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Analysis of Electricity Consumption in the Faculty of Engineering with Integration of Renewable Solar Power System

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Load analysis of electricity consumption in the engineering lecture theatre of the University of Lagos, towards a retrofit with *Mimosa pudica*–based solar cells, is investigated. A walk-through energy audit of the demand of lighting, space cooling, ventilation, thermal comfort and the energy-powered operation of educational equipments, is conducted. A process flow analysis of integrating the flat-roofed theatre with the design and development of *Mimosa pudica* wafers is anticipated. The balance of demand and supply, from the local grid coupled with the independent renewable supply from the organic solar power production, is modelled with *EnergyPlus* energy simulation software. The reliability and/or sustainability of the local grid will be improved with the proposed design and demonstration of independent power generation for the Faculty of Engineering using renewable solar energy resources.

I. Introduction

REVIEW of the prices of electricity in the Nigerian energy market has recently led to interesting discourse about the need for deregulation of the market among the major stakeholders in the developing nation's moribund power sector. With the enormous available renewable resources, in addition to being one of the largest oil producing countries in the world, it is difficult to justify the fact that Nigeria's power production capacity still stands at about 4,000 MW for a population of more than 150 millions. However, the power reform plan of the current administration, among other initiatives, is proposing a Feed-In-Tariff (FIT) program (to be administered by the National Electricity Regulation Commission) for generation of power through the renewable energy sources. If this proposal is adopted by the major stakeholders, and launched by January, 2012, power rated with installed capacity above 1 MW and fed into the national grid will be paid based on the technology of the renewable power project (□34.8/kWh for solar photovoltaic; □12.0/kWh for wind; and □20.4/kWh for small hydro). Comparatively, the Province of Ontario launched its FIT programs in 2009 for both residential-scaled or micro FIT and commercial scaled FIT projects, administered by the Ontario Power Authority (OPA), with 80.2 cents/kWh for solar photovoltaic projects. Without considering the differential costs for operation and maintenance (O&M), transportation, and feasibility study, it implies that the proposed purchase of about 20 cents/kWh of solar photovoltaic-based power by the Nigerian

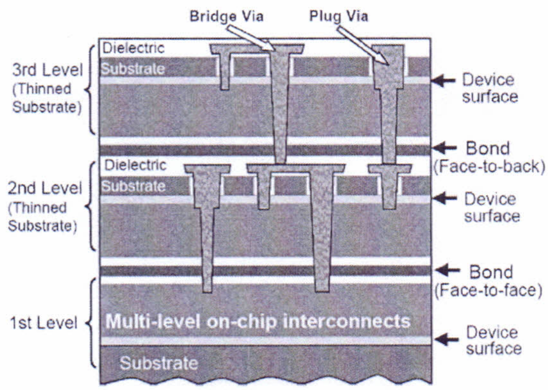

Figure 1: Schematic Representation of a Stacked Bonding Structure in Organic Wafer [Ref. 2]

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purchasing agency is about 25% of the offering in the Province of Ontario. Even with the solar energy potential of up to 7 kW/m^2/day in the northern part of Nigeria, the economic viability of any renewable energy project in Nigeria depend on the accurate capture of all factors, including the demand analysis, energy storage, reliability of the grid, applicable energy conversion technique, regulatory procedure, procurement of appliances, etc. Without prejudice to the incentives through the FIT program, clean energy practice starts with effective conservation of the available electricity in the local grid. Inspite of the efficiency-edge of silicon-based photovoltaic cells in the conversion of solar energy into electricity, the pursuit of the renewable-edge with organic solar cells has driven recent investigations of suitable wafer technologies for the manufacturing of solar cells at lower temperature.

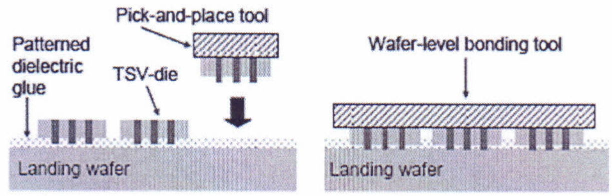


Figure 2: Illustration of the Die Pick-and-Place Process [Ref. 1]

Certain crystalline organic dye compounds, such as 3,4,9, 10-perylenetetracarboxylic dianhydride (PTCDA), can be vacuum deposited onto several different semiconductor wafer surfaces without inducing measurable changes of the underlying semiconductor properties, almost all the semiconductor properties of organic materials are destroyed under the existing wafering of silicon-based semiconductors[1]. An organic-on-inorganic method was adopted by Forrest et al[1] in order to access semiconductor properties, like the free carrier concentration, the deep level density and energy, and the epitaxial layer thickness deep within the wafer. Sidler et al[2] recently used stencil lithograpy for the patterning of an organic pentacene-based thin film transistor on a film coated polyimide film. Other properties peculiar to porous Si-based semiconductors, including crystal structure, chemical composition, electrical conductivity, career mobility, thermal conductivity, optical properties (like luminiscence and index of refraction), band gap, and mechanical properties, are reviewed by Korotcenkov and Cho[3] in their study of the state of art of silicon porosification.

Occupancy in engineering lecture theatre at the University of Lagos is similar to the behavior at schools, in many recent studies[4-5]. Higher occupancy than any other buildings, with significant indoor environmental problems, while ventilation levels are below the recommended rates, is reported. The modeling of the volatile organic concentration (VOC) depends on the development of the complex and stratified compartments that constitute the facility. Accurate assessment of individual building will enable the forecasting of energy demand for the design of the proposed independent power plant. Until recently, and with the nation's electricity generation, transmission, distribution and supply under the management and regulation of the Power Holding Company of Nigeria (PHCN), the costs of running the much-needed, economic-driven power system have not been sustainable. For instance, the Special Adviser to the President on Power recently said, as quoted: "Nigeria requires a capital investment of about □520 billion every year to enable her increase generation capacity of 4,200MW to 13,000MW by 2013...increasing transmission and distribution from 5,800 to 9,000MW by 2012 also requires a capital investment of □200 billion every year."[6] Retrofitting the flat-roofs of suitable buidlings for power

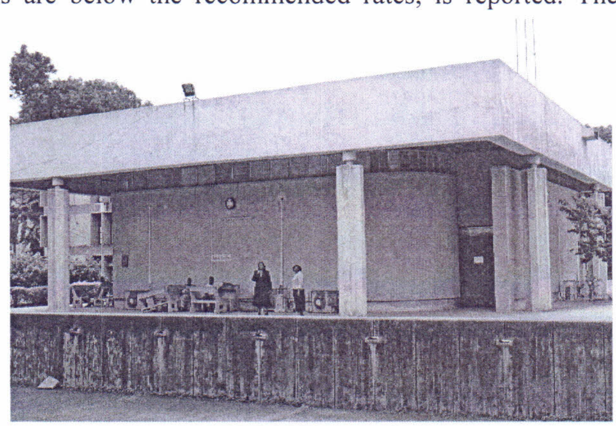


Figure 3: Pictorial View of the Engineering Lecture Theatre Based Energy Stock

generation from renewable energy resources, like the proposed organic-based solar wafers, can be helpful in reducing these enormous costs.

This study proposes the demonstration of the potential of *Mimosa pudica* wafers for conversion of solar energy into electricity. The promotion of clean energy technologies, with possible improvement in the thermal comfort and indoor air quality within the facility, can contribute to environmental sustainability, and eco-friendliness.

II. Description of the Energy Stock Audit

Assuming two components of energy commodities, including, *Mimosa pudica*-based renewable energy, and electricity from the local grid, to the Engineering Lecture Theatre (ELT), as shown in Fig. 4, the proposed model will enable the determination of the quantity of these component supplies. In a separate study, Ogedengbe et al[7] proposes the inclusion of consumer's energy demand in the estimation of the design load for the integration of solar photovoltaic systems. Energy audit of the ELT involves the recording of various characteristics of the building envelope, including the walls, ceilings, floor, doors, windows, and skylights. For each of these components, the area and resistance to heat flow (R-value) represent useful characterisation of the building thermal performance, including the leakage rate or infiltration of air through the ELT. The audit will also assess the efficiency, physical condition, and programming of mechanical systems such as the ventilation and air conditioning equipment. Krarti [8] in the reported IEA-ECBCS Annex 11 ASHRAE document elaborates the process of the audit, including the analysis of building and utility data; the survey of the real operating conditions; the understanding of the building behavior and of the interactions with weather, occupancy and operating schedules; the selection and the evaluation of energy conservation measures; the estimation of energy saving potential; and the identification of customer concerns and needs.

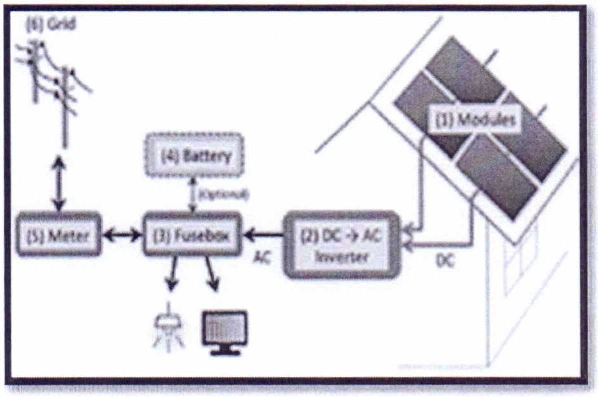


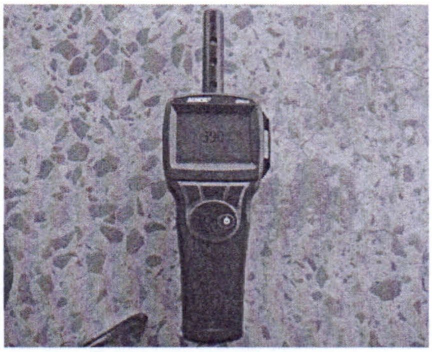
Figure 4: Schematic of a grid-connected Faculty of Engineering Buildings with *Mimosa-pudica* Solar Power (Source: Wikipedia)

An energy system control volume comprises the external boundary of the energy stock, including the flat-roofed, fully bonded wafers. *EnergyPlus* energy simulation software will be utilized, in addition to other add-ons and third party softwares like Google sketchup. The boundary of this building structure encloses a composite mass of dielectric and substrate, representing transport of heat transport with significant energy conversion mechanisms. These scalar transport of energy and species variables can be predicted based on the following form of energy conservation equations [9]

$$\frac{\partial(\rho c_p T)}{\partial t} + \nabla \cdot (\rho c_p v T) = \nabla \cdot (k \nabla T) \quad (1)$$

$$\frac{\partial(\rho c_p C)}{\partial t} + \nabla \cdot (\rho c_p v C) = \nabla \cdot (k \nabla C) \quad (2)$$

A walk-through audit of the ELT enables the analysis of the energy demand and supply from a grid-connected *Mimosa pudica*-based solar system on the flat roof of the energy stock (see Fig. 4). Thermal comfort and indoor air quality investigation involves the consideration of the building materials and the use of certain instrumentation, including clamp meter for energy consumption, mini-weather station for the building temperature, relative humidity and air velocity, CO_2 meter for the concentration, noise meter for the noise level, and the head count of the number of occupants. Other essential materials as used in this research include indoor air quality meter, and meter tape (see Fig. 5).

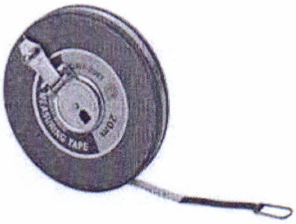


Indoor air quality meter

Mini weather station

Noise meter

Clamp meter



Meter tape

Figure 5: Instrumentation for a Walk-through Energy Audit

III. Energy Consumption Analysis

In a developed economy where the energy sector is fully deregulated, historical data of electricity consumption is conveniently communicated to Market Participants through the Electronic Business

Transaction ("EBT") system[10]. Pipe document including transactions like historical usage and payment information for low-volume consumers can be requested for up to 24 months from the local distribution companies. However, due to a developing economy and deregulated electricity market in Nigeria, the energy consumption data for the ELT cannot be assessed. The information about the electrical appliances and historical data of energy consumption within the building is obtained manually from the building's property manager. Using appropriate instrumentation as shown in Fig. 5, the characteristics of the building envelope and the load sources are collected, as tabulated in Table 1 and 2.

Table 1: Physical Properties of the Elements of the ELT Building Envelope

Element	Quantity	Orientation	Area [length x breadth]	Thickness	R-value
Roof	1		19 x 19 m		1.11
Wall	4	W, E, N, S		0.5 m	1.28
Ceiling	1		16.18 x 16.18 m		1.11
	1	W	2.32 x 1.74 m		
Door	1	E	2.32 x 1.74 m		2.17
	1	NE	2.20 x 1.74 m		

Table 2: Electrical Load Source and Appliances

Source	Quantity	Model	Wattage
Lighting (Fluorescent)	18	NEWCLIME 40W	720 W
Lighting (Energy saving)	16	20W	640 W
Audio Speaker	2		200 W
Air conditioner	10	CU-PC18JKF	20,500 W
Standing Fan	2	"OX" 660mm	170 W
Ceiling Fan	9	O.R.L	450 W
		Total	22,635 W

The thermophysical quality within and outside the ELT is characterises, using the mini weather station. Tables 3 and 4 show the measured relative humidity, air velocity, of level of CO_2 concentration, and the noise level. The load estimation of the building was done, taking into account every electrical appliance in the building. Using the R-values of the different materials, and EnergyPlus, the forecast of the thermal comfort and indoor air quality for various parametric configuration of the grid-connected *Mimosa pudica –based* solar power system can be simulated.

Table 3: Energy consumption and thermophysical characteristics of the ELT (Period 1: 8AM – 10AM)

Day	ENERGY CONSUMPTION (KWh)	CO_2 PPM	INDOOR R.H	OUTDOOR R.H	NOISE LEVEL (dB)	INDOOR TEMP. (^oC)	OUTDOOR TEMP. (^oC)	AIR VELOCITY (m/s)	OCCUPANCY
1	0	932	73.1	89	83.1	30.4	27	0	200
2	1.88	525	79.6	84	64	29.3	28	0	78
3	2.4	645	70.2	74	67.7	29.7	29	0	101
4	2.8	667	69.8	70	62	30.7	31	0	150
5	2.64	625	70.9	74	68	30	30	0	135
6	7.824	530	72.6	74	57	28	30	0	75
7	31.840	914	70	79	53.9	31.8	30	0	79
8	33.56	879	68	75	52	31.6	30	0	81
9	50.928	605	66.4	74	56.6	27	29	0	80
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Table 4: Energy consumption and thermophysical characteristics of the ELT (Period 2: 12PM – 2PM)

Day	ENERGY CONSUMPTION (KWh)	CO_2 PPM	INDOOR R.H	OUTDOOR R.H	NOISE LEVEL (dB)	INDOOR TEMP. (°C)	OUTDOOR TEMP. (°C)	AIR VELOCITY (m/s)	OCCUPANCY
1	0	831	63.5	40	66.8	32.7	33	0	190
2	11.184	632	62.4	41	54	32.6	34	0	135
3	11.04	624	61.8	59	65.7	32.9	32	0	130
4	10.08	619	61.2	62	52.7	32.3	32	0	103
5	0	475	68.9	63	72.4	32.4	33	0	80
6	0	406	67.9	55	60	32.8	33	0	30
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8	0	354	80.5	70	56.8	28.1	33	0	20
9	68.804	622	64.9	56	52	28.7	34	0	83
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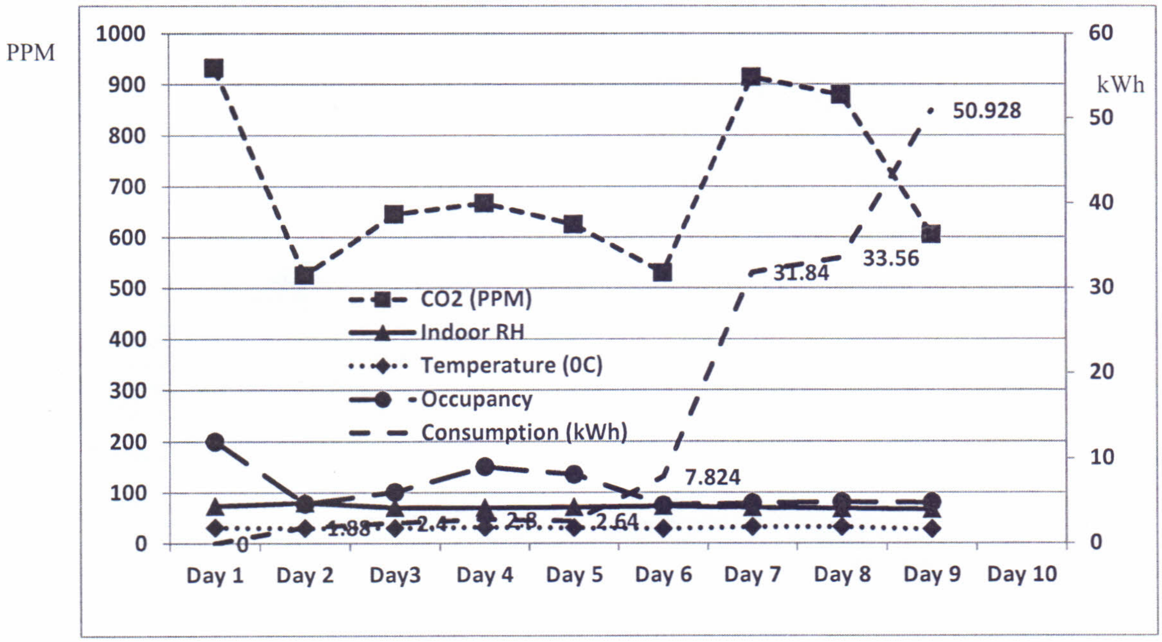

Figure 6. Energy consumption and thermophysical characteristics of the ELT (Period 1: 8AM – 10AM)

Proposing a four-predictor variables regression analysis, including the indoor concentration of CO_2, indoor relative humidity level, occupancy, and indoor temperature, an aggregate electricity consumption forecast model can be developed. The forecast of electricity consumption for the Faculty of Engineering represents a significant planning tool for the proposed independent power generation in order to arrest the problem of erratic power supply from the grid. Equation 3 captures the power consumption, P_i, for all the energy stocks within the Faculty of Engineering, including the engineering lecture theatre, offices, laboratories, workshops, and classrooms.

$$P_i = a_{i0} + \sum_{j=1}^{4} a_{ij}X_{ij} \quad ,i = 1,2,3, \dots n \qquad (3)$$

where n represents total number of energy stocks, X_{ij} is the predictor variables, and the regression coefficients are denoted by a_{ij}. using the ELT as example of energy stock, Figs. 6 and 7 obviously show that level of CO_2 concentration increases with occupancy. While the relationship between all the predictor variables is sufficiently non-linear, additional complexity (due the fact that the ASHRAE standard for indoor air quality is necessary to be factored in the forecast of the aggregate power consumption) is characterized by the proposed model. The description of the predictor variables are as follows: X_1 is the CO_2 concentration, X_2 is the indoor relative humidity, X_3 is the temperature, and X_4 is the occupancy of the energy stock, while the criterion variable is the electrical energy consumption of the energy stock.

Table 5. Regression Coefficients of the Energy Stock

Period	*Regression Coefficients*				
i	a_0	a_1	a_2	a_3	a_4
1	319.33	0.09	-2.00	-6.46	-0.27
2	1.32	0.35	-0.47	-2.25	-0.90

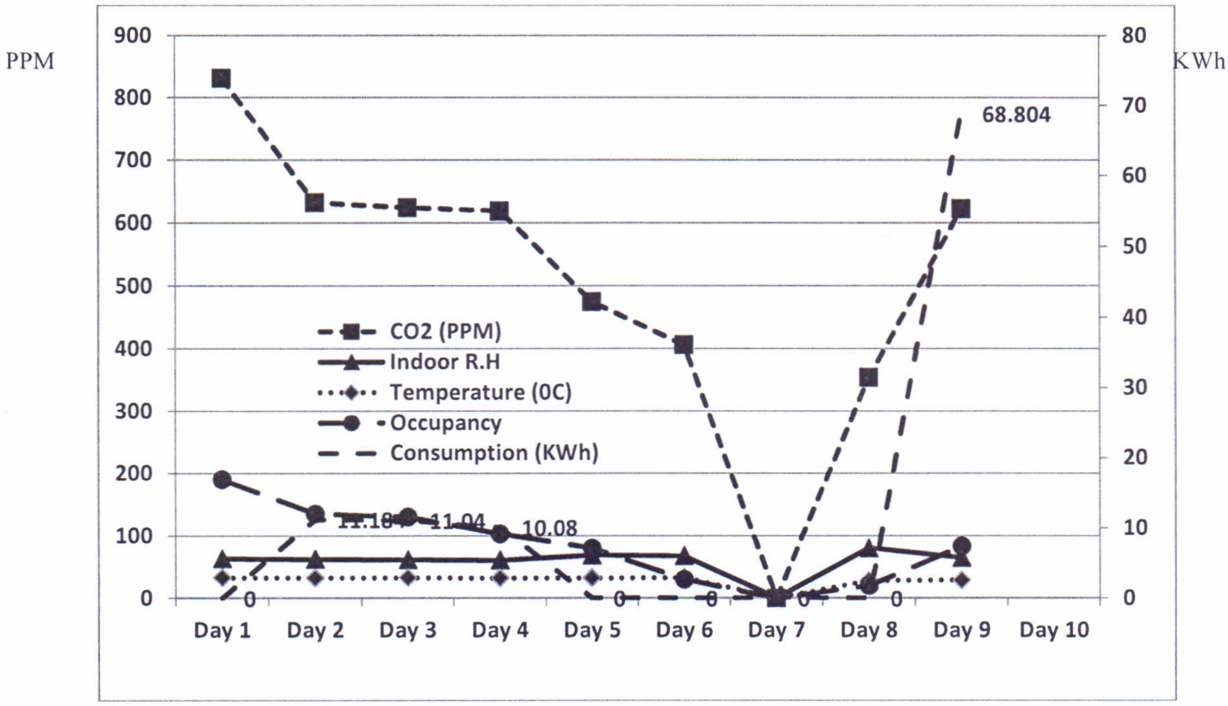

Figure 7. Energy consumption and thermophysical characteristics of the ELT (Period 2: 12PM – 2PM)

IV. SUMMARY OF CONCLUSIONS

The present work presented brief analyses of the energy demand in emerging Nigeria's electricity market and described the potential of the use of non-fossil fueled, but renewable energy source of high potential[11]. The application of thermo physical technique to feed power to the Engineering Lecture Theatre as an example is demonstrated in the paper. It is recommended to actively utilize these renewable energy sources in Nigeria to feed the grid at economical rates.

References

[1] S.R Forrest, M.L Kaplan, and P.H Schmidt, "*Organic Thin Film for Semiconductor Wafer Diagnostics*", Ann. Rev. Material Science, 1987, 17, pp. 189-217.

[2] K Sidler , N. V. Cvetkovic, V Savu, D Tsamados, A. M. Ionescu, J Brugger, "*Organic Thin Film Transistors on Flexible Polyimide Substrates Fabricated by Full-Wafer Stencil Lithography*", Sensors and Actuators, 162 (2010), 155 – 159.

[3] G Korotcenkov and B.K Cho, "*Silicon Porosification: State of the Art*", Critical Reviews in Solid State and Materials Sciences, 35: 153 – 260, 2010.

[4] M Mendell and G.A Hearth, "*Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance? A Critical Review of the Literature*", Indoor Air – International Journal of Indoor Air Quality and Climate, 15 (1), 2005, 27-52.

[5] J Daisey, W.J Angell and M.G Apte, "*Indoor Air Quality, Ventilation and Health Symptoms in Schools: An Analysis of Existing Information*", Indoor Air – International Journal of Indoor Air Quality and Climate, 13 (1), 2003, 53-64.

[6] B. Nnaji, "Special Adviser to the President on Power", This Day Newspaper, pp. 7, Friday, November 26, 2010.

[7] E.O.B Ogedengbe, Z Adem and D Kraehling, "*Demand Side Monitoring with Solar PV-Based Renewable Energy Supply to Commercial Energy Sector*", 26th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, Germany, 6CV.1.16, PV Taking-Off: Large Scale Deployment, Sept 5-8, 2011.

[8] M.Krarti, (2000). Energy audit of building systems: an engineering approach. CRC Press. ISBN 0-84939-587-9

[9] E.O.B Ogedengbe and G.F Naterer, "*Convective Flux Dependence on Upstream Flow Directionality in Finite Volume Computations*", *Numerical Heat Transfer A*, Vol. 51, n. 7, pp. 617 – 633, 2007

[10] E.O.B Ogedengbe, D. Kraehling and Z.A Adem, "*Demand Side Monitoring of Energy Systems in Ontario's Residential and Commercial Sectors*", 9th Annual International Energy Conversion Engineering Conference (IECEC 2011), 31 July – 3 August 2011, San Diego, California, AIAA 2011-5871.

[11] E.E.Khalil, *The Role of Solar and Other Renewable Energy Sources on the Strategic Energy Planning: AFRICA's Status & Views*, *Proceedings ASHRAE, Paper ASHRAE-2012-CH-12-C009*, January 2012