# Non-Linear and Linear Baseline Energy Modelling Comparative Studies in Educational Buildings

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## Abstract

Baseline energy model is a powerful tool in describing energy consumption for any buildings at a certain period of time. Baseline energy model main task is to predict the energy consumption if energy conservation measures were implemented for energy saving calculation purposes. A simple and practical approach to model a baseline energy utilizing linear regression method is undeniable to be inferior. Linear regression work best with energy consumption that behaves linearly but a practical and simple approach to model a baseline energy for energy consumption that behaves in a non-linear manner have to be establish. Thus, this paper main intention is to model a baseline energy using Non-Linear Auto Regressive with Exogenous Input Model with Artificial Neural Network (NARX-ANN) method as the model estimator. Two buildings in a University compound will be used to model the baseline energy consumption. Multiple regression model will be used in order to compare the results of the baseline energy models developed with NARX-ANN method. It is found that NARX-ANN performs better in terms of error measurement. It is hoped that a better baseline energy models can be developed in order to provide less error if energy saving calculation purpose will be implemented.

*Keywords*: *baseline energy; energy consumption; predict; linear regression; NARX-ANN;*

## 1. Introduction

Buildings are the main consumer of of electricty [1] and will consume up to 40% of the generated electricity. In 47 years time from 2003, there will be an increase of 30% energy utilisation in building sector [2]. Energy consumption in educational buildings especially universities is critically increasing. Due to the fact not only educational buildings have to facilitate students, it also have to facilitate staff and workers. It is therefore became a compulsory tasks to provide conducive workspace and comfortable environment for all people that inhabit universities compound and spaces. No debate can deny due to heavy consumption of energy, green house gas (GHG) emission will drastically increase [3].

GHG emissions that results from heavy energy consumption from buildings requires energy conservation measures (ECM). ECM can be related to awareness, energy management and retrofiting of old inefficient loads [4]. For a proper energy saving calculations, International Performance Measurement and Verification Protocol (IPMVP) [5] have been created for the standard and protocol that have to be followed to serve the purpose of energy saving calculation. Predictions of energy before ECM are being implemented have to be made for subraction purpose with the energy consumption recorded after ECM were conducted. The misunderstood of energy saving concept have to be curbed because people often understood that energy saving were calculated by subtracting the energy recorded for the current month with the previous month.

Facilitating to apprehend the misunderstood of energy saving concept, baseline energy served this purpose. Baseline energy will act as a tool that demonstrates a comparison before and after any retrofitting are being made in any systems [6]. Independent variables that have an impact towards energy consumption before any ECM are being implemented have to be identified to predict the energy consumption. Modelling the baseline energy consumption may become a challenging task due to energy consumption is a non-linear function of occupancy and surrounding weather and temperature, dynamic climate change, human behaviour. In addition, almost all system in the world behaves in a non-linear manner [7].

Baseline energy modelling in an educational buildings in [8, 9] creates an important findings and information. Certain non-linear approach to model the baseline energy consumption have been attempted where authors in [8] effectuate a high quality comparative studies where different method for baseline energy modelling were proposed. Weak regression model is visible but Neural Network came up with a high Variance Account For (VAF) and small Mean Squared Error (MSE) and Mean Absolute Error (MAE). Possibilities of a weak statistics index is probably due to the employment of independent variables that are not necessarily related to energy consumption. Meanwhile authors in [9] discourse the interrelation of occupancy, buildings and technology pertaining to the energy consumption and demand of educational buildings by means of regression model. The absence of the coefficient of determination $R^2$ value induced questionable goodness of fit of the model eventhough positive correlation between energy consumption and weather were present. From the previous work it shows that regression model have been used to develop baseline energy model but there is certain weak point where the model developed are not accurate enough for the non-linear parts. In other hand non-linear model can be improve where

the early selection of variables may not necessarily be to much where it may overfit the baseline energy model.

Thus the intention of this paper is to model the baseline energy consumption in an educational buildings utilizing linear multiple regression model and non-linear Auto Regressive with Exogenous Input –Artificial Neural Network (NARX-ANN) model. Baseline energy models will be develop and compared to the strength of the non-linear model oppose to the linear model. The paper are being construct in six section as follows: section II explained the linear regression model associated with baseline energy modelling. Section III described the artificial neural network (ANN) breif theory and its application in baseline energy modelling. NARX-ANN that have been used for prediction and modelling purpose are being mentioned in section IV. Development process of the baseline energy model will be explained in the methodology section V. Details of the modelling results and comparison between linear regression model and NARX-ANN method experimentation will be discuss in section VI. The paper end with conclusion in section VII and references.

## 2. Regression model

Regression model is a linear prediction method used to predict future behaviour depending on single or multiple variables. Due to its simplicty in calculation and approximation, it has been widely used to determine the correlation of variables that related to behaviour of any particular system. Single linear regression only use linear equation (1)

$$y = mx + c \qquad (1)$$

where y is the output at certain time, m is the weight of the variable, x is the variable of the system and c is the intercept. For a non-complex linear model where only one variable that correlates to the behaviour of the system, input x are regressed with the weight of the variable to produce the prediction output y.

For a prediction model that have been identified to have more than one variable that affecting the system, multiple regression model is more suitable where linear equation are being added with more weights and variables as in (2)

$$y = m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots + m_n x_n + c \qquad (2)$$

where y is the output at certain time, m is the weight of the variable, x is the variable of the system and c is the intercept. Variables are regressed with the equation and the behaviour of the system can be predict. From equation (1) and (2) it can be seen that the regerssion model only utilize input variables to predict the future output y at certain time.

## 3. Artificial Neural Network

Human brain is a powerful organ in a human body that can be describe as a highly non-linear parallel network computer with complicated interconnetion. This network are being called neural network which consists of neuron that are being interconnected together to perform multiple tasks. Synapses bonded neuron creates a neural network that carries certain weight for knowledge storing purpose. Inspired by the human brain system, replication of the system are being translated and modelled mathematically to become an artificial neural network.

The main tasks of the artificial neural network is to build and generalized a predictive model based on its learning of historical input data. The most basic and common neural network is called a multilayer perceptron shown in Figure 1. The multilayer perceptron consists of basic layer named input layer, hidden layer and output layer. This aritificial neural network is also known as

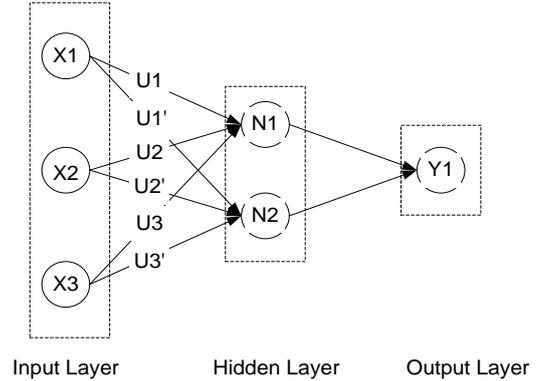the feedforward neural network with multiple input and single output.



Input Layer        Hidden Layer        Output Layer

**Fig. 1**: Multilayer Perceptron Artificial Neural Network

This neural network structure will take the independent input $X_1$ $X_2$ and $X_3$ that will be fed to the neuron in the hidden layer $N_1$ and $N_2$. The receiving input from $X_1$ $X_2$ and $X_3$ will become $U_1$, $U_1$', $U_2$, $U_2$', $U_3$ and $U_3$' respectively. Summation will occurred in the neuron where activation function $f(\varphi)$ are being added together with weight W and bias $b$ in neuron $N_1$ and $N_1$:

$$f(\varphi N_1) = W_1 U_1 + W_2 U_2 + + W_3 U_3 + b \qquad (3)$$

$$f(\varphi N_2) = W_1 U_1' + W_2 U_2' + W_3 U_3' + b \qquad (4)$$

It is being processed with adjustable weight and biased. Once the processed input and weight in the neuron have been completed it will be passed to the output layer and will give the prediction answer $(t_{predict})$ :

$$y(t_{predict}) = f(\varphi N_1) + f(\varphi N_2) \qquad (5)$$

The number of neuron can have a different value where:

$$y(t_{predict}) = f(\varphi N_1) + f(\varphi N_2) + f(\varphi N_3) \dots + f(\varphi N_n) \qquad (6)$$

$$y(t_{predict}) = \sum_{n=1,2,3\dots} f(\varphi Nn) \qquad (7)$$

This process will be repeated in recursive manner with numbers of iterations until the neural network able to predict the output as close to the input historical data. The weights of the neuron were taught and trained by supervised learning method.

## 4. Non-Linear Auto Regressive with Exogenous Input

Non-linear Auto Regressive with Exogenous (NARX) input is a non-linear model that utilizes past input and past output in for time series prediction. NARX model is derived from the Autoregressive exogenous (ARX) model. The model consists of lag term regressor which is repeated in the dynamic network with feedback connections. NARX can be describe in the equation (8)

$$y_t = F(y_{t-1}, y_{t-2}, y_{t-3}, \dots u_t, u_{t-1}, u_{t-2}, u_{t-3}, \dots) + \varepsilon_t \qquad (8)$$

In equation (1) the current output $y_t$ are regressed with the previous output $y_{t-1}, y_{t-2}, y_{t-3}, \dots y_{t-n}$ and the exogenous input $u_t, u_{t-1}, u_{t-2}, u_{t-3}, \dots u_{t-n}$. $F$ is a non-linear function where it can be represented with any suitable technique such as polynomial, artificial neural network, wavelet network and many other techniques. The previous output, the exogenous input and the non-linear function can be called as the regression estimator or the structure of the NARX model. The variety of non-linear function

representation $F$ in the NARX model made it a powerful tool for non-linear system behavior. Two possible ways exist to implement the combination of NARX model with a feedforward ANN. The architecture of the NARX network are being shown in Figure 2 where it consists of parallel and series-parallel architecture [10, 11].
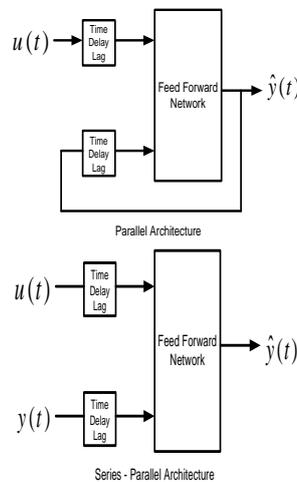


**Fig. 2:** NARX Model architecture

Energy consumption prediction [12] have been conducted in a building that is located in a University compound. NARX-ANN model have been used for the prediction purpose. The predicted electric demand consumption have been conducted in a building that situated in a Mediterranean base climate. It is the second intention of this paper to model an energy baseline in an educational building using NARX-ANN model. The building is located in Johor darul Ta'zim the southern state of Malaysia where there is an equatorial climate being hot and humid throughout the year. Developed NARX-ANN baseline energy model will be compared with the baseline energy model developed using multiple regression model. Detail of the development of the baseline energy model will be discussed in the methodology section.

# 5. Design Methodology

Initial step in conducting any experiments are based on apparent methodology for a clear guidance without any swerved path from the topic and objectives. This paper primary objective is to model the baseline energy consumption and to compare the developed model between multiple regression model and NARX-ANN model. The framework of the proposed methodology in Figure 3 will be detailed out in the subsections This work is a continuation of work that have been published in [13] where certain similarities in multiple regression model, academic buildings data collection and variable are presence analysis on NARX-ANN model are being added to improve the work.

## 5.1 Academic Buidings

International Performance Measurement and Verification Practise (IPMVP) [5] proposed four different protocols for measurement and verification (M&V) procedure. The protocols identified Option A - retrofit isolation with key parameter measurement, Option B – retrofit isolation with all parameter measurement, Option C – whole facility and Option D – calibrated simulation.
Option C form the IPMVP will be adhered in this work as a standard to be followed in modelling the baseline energy consumption corresponding to energy data and variable selection. In this work, Faculty of Electrical Engineering (FKE) and Al-Khawarizmi buildings is the selected case studies located in UiTM Johor branch, Pasir Gudang campus. FKE building contained 4 classrooms, 12 laboratories, meeting 6 rooms and 70 staff rooms.

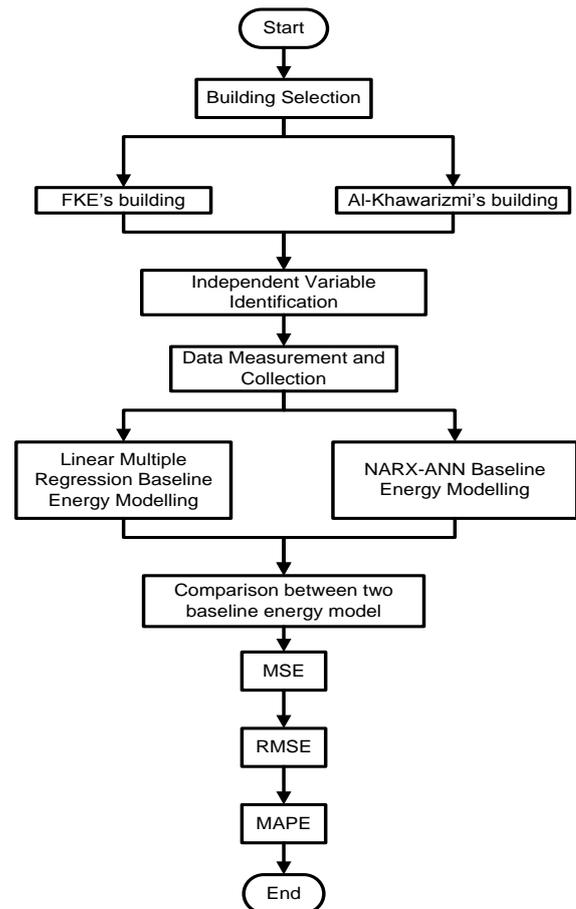While Al-Khawarizmi buildings only consist of class rooms and computer laboratories.



**Fig. 3**: Framework of the proposed methodology

## 5.2 Data Collection and Variables Selection

Energy consumption will be recorded using Fluke1750 in the main switch room from the feeding transformer at the interval of 30 minutes. Data will be recorded during non-lecture period. Occupancy of staff and outside temperature will be the main independent variables for FKE's building. The occupancy of staff, students and outside temperature is the main independent variables for for Al-Khawarizmi's building. During the non-lecture period, there are no students occupying classrooms and laboratories thus the FKE building can be considered as an office building. During the non-lecture period, Al-Khawarizmi's building is being fully utilized for examinations. The selection of examination period during non-lecture period is because the building will not be utilized during non-lecture period.

The occupancy of staff in FKE's building are based on the recorded clock in and clock out of the FKE's staff. Timetable of the examination that are being conducted have provided the sufficient occupancy data of staff and students in the in the Al-Khawarizmi during the commencing of the examination session. Temperature data are being extracted from www.weatherunderground.com based on the nearest satellite station from the campus location. Temperature data that are being extracted is the history data that have been recorded.

## 5.3 Multiple Regression Model and NARX-ANN Model

The modelling of the baseline energy starts with linear multiple regression analysis. The correlation of the independent variable data with respect to the energy consumption will be based on the coefficient of determination $R^2$ for FKE's and Al-Khawarizmi's building. 1240 hourly data points have been recorded for FKE's

building. Data are being collected from 16th March 2017 until 30th May 2017. A total of 408 hourly data points from 16th March 2017 until 9th April 2017 will be used as training data of the regression model. The other 832 data will be used as a testing data which is from 10th April 2017 until 31st March 2017.

Al-Khawarizmi building have a total of 504 hourly data points. The data are being collected from 27th March 2017 until 16th April 2017. From the data, 168 hourly data points from 27th March 2017 until 1st April 2017 will be used as a training data. The remaining 336 data will be used as a testing data which is from 2nd April 2017 until 16th April 2017. It is important for the data to be separated for training and testing period to avoid biasness to the baseline energy model. Due to certain confidentiality, the data that have been collected will not be revealed here. Prediction will be made by substituting the testing data in the equation generated by the multiple regression analysis.

The second model for the baseline energy modelling is NARX-ANN model. The model will be using the same energy and variable data collected. Trial and error based method [14] for the architecture of neuron and number of lag terms for the input of the NARX will be used. Training testing and validation data are being distributed with 70% 15% and 15% respectively as suggested by available and previous work using ANN as a prediction and modelling [15]. Levenberg-Marquadt algorithm will be used for NARX-ANN as it provide high accuracy and precision [16].

### 5.4 Proposed Baseline Energy Models

Construction of the baseline energy models for both of the buildings are based on hourly data where a strong point in terms of prediction accuracy is in the upper hand. FKE's building and Al-Khawarizmi buildings have a different behavior during the non-lecture period thus a different baseline energy model will be built.

FKE's building baseline energy model were formed by working days data only. Prior investigation of energy pattern in FKE's building unveiled that during weekend the energy consumption is very low compared to work days. Meanwhile, Al-Khawarizmi baseline energy model will include weekends and weekdays as the examination session involved weekends.

Comparison between actual and predicted baseline energy model will be executed by means of Mean Squared Error (MSE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). All of the equation are being shown in Equation (9), Equation (10) and Equation (11) respectively. In Equation (9) and Equation (10) $Y_i$ is the predicted value and $y_i$ is the actual value. In Equation (11) $A_t$ is the actual value while $F_t$ is the forecasted value.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - y_i)^2 \tag{9}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Yi - yi)^2}{n}}$$
(10)

$$MAPE = \frac{100}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right|$$
(11)

## 6. Results and discussions

### 6.1 Multiple Regression Model.

The result of regression statistics for FKE's building and Al-Khawarizmi's building are being shown in Table I and Table II respectively. In Table 1, the coefficient of determination $R^2$ for FKE's building showed that the value is above 0.75 which is the minimum value of acceptable linear correlation in IPMVP. The multiple regression creates a linear equation (12):

$$y = 1.31x_1 + 3.71x_2 - 82.22 \tag{12}$$

where 1.31 is the weight for number of staff $x_1$, 3.71 is the weight for outside temperature $x_2$ and -82.22 is the intercept. Mean while, Table 2 shows the coefficient of determination $R^2$ for Al-Khawarizmi's building with the value of 0.86 that is above the acceptable linear correlation of 0.75 in IPMVP. The multiple regression yields the equation (13):

$$y = 0.037x_1 + 0.091x_2 + 1.17x_3 - 11.34 \tag{13}$$

where 0.037 is the weight for number of student $x_1$, 0.091 is the weight for number of staff $x_2$, 1.17 is the weight for outside temperature and -11.34 is the intercept value.

The remaining testing data for the FKE's building and Al-Khawarizmi building are fed in the equation respectively. The results is the prediction of energy consumption in the buildings. The prediction of energy have been plotted in Figure 3 and Figure 4 for FKE's building and Al-Khawarizmi's building respectively.

In Figure 3, the predicted energy is being plotted in the same graph with the measured energy. It can be clearly seen the predicted energy is largely deviated from the measured energy during 20th April 2017 until 4th May 2017. There are certain period that the predicted energy is deviated from the measured energy but measured energy but the deviation is not large compared to the deviation on 20th April 2017 until 4th May 2017.

In Figure 4, predicted energy is being plot with the measured energy. It is being observed that the predicted energy is not highly deviated from the measured energy. This is due to the fact that the $R^2$ is approaching to 1. Eventhough it is approaching to 1 there are certain parts at the lower peak of the energy the prediction is highly deviated from the measured energy.
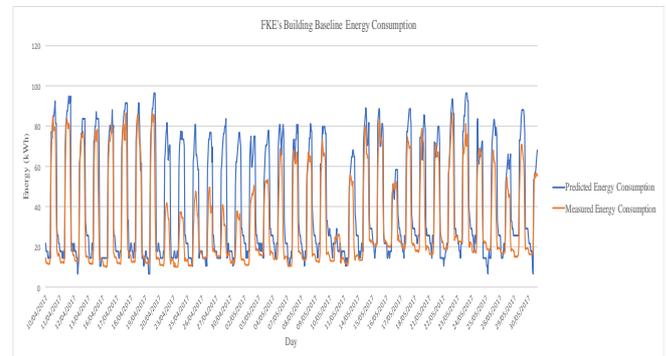


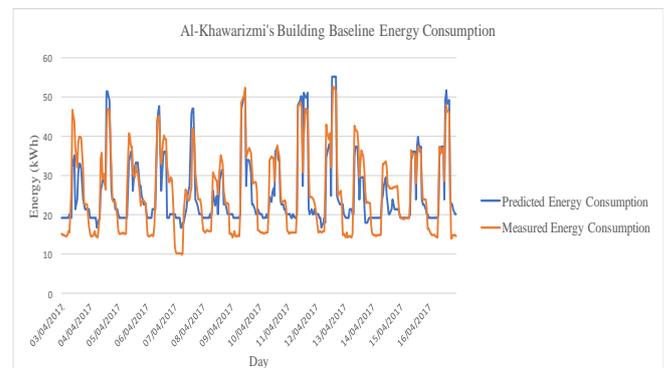**Fig. 4**: Multiple Regression Model Energy Prediction FKE's Building



**Fig. 5**: Multiple Regression Model Energy Prediction Al-Khawarizmi's Building

**Table 1:** FKE's Building Regression Statistics

| Regression Statistic | |
|---|---|
| Multiple R | 0.87 |
| R Square ($R^2$) | 0.77 |
| Observations | 408 |

**Table 2:** Al-Khawarizmi's Building Regression Statistics

| Regression Statistic | |
|---|---|
| Multiple R | 0.92 |
| R Square ($R^2$) | 0.86 |
| Observations | 168 |

## 6.2 NARX-ANN Model

Measured energy data and independent variable data have been fed to the NARX-ANN model. The NARX-ANN architecture for FKE's building and Al-Khawarizmi's building is being shown in Table 3 and Table 4 respectively. After several trail and error process, the suitable value for FKE's building is 60 number of neurons 70 input lag term and 3 output lag term. This trial and error process are being repeated for Al-Khawarizmi's building where the suitable value is 30 number of neurons 50 input lag term and 10 output lag term. Figure 6 and Figure 7 shows the regression plot of the FKE and Al-Khawarizmi's building respectively. The training plot in both of the figure suggest that the independent variables is highly correlated with the energy. The total overall regression plot depicts that the independent variables have a moderate correlation with the energy due to certain data of the distribution are distributed far from the straight line but still is higher compared to the multiple regression R value in Table 1 and 2.

The prediction results have been plotted in Figure 8 and Figure 9 for FKE's building predicted energy consumption and Al-Khawarizmi's building predicted energy consumption. In Figure 8 and Figure 9, there are existence of cyclical peak at certain time where energy consumption is high and at a certain time energy consumption is minimum. The cyclical peak indicate that prediction model followed the behavior of energy. The cyclical peak occured around 12.00pm until 3.00pm is a peak time where at this particular moment people occupied the buildings is using electrical loads heavily due to outdoor temperature is very hot. But at certain high peak and lower peak the value deviated with spiking behavior. This is expected because the model can't fully represent the energy behavior with respect to the independent variables but try to present accurately.

**Table 3**: FKE's Building NARX-ANN Model Architecture

| | |
|---|---|
| Hidden Layer | 1 |
| Number of Neurons | 60 |
| Input Lag Term | 85 |
| Output Lag Term | 3 |

**Table 4**: Al-Khawarizmi's Building NARX-ANN Model Architecture

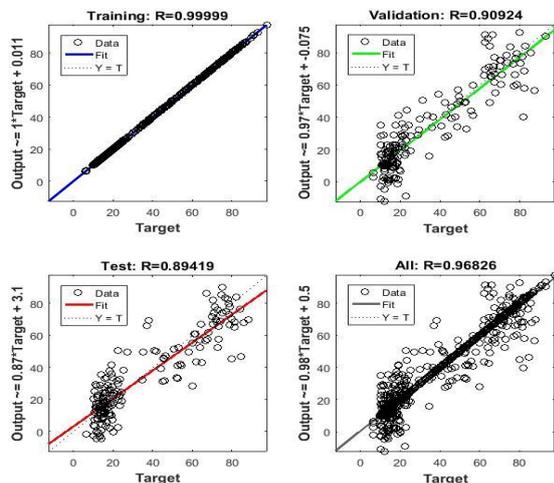| | |
|---|---|
| Hidden Layer | 1 |
| Number of Neurons | 20 |
| Input Lag Term | 50 |
| Output Lag Term | 10 |



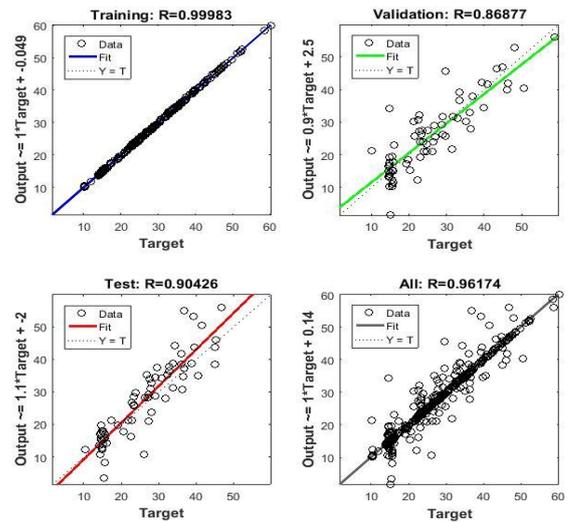**Fig. 6:** NARX-ANN Model FKE's Building Regression Plot



**Fig. 7:** NARX-ANN Model Al-Khawarizmi's Building Regression Plot.
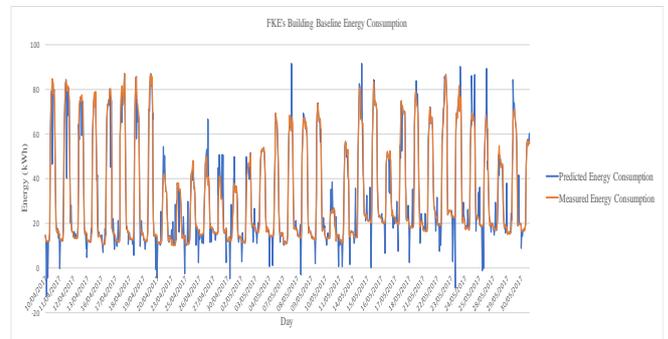


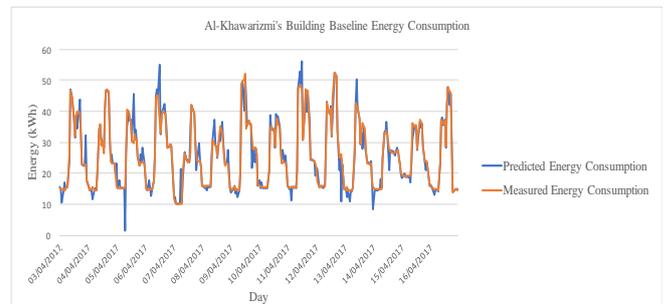**Fig. 8:** NARX-ANN Model Energy Prediction FKE's Building



**Fig. 9:** NARX-ANN Model Energy Prediction Al-Khawarizmi's Building

## 6.3 Comparison between Multiple Regression Model and NARX-ANN Model

Comparison have been made between multiple regression model and NARX-ANN model for the predicted baseline energy consumption with statistical error measurements. Table 3 and Table 4 shows the error measurement for FKE's building and Al-Khawarizmi's building respectively. The comparison were made with the same amount of data points. It can be clearly seen in both of the tables, NARX-ANN baseline energy model give a very low value of MSE, RMSE and MAPE compared to the value of multiple regression model. It implies that NARX-ANN baseline energy model have a good model of fit due its low value of MSE, RMSE and MAPE.

**Table 3:** Comparison between Multiple Regression Model and NARX-ANN Model FKE's Building

| Error Measurement | Multiple Regression Model | NARX-ANN Model |
|---|---|---|
| Mean Square Error | 269.49 | 42.2 |

| | | |
|---|---|---|
| (MSE) | | |
| Root Mean Square Error (RMSE) | 15.41 | 6.49 |
| Mean Absolute Percentage Error (MAPE) | 0.41 | 0.11 |

**Table 4:** Comparison between Multiple Regression Model and NARX-ANN Model Al-Khawarizmi's Building

| Error Measurement | Multiple Regression Model | NARX-ANN Model |
|---|---|---|
| Mean Square Error (MSE) | 25.21 | 8.61 |
| Root Mean Square Error (RMSE) | 5.02 | 2.93 |
| Mean Absolute Percentage Error (MAPE) | 0.19 | 0.05 |

## 7. Conclusion

This paper has discussed and compare the linear and non-linear modelling with respest to the predicted baseline energy model in an educational campus building. Baseline energy consumption have been modeled using the multiple linear regression model and NARX-ANN model. From the results it can be seen that linear regression model is able to predict the energy consumption but at a certain point, regression model can't predict the non-linearity dynamic behaviour of human being and temperature. On the other hand NARX-ANN model is able to predict the non-linear dynamic behaviour of human being and temperature towards the energy conumption. The value of MSE, RMSE and MAPE of the baseline energy model shows that NARX-ANN model have a low value of error compared to the multiple linear regression model. It implies that NARX-ANN baseline model proof to be more reliable than multiple regression model for its low value of MSE, RMSE and MAPE. From this results it shows that non linear NARX-ANN model is in favour to be use as prediction tool compared to multiple regression model network. Even though NARX-ANN have a low value of statistical error, the architecture of the model i.e. number of neurons, input and output lag term have to be tested several times by using trial and error method in order to fulfil the autocorrelation requirement. This is a drawback of the model where for a future reccomendation for the architecture selection the NARX-ANN model can optimized by an optimization method. Optimization method can overcome the recursive trial and error method by calculating itteratively the suitable architecture selection for the NARX-ANN model

## Acknowledgement

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