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Full Length Research Paper

Assessing effectiveness of utilization of passive design parameters on active energy consumption in public buildings in warm-humid climate

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Energy requirement in buildings for physiological comfort can be in form of active or passive energy. When the buildings are not energy conscious and passive energy is not well utilized to achieve the desired comfort level, the use of active energy becomes necessary. The mean minimum satisfaction rating of 1.13 which was significantly correlated at 0.01 level, and mean maximum satisfaction rating of 3.34 which was significantly correlated at 0.05 level were achieved. Various strategies for energy conscious building design were highlighted. The study revealed in the regression models that the contribution and effectiveness of the sets of explanatory variables varied. The regression equations for each of the subsectors of the public buildings was with $0.610 \geq R^2 \geq 0.099$, $0.520 \geq AR^2 \geq 0.033$ and $0.227 \geq$ significant level ≥ 0.000. The effectiveness/contribution of utilization of most effective independent variables of climate responsive design (CRD) parameters on active energy consumption (Ec) are $0.327(32.7\%) \geq SR^2 \geq 0.000(0.0\%)$.

Key words: Buildings, physiological comfort, passive energy, active energy, energy conscious building design, climate responsive design (CRD) parameters.

INTRODUCTION

Buildings provide the microclimate required for human existence and define spaces for all human activities. As observed by Olanipekun (2002) and Lawal (2008), buildings are essential modifiers of the microclimate; a space isolated from climate temperature and humidity fluctuations sheltered from prevailing winds and precipitation, and with enhancement of natural light. It has also been observed that effect of extreme climatic condition, which is discomfort, could be reduced by provision of environmental services (Luff, 1984).

Parameters like temperature, relative humidity and solar radiation should be considered in building design (Doxiadis, 1996). Also, buildings in these areas should respond to passive energy and have minimum use of active energy for comfort. Building design in tropical areas particularly in warm humid climate should aim at minimizing heat gain indoors and maximizing evaporative cooling of the occupants of the spaces so as to achieve thermal comfort.

Thermal performance of buildings

Thermal performance and efficiency of buildings should be measured through climate responsive design. The use of site and climate for design with regard to thermal efficiency has further potential for reducing active energy which is the operational energy of the building.

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Due to the increased concern for active energy consumption (Ec) for provision of thermal and visual comfort, design criterions have been developed to assist with saving of the energy through life cycle costing. This fundamentally involves the computation of the capital cost of the building and cost of operating the building over its projected life as stressed by Chand (1976). The active energy cost often exceeds the capital costs of public buildings. Climate conscious design requires a thorough understanding of the local climate and the employment of several strategies and systems for the creation of an agreeable micro-climate with a minimal consumption of active energy.

Ways of moderating the indoor climate in building as analyzed by Jackson and Jackson (1997) include (1) the choice of proper site of the buildings, (2).developing proper shape and size for the buildings, (3) proper orientation of the buildings, (4) providing good ventilation, (5) providing adequate window sizes for natural ventilation, (6) providing appropriate vegetation and (7) selecting adequate building fabrics. The aforementioned are passive energy techniques that building designers should follow to moderate indoor climate. Also, Larsen (1998) stated that body comfort should govern building design in the tropics and elsewhere.

More often than not, active energy is not adequate in moderating indoor climate for human comfort. Designers then resort to the use of these passive energy techniques to provide the needed comfort for building users. Observations have shown that most buildings in our environment utilize more of active energy for the both thermal and visual comfort thus, showing that these building are not climate responsive.

The attainment of a high level of comfort in buildings (residential and public) depends a great deal on the amount of solar radiation exclude from the interior spaces (Ajibola, 2001). Design considerations determining human health, comfort and well being in a building should aim at preventing solar radiation and allow for adequate illumination. When these factors are not adequately considered much active energy would be used for air-conditioning, illumination to attain a high level of comfort (thermal and visual) in buildings. There is however, the need for the designers to minimize the use of active energy.

Passive design strategies seek to reduce active energy budget of the building by paying attention to utilization of natural illumination and ventilation through orientation, insulation, window placement and designs (Larsen, 1998). Chand (1976) affirmed that passive design approach makes use of natural energy in the environment which is available to the building through the use of the microclimate, the building form and fabric.

Problems of building design parameters and materials in the tropics towards controlling the harsh climate have been highlighted by various authors such as Koenigsberger (2001), Vanstraaten (1987) and Ngoka (1976) among others. The factors highlighted affect the thermal performance of buildings generally and when observed an optimum comfort level would be achieved indoor.

A comfortable environments are being demanded worldwide where working or pleasure tasks can be carried out unhindered physically or mentally (Page, 2000). Air and surface temperatures, humidity, air movement and air purity play a part while psycho-sociological factors also have important role to play. The attitudes of space users, the organization of indoor spaces, colour schemes and many other factors can all have influence on our mood work output. Thus, there is interaction between all these factors, which complicate the comfort problem further. Such factors can be grouped under three headings: physical factors (sound, light, area-volume, radiation, air movement, temperature, inspired air, force field, relative humidity and atmospheric pressure), organism factors (age, diet and sex) and reciprocities factors (activity, clothing exposure and social level) (Derek and Brain, 1978).

Table 1 shows average emissivities, absorptivities and reflectivities for some surfaces common to buildings. Emissive, designated by e, is the ability of a material and its surfaces to radiate or emit energy. Rough surfaces emit radiation better than highly polished surfaces. Absorptive (σ), is the ability of a material and its surface to absorb heat. In opaque materials, energy that is not absorbed is reflected. In terms of colour; darker colours are more absorptive than lighter colours. Maxine (1999) was of the opinion that materials painted with black paint will absorb 90% of the solar radiation that falls on it.

Radiant heat transfer is the exchange of heat energy in the form of electromagnetic waves between two or more bodies of different temperature separated by space or a medium that is transparent or non-absorbing to the heat waves. A characteristic of this mode of heat transfer is that space or medium through which the heat rays pass is not heated up by them to any significant level. An example of this is the radiation received by the earth from the sun. The intensity of radiation emitted by a body depends in the nature and temperature of the body. Stefan-Bolzmain (2003) stated that heat radiated by a black body is proportional to the fourth power of its absolute temperature.

Difference in thermal response of heavy weight and lightweight structures exposed to variations of external temperatures and solar radiation according to Ezeilo (1998) will depend on their heat storing capacity. A good amount of heat can be absorbed without a significant rise to its temperature in heavyweight structures while lightweight structures will transmit heat almost directly to the interior of the building. The degree of heat gain or loss through light-weight structures depends on their thermal resistance but heavy-weight components depend on both the influence of heat, storing capacity and thermal resistance.

Thermal comfort and human performance

Human beings partake in various activities within building enclosures. These activities can only be performed best when the environmental conditions are favorable. Inside a building, people are affected either positively or negatively because of the physiological reactions and psychological responses to the thermal environment. Thermal comfort plays a significant role inhuman performance at both mental and physical levels.

The level of performance of given tasks would indicate the level of influence generated by the impulses caused by the varied environmental parameters. According to Markus and Morris (1980), thermal conditions will affect levels of arousal, vigilance, fatigue, attention and boredom.

Wyon (2000) showed that two conditions of equal thermal comfort were achieved using different combinations of clothing and temperature which led to no difference in the performance of a wide range of mental tasks. This infers that different means of achieving the same comfort state do not result in different performance. As far as physical work is concerned, it is established that increasing metabolic rate causes the production of greater body heat and a rise in body temperature. This will result either in heat stress or in the need for more frequent rest pauses. More usually, the rate of working is deliberately or unconsciously adjusted to the opposite direction, to involve a lower metabolic rate, and hence a slower performance (Markus and Morris, 1980).

METHODOLOGY

Study area

Southwestern Nigeria lies within longitude 2° 48'- 6° 0'E and latitude 5° 5' - 9^0 12'N. Southwestern Nigeria is located in the south western part of Nigeria and shares land borders with the Republic of Benin in the west, Kogi and Edo States in the east and Kwara State in the north. Its coast in the south lies on the Gulf of Guinea on the Atlantic Ocean. The largest and most influential ethnic group in Southwestern Nigeria is Yoruba. In terms of religion, Southwestern Nigeria is roughly split half and half between Muslims and Christians with a very small minority who practice traditional religion. Southwestern Nigeria is divided into six states namely Oyo, Ogun, Osun, Ekiti, Ondo and Lagos. Southwestern Nigeria's largest city is Lagos. Lagos has grown from 300,000 in 1950 to an estimated 15 million today, and the Nigerian government estimates that city will have expanded to 25 million residents by 2015.

Means of obtaining the data

Data on physiological feeling of operators of public buildings were obtained and their performances in respect of utilization of climate responsive design (CRD) parameters from the respondents' responses rated on a five-point performance rating were obtained through questionnaires. Data on active energy utilization level (KWh) based on types, numbers and watts of electric bulbs, air conditioners and electric fans used by operators of public buildings and numbers of hours these electrical fittings were used in a day and were obtained by physical inspection and through questionnaires.

Treatment of the data

The relationship between the data on active Ec as dependent variable (DV) and level of utilization of (passive energy) CRD parameters as independent variables (IVS) were considered. Two types of relationship were established. The Pearson correlation co-efficient was used to achieve the correlation among pairs of variables. Multiple regression analysis (MRA) was used to assess the relationship between active Ec as the independent variables. Analysis of variance (ANOVA) test was also used to test the significance of regression coefficient for active Ec and contribution/effectiveness of utilization of most effective independent variables of CRD parameters was assessed by squared semi-partial correlation (Sr^2).

RESULTS AND DISCUSSION

The information gathered were edited and analyzed. Table 1 shows the distribution of mean satisfaction rating of utilization of passive energy/CRD parameters in public buildings based on the subsectors. This indicated that mean minimum satisfaction rating of 1.13 which was significantly correlated at 0.01 level and mean maximum satisfaction rating of 3.34 which was significantly correlated at 0.05 level were achieved.

Table 2 shows the summary of the main statistics of active Ec (kWh) and most effective independent variables of CRD parameters. This revealed the regression equations for each of the subsectors of the public buildings and was with $0.610 \geq R^2 \geq 0.099$, $0.520 \geq AR^2 \geq 0.033$ and 0.227 ≥ significant level ≥ 0.000. Table 3 shows the summary of analysis of public buildings based on recommendation from Mahoney tables on public building subsector basis. It revealed the frequencies of buildings that satisfied the recommendations from Mahoney analysis towards achieving passive building designs with minimal active Ec based on public building subsectors. Two types of relationships were established. The first is the correlation existing among pairs of all the variables identified. The Pearson correlation co-efficient was used to achieve this. Secondly, MRA was used to assess the relationship between active Ec as the DV and some selected CRD parameters as IVS. Table 4 shows the summary of contribution/effectiveness of utilization of most effective IVS of CRD parameters and active Ec; this revealed the effectiveness/contribution of utilization of most effective IVS of CRD parameters on active Ec as $0.327(32.7\%) \geq SR^2 \geq 0.000(0.0\%)$. ANOVA tables were prepared to test the significance of regression coefficient for active Ec in public building subsectors under study. Regression coefficient and squared semi partial correlation for active Ec were also prepared for public buildings in all the subsectors.

Tables 5, 6, 7, 8 and 9 showed the ANOVA testing for the significance of regression coefficient for active Ec

Table 1. Distribution of mean satisfaction rating of utilization of passive energy/CRD parameters in public building based on subsectors.

Passive energy/ CRD parameters	Public building subsectors				
	Educational institution buildings	Office buildings	Hospital buildings	Hotel buildings	Mean
X_1	2.82 a	3.00 a	3.18 a	3.28 a	3.07 a
X_2	3.56 a	3.04 a	3.29 a	3.22 a	3.28 a
X_3	2.77 a	2.91a	2.88 a	3.22 a	2.95 a
X_4	3.03 c	3.09	2.79 a	2.39 a	2.83 a
X_5	1.13 a	1.20 b	1.18 b	1.06 c	1.15 a
X_6	3.08 a	2.82 a	3.12 a	2.94 a	2.99 a
X_7	2.92 a	3.00 a	2.82 a	3.00 a	2.94 a
X_8	3.34 b	3.18 a	3.27 b	2.83 a	3.16 a
X_9	2.85 b	2.96 a	2.91a	2.06 a	2.69 a
X_{10}	3.33 b	2.91a	2.70 a	2.72 a	2.92 a
X_{11}	2.90a	2.78 a	2.67 a	2.67 a	2.76 a
Mean	2.81	2.75	2.62	2.69	2.72

Source: Authors analysis of fieldwork (2005). Means with letter (a), Significantly correlated at 0.01level; (b), significantly correlated at 0.05 level; (c), high correlation coefficient. The mean are gotten from respondents agreement rating of performance: 1, Strongly dissatisfied; 2, dissatisfied; 3, partially Satisfied; 4, satisfied; 5, strongly satisfied; X_1, natural thermal comfort level; X_2, natural visual comfort level; X_3, location of windows facilitating adequate ventilation; X_4, fabrics preventing heat gain into the building; X_5, presence of courtyard; X_6, size of windows facilitating adequate ventilation; X_7, location of windows facilitating adequate cross ventilation; X_8, spatial organization; X_9, adequate landscape; X_{10}, orientation of the building facilitating adequate natural illumination; X_{11}, orientation of the building facilitating adequate cross ventilation.

Table 2. Summary of the main statistics of active Ec (kWh) and most effective IVS of CRD parameters.

Subsector/State	R^2	AR^2	Regression equations	Sig
All subsectors	0.179	0.167	$EC = - 1.290 + 0.651x_1$	0.000
Hotel buildings	0.535	0.435	$EC = 2.906 + 5.661x_5 - 2.284x_6 + 2.628x_{10}$	0.011
Office buildings	0.099	0.033	$EC = 4.837 - 0.733x_7 + 0.06948x_3$	0.227
Educational institution buildings	0.366	0.270	$EC = -11.033 + 1.499x_2 -2.716x_3 + 6.982x_5 + 1.477x_6 + 2.013x_9$	0.008
Hospital buildings	0.610	0.520	$EC = 5.070 - 0.689x_1 + 1.581x_2 - 0.583x_3 - 1.369x_8 - 1.155x_{10}$	0.000

Source: Authors analysis of fieldwork (2005). X_1, Natural thermal comfort level; X_2, natural visual comfort level; X_3, location of windows facilitating adequate ventilation; X_4, fabrics preventing heat gain into the building; X_5, presence of courtyard; X_6, size of windows facilitating adequate ventilation; X_7, location of windows facilitating adequate cross ventilation; X_8, spatial organization; X_9, adequate landscape; X_{10}, orientation of the building facilitating adequate natural illumination; X_{11}, orientation of the building facilitating adequate cross ventilation.

Table 3. Summary of analysis of public buildings based on recommendation from Mahoney tables on public building subsectors basis.

Recommendation	Educational Institution buildings	Office buildings	Hospital buildings	Hotel buildings	Total (%)
Layout					
1) Building orientation on east-west axis to reduce exposure to sun	53.28%	37.77%	39.40%	38.88%	42.22
2) Compact courtyard planning					
Spacing					
3) Open spacing for breeze penetration	35.90	62.22	48.48	22.22	45.93
4) As 3 but protection from cold /hot wind					
5) Compact planning					

Table 3. Contd.

Air movement					
6) Rooms single banked. Permanent provision for air movement	51.28	53.33	54.55	33.33	50.37
7) Double banked rooms with temporary Provision for air movement	47.72	46.67	45.45	66.67	49.63
8) No air movement requirement					
Openings					
9) Large openings. 40-80% of N and S walls	25.64	26,67	18.18	22.22	24.44
10) Very small openings. 10-20%	38.46	40.00	30.30	16.67	34.08
11) Medium openings. 20-40%	35.90	33.33	51.52	61.11	44.48
Walls					
12) Light walls, short time lag.	5.13	13.33	8.09	22.22	11.11
13) Heavy external and internal walls.	94.87	86.67	90.91	77.78	88.89
Roofs					
14) Light insulated roofs.	85.66	78.45	82.75	66.62	76.30
15) Heavy roofs, over 8 h time lag.					
Outdoor sleep					
16) Space for outdoor sleeping required.					
Rain protection					
17) Protection from heavy rain needed	4.27	12.64	7.85	18.67	8.89

Source: Authors analysis of fieldwork (2005).

Table 4. Summary of the contribution/effectiveness of utilization of most effective IVS of CRD parameters on active Ec (kWh).

Subsectors/State	Most effective IVS	Contributions/effectiveness of utilization (%)
All subsectors	X_1	0.029 (2.9)
Hotel buildings	X_5	0.123 (12.3)
	X_6	0.238 (23.8)
	X_{10}	0.327 (32.7)
	X_7	0.023 (2.3)
	X_3	0.00 (0.0)
Educational institution buildings	X_2	0.084 (8.4)
	X_3	0.159 (15.9)
	X_5	0.162 (16.2)
	X_6	0.071 (7.1)
	X_9	0.086 (8.6)
Government hospital buildings	X_1	0.015 (1.5)
	X_2	0.076 (7.6)
	X_3	0.006 (0.6)
	X_8	0.057 (5.7)
	X_{10}	0.017 (1.7)

Table 4. Contd

Government office buildings	X_3	0.000 (0.0)
	X_7	0.023 (2.3)

Source: Authors analysis of fieldwork (2005). X_1, Natural thermal comfort level; X_2: natural visual comfort level; X_3: location of windows facilitating adequate ventilation; X_4, fabrics preventing heat gain into the building; X_5, presence of courtyard; X_6, size of windows facilitating adequate ventilation; X_7, location of windows facilitating adequate cross ventilation; X_8, spatial organization; X_9, adequate landscape; X_{10}, orientation of the building facilitating adequate natural illumination; X_{11}, orientation of the building facilitating adequate cross ventilation.

Table 5a. ANOVA table testing the significance of regression co-efficient for active Ec (kWh) in educational institution buildings.

Model	Sum of squares	Df	Mean square	F	Sig	F table
Regression	415.100	5	83.020	3.808	0.008	2.53
Residual	719.518	33	21.804			
Total	1134.618	38				

Table 5b. Regression co-efficient and squared semi partial correlation for active Ec (kWh) in educational institution buildings.

Model	Unstandardized coefficients		Standardized coefficients	t	Sig	Sr^2 (Cum)
	B	Std error	Beta			
(Constant)	-11.033	4.752		-2.322	0.027	
X_2	1.499	0.718	0.294	2.088	0.045	0.084 (0.084)
X_3	-2.716	0.944	-0.503	-2.877	0.007	0.159 (0.243)
X_5	6.982	2.402	0.433	2.907	0.006	0.162 (0.405)
X_6	1.477	0.771	0.287	1.817	0.064	0.071 (0.476)
X_9	2.013	0.949	0.344	2.120	0.042	0.086 (0.562)

Table 6a. ANOVA table testing the significance of regression co-efficient for active Ec (kwh) in office buildings.

Model	Sum of squares	Df	Mean square	F	Sig	F table
Regression	82.274	3	27.425	1.507	0.227	2.84
Residual	745.968	41	18.194			
Total	828.241	44				

Table 6b. Regression co-efficient and squared semi partial correlation for active Ec (kWh) in office buildings.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Sr^2 (Cum)
	B	Std error	Beta			
(Constant)	4.837	2.788		1.735	0.090	
X_7	-0.733	0.714	-0.176	-1.026	0.311	0.023 (0.023)
X_3	6.948E-02	0.740	0.016	0.094	0.926	0.000 (0.023)

Table 7a. ANOVA table testing the significance of regression co-efficient for active Ec (kWh) in hospital buildings.

Model	Sum of squares	Df	Mean square	F	Sig	F table
Regression	466.559	6	77.760	67.81	0.000	2.47
Residual	298.169	26	11.468			
Total	764.729	32				

Table 7b. Regression co-efficient and squared semi partial correlation for active Ec (kWh) in hospital buildings.

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig	Sr^2 (Cum)
	B	Std error	Beta			
(Constant)	5.070	3.283		1.544	0.135	
X_1	-0.689	0.693	-0.198	-0.994	0.329	0.015 (0.015)
X_2	1.581	0.704	0.478	2.247	0.033	0.076 (0.091)
X_3	-0.583	0.900	-0.136	-0.648	0.523	0.006 (0.097)
X_8	-1.369	0.705	-0.264	-1.941	0.063	0.057 (0.154)
X_{10}	-1.155	1.092	-0.217	-1.058	0.300	0.017 (0.171)

Table 8a. ANOVA table testing the significance of regression co-efficient for active Ec (kwh) in hotel buildings.

Model	Sum of squares	Df	Mean square	F	Sig	F table
Regression	130.192	3	43.397	5.361	0.011	3.34
Residual	113.322	14	80.94			
Total	243.514	17				

Table 8b. Regression co-efficient and squared semi partial correlation for active Ec (kWh) in hotel buildings

Model	Unstandardized coefficients		Standardized Coefficients	t	Sig	Sr^2 (Cum)
	B	Std error	Beta			
(Constant)	2.906	3.886		0.748	0.467	
X_5	5.661	2.936	0.353	1.928	0.074	0.123 (0.123)
X_6	-2.284	0.853	-0.566	-2.677	0.018	0238 (0.361)
X_{10}	2.628	0.837	0.665	3.140	0.007	0.327 (0.688)

Table 9a. ANOVA table testing the significance of regression co-efficient for active Ec (kWh) in all public buildings.

Model	Sum of squares	Df	Mean square	F	Sig	F table
Regression	581.046	2	290.523	14.414	0.000	2.99
Residual	2660.529	132	20.156			
Total	3241.574	134				

Table 9b. Regression co-efficient and squared semi partial correlation for active Ec (kWh) in all public buildings.

Model	Unstandardized coefficients		Standardized coefficients	t	Sig	Sr^2 (Cum)
	B	Std error	Beta			
(Constant)	-1.290	1.565		-0.824	0.411	
X_1	0.651	0.299	0.171	2.173	0.032	0.029 (0.029)

(kWh), and regression coefficient and squared semi partial correlation for active Ec (kWh) in all the public education sectors.

Conclusion

Based on the assessment of contribution or effectiveness of each of the explanatory passive design parameters or CRD parameters on active Ec, climate or the humid region of Southwestern Nigeria is homogenous and that the energy requirement in each of the public building subsectors varied from one to the other.

It was also observed from the analysis that key determinants of the active Ec level for psychological comfort (thermal and visual) in each of the public building subsectors varied and this can be seen from the computed MRA.

RECOMMENDATION

1) Designers in the warm humid region of Southwestern Nigeria should take the issue of utilization of passive design parameters into consideration when designing public buildings.
2) Due to shortage of supply of active energy and its high cost in public buildings, its wastages should be appreciated.

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