International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 10, October 2014

Analysis of Energy Consumption in a Residential Building

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Abstract: ***This research investigates the use of regression techniques and autocorrelation analysis to analyse raw data obtained from daily meter reading and develop accurate energy consumption prediction models for the buildings. The study is based on energy consumption from May to August 2007 for the building, obtained from daily logging of the electric meter readings. The independent and regressor variables needed for this research include; Average external temperature, Heating degree-days and other variables developed from the data. The study results show that data from meters can be used to develop accurate energy prediction model and strong variables for the model can be developed from the original data.***

Keywords: Regression, Regressor, Correlation, Time, Energy consumption, autocorrelation

1. Introduction

Energy use in residential buildings, most of the time, is invisible to the user. Building occupants pay less attention to the actual energy they consume in general and in some cases they end up paying high energy bills without much concern. People often have only a vague idea of the amount of energy they use daily for different purposes and what sort of difference they could make if they change their day to day behaviour on energy usage and also invest in energy efficiency measures.

2. Objective

The objective of the study is to analyse and to improve the energy consumption in residential buildings.

3. Literature Review

Meter reading is a feedback tool for energy consumption. Early studies on energy feedback were carried out during the 1970s mostly by psychologist. As at that time typical early feedback experiment normally involve posting a note on the energy consumer's front door or kitchen window each morning displaying detailed energy consumption of the previous day and also comparing it with some reference level. Feedback was also viewed as an interruption in the normal order of things and was often interpreted in terms of behaviour reinforcement and it motivated individuals who were seen as relatively passive and motivated by reward and sometimes punishment, (Darby, 2006). Different researchers came up with different meaning and interpretation of feedback later on and more emphasis was laid on domestic sector because household's expenditure on energy was rising at an alarming rate. Evans and Herring (1989) investigated household spending on energy and found out that the domestic sector became the largest energy using sector in UK in 1985 accounting for 30% of UK consumption and 27% of total expenditure on energy. Households spent approximately constant proportion of their income on electricity and general energy. This has been increasing despite efforts geared at maximising energy efficiency. Government was creating more awareness on energy conservation and more research was being conducted on ways of reducing energy usage generally.

Studies by Dunster et al (1994) carried out on local authority homes, suggested that the number of local authority homes rose slightly up to 1980 but have shown a marked decline since then. This is as a result of the rise and fall in the number of local authority homes. They found out that peaks in energy use generally correspond with troughs in the external temperature as would be expected. However, owner occupied buildings have been springing up lately with much demand thus there was need for more energy efficient measures. Some researchers went into further numerical analysis of energy consumption and the relationship between various variables involved in the process. External temperature was found to have much impact in overall energy consumption irrespective of the behaviour of the occupants in the building.

Moss (1997) outlined two common parts of readings used in measuring the performance of space heating systems as, energy consumption and Degree days, and consumption and average mean daily outdoor temperature. This according to him establishes whether or not there is a degree of association between energy consumption and mean outdoor temperature for buildings. People always assumed that two similar and identical buildings would have the same energy consumption. Beggs (2002) carried out more research during which he tried to identify accurate and numerical analysis for determining trends and patterns in energy consumptions. He suggested that normalised performance indicators (NPI) can be used in eliminating the inherent problems which are encountered during energy consumption comparison of different buildings. He found that two similar buildings types in different locations have different energy used due to different climates, different operating hours, and different levels of exposure etc. The concept of NPI was developed to address these problems. With the Kyoto protocol in place, more effort was geared towards achieving energy efficiency in buildings. Waters (2003) suggested that residential buildings should be designed and constructed to make reasonable provision of fuel and power. He stated four points which needs to be put into consideration to achieve energy efficiency in buildings. Limited heat loss through fabric of building, ensuring that space and hot water systems provided are energy efficient, ensuring that lighting systems are designed to use energy efficiently and providing sufficient information to building occupants to enable them operate and maintain the building in an energy efficient way. His suggestions with regards to energy saving measures were consistent with Beggs findings.

4. Meter as a Feedback Device

The role of the meter is to provide a point of reference so as to ensure improved billing and also a point of reference. Feedback can be direct or indirect. Direct feedbacks are immediate feedbacks from meter or an associated display. The meter must be clearly visible within the building where there is no separate free standing display. It can be described as a feedback that is available on demand and it may take the form of direct displays, interactive feedback through a computer or self meter-reading. This form of meter feedback is not very effective on the part of the energy user because they are seen as numerical digits and only energy conscious individuals usually take time to monitor the rate at which the meter runs and also the daily consumption in (Kilowatt hour) kWh. Indirect feedback includes processed feedback or feedback that has been processed in some way before reaching the energy user. Indirect feedback seems to be much more effective as the raw meter data taken is processed by the utility company and later sent out to customers. Changes in space heating consumption and impact of energy efficiency measures are well influenced by indirect feedback. Savings of up to 10% can be attained through indirect feedback, but are dependent upon the quality of the indirect information. This form of feedback is easily interpreted by the building occupants or energy users because it details out total energy consumed and it always includes previous /last meter reading which helps the tenant to spot out unusual energy use. On the average, tenants respond more to indirect feedback because it usually comes along with the monetary value of the energy used.

However, periodic meter reading and billing will show up longer term effects as users would be able to monitor the progress and impact on their energy efficiency investments at homes. Meter reading display shows promise for energy and carbon savings at low cost because it compels building occupants to change their behaviour and pattern of energy use. Savings from meter reading always vary according to technology under considerations and the standard electric meter can be used to give the basic form of energy consumption feedback.

Furthermore, electric meter can only be effective if it is installed as individual units, rather than bulk metering. With bulk metering, consumption of energy in units is not individually metered and the landlord is usually billed for the building gross consumption thus incorporating the cost of consumption into the rent. There has always been a utility bias against sub metering in the past because of cost and other issues. Cost of installation of individual electric meters for each flat/unit meant increased cost in general. Cost resulting from local utility sometimes prompts landlords to disconnect individual meters as they required numerous bills which in turn translate into high mailing costs and sometimes collection problems.

Despite the high cost and cons which most people associate with individual feed metering, there are so many pros which suggest that sub metering is an effective way of monitoring energy consumption. There is fairness in sub metering buildings as tenants only pay for the energy they use and as such, it prevents a situation where low energy users are inadvertently subsidising heavy users. In bulk metered buildings, there are no relationships between an individual tenant's energy consumption and their monthly expenses because total cost for the whole building is averaged and incorporated in to the rent. Meters don't function as a good feedback device in such situation because there's no incentive to minimise consumption in this. There is always a fairness problem associated with this form of feedback because it encourages tenants to monitor their individual meter units thereby benefiting directly from energy consumption.

5. Methodology

Regression analysis technique would was used in developing the energy consumption model for this research. This is because the method is supported by statistical theories as producing good estimates according to certain statistical theories and the error of the model would be used in determining the accuracy of the results. Regression analysis is one of the most popular techniques for predictive modelling and the least square method is generally used for estimation purposes in the multiple regression models.

6. Analysis and Results

Energy consumption for building is shown in Fig 1 and this covers energy use between (26th May to 25th Aug) 2006. This data was recorded daily over a period of three months and was used in developing an energy consumption prediction model for the building.

ISSN (Online): 2347-3878
Volume 2 Issue 10, October 2014

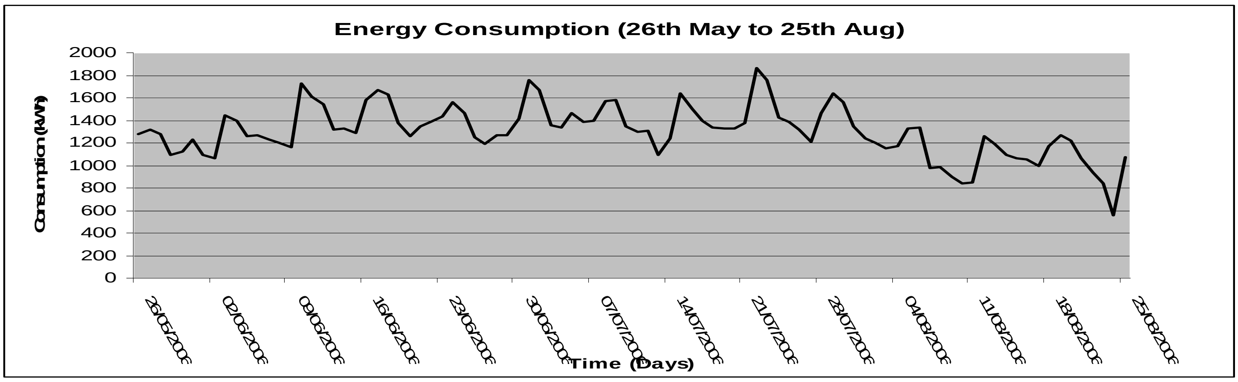

Figure 1: Energy consumption (Building)

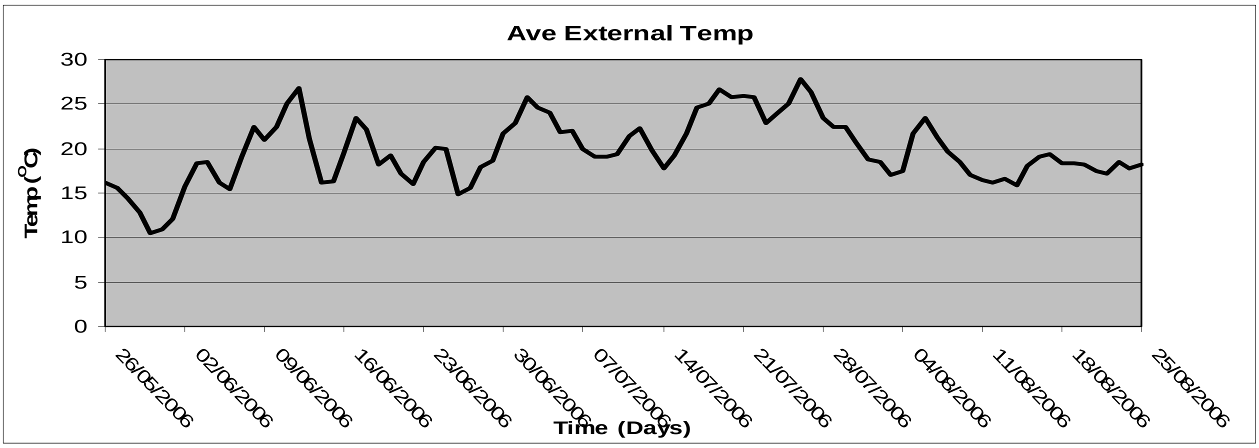

Figure 2: Average External Temp (26^{th} May to 25^{th} Aug)

Plotting the energy consumption against the external temperature produces a scatter plot as shown in Fig 3 and this scatter shows the relationship between the two set of data.

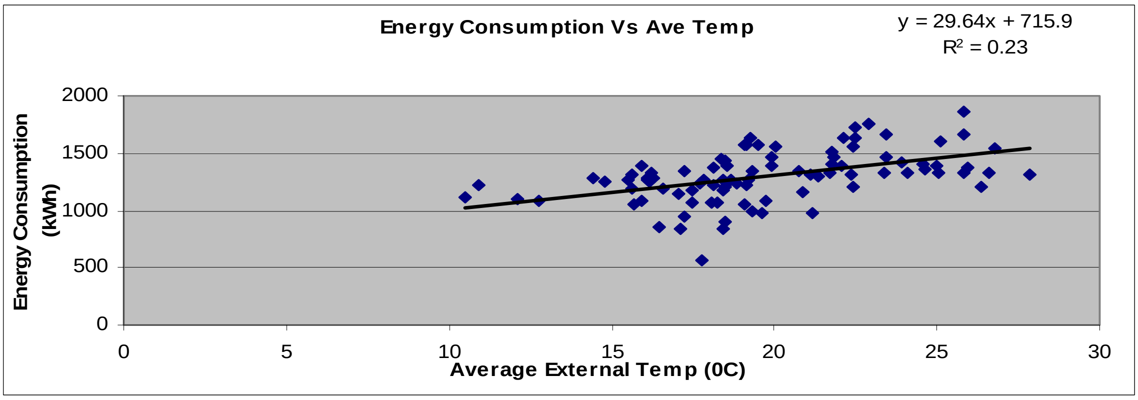

Figure 3: Scatter plot (Consumption Vs Temperature)

The most important information gotten from the scatter plot is the linear regression statistic which gives the r^2 value of the energy consumption and the external temperature. This is equivalent to the square of the r value taken from a simple correlation test.

The correlation between the energy consumption and the heating-degree days is -0.15. This shows that there is poor statistical significance between the associations of both variables. Furthermore, the correlation results show that average external temperatures would explain 23% of the total variation in the energy consumption of the building if it was used in developing a predictive model ($0.47^2 = 0.23$) while cooling degree-days would explain only 17% of the total variation in the energy consumption if it was also used in developing a predictive model ($0.42^2 = 0.17$). This implies that the average temperature and cooling degree days, if used alone for linear regression cannot produce a good predictive model for the building and there would be poor line fit in the model. This is illustrated in Fig 4 and Fig 5.

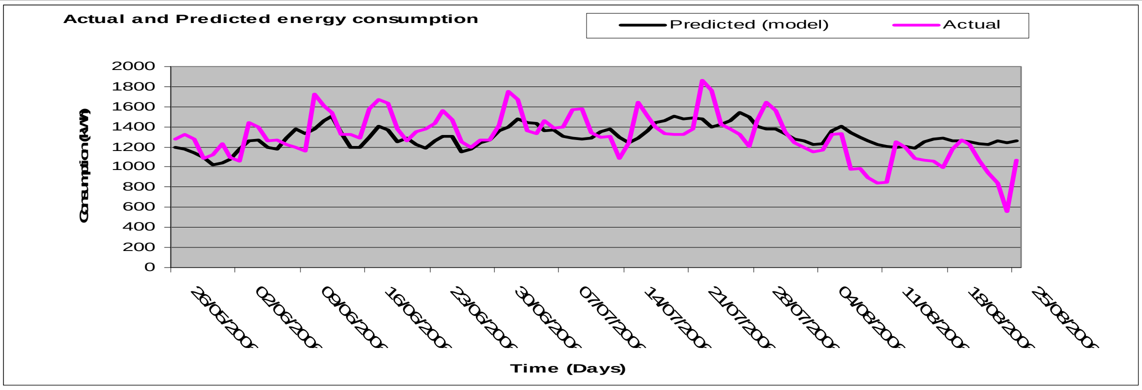

Figure 4: Actual and Predicted consumption (Temp as variable)

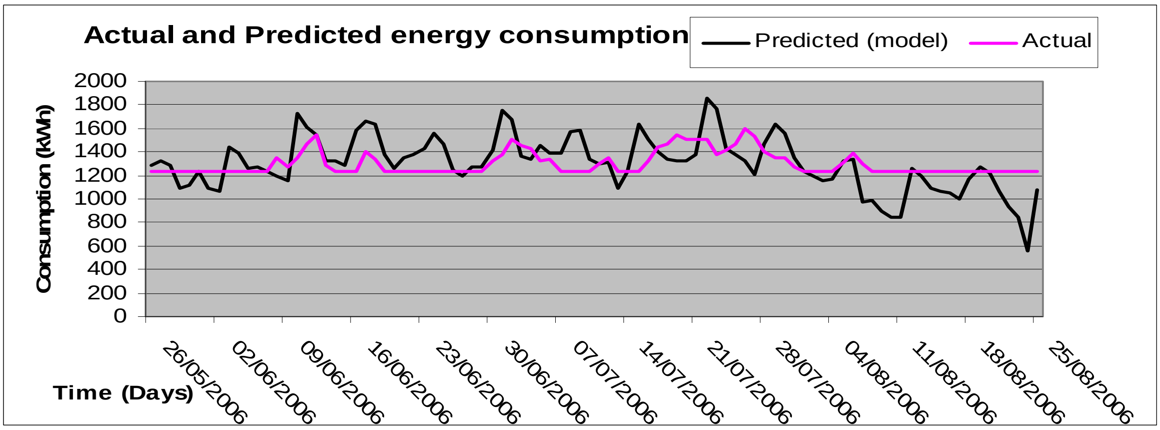

Figure 5: Actual and Predicted consumption (Cooling degree-days).

However, this may vary from building to building and in some cases the average temperature or the cooling degree days may be used in developing a model for the building. A better model can be developed when a regressor variable with good correlation with the dependant variable is added to the regression model. A high $\mathbf{r}^2$ value would be needed in other to develop a good prediction model for the building because the high value represents the percentage at which the regressor variables explain the variation in the dependant variable.

7. Fourier Analysis

A clearer picture of the pattern of consumption needs to be identified in other to develop a model for energy consumption. This can be investigated by carrying out Fourier analysis on the energy consumption of the building. This analysis would help in decomposing the energy consumption data in to simple wave forms which enables one to identify easily which frequencies are contained in the wave form. The number of input values for the Fourier transform must be a power of 2**.** Therefore for this analysis with 92 input values, 64 inputs are used. Using Microsoft excel to perform the Fourier transform reveals three peaks as shown in Fig 6. The first peak has 3 cycles per 64 days which shows that an event repeats itself every 21 days (64/3). This could be a monthly pattern or the effect of monthly activities that occurs once in every month. The second peak is the highest peak with 9 cycles per 64 days which again shows that event repeats itself every 7 days (64/9). This event is a weekly one because it occurs every 7days which is a common feature for most residential dwellings. The third peak has 18 cycles per 64 days which also indicates an event that repeats itself every 3days (64/18). This event might be as a result of the consequences of the weekly pattern that repeats itself every 7 –days.

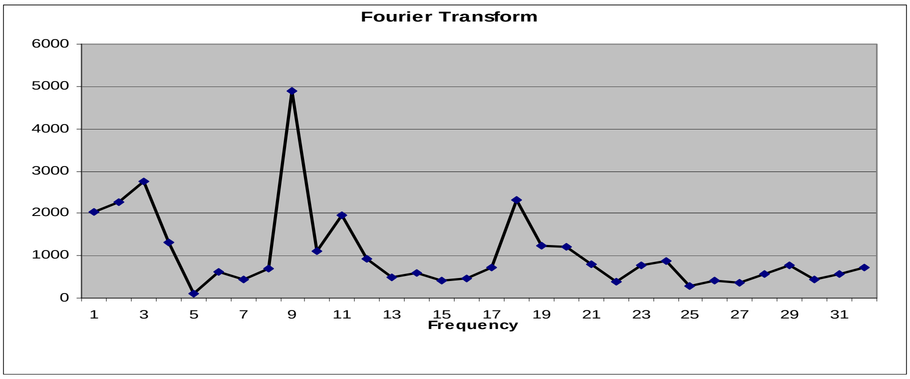

Figure 6: Fourier Transform (a)

8. Regressor Variables

Table 1: Multiple regressions output (1-day, 7-days and Temp))

SUMMARY OUTPUT

Regression Statistics	
Multiple **r**	0.80766073
r Square	0.65231585
Adjusted **r** Square	0.63943866
Standard Error	140.399617
Observations	85

ANOVA

	df	SS	MS	F	Sig F
Regression	3	2995642	1E+06	50.657	1.5E-18
Residual	81	1596676	19712		
Total	84	4592318			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-93.8808854	122.0808	-0.769	0.4441	-336.78	149.02	-336.78	149.022
1-day lag	0.37940163	0.085045	4.461	3E-05	0.21019	0.5486	0.2102	0.54861
7-days lag	0.49085394	0.087075	5.637	2E-07	0.3176	0.6641	0.3176	0.66411
Ave ext temp	12.5764252	5.403669	2.327	0.0224	1.82482	23.328	1.8248	23.328

The Multiple r value in the above result represents the correlation coefficient for the multiple regressions of the three regressor variables (1-day lag, 7-days lag, and average external temperature). This coefficient reflects only the degree of association between these three variables. This value indicates the percentage of total variation of energy consumption of the building explained by the three regressor variables (1-day lag, 7-days lag, and average external temperature). The sum of the squares (2995642+1596676 = 4592318) is the squared error that would occur if the mean of the dependent variable (energy consumption) was used to develop the energy consumption prediction model for the building. The value of the regressor variables reduces the error by 65% (2995642 / 4592318 = 0.65).

The adjusted r^2 value is a standard downward adjustment to penalize for the possibility that, with many regressor variables, some of the variance may be due to chance. This adjustment penalty reduces as more regressor variables are added. For this analysis, the adjusted r^2 was used because it provides acceptable results since it takes other regressor variables into account. Another measure for the accuracy of the prediction model is the standard error of estimate which is the square root of the sum of the squared errors divided by the degree of freedom. It is a measure of the variation line because it represents an estimate of the standard deviation of the actual dependent values (energy consumption) around the regression line. It can also be used as a measure to assess the absolute size of the prediction error because it is the standard deviation of the predicted errors.

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The main output used in developing the energy prediction model from the multiple regression analysis is the coefficients. The coefficient from the excel output are shown in the coefficient column and the value for each regressor variable is shown for each variable row. Therefore the predicted energy consumption value for each day is the intercept plus the regression coefficient times its value of the regressor variable. Fig 8 shows the plot of the actual energy consumption and the predicted model consumption.

$$PREDICTED = -93.8808854 + 0.37940163\mathbf{X1} + 0.49085394\mathbf{X2} + 12.5764252\mathbf{X3}$$

Where X1 = Energy consumption for previous day (1-day lag)
X2 = Energy consumption seven days ago (7-days lag)
X3 = Average external temperature

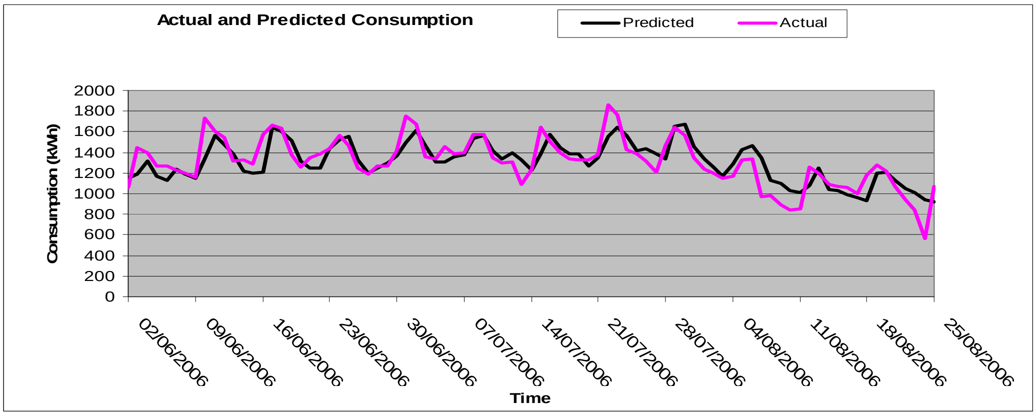

Figure 8: Actual and Predicted consumption (1-day lag, 7-days lag and Temp)

Moreover, the value of the adjusted r^2 which is 0.63 shows that the three regressor variables (1-day lag, 7-days lag and average external temperature) explains about 63% of the variance. For statistical significance of the independent and regressor variables, a high t-value and a low P value is needed. It's important to note that the P – value needs to be lower than 0.05 otherwise, it would not be statistically significant at 5% level. This can be looked up in the table of r. From table 3, it can be observed that the average external temperature has a high P value and therefore is not significant at 5% level. The other regressor variables (1-day and 7-days lag) both have low P values and are statistically significant at the 5% level. Excluding the average external temperature in the model increases the overall statistical significance of the model.

Table 2: Table of r

Degrees of Freedom	*Probability, p*		
	0.05	**0.01**	**0.001**
1	0.997	1.000	1.000
2	0.950	0.990	0.999
3	0.878	0.959	0.991
4	0.811	0.917	0.974
5	0.755	0.875	0.951
6	0.707	0.834	0.925
7	0.666	0.798	0.898
8	0.632	0.765	0.872
9	0.602	0.735	0.847
10	0.576	0.708	0.823
11	0.553	0.684	0.801
12	0.532	0.661	0.780
13	0.514	0.641	0.760
14	0.497	0.623	0.742
15	0.482	0.606	0.725
16	0.468	0.590	0.708
17	0.456	0.575	0.693
18	0.444	0.561	0.679
19	0.433	0.549	0.665
20	0.423	0.457	0.652
25	0.381	0.487	0.597
30	0.349	0.449	0.554
35	0.325	0.418	0.519
40	0.304	0.393	0.490
45	0.288	0.372	0.465
50	0.273	0.354	0.443
60	0.250	0.325	0.408
70	0.232	0.302	0.380
80	0.217	0.283	0.357
90	0.205	0.267	0.338
100	0.195	0.254	0.321

Table 3: Multiple regression output

SUMMARY OUTPUT

Regression Statistics	
Multiple **r**	0.793136
r Square	0.629065
Adjusted **r** Square	0.620018
Standard Error	144.1312
Observations	85

ANOVA

	df	SS	MS	F	Sig F
Regression	2	2888867.2	1E+06	69.53	2E-18
Residual	82	1703451	20774		
Total	84	4592318.2			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	45.76027	109.14526	0.4193	0.676	-171.36	262.88	-171.36	262.885
1-day lag	0.459519	0.0798338	5.7559	1E-07	0.3007	0.6183	0.3007	0.61833
2-days lag	0.499016	0.0893172	5.587	3E-07	0.3213	0.6767	0.32134	0.6767

This exclusion leaves 1-day lag and 7-days lag as regressor variables and these further increases the overall significance F of the model and this is shown in table 3. The value of the adjusted $\mathbf{r}^2$ has reduced from 0.63 to 0.62 which still shows that the two independent variables 91-day lag and 7-days lag) explains about 62% of the variance which suggests that the model is well specified. The standard error of the coefficient is the standard error of the estimate of the independent variables. The value of the coefficients divided by the corresponding standard error gives the calculated partial **t**-test of the hypothesis that the coefficient is zero.

Using 1-day lag, the t- value is 0.459519 / 0.0798338 = 5.7

The t- values are recorded in the t -Stat column in the regression output table. Also, high t- values and low P values shows that that the prediction model is a reliable one.

However, the adjusted r^2 value which measures the total variability in the response that is accounted for by the model, does not guarantee that the model fits the data well. The r^2 value is a numerical method for model validation and a high value indicates a high variability response but this tends to be focused on a particular aspect of the relationship between the model and the data and it compresses the information into a single number or result. This does not imply that the high r^2 value from the multiple regression in table 3 is not valid for our analysis, rather for this model, it helps in validating the strong numerical relationship between the model developed and the dependent variable used for the analysis.

9. Conclusions

Regression analysis and partial autocorrelation function are used in developing energy consumption models for buildings, as indicated by this research. It has been shown that autocorrelation function helps in identifying and selecting regressor variables for regression analysis. It also shows seasonality and strong correlation which is a good criterion for regressor variable selection because it provides better fit for the prediction of energy consumption. This research, consistent with the findings of Lowry et al. (2007), Abdel-Aal and Al-Garni (1996) indicates that using information available from an energy consumption data provides better fit for the prediction of consumption.

References

[1] Abdel-Aal R.E & Al-Garni A.Z (1996), Forecasting Monthly Electric Energy Consumption in Saudi Arabia Using Univariate Time-Series Analysis. Research paper, Energy research laboratory and King Fahd University of petroleum and minerals, Saudi Arabia.

[2] Beggs C (2002), Energy: Management, Supply and Conservation. Oxford: Butterwort – Heinemann, Jordan hill, Oxford.

[3] Darby S (2006), The Effectiveness of Feedback on Energy consumption: a review for Defra of the Literature on Metering, Billing and Direct Displays, Report Environmental change institute, University of Oxford.

[4] Dunster J.E, Michel I and Shorrock L. D (1994), Domestic Energy Factfiles: Owner Occupied Homes

ref BR271, Local Authority Homes ref BR272 and Private Rented Homes ref BR273 (1994) Building Research Establishment, Garston, Watford.

[5] Lowry G, Bianeyin U.F, Shah N (2007), Seasonal autoregressive modelling of water and fuel consumptions in buildings. Research Paper, [a] Department of Engineering systems, London South Bank University, London UK, [b] School of Engineering and Design, Brunel University, Uxbridge, UK.

[6] Moss J.K and Moss K (1997), Energy Management and Operating Cost in Buildings. Spon Pr Publishers