Green approach to reducing electricity consumption in Ghana - current status and future prospect: a review

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ABSTRACT

The construction sector offers numerous advantages to the world. Some of which include the provision of buildings, streets, tunnels etc. The change in climate is one of the many challenges in this dispensation which requires that techniques and strategies should be developed for the purpose of efficient energy supply. This brings into light the need to design methods for the calculation of energy use in buildings. A few empirical research has been conducted concerning the study of the causal links between urban growth and the consumption of electricity in the specific case of Ghana. It has been found out that the insulation of walls and ceiling has the tendency to reduce building energy consumption by 70-80% and 65% respectively, as compared to a building of the same type and material but without insulation. The climatic condition of Ghana is such that the south-western part is hot and humid and the northern part experiences a hot and dry climate and has a warm eastern coastal belt. In simple term, Ghana is a hot temperate zone. Nonetheless, the climate varies with time. It is therefore paramount to introduce building insulators to reduce the energy requirement of the buildings especially in the residential sector of the country. This paper will therefore consider the introduction of thermal insulation on building façade in Ghana and the mathematical model to achieving optimum thickness suitable for a particular region or city. The mathematical model for determining the threshold values for CDD and HDD is also considered.

Keywords: Climate, insulation, temperate, façade, CDD and HDD.

1. Introduction

One of the largest industries in the world is the construction industry. It has a significant impact on the social, cultural and economic well-being of the people in the society. These impacts can be realized during the lifecycle period of the building. Some of the positive impacts include; the provision of employment opportunities, provision of facilities and buildings to satisfy the requirements of human needs and contribute to the gross domestic product (GDP) of the country. The construction industry in Australia contributes 7.5% to the GDP and again provides not less than 1 million jobs [56]. Even though the construction industry is providing a lot of advantages to the environment yet the negative impacts imposed on the industry by the environment shouldn't be overlooked. A typical example is the negative impacts associated with climate change. Climate change is one of the challenges of the 21st century which demands strategies and techniques for efficient energy supply [15]. Thus, the need to design methods for the calculation of energy use of buildings. Most research works conducted concerning climate change are done in Turkey and Greece [44]. Ghana is located only a few degrees north on West Africa's Gulf of Guinea and shares a border with Burkina Faso on the north, Togo on the east, and Côte d'Ivoire on the west. The country is found on the Greenwich meridian line which passes through Tema, about 24 km east of the capital, Accra [8]. The climate of Ghana is tropical. The south-western part is hot and humid and the northern part experiences a hot and dry climate and has a warm eastern coastal belt. The generation of power in the country has gone through several phases: generation of power by diesel generators and the stand-alone electricity supply systems which are owned by factories, through to the hydro phase power generator (Akosombo dam) and a thermal complement phase (here power is generated by light crude oil and/or gas). A wide-ranging policy outlined by the Ghana Poverty Reduction Strategy (GPRS 2006-2009) was purposely set to encourage the energy subsector to ensure a dependable supply of high-quality energy to support the growing agro-industrial and residential sectors [4]. Ghana has devised many strategies to improve its electricity and energy sector. One target is to have universal access to electricity by 2020, where 30% of the rural area will be supplied with electricity by decentralized renewable energy (RE) [26]. The main objective of the Ghana SE4ALL Action Plan from 2013 is to ensure modern energy for the rural communities [27]. The Energy Sector Strategic Development Plan and the National Energy Policy are two institutional frameworks, which aim to facilitate access to sustainable energy, high quality and utilization of RE technologies [33, 26]. It has been projected by Aboh that the total electricity consumption in Ghana will rise from 3721.7 GWh in 2008 to 65,239.6KWh by 2030 [4]. There has been a few empirical research concerning the study of the causal links between urban growth and the consumption of electricity in the specific case of Ghana. Thus, the question of the efficient use of electricity in Ghana has now become very important to researchers. The recent power crises of the country with increasing severity which has threatened the economic growth of the country as well as the rationing system, job and income losses, the slowdown in industrial activity, loss of life are now communicating to concerned citizens what seems perennial on the development agenda of Ghana. The construction industry is known to be one of the largest industries with the largest electricity consumption in the world. Buildings have an important share of the total energy consumption all over the world. The bulk of energy produced by countries with hot climatic conditions is consumed by ventilation and air-condition systems. The temperature of a room has two main effects on refrigerating appliances. First, the difference in temperature between the room and compartment determines the heat gain into the refrigerating appliance. Again, an increase in room temperature leads to a reduction in the overall energy efficiency of the refrigeration system by increasing the difference between the condensing and evaporating temperature through the wall insulation and door seals of the refrigerating device [28]. When the efficiency of a refrigerating appliance decreases, its consumption of electrical power increases. It can be stated intuitively that most citizens especially in the residential sectors use refrigerators due to the hot climatic condition. Research conducted by [18] shows that 1140 kWh/year of electricity is consumed by 100 refrigerators in the residences in Accra. This energy consumed is more than twice that which is allowed by the MEPS (Mandatory Energy Performance Standards) in the U. S. and Europe. The transfer of heat through building facades (especially through roofs and walls) represents a major component of buildings' thermal load. The effective use of thermal insulation can produce a significant reduction in the overall energy consumption of the building. According to [1], the Gulf Countries Cooperative Council (GCCC) introduced a regulation on the use of thermal insulation which set the level of thermal resistance to the minimum (resistance for walls and roofs are 1.35m^2 K/W and 1.75 m2 K/W respectively). Nevertheless, most buildings within the region are not insulated and have resulted in higher energy consumption. According to [2], an apartment in Dammam in Saudi Arabia to a similar one in the United States of America, Arizona uses twice as much energy as that in Arizona. Recent studies reveal that energy consumed by buildings has reached 40% of total energy consumption [29]. According [29], the insulation of walls and ceiling reduces building energy consumption by 70-80% and 65% respectively, as compared to a building of the same type and material but without insulation. As it has been said earlier, Ghana has a hot climate and is therefore paramount to introduce building insulators to reduce the energy requirement of the residential sector to the minimum level for efficient use in the industrial sector keeping in mind the Ghana Poverty Reduction Strategy. This paper will consider the introduction of thermal insulation on building façade in Ghana and the mathematical model to achieving optimum thickness suitable for a particular region or city.

2. Research works concerning the topic

The advantages of constructing green have compelled many researchers to divert their attention to the study of green construction. Green construction addresses some of the world's major problems such as the efficient use of energy and water. As a result, many models have been developed by researchers to manage the use of energy in buildings. OnSSET is one of the models developed to assess household demand and to identify the available resources necessary to meet the demand cost-effectively [42]. Home energy management program is an intelligent program designed to control and manage the consumption of electricity more efficiently. It improves and saves the bills of consumers as well as utilities. This method is usually implemented by MATLAB for technical validation and solutions [3]. Interview conducted by Chen Min revealed that the information barrier, cost barrier, climate barrier and the condition of the outdoor are the obstacles to the efficient use of energy in industries [10]. A research study conducted on the reduction of electrical energy consumption through behavioural changes shows that energy-efficient campaigns and energy-efficient charrettes have a positive impact on decreasing electricity consumption. Motivation, leadership and communication were found to be necessary to reduce electrical consumption in schools and offices [21]. Green computing is one of the technologies developed to control e-devices by managing their energy consumption and reducing their heat production. This helps to save a vast amount of energy [9]. The use of energy for cooling or heating during summer or winter periods to provide thermal comfort for occupants has made it necessary to consider the degree days. To find the most energy-efficient methods for the various climates in Mexico, a comparative analysis of the insulation method applied to low income single-family houses was conducted. The result shows that insulating the roof is best for a temperate climate and that of the walls is most effective for cities with yearlong warm weather. From the energy consumption data and the cost of electricity in Mexico, the net annual energy savings were computed including the annual initial cost of investment in better insulation [39]. [54] used the DeST simulation software to predict a building's cooling and heating loads for a year of 8760 hrs when determining the optimal thickness required for different insulation materials. Thus, the number of heating degree-days directly affects the optimum thickness of the insulation of the building exterior walls. The best insulation material is different for different climate zones due to the different climatic conditions. Building insulation reduces electrical energy consumption by 70-80%. That of ceiling insulation reduce energy consumption by 65%, as compared to the building of the same type and insulation [29]. Most studies also consider the use of different fuels apart from electricity to determine the optimal insulation thickness for a wall. This was done under different insulation materials [36]. Other researchers have also established the fact that the operation of the air conditioner is affected by the human thermal experience. The operation of the air conditioner is directly proportional to the deviation of the indoor temperature from the human comfort range. This increases the operating frequency of the air conditioner [48]. Work is done by other researchers also reveals that under the continuous energy usage mode, the annual cooling and heating effect of the exterior thermal insulation is better than that of the interior thermal insulation [22]. In most cases, the life cycle of the insulation is calculated using the net present value (NPV) technique for the various types of insulation materials and the different types of external wall structures. A sensitivity analysis is also considered to factor in the change in the discount rate and for labour rates [19].

3. Why the green approach?

The Green approach in construction considers the efficient ways of a building considering environmentally friendly factors. It considers in totality the benefits related to the economic aspect of the building, human aspect, thermal comfort, and the indoor environmental quality.

3.1 Economic

According to [13], the social and economic requirements of green construction include education, affordability, cohesion, economic value, access, impacts to the local economy, cultural perception, indoor health and inspiration [12]. The benefit of building green is not only realized in the energy savings but also its potential value of saving cost [44]. The payback period is then reduced as a result. Nevertheless, the significance of green buildings can be realized in the cultural, social, and economic aspects of sustainability [41]. Emphasis is mostly placed on the environmental aspect of building green.

3.2 Environment

There is a lot of advantages that green buildings provide to the environment. Green buildings improve the biodiversity of the urban sectors and help to protect the ecosystem through sustainable land use [31, 14]. Green building reduces the demolishing and construction waste of a sustainable building design [5, 52]. To reduce the impact of the construction and demolition on the environment, the recycling waste must be above 90%. This provides an opportunity for reuse and recycled materials in new buildings [20]. Generally, green buildings provide higher performance which can be seen from their energy efficiency, water efficiency and reduction in carbon emission. A large amount of carbon emission reduction can be achieved if LEED rating were adopted in new construction works [34].

3.3 Thermal comfort

The comfort of building occupants is related to the complex dynamics of humidity and temperature [54]. This has geared the attention of researchers towards the study of algorithms and techniques such as simulation and the measurement of the level of thermal comfort in green buildings as compared to conventional buildings. The range of room temperature can now propose which dependents on some factors such as physiology, psychology, culture and the behaviour of the building occupants [47, 24, 23].

3.4 Health and productivity

The health and the productivity of building occupants is better in green buildings compared to conventional buildings [51, 66, 67]. The productivity in a green building increases to about 25% and absenteeism reduces significantly [45]. A study conducted by [11] which considers the survey of 31 GGCA certified office of buildings reveals that the employers attest to the health and productivity benefits associated with green office. Notwithstanding, in residential buildings, there is always a negative correlation between the energy efficiency of residential property and the rental premium i.e. bundling the cost of energy with the rent. Thus, this calls for more comprehensive research on how to provide a cost-benefit analysis of green buildings so that the decision-making process can be better informed [55].

3.5 Indoor environmental quality

Green buildings also take into consideration indoor environmental benefits such as the use of the non-volatile organic compound.

4. Design of External Insulation Wall and Roof

Many parameters are considered in the selection of thermal insulation. They include compressive strength, transmission, and water vapour absorption, cost, resistance to fire, durability, ease of application, and thermal conductivity. Thermal insulation does not always have the same effectiveness for all types of buildings. The optimum insulation thickness can be determined using the Life Cycle Cost Analysis which is dependent on the parameters such as the cost of fuel for cooling or heating (in this case electricity will be considered since most buildings in Ghana depends on electricity), climatic condition, cost of insulation, type of insulation, properties of the insulation material and the wall and the Present Worth Factor (PWF).

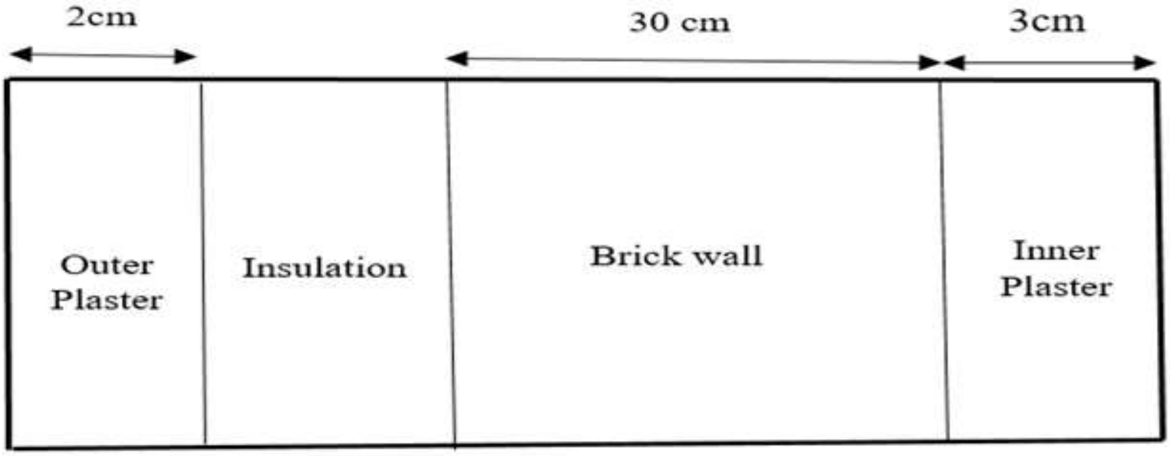


Fig. 1 Cross-Sectional View of an External Insulated Wall

External walls are mostly made of brick and varieties of concrete. To minimize heat loss/gain insulating material is mostly placed in between the walls (sandwich), outside, or inside. In this paper, insulation is placed outside the external wall

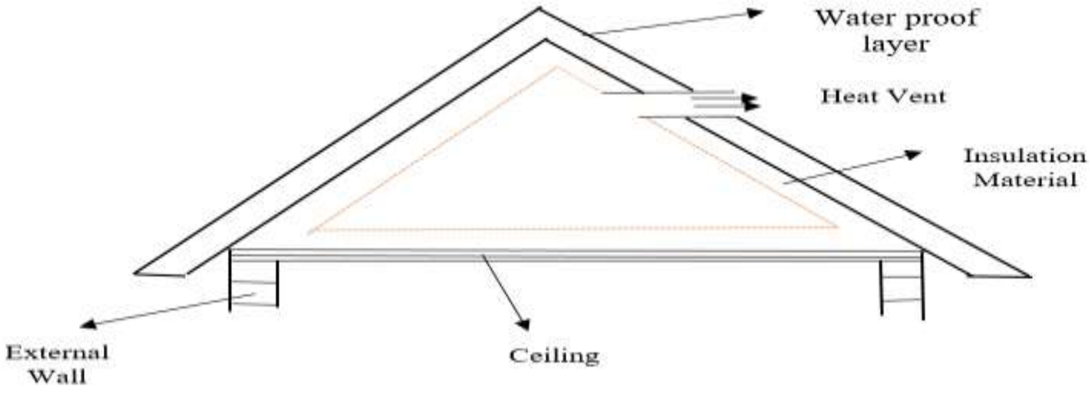


Fig. 2 Cross Sectional View of Insulated Roof

5. Using DeST simulation tool for cooling or heating load prediction

Cooling load is the amount of energy required to cool the room to achieve thermal comfort during hot hours (especially during the summer period or in hot temperate zones) whereas heating load is the amount of energy required to heat the room to achieve thermal comfort during cold hours (during winter). Designer's Simulation Toolkit (DeST) is an effective building energy simulation tool developed by the University of Tsinghua, Beijing, China in the year 1989. DeST has become a widely-used platform for the calculation of building thermal processes and for dynamic simulation of the distribution of building energy. Thus, DeST is a good platform to predict the heating or cooling load required to achieve thermal comfort in a room due to the daily or seasonal temperature variation. [58], used the DeST simulation software to predict a building's cooling and heating loads for a year of 8760 hrs when determining the optimal thickness required for different insulation materials. The software generates a special graphical user interface based on AutoCAD for all the simulation processes to prevent the loss of additional modelling work as a result of conversion [46]. To obtain the room's heat balance, the energy balance equation of the room's discrete points is solved to determine the response coefficient of the room to each thermal distribution. The air temperature of a room can be calculated by equation (1). This describes the degree of heat energy in the room.

$$T_{t,i}(\tau) = T_{ta,j}(\tau) + \sum_j \varphi_{j,0,i} T_{t,j}(\tau) + \sum_j \varphi_{hvac,i} A_{hvac,i}(\tau) + \varphi_{hvac,i} A_{hvac,i} + \varphi_{hvac,i} cp\, \rho D_{outdoor,i}(\tau)\left[T_{outdoor}(\tau) - T_{t,i}(\tau)\right] + \sum_j \varphi_{hvac,i}\, cp\, \rho D_{j,i}(\tau)\left[T_{outdoor}(\tau) - T_{t,i}(\tau)\right] \quad (1)$$

Where, $T_{t,K}(\tau), T_{t,k}(\tau)$ – the room temperature of the current time in i and j rooms; $T_{ta,j}(\tau)$ – the room temperature of room i when natural ventilation, air conditioning and adjacent room heat transfer are not affected at the current moment; $\varphi_{j,0,i}$ – the influence coefficient of room j on the room temperature of room i at the present moment.; $\varphi_{hvac,i}$ – the influence coefficient of air conditioning heat on room temperature in the room i at the current time; $A_{hvac,i}(\tau)$ – the air conditioning heat quantity (or cooling) needs to be put into the room i at the moment (air condition is a system that gives automatic control, within predetermined limits of the environmental conditions, by heating, cooling, humidification, dehumidification, cleaning and movement of air in a building); $D_{outdoor,i}(\tau)$ – the ventilation quantity from i the outdoor ventilation quantity at the current moment; $T_{outdoor}(\tau)$ – the outdoor temperature at the current moment; $D_{j,i}(\tau)$ – the ventilation quantity from jth adjacent room to room i.

6. Methodology for optimization

6.1 Heat transfer Co-efficient for Insulation optimization

The plastering layer of the exterior walls is first removed. The exterior wall envelope structure is considered without adding any insulation. The characteristics of the exterior wall of the building envelope are studied with the assumption that other envelope structures remain unchanged. The building cool and heating loads are then simulated for the whole year base on the different layers of insulation with different material types and thicknesses. The index of the cool and heat loads accumulated are obtained. The layer without any insulation is taken as the reference. The types and thickness of the different insulation applied on the exterior walls concerning the energy-saving rate are noted. The economic evaluation based on the different insulation thicknesses is computed using the life cycle cost analysis method. The heat transfer coefficients after the addition of the thermal insulation layer on the surface of the wall are computed using equation (2). By so doing, the thermal characteristics of the whole wall are changed, and finally reducing the rate of the building energy consumption making the building energy efficient.

$$U = \frac{1}{\sum K_i} = \frac{1}{K_1 + K_2 + \cdots K_n} = \frac{1}{\sum_{i=1}^{n} \frac{\mu_n}{\lambda_i}} \qquad (2)$$

Where, $K_1, K_1 \dots K_n$ is the thermal resistance of each layer of a specific material, m^2 K/W; $\mu_{1,}\, \mu_2 \dots \mu_n$ is the thickness of each insulation layer, W/(m.K); $\lambda_1, \lambda_2 \dots \lambda_n$ is thermal conductivity coefficient (W/m.K). Thermal conductivity coefficient λ is the parameter of a material that depends on the physical property of the material, temperature, pressure and water content of the material [37]. A material with a large λ is a good heat conductor and the one with a small λ is described as a thermal insulator. With this research, the smaller the value of λ the better. Table1 gives a list of some important thermal conductivity coefficients at 20°C and 1 bar (100 kPa) related to the topic. For public buildings, an insulation thickness is said to be optimum if $U \leq 1$. This is stipulated in the "Design standard for energy efficiency of public buildings [53]". The accumulated heating and cooling load indices for the year are then analysed separately. The effect of the thickness of the different types of insulation material on the total load index within the year is then analysed. To factor in the total cost of the building, the material cost is considered. This will help to make a good decision on the selection of the optimum insulation material type and thickness keeping in mind the objective of making the building energy efficient.

Material	Thermal conductivity coefficient
Concrete –	
• Lightweight	0.1 – 0.3
• Medium	0.4 – 0.7
• Dense	1.0 – 1.8
Cement	1.01
Sand	0.06
Sandstone	3.00
Porcelain	1.05
Firebrick	1.09
Asphalt	1.26
Insulating Material	Thermal conductivity coefficient
Asbestos cloth	0.13
Comnressed straw	0.09
Cotton wool	0.029
Diatomaceous earth	0.06
Diatomite	0.12
Expanded Polyestyrene	0.03/0.04
Felt	0.04
Glass fibre quilt	0.043
Glass wool quilt	0.040
Hardboard	0.13
Hardboard	0.034
Kapok	0.07
Magnesia	0.07
Magnesia	0.04
Mineral wool quilt	0.04
Plywood	0.13
Polyurethane foam	0.03
Rock wool	0.045
Rubber natural	0.130
Sawdust	0.06
Slag wool	0.042
Urea formaldehyde	0.040
Wood	0.13-0.17
Wood wool	0.10-0.15

6.2 Economic Analysis

In the previous analysis, the optimization was based solely on the heat transfer coefficient of the different thicknesses of the different insulation material. In this analysis, the life cycle cost analysis will be considered as a tool to establish the relationship between material thickness, material cost, energy cost and total cost. This model will help determine the economic thickness value and the total expenses per unit area of the external wall. In this model, the average time for heating and cooling during cold hours and hot hours will be predicted for the entire city or region respectively. The degree-days method will be used to determine the Cooling Degree-Days (CDD) and the Heating Degree-Days (HDD) based on the solar heat gain through the building façade [35]. HDD is the measurement designed to determine the energy demand to heat a building. That is, at what outside temperature requires that the heat energy should be increased in the indoor to achieve thermal comfort. On the contrary, CDD is the measurement designed purposely to quantify the energy demanded to cool the interior of a building. That is, at what outdoor temperature requires that the indoor heat energy should be decreased to achieve thermal comfort. Simply put, the CDD and HDD are quantitative indices that is designed to cool or heat a room i.e. business, home, etc. [51].

6.3 Degree Days and Solar Radiation

Degree-days is one of the simplest methods for the estimation of annual energy consumption of a building. This method assumes that building energy needs is proportional to the difference between the daily outdoor temperature and the base temperature. The base temperature can be defined as the outside temperature above or below which cooling is needed (Kaynakli and Kaynakli, 2016). The base temperature is normally taken to be the threshold temperature at which the majority of the citizens within a particular locality claim to be hot or cold. A study conducted by [30] gives knowledge on how the base temperature of a particular city or region can be obtained. Due to the climatic change and variability in Ghana [12], it will be necessary to consider how the base temperature can be determined. This will be of much help to the current and even to the future generation. [11] have projected that there will be high temperatures and low rainfall in the year 2020, 2050, and 2080, and desertification will proceed at a rate of 20,000 hectares per annum. This means that one of the main sources of Ghana's power generation, Hydropower generation, will be at risk. Taking into consideration the solar heat gain through the external walls of a building, the number of annual HDD can be expressed as follows [17]

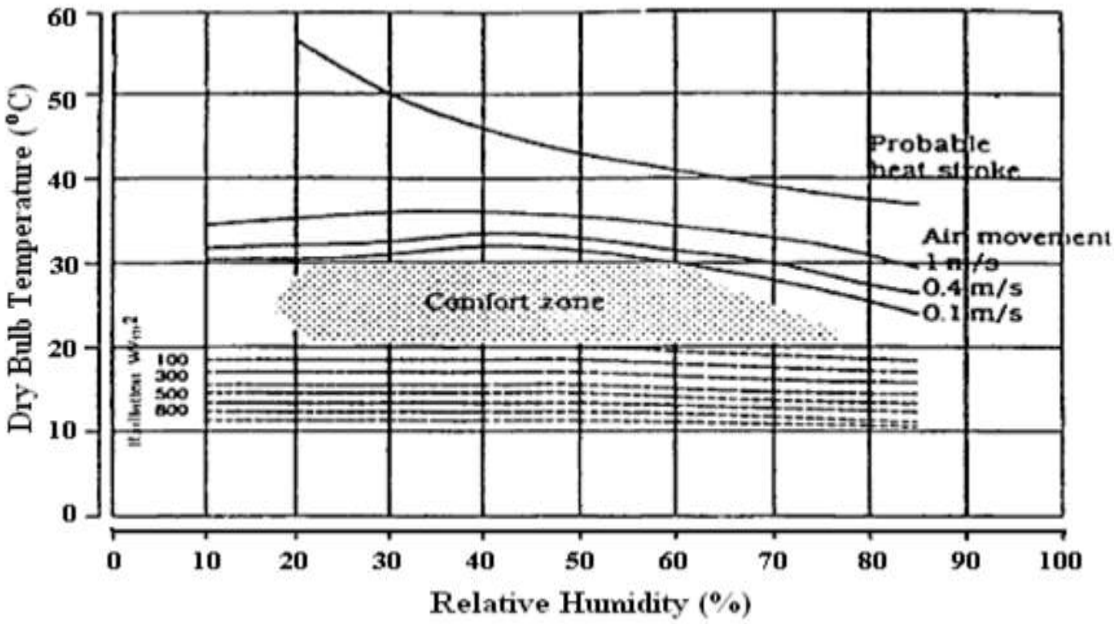
6.4 Determining a new threshold for CDD and HDD

A building's passive thermal design is largely dependent on the bioclimatic charts of the local climatic condition. This chart depends on the atmospheric pressure of a particular location which is only available at sea level. According to [40], the sensation of comfort is dependent on six factors: rate of metabolism, humidity, airspeed, mean radiant temperature (MRT), the clothing level (adds to temperature and humidity). The predicted mean vote means the votes raised by the majority of the population expressing thermal comfort within a particular locality or environment.

Thermal neutrality [31]

$$T_{neutrality} = 11.9 + 0.534T_{outdoor} \qquad (3)$$

The olgyay diagram is a chart for determining the thermal comfort for a particular geographic location. The constant comfort of the olgyay's chart is in a range of 20 to 30ºC. The chart considers the levels of comfort outside the specified range by taking into account the wind speed, mean radiant temperature and solar radiation. This chart mostly considers the outdoor temperature disregarding the indoor temperatures making it suitable for hot humid climates where the fluctuation between the indoor and the outdoor temperatures is minimal. The chart considers the levels of comfort outside the specified range by taking into account the wind speed, mean radiant temperature and solar radiation. To utilize the bioclimatic chart, the average monthly condition is first identified. The daily maximum temperature is first calculated and linked with the average minimum daily absolute humidity to form the point $(\overline{T}_{max}, \overline{H}_{min})$. Similarly, the average daily minimum temperature is linked with that of the average daily maximum absolute humidity, $(\overline{T}_{min}, \overline{H}_{max})$. The proper passive cooling strategy for the month is predicted based on the point at which the two points meet.



Olgyay Biometric Chart [6]

It should be noted that most of the research studies in the field of *HDD* and *CDD* monitoring are conducted by researchers from Turkey and Greece [5]. Threshold degree day temperature is the total mean deviation of the daily temperature of human comfort. To determine the climatic comfort, usually, the top and bottom borders are set as non-comfort. i.e. that of Greece confirmed a base temperature of 14, 15 and 18 as the criterion for determining HDD and a base temperature of 24 and 26 as the criterion for determining CDD (Matzarakis and Balafoutis 2004; Papakostas *et al.*, 2010,43) and setting i.e. $P_{10} - P_{100}$ threshold frequencies for the data set. This means that most of the thermal comfort obtained at a particular geographical area is below 10% or equal to 10% as the bottom border P_{10} and less than 100% or equal to 100% as the top border. These are the domains for determining the thermal comfort base on the distribution of the data set. It is generally believe that the local people in a particular geographical location can adapt themselves to their surrounding climate. Thus, their bio-comfort and tolerance is different for different climate. Therefore the need for threshold. First, the bioclimatic condition of a number of selected weather stations in different cities will be analyse. The base temperature (threshold temperature) for *HDD* and *CDD* will then be calculated. Finally, the new values of *HDD* and *CDD* will be calculated. The domains may be computed using the expression;

$$P_x = \frac{(n+1)}{100} S \tag{4}$$

Where P_x the threshold rank of the percentile i.e. for 10, 25, 60, 75 and 90%; n is the number of samples and S is the percentile. $P_{10} - P_{50}$ – will be categorize as ideal comfort zone; $P_{50} - P_{80}$ – as favourable comfort zone; $P_{80} - P_{100}$ – comfort zone.

Psychometric Chart for a working environment

This chart is very essential for the design of HVAC systems. It takes into consideration the relationships relative and absolute humidities, dry and wet bulb temperatures, enthalpy and specific volume. These parameters can be specified for different altitudes using the Psychometric chart. These charts can be used a reference to predict better comfort zones in the design of HVAC system for a particular environment. The equations designed for this chart is based on the closeness of the air-water vapour mixture to ideal gas [50]. That is the ambient air is treated as the mixture of the two components: water vapour and dry air. The set of function is plotted on domain of absolute humidity $H: kg\, H_2O/kg$ for dry air versus dry bulb temperature T: °C. H is a function of temperature T.

$$H = f(T) \tag{5}$$

Dry temperature values is first chosen for the abscissa. The range is normally selected at sea level i.e. P = 101325 Pa, at a range usually from -10 to 55 °C. The vapour pressure (Pa) for each T °C can obtained by the following expression;

$$P_v = 610.78 \exp\left(\frac{21.874\, T}{265\ 6+0.9615T}\right) \tag{6a}$$

$$for \begin{cases} -40^oC \le T < 0^0C \\ -40\frac{kJ}{kg} \le h < 9.43 kJ/kg \\ 12.838\, P_a \le P < 610.78\, P_a \end{cases}$$

$$P_v = 610.78 \exp\left(\frac{17.269T}{237.78+T}\right) \tag{6b}$$

$$for \begin{cases} 0^oC \le T < 63.0^0C \\ 9.43\frac{kJ}{kg} \le h < 537\, kJ/kg \\ 610.78\, P_a \le P < 22870.52\, P_a \end{cases}$$

$$P_v = 610.78 \exp\left(\frac{17.269T}{236.3+1.015857T}\right) \tag{6d}$$

$$for \begin{cases} 63^oC \le T \le 110^0C \\ 537\frac{kJ}{kg} \le h \\ 33870.52\, P_a \le P \le 143292.97\, P_a \end{cases}$$

Where the vapour pressure will be used for the relative humidity curves. The correlation will be used to find the temperature as a function of vapour pressure and hence the range of pressure is given. The ordinate of the plot is the absolute humidity and for the range of temperature at atmospheric level (kg H_2O/kg Dry air). The first curve to be considered is the absolute humidity curve at saturation (i.e. 100% relative humidity). The equation can be found as

$$H = \frac{0.62198\, P_v}{P - P_v} \tag{9}$$

Whereas H - absolute humidity (kg moist/kg dry air); P_v - vapour pressure (Pa); P – atmospheric pressure (Pa), (where P = 101, 325 Pa at sea level).

The rest of the relative humidity (RH) curves takes the same expression with appropriate or specified proportion of the vapour pressure;

$$H = \frac{0.6219 y P_v}{P - y P_v} \tag{10}$$

Where y is the coefficient of the RH, e.g. for a relative humidity of 60%, y = 0.6. y ranges usually from 0.1 to 0.9 in addition to the absolute saturation curve, y = 1.0. the vertical grid lines will stretch from the abscissa to the saturation line. Two points makes a straight line and is taken to be (T, 0) and (T, H_s); T – dry bulb temperature; H_s – corresponding absolute humidity at 100% RH which can be calculated using equation (6) (the saturation curve). P_v can be calculated using equation (7) for each value of T.

6.4.1 Horizontal grid lines

The horizontal gridlines stretches from the vertical axis to the saturation curve (100% relative humidity curve). The two points include $T_{dewpoint}, H$ and $T_{dewpoint}, H$. $T_{dewpoint}$ – Dew point corresponding to each absolute humidity. T_{max} Chosen maximum dry bulb temperature. From (7):

$$P_v = \frac{P_W}{0.62198+H} \tag{11}$$

$P_v = 610.78 \exp\left(\frac{AT}{B+CT}\right)$ where A, B and C are the appropriate constants in (6). T can then be expressed as

$$T = \frac{B\ ln\left(\frac{P_v}{610.78}\right)}{A - C \ln\left(\frac{P_v}{610.78}\right)} \tag{12}$$

6.4.2 Specific volume curves

These curves originate from the point $(T_0, 0)$, abscissa, where the absolute humidity is zero and end at the point (T_s, H_s), saturation curve. Thus, T_s, H_s and T_0 must be determined. For

101,325 Pa, the range of atmospheric constant specific volume curves can be chosen from 0.75 to 0.95 m^3/kg dry air. A trial run will be necessary. The specific volume can be express as;

$$v_s = \frac{287.05(T+273.16)}{P-P_v} \tag{13}$$

For every constant specific volume curve v_s, T_s, H_s and T_0 is be determine. Calculate the dry bulb temperature for each v_s value at which the line intercept the saturation curve. Since T_s is dependent on the range of h as given above in **, it can be determined by using the numerical method used to determine T. Now, T_{i+1} can be derived using Newton-Raphson iterative equation [6] as given below;

$$T_{(i+1)} = T_{(i)} - \frac{g(T_{(i)})}{g'(T_{(i)})} \tag{14}$$

The first derivative of g (T) is determined using a central finite difference with step size δ due its complexity [6].

$$g'\left(T_{(i)}\right) \cong \frac{g(T+\delta)-g(T-\delta)}{2\delta} \tag{15}$$

Finally, $T_{(i+1)}$ can be express as

$$T_{(i+1)} = T_{(i)} - \frac{2\delta \times g(T_{(i)})}{g(T_{(i)}+\delta)-g(T_{(i)}-\delta)} \tag{16}$$

Where $\delta = 0.005$ leads to rapid convergence.

The enthalpy diagonal axis is added by extending the length Δ beyond the saturation line where Δ is chosen arbitrarily. (T, H$_s$) form one point where the rest of the point can be determined using basic geometry. Any reasonable temperature value i.e. 20^{o}C can be chosen for the iterative numerical method as discussed above. At the center of each zone defines the thermal comfort (thermal neutrality) of a person. The maximum humidity should not exceed 12 g/kg dry air. The comfort zone as specified by ASHRAE will adopted. This is the zone where 80% of the slightly active people (office) find the environment to be thermally comfortable. ASHRAE defined the comfort zone for 0.5 col of short sleeved shirt and pant (0.44ft^2.h.^{o}F/Btu). One will feel thermally comfortable when at the center of the zone and the sensation gradually changes by +0.5 as the person shifts towards the boundary of the zones (feels warmer). The person feels colder as he/she moves by -0.5 towards the boundaries. The zones are suitable for air speed less than 0.2m/s for sedentary activity.

6.4.3 Calculating the HDD and CDD of a geographical area

$$HDD = \sum_1^{365}(T_b - T_{solar\ air})^+ \tag{17}$$

Where T_b represent the base temperature and $T_{solar\ air}$ represent the solar air temperature. The plus sign above the parenthesis indicates that only positive values must be taken into consideration. Hence, the difference in temperature must be considered as zero when $T_{solar\ air} > T_b$. Again, the annual number of cooling degree-days (CDD) can be expressed as follows

$$CDD = \sum_1^{365}(T_{solar\ air} - T_b)^+ \tag{18}$$

The $T_{solar\ air}$ can be estimated using the equation as expressed below;

$$T_{solar\ air} = T_o + \frac{\alpha_s \chi_s}{H_o} - \frac{\varepsilon\sigma\left(T_o{}^4 - T_{surface}^4\right)}{H_o} \tag{19}$$

Where T_o is the temperature of the outside air; α_s is the solar absorptivity of the wall surface, H_o is the outer surface combined radiation and convection heat transfer; χ_s incident rays of the solar radiation on the surface of the wall (W/m^2), ε is the emissivity of the surface, σ is the Stefan-Boltzman constant $T_{surface}$ is the surrounding and sky temperature.

The mathematical computation for the estimation of the air-conditioning power consumption per unit area during cold seasons is given in equation (5).

$$A_a = \frac{T_{indoor} K \times HDD T_a}{EER} \tag{20}$$

Also, the equation below gives the calculation of air-conditioning power consumption per unit area in hot seasons.

$$A_b = \frac{T_{indoor} K \times CDD T_b}{COP} \tag{21}$$

Where, A_a, A_b is the power consumed by the air-condition in the cold and hot seasons per unit area of respectively, kW.h/m^2; CDD, HDD are the cooling and heating degree days respectively; EER, COP are the energy efficiency ratios or coefficient of performance for the air condition systems operating in hot or cold seasons; T_a base temperature for CDD; T_b is the base temperature for HDD. T_{indoor} is the indoor temperature. To calculate the tonnage of an air-condition cooling capacity, the following equation can be used (when given in Watts);

$$EER\ (Energy\ Efficiency\ Ratio) = \frac{Cooling\ Capacity\ (in\ Watts)}{Input\ Wattage\ (in\ Watts)} \tag{22}$$

Or using the Carnot cycle

$$COP_{Carnot} = \frac{T_{indoor}}{T_{outdoor} - T_{indoor}} \tag{23}$$

Where T_{indoor} is the indoor temperature and may be measured in K (Kelvin) or R (Rankine). The corresponding EER can be obtained by multiplying COP_{Carnot} by 3.413 and is expressed as;

$$EER_{Carnot} = 3.413(COP_{Carnot}) \tag{24}$$

7. Life Cycle Cost Analysis

The total operating cost of the building is obtained by the adding together the cost of then insulation layer and the power consumed by the air-condition. This can be expressed by the equation given below;

$$C = C_{in} + C_H \tag{25}$$

$$C_{in} = C_i \mu \tag{26}$$

$$C_H = PWF \times C_E \tag{27}$$

$$C_E = \xi \times (A_a + A_b) \tag{28}$$

Where, C – is the total operation cost per unit area RMB/(m^2. a); C_H – the total cost of electricity consumption per unit area of the air-conditioning, RMB/(m^2. a); C_{in} – the cost of investment per unit area of insulation (installation and material costs), RMB/(m^2.a); C_E – the power consumed by the air-condition per unit area, RMB/(m^2.a); C_i – the cost per unit volume of the installation material, RMB/ (m^2.a); ξ- price of electricity in Ghana, RMB/kW. h; η – thickness of the insulation material; PWF – the present worth factor in the life cycle which is expressed as future value converted to present value.

For the PWF, when

$$g < i, \qquad I = \frac{i-g}{1+g} \qquad \text{and} \qquad PWF = \frac{(1+i)^N - 1}{I(1+1)^N}$$

(29)

$$g > i, \qquad I = \frac{g-i}{1+i}$$

(30)

$$g - i \qquad , \qquad PWF = \frac{1}{1+I}$$

(31)

Where g - inflation rate; I – discount rate; i is the interest rate of the bank.

8. Economic optimization of insulation thickness

As already described above, the total cost per unit area of an insulation material can be computed by considering the combination of both the accumulated heating and cooling load. Therefore, total cost per unit area of the insulation material can be obtained using the expression as follows;

$$C = \frac{0.0052 \times PWF \times C_E}{R_{bw} + \frac{\mu}{\lambda}} \times \left(\frac{HDDT_a}{EER} + \frac{CDDT_b}{COP}\right) + C_i\mu \qquad (32)$$

Where, R_{bw} is the total thermal resistance of the base wall (not considering the layer of insulation), (m^2.K)/W.

When $\frac{dC}{d\mu} \approx 0$, the total cost C approaches the minimum value and the optimum economic thickness μ_{opt} is obtained by the relation;

$$\mu_{opt} = \sqrt{\frac{0.0052 \times PWF \times \left(\frac{HDDT_a}{EER} + \frac{CDDT_b}{COP}\right) \times C_i\mu}{C_i}} - R_{bw}\lambda \qquad (33)$$

Result and Discussion

DeST is a dynamic tool that takes into account the time variation of a system. The life cycle cost analysis considers the thermal conductivity coefficient which is a necessary parameter for predicting the thickness of an insulation. Thermal conductivity coefficient λ in turn depends on the physical property, temperature, pressure and water content of the external wall. These are the factors based on which heat is transferred into the interior of a room. The outside temperature is required to determine the temperature of the inside. The dynamic nature of the temperature in Ghana makes it necessary to consider the threshold values of the *HDD* and the *CDD*. The life cycle cost analysis factors in the thermal conductivity coefficient of the exterior wall in the prediction of the most economic insulation material.

Conclusion

The weather condition of Ghana is dynamic in nature and will therefore requires a dynamic tool to simulate the cooling and heating loads. DeST performs dynamic simulation and is therefore a good tool for predicting the heat and cooling loads in Ghana. The *HDD* and *CDD* method is chosen because it is one of the simplest methods for determining the annual average temperature of a geographical area. The life cycle cost analysis is a good method since it takes into consideration the thermal conductivity of the exterior wall.

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