Building and Construction Authority

ENERGY EFFICIENCY IN BUILDING DESIGN

Programme

18th April 2001

08:15 am	Registration
08:45 am	Guests and participants to be seated
09:00 am	**Opening Address by Guest-Of-Honour** *Assoc Prof Koo Tsai Kee* *Senior Parliamentary Secretary* *Ministry Of National Development*
09:15 am	**Enhancing the Energy Standard** *by Mr Thomas Goh* *Building & Construction Authority (BCA)*
09:45 am	**Building Energy STandards ("BEST" Software)** *by Assoc Prof Chou Siaw Kiang* *National University of Singapore (NUS)*
10:15 am	Refreshments
10:45 am	**Energy Audit for Building** *by Assoc Prof Raymond Wong* *Nanyang Technological University (NTU)*
11:15 am	**Energy Efficiency of Office Buildings in Singapore** *by Assoc Prof Lee Siew Eang* *National University of Singapore (NUS)*
11:45 am	**Q & A Session** *Panel of speakers from: BCA, NUS and NTU*
12:30 pm	Lunch at Orchard Hotel Ballroom 3

ENERGY EFFICIENCY IN BUILDING DESIGN

Seminar Information

18th April 2001

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⌘⌘⌘ ***Thank you for your kind co-operation*** ⌘⌘⌘

ENERGY EFFICIENCY IN BUILDING DESIGN

Enhancing the Energy Standard

Presented by

Mr Thomas Goh
Unit Head, Energy Efficiency Section
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BCA SEMINAR ON ENERGY EFFICIENCY IN BUILDING DESIGN 18 APRIL 2001

ENHANCING THE ENERGY STANDARDS

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SYNOPSIS

The [1]Building and Construction Authority or BCA has been actively involved in energy conservation in buildings. In September 1979, a set of prescriptive energy standards was incorporated in the Building Control Regulations. The most prominent standard is the maximum Overall Thermal Transfer Value (OTTV) of 45 W/m^2 prescribed for air-conditioned building envelope. To keep abreast with advances in technology and global trend these standards were regularly reviewed. As a result of the review, it was found that OTTV does not reflect closely the thermal performance of a building. A more accurate formulation was obtained. The new formulation is known as the Envelope Thermal Transfer Value (ETTV). To improve the thermal performance of building envelope, it is also proposed to enhance the OTTV of 45 W/m^2 to 35 W/m^2. Feedback on ETTV and the enhancement from 45 W/m^2 to 35 W/m^2 was sought from the various parties in the building industry. Public comment was also invited through news release and the BCA website.

Implement
end 2001 / early 2002.

[1] BCA was established on 1 April 1999 as a result of the merger between the Construction Industry Development Board (CIDB) and the Building Control Division of the Public Works Department (PWD).

INTRODUCTION

BCA has been actively involved in energy conservation in buildings since the energy crisis in the 1970s. The former Building Control Division chaired a committee on energy conservation to spearhead a 2-year research project with the participation of various professional bodies, universities, statutory boards and some other government departments. The recommendations of the committee were incorporated in the Building Control (Space, Light and Ventilation) Regulations gazetted in August 1979. Since then the energy standards have been reviewed to take into consideration advances in building technology and improvement in energy efficiency of building services.

CURRENT ENERGY STANDARDS

Compliance with the energy standards are required during the building plans submission stage. Building designs that do not meet the required standards would not have their building plans approved. This is to ensure that buildings are designed to an acceptable level of energy efficiency. The Certificate of Statutory Completion for the building is issued after the works have been completed in accordance with the approved plans.

Before 1st July 2000

Building plans that were submitted to BCA for approval before 1st July 2000 were required to comply with the following energy standards:

a. Building envelope OTTV of air-conditioned building

The OTTV for the gross area of exterior walls shall not exceed 45 W/m^2.

b. Roof OTTV of air-conditioned building

Where the roof is provided with skylights or any other material, which allows the passage of light through, the OTTV for the gross area of the roof shall not exceed 45 W/m^2.

c. Maximum thermal transmittance for roof of air-conditioned building

For any other type of roof not mentioned in (b) above, the average thermal transmittance for the gross area of the roof shall not exceed the prescribed limits shown in the table 1 below.

Table 1

Weight Group	Weight Range (kg/m^2)	Max. Thermal Transmittance ($W.m^2$ °K)
Light	Under 50	0.5
Medium	50 to 230	0.8
Heavy	Over 230	1.2

d. Maximum lighting load density

The lighting load density shall comply with the limit specified in the Handbook on Energy Conservation in Buildings and Building Services.

e. Zoning for temperature control

(1) At least one thermostat for the regulation of space temperature shall be provided for each separate air handling system and zone.

(2) Each air handling system shall be equipped with a readily accessible means of shutting off or reducing the energy used for the air-conditioning system during periods of non-use or alternative uses of building spaces or zones served by the system.

(3) For the purpose of meeting the requirements of paragraph (2), the following devices shall be regarded as satisfactory:

(a) manually adjustable automatic timing devices;

(b) manual devices for use by operating personnel; or

(c) automatic control systems.

f. Air-conditioning or mechanical ventilation system.

The design and installation of —

(a) any air-conditioning or mechanical ventilation system; or

(b) the alteration or extension of any existing air-conditioning or mechanical ventilation system,

shall be in accordance with the provisions of the regulations and with the Code of Practice for Mechanical Ventilation and Air-Conditioning in Buildings - SS CP 13.

g. Energy Auditing.

All buildings used or intended to be used as offices, a hotel or shop or a combination thereof shall be provided with data logging facilities for the collection of data for energy auditing.

From 1st July 2000 Onwards

Several code of practices were recently revised by the Singapore Productivity and Standards Board and launched in Feb 2000. The revision affected some of the energy standards under BCA's purview. Since the industry would need sufficient time to be familiar with the revised codes only building plans submitted to BCA for approval from 1 July 2000 onwards are required to comply with the revised energy standards. Those standards that are not affected by the revision would continue to be applicable. The revised energy standards are:

a. SS CP 13:1999

CP 13:1999 was extensively revised. The revision includes indoor air quality guidelines from the Ministry of the Environment, energy conservation guidelines from BCA's 'Handbook on Energy Conservation in Buildings and Building Services' and fire safety requirements from FSB's 'Fire Precaution in Buildings.' However, only specific sections of CP 13 are under the

purview of the BCA. They are enumerated below and supersede the technical requirements in Division 9 of the Building Control Regulations.

i Section 5 - Ventilation rates (cl 5.1 to 5.3)
ii Section 6 - Mechanical ventilation systems (cl 6.1 to 6.3 excluding fire safety related sub-clauses)
iii Section 7 - Air-conditioning design (cl 7.1 to 7.9 excluding fire safety related sub-clauses)

b. SS CP 24:1999

The revised CP 24:1999 sets the minimum energy efficiency standards for four major energy consuming equipment and system, viz. air-conditioning equipment, water heaters, electric motors and artificial lighting system. However, only the lighting power budget section of CP 24 is implemented.

c. SS CP 38:1999

For artificial lighting, the design illuminance shall be in accordance with the Code of Practice for Artificial Lighting in Buildings - SS CP 38:1999.

ENHANCEMENT OF ENERGY STANDARDS

In collaboration with the two local universities, BCA has reviewed the energy efficiency regulations. The energy standards to be enhanced includes the following:

a The ETTV Formulation

OTTV is a measure of the average heat gain into a building through its envelope. It is measured in W/m^2. An air-conditioned building with a higher OTTV will impose a greater load on the air-conditioning system, which would have to expend more electrical energy in removing it. The Building Control Regulations stipulate that all air-conditioned buildings must be designed to have an OTTV of not more than 45 W/m^2. This is aimed at achieving adequately designed building envelopes to cut down external heat gains and hence reduce the cooling load of air-conditioning systems.

. The OTTV concept takes into consideration three basic elements of heat gain through the external walls and windows of a building. These are:

- heat conduction through opaque walls;
- heat conduction through glass windows;
- solar radiation through glass windows.

These three elements of heat gain constitute the OTTV formulation as follows:

$OTTV = TD_{eq} \times (1-WWR) \times U_w + \Delta T \times WWR \times U_f + SF \times CF \times WWR \times SC$ where

WWR : window-to-wall ratio

U_w : thermal transmittance of opaque wall (W/Km^2)

U_f : thermal transmittance of fenestration (W/Km^2)
TD_{eq} : equivalent temperature difference (K)
ΔT : temperature difference (K)
SF : solar factor (W/m^2)
CF : correction factor for solar heat gain through fenestration
SC : shading coefficients of fenestration

The various weather-dependent factors in the OTTV formulation, such as SF, TD_{eq} and ΔT, were derived from isolated solar and temperature measurements carried out in the late 70's at the National University of Singapore and the meteorological stations. As the weather data were incomplete, the factors derived from them also inherited certain degree of inaccuracy.

Research done since 1985 using computer simulation and a complete set of weather data revealed that the present OTTV does not correlate well with the cooling energy required to remove the heat load. Furthermore, it was found that the existing OTTV formulation does not properly account for the relative contributions of the three elements of heat gain through the envelope. Since then, much research had been performed at the National University of Singapore to obtain a more accurate formulation for OTTV that correlates closely with the cooling energy imposed on air-conditioning systems. To differentiate the new formulation from the original OTTV formulation, the term 'Envelope Thermal Transfer Value' (ETTV) has been given to the new formulation.

The new ETTV formulation is basically a modified version of the original OTTV formulation. Details of the formulation are given in Appendix A. The various weather-dependent factors in the new formulation are determined through vigorous computer simulations, which provide an accurate account of the three elements of heat gain through the envelope. Thus, the ETTV formulation is better able to reflect the total heat gain through a building envelope under local weather conditions.

Computer simulations have been performed to compare the correlation of OTTV and ETTV with the total heat gain through the building envelope. The results are as follows:

Table 2: OTTV and Heat Gain Correlation

Cases	Annual total gain through envelope (x 10^3 kwh)	% increase in total gain through envelope
Reference case	273.1	-
10 % increase in OTTV	314.5	15.2
15 % increase in OTTV	328.7	20.4
25 % increase in OTTV	366.1	34.1
35 % increase in OTTV	408.4	49.5

Table 3: ETTV and Heat Gain Correlation

Cases	Annual total gain through envelope (x 10^3 kwh)	% increase in total gain through envelope
Reference case	273.1	-
10 % increase in ETTV	298.9	9.4
15 % increase in ETTV	313.5	14.8
25 % increase in ETTV	339.2	24.2
35 % increase in ETTV	366.9	34.3

Table 2 shows that an increase in OTTV results in a much higher increase in heat gain in terms of percentage. On the other hand, Table 3 shows that the percentage increase in the total heat gain through the building envelope is almost equal to the percentage increase in ETTV. Hence, ETTV correlates much better than OTTV with the total heat gain through the envelope.

b The ETTV Equivalent of 45W/m^2 in OTTV

The key difference between the ETTV formulation and the OTTV formulation lies in the magnitude of the Solar Factor (SF) which determines the amount of radiation gain through the windows. The SF used in the OTTV formulation is 130W/m^2 while the SF for ETTV is given as 210 W/m^2. Hence, the ETTV of a building will be higher than its OTTV. For a reference building model that meets the current OTTV requirement of 45 W/m^2, its ETTV works out to be approximately 65 W/m^2.

c Roof Thermal Transfer Value (RTTV)

Based on the same approach used in formulating ETTV, a new Roof Thermal Transfer Value (RTTV) formulation has also been developed. Please refer to Appendix B for the new RTTV formulation.

d Enhancing Thermal Performance of Building Envelope

In the ETTV formulation, the two most critical factors are the Window-to-Wall Ratio (WWR) and the Shading Coefficient of glass (SC). WWR represents the relative size of the windows and usually varies within a narrow range of 0.3 to 0.6 for practical design consideration. On the other hand, SC is a function of glass technology and can vary over a wide range depending on the type of glass used.

The current standard of 65W/m^2 for ETTV (45W/m^2 for OTTV) was derived from a model building with a WWR of 0.33, which was glazed with glass having a SC of 0.6. (*A SC of 0.6 was considered to be optimum for the range of 'non-reflective glass' available in the late 70's.*) Therefore, for consistency and ease of comparison, a review of the ETTV standard would have to be based on the same model building using the latest technical information available from the glass industry as reference.

A parametric study was carried out for a range of WWR from 0.3 to 0.7 and SC from 0.2 to 0.6 to determine the corresponding ETTV of the model building. The result of this study is presented in Appendix C.

For the same reference WWR of 0.33 as used in the 1979 standard, Appendix C shows that the ETTV could vary from a low of 35W/m^2 to a high of 65W/m^2 corresponding to the range of SC from 0.2 to 0.6. The new ETTV standard is thus confined to this range of value. A low value for the new ETTV standard would mean fewer choices of glass types for use in building design. On the other hand, a high value would have marginal improvement on energy efficiency.

Architects and developers are naturally concerned about the impact of an enhanced ETTV on design choices and construction costs. Hence, the new ETTV standard would be set at the mid-point (50W/m^2) between the lower bound (35W/m^2) and the upper bound (65W/m^2) of the range. Appendix C shows that an ETTV of 50W/m^2 corresponds to a SC of 0.4. (*For the same model building, an ETTV of 50W/m^2 is equivalent to an OTTV of 35W/m^2.*)

A literature survey based on some glass catalogues has indicated that glass with SC of 0.4 or better is available readily and at reasonable cost. A random survey done on several existing and recently completed government and private buildings has shown that 18 out of 25 buildings complied with the proposed enhanced OTTV standard. Recently completed buildings like the SIA Building, PWC Building, The URA Centre and Tuas Checkpoint achieved an OTTV standard below 30 W/m^2. Please see Appendix D.

e. Introduction of the system analysis approach

The existing prescriptive standard is inflexible in that it requires all the systems to comply with the minimum requirements. The proposed system analysis approach offers much greater flexibility. In this method, the designed building is compared to a prototype building, which is modelled using the existing prescriptive standards. If the total energy consumption of the designed building is lower than that of the prototype, then compliance is achieved. It allows certain system to exceed the minimum requirements on condition that energy performance for the other systems in the building is improved to compensate for the non-compliance of the specific systems. The proposed system analysis approach is based on the energy budget method of ASHRAE/IES Standard 90.1 on energy efficient design of new buildings.

A computer programme, Building Energy STandard (BEST), has been developed by NUS in collaboration with BCA to facilitate the implementation of the energy budget method. BEST is one of the recognised software for demonstrating compliance under the system analysis approach.

f. Efficiency of Air-Conditioning Equipment

With energy efficient equipment readily available, the coefficient of performance of air-conditioning equipment shall comply with the minimum performance rating in accordance with the relevant provisions of the Code of Practice for Energy Efficiency Standard for Building Services and Equipment - SS CP 24:1999.

IMPLEMENTATION OF THE ENHANCED STANDARDS

Feedback on ETTV and the enhancement from 45 W/m^2 to 35 W/m^2 was sought from the Singapore Institute of Architects, Institution of Engineers Singapore, Association of Consulting Engineers Singapore and Real Estate Developer's Association of Singapore. Through news release and the BCA website the public was also invited to comment on the enhancement. No substantive comment was received.

BCA is planning for a trial implementation of the revised standards. After the trial implementation, the results would be reviewed before the new standards are legislated.

CONCLUSION

ETTV gives a more accurate correlation with the total heat gain through a building envelope and, hence, is a more reliable indicator for energy efficiency. It would replace the current OTTV formulation for envelope. Similarly, the OTTV formulation for roof would also be replaced with the new RTTV formulation. To enhance the thermal performance of the building envelope, a thermal transfer value of 50 W/m^2 would be the new ETTV and RTTV standard. The system analysis approach allows for flexibility in design without compromising energy efficiency while the requirement on energy efficient equipment is introduced to ensure that only energy efficient equipment are used.

When compared to the old standards, it is estimated that the new standards on OTTV, maximum lighting power budget and the efficiency of air-conditioning equipment could reduce electricity consumption by as much as 24%.

REFERENCES

1. Turiel, I., Curtis, R. B., and Levine, M. D., Energy 10,95 (1985)

2. Turiel, I., Curtis, R. B., and Levine, M. D. (1988). 'Analysis of overall thermal transfer value (OTTV) energy conservation standards for Singapore office buildings', *ASHRAE Trans.*, 90 (2B), 647-661.

3. Chou, S.K and Lee, Y.K. (1988). 'A simplified overall thermal transfer value equation for building envelope', Energy, the International Journal, 13(8), pp. 657-670.

4. Chou, S.K. and Chang, W.L. (1996). 'A generalised methodology for determining the total heat gain through building envelopes,' International Journal of Energy Research, Vol. 20, pp 887-901.

5. SS CP 13: 1999 Code of practice for mechanical ventilation and air-conditioning in buildings, PSB, 1999.

6. SS CP 24: 1999 Code of practice for energy efficiency standard for building services and equipment, PSB, 1999.

7. SS CP 38: 1999 Code of practice for artificial lighting in buildings, PSB, 1999.

8. Building Control Regulations (Cap 29, Rg 1)

Envelope Thermal Transfer Value (ETTV) Formula

The Envelope Thermal Transfer Value (ETTV) formula is given as:

$$ETTV = 11.9(1 - WWR)U_w + 3.37(WWR)U_f + 210.9(WWR)(CF)(SC)$$

where

ETTV : envelope thermal transfer value (W/m^2)
WWR : window-to-wall ratio
U_w : thermal transmittance of opaque wall (W/Km^2)
U_f : thermal transmittance of fenestration (W/Km^2)
CF : solar correction factor for fenestration*
SC : shading coefficients of fenestration

*Table: Solar Correction Factors (CF) for Walls

Pitch Angle	Orientation							
	N	NE	E	SE	S	SW	W	NW
70°	1.17	1.33	1.47	1.35	1.21	1.41	1.56	1.38
75°	1.07	1.23	1.37	1.25	1.11	1.32	1.47	1.28
80°	0.98	1.14	1.30	1.16	1.01	1.23	1.39	1.20
85°	0.89	1.05	1.21	1.07	0.92	1.14	1.31	1.11
90°	0.80	0.97	1.13	0.98	0.83	1.06	1.23	1.03
95°	0.73	0.90	1.05	0.91	0.76	0.99	1.15	0.96
100°	0.67	0.83	0.97	0.84	0.70	0.92	1.08	0.89
105°	0.62	0.77	0.90	0.78	0.65	0.86	1.01	0.83
110°	0.59	0.72	0.83	0.72	0.61	0.80	0.94	0.78
115°	0.57	0.67	0.77	0.67	0.58	0.75	0.87	0.73
120°	0.55	0.63	0.72	0.63	0.56	0.71	0.81	0.69

Roof Thermal Transfer Value (RTTV) Formula

The Roof Thermal Transfer Value (RTTV) formula is given as:

$$RTTV = 12.5(1-SKR)U_r + 4.8(SKR)U_s + 485(SKR)(CF)(SC)$$

where

RTTV : roof thermal transfer value (W/m^2)
SKR : skylight ratio of roof, (skylight area/gross area of roof)
U_r : thermal transmittance of opaque roof (W/Km^2)
U_s : thermal transmittance of skylight area (W/Km^2)
CF : solar correction factor for roof *
SC : shading coefficient of skylight portion of the roof.

*Table: Solar Correction Factors (CF) for Roof

Pitch Angle	Orientation							
	N	NE	E	SE	S	SW	W	NW
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10°	0.99	0.99	1.00	1.00	1.00	0.99	0.99	0.99
15°	0.98	0.98	0.99	0.99	0.99	0.98	0.98	0.98
20°	0.96	0.97	0.98	0.98	0.97	0.97	0.97	0.96
25°	0.93	0.95	0.96	0.96	0.95	0.95	0.95	0.94
30°	0.91	0.92	0.94	0.94	0.93	0.93	0.93	0.91
35°	0.88	0.90	0.92	0.91	0.90	0.90	0.90	0.89
40°	0.84	0.87	0.89	0.88	0.87	0.87	0.87	0.85
45°	0.8	0.83	0.86	0.85	0.83	0.84	0.84	0.82
50°	0.76	0.80	0.83	0.82	0.79	0.80	0.81	0.78
55°	0.72	0.76	0.80	0.78	0.75	0.76	0.78	0.75
60°	0.67	0.72	0.76	0.74	0.70	0.73	0.74	0.71
65°	0.63	0.68	0.73	0.70	0.66	0.69	0.71	0.67

ETTV for Different WWR and SC

SC / WWR	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
0.30	35.38	38.54	41.71	44.87	48.03	51.20	54.36	57.52	60.69
0.33	36.54	40.02	43.50	46.98	50.46	53.94	57.42	60.90	**64.38**
0.35	37.31	41.00	44.69	48.38	52.07	55.76	59.45	63.15	66.84
0.40	39.24	43.46	47.68	51.89	56.11	60.33	64.55	68.77	72.98
0.45	41.17	45.92	50.66	55.41	60.15	64.90	69.64	74.39	79.13
0.50	43.10	48.37	53.65	58.92	64.19	69.46	74.74	80.01	85.28
0.55	45.03	50.83	56.63	62.43	68.23	74.03	79.83	85.63	91.43
0.60	46.96	53.29	59.61	65.94	72.27	78.60	84.92	91.25	97.58
0.65	48.89	55.74	62.60	69.45	76.31	83.16	90.02	96.87	103.72
0.70	50.82	58.20	65.58	72.96	80.35	87.73	95.11	102.49	109.87

Appendix D

OTTV of Major Government and Private Buildings

S/No	Building Project	OTTV(W/m^2)
1	Changi Airport Terminal II Expansion (North Finger)	20.4
2	Changi Airport Terminal II Expansion (South Finger)	22.1
3	The Treasury	26.6
4	SIA Building at Robinson Rd	26.6
5	Tuas Checkpoint	28.2
6	Causeway Point	28.4
7	PWC Building	29.2
8	URA Building	29.3
9	Ngee Ann City	30.7
10	NTUC Income, Tampines Point	32.2
11	Immigration Building	32.8
12	Singapore Art Museum	33.8
13	Institute of Health Building	34.0
14	Compac Centre, Tampines Plaza	34.0
15	Changi Airport Terminal II	34.1
16	Revenue House	34.5
17	West Mall	34.7
18	MOE HQ	34.9
19	National Dental Centre Building	35.4
20	Keppel Tat Lee Bank Building at Market St	36.3
21	Civil Service College Building	36.4
22	Republic Plaza	38.8
23	ISEAS Building	37.9
24	National Development Building	39.9
25	KK Hospital	41.4

ENERGY EFFICIENCY IN BUILDING DESIGN

Building Energy STandards ("BEST" Software)

Presented by

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ENERGY EFFICIENCY IN BUILDING DESIGN

A SEMINAR ORGANISED BY THE BUILDING AND CONSTRUCTION AUTHORITY (BCA) OF SINGAPORE, 18 APRIL 2001

BUILDING ENERGY STANDARD (BEST)

-AN ENGINEERING TOOL FOR COMPLIANCE OF ENERGY PERFORMANCE STANDARDS

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SYNOPSIS

We highlight the importance of building energy simulation and describe its various applications aimed at achieving energy efficiency solutions. The advent of desktop computing has made it possible to perform detailed calculations and building energy performance simulation at low costs. With appropriate computerised engineering tools, professionals would be able to evaluate various energy saving options before deciding on implementation. In this presentation, we also describe and teach the use of a specially developed computer code for energy standards compliance and energy efficiency calculations.

INTRODUCTION

Large commercial buildings that require air conditioning all year round are energy-intensive. Air conditioning typically contributes more than half of the energy consumption of a commercial building. As the building sector accounts for more than one-third of the total electrical consumption in Singapore, it is imperative that today's buildings be designed for energy efficient operation throughout its lifetime. To achieve this, the response of a building to weather conditions and load changes need to be well understood. Conventional design methodologies are now being surpassed by computerised engineering tools that allow the performance of the building to be simulated long before its construction.

Meanwhile, building authorities worldwide have begun or completed the drafting of building performance standards taking advantage of the proliferation of personal computers and the rapid increase in computational power available to run sophisticated building simulation programs. Ensuring energy efficiency is important because it helps to reduce a nation's energy needs and leads to better utilization of existing energy resources. Concentrated efforts to reduce energy consumption will help to mitigate adverse impacts on our environment. Achieving energy efficiency also helps to reduce our dependence on fuel imports and improve our economic competitiveness.

It is to this end that the Building and Construction Authority (BCA) formulated the Building Energy Efficiency Master Plan (BEEMP) as part of Singapore's efforts to improve building energy efficiency. This plan contains programmes and measures dealing with energy efficiency that span the whole life cycle of a building. Today, the need to achieve higher energy efficiency and better building designs has spurred BCA to focus on an energy performance standard for buildings in Singapore. This is a substantial upgrade from standard criteria as specified in the Handbook on Energy Conservation in Buildings and Building Services [1].

Correspondingly, Building Energy Standards (BEST), a Windows based software has been developed by the National University of Singapore (NUS) in collaboration with BCA. It is designed to be used as an engineering tool for compliance with the building envelope, air-conditioning and mechanical ventilation systems and artificial lighting requirements as depicted in the BCA Approved Document as well as the overall energy performance criterion.

BUILDING ENERGY SIMULATION (BES)

The thermal interactions between a building and its environment are complex. To account for the complexities of the energy transfer processes occurring between the external environment and the building and among its various components and systems, building energy simulation (BES) is adopted as a standard technique. BES is a necessary routine employed to analyse the energy performance of a building as an integrated system. With BES, the possibility of a prediction of future reality at the

design stage can now be realised [2] and can lead to a more energy efficient building stock. While the more detailed BES tools remain mostly within the research community, the wide-spread availability of desk-top computing and global connectivity offered by the internet have contributed significantly to the application of BES in professional practice as design tools. Hong and others [3] provide valuable information on BES and the various engineering tools available to professionals.

BES involves the use of computer analysis techniques to determine the energy performance of a building and its systems. Besides offering an effective design decision support, building energy simulation can be applied in practice by designers with limited knowledge of technology [4]. Nowadays, BES is used in areas such as building design, operation, management and air-conditioning system design. Some applications of BES [3] are highlighted in the following sections:

1. Study of load profiles and energy usage patterns of building
2. Selection of building systems for better energy performance of building
3. Economic analysis
4. Calculation of energy budget of a building
5. Evaluation of energy saving options
6. Complying with building regulations, codes, and standards

BES can be employed to design the building to the requirements of local building regulations, codes, and standards. Subsequently, BES can supplement energy auditing to check the energy performance of the as built building.

ENERGY PERFORMANCE STANDARDS

There are currently many computerised BES codes available to professionals. As different BES codes vary in complexity, calculation algorithms, ease of use and cost, the codes have their advantages and disadvantages. The user's experience and computer literacy skills also play an important role in performing building energy simulation. It is foreseen that BES will be more frequently and widely applied in building design and analysis as it can be under-taken with greater ease and lower costs using personal computers.

The Department of Mechanical Engineering of the National University of Singapore has developed a window-based, BES code, BEST, specifically aimed at performing standard compliance calculations. BEST (synonym for Building Energy STandards) is a design tool that can be used by engineers, architects and building services professionals to meet the requirements of prescriptive and energy performance standards relating to air-conditioned commercial buildings. With this software, users are able to perform building energy calculations while designing an energy efficient building.

The energy performance standard calculations adopted in BEST require the user to specify two buildings, namely the design building and the prototype building. The

design building is the proposed building under study having the actual design specifications and operating conditions. This building may deviate from the prescriptive standards when its energy estimate is being determined. On the other hand, the prototype building has the same design, shape, size and usage of the proposed building, but meets all the requirements of the prescriptive standards. This building is used to establish an annual energy consumption budget for the building being designed. Figure 1 illustrates the compliance process for the prescriptive and energy performance standards incorporated in BEST.

The above methodology is in line with the Building Energy Cost Budget Method proposed by ASHRAE Standard 90.1 [5]. Using a simple yet accurate energy analysis procedure, the methodology, as illustrated in Figure 1, is to determine the annual energy demand and consumption of both the prototype building and the design building. Then, for the proposed design to comply with the energy performance standard, its annual energy consumption must be shown to be lower than that of the prototype building. This approach effectively allows professionals to innovate and achieve the standard with suitable trade-offs.

Among other possible trade-offs, of interest is the energy saving options made available by the energy performance standard. When considering retrofitting of the existing building or embarking on the design of a energy conscious building, these saving options could be used to reduce the annual energy estimate of the designed building.

- BEST is capable of the following:

(i) Calculation of the envelope thermal transfer value (ETTV) and the roof thermal transfer value (RTTV) for prescriptive standard compliance.

(ii) Estimation of the annual energy consumption of buildings.

(iii) Estimation of the peak design loads for air-conditioning equipment sizing and zone thermal comfort design.

(iv) Calculation of the building's lighting power allowance and receptacle power density using user-defined design values.

(v) Prediction of effects of multi-parametric changes on the energy use of buildings.

(vi) Selection of energy saving options to reduce annual energy consumption of buildings.

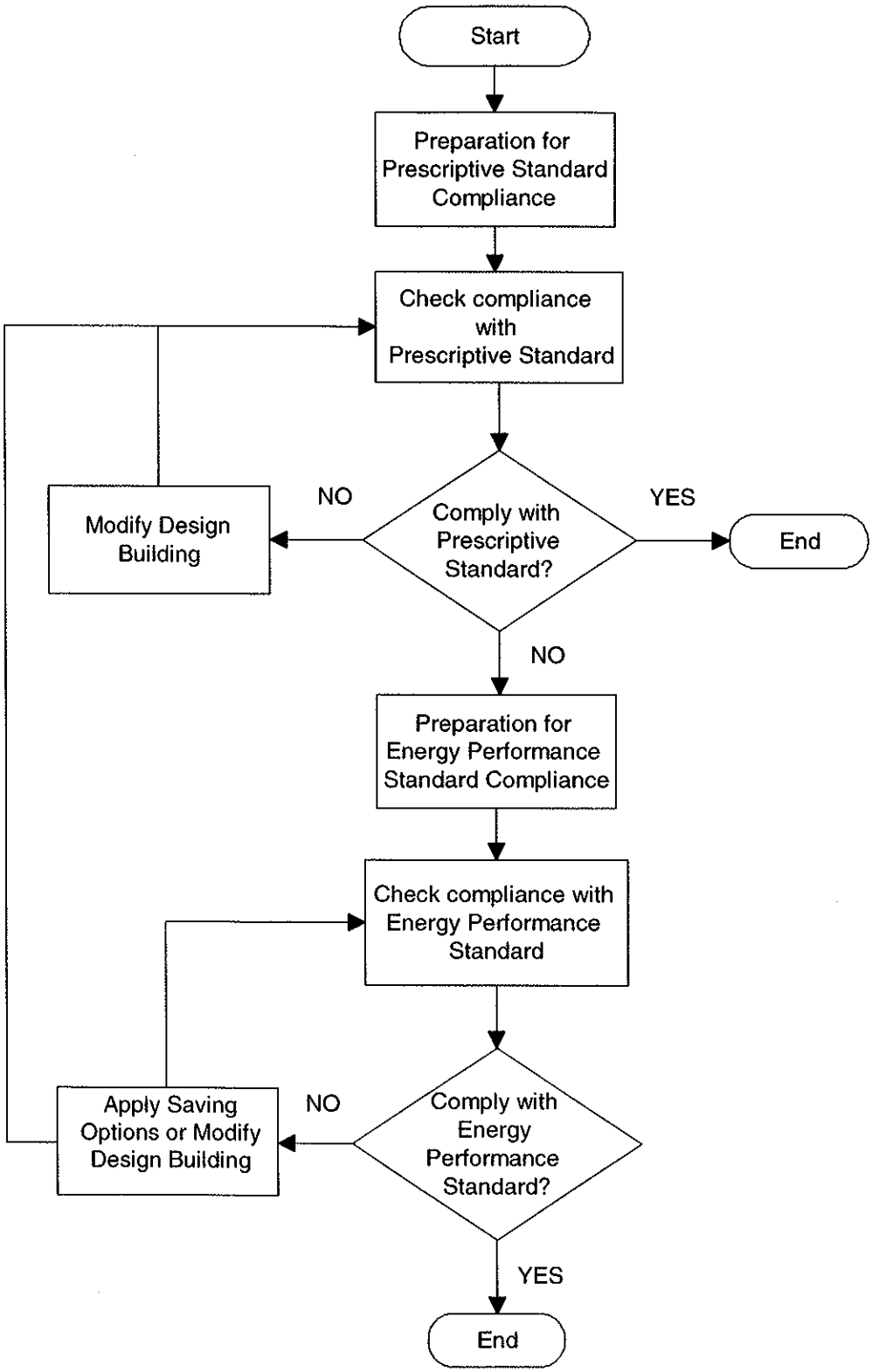

Figure 1: The compliance process for the energy performance standard.

BUILDING ENERGY STANDARDS (BEST)

BEST uses the standard Windows Graphics User Interface (GUI) that contains forms, which allow the user to enter the necessary data and read the desired results. The forms are represented through a main interface, which provide easy access to sub menus. These sub menus which facilitates the viewing of the various inputs and outputs are as follows:

1. Inputs and Standards Sub Menu

The Inputs and Standards sub menus contain forms that allow the end user to input the basic information. Through these forms, which have input objects, the end user is allowed to input the abovementioned information into BEST. The basic input requirements and the corresponding sub menus and forms in which these inputs can be made are summarized in Table 1. The energy performance standard and one of the prescriptive standard forms are illustrated in the Appendix.

2. Results Sub Menu

The results obtained from the building energy calculations performed in BEST are represented through the results sub menu. This sub menu contains a result summary form and a final summary form that presents the annual energy estimates without saving options and with savings option respectively. In addition, a total savings summary form is also included in this sub menu to show the amount of energy saved using the various saving options available in BEST. The result summary form is shown in the Appendix.

3. Savings Sub Menu

The various saving options incorporated into BEST are available to the user through forms in the Savings sub menu. These options include daylighting, solar water heating, and the use of heat pump, heat wheel as well as external shading devices.

(i) The heat pump energy recovery system is a cost-effective option for meeting hot water requirements in buildings. Operating with an efficient thermodynamic cycle, it could reduce energy costs and conserve valuable energy resources.

(ii) Another energy saving option is to use a heat wheel energy recovery system. The heat wheel is basically a rotary regenerator where heat transfer is achieved with a disk rotating between a cold air duct and a warm air duct.

(iii) Another energy saving option is to use solar energy to provide for water heating in buildings. Solar collectors with relatively good conversion efficiency could be used for moderate temperature applications in buildings.

(iv) The use of external shading devices to reduce heat due to solar radiation into buildings is another possible saving option. BEST is capable of calculating the effective shading coefficient of the external shading devices at each building facade. The method of computing horizontal, vertical and egg-crate types of shading devices is contained in a handbook [1].

(v) Daylighting involves the strategy to bring natural light from outside a building into the building. There is potential for savings in commercial buildings as lighting energy consumption of a building may be reduced during its peak operating period. Also, daylight is cooler than electric light while having higher luminous efficacy.

The forms and required inputs for the respective various saving options are summarized in Table 2. A sample form of one of the saving options in the Savings sub menu is illustrated in the Appendix.

In addition, the Savings sub menu form also contains the Life Cycle Cost and the Tariff Rates forms. The Life Cycle Cost (LCC) methodology employed in BEST would allow the user to be able to calculate and present the cost of a building's energy consumption as well as investments made in implementing saving options. In order to calculate the cost of electricity to a building, tariff rates levied onto electricity bills must be know. The user can input these rates in the Tariff Rates forms. The method used to calculate the electricity cost in BEST mimics the actual billing structure levied upon the consumer by Singapore Power. With these forms, the user has the capability of making cost effective choices for a given building, facility or system in deciding to accept or reject a given investment aimed at lowering building cost.

Sub Menu	Form	Inputs Required
Inputs sub menu	Project slate form	Project description Building description Building type Company description
	Equipment fraction form Lighting fraction form People fraction form	Operation schedules Equipment schedule Lighting schedule People schedule
	Lighting form	Lighting data* Space category Area of space Ceiling height Designed light density
	Receptacle form	Receptacle data* Space category Area of space Designed number of occupants Design receptacle power density
Standards sub menu	Wall properties form	Number of Wall* Wall thermal transmittance*
	Fenestration properties form	Number of Fenestration* Fenestration thermal transmittance*
	ETTV form	Envelope thermal transfer value (ETTV) properties* Wall or Fenestration type Wall or Fenestration area Pitch angle Orientation
	External shading devices form	External shading devices properties Types of shading devices Equipment power consumption per unit area Horizontal angle of inclination
	RTTV form	Roof thermal transfer value (RTTV) properties* Roof Type Roof area Shading coefficient Pitch angle
	Energy performance form	Building type
		Gross floor area of building
		Building's operation period Operation hours per day Operation days per week
		Cooling plant's setup Rated COP Type of chiller used Design outdoor air Design setpoint temperature Prototype setpoint temperature

* Multiple information can be specified

Table 1: Basic Input Requirements for BEST

Sub Menu	Form	Inputs Required
Savings sub menu	Heat pump form	COP of heat pump Fraction of hot water provided by heat pump Amount of hot water usage per month Temperature of hot water required
	Heat wheel form	Volume of air-conditioned air in design building Percentage of fresh air intake per hour Percentage of fresh air passing through heat wheel per hour Effectiveness of heat wheel Temperature of fresh air leaving heat wheel Relative humidity of fresh air leaving heat wheel COP of design building chiller
	Solar hot water heating form	*Gradient from graph of η vs $(T_i-T_a)/T_T$ *Y-intercept from graph of η vs $(T_i-T_a)/T_T$ Amount of hot water usage Temperature of hot water required Solar fraction
	Daylighting form	Window to wall ratio Transmittance Fraction of floor within 6.0m from window Lighting intensity level

* Data supplied by manufacturer

Table 2: Input Requirements for BEST Saving Options

4. Utilities Sub Menu

Besides functioning as a design tool, BEST also incorporates a number of additional features that are accessible to the end user via the Utilities sub menu. These features are:

(i) Parametric analysis. This feature has built-in functions that allow the end user to vary a number of parameters to see its effects on ETTV, annual cooling energy and annual total energy consumption of the design building.

(ii) Quick energy estimates. This feature allows the end user to enter certain parameters of the design building to make a quick estimate of the building's annual cooling energy without having to fill in the various input forms in the sub menus.

(iii) PEAKLOAD. This is an external windows based software that allows the end user to calculate the design day cooling loads of a building based on the ASHRAE transfer function method [6].

(iv) Thermal Transmittance Kalculator (TASK). This is another external window based software that was developed to complement the use of BEST. It was developed with close reference to the various methods of computation recommended in the ASHRAE Handbook of Fundamentals – 1980 [7]. TASK allows the end user to compute the thermal transmittance or U values of walls and fenestrations quickly and easily.

(v) ETTV calculator. This feature allows the end user to determine the maximum allowable ETTV for a building given the prescriptive limit for the OTTV. In essence, the ETTV calculator serves as an easy-to-use tool for converting OTTV to ETTV.

A sample form in the Utilities sub menu is shown in Appendix A.

5. On-Line Help Menu

In addition to the sub menus in BEST, a Win Help file BEST.HLP is available to help the end user operate BEST efficiently and cost-effectively when calculations are performed in complying with the building energy standards. This help file can be accessed via the on-line help menu or by pressing the F1 key anytime when BEST is being run. The file also contains 5 worked examples for different building types with and without applying saving options to demonstrate the use BEST to new users.

DISCUSSION

There are many issues pertaining to the use of BES for specific purposes, the choice of building simulation package to be used, and the development of such engineering and design tools [8]. Factors affecting the choice of BES packages include costs, ease of use, program interface, performance of program and background knowledge of user. In Singapore, large commercial buildings are becoming more energy intensive because of the demand for more sophisticated services and thermal comfort. With the availability and lower costs of computer technology nowadays, appropriate computerised engineering tools can be used for the design and operation of energy-efficient large buildings to meet thermal comfort and indoor air criteria. Building energy simulation can also be performed at lower costs.

In addition, the internet can serve as an effective medium for introducing and disseminating information on building energy simulation to interested parties [9], including building professionals and academics.

CONCLUSION

New technologies in planning, design and operation for energy efficiency often require the use of computers, and with the advent of desktop computing, building energy simulation is expected to grow in importance. A new energy performance standard is being proposed for use in Singapore so as to achieve higher efficiency levels and greater energy savings. We demonstrated an engineering compliance software, BEST, tailored for use by professionals to perform calculations aimed at achieving energy efficiency in buildings and compliance of energy performance standards. Ultimately, it is worth emphasizing again that energy efficiency will have to be translated to "in the pocket" savings for the public for it to be readily accepted and practised.

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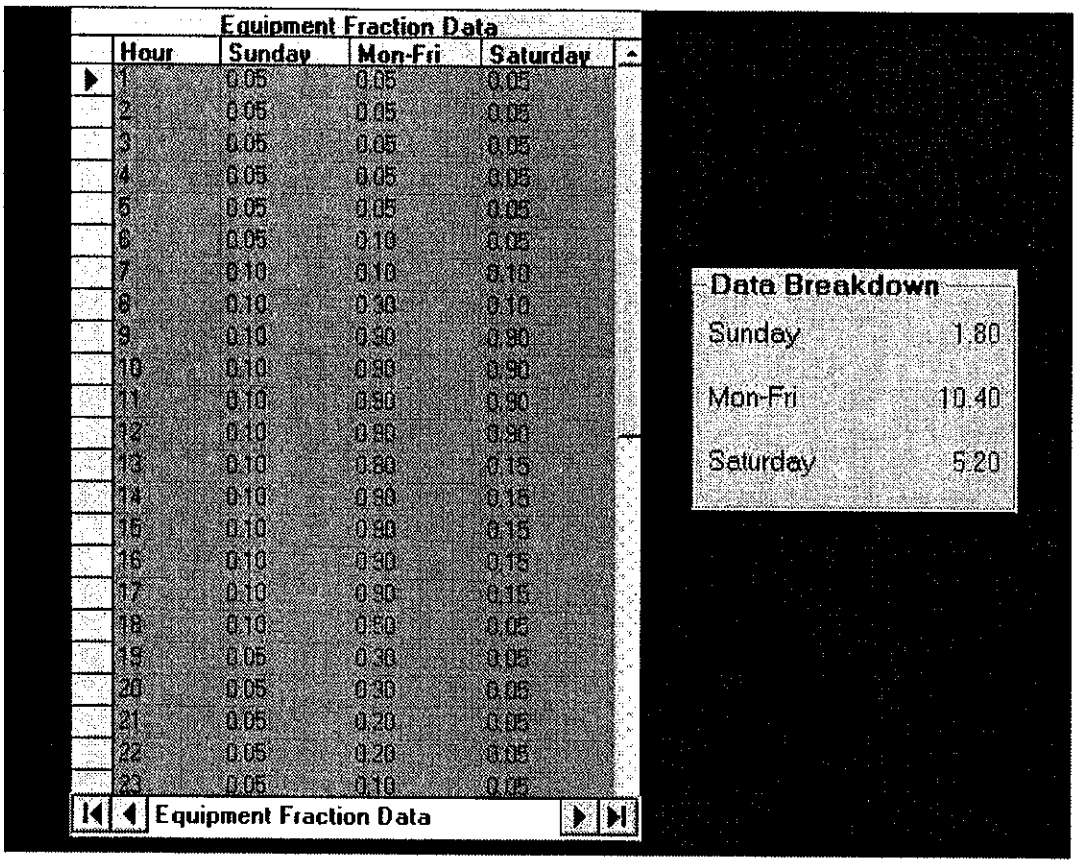
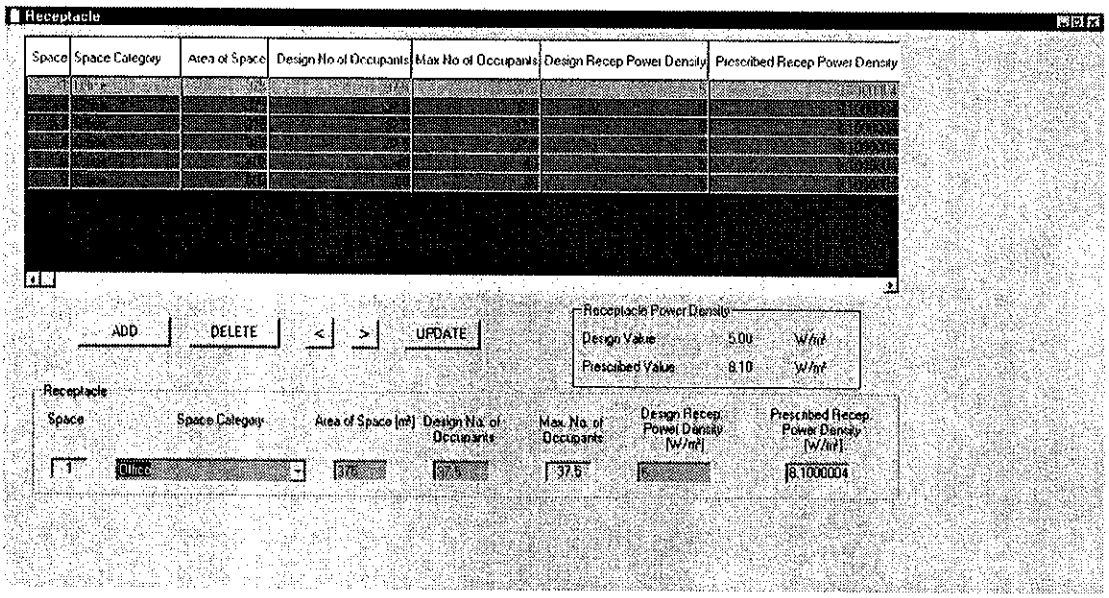
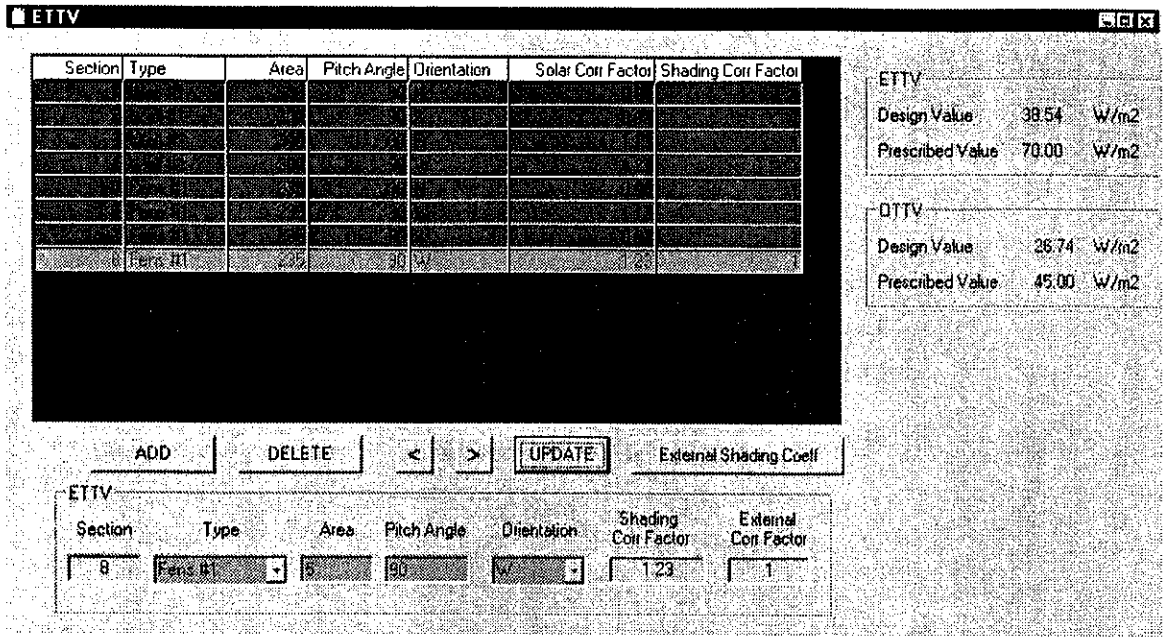
APPENDIX



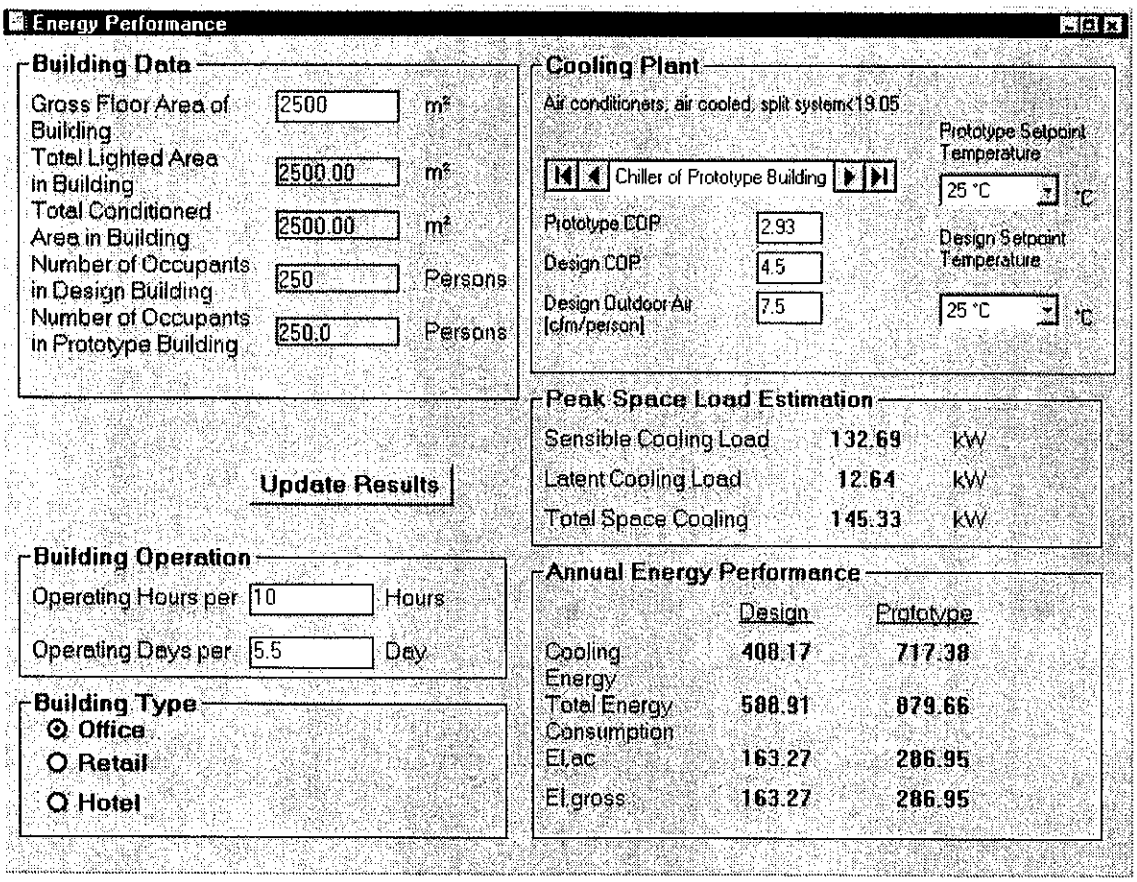
FigureA-1: The Equipment fraction form in the Input sub menu in BEST.



FigureA-2: The Receptacle prescriptive standard form in the Input sub menu in BEST.



FigureA-3: The Envelope Thermal Transfer Value (ETTV) form in the Standards sub menu in BEST.



FigureA-4: The Energy Performance standard form in the Standards sub menu in BEST.

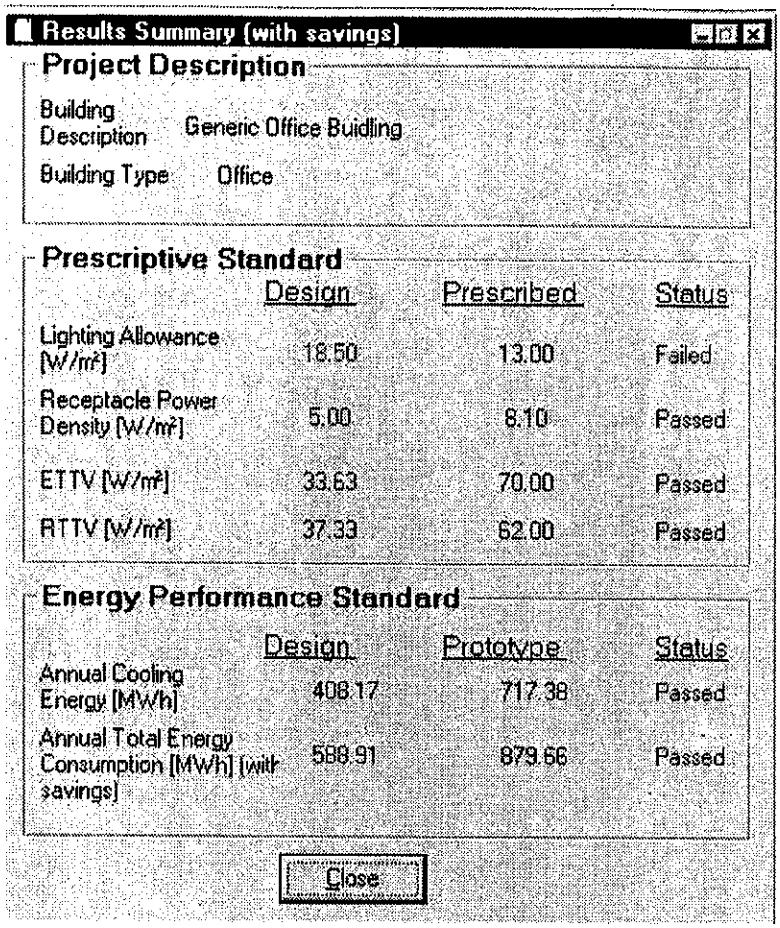
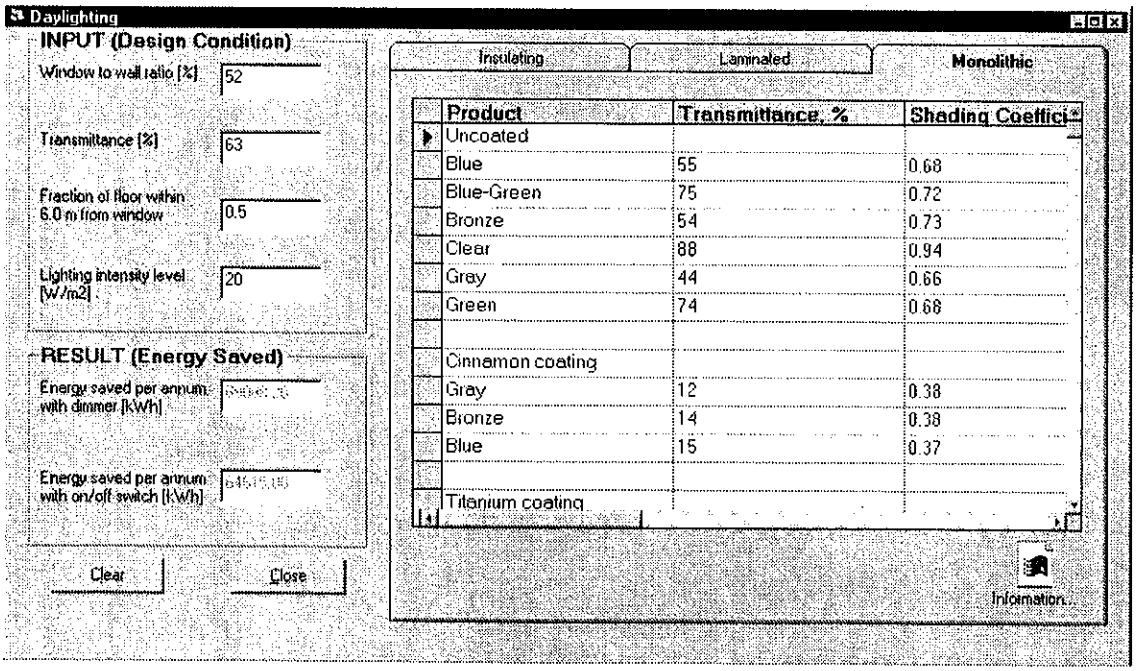
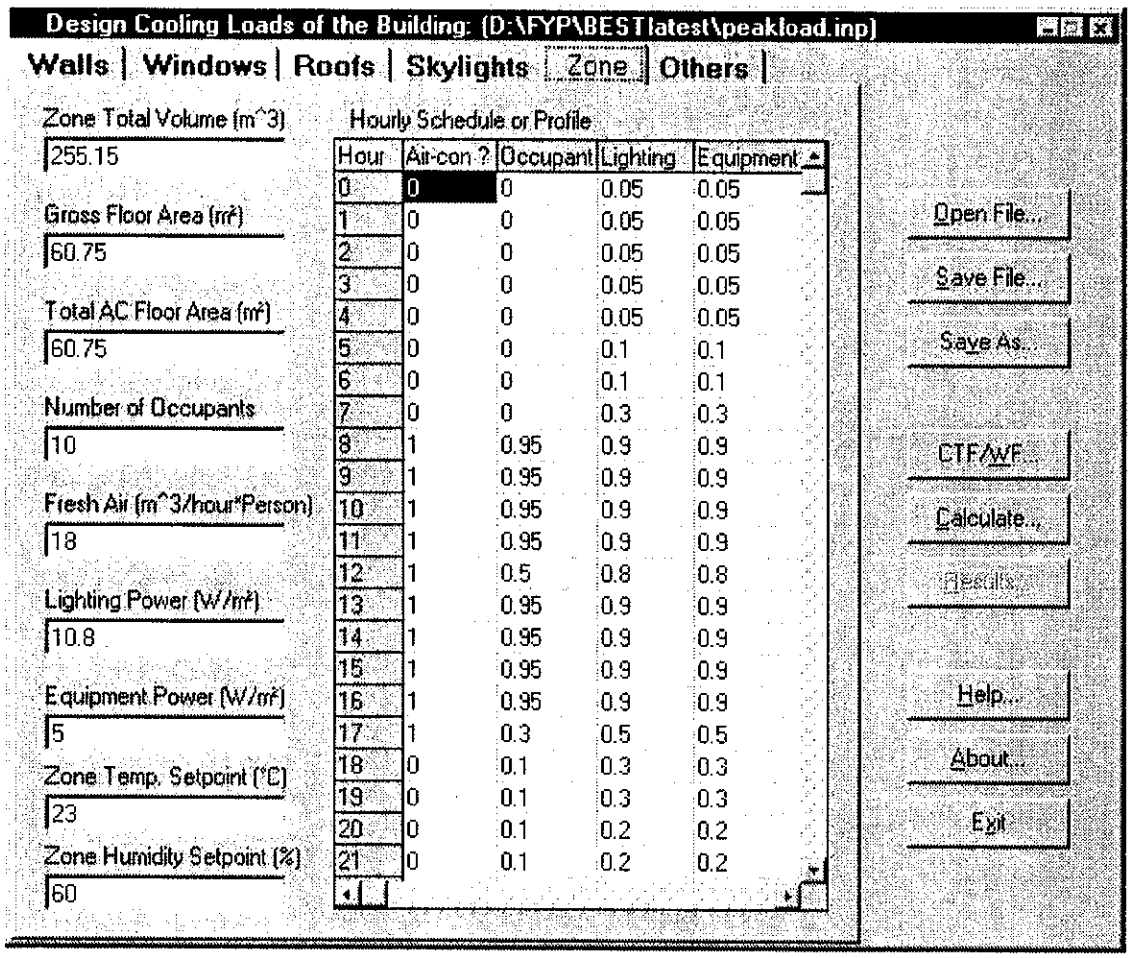


Figure A-5: The Final Summary form in BEST showing the summary of results for the prescriptive and energy performance standard with saving options.



FigureA-6: The PEAKLOAD software incorporated in BEST through the Utilities sub menu in BEST.



FigureA-1: The energy performance standard form in the Standards sub menu in BEST.

ENERGY EFFICIENCY IN BUILDING DESIGN

Energy Audit for Building

Presented by

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1. INTRODUCTION

The energy audit in a building is a feasibility study. For it not only serves to identify energy use among the various services and to identify opportunities for energy conservation [1], but it is also a crucial first step in establishing an energy management programme. The audit will produce the data on which such a programme is based. The study should reveal to the owner, manager, or management team of the building the options available for reducing energy waste, the costs involved, and the benefits achievable from implementing those energy-conserving opportunities (ECOs).

The energy management programme is a systematic on-going strategy for controlling a building's energy consumption pattern. It is to reduce waste of energy and money to the minimum permitted by the climate the building is located, its functions, occupancy schedules, and other factors. It establishes and maintains an efficient balance between a building's annual functional energy requirements and its annual actual energy consumption.

2. STAGES IN ENERGY PROGRAMME

The energy audit may range from a simple walk-through survey at one extreme to one that may span several phases. These phases include a simple walk-through survey, followed by monitoring of energy use in the building services, and then model analysis using computer simulation of building operation. The complexity of the audit is therefore directly related to the stages or degree of sophistication of the energy management programme and the cost of the audit exercise.

The first stage is to reduce energy use in areas where energy is wasted and reductions will not cause disruptions to the various functions. The level of service must not be compromised by the reduction in energy consumed. It begins with a detailed, step-by-step analysis of the building's energy use factors and costs, such as insulation values, occupancy schedules, chiller efficiencies, lighting levels, and records of utility and fuel expenditures. It includes the identification of specific ECOs, along with the cost-effective benefits of each one. The completed study would provide the building owner with a thorough and detailed basis for deciding which ECOs to implement, the magnitude of savings to be expected, and the energy conservation goals to be established and achieved in the energy management programme. However, the ECOs may yield modest gains.

The second stage is to improve efficiency of energy conversion equipment and to reduce energy use by proper operations and maintenance. For this reason, it is necessary to reduce the number of operating machines and operating hours according to the demands of the load, and fully optimize equipment operations. Hence the ECOs would include the following:

- Building equipment operation,
- Building envelope,
- Air-conditioning and mechanical ventilation equipment and systems,
- Lighting systems,
- Power systems, and
- Miscellaneous services.

The first two stages can be can be implemented without remodelling buildings and existing facilities.

The third stage would require changes to the underlying functions of buildings by remodelling, rebuilding, or introducing further control upgrades to the building. This requires some investment.

The last stage is to carry out large-scale energy reducing measures when existing facilities have past their useful life, or require extensive repairs or replacement because of obsolescence. In this case higher energy savings may be achieved. For these last two stages, the audit may be more extensive in order to identify more ECOs for evaluation, but at an increased need for heavier capital expenditure to realize these opportunities.

3. SURVEYING THE BUILDING

A walk-through survey of a building may reveal several ECOs to the experienced eye of the auditor. The survey could be divided into three parts.

3.1 Preliminary survey

Prior to the walk-through survey, the auditor may need to know the building and the way it is used. The information can be obtained from:

- architectural blueprints,
- air-conditioning blueprints,
- electrical lighting and power blueprints,
- utility bills and operation logs for the year preceding the audit,
- air-conditioning manuals and system data, and
- building and plant operation schedules.

3.2 Walk-through

Thus having familiarized with the building, the walk-through process could be relatively straightforward if the blueprints and other preliminary information available describes the building and its operation accurately. The process could begin with a walk around the building to study the building envelope. Building features such as building wall colour, external sun-shading devices, window screens and tint, and so on are noted as possible ECOs.

If a model analysis is included in the study, the building must be divided into zones of analysis. The survey inside the building would include confirmation that the air-conditioning system is as indicated on plans. Additions and alterations would be noted. The type and condition of the windows, effectiveness of window seals, typical lighting and power requirements, occupancy and space usage are noted. These information could be compared against the recommendations in the relevant Codes of Practices such as CP 13:1999 [2] and CP 24:1999 [3].

System and plant data could be obtained by a visit to the mechanical rooms and plant room. Nameplate data could be compared against those in the building's documents, and spot readings of the current indicating panels for pumps and chillers recorded for estimating the load on the system.

3.3 Operator's input

The auditor may discuss with the building maintenance staff further on the operating schedules and seek clarification on any unusual pattern in the trend of the utility bills. Unusual patterns such as sudden increase or decrease in utility bills could be caused by changes in occupancy in the building, or change in use by existing tenants. It is not uncommon for tenants to expand their computing operations that may increase the energy use significantly.

3.4 Report

At this stage, ECOs could be found in measures such as:

- Reduce system operating hours,
- Adjust space temperature and humidity,
- Reduce building envelope gain,
- Adjust space ventilation rates and building exfiltration,
- Review system air and water distribution,

- Adjust chiller water temperatures, and
- Review chiller operations.

The benefit from adopting each ECO should be compared against cost of implementation. Caution should be exercised in the cost-benefit analysis given the wider range of certainty of the projections made. However, a survey at this level may be sufficient for small buildings.

4. MEASUREMENTS

The capability of the energy auditor and the scope of an audit could be extended by the use of in-place instrumentation and temporary monitoring equipment. In-place instrumentation refers to existing utility metering, air-conditioning control instrumentation and energy management systems (EMS). Such facilities have been required by legislation since 1989 and its use is recommended in the current version of CP13:1999 [2]. The use of in-place utility metering and temporary monitoring equipment in energy auditing can yield valuable information about the building systems such as:

- Energy signature and end-use consumption analysis,
- Discovery and identification of ECOs,
- Quantification of energy use and misuse,
- Establishing bounds for potential energy reduction, and
- Data acquisition for further calculation and analysis.

4.1 Existing information

Existing instrumentation such as utility meter readings, and energy billings could be used to establish energy consumption patterns for the building. The regularity of consumption pattern is an indicator that no significant change in consumption occurred prior to the audit. This can also be used to check the validity of projections based on extrapolated short-term monitored data. Utility data could be used to establish useful indices such as kWh/m^2/year to compare relative energy performance of buildings.

Air-conditioning control instrumentation such as chilled water temperature probes, water flow meters could be used to estimate cooling load demand and plant operation. For example, chilled water temperature outside the designed range may indicate that cooling coils may be operating under off-design conditions.

4.2 Short term monitoring

The building may not be equipped for monitoring energy consumption and it may be necessary to install temporary measurement devices such as instantaneous recorders (strip chart, data loggers, etc) and totalizing recorders (kWH meters) to obtain data over the period of a week for the study.

Monitored data is also useful for completing the energy model of a building for use in some building energy simulation software. For example the total building energy consumption would include energy used in the vertical transportation system and potable water pumps which are not modelled in the software.

An estimate for annual consumption is extrapolated from the typical week consumption profile. Regularity of the weekly consumption profile means that the annual consumption could be estimated with confidence and the value used to cross check with the annual energy bills.

5. MODEL ANALYSIS

Building energy consumption in simplest terms is just the product of rate of consumption of a system and the period of operation. In lighting systems, its energy consumption could be determined manually with precision as it does not interact with other consumption variables. Energy consumption of cooling systems, however, is many times more complicated as it is affected by the internal heat gain within a building as well as weather variables which varies in a complex manner over time.

Building model analysis using computers offers several improvements over manual calculations. These include:

- Precise schedule of building parameters,
- Precise determination of weather impact,
- Specification of part load performance of plant and equipment, and
- Consideration of parameter interactions such as lighting load on air-conditioning consumption.

5.1 Software

Some software such as DOE-2 [4] permit hour-by-hour calculations of building consumption for the entire 8760 hours of the year, but require thorough knowledge of the software to carry out accurate and meaningful analysis. Simplified software based on consumption analysis on characteristic days in a year such as BUNYIP [5] may also be considered. However, the improvements in computational power of the desktop PC has introduced several powerful features and user-friendly graphical interface possible in more recent versions of such software making it more accessible to the practising engineer.

5.2 Analysis

The general procedure for an analysis would be to establish a model giving an annual consumption within 10% of the measured data. This establishes the base model. The impact of ECOs on energy consumption would be compared against the base model. ECOs could be considered singly or in combinations to determine interactions between them. The results of the energy savings in each analysis should not be taken as absolute but rather taken to be relative to the base run so as to give an indication of the order of magnitude of savings. Thus those ECOs which shows significant gains would be implemented.

6. CASE STUDY OF MULTI-TENANTED OFFICE BUILDING

This is an audit on an office building of 22,300 m^2 gross area of which 16,700 m^2 is conditioned. The building air-conditioning system was served by a central chilled water plant which has a total capacity of 800 RT from two chillers (COP 5.87).

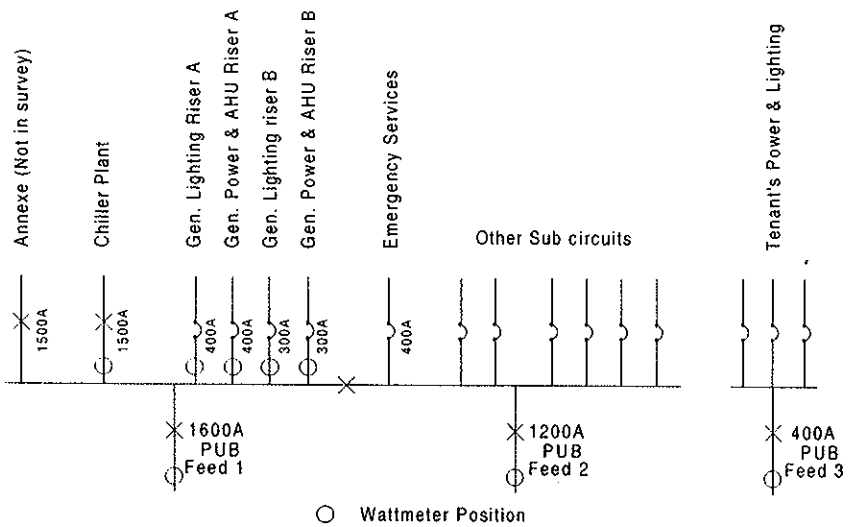

Figure 6.1 Example of wattmeter location for short term monitoring.

The main single line electrical schematic diagram shown in Figure 6.1 indicates the location of clip-on instrumentation used for whole building and end use power monitoring. Clip-on power and current transducers with dc output are used to measure the energy use in the main and selected sub-circuits. A stand-alone type data logger captured the output signal from the transducers and stores the data in

the integral storage which is downloaded periodically for analysis on a micro-computer. A modem link could also be used for remote data retrieval.

A typical 24-hour consumption profile of an office building is shown in Figure 6.2. Power consumption attributed to chiller plant, lighting, general lighting and AHU fans, and other services are also shown. The energy signature help identify the operating hours of the building and also some energy conserving measures being practiced. The dip in AHU fan consumption between 1200 - 1300 h on weekdays is attributed to switching off AHUs during lunch breaks. Savings could be identified easily for graphical presentation to management. A high base load during off hours could mean that some services may be operated outside normal hours. This could be checked against the operation schedule to identify wasteful operational practices. In this instance, the base load is about 80 kW and is attributed to extensive outdoor lighting.

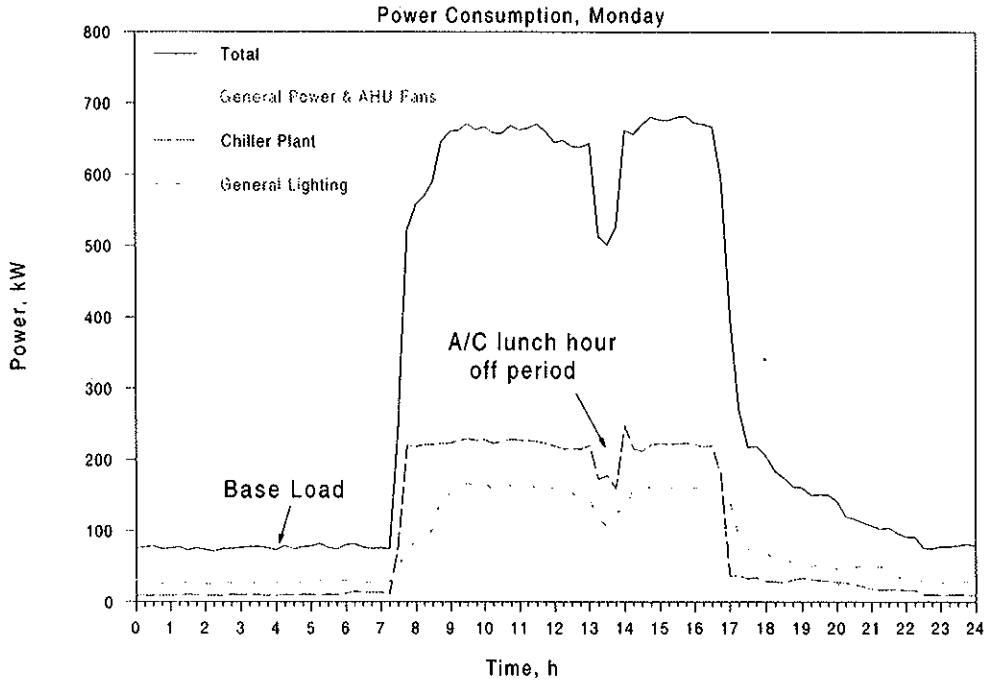

Figure 6.2 Typical weekday consumption profile of an office building

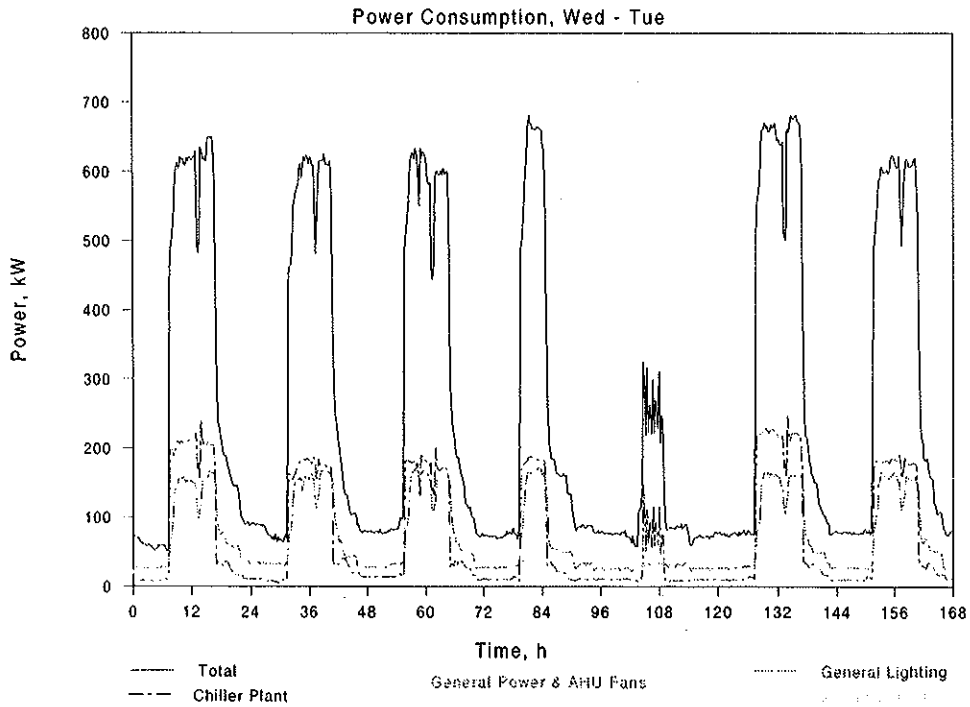

Figure 6.3 Example of weekly consumption profile of an office building.

Figure 6.3 shows a typical week consumption profile. The plot of the energy end-use by systems is shown in Figure 6.4. An upper boundary could be defined for consumption by general lighting. This would prevent overestimate of savings in selecting ECOs as each ECO is concerned with a particular parameter in building operation whereas in fact the ECO may have secondary effects on other parameters in the building operating dynamics.

The annual electricity consumption of 2037 MWh was obtained from 12 consecutive monthly records kept by the operator's manual logging of the electricity meter and confirmed by checks with the utility bills. The annual energy intensity was 122 kWh/m^2/year as opposed to the value of 142 kWh/m^2/year or the base simulation model. As the building has implemented an energy management programme, the additional ECOs that the audit could suggest was to delay the air-conditioning plant start-up by 15minutes every day to save about 45.6 MWh per annum, and to do an extensive upgrade of the fluorescent luminaires. The luminaire upgrade could save an additional 31 MWh of energy by a 5% reduction of the connected lighting energy intensity to 12 W/m^2.

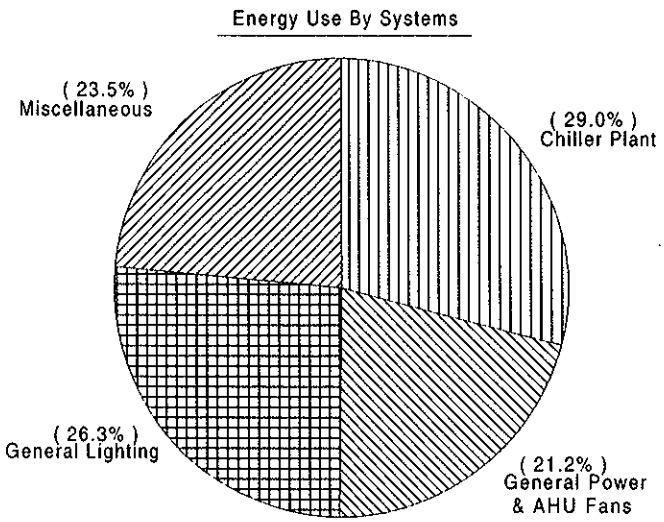

Figure 6.4 Example of energy consumption by services in an office building

7. SUMMARY

The objective of energy audit is to identify the end use of energy in a building and its ECOs; and as a feasibility study leading to implementation of an energy management programme. The audit procedure can be expanded as needed in the various phases of the energy programme, with the application of each succeeding phase yielding more information on energy use, and more opportunities for raising energy efficiency.

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ENERGY EFFICIENCY IN BUILDING DESIGN

Energy Efficiency of Office Buildings in Singapore

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ENERGY EFFICIENCY OF OFFICE BUILDINGS IN SINGAPORE

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Introduction

Energy in the form of electricity is used in building to operate equipment for the safety, efficiency and comfort of its occupants and users. Such equipment includes emergency systems, airconditioning, lighting, transportation, office systems and other appliances.

In the absence of natural resources fundamental to the generation of electricity, energy will remain a critical factor for the Singapore economy for the immediate and long-term future. This would have direct impacts on building designers, managers and owners. It is important to monitor and manage the cost pressure in the operation and maintenance of buildings with respect to energy. It is important to ensure global competitiveness in the area of environmental performance and efficiency.

Hence, the trend towards energy efficient building is not a passing trend like the energy crisis of the 1970s. Energy efficiency of building has emerged as a permanent performance factor to be considered in the cost and environmental equations. Knowledge base and understanding in energy efficiency of buildings will formalize and become a core competence of building designers, managers and owners.

An office building is defined as a building where spaces in a building or part of the building are used or intended to be used for rendering services such as agency, commission, banking, administrative, legal, architectural, engineering and other professional services. According to the Urban Redevelopment Authority's statistics of 1998, there are a total of 511 office and office cum retail buildings in Singapore. Among them 21% are within public sector ownership.

Figure 1 below shows the electricity consumption distribution in Singapore for the year 1999. The office buildings' consumption has been included in the non-manufacturing sector. It is additional shown to illustrate its contribution to the whole sector. It can be seen that electricity consumption in buildings, excluding the industry sector, is 57%. The domestic sector alone, that is the residential portion of the electricity consumption, is 20%. The consumption of office buildings, which is a part of the non-manufacturing sector, is responsible for 12% of the overall non-manufacturing sector's consumption. In view of the large residential build-up space as compared to the total office space, office may indeed be considered as major energy user among the various building types.

The data of Figure 1 also clearly illustrate the importance of the building sector in contributing to the overall energy efficiency of Singapore.

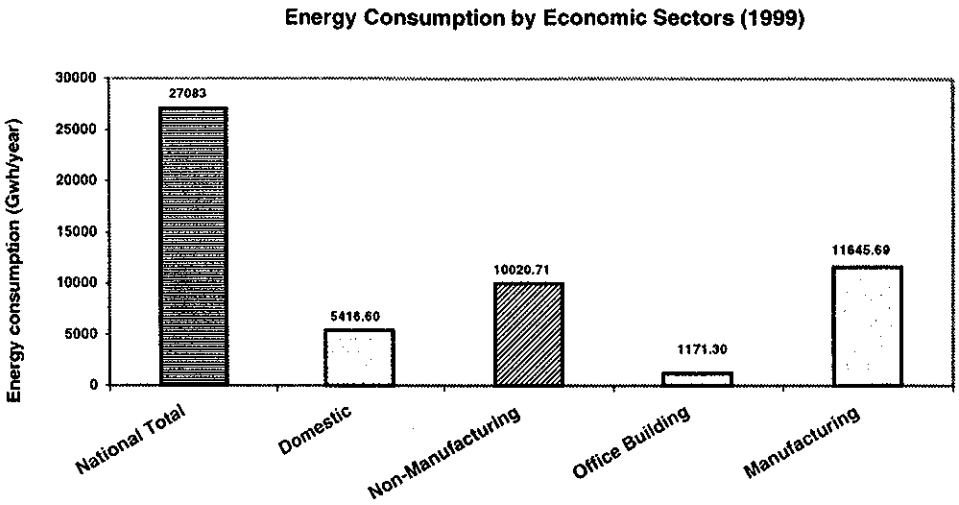

Figure 1: Electricity consumption among different economic sectors in Singapore. *(Source: Singapore Power's Annual Report 1999)*

This paper presents findings of a recent study conducted. It examines the overall trends of energy consumption among office buildings in Singapore. An attempt is made to benchmark the energy performance of office buildings. A total of 104 office and office cum retail buildings have been studied.

Methodology and Profile of Building Samples

Surveys were conducted on the energy consumption of buildings. The survey aimed to obtain the total as well as a break down of energy consumption, between the landlord and the tenants, of a building. Data were collected through a questionnaire survey including information about the function, and operational and occupancy characteristics of the building. 10% of the data collected, including both the landlords' and tenants' electrical consumptions were verified on site.

The data set collected includes the age of the building, age since the latest refurbishment, occupancy rate (OR), the total gross floor area (GFA), scheduled operating hours (OH), indoor environmental setting, systems' performance data, and two years' monthly electricity consumptions.

Statistical analyses on the characteristics and distribution of data, as well as relationship such as correlations between different parameters were investigated. The observed data values for the total energy consumption, the landlord and the tenants have all been tested and were found to satisfy the normal distribution function.

A total of 163 letters of invitation and questionnaires were sent out inviting participation for the study. An 86% response rate was achieved with 104 building managements responded to the survey. The building samples collected therefore represent a 3.7% sampling error using the stratified sampling random estimation technique. Among the 104 buildings that responded, there are 44 public sector buildings and 60 private sector

buildings. 82 are office buildings in use and 22 are office cum retail buildings. In the latter group the retails function is a negligible portion of the total office space.

The buildings studied have average design efficiency, gross lettable area (GLA) to gross floor area ratio, of 74% with a 95% confidence interval of +/- 6.3%. They also have an average ratio of airconditioned area to gross floor area of 80% with a 95% confidence interval of +/- 2.5%. These show that the cohort of buildings studied have rather similar design profiles and standards. The low spread of building design efficiency, and the large sample population with a sampling error of about 3.7% means that the data obtained provide a reliable profile of office buildings' energy performance in Singapore.

The respondents may be classified into three categories as follows:

i. Owner Occupiers
There are 30 such buildings. Typically, these buildings are owned, occupied and operated by one user group. There is therefore no tenant. The owner pays one bill. The data available are global energy consumption of the entire building including both common and office space.

ii. Landlord Operated
There are 64 such buildings. These buildings are owned and managed by landlords or his agents on a rental basis. There are two groups of data obtained, the landlords' consumption for the common area and facilities, and the tenants' consumption. The landlords' consumption typically covers the central airconditioning system, artificial lighting (both indoor and outdoor) for the common area not within any tenant's premises, vertical transportation system, mechanical ventilation systems and cleaning and other functions in the common area. The tenants' consumption refer to that used within the tenants' premises. These usually include consumptions by lighting, office equipment, computers, and other small appliances.

iii. Mixed Landlord and Tenants Occupation
There are 10 such buildings. Under this category, the landlords own and occupy part of the building. The landlords' portion of the consumption therefore includes that of the common area and facilities, and the office space occupied by the landlords.

Energy Consumption Patterns of Office Buildings

Seasonal Variation

The monthly office energy consumption pattern in Singapore is different from that observed in the temperate zones. All the office buildings studied do not exhibit significant seasonal variation in energy consumption over the year. Figures 2 and 3 show some of the typical monthly energy consumption distribution over the year.

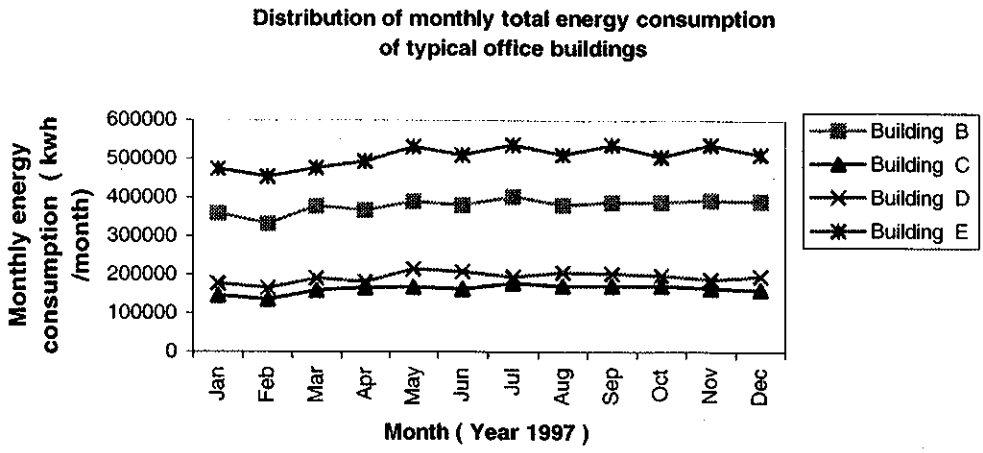

Figure 2: Distribution of monthly total energy consumption of four buildings of different sizes.

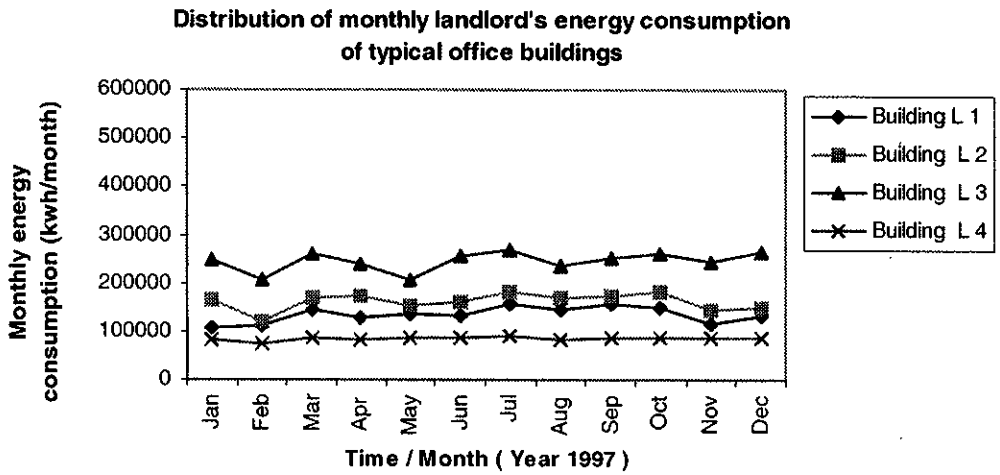

Figure 3: Distribution of monthly landlord's energy consumption of four buildings of different sizes.

The monthly consumption variation over a year about the mean is 6.63% and 7.92% respectively for the total and landlord's consumption. This may be attributed to the small variation in the external climatic conditions and the facts that the volume of commercial activities does not fluctuate significantly over the year.

Distribution of Energy Efficiency

Owing to the significant variation in building size among the sampled buildings, the energy performance of individual building is evaluated according to its energy efficiency. This is calculated using the formula,

$$\text{Energy Efficiency, } EE = \frac{\text{Energy Consumption}}{GFA - GLA\,(1 - OR)} \times OHF \qquad \text{eqn (1)}$$

Where:
- GFA = gross floor area of the building in m^2 adjusted for car park area
- GLA = gross lettable area in m2.
- OR = average occupancy rate of the building over the period of assessment.
- OHF = operating hour factor, a ratio of the mode operating hour per week (55 hours) to that of the building concerned.

From eqn(1) above, it can be seen that the energy efficiency concerned has been normalized for the an operating hours of 55 hours and adjusted occupancy rate. This would provide better comparative study between buildings. Calculations have been made for both the total and the landlord's consumption. In this way, the overall energy efficiency of a building, and individual landlord energy efficiency may be studied.

The distribution of the total energy efficiencies and the landlord's energy efficiencies of the 104 buildings studied are given in Figures 4 and 5.

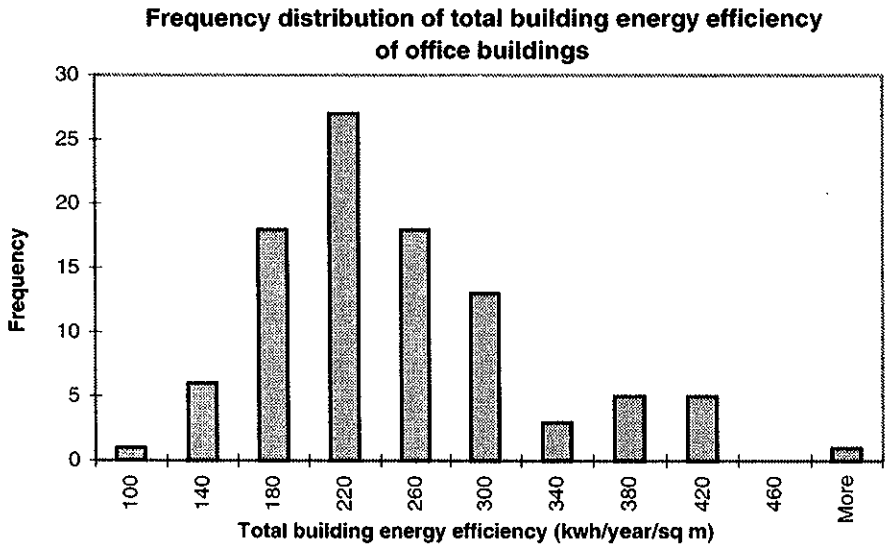

Figure 4: Frequency distribution of total energy efficiency of office buildings.

Figure 4 shows that the frequency distribution of the total energy efficiencies is largely a right skewed normal distribution with a skewness value of 0.89 indicating the closeness of the symmetry bell shape distribution. It follows that approximately 50% of the buildings studied have energy efficiencies below the mean value of 231.23kWh/m^2.

Figure 5 shows a similar frequency distribution for the landlord's energy efficiency, with a very slight right skew to normal distribution. The skewness value is 0.73, and a mean value of 144.49 kWh/m^2.

The results therefore show that the energy efficiency and hence the various probability functions of the samples can be described using normal distribution function. Cumulative percentile curves may therefore be plotted for the two efficiency parameters.

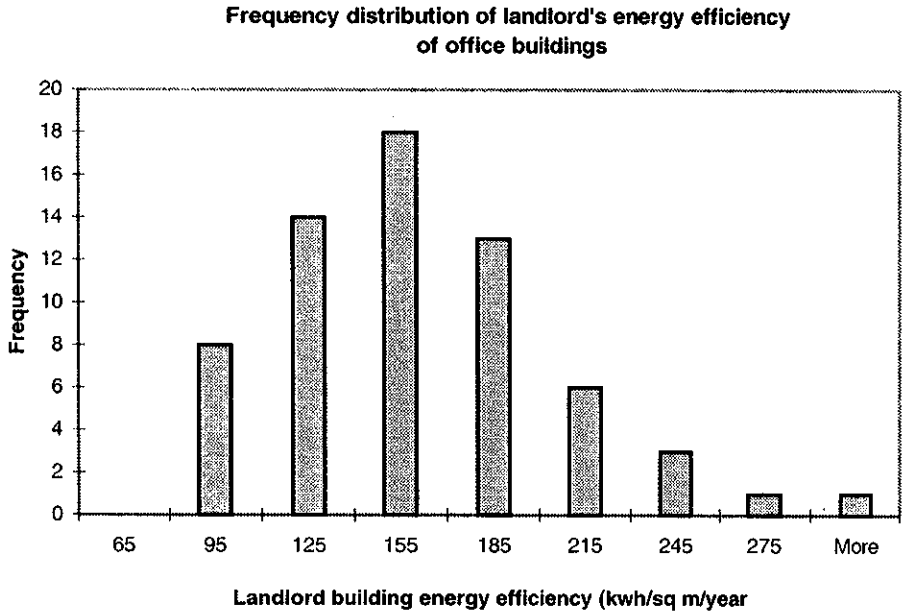

Figure 5: Frequency distribution of landlord's energy efficiency of office buildings.

Benchmarking of Office Buildings in Singapore

The total energy consumption versus the gross floor area (GFA) of all the 104 buildings studied is plotted as shown in Figure 6. The results show that the energy consumptions of office buildings are directly proportionate to the gross floor areas. There is a correlation coefficient of 0.88 meaning that based on the GFA alone one 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. This can be a useful design benchmark for consultants or building managers. These results have been translated into a cumulative percentile distribution curve as shown in Figure 7. From the cumulative distribution curve, a building manager is able to determine the energy performance of his building in terms of percentile position based on the energy efficiency of his own building. This is a benchmark measure of his own building versus the energy performance of the cohort of 104 office buildings captured in this study.

Hence Figure 7 presents a useful data set for office buildings in Singapore where property manager can benchmark and target energy performance of his own building. Designers too can use this as a benchmark when they are designing new office buildings in Singapore. It is now possible for owners to identify and set realistic targets for the consultants to achieve, and in doing so ensure that his building stays within the top leagues of the industry. Building managers of existing buildings can determine where is the current performance level of his building and set realistic target to achieve for enhance energy efficiency. He can estimate the amount of saving possible and hence justify the amount of funding to achieve the target.

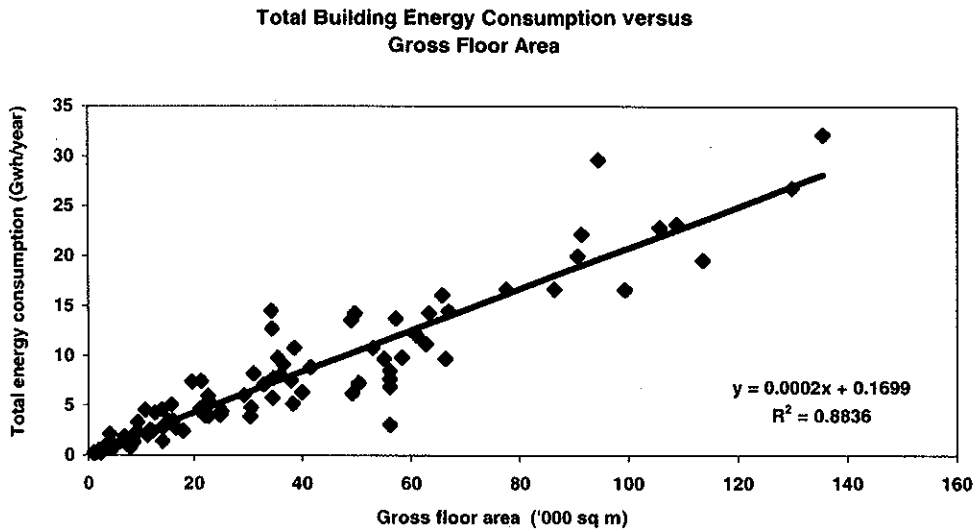

Figure 6: Distribution of total building energy consumption of office buildings versus the gross floor area of buildings.

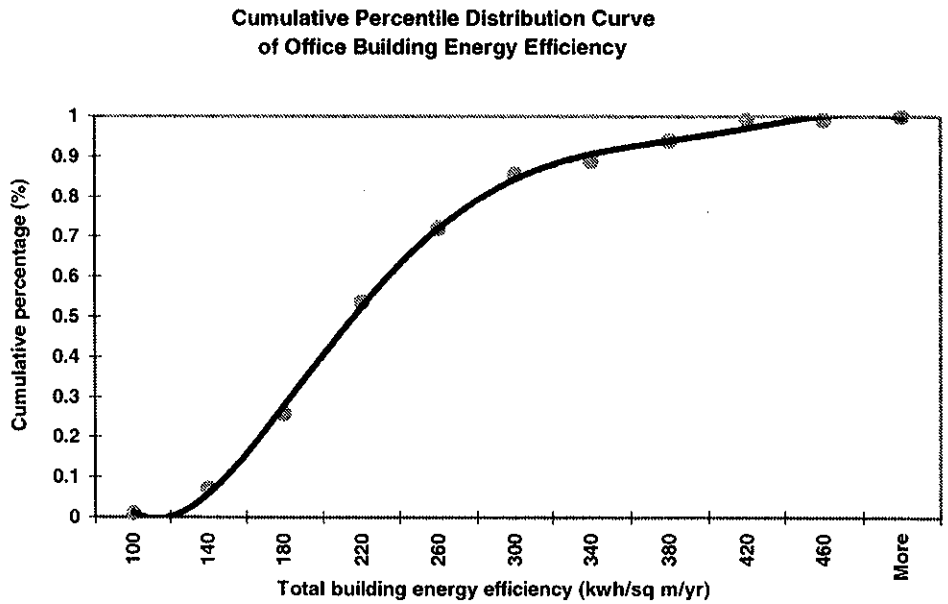

Figure 7: Cumulative percentage distribution curve of energy efficiency of office building.

Hence Figure 7 presents a useful data set for office buildings in Singapore where property manager can benchmark and target energy performance of his own building. Designers too can use this as a benchmark when they are designing new office buildings in Singapore. In another word, it is possible for a owner to identify and set a realistic target for the consultants to achieve, and in doing so ensure that his building stays within the top leagues of the industry. Building managers of existing buildings can determine where is the

current performance level of his building and set realistic target to achieve for enhance energy efficiency. He can estimate the amount of saving possible and hence justify the amount of funding to achieve the target.

Energy Usage Pattern Among Singapore's Office Buildings

The data of the previous section is useful for measuring the total standing of an office building in Singapore. If a building manager found his building to be under performing, he may engage an energy services company to conduct an energy audit to determine where and how his building has under performed. In another word data with greater resolution or more details are needed. From a researcher's point of view, further benchmark information is needed at lower levels such as landlord and tenant levels. It is also useful to determine the energy performance indicators and identify the key indicators. This is useful information for building designers and managers.

Figure 4 shows the distribution of energy consumption between the landlords and the overall consumption of tenants. The landlord's consumption includes all the main and central airconditioning, lighting in common area, transportation systems and all other equipment such as pumps and ventilating fans and so on. The tenants' consumptions are mainly in the areas of lighting and appliances including fans, printers, computers and so on. It can be seen from Figure 4 that the landlord's consumption is 62% of the total consumption. The remaining 38% consumption is attributed to the tenants.

In this case, the results show a significant variation in the ratio of tenants to landlord energy consumption. This is due to the different arrangements for different buildings depending on the services and facilities provided by the landlord. However with a 95% confidence interval of +/- 2.80 % for the entire population of 104 buildings, it is reasonable to conclude that 62% of landlord consumption is a representative profile for the majority of the buildings studied.

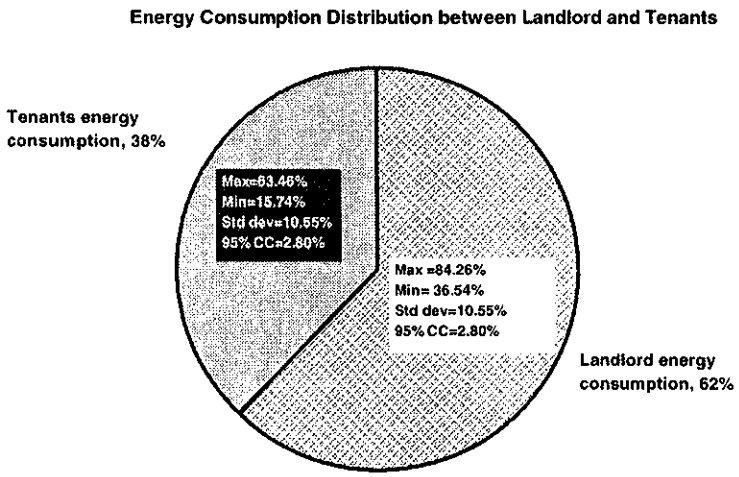

Figure 8: Energy consumption distribution between landlord and tenants of office buildings.

The cumulative energy consumption curve of landlords is given in Figure 9 below. The total building consumption cumulative curve is also plotted for comparison. One can observe that the total building energy consumption is significantly spread as compared to that of the landlords' consumption. All the 104 buildings studied are clustered in the range of 68 to 270 kWh/(sqm.yr). Energy performance ranking for landlord is therefore relatively more sensitive to minor increment. 75% of the buildings studied have energy efficiency indices of between 100 and 200 kWh/(sqm.yr). This is relatively competitive. In comparison, for total energy consumption, the bottom 20% of buildings had energy efficiency ranging between 300 and 460 kWh/(sqm.yr).

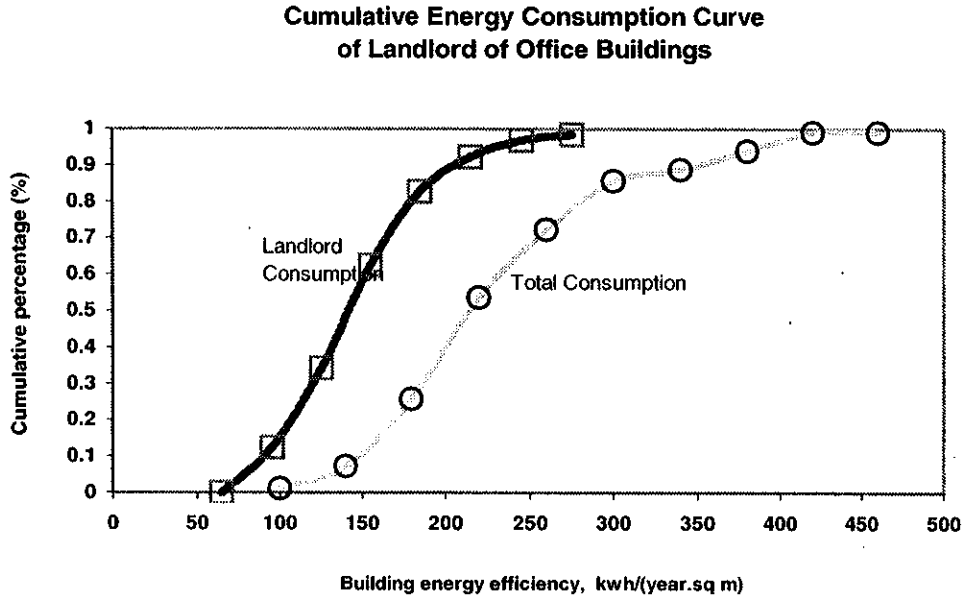

Figure 9: Cumulative energy consumption curve of landlords of office buildings.

The detailed consumption variations among the office buildings are presently being investigated under three grouping in terms of building energy consumption. The three different groups of buildings are those with energy efficiency (EE) falling within the top 25 percentile, those with EE falling between 26 and 75 percentile, and those with EE above the 75 percentile.

Tenancy Type and Energy Consumption

From the verified tenants' energy consumption, a few main office user groups were investigated. They are the banking and finance offices, the trading and marketing firms, the professional consultants offices, and the representative offices. The cumulative energy consumption curves of these four types of offices are as shown in Figure 10.

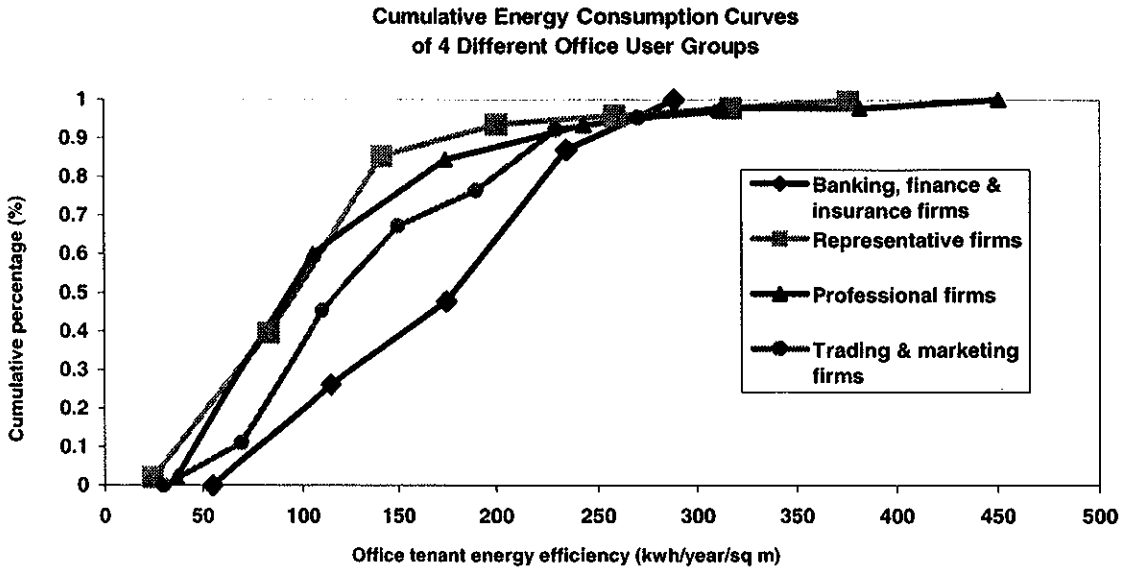

Figure 10: The cumulative energy consumption curves of four tenancy groups.

Figure 10 results are plotted according to the EE of the various offices. The results show an interesting characteristic in that these users do not have linear energy consumption with respect to floor area. Hence for tenants in the same grouping, their energy consumption may be significantly different. Most notable is the group of representative firms, where energy consumption per square metre can vary from 25 kWh/(sqm.yr) to 370 kWh/(sqm.yr). This represents a 1400% increase. The professional offices exhibit the same trends. There is therefore important message for large tenants to examine their consumptions. A knowledgeable building manager can leverage on their core strength in energy efficiency and help his tenants to save energy and develop stronger owner and tenants business relationship.

Factors Influencing Energy Consumption In Building

There are two major groups of factors influencing the total energy consumption of buildings. They are:

1. Energy consumed by the physical building systems and elements in providing an internally desired environment. This group of factors includes the indoor environment settings, the various building services systems, and physical elements such as the envelope system.

2. Human factors such as the quality issues, habits and cultural background of the building users. This involves the thrift and attitude of building users, perception of owners, habits and educational standards of people and so on.

Researches of the 70s have shown that it is possible to bring about significant energy saving through improving building design and systems' development. This saving is frequently negated by building users. For example, in the case of residential buildings,