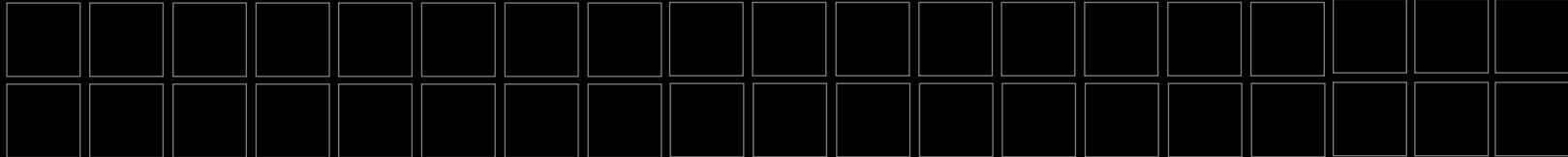
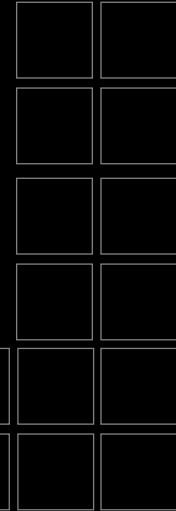




EC-ASEAN Energy Facility (EAEF)

Projects 64 and 68 Commencement Meeting



Methodology of Building Energy Performance Benchmarking



Presentation Outline

1. Review of Benchmarking Practices

2. Benchmarking Procedure

3. Key Elements of Benchmark Development

- Sampling
- Terminology and Data Collection Forms
- Investigating Parameters & Normalization Factors
- Data Collection
- Statistical Analysis
- Benchmarking Curve
- Web-based Benchmarking System

4. Done Work

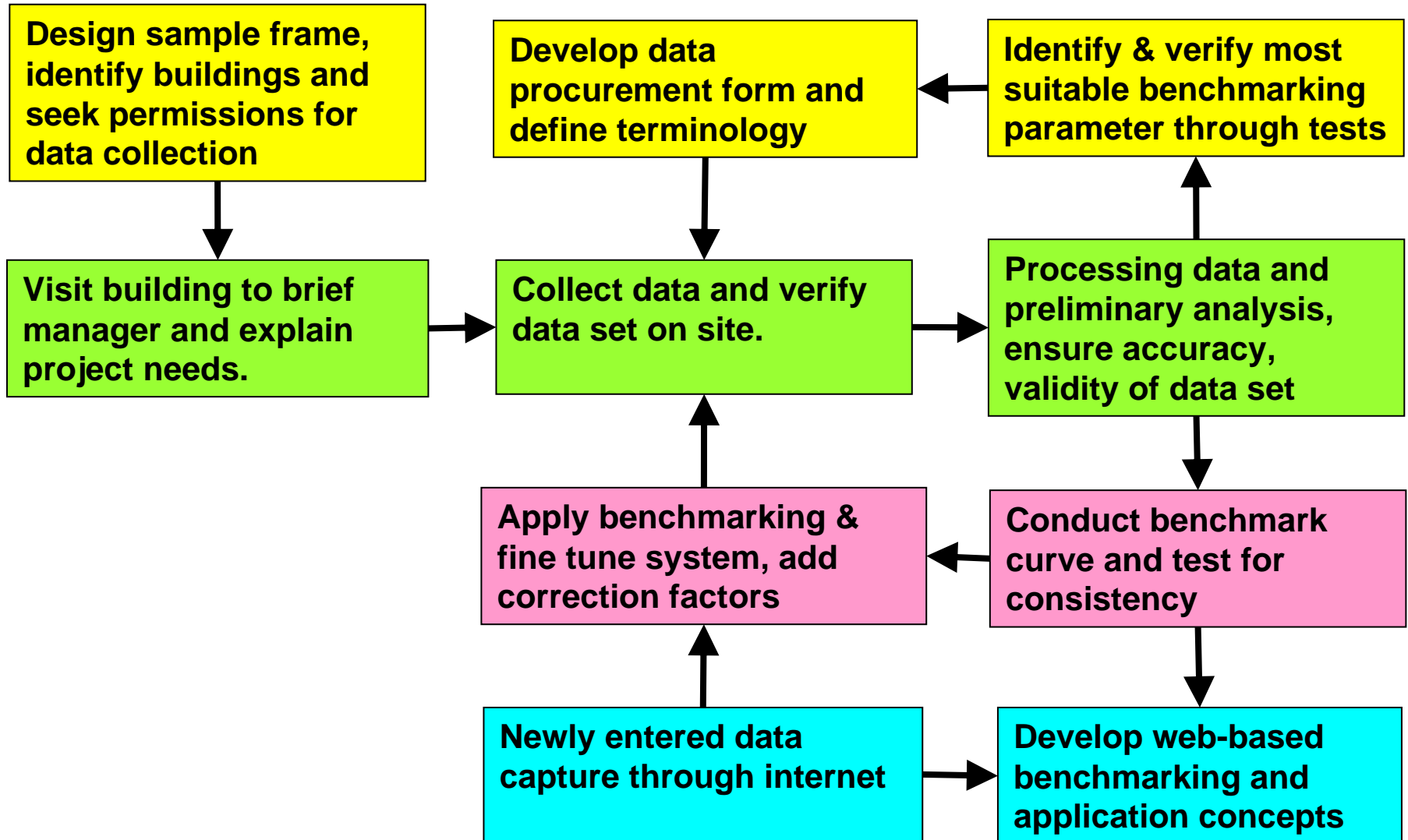


1. Review of Benchmarking Practices

Benchmarking has been demonstrated as an effective tool for energy efficiency improvement with diverse types of buildings and equipment.

- **For example, Energy-Star program operated by EPA in the US.**

2. Benchmarking Procedure





3. Key Elements of Benchmarking Development

3.1 Sampling

Identify population, sample size, sampling error

Proposed Building Types:

1. Commercial Office Building– Population: 410 buildings in Singapore; 400 Buildings in KL, Malaysia.
2. Hotel

Potential Candidates

- Data Centre; Sports Centre; Hospital; Institutional Buildings, and etc.



3. Key Elements of Benchmarking Development

3.1 Sampling

Identify population, sample size, sampling error

- Given sample error 5%, sample size for commercial office buildings is around 110 buildings in Singapore and 100 buildings in KL.

At 95% level of confidence

$$n = 3.84 (S/E)^2$$

Where: n– Sample size

S– Sample Standard Deviation: estimated as one-six of the range.

E– Error Factor: ± 10 kWh/m²/year



3. Key Elements of Benchmarking Development

3.2 Terminology and Data Collection Forms

- **The terms used must be defined and standardised for all members involved. These may include GFA, Total Energy Consumption, Landlord Energy Consumption, Tenants Energy Consumption, etc.**
- **A complete set of data collection forms will be compiled and agreed upon. These include Utility Data, General Building Information, Building Utilization and Occupancy Schedules, Various Systems Information, Building Control and Automation, etc.**



3. Key Elements of Benchmarking Development

3.2 Investigating Parameters and Normalization Factors

- **Based on the first data set collected and/or review of previous studies, investigation with all the key parameters will be conducted to determine the level of correlation.**
- **Deviation from correlation will be investigated to determine if correction factors are required for specific deviation in the main data set.**
- **Key Indicators: Energy Usage Indices (EUI) (e.g. kWh/m²/year), Cost Indices (e.g. \$/kWh), Power Load (W/m²), etc.**



3. Key Elements of Benchmarking Development

3.2 Investigating Parameters and Normalization Factors

Potential parameters:

- **GFA, ACA, Data Centre Area, Car-park Area, Building Volume, Building height, Envelope Surface Area, Ratio of envelope area to building volume, or other building geometrical features.**
- **Number of Occupants, Occupancy rate, Operating Hours, etc.**
- **Indoor Environmental and Outdoor Climatic Conditions**
- **Equivalent Primary Energy Use & Pollution**



3. Key Elements of Benchmarking Development

3.3 Data Collection

1. **Preliminary Data Collection— Utility Data, Building Geometrical Features, General Building Information, List of Equipment, Brief Description of Systems, etc.**
2. **Walk-Through— Review of the energy consumption profile; occupancy schedule, O&M practices, and future plans; learning of special problems or needs of the facility; familiar with the building's construction, equipment, O & M; confirm the floor plan; examine systems and their specifications; identify low-cost/no-cost energy and cost saving potentials/ measures; conduct spot measurements.**



3. Key Elements of Benchmarking Development

3.3 Data Collection

- 3. Detailed Data Collection— Detailed review on mechanical and electrical system design, specifications, installed condition, maintenance practices, and operating methods; Measure and/ or log on key parameters (e.g. energy use, power load, environments, operating hours, chill water temperatures, ventilation rate, supply and return air temperatures; Distribution of energy use; determine potential energy and cost saving measures.**



3. Key Elements of Benchmarking Development

3.4 Statistical Analysis (Outline)

A. Accuracy and Validity of Data Set

- Normality of Distribution Pattern

B. Correlation Analysis

- Simple Linear Regression
- Multi-Linear Regression
- Artificial Intelligence & Other Methods

C. Determination and Normalization of building energy performance indicators



3. Key Elements of Benchmarking Development

3.4 Statistical Analysis

A. Accuracy and Validity of Data Set

- **The ready set of checked data from building owners will be subject to elaborate statistical tests to ensure that the data set in normal distribution, representative of the population of data.**



3. Key Elements of Benchmarking Development

3.4 Statistical Analysis

A.1 Normality of Distribution Pattern

- **Approach I– The normality testing is evaluated by constructing the frequency distribution of the data, and plotting histogram distribution pattern. The descriptive summary (i.e. mean, median, standard deviation, etc) is computed and compared with the theoretical and practical properties of normal distribution.**



Key Elements of Benchmarking Development

3.4 Statistical Analysis

A.2 Normality of Distribution Pattern

- **Approach II– Normal probability plot, which is two dimensional plot of the observed data values on the vertical axis with their corresponding quantile values from a standard normal distribution (Z-value) on the horizontal axis. If the plotted points lie either on or close to an imaginary straight line arising from lower left corner to the upper right corner of the graph, the data set is approximately normally distributed.**



Key Elements of Benchmarking Development

3.4 Statistical Analysis

B. Correlation Analysis

- To determine independent and significant variables of building energy performance.
- To establish predictable models for building energy consumption, efficiency and cost. Hence, the energy and cost savings can be predicted/ estimated.



Key Elements of Benchmarking Development

3.4 Statistical Analysis

B. Correlation Analysis

- **Simple Linear Regression**

$$TBEC = \beta_0 + \beta_1 GFA$$

Where:

TBEC– Total Building Energy Consumption (kWh/Year)

GFA– Gross Floor Area (M²)



Key Elements of Benchmarking Development

3.4 Statistical Analysis

B. Correlation Analysis

- **Multi- Linear Regression**

$$TBEC = \beta_0 + \beta_1 GFA + \beta_2 OH + \beta_3 OC$$

Where:

TBEC– Total Building Energy Consumption (kWh/Year)

GFA– Gross Floor Area (M²)

OH– Operating Hour

OC– Occupancy Rate



Key Elements of Benchmarking Development

3.4 Statistical Analysis

B. Correlation Analysis

- **Artificial Intelligence & Others Methods**

For example: Neuro-Fuzzy Network, Dynamic Modeling, Nonlinear Regression, etc.

Targets: nonlinear and/ or complex relationships.



3. Key Elements of Benchmarking Development

3.5 Benchmarking Curves

- **Cumulative Percentile Curve (Ogive Curve) for the normalized key indicators, for example kWh/m²/year, which allows benchmarking the energy consumption and efficiency of buildings, with various building size, occupancy rate, operating hours, and etc.**
- **Levels of Benchmarking: Whole Building Level & System Level**
- **The benchmarking curve first developed with be subject to real world test by keying in specific data to validate expected outcomes.**



3. Key Elements of Benchmarking Development

3.6 Web-based Benchmarking System

- Discuss with web page designer and system providers to create an application concept for web-based benchmarking.
- Report generation, security, presentation, explanatory notes and tutorial, data verification and collection through the web will all be discussed and integrated into one system.
- The success of the system relies on the accuracy and integrity of benchmarking database, results of the correlation analysis, which identifies significant parameters, and the predicting models.



4. Done Work

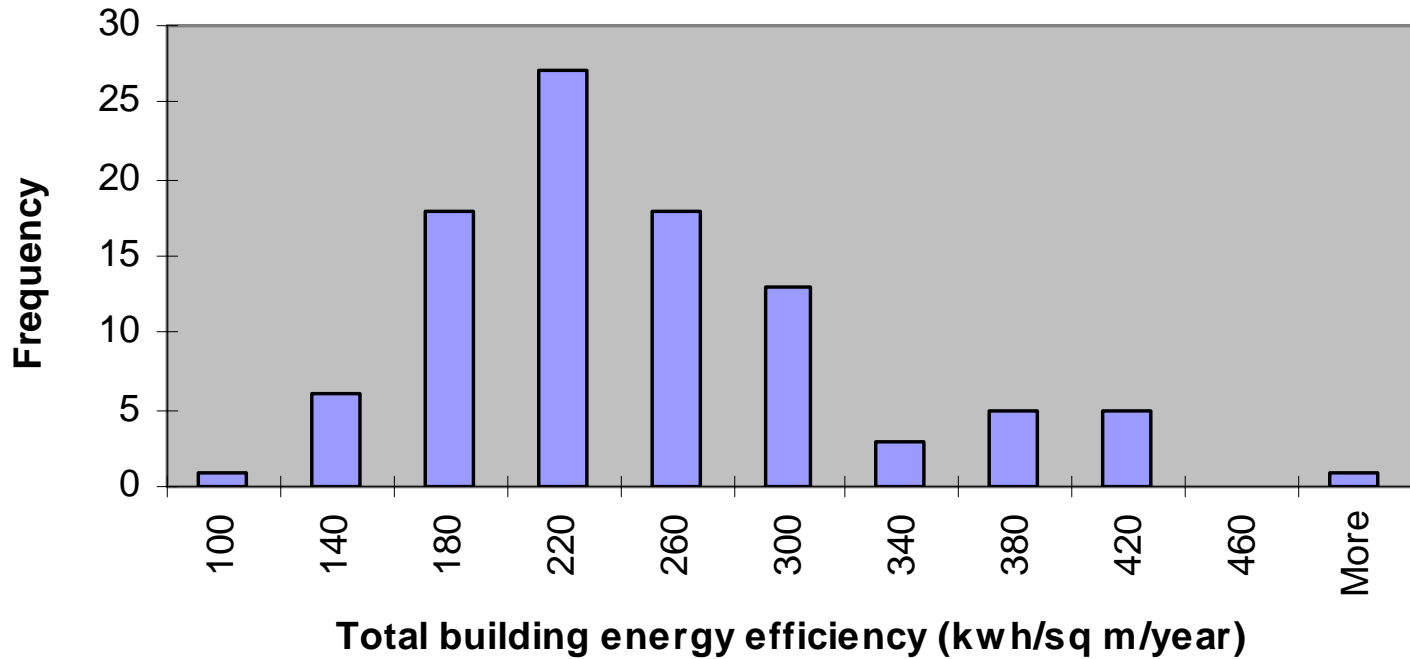
Project I– 104 commercial office buildings' whole building level energy performance benchmark (2002)

Project II– 16 commercial office buildings' system level energy performance benchmark (2003)

Project III– 6 Data centres' system level energy performance benchmark (2004)

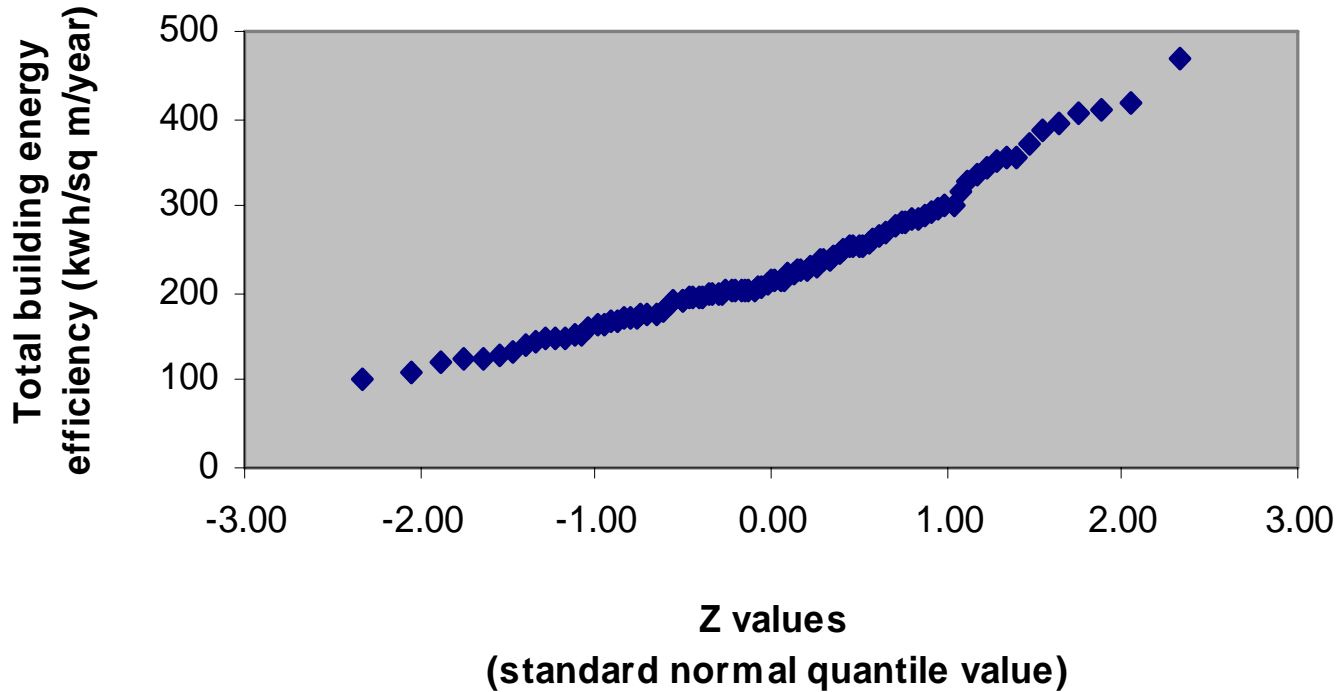
Project IV– 6 Hotels' whole building level energy performance benchmark (2003)

Normal distribution pattern of total building energy efficiency of office building in Singapore



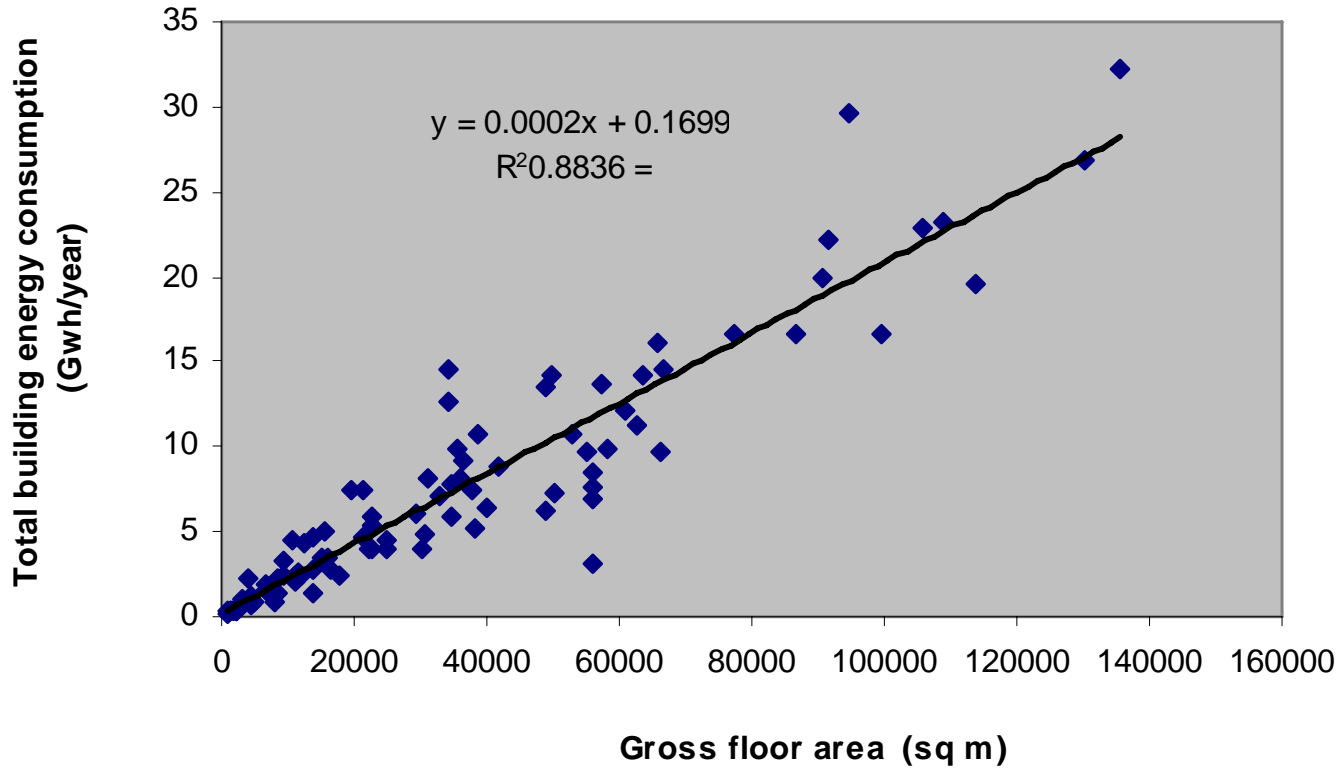
104 commercial office buildings' energy performance benchmark (2002)

**Normal probability plot for the total building energy efficiency of the office building in Singapore
(Right -Skewed Distribution)**



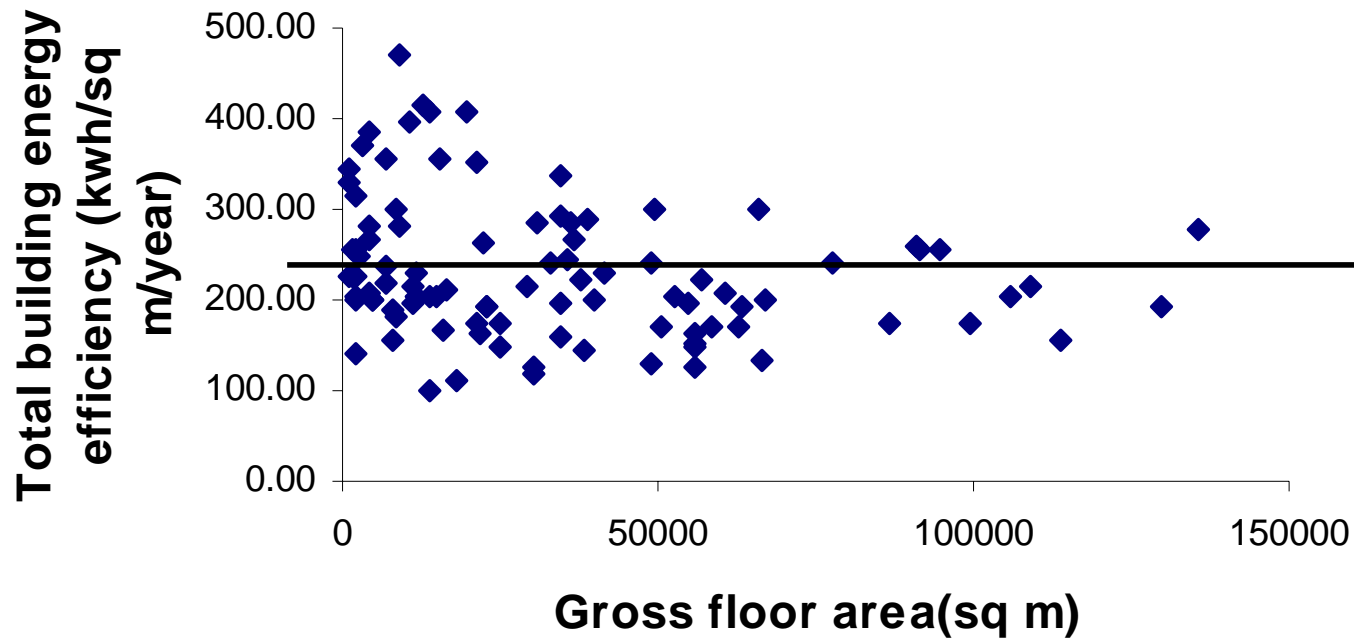
104 commercial office buildings' energy performance benchmark (2002)

The relationship of total building energy consumption versus gross floor area



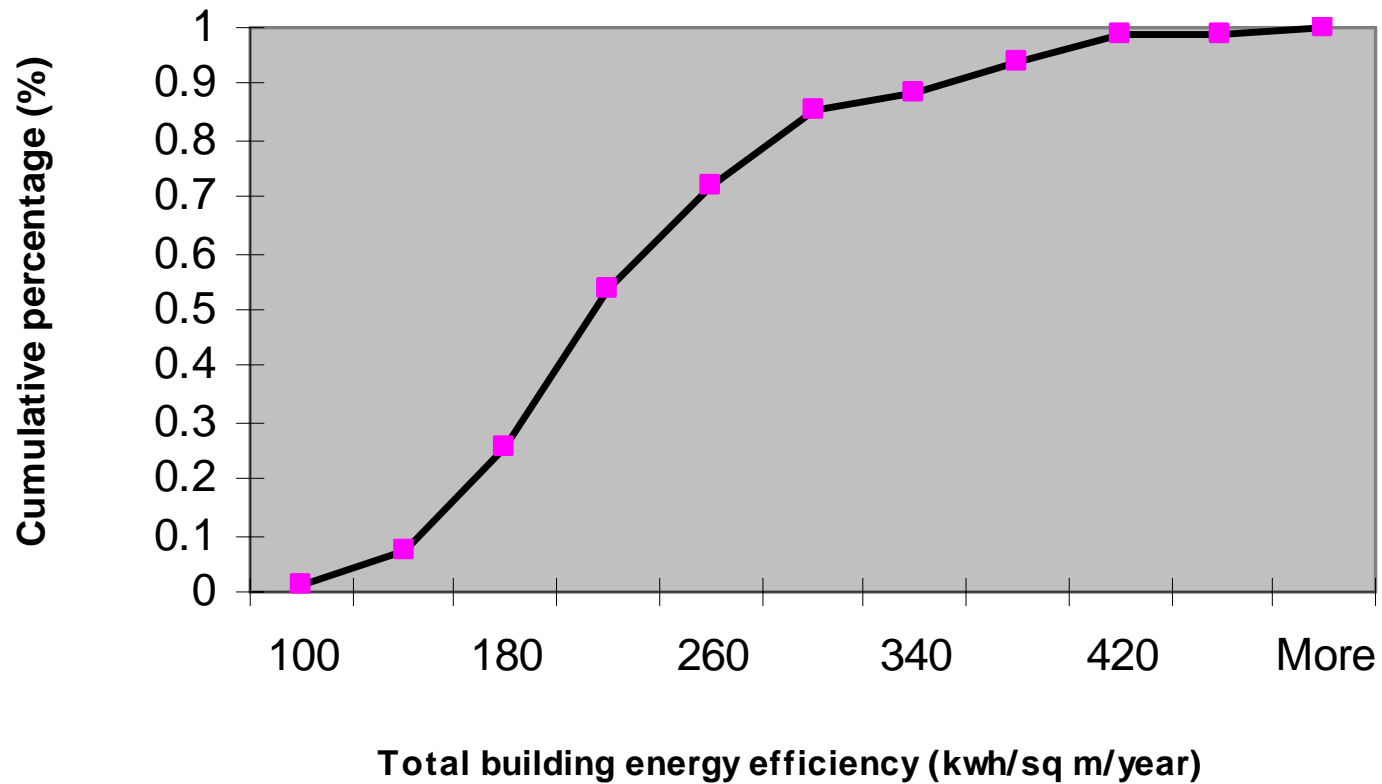
104 commercial office buildings' energy performance benchmark (2002)

Total building energy efficiency versus gross floor area for office building in Singapore



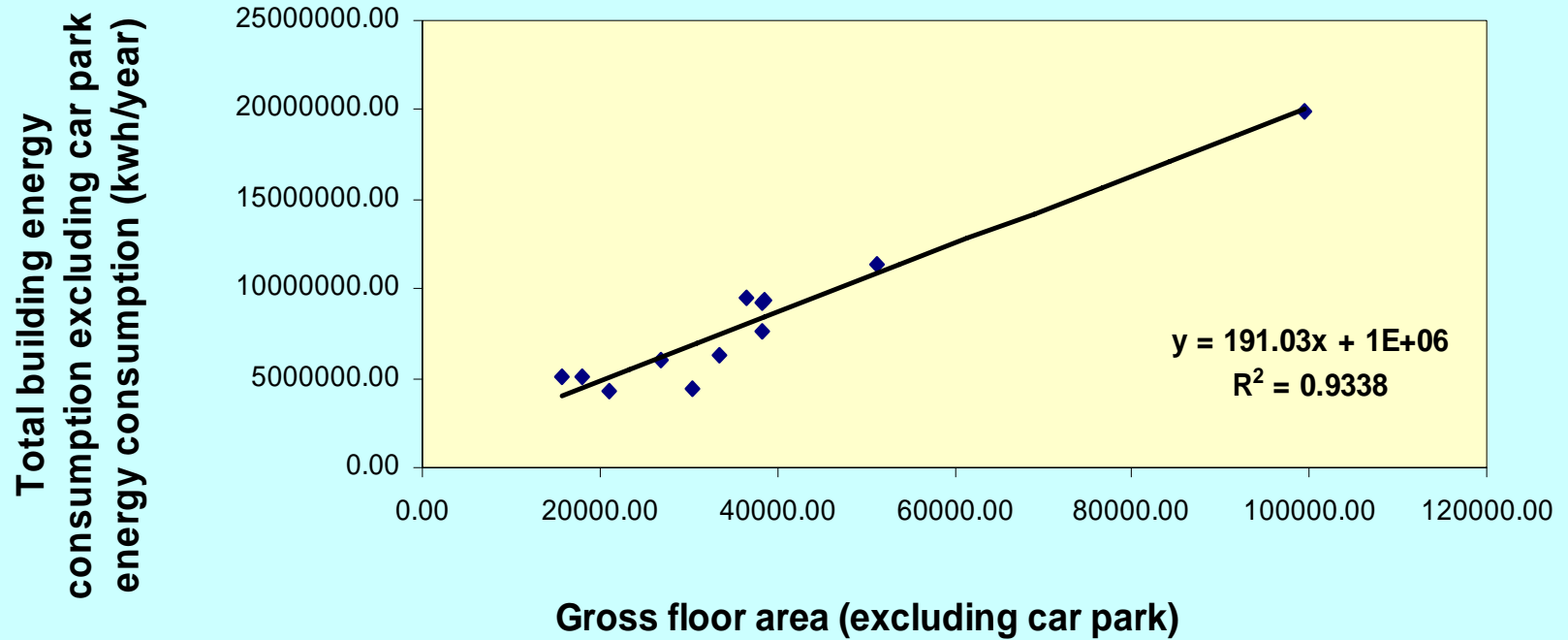
104 commercial office buildings' energy performance benchmark (2002)

Ogive curve of total building energy efficiency of office building in Singapore



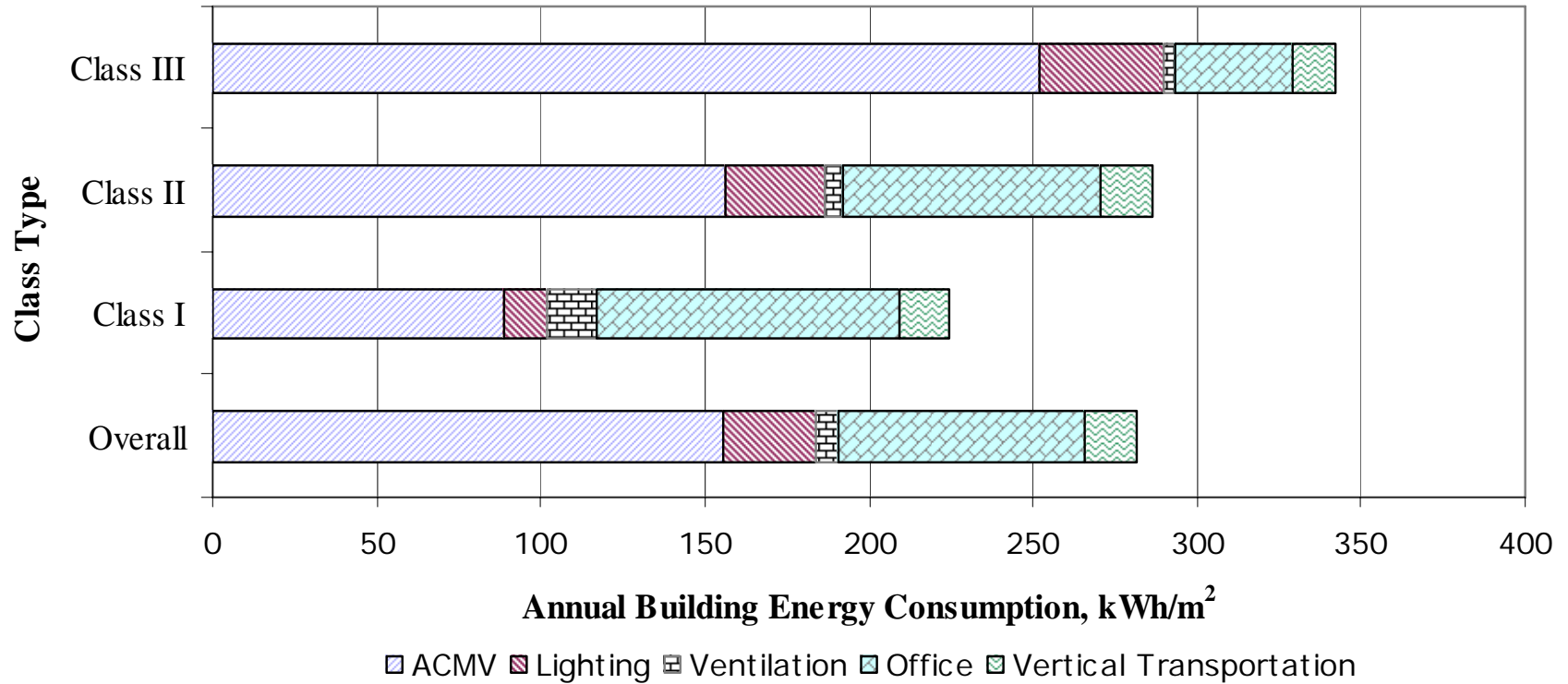
104 commercial office buildings' energy performance benchmark (2002)

Total building energy consumption (excluding car park) versus gross floor area excluding car park



16 commercial office buildings' energy performance benchmark (2003)

Typical Building Energy Benchmark Chart



16 commercial office buildings' energy performance benchmark (2003)



Statement

- This document has been produced with the financial assistance of the European Union. The contents of this document are the sole responsibility of Energy Sustainability Unit (Centre for Total Building Performance) and can under no circumstances be regarded as reflecting the position of the European Union.***



EAEF Project 64 & 68's Commencement Meeting



Thank you