**Proceedings of the Second IASTED Africa Conference
Power and Energy Systems (AfricaPES 2008)
September 8-10, 2008 Gaborone, Botswana**

FORECASTING MODEL FOR ENERGY CONSUMPTION IN SOUTH AFRICA CORRELATED WITH THE INCOME

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ABSTRACT
This paper presents a mathematical model that forecasts the energy consumption in South Africa. The model is correlated to the income of the consumers. The study made use of the real energy consumption audit in South Africa. The mathematical model in this work is developed around the variables identified from the survey. The model can be applied to other utilities worldwide with some modifications in the influencing parameter values.
The model developed was used to study the effect of certain indices; such as society, personality, and fixed contribution index on the electricity consumption. Different results obtained and presented in this work clearly show that the income is a major determinant of energy consumption.

KEY WORDS
Electric consumption, modelling,

1. Introduction

Demand-Side-Management (DSM) programs influence the customer electricity usage to such an extent that it produces changes in the utility load shape in ways that benefit both the customer and the utility. Changing the load shape through DSM allows a utility to match its generation capacity with the load more closely. This inevitably reduces the capital and the operating costs for the utility. The cost saving in a way can be passed on to the customers to achieve a mutual benefit.
Escalating fuel costs and regulatory pressures, as well as increased customer sensitivity to energy costs are some of the problems which have caused the municipalities to consider demand-side-options as viable alternatives to traditional resource planning. DSM involves planning, analysis and implementation of load-shaping options, like load management, strategic conservation. Selective load growth can result in the efficient use of the resources and reduced costs to both the customer and the municipalities. DSM approaches and techniques involve a partnership between the utility and the customers, seeking common ground to maximize mutual benefit [1].
In South Africa, some municipalities and local service providers are currently undertaking activities seeking to produce desired changes in the utility's load shape [2]. Some of these activities can be classified as DSM initiatives, while others do not. The reason for this is that the latter group of activities tends to focus on achieving load impacts, which are not necessarily oriented towards bringing in increased customer satisfaction [3]. The South African government recognizes the importance and potential of energy efficiency and accordingly commits itself in promoting the efficient use of energy in all demand sectors. Furthermore, the government also commits itself to investigate the establishment of an appropriate institutional infrastructure and capacity to facilitate the implementation of certain effective energy efficiency strategies [3].
With electricity consumption growth in the electrification (residential) sector expected to be in excess of 15% p.a. over the next ten years, the implications for Eskom (South African power utility) and the local supply authorities are profound. New power plant(s) would be needed to meet this new load type, i.e. a generation plant capable of running for relatively short periods during the day and only for few months of the year. The capacity utilization of the new plant(s) would thus be extremely low, compared to the current installed capacity [3]. Hence, an effective energy consumption model would be beneficial for optimum capacity utilization according to the demand.
The remaining of this paper is organized as follows. In Section-2, the problem of electricity consumption and load shaping are discussed briefly. In Section-3, the energy consumption audit is described. In Section-4, we present the determination of the load factor. Section-5 discusses about the economic approach for the energy consumption. The derivation of the mathematical model is described in details in Section-6. Effects of the different parameters on the modeling are described in Section-7, and conclusions are given in Section-8.

2. Problem Description

A literature review revealed that similar shortages of reliable and disaggregated data worldwide were overcome by studies [3, 4, 5]. The studies concentrated on the main determinants of household energy consumption, e.g., household income, place of residence, kind of housing, energy end-uses, stock of appliances, other household characteristics, as well as the climate. Residential energy consumption, according to previous studies, varies according to the place of residence (metropolitan, urban and rural). It has, for example, been found that while the gross demand for electricity is fairly similar for urban and rural users, there are some differences in its end-usage. In developing areas a larger portion of electricity is used for

lighting purposes, while a smaller part is used for heating when compared to the developed areas [4]. The general reason for this is that people in the developing areas tend to use other fuels to a greater extent and fulfill a portion of their heating requirements from these fuels. It was furthermore discovered that whenever people earn less in a certain developing area, the household expenses, especially the electricity consumption tend to be smaller, therefore requiring less illumination and air conditioning [5]. Therefore, according to the particular kind of housing in a particular area, it can be determine certain (fixed) residential energy consumption patterns. Factors necessary to be considered in this connection include the size of a house, the number of persons and the gross incomes of the occupants.
With regard to the kind of energy used by the occupants, energy consumption studies generally distinguish amongst the various sources applicable to a particular country. In South Africa, the followings are important: Electricity, Coal, Gas and Domestic oil and paraffin.
Electricity is known to be the most widely used energy input for domestic purposes, followed by the coal, which are used mainly in developing areas. Domestic oil is used mainly in static machines drives, while gas and paraffin form a small percentage of the total energy requirement.
In [2], it is stated that with the mass electrification drive in South Africa, the domestic energy sector during the year 2000 reached 62.95% of electrified houses, over and against the 37.05% non-electrified houses, while the situation in 2001 reflected figures of 66.1% electrified houses, over and against 33.9% non-electrified houses, which indicates an increase of 3.15% in energy consumption. Previously most of the studies and strategies have been done in the developed areas. To properly measure and understand the total quantity and figures relating to energy consumption in all of the areas, the strategy on behalf of the residential load management will be to effectively utilize the existing systems with its load, in order to introduce some new load management systems where they do not exist. Based on this approach, income could be regarded as the most variable element effecting the electricity consumption in the developing areas.

3. Investigation Method

An energy audit can be presented as a technical revision of energy used, or as a process to obtain information regarding the use of the energy, which can be either within the organization or in the private sector. An energy audit is not a substitute for a planned energy management program, which is integrated into an organization's operation. Energy auditing is only one element of an energy management information system. The work in this paper is based on an audit conducted to gain more information to support possible changes and improvements. The options for improvement are put into a financial context. As energy is an integral part of any residential activity, an audit in this case often exposes opportunities to improve comfort, or safety in that particular area.

3.1 Walk-through audit

A walk-through audit was conducted at Orange Farm, which is situated in the Gauteng province, South Africa. It has been found that a huge increase in electricity consumption has been apparent since 1996, when most of the developing areas were electrified by Eskom. The main interest in the questionnaire which was served to every household contained an inventory of energy used and the descriptions of the appliances been used in every different house. The audit was conducted using 19 houses in the locality, divided into three different main groups.

- The First group consisted of houses which contained more than 3 rooms.
- The second group consisted of houses containing less than 3 rooms.
- The last group was represented by people living in shacks (informal housing).

Different questions were directed to the people of these groups, as particularly related to the link between their income and their energy consumption, the number of rooms, as well as the number of people living in these houses. In most of the cases in this area, irrespective of the size of the houses, there were a large number of people occupying (sharing) these facilities.

3.2 House-hold income

The audit revealed that average monthly income of a household is about R 1800 (R indicates South African Rand). About 49% of the households have an income below R 1000 per month. Some households rely heavily on the governmental grants, such as for children, while others get support from their family members.
Some of these families have, amidst these kinds of situations, only two or three people being employed. In the majority of the cases, the audit revealed that only the property owners of the households were responsible for the payment of the electricity and the purchase and payment of electrical appliances.

3.3 Electricity Consumption

During the month of January 2004 the average consumption per household, in the sample considered, could be calculated to have been around 350 kWh per month. About 57% of the households used less than 350 kWh, as been indicated in Table 1. The electricity has been used for cooking, lighting and other utilities, such as TV and radio. Table 1 shows separately the items measured directly during the audit, and items derived from them.
The sample of 19 houses from the small locality it has in the first approach been considered sufficient to reflect the whole spectrum of electricity consumption in that area. As stated in Table 1, direct measurements during the audit involved the house number (first column), the total electricity consumption in each house (second column) and the average daily hour of operation (third column).

The second and third column data were extracted from the questionnaire. All the electrical appliances used in every house were surveyed to obtain the details of the power (kW) rating, (e.g. fridge, kettle, iron, TV, radio, etc). Multiplying the total power for a day by the daily hours of operation gave the kWh/day (fourth column). The parameter kWh/day multiplied by the number of days in a month (30 days) gave the kWh/month estimate (fifth column).

Table 1 Energy Consumption & Income Audit

House		Measurements During survey		Deductions from Survey results	
No.	Income (Rand)	Total Cons. (kW)	Average Hour/day operation	kWh/day	kWh/ month
1	200	2.1	3	6.3	189
2	300	3.6	2	7.2	216
3	900	2.6	4	10.4	312
4	2800	4.5	3	13.5	405
5	800	3.3	3	9.9	297
6	1200	5.5	2	11.0	330
7	3500	2.4	7	16.8	504
8	3900	6.9	3	20.7	621
9	3950	10.6	2	21.2	636
10	3600	5.7	3	17.1	513
11	3700	9.0	2	18.0	540
12	1100	3.7	3	11.1	333
13	1050	3.5	3	10.5	315
14	1050	10.5	1	10.5	315
15	3950	11.8	2	22.0	660
16	1100	5.7	2	11.4	342
17	1150	6.0	2	12.0	360
18	1100	5.6	2	11.2	336
19	550	8.5	1	8.5	255

Table 2 Daily Load Factor

House	Demand (kW)	Av. Power Cons. (kW)	Average kWh/day	kWh/ month	Load Factor (%)
1	2.2	2.1	6.3	189	12
2	4.3	3.6	7.2	216	7
3	2.9	2.6	10.4	312	15
4	5.1	4.5	13.5	405	11
5	3.8	3.3	9.9	297	11
6	5.8	5.5	11.0	330	8
7	2.5	2.4	16.8	504	28
8	7.8	6.9	20.7	621	11
9	12.6	10.6	21.2	636	7
10	6.5	5.7	17.1	513	11
11	12.5	9.0	18.0	540	6
12	3.9	3.7	11.1	333	12
13	4.4	3.5	10.5	315	10
14	11	10.5	10.5	315	4
15	23	11.8	22.0	660	4
16	5.9	5.7	11.4	342	8
17	6.3	6.0	12.0	360	8
18	5.8	5.6	11.2	336	8
19	8.6	8.5	8.5	255	4

4. Load Factor Determination

The increase of the load factor will diminish the average unit cost (demand and energy) of kWh. The improvement of the load factor, it would imply cost saving. The load factor corresponds to the ratio between the actual load energy consumption (kWh) and the maximum power installed (demand) for the period of time [2].

$$\text{Load Factor} = \frac{\text{Consumption during a period}}{\text{Demand} \times \text{No. of hours in the period}} \times 100 \qquad (1)$$

Analyzing the load profile and the demand profile, it is possible to improve the load factor by taking some steps.
In Table 2 the information is obtained from the audit questionnaires as explained in Table 1, that the load has been disaggregated in every house noting from the measured load data; column "Demand" (table 2) represents the power installed in each house. The result in the load factor column was evaluated using equation (1). Every house was analyzed with appliances and the time those appliances are being used. As the calculation of the load factor depends on the daily consumption, so the load factor is the day load factor.

Table 3 Estimation of Energy Consumption from the Monthly Electricity Expenditure

House	Subsidy (Rand)	Amount spent Rand/month	kWh/ month
1	10	50	172.9
2	10	60	204.2
3	10	100	317.0
4	10	130	408.5
5	10	80	262.6
6	10	100	320.9
7	10	165	510.0
8	10	200	612.7
9	10	210	583.6
10	10	165	510.0
11	10	170	525.2
12	10	100	320.9
13	10	100	320.9
14	10	100	320.9
15	10	210	641.1
16	10	110	350.1
17	10	110	350.1
18	10	120	350.1
19	10	80	262.6

5. Economic Approach for the Monthly Electricity Consumption

The household income is viewed upon as the most important determinant of household energy consumption. Lifestyle, housing characteristics, family sizes, and appliance ownership are some of the other factors. One of the most common issues is the diversity maximum demand which reflects the highest average load that a large group of customers can muster over a certain period. With the amount spent per month by every customer, knowing the income, it can be determined the consumption in the household. Together with the financial statement, it can be modeled the energy consumption per household as:

$$kWh = \frac{\text{(Amount spent/month)+(Subsidy/month)}}{\text{Rate of electricity /100kWh}} \qquad (2)$$

Table 3 shows the estimate of the monthly electricity consumption (kWh) from the expenditure. The subsidy is a constant of R10/month. Taking an example, house one in the first row of Table 3, the amount spent for the month of January was to buy a voucher of R50 (most of the customers are pre-paid ones) plus the subsidy, and the rate of Eskom in the same month was R34.27/100 kWh. Applying equation (2), the energy consumption for house 1 is evaluated to be 172.9 kWh.

Estimation of the energy consumption as calculated from the monthly electricity expenditure (shown in Table 3) is relatively close to the actual value determined from the survey (Table 1 and 2). The reason is that people usually provide more precise and accurate estimate for the expenditure, then the Eskom tariff is known, hence the estimate is quite realistic. On the other hand, consumption estimate based on the survey, depends solely on user feedback of installed appliances and operating hours. Some of the appliances can get damaged or new appliances could be bought, which would vary the total kW consumption. And it is also very hard to get a real measure of the operating hours. Hence, the uncertainty factors and the error are higher for the energy audited than the energy modeled from the expenditure data.

Table 4 Energy Audited, Energy Modeled and Error

House	kWh/ month (audited)	kWh/ month (modeled)	Error (%)
1	189	172.9	-9.31
2	216	204.2	-5.78
3	312	317.0	1.58
4	405	408.5	0.86
5	297	262.6	-13.1
6	330	320.9	-2.84
7	504	510.0	1.18
8	621	612.7	-1.35
9	636	583.6	-8.98
10	513	510.0	-0.59
11	540	525.2	-2.82
12	333	320.9	-3.7
13	315	320.9	1.84
14	315	320.9	1.84
15	660	641.1	-2.95
16	342	350.1	2.31
17	360	350.1	-2.83
18	336	350.1	4.03
19	255	262.6	2.89

Table 4 shows the difference between the energy audited and the energy modeled from the financial statement. The last column in Table 4 represents the error, obtained using (3). The error can be used to verify whether the information given to us by the household was true or not.

$$\%Error = \frac{Energy\ Modeled - Energy\ Audited}{Energy\ Modeled} \times 100 \quad (3)$$

6. Mathematical Model

Figure 1 shows the experimental curve of the monthly electricity consumption against the monthly income of the households as found out from the audit.

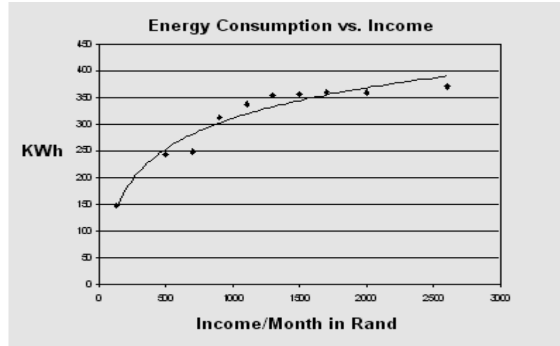

Figure 1. Energy Consumption versus Income (Experimental Curve)

The monthly electricity expenditure (E) can be divided into two parts: fixed E_f and dynamic E_d expenditure.

$$E = E_f + E_d \quad (4)$$

Due to the mass electrification drive in South Africa, most of the households are expected to have the basic electricity usage, at least for the lighting purpose. This is the factor that makes up the fixed expenditure component E_f, which can be estimated to be directly proportional to the monthly total income (x) of any household. The proportionality constant should practically be 1-5% of the total income considering the developing economic status of the study site.

$$E_f \propto x \quad (5)$$

So: $E_f = kx$ (6)

where, k is the fixed contribution factor (ideally varying from 1 to 5% of x, i.e. between a value of 0.01 - 0.05).

The dynamic expenditure (E_d) depends on the monthly total income as well as willingness of the people to use electricity. For the dynamic expenditure, the income factor usually has an effect from the society. This is because people from a particular locality, especially from a developing economic background usually have more or less similar economic and earning profile. Even if the earning profile differs, the usual tendency for electricity usage in a particular locality is quite similar. So, a parameter (c) is introduced to model the joint effect of society and the income (x) on the dynamic expenditure.

$$\partial E_d / \partial x = E_d / cx \quad (7)$$

$$\partial E_d / E_d = c \times \partial x / x \quad (8)$$

The willingness of the people to use electricity has a profound effect on the dynamic expenditure. Electricity awareness can motivate people to increase their electricity usage. Training and campaigning can build the electricity awareness especially in a developing area. Then it was introduced a personality index (p) to model the willingness of the people and their electricity awareness.

$$\partial E_d / \partial p = E_d / p \quad (9)$$

$$\partial E_d / E_d = \partial p / p \quad (10)$$

Combining (8) & (10), and neglecting other influencing factors as discussed in section 5, the model of the dynamic expenditure E_d can be written as:

$$dE_d / E_d = dp / p + c^{-1} \times dx / x \quad (11)$$

Integrating both sides of equation (11) and neglecting the constant of integration the result is:

$$log_e E_d = log_e p + c^{-1} log_e x \quad (12)$$

Equation (12) can be re-written as:

$$E_d = px^{1/c} = px^s \quad (13)$$

where $s=1/c$ is the society index.
Combining equations (4), (6) & (13), we get the monthly electricity expenditure:

$$E = kx + px^s \quad (14)$$

The actual monthly electricity expenditure consists of the payable amount for the consumed electricity E_c minus the subsidy E_{sub}.

$$E = E_c - E_{sub} = kx + px^s \quad (15)$$

From equation (15), it can be derived the monthly electricity (energy) consumption E_c as:

$$E_c = E_{sub} + kx + px^s \quad (16)$$

The subsidy as in the audit is R10/month. Considering the Eskom tariff of R34.27 per 100kWh, we get the subsidy E_{sub} as 30 kWh/month. Choosing the fixed contribution factor, k as 1% of the total income and the tariff of R34.27/100kWh, we set k= 0.01×(100/34.27) = 0.02918. For further analysis it was chosen the personality index, p = 30 (i.e., 30% awareness) and the society index s = 0.3 (i.e. 30% influence by the society). Setting the parameters as discussed above, the equation (16) becomes:

$$E_c = 30 + 0.02918x + 30x^{0.3} \quad (17)$$

Figure 2 shows the monthly electricity consumption E_c versus the income following the mathematical modeling as per equations (16) & (17). The income x is varied from R0-R3000 per month, in line with the audit and the developing economy of the project site. Comparison of the curves in Figure 1 and 2 indicates the validity of the developed mathematical model. Nevertheless, the model can be extrapolated to get an estimate for any specific income (developing economy). However, the mathematical modeling heavily depends on parameters like the fixed contribution factor, personality index and society index which depend on the economic infrastructure. Figure 3 and equation (17) have been achieved assuming a developing economy. Varying economic effects of these parameters are discussed in the following section.

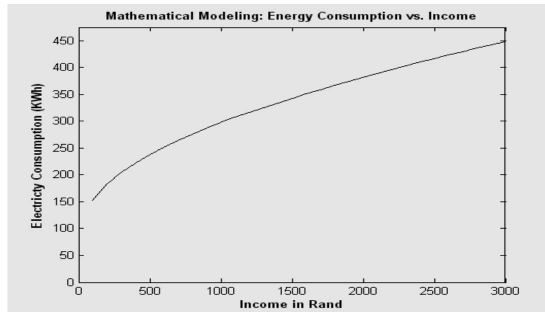

Figure 2. Energy Consumption versus Income (Mathematical Modeling)

Figure 3 shows another validation of the mathematic model.

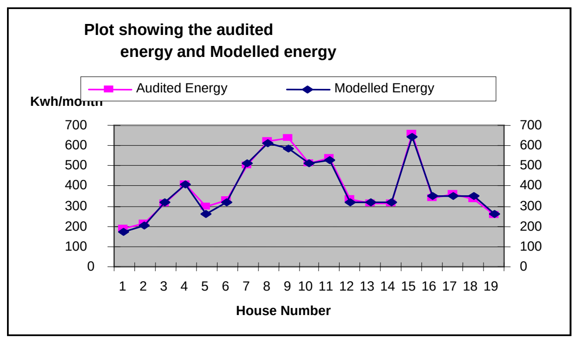

Figure 3. Model validation

7. Effect of Different Parameters

In this section, we discuss the effects of the three different parameters on the mathematical modeling.

7.1 Effect of the Fixed Contribution Factor

The fixed contribution factor (k) influences the fixed expenditure. A low percentage value of k in respect to the total income is expected for a developing economy. For example, in this particular modeling we have chosen a low value of 1%. Higher values of k indicate more basic electrical expenditure, hence, better standard of living and possibly a more developed economic infrastructure. Figure 4 shows the changing curves of the energy consumption against the income for the varying fixed contribution factor. The fixed contribution factor was varied from 0-10% (in steps of 1%), keeping the other two influencing parameters constant.

7.2 Effect of the Personality Index

Personality index (p) is a key parameter to influence the dynamic expenditure. Growing awareness for electricity is readily reflected by the personality index. Hence, an increasing personality index indicates growing dynamic electrical expenditure, i.e., growing electrical usage and a growing economic infrastructure. Ideally, a person can be 0-100% inclined to electricity usage; however, medium values as per the economy should be used for an optimum personality index. The personality index, especially for a developing economic infrastructure, can be improved to some extent by proper electricity awareness program, promotional campaign and the like. For the model in this paper, we assumed a 30% personality index for the developing economy of the project site. Figure 5 shows the changing curves of the energy consumption against the income for the varying personality index. The personality index was varied in steps of 10% from 0-100%, while keeping the other two influencing parameters constant.

7.3 Effect of the Society Index

The society index (s) also influences the dynamic electrical expenses. Unlike the personality index which depends on individual, the society index takes into account the collective influence of the whole society. Hence, fundamentally it is quite different in nature than the personality index factor. A small change in the society index can have a big impact on the electricity consumption due to the collective influence of the whole society. It is not expected abrupt changes in the society index because a collective influence could only be changed over due course of time. It would also depend on various factors of economy. As the people in a specific locality usually have similar electrical usage norm, slight improvement in the society index indicates overall economic growth. Hence, society index is a key parameter in differentiating a developing economic infrastructure from a developed one. For the model in this paper, we assumed a 30% influence by the society index for the developing economy of the project site.

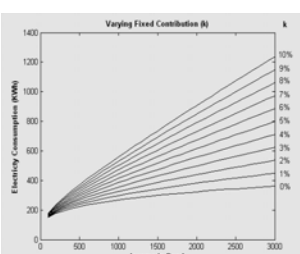

Figure 4. Effect of the Fixed Contribution Factor on the Mathematical Modeling

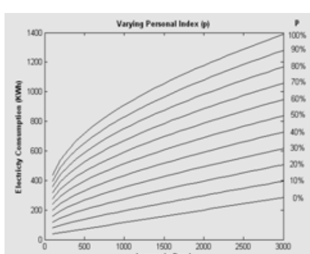

Figure 5. Effect of the Personality Index on Electricity Cons. (Mathematical Modeling)

Figure 6 shows the changing curves of the energy consumption against the income for the varying society index. The society index was varied from 0-50% (in steps of 10%), keeping the other two influencing parameters constant. The bigger impact of the changing society index in reflected in Figure 6, as the changing curves appears to be logarithmic in nature, i.e., a small change in the society index has a bigger impact compared to the other two parameters discussed above.

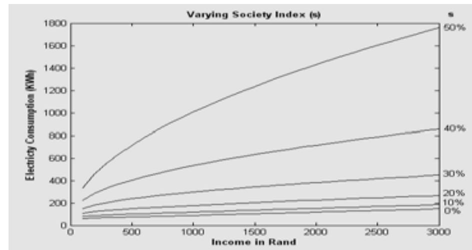

Figure 6. Effect of the Society Index on the Mathematical Modeling

8. Conclusion

With the mathematical model presented in this paper, it is evident that the income can be seen as the main determinant of the energy consumption. Based on the results presented in this paper, the electricity regulators are planning a wider audit which will cover a bigger number of houses and more suburbs of various demography representations.

The model presented in this paper, can be applied to all parts of South Africa, as well as by other utilities worldwide with some modifications in the influencing parameter values. The changing elements would be the three influencing parameters, the fixed contribution factor, the personality index and the society index. Values of these parameters should be changed depending on the economic infrastructure of the place. From practical point of view, the mathematical model derived from the income and the economic infrastructure can be very effective. Keeping in mind the effects of the economic infrastructure on the mathematical model, the model could be effectively extrapolated to predict a load-profile for a particular locality or community based on the household income data. This method can also be used as a validation method for other approaches in the load shaping, load profiling and load prediction.

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