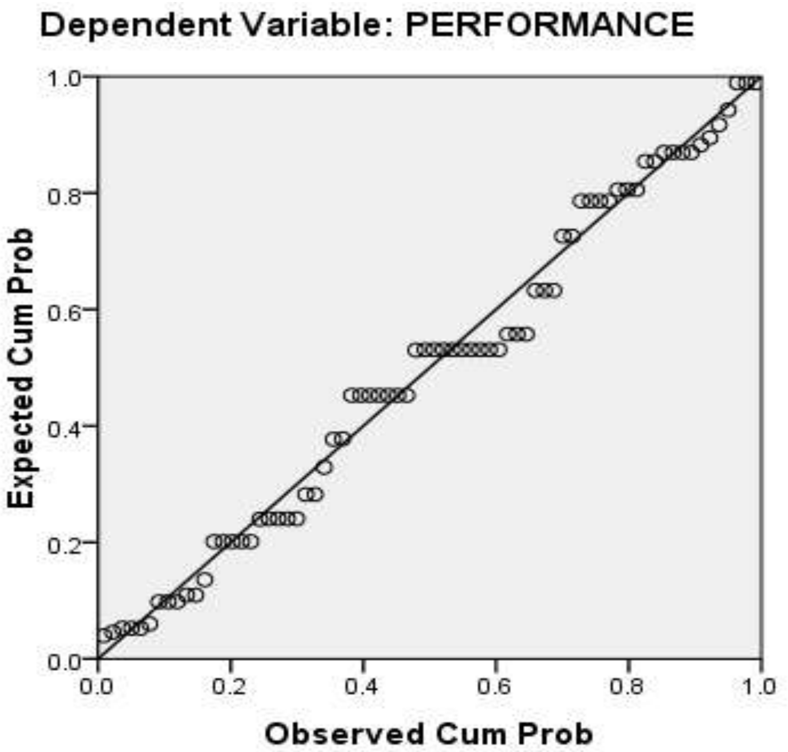


**Figure 3: The Normal P-P Plot of Regression Standardized Residual**

**Critical Constraints to Energy Efficient Design**

Table 3. Shows the level of the critical barriers (CB) which falls mainly into two categories: level (3) 'sometimes experience' (Mean= 2.60-3.39) and often experience (3.40-4.19). Table 3. Indicates that lack of awareness was the most critical constraint to energy efficient design in



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the perspective of Architect (Mean=3.91). This was followed by client budget (Mean= 3.66), lack of skilled labour (Mean=3.21), lack of enforcement of compliance during construction (Mean=2.97) and Access to energy- efficient materials (Mean=2.65) was the least critical constraints to the integration of energy –efficient building design.

**Table 3: Critical Barriers to EED**

| Critical Barriers | Mean | StdDev't | LoB |
|---|---|---|---|
| Lack of awareness | 3.91 | 0.54 | 3 |
| Client's budget | 3.66 | 0.66 | 3 |
| Skilled labour | 3.21 | 0.55 | 3 |
| Lack of enforcement of compliance during const. | 2.97 | 0.65 | 3 |
| Access to Energy Efficient Materials | 2.65 | 0.57 | 3 |

Notes: Level of Barrier (LoB):

5= very often experience (mean = 4.20 – 5.00); 4 = often experience (3.40 - 4.19);

3 = sometimes experience (2.60 – 3.39); 2= seldom (1.80 – 2.59); 1= not experienced (< 1.80).

## CONCLUSION

The following conclusions were drawn based on the major findings of the study. The architect were with the view that There was a significant, positive correlation between building envelope/orientation related decisions and energy performance of public buildings (**$r = 0.855$, $p < 0.01$**). Similarly, there was also a significant, positive correlation between site condition related decisions and energy performance of public buildings (**$r = 0.849$, $p < 0.01$**). This supports the hypothesis that there is a significant, positive correlation between building envelope/orientation related decisions, site condition related and energy performance of public buildings. The study further shown that the variables proposed in the framework (building envelope/orientation related decisions and site condition related decisions) together can explain 81.7 percent of the variation in energy performance as a dependent variable. The F- ratio of 159.144 ($p < 0.01$). It was again reveal that factors that contributed significantly to this relationship were Passive solar technique, Natural ventilation, Temperature of the building site, Day lighting technique and Site shading strategy. The study indicates that the most critical constrain to energy efficient design were lack of public awareness followed by client budget and lack of skilled labour.

## RECOMMENDATIONS

Based on the findings of the study, the following recommendations are made towards improving the adoption of Energy-efficient building design and construction practices in Ghana. These recommendations could form the basis for interventions designed to overcome or reduce the energy challenges in Ghana.



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- Architects are encouraged to adopt the EED framework designed as an appropriate strategy in the design of public buildings to improve the energy performance of public buildings.

- Architects should be more concerned with passive solar technique, provision of natural ventilation, and day lighting technique of building envelope/ orientation related decisions as well as temperature of the building site, and site shading strategies of site condition related decisions when designing public buildings as these considerations have greater impact on energy-efficiency of buildings.

- Finally, the government through the Ministry of information, Metropolitan, Municipal and District Assemblies could educate the general public about the importance of energy efficient buildings. Such consumer education efforts would publicize the techniques employed and the energy cost savings that could result

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