Benchmarking Industrial Building Energy Performance

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ABSTRACT

This paper describes the development of an accurate benchmarking system for high-rise industrial buildings in Singapore. In total, 62 flatted factories were investigated. In Singapore and the region, 'flatted factory' is a term used for high-rise ready built multi-tenanted factories (typically 7-stories high) designed for light industries. These flatted factory complexes are typically developed and owned by the landlord and tenanted to various small to medium size enterprises for light manufacturing, product processing and warehousing activities. Common spaces, shared amenities and services are maintained and operated by the landlord.

Investigations were conducted to determine the detailed energy consumption pattern of the landlord. The landlord's energy use includes energy expended in common corridors, lobbies, staircases, washrooms, lifts, plant rooms and car parks etc. Detailed building information collection and analytical studies have been conducted. Results show that the volume of the landlord's spaces and the number of lifts are the two key energy indicators of landlord's energy consumption. From on the results obtained, a benchmarking system has been developed.

The benchmarking curve established provides property managers with an achievable energy performance profile and classification. The normalized energy-use intensities (EUI) ranged from 1.02 kWh/m^3/year to 28.10 kWh/m^3/year, with a mean and median of 11.71 kWh/m^3/year and 11.10 kWh/m^3/year respectively. The less energy-efficient factories have been identified for energy performance upgrading. The findings show despite the apparent rationalized and standardized design of this group of factory buildings, the energy performance gap is large between the most and least efficient buildings. It may be concluded that with proper targeting and management, significant energy savings may be achieved.

Introduction

The success of high-rise industrial buildings housing light manufacturing processes is a hallmark of industrial developments in Singapore. This approach is now widely adopted by many Asian cities including China and India. This industrial building type is commonly known as the "flatted factory". They are high-rise ready built multi-tenanted factories (typically 7-storeys high) designed for light industries. Frequently, they are developed in clusters owned and managed by the landlord or his agent, and tenanted to various small to medium size enterprises for light manufacturing, product processing and warehousing activities. Common spaces, shared amenities and services are maintained and operated by the landlord. Benchmarking energy performance of this building type is a step towards energy efficient development among industrial buildings.

This paper describes a study conducted on 62 flatted factories in Singapore with the aim of developing an accurate energy benchmarking system for this factory type. An accurate benchmarking system provides a useful tool for identifying the marginal and poor performers, without subjecting the landlord to detailed and expensive evaluation processes.

Background

Extensive work around the world has been carried out to study the energy performance of office or commercial buildings. One of these includes a local energy survey carried out by Singapore Public Utilities Board in 1990 from end 1988 to end 1989 on 45 commercial buildings. In a recent study, Lee (2001) investigated 104 office buildings and developed a classification system to profile energy performance of office buildings in different performance levels. In the area of flatted factory buildings and with particular reference to the tropical context, there is no in-depth energy study conducted to date. Energy benchmarking studies conducted in the temperate region frequently focus on establishing process energy benchmarks by stage of production in the various industry sectors (NRCan, 2002; Industry, Science and Resources, 2000; Phylipsen et al, 2002), rather than examining the efficiency of the industrial building itself. In the case of flatted factories, the common spaces and amenities may be considered a major resource base similar to that of an industrial process or support services. It therefore requires careful study and benchmarking.

Methodology

Building information templates were designed to facilitate data collection. Information collected includes properties of building design and materials used, size and height of building, properties of common amenities and services, operation, management and occupancy rate of building, and tenancy types and characteristics. Field interviews were conducted with the factory facility manager to verify the data provided by the landlord. With respect to the energy consumption data, a high level of data accuracy is achieved as it was extracted directly from the original monthly energy bills for each flatted factory over a period of one year.

Random sampling method was employed and a total of 77 questionnaires were sent out to the various facility personnel inviting participation for the study. An 81% response rate was achieved with 62 building managements responded to the survey. The flatted factory samples collected represent a 5.7% sampling error.

The flatted factories studied have average design efficiency (gross lettable area (GLA) to gross floor area ratio) of 71% with a 95% confidence interval of +/- 2.1%. The Gross Floor Area (GFA) is defined as the covered floor space (whether within or outside a building and whether or not enclosed) measured between party walls including thickness of external walls and any open area used for commercial purposes. The results show that this group of buildings is highly rationalized and standardized in terms of architectural design and planning. The low spread of flatted factory design efficiency, and the large sample population with a sampling error of about 5.7% means that the data obtained provide a reliable profile of flatted factories' energy performance in Singapore.

Simple linear regression as well as stepwise least-squares multivariate linear regression models were applied to identify the key energy indicators of electricity use in flatted factories. By normalizing the energy consumption by the key energy indicators, an energy benchmarking curve is established. This allows for better comparative studies between flatted factories. The wide range of normalized energy-use intensities (EUI) obtained from different flatted factories show that there are significant opportunities for energy efficiency development. From the benchmarking curve, individual owner of flatted factory can rapidly determine the performance of his/her factory in terms of percentile positioning with respect to the entire cohort of factories, and ascertain the amount of energy saving accruable.

Profile of Flatted Factory Building Samples

The high-rise flatted factories studied are sampled from 35 industrial estates spread across Singapore. These flatted factories are restricted for light industry usage only. Examples of clean and light industries include (1) software design and development (2) manufacture of paper products without printing activities (3) manufacture of wearing apparel (except footwear) without dyeing and / or bleaching operations and (4) printing and publishing. These factories are designed to integrate marketing, management, production, storage and other industrial activities. They are served by cargo/passenger lifts and loading bays. One important point to note is that these flatted factory buildings are naturally ventilated, with no cooling systems for the landlord's area. The landlords' energy consumption typically covers the artificial lighting for the common area not within any tenant's premises, vertical transportation system, mechanical ventilation systems, pumps and water tanks operation, emergency services and installations, cleaning and other functions in the common area, as well as carpark consumption.

Annual electricity consumption of the sampled flatted factory buildings differ a great deal, ranging from 18,939 kWh to 1,709,934 kWh (See Table 1). This significant variance is largely due to the large range in gross floor area (GFA). The average annual electricity consumption of the 62 flatted factory buildings is 360,958 kWh with a standard deviation of 315,567 kWh. The large standard deviation (87% of the average consumption) recorded is an indicator of the large variation in total electrical energy usage between flatted factory buildings of different floor area.

Table 1. Summary Information on Flatted Factory Building Sample

Number of Flatted Factory Buildings	62
Range of GFA (m^2)	9,045 – 82,005
Range of Landlord's Area (m^2)	2,699 – 32,923
Annual Electricity Consumption of Landlord's Area (kWh)	18,939 - 1,709,934
Average Annual Electricity Consumption of Landlord's Area (kWh)	360,958
Standard Deviation of Annual Electricity Consumption of Landlord's Area (kWh)	315,567

Key Energy Indicators

Least Square Linear Regression

Currently, most energy performance assessments are based on gross floor areas, i.e. normalized energy-use intensities (EUI) is defined as the electric energy per unit of gross floor area. The use of EUI based on gross floor area may not be adequate in evaluating energy use performance in all building types (Deng, 2002). As such, least square linear regression analysis technique was used to process the surveyed data. The landlord electricity consumption figures for 12 months from each flatted factory were correlated with a number of flatted factory building characteristics in order to find the best possible explanatory energy indicator based on the available data. Figure 1 shows an example of the graphical display of a regression analysis of electric energy use against the volume of landlord's area. The R^2 values for landlord electric energy use against a number of potential electric energy performance explanatory indicators are shown in Table 2. For flatted factory energy performance, it appears that two best explanatory indicators are related to landlord's area-- landlord's area and volume of landlord's area. Both landlord's area and volume of landlord's area have high R^2 values of 0.807 and 0.855 respectively. As the volume of landlord's area is deemed to be the major determinant of the variation of energy use between flatted factory buildings, it is now justified to use volume of landlord's area as a normalization factor for the calculation of the normalized energy-use intensities (EUI). There is an imperative need that the actual electricity consumption data is normalized so that the EUI can render a more accurate comparison of energy performance between flatted factory buildings. In the case of flatted factory buildings, there is no need to normalize the electrical energy consumption data using the operating conditions. This is because the sampled flatted factory buildings have similar operating conditions for the landlord's area.

Figure 1. Landlord Annual Energy Consumption versus Volume of Landlord's Area

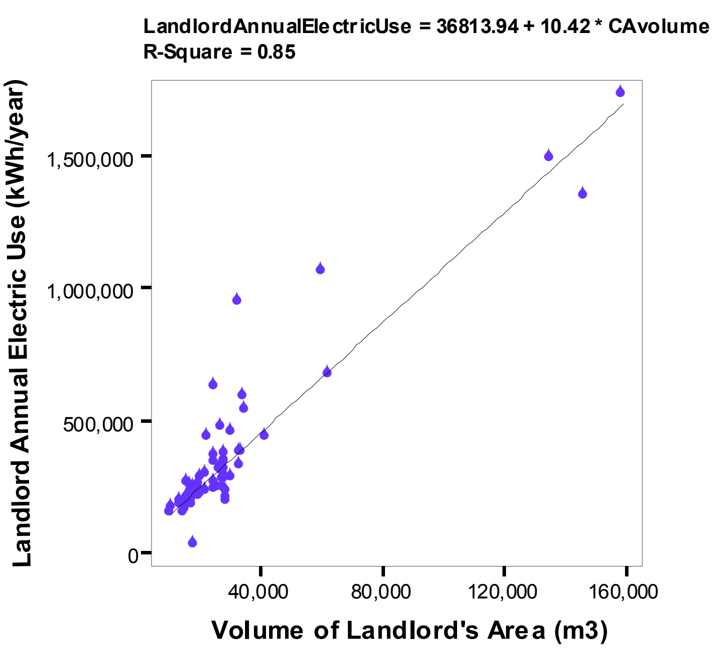


Table 2. R^2 Values for Landlord Electric Energy Use Against Potential Energy Indicators

Potential Energy Performance Indicators	R^2 values
Gross floor area	0.684
Rentable area	0.481
Landlord's area	0.807
Number of lifts	0.606
Floor-to-floor height	0.463
Volume of flatted factory	0.798
Volume of landlord's area	0.855
Age	0.339
Occupancy rate	0.011

Stepwise Least-Squares Multivariate Linear Regression

A stepwise multivariate linear regression analysis was used to identify the key energy indicators that can simultaneously have an impact on the energy performance of flatted factory buildings. All the nine potential energy performance indicators were selected for the stepwise regression. Table 3 below shows a summary of the result arising from the stepwise regression.

Table 3. Results from Multivariate Stepwise Linear Regression

Model	Equation	R^2	Adjusted R^2	P-Value
1	Ê = 3136.47 + 0.868 (Volume of landlord's area)	0.854	0.852	< 0.0005
2	Ê = 4306.386 + 0.708 (Volume of landlord's area) + 1930.804 (Number of Lifts)	0.881	0.877	< 0.0005
3	Ê = 4306.386 + 1.150 (Volume of landlord's area) + 2251.767 (Number of lifts) – 2.423 (Landlord's area)	0.890	0.884	< 0.0005

R^2 (the Coefficient of Determination) is the percent of the Total Sum of Squares that is explained; i.e., Regression Sum of Squares (explained deviation) divided by Total Sum of Squares (total deviation). This calculation yields a percentage. The weakness of R^2 is that the denominator is fixed and the numerator can only increase. Therefore, each additional variable used in the equation will probably contribute to a larger numerator no matter how small is the increase, thus resulting in a higher R^2. The Adjusted R^2 value is an attempt to correct this shortcoming in the R^2 value by adjusting both the numerator and the denominator by their respective degrees of freedom.

Since R^2 values tend to over-estimate the success of the model, it is best to examine the adjusted R^2 values instead. From Table 3 above, it is evident that the volume of landlord's area remains the most consistent key energy indicator of landlord energy performance of flatted factory building. Model 1 which includes only volume of landlord's area may account for 85% of the variance. The inclusion of the number of lifts in Model 2 resulted in an additional 2% of the variance being explained. The final Model 3 also included landlord's area and this model accounted for 88% of the variance. As $p < 0.0005$, all 3 models are considered significant. In checking for multicollinearity, it was found that the variance inflationary factor (VIF) > 5 for

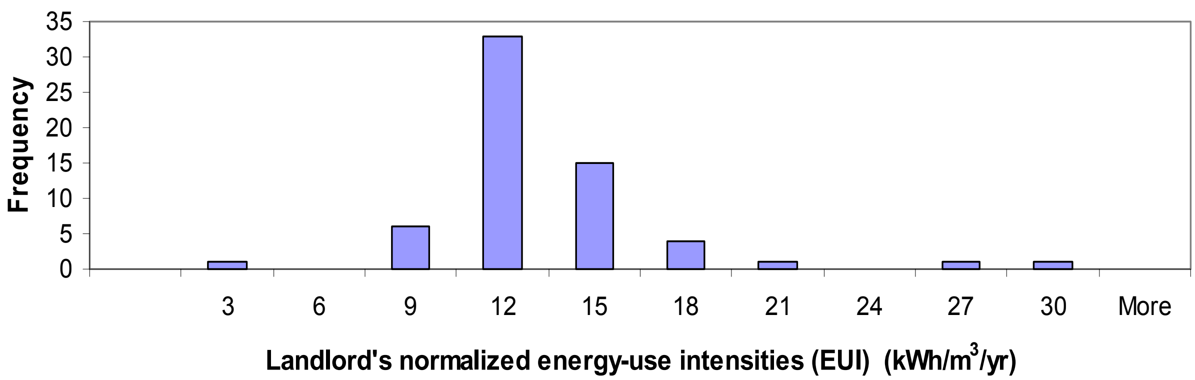
Model 3, hence multicollinearity exists. As such, Model 1 and Model 2 are deemed to be the only valid regression models. Since the inclusion of number of lifts as an energy explanatory indicator only improves the adjusted R^2 by a mere 2%, it can be concluded that the volume of landlord's area alone is sufficient to explain 85% of the variability in energy performance of flatted factory buildings. Hence, it suffices to use volume of landlord's area as the sole normalization factor.

Distribution of Energy Efficiency

A simple approach often used to benchmark building energy use is to compare to the average energy performance of a group of similar buildings. The possibility of benchmarking an individual building against an average was investigated as shown in Figure 2. Figure 2 shows a frequency distribution for the landlord's normalized energy-use intensities (EUI) of flatted factories, with a very slight right skew to normal distribution. The mean value and median value is 11.71 kWh/m^3/year and 11.10 kWh/m^3/year. The skewness value of 0.68 indicates the closeness of the symmetry bell shape distribution. It follows that approximately 50% of the buildings studied have normalized EUI below the mean value of 11.71 kWh/m^3/year.

Benchmarking normalized EUI to an average would likely lead the owner to no action in most cases as excessive EUI are not apparent. Since the results in Figure 2 show that the EUI and hence the various probability functions of the samples can be described using normal distribution function, the cumulative percentile curve should therefore be plotted as it offers improved benchmarking over averages.

Figure 2. Frequency Distribution of Landlord's Normalized Energy-Use Intensities (EUI) of Flatted Factories



Benchmarking of Flatted Factory Buildings in Singapore

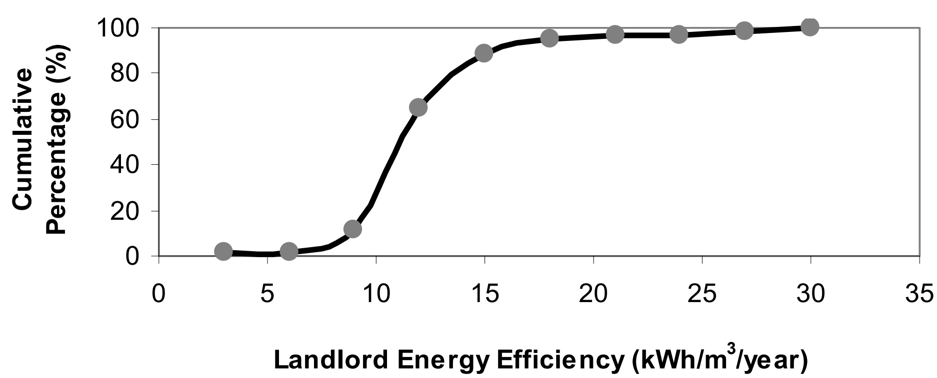
The results in the earlier section showed that the energy consumptions of flatted factory buildings are directly proportionate to the volume of landlord's area. The high correlation coefficient of 0.85 indicates that the volume of landlord's area alone can predict or estimate the energy consumption of a building to a good degree of accuracy with the exception of a small percentage of buildings. These results have been translated into a cumulative percentile distribution curve as shown in Figure 3. From the cumulative distribution curve, the facility manager of the factory is able to determine the energy performance of his factory building in terms of percentile position based on the normalized energy-use intensities (EUI) of his own factory building. This is a benchmark measure of a flatted factory building versus the energy performance of the cohort of 62 flatted factory buildings captured in this study.

It can be observed from the energy performance ranking for landlord is rather sensitive to minor increment. 70% of the buildings studied have normalized EUI of between 10 and 15 kWh/m^3/year. This is relatively competitive.

Hence Figure 3 presents a useful data set for office buildings in Singapore where property manager can benchmark and target energy performance of his factory building. Designers too can use this as a benchmark when they are designing new office buildings in Singapore. It is now possible for industrial landlord to identify and set realistic targets for the consultants to achieve, and in doing so ensure that his factory building stays within the top leagues of the industry. Factory building managers of existing buildings can determine where the current performance level of his factory building is and set realistic target to enhance energy efficiency. He can estimate the amount of savings possible and hence justify the amount of funding to achieve the target.

On the whole, the normalized energy-use intensities (EUI) calculated based on the volume of landlord's area of flatted factory in Singapore is generally on the low side as compared with the benchmarking metrics established by Royal Institution of Chartered Surveyors (RICS) in 1993 which ranges from 29 to 38 kWh/m^3/year. However, it should not be concluded that factories in Singapore are comparatively more energy efficient as details on the sampled factories in the UK is not known. For example, climatic differences have not been taken into account so it is unfair to compare benchmarks developed for the tropical and temperate regions. Also, it is likely that the factories in the temperate regions have either heating or cooling systems which may indirectly attribute to a higher normalized EUI. Furthermore, this energy benchmark for the factories in UK was developed more than a decade ago, thus it cannot be assumed that the figures are representative of the factories today.

Figure 3. Cumulative Percentile Distribution Curve of Flatted Factories Normalized Energy-Use Intensities (EUI)



The detailed consumption variations among the flatted factories are being investigated under three grouping in terms of building energy consumption. The three different groups of buildings are those with normalized EUI falling within the top 25 percentile, between 26 and 75 percentile, and those above the 75 percentile.

Conclusion

Most distributions of normalized energy-use intensities (EUI) for buildings are skewed. As a result, using the average performance of a group as an energy benchmark is often a poor energy performance indicator. Cumulative distributional energy benchmarking appears to be better approximations, serving as an effective preliminary benchmarking tool for owners and managers until the accuracy is confirmed. The energy benchmark curve developed for flatted factory buildings can aid industrial landlord to prioritize buildings for improvements, assessing energy savings potential in flatted factory buildings targeted for retrofitting work. This benchmark also helps to establish an acceptable energy performance for new flatted factory buildings. Currently, more work in this area is being done to target at improving energy benchmarks for flatted factory buildings beyond simplified cumulative distributions. Regression modeling can be performed to relate normalized EUI to the important secondary energy indicators flatted factory buildings. To do this, more data on the factory building characteristics are being collected. The results can then be used to develop a spreadsheet-based, energy-benchmarking tool for flatted factory buildings that is more accurate than comparisons to average normalized EUI and simple EUI cumulative distributions.

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