Modeling and Forecasting of Energy Demands for Household Applications

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Energy use is on the rise due to an increase in the number of households and general consumptions. It is important to estimate and forecast the number of houses and the resultant energy consumptions to address the effective and efficient use of energy in future planning. In this paper, the number of houses in Brunei Darussalam is estimated by using Spline interpolation and forecasted by using two methods, namely an autoregressive integrated moving average (ARIMA) model and nonlinear autoregressive (NAR) neural network. The NAR model is more accurate in forecasting the number of houses as compared to the ARIMA model. The energy required for water heating and other appliances is investigated and are found to be 21.74% and 78.26% of the total energy used, respectively. Through analysis, it is demonstrated that 9 m² solar heater and 90 m² of solar panel can meet these energy requirements.

1. Introduction

Energy consumption in a building day by day increasing due to household appliances and construction materials. Like any other developed country, Brunei Darussalam is seeing an increase in the population due to its quality liveable conditions. In this regard, the number of housing units needs to be increased to cater for the increased population. This increase in housing units is also increasing to cater for the increased population. This increase in housing units, in turn, is increasing the demand for electrical energy. For any developed country, the residential energy demands at least 36% of the total energy consumption.[1] In Brunei Darussalam, it is from 49% to 67%, which means a large portion of the generated energy is used in the housing sectors. The saving of energy in this sector will have a positive impact toward the economy of this country. Based on this notion, and the fact that Brunei Darussalam enjoys the high intensity of solar radiation because of its location near the equator. The government of this country has built a solar farm, lately. This firm, called Tenaga Suria Brunei (TSB), in Seria of Kuala Belait district, has a nominal capacity of 1.2 kWh, it covers an area of 12 000 m² with a generation capacity of 1344 MWh. It consists of 9234 pieces of solar panels and supplies power to 200 households. Therefore, the number of solar panels required per house is 46–47. Similar energy saving ideas have been reported in the literature.

A single hidden layer feed-forward neural network has been used in[2] to estimate the energy consumption in the building. A building information modeling has been used to predict energy uses in a small-scale construction in the UK.[3] Real energy consumption and usages of a room air conditioner in China have been calculated in.[4]

In meeting the energy needs of a selected urban residential building in the three major cities in Egypt, building integrated photovoltaics (BIPV) method have been studied in.[5] Significant energy savings have been achieved by tracking, monitoring, and detecting abnormal energy consumption behavior of building equipment in.[6]

An automated method for saving energy has been proposed by determining when an electrical device is triggered by households’ residents solely from its power trace.[7] A comparative analysis of energy use in Polish households has been done and compared to selected countries of the European Union in the context of European energy policy.[8] A method has been proposed to assess the energy performance in four dwellings by tracking and quantifying the effect of zero and low-cost energy efficiency in Mauritian household.[9] An efficient graph-based algorithm for comparison and prediction of household-level
energy use profiles has been presented in.\textsuperscript{[10]} The performance of a domestic hot water heating system with solar concrete collectors integrated with building structures has been studied and found that the solar water heater with straight and serpentine tubes consumes more area than the other conventional solar water heaters.\textsuperscript{[11]}

The energy performance of a solar water heating system of two different models of storage, namely, fully mixed tank and stratified tank have been studied under Algers climate conditions and found that the performance of a stratified storage tank is better than the fully mixed tank.\textsuperscript{[12]} Ahmed Aisa and Tariq Iqbal\textsuperscript{[13]} have used a solar thermal energy storage system to determine the temperature of a tank and the heat loss of a system for domestic water heating purposes in a detached house setting. A new multiobjective optimization model of combined cooling and heating power (CCHP) system to improve the utilization of renewable energy sources and the shortcoming of solar energy driven by combining solar energy and internal combustion engine has been proposed in.\textsuperscript{[14]}

The long-term performances of photovoltaic systems have been evaluated with monthly mean weather parameters and hourly solar radiation data using MATLAB program in 10 individual houses situated in the remote site of Ghardaia region.\textsuperscript{[15]}

A novel combined heating system consists of solar kanger and solar air heating system and has been proposed to meet the heating demand in north China and to reduce the pollution of traditional Chinese kang in demonstration buildings that were built in Huzhu, Qinghai province, China.\textsuperscript{[16]} In this paper, Spline interpolation, ARIMA forecasting models and Nonlinear Autoregressive Neural Networks Time Series Forecast have been used to forecast the number of houses and energy uses.

To address the constant rise in the energy use in Brunei Darussalam, a study on estimating the growing number of houses and the resultant energy consumptions has been presented in this paper. Also, an option of solar energy use to circumvent the energy-consumption issue has been explored.

2. Data Collection

Since the year 1991, in every ten years, the government of Brunei Darussalam has been conducting housing census by types and districts. From the Government of Brunei census book,\textsuperscript{[17]} the data on the total number of house for the years 1991, 2001, and 2011 for the districts of Brunei-Muara, Kuala-Belait, Tutong, and Temburong have been collected for this study, which has been presented in Table 1.

3. Results and Discussion

3.1. Spline Interpolation and Time Series Forecasting Models

To estimate the number of houses from 1991 to 2015, two methods namely; Spline Interpolation and ARIMA have been used. The former has been used to interpolate a number of houses for each year from 1991 to 2011, and the latter has been applied to forecast the number of houses from 2012 to 2015.

3.2. Spline Interpolation

Spline interpolation is considered as one of the polynomial interpolation methods because the interpolation error can be made smaller even when using low degree polynomials for the spline. In this case, observed data are treated as the “knots or points” by which the spline (i.e., elastic ruler) is bent to pass. The method to mathematically model the shape of the elastic ruler, fixed by \( (n + 1) \) knots \( \{(x_i, y_i): i = 0, 1, ..., n\} \) is to interpolate different values between all the pairs of knots \( (x_i, y_i) \) and \( (x_{i+1}, y_{i+1}) \) with polynomials \( y = q(x), i = 1, 2, ..., n \). These values are calculated by the curvature of a curve \( y = f(x) \), which is given by

\[
k = y'' \left(\frac{1}{1 + y'^2}\right)^{1/2}
\]

where the shape \( (k) \) of the spline minimizes the bending by passing through all knots where \( y' \) and \( y'' \) will be continuous everywhere at the knots.

3.3. ARIMA Time Series Forecast

After using Spline interpolation to estimate missing value from 1991 to 2011, we have a new dataset \( X_T = \{X_1, ..., X_T\} \), that can be considered as a time-series for a length of time \( T \), where data each data item is observed periodically by year. In this case, it is necessary to forecast a future value \( X_{T+k} \), at \( (T+k) \)th time interval where \( k > 0 \). An autoregressive integrated moving average (ARIMA) model could be a good method to be applied. For a given time series of data \( X_t \) where \( t \) is an integer index, and the \( X_t \) are the real numbers, an autoregressive moving average model, i.e., ARIMA \((p, d, q)\) model is given by

\[
X_t - \alpha_1 X_{t-1} - \cdots - \alpha_p X_{t-p} = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q}
\]

Equation (2) is modified as,

\[
\left(1 - \sum_{i=1}^{p} \alpha_i L^{i}\right) X_t = \left(1 + \sum_{i=1}^{q} \theta_i L^{i}\right) \varepsilon_t
\]

where \( L \) is the lag operator (i.e., \( L X_t = X_{t-1} \) for all \( t > 1 \)), \( \alpha_i \) are the parameters of the autoregressive part of the model, \( \theta_i \) are the parameters of the moving average part and \( \varepsilon_t \) are the error terms. The error terms \( \varepsilon_t \) are generally assumed to be independent, and identically distributed random variables sampled from a normal distribution with zero means. Assuming that the polynomial has a unit root (a factor of \( (1 - L) \)) of multiplicity \( d \). Equation (3) can be modified as

| Year     | Brunei-Muara | Belait | Tutong | Temburong |
|----------|--------------|--------|--------|-----------|
| 1991     | 34 775       | 10 156 | 6120   | 1489      |
| 2001     | 24 125       | 9201   | 4661   | 1135      |
| 2011     | 45 953       | 10 559 | 7241   | 1640      |

Table 1. Number of occupied housing units.
The estimated number of houses using Spline interpolation and ARIMA model are shown from Figures 1 to 4 for four districts in Brunei Darussalam. From Figures 1 to 4, it is observed that the increased number of houses for four districts is linear with different rate of increase for the census period of 1991 to 2011. The forecasting number of houses is more agreeable with the census data. The estimated number of houses from the two models is tabulated in Table 7. Using these data, the following computations have been carried out. The electrical energy generation and consumption data for different districts of Brunei Darussalam have been collected from Brunei Darussalam Statistical Year Books 2010, 2014, and 2015, as presented in Table 8, while Table 9 presents water production and consumption data, collected from the same year books.

### 3.4. Nonlinear Autoregressive Neural Networks Time Series Forecast

A nonlinear autoregressive (NAR) neural network is a type of dynamic neural networks which includes the tapped delay lines used for nonlinear forecasting. A NAR neural network predicts a time series $y$ at time $t$ ($y(t)$), given $d$ past values of $y(t)$ as follows

$$y(t) = f(y(t - 1) + y(t - 2) + \cdots + y(t - d)) + \varepsilon(t)$$

The function $y(\cdot)$ is approximated by training of the neural network by optimizing the network weights and neuron bias and $\varepsilon(t)$ is the error of the approximation of the series $y$ at time $t$. Figure 5 shows an architecture of NAR neural network for forecasting $y(t)$.
based on \( d = 4 \) with one hidden layer consisting of 10 neurons and one output layer neuron. The decision about the number of hidden layers and neurons per layer depends on the training data and can be optimized through various configurations (i.e., different number of hidden layers and number of neuron in each layer) to minimize the prediction error. In this paper, the NAR neural network was implemented using Neural Network Toolbox in MATLAB R2016a. The network was created and trained in open loop form with one hidden layer (consisting of 10 neurons), and different values for the delay were tested. Training with open loop prediction is more efficient than with closed loop prediction due to the flexibility of providing the network with correct feedback inputs in order to produce the correct feedback outputs. After the training phase, the network was converted to closed loop form for predicting the number of houses for the next four years.

Three learning algorithms, namely Levenberg–Marquardt, Bayesian Regularization and Scaled Conjugate Gradient were applied for training, and their results were compared. Levenberg–Marquardt is a Jacobian calculation based backpropagation procedure which is time efficient but it requires more memory space. The training phase automatically stops when an increase in the mean squared error of the validation samples is detected. Bayesian Regularization is also a Jacobian calculations based algorithm which provides better results for difficult, noisy and small datasets. However, this algorithm typically requires more time for training. The training phase for this algorithm is stopped according to the adaptive weight minimization (regularization) criterion. Scaled Conjugate Gradient is suitable for large problems because it uses gradient calculations, which requires less memory. Hence, this algorithm is more memory efficient as compared to previous techniques. The training for this algorithm automatically stops when an increase in the mean squared error of the validation samples is detected.

In this study, NAR neural networks were used to build a time series model for estimating and forecasting the number of houses in different districts of Brunei Darussalam. The network structure contains one input (i.e., number of houses at time \( t - 1 \)), and one output (i.e., the number of houses for time \( t \)). The number of delays was determined based on the values of mean squared error (the average squared difference between outputs and targets) and the regression value (it measures the correlation between outputs and targets) after training and testing phases. Three NAR neural networks were implemented by dividing the data randomly into training (70%), validation (15%), and testing (15%) groups. Different values of delays were tested, and based on the minimum value of mean squared error and maximum value of regression coefficient, the delay was set to 4 for prediction of a number of houses. An example of training, validation and testing performance curves (mean squared error values) for the Levenberg–Marquardt NAR model is shown in Figure 6. Tables 10 to 13 show the forecast of a number of houses for...
four districts of Brunei Darussalam for the years 2012 to 2015. Tables 14 to 16 show the total number of estimated houses for the year 2005 to 2015 using three different training algorithms (Levenberg–Marquardt, Bayesian Regularization, and Scaled Conjugate Gradient). Moreover, the estimation error for a number of houses and percentage of estimation error for a number of houses have been shown in Tables 17 and 18, respectively, for three NAR neural networks and ARIMA model. Figures 7 and 8 indicate that the lowest value of mean absolute error for estimation of a number of houses was found for Levenberg–Marquardt NAR model while the highest value of mean absolute error for estimation of the number of houses was observed for Scaled Conjugate Gradient NAR model. These figures also suggest that the nonlinear models (Levenberg–Marquardt, Bayesian Regularization) are more accurate in estimating the number of houses as compared to the linear ARIMA model.

### 3.5. Household Energy Consumption

In Brunei Darussalam, the major energy consuming sectors are the residential and commercial ones. The percentage of energy consumption in the residential sector from the year 2005 to 2015 is shown in Figure 9. It is seen that the percentage of energy consumption in the year 2005 is 67.3. Apart from this, energy consumption has been found to be hovering around 50% up to the investigated year 2015. This means that a major portion of electrical energy is consumed in the residential sector alone. The energy consumption per house is shown in Figure 10. The energy consumption per house in the year 2005 was at its highest, which was 33.9 MWh. Whereas the energy consumption from the year 2006 to 2015 has been found to 30 MWh on average. Though the energy between 2006 and 2015 has been found to be almost steady, the total consumption sees an increase since the number of houses increases at a rate of 1.94% from year to year.

### 3.6. Household Water Consumption

Annual water consumptions in m$^3$ per house are plotted in Figure 11. This annual water consumption per house shows an increasing trend starting from 810.7 to 1064 m$^3$ per year.

### Table 7. Estimated number of houses.

| Year | Brunei-Muara | Tutong | Kuala Belait | Temburong | Total |
|------|--------------|--------|--------------|-----------|-------|
| 2005 | 39 182.84    | 6608.96| 10 383.44    | 1573.76   | 57 749|
| 2006 | 40 298       | 6722.75| 10 426.5     | 1589.87   | 59 037.13|
| 2007 | 41 418.44    | 6833.16| 10 464.04    | 1603.96   | 60 319.6|
| 2008 | 42 544.16    | 6949.00| 10 496.06    | 1616.015  | 61 596.43|
| 2009 | 43 675.16    | 7043.84| 10 522.56    | 1626.04   | 62 867.6|
| 2010 | 44 811.44    | 7144.11| 10 543.54    | 1634.035  | 64 133.13|
| 2011 | 45 953       | 7241   | 10 559       | 1640      | 65 393|
| 2012 | 47 094.56    | 7337.89| 10 574.46    | 1645.965  | 66 652.88|
| 2013 | 48 236.12    | 7434.78| 10 589.92    | 1651.93   | 67 912.75|
| 2014 | 49 377.68    | 7531.67| 10 605.38    | 1657.895  | 69 172.63|
| 2015 | 50 519.24    | 7628.56| 10 620.84    | 1663.86   | 70 432.5|

### Table 9. Water production and consumption.

| Year | Total houses | Water production [Thousand m$^3$] | Water consumption [Thousand m$^3$] | House hold consumption [%] | Per house consumption [m$^3$] |
|------|--------------|----------------------------------|-----------------------------------|---------------------------|-----------------------------|
| 2006 | 59 077       | 138 263                          | 47 892                            | 34.6                      | 810.7                       |
| 2007 | 60 348       | 137 712                          | 51 478                            | 37.4                      | 853.0                       |
| 2008 | 61 613       | 142 475                          | 54 783                            | 38.5                      | 889.1                       |
| 2009 | 62 870       | 151 514                          | 63 227                            | 41.7                      | 1005.7                      |
| 2010 | 64 120       | 160 234                          | 68 262                            | 42.6                      | 1064.6                      |
| 2011 | 65 361       | 166 161                          | 66 781                            | 40.2                      | 1021.7                      |
| 2012 | 66 595       | 167 396                          | 72 899                            | 55.4                      | 1343.8                      |
| 2013 | 67 822       | 162 990                          | 80 819                            | 49.6                      | 1191.6                      |
| 2014 | 69 041       | 166 129                          | 90 343                            | 54.4                      | 1308.5                      |
| 2015 | 70 254       | 152 471                          | 87 719                            | 57.5                      | 1248.6                      |

### Table 8. Energy generation and consumption.

| Year | Total houses | Energy generation [GWh] | Energy consumption [GWh] | Residential energy use [%] | Per house consumption [MWh] |
|------|--------------|-------------------------|-------------------------|---------------------------|-----------------------------|
| 2005 | 57 797       | 2912.8                  | 1960.3                  | 67.3                      | 33.9                        |
| 2006 | 59 077       | 3298.3                  | 1649.7                  | 50.0                      | 27.9                        |
| 2007 | 60 348       | 3394.8                  | 1768.0                  | 52.1                      | 29.3                        |
| 2008 | 61 613       | 3423.5                  | 1870.1                  | 54.6                      | 30.4                        |
| 2009 | 62 870       | 3611.5                  | 1955.0                  | 54.1                      | 31.1                        |
| 2010 | 64 120       | 3792.2                  | 1887.2                  | 49.8                      | 29.4                        |
| 2011 | 65 361       | 3723.0                  | 1935.6                  | 52.0                      | 29.6                        |
| 2012 | 66 595       | 3928.7                  | 1997.9                  | 50.9                      | 30.0                        |
| 2013 | 67 822       | 3961.8                  | 1986.1                  | 50.1                      | 29.3                        |
| 2014 | 69 041       | 4004.6                  | 2016.4                  | 52.0                      | 30.5                        |
| 2015 | 70 254       | 4198.8                  | 2231.3                  | 53.1                      | 31.8                        |
from the year 2006 to 2010.\(^\text{[17]}\) Afterward, there is an abrupt increase from 2011 to 2012 due to weather condition. It then decreases and remains at an average value of 1250 m\(^3\). The overall yearly rate of increase in water consumption has been

| Year | Brunei-Muara | Tutong | Kuala Belait | Temburong | Total |
|------|--------------|--------|--------------|-----------|-------|
| 2005 | 39 182.84    | 6608.96| 10 383.5     | 1573.76   | 57 749.06 |
| 2006 | 40 298       | 6722.75| 10 426.55    | 1589.87   | 59 037.17 |
| 2007 | 41 148.44    | 6833.16| 10 464.08    | 1603.96   | 60 319.64 |
| 2008 | 42 544.18    | 6940.19| 10 496.09    | 1616.01   | 61 596.47 |
| 2009 | 43 675.16    | 7043.84| 10 522.57    | 1626.04   | 62 867.61 |
| 2010 | 44 810.56    | 7144.11| 10 543.59    | 1634.03   | 64 132.29 |
| 2011 | 45 947.29    | 7241   | 10 559.22    | 1640     | 65 387.51 |
| 2012 | 47 078.82    | 7334.58| 10 569.59    | 1640     | 66 626.92 |
| 2013 | 48 187.57    | 7425.18| 10 574.64    | 1645.81   | 67 833.2 |
| 2014 | 49 291.29    | 7513.66| 10 579.89    | 1645.56   | 69 026.4 |
| 2015 | 50 358.59    | 7601.57| 10 571.8     | 1642.99   | 70 174.95 |

| Year | Brunei-Muara | Tutong | Kuala Belait | Temburong | Total |
|------|--------------|--------|--------------|-----------|-------|
| 2005 | 39 184.44    | 6608.97| 10 383.44    | 1573.76   | 57 750.61 |
| 2006 | 40 300.14    | 6722.75| 10 426.5     | 1589.88   | 59 039.27 |
| 2007 | 41 420.77    | 6833.14| 10 464.04    | 1603.96   | 60 321.91 |
| 2008 | 42 546.2     | 6940.16| 10 496.06    | 1616.01   | 61 598.43 |
| 2009 | 43 676.32    | 7043.81| 10 522.56    | 1626.04   | 62 868.73 |
| 2010 | 44 810.98    | 7144.1 | 10 543.54    | 1634.04   | 64 132.66 |
| 2011 | 45 947.29    | 7241   | 10 559       | 1640     | 65 390.1 |
| 2012 | 47 078.82    | 7334.58| 10 569.83    | 1643.93   | 66 640.9 |
| 2013 | 48 187.57    | 7425.18| 10 574.31    | 1648.82   | 67 881.93 |
| 2014 | 49 291.29    | 7513.66| 10 579.12    | 1645.66   | 69 113.37 |
| 2015 | 50 358.59    | 7601.57| 10 571.8     | 1642.99   | 70 334.33 |

| Year | Brunei-Muara | Tutong | Kuala Belait | Temburong | Total |
|------|--------------|--------|--------------|-----------|-------|
| 2005 | 39 071.7     | 6610.4 | 10 397.48    | 1566.13   | 57 645.71 |
| 2006 | 40 264.24    | 6723.94| 10 438.69    | 1586.57   | 59 013.44 |
| 2007 | 41 526.61    | 6828.15| 10 471.58    | 1604.34   | 60 430.68 |
| 2008 | 42 791.46    | 6923.75| 10 499.18    | 1618.3    | 61 832.69 |
| 2009 | 43 978.18    | 7019.98| 10 522.61    | 1628.51   | 63 149.28 |
| 2010 | 45 028.81    | 7192.32| 10 541.88    | 1635.6    | 64 335.61 |
| 2011 | 45 924.16    | 7256.91| 10 556.82    | 1640.27   | 65 378.16 |
| 2012 | 46 676.6     | 7397.34| 10 567.53    | 1643.11   | 66 284.58 |
| 2013 | 47 440.22    | 7566.58| 10 572.97    | 1644.11   | 67 223.88 |
| 2014 | 47 802.65    | 7660.44| 10 579.03    | 1643.72   | 67 685.84 |
| 2015 | 48 776.92    | 7812.39| 10 584.61    | 1642.65   | 68 816.57 |

| Year | Brunei-Muara | Tutong | Kuala Belait | Temburong | Total |
|------|--------------|--------|--------------|-----------|-------|
| 2005 | 47 078.82    | 7144.11| 10 543.59    | 1634.03   | 64 132.29 |
| 2016 | 48 187.57    | 7334.58| 10 569.59    | 1645.81   | 67 833.2 |
| 2017 | 49 291.29    | 7513.66| 10 579.89    | 1645.56   | 69 026.4 |
| 2018 | 50 358.59    | 7601.57| 10 571.8     | 1642.99   | 70 174.95 |
calculated and found to be 6% per household. The water consumption is divided into two categories, namely, household and commercial. The percentage of water use per household is shown in Figure 12. Here, it observed that the household percentage of water consumption has an increasing rate starting at 34.6% to 57.5%. However, there is a sharp increase from 40.2% to 55.4% for the year 2006 to 2012.

From Figures 7 and 8, it can be anticipated that the demand for domestic energy to warm up the water will increase in future. On average, the water consumption in a house for different water-related purposes is shown in Figure 13. It is seen that 52% of total water consumption per house results from everyday shower-use.

Generally, warm water is preferred in the shower, and this requires electrical energy overhead. In this case, the amount of required electrical energy needs to be calculated by using Equation (1). The volume of the water to be heated in m$^3$ is calculated from the water consumption in m$^3$ multiplied by the
percentage of water use in the shower (52%) using Figures 11 and 13, respectively. It is then converted to mass \((m)\) in kg by multiplying the calculated volume with the standard water density. For each year of investigation, the electrical energy required to warm up the water \(W_{HE}\) is calculated as

\[
W_{HE} = 2.77 \times 10^{-4} m C_p \Delta T
\]

where \(W_{HE}\) in kWh, \(m\) is the mass of water in kg, \(C_p\) is the specific heat of the water in \(kJ \cdot kg^{-1} \cdot K^{-1}\), \(\Delta T\) is the temperature difference between the supply-water and the room temperature.

The percentage of energy use for heating the water is calculated from the ratio between \(W_{HE}\), and the total consumed energy used from Figure 10.

The percentage of electrical energy required to heat the water for every house from the year 2006 to 2015 have been plotted in Figure 14[20]. The highest percentage of electrical energy required to heat the water is found to be 28% in the year 2012.

The energy consumption in the other appliances (EOA) in a house is calculated by subtracting the energy used for
water-heating from the total consumed energy per house. The energy for heating water and other appliances are plotted together in Figure 15.

### 3.7. Solar Energy as an Option to Cut Down the Energy Expenses

Solar energy can be used in cutting down the cost associated with energy. It can be used in two ways, namely, direct heating and electricity generation by using a solar panel. In Brunei, the roof area of a typical two-storied house is around 500 m². Part of this roof area will be used for solar heating and solar power generation. The collector yield $C_y$ is calculated as

$$C_y = S_R \times \eta_c \times \eta_{sys}$$

where $C_y$ is the collector yield, kWh day$^{-1}$ m$^{-2}$, $S_R$ is the solar radiation per day m$^{-2}$, $\eta_c$ is the efficiency of the collector, $\eta_{sys}$ is the efficiency of the system.

Averaging the solar radiation data from 2010 to 2011, solar radiation is found to be 4.96 kWh day$^{-1}$ m$^{-2}$. Assuming the collector and the system efficiencies 0.61 and 0.85, respectively. The collector yield is found to be 2.57 kWh day$^{-1}$ m$^{-2}$. The energy demand per day ($Q_d$) can be determined as

$$Q_d = \frac{W_{HE} \times 1000}{365}$$

By considering the highest water heating value, per day energy has been found to be 23 kWh. The required area of the solar collector ($A_c$) can be determined as

$$A_c = \frac{Q_d}{C_y}$$

The area of the collector has been found to be 8.95 m$^2$. The rest of the area can be used for the solar panel to generate electricity for other appliances at the house.

Polycrystalline Silicon with a dimension of 1.956 m $\times$ 0.992 m can generate a maximum solar power of 300 W and a resultant current of 15 A. Using the minimum sunshine hour of 5 h, the energy generation per day ($E_G$) can be calculated as

$$E_G = \frac{300 \times 5}{1000} = 1.5 \text{kWh}$$

The per day energy demand ($E_{DS}$) from the solar panel can be determined as

$$E_{DS} = \frac{EOA \times 1000}{365}$$

For a maximum energy value of 25 MWh per year energy of the other appliances, the per day energy demand from the solar panel is found to be 68.5 kWh. Therefore, the number of the required solar panel ($N_{SP}$) is determined as

$$N_{SP} = \frac{E_{DS}}{E_G}$$

In this case, the number solar panels are to be 46 with an area of 89.24 m$^2$ which is in an agreement with an established solar energy plant named as “Tenaga Suria Brunei (TSB)” located in Seria Kuala Belait district.

The plant at TSB covers an area of 12 000 m$^2$ with a total number of 9234 solar panels supplying 200 households with a generation of 1344 MWh per year. It has a rated capacity of 1.2 MWp. The yearly yield factor ($Y_f$) is calculated as

$$Y_f = \frac{EG_a}{Pr} = \frac{1344}{1.2} = 1120 \text{h}$$

where $EG_a$ is the generation per year in MWh, $Pr$ is the rated power in MW.

### 4. Conclusion

The number of houses in the four districts of Brunei Darussalam is estimated from the census data using two models. The mean absolute error for the number of houses have been determined using three different training algorithms, namely, Levenberg–Marquardt, Bayesian Regularization and Scaled Conjugate Gradient and ARIMA model. The values of mean absolute errors for those methods are found to be 0.0442, 0.0594, 0.6388, and 0.0876, respectively. In addition, the energy consumption per household is found out from the energy consumption data and the estimated number of houses. The average consumption per household is found to be 30.3 MWh for the investigated year from 2005 to 2015. This amount of electrical power is proposed to generate using solar panels, which has an annual yield factor of 1120 h. This consumption is divided into two broad categories, namely, water heating and other appliances. The energy required for water heating purposes is 21.74%, whereas the energy required for other appliances is 78.26%. It has been found that the solar water heater of 9 m$^2$, and the solar panel of 90 m$^2$ are required to meet the
necessary energy demand for any household with the rooftop area of 500 m².

**Conflict of Interest**
The authors declare no conflict of interest.

**Keywords**
energy consumption, NAR neural network, number of houses, solar panels, solar water heater, spline and ARIMA models

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