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Research paper

Analysis of Electrical Energy & Water Consumption in a Hostel Building through Regression Analysis

Siddhartha[1]*, Maya Yeswanth Pai[2]

[1]*Assistant Professor, Dept of E & E Engineering, Manipal Institute of Technology, constituent college of MAHE, Manipal*
[2]*M. Tech Scholar, Dept of E & E Engineering, Manipal Institute of Technology, constituent college of MAHE, Manipal*
**Corresponding Author: Siddhartha.mit@manipal.edu*

Abstract

This paper focuses on determination of building factors affecting electricity and water consumption of a residential building in India. Among various factors like temperature, occupancy schedules, building envelope, lighting and HVAC Loads, two determinant factors are selected after collecting annual energy and water consumption information for the residential building for a period of one year. Along with that, weather information for the same building is collected and a correlation analysis is performed to determine the effect of the determinant factors on the consumption. Based on the correlation results, the factor affecting the consumption is determined. After which using a statistical method i.e. Linear Regression Analysis, the best possible model is determined based on the results obtained from the regression. The model capable of predicting the consumption with least error and high value of correlation is chosen and the equation of the model is used for prediction purposes.

Keywords: *Building Information Factors (BIF), Energy conservation, Regression Analysis, Energy, Building, Correlation.*

1. Introduction

In the recent times, there is a growing focus on producing efficient methodologies for managing energy consumption in buildings. The purpose is, to reduce the escalating energy prices and for improving the worsened state due to the climatic conditions. As the energy use is escalating at an alarming rate, desperate measures are being implemented to curb the dwindling of energy resources, depletion of the ozone layer and to develop substitutes for the depleting resources. The main area where reduction of energy consumption is sought after is in buildings. Buildings are an area of prime focus because they have exceeded other major sectors such as industry and transportation, in terms of energy consumption, where both residential and commercial buildings account for 40% and 20% of the total consumption in developed countries and even more in developing countries. Factors such as increase in population, time spent inside the buildings along with a requirement for higher levels of comfort have ensured a constant rise in energy demand which will continue to trend in the future.

Hence, it is critical that energy policies at the international, national and regional levels focus on energy efficiency in buildings and prioritize it so that critical resources such as water, electricity and gas are used efficiently. India is the one of the largest countries with a rapid rate of population increment. Due to this large population, proper implementation of energy efficient measures or increase in the energy efficiency of already existing systems for residential or commercial buildings would bring about significant energy savings and result in reduction of load on the existing energy resources. Improving energy efficiency in new buildings is one of the easier and less expensive options to decrease a building's energy use, owner operating costs, and carbon footprint.

There are several suitable methods which can be used to develop a suitable mathematical model. Various methods are available to achieve such models, of which statistical regression analysis, simulation tools etc are most commonly used.

Amongst these options, models developed on the basis of statistical regression enjoys popularity and thus are used to develop baseline case models. Here, utility data collected over a span of time is regressed with weather data and other important parameters which play a vital role in energy consumption of buildings. To achieve this, Simple and Multiple Regression Analysis (MRA) is conducted not only to reveal the relation among the elements such as weather information toward energy and water consumption model but also to estimate electrical energy and water use forecast.

2. Methodology

In this paper, the estimated effects of various factors affecting energy consumption in the residential building are evaluated to establish a useful building information-based knowledge system.

The following procedure is used to identify prediction model:

1) The annual energy consumption details for space heating and cooling of the building is collected
2) The weather data is collected from local Meteorological Bureau to determine suitable independent/ predictor variables.
3) A study is conducted on two important factors: temperature and humidity of the residential building; affecting the heating and cooling loads of the building which in turn influence the electricity and water usage of the building. This is done using Pearson's Correlation Coefficient.

4) After sufficient correlation is observed between the variables and the consumption value, Multiple Regression Analysis is conducted between the consumption values obtained and the weather data.
5) Simple and Multiple Regression Analysis (MRA) is used to estimate electricity energy and water use forecast.
6) Comparison between single variable linear model and multiple variable regression models.
7) The regression coefficients and the regression constant of the models are obtained, and the equation is determined.
8) The predicted annual energy consumption is calculated using both the models.
9) The error in the model is determined and the model with least quantum of error is selected for further prediction purposes.

3. Regression Modeling

3.1. Correlation Analysis

The relationship that exists between any two variables can be determined through Correlation analysis. Correlation coefficient 'r' is used to derive linear relationship between any two variables. The value of 'r' varies from -1 to 1, where a range from -0.7 > r > -1 and 0.7 < r < 1 represents a strong association.

The analyzed value depicts how a change in one variable will affect the correlated variable. This paper aims to perform such an analysis between two weather dependent variables with electrical energy and water consumption. This analysis will help to decide which variable influences the electrical energy and/or water consumption the most. The correlation r between two variables is:

$$\boxed{r = \frac{\Sigma(x.y)}{\sqrt{\Sigma x^2 * \Sigma y^2}} ---------- 01}$$

$where\ x = x_i - x'(x_i\ is\ the\ x\ value\ for\ observation\ i\ and\ x'is\ the\ mean\ value\ of\ x$

$where\ y = y_i - y'(y_i\ is\ the\ y\ value\ for\ observation\ i\ and\ y'is\ the\ mean\ value\ of\ x$

3.2. Single variable regression models

The Single variable regression the value of one variable is predicted based on the value of another variable. The variable to be determined based on the value of the known variable is known as dependent variable or the criterion variable, and the variable that the prediction is based on is known as the independent variable or the predictor variable.

In this study, as the operation schedule of the building under consideration was regular and hardly changed between months, weather parameters were treated as the main factors. Here, outdoor dry-bulb temperature and relative humidity have been considered as independent variables. An attempt is made to determine the value of electricity and water consumption values based on dry-bulb temperature and relative humidity as the independent variables. Here the outside air dry-bulb temperature and relative humidity is taken to be the regression variables in single variable models.

In this paper energy and water consumption data was regressed with dry-bulb temperature and relative humidity as the independent variables -

$$E = a + bT \quad (2)$$

$$E = a + cRH \quad (3)$$

$$W = a + bT \quad (4)$$

$$W = a + cRH \quad (5)$$

Where E is energy consumption (kWh), W is water consumption (m^3), T is outside air dry-bulb temperature (℃), RH is relative humidity, a and b are regressed parameters found through single variable regression.

3.3. Multiple variable regression models

In the study using Multiple variable regression, the models include the impact of %RH and DBT. And tries to bring about a correlation between the variables. The mathematical models used were as follows,

$$E = a + bT + cRH \quad (6)$$

$$W = a + bT + cRH \quad (7)$$

where RH is the relative humidity, T is outside air dry-bulb temperature.

3.4. Criteria for Best Regression Model

The assessment of the quality of fit of any regression model, developed as a statistical tool, incorporates analysis of CV-RMSE and R^2 as two essential parameters. Root Mean Square of Error (RMSE) is simply the squared value of the variance, which is also know as standard error. CV-RMSE ensures normalization of such errors, and has an acceptable tolerance of ±15%

4. Case Study

A residential building of floor area 4000 m² is considered for the analysis. Utility bills: Electricity and Water bills. The period of all utility bills is from 2014 to 2015. The factors influencing electricity energy and water consumption can be largely categorized into either Human-Factors or Building-Factors corresponding to the Occupant's information including the number of residents, behavioral patterns of energy use or the Building information such as physical properties of buildings. Plus, temperature and relative humidity can be regarded as Environmental-Factors. The weather data is taken from local meteorological bureau and possible independent variables are identified, using correlations analysis for selection of predictor variable. The variables are regressed using single and multiple variable regression models. The standard estimate error, coefficient of determination and regression coefficients are determined.

4.1 Correlation analysis

The correlation coefficient r between monthly energy bills and two weather data that was outdoor dry-bulb temperature (T) and relative humidity were calculated respectively. According to Table.1, shows the correlation coefficients 'r' of the building. Monthly Average temperature has higher correlation value to electricity use than water use. Average relative humidity correlation with energy consumption shows that the correlation is inversely proportional. Correlation coefficient between electrical energy and water consumption shows high correlation of 0.944

Table 1: Correlation coefficients relating the selected variables

		E_{con}	W_{con}	$T_{Monthly}$	$RH_{Monthly}$
E_{con}	N	12			
	r	1	0.9441	0.4826	-0.459
	covariance	0.975	14.688	6.285	38.74
W_{Con}	N	12			
	r	0.9441	1	0.4415	-0.3409
	covariance	14.688	22.560	8.336	41.687

$T_{Monthly}$	**N**	12			
	r	0.4826	0.4415	1	-0.4429
	covariance	6.285	8.336	15.807	45.33
$RH_{Monthly}$	**N**	12			
	r	-0.459	-0.3409	-0.4429	1
	covariance	38.74	41.687	45.33	85.34

Where E_{con} = Monthly Energy Consumption, W_{con} is Monthly Water Consumption; $T_{monthly}$ is Average Monthly Temperature, $RH_{monthly}$ is the average monthly humidity and r is the Correlation coefficient

4.2 Single Variable Models

The energy consumption and water consumption values are regressed individually with monthly average temperature and monthly average humidity values obtained. The resulting values of R and standard error values for each regression are studied carefully.

Table 2: Single variable Regression Results (Energy consumption with T, RH)

Electricity Consumption	**R**	**R^2**	**Adjusted R^2**	**Std. Error of Estimate**
Monthly Average Temperature	0.483	0.234	0.227	0.8354
Monthly Average Humidity	0.458	0.210	0.203	0.8481

Table 3: Single variable Regression Results (Energy consumption with T, RH)

Water	**R**	**R^2**	**Adjusted R^2**	**Std. Error of Estimate**
Monthly Average Temperature	0.443	0.196	0.190	1.239
Monthly Average Humidity	0.341	0.116	0.109	1.299

From the regression results of the single variable regression obtained as shown in Table. 2 and Table. 3, we can see that a single valued model with monthly average temperature as the dependent variable can predict the value of energy and water consumption better than models with monthly average humidity as the R value for models depending on humidity values is lesser than the R values of models depending on temperature and also have a higher error value as compared to values based on temperature

4.3 Multiple variable regression models

The energy consumption and water consumption values are regressed together with monthly average temperature and monthly average humidity values obtained. The resulting values of R and standard error values for each regression are studied carefully.

Table 4: Multiple variable regression results for electricity consumption with weather information

Electricity Consumption	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
Monthly Avg. Temperature and Monthly Avg. Humidity	0.555	0.309	0.154	0.796

Table 5: Multiple variable regression results for water consumption with weather information

Water Consumption	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
Monthly Avg. Temperature and Monthly Avg. Humidity	0.472	0.223	0.210	1.224

From the regression results of the multiple variable regressions obtained as shown in Table. 4 and Table. 5, we can see that a multiple variable regression model for electricity consumption has a higher value of R as compared to its single variable counterpart. The same is the case with water consumption values. This implies that it is better to consider both the variables together for prediction of the consumption as the effect of both the variables are considered together in determining the consumption. Also, the error obtained in the single value model is more than the multiple variable models for both electricity and water consumption, hence it can be chosen for predictive modeling purposes over single variable models.

5. Conclusion

In this paper, both electricity energy and water use of a typical apartment complex is analyzed based on BIF. And crucial features affecting energy and water consumption in apartment buildings were identified. Also, from the regressed coefficients obtained using single and multiple regression It was observed that the Electricity Consumption can be best modeled using multiple regression analysis with both temperature and humidity playing a crucial role in its consumption with an error of 0.2% with respect to the measured values, whereas the Water consumption is best modeled with Single Variable Analysis with humidity playing a better predictor variable than temperature providing an error of 0.1% with respect to the measured values.

Some discrepancies observed in the results are due to variation in the occupancy of the building and also due to improper metering. Future work includes - 1) Investigation of various BIF factors affecting energy use, and 2) Verification of the model with more case studies.

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