Energy and Buildings 85 (2014) 79–85

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Developing building benchmarking for Brunei Darussalam

V. Shabunko*, C.M. Lim, S. Brahim, S. Mathew

Faculty of Science, Universiti Brunei Darussalam, Brunei Darussalam

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form 16 August 2014
Accepted 20 August 2014
Available online 18 September 2014

Keywords:
Energy efficiency
EnergyPlus
OLS
SVM
Benchmarking method
Residential buildings

ABSTRACT

This paper demonstrates the use of benchmarking methods for residential buildings in an energy rich economy. Three bottom-up methods were used, ordinary least square (OLS), support vector machines (SVM), and engineering modelling (EM). EM highlighted the energy inefficiency in these buildings, where the EM simulations showed the potential of halving the average measured consumption of 20.5 MWh/year. SVM could demarcate buildings and households with consumption of >16.0 MWh/year which are considered to be inefficiency. OLS is simple to use and the non-linear least square, showing $R^2 > 0.8$, performs better than linear least square fit. This work allows two EUI benchmark measures to be determined and they have average values of 2035 kWh/person/year and 56 kWh/m²/year.

1. Introduction

The operation cost of a building is greatly dominated by fuel and power consumption. A typical energy profile of a developed economy shows at least 36% of energy consumption is by the building sector [1]. This is a significant proportion of the total energy consumption, and any successful energy savings in this sector would significantly improve the energy efficiency in the economy.

Energy benchmarking of buildings allows the energy performance of buildings to be compared for the purpose of effective energy management and building designs. Energy benchmarking can be used to standardize energy consumption indicators and define the baseline of energy efficiency in a given economy. Energy management is used to attain or improve on the benchmarked level, and the models used in some benchmarking methods could be extended to include the energy management of buildings as reported by Li and Wen [2]. The concept of energy benchmarking for buildings is not new, and the methodologies for benchmarking, rating and even labeling have evolved over the years. Lombard et al. [3] has provided a comprehensive discussion in defining the fundamental parameters crucial for energy benchmarking for buildings, which could be useful for grasping the fundamental concepts of benchmarking.

The methodology in setting the benchmark can be simplistic, like normalization, or in more elaborate techniques, like machine learning and engineering modelling [4,5]. In comparing the energy performance of buildings, benchmarking has to be resilient to factors like weather changes and variation in building utilization. The selection of benchmarking methods is determined by constrains such as sample size and the resolution of the data.

This paper describes benchmarking methodologies for the residential sector in Brunei Darussalam. In the residential sector, 98% of its energy supply is electricity. In Brunei Darussalam, the power generation is almost 100% by natural gas and the tariff structure can be viewed at the Department of Electrical Services (DES) homepage [6].

A majority, 60%, of the electricity consumed is used for space cooling [7]. The main features of the climate in Brunei are small temperature variations throughout the year both seasonally and with slight variations in different parts of the country. There is abundance rainfall in the winter monsoon season, where the total annual rainfall exceeds 2300 mm throughout the country. It has a diurnal temperature range of 21–36 °C. The relative humidity (RH) is usually between 65 and 98% [8].

In the 2011 national population and housing censors, Brunei has a total of 68,208 households. The distributions are concentrated in the city area. The national housing scheme has over the years developed clusters of houses or estates, mainly detached, terrace and single houses. The size of the housing estates can vary from just over 1000 units to 4000 units.

This study has selected 3 of such housing estates with a total of 256 samples. These are the Meragang, Panaga, and Menteri housing estates. The residential houses in the Menteri estates are over 10 years and with floor area of 300 m² and above. The Meragang and Panaga housing are new developments with just over 2 years

* Corresponding author. Tel.: +673 7144266; fax: +673 2461502.
E-mail addresses: veronikashabunko@yahoo.com, 12h1205@ubd.edu.bn (V. Shabunko).

http://dx.doi.org/10.1016/j.enbuild.2014.08.047
0378-7788/

Fig. 1. Location and sample types.

Source: Google.

of occupancy period, and their floor areas are 135–250 m^2. The locations of the samples are shown in Fig. 1.

The building envelope of the samples is commonly fabricated with a single layered external brick wall and the roofing is usually ceramic tiles or steel. The roof and internal ceiling is normally insulted with rock wool, which serves as a heat and sound insulator. Table 1 provides the general dimensions and material descriptions of the building envelope used by the samples. These are the typical specifications, however, variations may occur for buildings over 10 years. These houses are built in accordance to the Brunei Building Code.

The internal walls and fittings, such as lighting, heating ventilation and air-conditioning (HVAC), can differ from house to house. The orientation of walls and windows with respect to the geographical directions differs, hence, variation in the heat transfer from the outside into the houses is expected. This study takes the average effects. The models assume an average effect by taking orientations for the four compass points. In general, the building envelope is common for the new houses, and the variations would be on the occupancy and the life-style. The occupancy level per unit floor area in the sample averages 4.9 per house. In the older houses, slight variations in the building envelope are expected as certain degree of changes and maintenance could change the external facade.

Table 1
List of typical building envelope of residential buildings in Brunei Darussalam.

	Materials
Partitions	• 12 mm thick gypsum plaster • 115/75 mm thick brick
Roof	• 10 mm gypsum plasterboard ceiling • Airspace pitch • 50 mm thick/60 kg^3 fiberglass insulation • 15 mm clay or metal roof tile
Ceiling	• 9–10 mm gypsum board • 75–100 mm rock wall fiberglass insulation
Window	• 3 mm single glass in aluminium frame

2. Methods

A selection of energy benchmarking methods has been reported, and the selection of these methods is determined by constrains and outputs. The constrains can be the accessibility of data, data size, and data coverage. This study deploys three methods, namely: (a) statistical, (b) machine learning, and (c) engineering modelling. These selected methods can be broadly categorized as bottom-up approach where dissociated data are used. The bottom-up methods require extensive data sets, and they involve elaborate data acquisition [9]. The selected benchmarking methods are not exhaustive to the data set. Many other methods could be deployed, example, principal component regression (PCR) method could be used to neutralize noise effect in the data set [10]. However, the methodologies deployed in this study is to demonstrate low cost methods using OLS to highly laborious benchmarking technique of engineering modeling (EM).

A review on statistical methods for energy benchmarking has been reported by Chung [11]. The simplest statistical approach is the *ordinary least square (OLS) method*, also known as a linear regression based statistical technique. OLS is a fast method for estimating energy use intensity (EUI). The factors contributing to the EUI are assumed to be linearly related, and OLS determines the best fit of the EUI over n number of observations. This is achieved by minimizing the intercept – a, coefficients – b_i, and random error – ϵ_i of the EUI expressed as:

$$\sum_{i=1}^{n}\epsilon_i^2 EUI_i = a + b_1 x_{1,i} + \cdots + b_j x_{j,i} + \epsilon_i \qquad (1)$$