



Analysis of Load Profiles and Recommendation for a mix of Sustainable Energy Technologies of a Residential-Commercial Estate

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ABSTRACT

This paper presents analysis of energy demand of a residential-commercial estate in both summer and winter seasons for a daily hourly interval of 24. Expected maximum electrical and thermal energy demand of the estate were assessed and found to be 3MW and 2.5MW respectively. These energy demands were subsequently matched, using EnergyPlus-V7.1.0 Software, with three proposed energy generating technologies which are recommended to power the estate. The energy technologies suggested were two combined heat and power (CHPs) of capacities 2 and 2.5MW and a 10MW stand-alone wind turbine with a capacity factor of 20%. A one (1 MW) back-up hydro pump energy storage was also recommended to be installed to store the excess energy generated. The excess energy was projected to be used during the peak daily demand periods and can also be sold to the neighboring estates. Recommendation for the CHP was based on the thermal energy to power ratios ranging from 0.2 to 0.6 in the summer and winter, respectively.

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INTRODUCTION

With the frequently alarming increase in energy tariffs from the distribution companies, estate developers in Nigeria and other developing countries are seriously searching for ways to sustainably generate their stand-alone (off-grid) energies at low cost. The Energy demand markets oscillates depending on the winter and summer seasonal variations. Drivers of this energy demand in developing countries like Nigeria include but not limited to whether, fuel source, environmental conditions, frequent power outage and geographical events. The energy price supplied to the end user is an average of costs incurred due to generation, transmission, and distribution. For big buildings such as estates having both residential and commercial outlets, with daily energy demand in excess of one megawatt (MW), installing a mix of stand-

alone off-grid energy generating systems for energy efficiency is worthwhile. The installation will aid in saving costs and energy losses due to long transmission and subsequent distributions. Available and accessible fuel sources often determine the sustainable energy mix to be considered (Dandajeh et al. 2019).

Building Energy load profile represents a graph of energy demand-electrical, heat, and coolth (kWh) from the grid and or renewable energy source over a defined period (hours, days, etc.). It shows how energy is utilized and the appliances which are switch on or off in the morning, afternoon, evening and the middle of the night for both summer and winter periods. This is particularly important in sizing devices for storing energy (batteries, pumped storage, etc.) as well as recommending a perfect mix of technologies to minimize energy



generated from the grid at higher efficiency and minimum cost (Elsadiq, 2005). Nigeria is endowed with large energy resources, but only about 61% of her entire 200million population is reported to have access to electricity (Dioha and Kumar, 2020).

To proffer valid solutions to energy management in buildings especially in Nigeria, it is therefore pertinent to investigate energy expenditure of a typical energy efficient building. An estate in the United Kingdom was considered. The estate has expected maximum demands of 3MW and 2.5MW for electricity and heating (including coolth) respectively. These demands were matched with four potential energy technologies and they include: two combined heat and power (CHP) units

(natural gas-powered reciprocating engine, boiler & absorption chiller), a wind turbine and a charge and discharge battery back-up storage system. It is noteworthy that the short run marginal cost of these sustainable energy technologies been determined previously by Dandajeh *eta al.* (2019).

METHODOLOGY

Load Values

Load values in megawatt (MW) energy for electricity, heat and coolth were metered for the estate in both summer and winter seasons. Table 1 summarized the average hourly and daily loads for each season. The estate is used as both residential and commercial building.

Table 1: Load values of energy showing electrical, heat and coolth demands

Time (Hours)	Electrical Demand (MW)		Heat Demand (MW)		Coolth Demand (MW)	
	Winter	Summer	Winter	Summer	Winter	Summer
1	1.856	1.396	1	0.2		0.2
2	1.821	1.331	0.8	0.2		0.2
3	1.803	1.245	0.8	0.1		0.2
4	1.772	1.262	0.9	0.1		0.2
5	1.706	1.249	1	0.1		0.2
6	1.714	1.232	1.3	0.2	0.1	0.3
7	1.902	1.411	1.5	0.3	0.1	0.4
8	2.292	1.744	1.6	0.3	0.1	0.5
9	2.455	1.951	1.6	0.3	0.2	0.7
10	2.454	2.025	1.4	0.3	0.3	0.8
11	2.465	2.037	1.2	0.3	0.3	0.9
12	2.482	2.058	1	0.4	0.3	1
13	2.488	2.077	1	0.3	0.3	1
14	2.487	2.056	1	0.3	0.4	1.1
15	2.488	2.031	1	0.3	0.4	1.1
16	2.481	2.012	1.4	0.3	0.4	1
17	2.669	2.049	1.6	0.4	0.4	1
18	2.862	2.055	1.8	0.4	0.4	0.9
19	2.795	1.968	1.8	0.4	0.5	0.8
20	2.701	1.888	1.7	0.4	0.4	0.6
21	2.575	1.813	1.6	0.5	0.4	0.6
22	2.39	1.766	1.6	0.5	0.2	0.3
23	2.168	1.788	1.4	0.4	0.2	0.2
24	1.933	1.59	1.2	0.3	0.2	0.2
Total	54.759	42.034	31.2	7.3	5.6	14.4

Load Profiles

Using the data in Table 1, the load profiles (energy demand over 24-hour period) for electrical, heat and coolth demands are represented in Figures 1, 2 and 3 respectively. This section also explains the rationale and possibilities of activities that would cause the trends on the load profiles for demands in electricity, heat and coolth.

Electrical Demand (ED)

Summer Electrical Demand (ED/Summer)

Figure 1 shows the load profile for electrical demand. The minimum load is in the night between 1am – 6am when the households were sleeping. This load

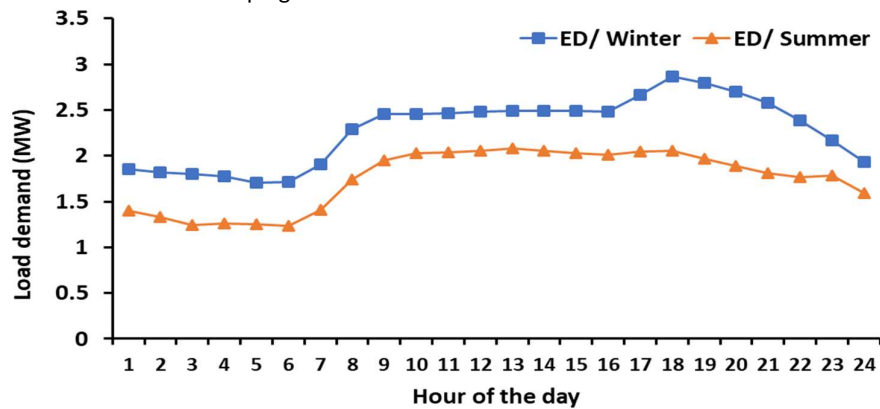


Fig. 1: A load profile of electricity demand for both summer and winter of an Estate in UK. Where ED = electricity demand

Winter Electrical Demand (ED/Winter)

Figure 2 shows the load profile for heat demand. The load profile is identified by two peak periods in the morning (9am) and evening (6pm). The load starts at 1 am with a substantial energy of 1.856 MJ due to hot water demand. This is planned to take advantage of cheaper electricity in the mid night.

As with the increase in demand from 6am – 9am, the same explanation of breakfast and showers applied just like the summer period. However, the steep increase in electricity consumption from 4pm – 6pm attests to the fact that most people come back from work and they switch on electric appliances such as: lights, electric cooker and oven to prepare

increased from 7am – 9am when the households are preparing for breakfast and taking showers. The demand remains fairly constant from 10am – 6pm in the evening. This is because, most of the occupant left for their offices or since air conditionings, computers, lightening loads are on within the commercial premises.

The load drop from 7pm – 10 pm and thereafter to 12 mid-nights depicts a closure of most commercial properties, hence, lighting and PCs loads are turn off. While this happens, air conditioning loads are reduced in the households due to lower temperature naturally in the night (Yohanis et al., 2008).

a dinner for the family. TVs could be on to watch evening news. Eventually, the demand drops as the households starts unwinding the activities of the day.

Heat Demand (HD)

Summer Heat Demand (HD/Summer)

Figure 3 shows the load profile for coolth demand. The heat demand starts at 1 am with a low hourly load of 0.2MW. This is because of high temperature associated with summer periods. The load profile increases steadily from 5am – 7am basically due to demand of hot water. The load curve becomes constant as the sun rises from 7am – 11am. The peak at 12pm designates a point when the households are having their lunch and that at 9 pm

represents the drop in temperature which calls for slight space heating.

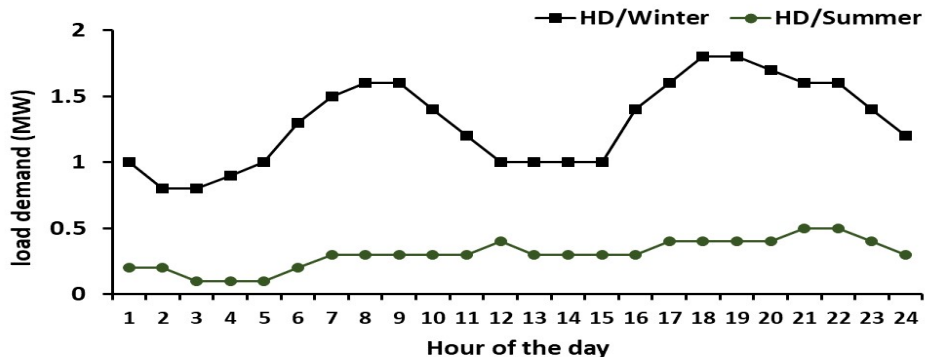


Fig. 2: A load profile of heating demand for both summer and winter of an Estate in UK. Where HD = heat demand

Winter Heat Demand (HD/Winter)

The load profile starts at 1am and then increases markedly from 3am – 8 am due increase in space heating and hot water demand. In winter, water and air are at low temperatures which are far lower than that in the summer. Decrease in load demand from 9am – 12pm and leveling-off from 12pm – 3pm are the results of sunrise which reduces space heating loads due to solar gain. A peak demand of 1.8MW is observed at 6pm.

The load curve starts with a constant demand of 0.2MW from 1am – 5am. It then starts to increase very fast from 6am – 12pm due to the corresponding increase in the insolation rate. Hence, increase in Air Conditioning (AC) and Refrigeration load demands. The demand starts to climb again between the hours of 2pm - 3pm and later declines due to daily insolation decrease and the fact that people are closing from businesses and therefore winding down to go back home. At this point, The AC and refrigerator are turned off.

Coolth Demand (CD)

Summer Coolth Demand (CD/Summer)

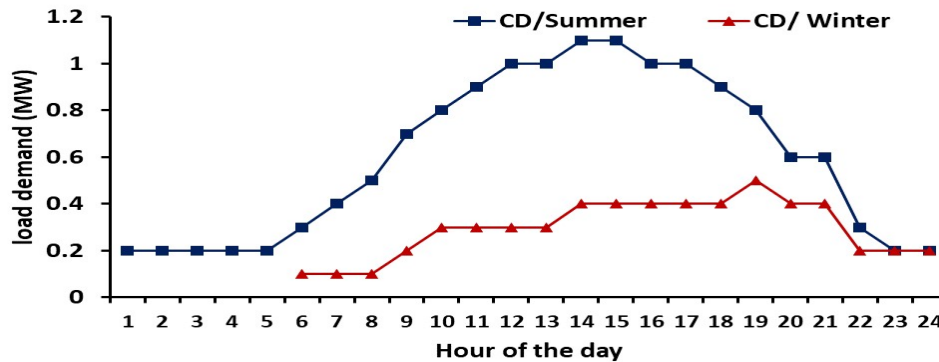


Fig. 3: A load profile of coolth demand for both summer and winter of an Estate in UK. Where CD = coolth demand

Winter Coolth Demand (CD/Winter)

The load profile starts at 1am and then increases markedly from 3am – 8 am due increase in space heating and hot

water demand. In winter, water and air are at low temperatures which are far lower than that in the summer. Decrease in load demand from 9am – 12pm and leveling-



off from 12pm – 3pm are the results of sunrise which reduces space heating loads due to solar gain. A peak demand of 1.8MW is observed at 6pm.

Energy Plus 7.10 Software

This software deals with energy efficiency analysis and thermal load simulation in buildings. The software evaluates and calculates heating and cooling loads, day lighting control, energy consumption, humidification, total internal radiance and heat gain at scheduled periods based on user's description of weather data, construction materials and mechanical systems (heating, ventilation and air conditioning (HVAC) of a building) Dandajeh and Ahmadu (2017). The software could therefore be used to match energy demand with sustainable energy technologies.

RESULTS AND DISCUSSION

Recommendation for suitable mix of Sustainable Energy Technologies

To recommend a mix of sustainable technologies, various factors such as: politics, resource availability, public perception, technological barriers and cost could be serious obstacles (Hoste, 2006). The energy technologies suggested were two combined heat and power (CHP) of capacities 2 and 2.5MW and a 10MW stand-alone wind turbine with 20% capacity factor. A one (1 MW) back-up hydro pump energy storage was also suggested to be installed to store the excess energy generated or the excess energy can be sold to the neighboring estates.

Combined Heat and Power (CHP)

The choice of 2 CHPs is made based on the following:

- i) Simultaneous requirements for electricity, heat and coolth (CIBSE, 2013)

- ii) Proven cost effectiveness and reduction of CO₂ emissions (Carbon trust)
- iii) On-site use of power with heat recovery and efficient fuel utilization with minimum losses.
- iv) Security of supply, hence; suitable for an island generation.
- v) Higher load factor, which could potentially maximize profit

Sizing of the technologies

CHP Units

According to carbon trust, sizing a CHP unit above the *base heat load* normally provides the best energy economics and subsequent minimization of heat dumping. The base load in the summer is 0.8 MW while the CHP units are sized as 2 MW and 2.5MW with load factors of 0.8 and 0.83 respectively. This is similar to the case study of *Freeman hospital in Newcastle* (Consulting, A and Analysis, E., 2007). The 2MW CHP unit is expected to handle most of the power and heat requirements within the CHP units. While the 2.5 MW CHP is genuinely proposed should in case of break down maintenance or malfunctioning of both the 2MW CHP & the wind turbine and also to supplement some energy demand within the estate.

Prime Mover Technology

Selection and recommendation of the prime mover is based on total thermal energy to power ratio (T/P) as proposed by Midwest CHP application center. The recommendation ranges are shown in Table 2 below.

Based on the summer and winter load profiles, The T/P ratios are calculated as follows

$$\text{Summer analysis: } T/P = \frac{7.3}{42.034} = 0.17 \sim 0.2$$

$$\text{Winter analysis: } T/P = \frac{31.2}{54.76} = 0.57 \sim 0.6$$



Table 2: Recommended prime mover technology based on T/P ratio (*Midwest CHP application center*)

Thermal energy to power ratio (T/P)	Recommended prime mover technology
0.5 - 1.5	Consider engines
1 - 10	Consider gas turbines
3 - 20	Consider steam turbines

It is therefore evident based on the calculations demonstrated to recommend a natural gas powered **reciprocating engine** as the prime mover. It has better load following and part load operation than most prime mover technologies.

Thermally activated machines: Absorption chiller

As the rule of thumb goes, when the T/P is less than unity, an absorption chiller should best be used as a means of providing the needed coolth by direct use of exhaust gases as heat recovery. It is with this effect that a double effect absorption chiller with coefficient of performance (COP) of 0.9 is recommended. This is due to its higher efficiency and therefore uses less energy for its operation.

Wind Turbine

The wind turbine is sized 10MW with a capacity factor (load factor) of 20%. This technically means that it can be able to provide up to 2MW of available power every hour (Boyle, 2004). In addition, since wind energy is intermittent, the excess energy generated will be stored using a **back- up** storage system (*charge and discharge Lithium-ion battery system*).

Back up storage: Li-ion battery

1MW Li-ion battery is recommended as the back-up storage system for the excess wind energy generated. This is based on the study carried out by Swierczyski (2010) on the best available energy storage systems for wind power. Among all the available options presented in Figure 4, Lithium ion battery is found to be compatible with wind energy since it can store up to 1MW of energy and operate as a stand- alone

system within a medium time scale. Other pertinent features include high efficiency, small weight and large cell voltage and power density. Although *pumped hydro* could also be collocated with wind power, its high capital cost and large capacity requirements make it not to be considered for this application.

Matching Technologies with Energy Demand

Table.2 and Table.3 illustrate how each of the above technologies is matched with the corresponding heat/coolth and power demands in both summer and winter periods respectively. Details procedure for using *EnergyPlus-V7.1.0 Software* can be found in Dandajeh (2017). As it can be observed, the excess energy generated by the wind turbine is being stored as back- up. This is later used at *peak periods* within the day and when the wind is not blowing more sufficiently to provide the necessary energy demand in the estate. The periods 1am -5am in the morning and 8pm – 12 am in the night are assumed to be moments when the wind is very strong (*it is completely based on assumptions not on weather forecast but California case study can buttress my assertion*). These are exactly the periods when Ni-ion battery charges and store the excess energy and discharges from 8am – 5pm during the periods of peak demand to supplement the power generated by both CHP and the wind turbine. At the end of the 24 hours, the total back-up energy in the storage system is zero ($\sum_1^{24} \text{Stored energy} = 0$) *i.e., assuming the storage system is perfectly efficient*. Since, what is already stored is used on the same day. It is also obvious that excess heat is generated by the 2-CHPs due to low demand of heat/coolth within the hours of

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1-5am and 8pm -12pm. This is particularly one of the challenge/risk of the system.

Table 3: Matching technologies with demand (Summer Analysis)

Hour	Electric Demand	Heat Demand	Tech 1		Tech2		Tech 3	Tech 4	Used Back-up energy at peak hours (MWh)	Excess Heat (MWh)
			CHP1 (2MW) Capacity	CHP2 (2.5MW) Capacity	Wind Turbine (10MW) Capacity	Back up Capacity (1MW)				
Of the Day	Demand (MWh)	Demand (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy Stored (MWh)			
HR	P	H	P	H	P	H	P	P		H
1	1.396	0.4	0.6313	0.48	0.2705	0	0.5436	0.0494		0.08
2	1.331	0.4	0.6019	0.48	0.2579	0	0.5183	0.0471		0.08
3	1.245	0.3	0.563	0.36	0.2413	0	0.4848	0.0441		0.06
4	1.262	0.3	0.5707	0.36	0.2446	0	0.4914	0.0447		0.06
5	1.249	0.3	0.5648	0.36	0.2421	0	0.4864	0.0442		0.06
6	1.232	0.5	0.5571	0.3	0.2388	0.2	0.4797	-		-
7	1.411	0.7	0.6381	0.42	0.2735	0.28	0.5494	-		-
8	1.744	0.8	0.7886	0.48	0.338	0.32	0.6791	-	0.04942	-
9	1.951	1	0.8822	0.6	0.3781	0.4	0.7597	-	0.04712	-
10	2.025	1.1	0.9157	0.66	0.3924	0.44	0.7885	-	0.04407	-
11	2.037	1.2	0.9211	0.72	0.3948	0.48	0.7932	-	0.04467	-
12	2.058	1.4	0.9306	0.84	0.3988	0.56	0.8014	-	0.04421	-
13	2.077	1.3	0.9392	0.78	0.4025	0.52	0.8088	-	0.06684	-
14	2.056	1.4	0.9297	0.84	0.3985	0.56	0.8006	-	0.06418	-
15	2.031	1.4	0.9184	0.84	0.3936	0.56	0.7909	-	0.06252	-
16	2.012	1.3	0.9098	0.78	0.3899	0.52	0.7835	-	0.0633	-
17	2.049	1.4	0.9266	0.84	0.3971	0.56	0.7979	-	0.02547	-
18	2.055	1.3	0.9293	0.78	0.3983	0.52	0.8002	-		-
19	1.968	1.2	0.8899	0.72	0.3814	0.48	0.7663	-		-
20	1.888	1	0.8538	1.2	0.3659	0	0.7352	0.0668		0.2
21	1.813	1.1	0.8198	1.32	0.3514	0	0.706	0.0642		0.22
22	1.766	0.8	0.7986	0.96	0.3423	0	0.6877	0.0625		0.16
23	1.788	0.6	0.8085	0.72	0.3465	0	0.6962	0.0633		0.12
24	1.59	0.5	1.0271	0.6	0.3081	0	0.2802	0.0255		0.1

Where: HR = hour, Tech = technology, P = power, H = heat, C = coolth,



Table 4: Matching technologies with demand (Winter Analysis)

Hour	Electric Demand	Heat Demand (MW)	Tech 1		Tech2		Tech 3	Tech 4	Used Back-up energy at peak hours (MWh)	Excess Heat (MWh)
			CHP1 (2MW) Capacity	CHP2 (2.5MW) Capacity	Wind Turbine (10MW) Capacity	Back up Energy stored (MWh)				
Of the Day	Demand (MWh)	Demand (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)	Energy generated (MWh)
HR	P	H	P	H	P	H	P	P	H	H
1	1.856	1	0.8393	1.2	0.3597	0	0.7227	0.0657		0.2
2	1.821	0.8	0.8235	0.96	0.3529	0	0.7091	0.0645		0.16
3	1.803	0.8	0.8153	0.96	0.3494	0	0.7021	0.0638		0.16
4	1.772	0.9	0.8013	1.08	0.3434	0	0.69	0.0627		0.18
5	1.706	1	0.7715	1.2	0.3306	0	0.6643	0.0604		0.2
6	1.714	1.4	0.7751	0.84	0.3322	0.56	0.6674	-		-
7	1.902	1.6	0.8601	0.96	0.3686	0.64	0.7406	-		-
8	2.292	1.7	1.0364	1.02	0.4442	0.68	0.8925	-	0.0657	-
9	2.455	1.8	1.1102	1.08	0.4758	0.72	0.956	-	0.06446	-
10	2.454	1.7	1.1097	1.02	0.4756	0.68	0.9556	-	0.06383	-
11	2.465	1.5	1.1147	0.9	0.4777	0.6	0.9599	-	0.06273	-
12	2.482	1.3	1.1224	0.78	0.481	0.52	0.9665	-	0.06039	-
13	2.488	1.3	1.1251	0.78	0.4822	0.52	0.9688	-	0.09562	-
14	2.487	1.4	1.1246	0.84	0.482	0.56	0.9684	-	0.09119	-
15	2.488	1.4	1.1251	0.84	0.4822	0.56	0.9688	-	0.08461	-
16	2.481	1.8	1.1219	1.08	0.4808	0.72	0.9661	-	0.07675	-
17	2.669	2	1.2069	1.2	0.5173	0.8	1.0393	-	0.06843	-
18	2.862	2.2	1.2942	1.32	0.5547	0.88	1.1145	-		-
19	2.795	2.3	1.2639	1.38	0.5417	0.92	1.0884	-		-
20	2.701	2.1	1.2214	2.52	0.5235	0	1.0518	0.0956		0.42
21	2.576	2	1.1649	2.4	0.4992	0	1.0031	0.0912		0.4
22	2.39	1.8	1.0808	2.16	0.4632	0	0.9307	0.0846		0.36
23	2.168	1.6	0.9804	1.92	0.4202	0	0.8442	0.0767		0.32
24	1.933	1.4	0.8741	1.68	0.3746	0	0.7527	0.0684		0.28

Where: HR = hour, Tech = technology, P = power, H = heat, C = coolth,



CONCLUSION

An hourly load profiles of a residential-commercial estate has been analyzed and a mixture of sustainable energy technologies was recommended. Maximum electrical and thermal energy demands of the estate were assessed and determined to be 3MW and 2.5MW respectively. EnergyPlus Software was used to match the three proposed energy generating technologies with the expected electrical and thermal demands. These recommended energy technologies were two combined heat and power (CHP) of capacities 2 and 2.5MW and a 10MW stand-alone wind turbine with a capacity factor of 20%. A one (1) MW back-up hydro pump energy storage was also suggested to be installed in order to store the excess energy generated. The excess energy was recommended to be used during the peak daily demand periods and can also be sold to the neighboring estates. Recommendation for the CHP was based on the thermal energy to power ratios ranging from 0.2 to 0.6 in the summer and winter respectively.

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