iSERV
Benchmark and data analysis

By

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Project websites:

Main website: http://www.iservcmb.info

Database website: http://www.iservcmb.eu

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Contents

Introduction

This document address the methodology to create the first set of benchmarking. The first set of values are also represented, for specific sectors and HVAC components.

Define different activities/subsystems benchmarking is a main output of the project. To reach the target a path was established; this is divided into:

A. Extended bibliography research to define the present state of the art and selection of the first set of benchmarks
B. Application of the selected set into the iSERV cmb database
C. Definition of new benchmarks, focusing on availability of hourly and sub-hourly data for different subsystem and Diagnosis values
D. Application of the new benchmarks, comparison with existing ones, feedback from users
E. Selection of new set of benchmarks and comparison.

First set of benchmarks for different sectors and subcomponents

The specific benchmark of HVAC sub-system/control will be developed in two different step: the first step is the usage of literature components system consumption for sector; the second is represented by the correction of those values based on the iSERV monitored data.

2.1 Bibliography research

Table 2 represents a list of the main articles analyzed for the benchmark purpose.

Almost all benchmarks analyzed should be separated in two groups: design data benchmarks and consumption benchmarks. Some of these are defined combining the two approaches.

We can conclude that all benchmarks presented are based on annual consumption, with few sub-metering cases.

The most interesting is the benchmark that combines data on system, building and occupation behaviour ("design data") and real consumption. An interesting approach [72, 73] is the collection of some characteristics for the same activities.

Of the 115 starting characteristics, most were found to have a statistically significant relationship to electric EUI in at least one census division, even though correlations were very small (this occurs in part due to very large sample sizes that are created when the CBECS weights are applied). These were refined down to 32 characteristics each of which had two properties 1) the characteristic had a statistically significant relationship to EUI in two or more census divisions, and 2) the characteristic provided a partial R *2 of at least 0.05 when correlated to electric EUI.*

[...] The characteristics are related to climate, the type of fuels used for heating and cooling, how the building is used, how it is operated and controlled, and what types of systems are utilized (heating, cooling, lighting, water heating, refrigeration).

The set of 32 characteristics were refined in an iterative process by removing those characteristics that were the least common and weakest predictors for the nine census divisions. This was an iterative process because the removal of one variable can affect the predictive ability of another and its statistical significance. The process produced 6 variables which were found to be the most common and correlated determinants of school electric use intensity in the nine census divisions. The two most common characteristics correspond to year of construction and the presence of walk-in coolers. The other four characteristics correspond to the use of electric cooling, the amount of natural gas used, the person responsible for the HVAC equipment, and roof construction.

Standard linear regression was performed on the final six variables to determine model coefficients for each census division. Models based on a small number of the strongest characteristics are simpler and are close approximations of estimates that an expanded model based on all significant variables would produce.

The aim of the benchmarking process is to give a standard approach for normalization of system consumption with respect to fundamental variables. Such variables will be different for different activities. While some variables are well established for some activity sector (as internal net surface, volume, climatic zone and working hours), other variables have to be statistically calculated with a covariance analysis.

Some activities demonstrated a particular correlation with specific values, as shown in Table 1.

Table 1: List of specific values for some activities

Activity	Specific variables to address	Notes
Office / Call center	N° of workers-n° of workstations	This value can be obtain by the internal electric load
Data center	Server consumption - n° of operations	
Supermarkets / Malls	Income – number of bills	This value can be measured by daily income or by the global amount of daily bills

Among the articles listed in Table 2, we chose the most interesting works, related to the purpose of our project, and did a critical analysis of each of them, as shown in the next paragraphs.

Table 2: List of publications collected

N°	Title	Year	Authors	Editor
1	Benchmarking Operation and Maintenance Costs of French Healthcare Facilities	2011	S. Sliteen, H. Boussabaine, O.Catarina	Emerald
2	Cost Savings by Application of Passive Solar Heating	2005	I.Spanos, M. Simons, K. L. Holmes	Emerald
3	Criteria for the Indoor Environment for Energy Performance of Buildings	2006	B. W. Olesen, O. Seppanen, A. Boerstra	Emerald
4	Energy Profiling in the Life-cycle Assessment of Buildings	2010	T. Crosbie, N. Dawood, J. Dean	Emerald
5	Estimating Buildings Energy Consumption and Energy Costs in Early Project Phases	2009	C. Stoy, S. Pollalis, D. Fiala	Emerald
6	Net Energy Analysis of Double Glazing for Residential Buildings in Temperate Climates	2001	T. Matthews, G. F. Treloar	Emerald
7	Validating Electric Use Intensity in Multi-use Buildings	2011	J. Elliott, A. Guggemos	Emerald
8	A Software Tool for Energy Audit Activities in Buildings	2008	A. Prudenzi, M. Di Lillo, A. Silvestri, M. C. Falvo	IEL
9	An Energy Efficient Clustering Algorithm for Event-Driven Wireless Sensor	2009	O. Buyanjargal, K. Youngmi	IEL
10	Building Energy-Saving Performance Control Theory and Application Research Based on Simulated Annealing Algorithm	2011	L. Hui, Z. Jing-xiao, Y. Chong-wang	IEL
11	Control, Estimation and Optimization of Energy Efficient Buildings	2009	J. Borggaard, J. A. Burns, A. Surana, L. Zietsman	IEL
12	Duty-Cycling Buildings Aggressively, Next Frontier in HVAC Control	2011	Y. Agarwal, B. Balaji, S. Dutta, R. K. Gupta, T. Weng	IEL

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N°	Title	Year	Authors	Editor
13	G-REMiT An Algorithm for Building Energy Efficient Multicast Trees in Wireless ad hoc Networks	2003	W. Bin, S. K. S. Gupta	IEL
14	Minimizing HVAC Energy Consumption Using a Wireless Sensor Network	2007	Y. Tachwali, H. Refai, J. E. Fagan	IEL
15	Reducing Energy in Buildings by Using Energy Management Systems and Alternative Energy-saving Systems	2011	O. Zavalani	IEL
16	Simulation of HVAC Systems Energy Consumption	2006	C. Teodosiu, I. Colda, C. Lungu, A. Damian	IEL
17	The Analysis of the Energy Efficiency of Refrigeration Stations in HVAC	2009	D. Xiaotong, Q. Xiaomei, A. Maoliang	IEL
18	Using Data Mining in Optimisation of Building Energy Consumption and Thermal Comfort Management	2010	G. Yang, E. Tumwesigye, B. Cahill, K. Menzel	IEL
19	A Method for Heating Consumption Assessment in Existing Buildings (Field Survey Concerning 120 Italian Schools)	2008	S. P. Corgnati, V. Corrado, M. Filippi	Elsevier
20	A Review of Bottom-up Building Stock Models for Energy Consumption in the Residential Sector	2010	M. Kavgic, A. Mavrogianni, D. Mumovic, A. Summerfield, Z. Stevanovic, M. Djurovic-Petrovic	Elsevier
21	An Investigation into the Heat Consumption in a Low-energy Building	2009	K. Wojdyga	Elsevier
22	Analysis of Variables that Influence Electric Energy Consumption in Commercial Buildings in Brazil	2010	M. M. Q. Carvalho, E. L. La Rovere, A. C. M. Gonçalves	Elsevier
23	Case Study of Zero Energy House Design in UK	2009	L. Wang, J. Gwilliam, P. Jones	Elsevier
24	Development of Energy Performance Benchmarks and Building Energy Ratings for Non-domestic Buildings (Primary School)	2008	P. Hernandez, K. Burke, J. O. Lewis	Elsevier
25	Energy Consumption and Potential Energy Savings in Old School Buildings	1999	V. Butala, P. Novak	Elsevier
26	Energy Consumption and the Potential of Energy Savings in Hellenic Office Buildings Used as Bank Branches	2011	G. N. Spyropoulos; C. A. Balaras	Elsevier
27	Energy Use in the Life Cycle of Conventional and Low-energy Buildings	2007	I. Sartori, A. G. Hestnes	Elsevier
28	Estimation Model and Benchmarks for Heating Energy Consumption of Schools and Sport Facilities in Germany	2011	E. Beusker, C. Stoy, S. N. Pollalis	Elsevier
29	Influence of Building Parameters and HVAC Systems Coupling on Building Energy Performance	2011	I. Korolijia, L. Marjanovic-Halburd, Y. Zhang, I. Hanby	Elsevier
30	Life Cycle Energy Analysis of Buildings : An Overview	2010	T. Ramesh, R. Prakash, K. K. Shukla	Elsevier
31	Methodology to Estimate Building Energy Consumption Using EnergyPlus Benchmark Models	2010	N. Fumo, P. Mago, R. Luck	Elsevier
32	Numerical Simulation of Cooling Energy Consumption in Connection with Thermostat Operation Mode and Comfort Requirements for the Athens Buildings	2011	C. Tzivanidis, K. A. Antonopoulos, F. Gioti	Elsevier
33	Study of the Potential Savings on Energy Demand and HVAC Energy Consumption by Using Coated Glazing for Office Buildings in Madrid	1998	J. Còrdoba, M. Macìas, J. M. Espinosa	Elsevier
34	The Analysis of Energy Consumption of a Commercial Building in Tianjin, China	2009	J. Zhao, N. Zhu, Y. Wu	Elsevier
35	Zero Energy Building – A Review of Definitions and Calculation Methodologies	2011	A. J. Marszal, P. Heiselberg, J. S. Bourelle, E. Musall, K. Voss, I. Sartori, A. Napolitano	Elsevier

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N°	Title	Year	Authors	Editor
36	A Concept of Capillary Active, Dynamic Insulation Integrated with HVAC System	2010	M. Bomberg	Springer
37	A Multi-objective Evolutionary Algorithm for an Effective Tuning of Fuzzy Logic Controllers in HVAC Systems	2010	M. J. Gacto, R. Alcalà, F. Herrera	Springer
38	A Multi-physical Simulation on the IAQ in a Movie Theatre Equipped by Different Ventilating Systems	2011	G. Petrone, L. Cammarata, G. Cammarata	Springer
39	A Simulation Environment for Performance Analysis of HVAC Systems	2008	N. Mendes, R. M. Barbosa, R. Zanetti Freire, R. C. L. F. Oliveira	Springer
40	Building a Business to Close the Efficiency Gap - the Swedish ESCO Experience	2010	K. Lindgren Soroye, L. J. Nilsson	Springer
41	Development of HVAC System Simulation Tool for Life Cycle Energy Management	2008	M. Ito, S. Murakami, M. Okumiya, S. Tokita, H. Niwa	Springer
42	Environmental Life-cycle Assessment of a Commercial Office Building in Thailand	2008	F. O. Kofoworola, S. H. Gheewala	Springer
43	Evaluation of Distributed Environmental Control Systems for Improving IAQ and Reducing Energy Consumption in Office Buildings	2009	D. W. Demetriou, H. E. Khalifa	Springer
44	Fuzzy Control of HVAC Systems Optimized by Genetic Algorithms	2003	R. Alcalà, J. M. Benitez, J. Casillas, O. Cordòn, R. Pèrez	Springer
45	Impact of Lifestyle on the Energy Demand of a Single Family House	2011	A. Korjenic, T. Bednar	Springer
46	Opportunities for Reversible Chillers in Office Buildings in Europe	2009	P. Stabat, D. Marchio	Springer
47	Overview of Energy Consumption and GHG Mitigation Technologies in the Building Sector of Japan	2009	S. Murakami, M. D. Levine, H. Yoshino, T. Inoue, T. Ikaga	Springer
48	Reducing Energy Use in the Buildings Sector (Measures, Costs and Examples)	2009	L. D. D. Harvey	Springer
49	Simulation of a Building and Its HVAC System with an Equation Solver (Application to Benchmarking)	2008	S. Bertagnolio, J. Lebrun	Springer
50	Simulation of a Building and Its HVAC System with an Equation Solver (Application to Audit)	2010	S. Bertagnolio, P. Andre, V. Lemort	Springer
51	Simulation-based Assessment of the Energy Savings Benefits of Integrated Control in Office Buildings	2009	E. Shen, T. Hong	Springer
52	Tools for Performance Simulation of Heat, Air and Moisture Conditions of Whole Buildings	2008	M. Woloszyn, C. Rode	Springer
53	Robustness of a Methodology for Estimating Hourly Energy Consumption of Buildings Using Monthly Utility Bills	2011	A. Smith, N. Fumo, R. Luck, P. J. Mago	Elsevier
54	Establishment of Energy Management Tools for Facilities Managers in the Tropical Region	2005	M. Haji-Sapar, S. E. Lee	Elsevier
55	Model-based Benchmarking with Application to Laboratory Buildings	2002	C. Federspiel, Q. Zhang, E. Arens	Elsevier
56	Office Buildings Efficiency and Capacity Benchmarks	2005	C. Stoy, S. Kytzia	Elsevier
57	Performance of a Five-storey Benchmark Model Using an Active Tuned mass Damper and a Fuzzy Controller	2003	B. Samali, M. Al-Dawod	Elsevier
58	Data Collection and Analysis of the Building Stock and its Energy Performance - An Example for Hellenic Buildings	2010	E. G. Dascalaki, K. Droutsa, A. G. Gaglia, S. Kontoyiannidis, C. A. Balaras	Elsevier
59	Virtual Building Dataset for Energy and Indoor Thermal Comfort Benchmarking of Office Buildings in Greece	2009	T. Nikolaou, I. Skias, D. Kolokotsa, G. Stavrakakis	Elsevier

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N°	Title	Year	Authors	Editor
60	Can Envelope Codes Reduce Electricity and CO2 Emissions in Different Types of Buildings in the Hot Climate of Bahrain ?	2009	H. Radhi	Elsevier
61	Benchmarking Success of Building Maintenance Projects	2010	W. M. E. Lam, P. C. A. Chan, W. M. D. Chan	Elsevier
62	A Study of Energy Efficiency of Private Office Buildings in Hong Kong	2009	W. Chung, Y. V. Hui	Elsevier
63	Benchmarking Energy Use Assessment of HK-BEAM, BREEAM and LEED	2008	W. L. Lee, J. Burnett	Elsevier
64	Evaluating the Scope for Energy-efficiency Improvements in the Public Sector : Benchmarking NHS Scotland's Smaller Health Buildings	2008	J. Murray, O. Pahl, S. Burek	Elsevier
65	Energy Efficiency Supervision Strategy Selection of Chinese Large-scale Public Buildings	2009	Z. Jin, Y. Wu, B. Li, Y. Gao	Elsevier
66	Benchmarking the Energy Efficiency of Commercial Buildings	2006	W. Chung, Y. V. Hui, M. Y. Lam	Elsevier
67	Benchmarking the Energy Performance for Cooling Purposes in Buildings Using a Novel Index-total Performance of Energy for Cooling Purposes	2010	W. Lee	Elsevier
68	The Characteristics and the Energy Behaviour of the Residential Building Stock of Cyprus in View of Directive 2002/91/EC	2010	G. P. Panayiotou, S. A. Kalogirou, G. A. Florides, C. N. Maxoulis, A. M. Papadopoulos	Elsevier
69	The Impact of Indoor Thermal Conditions, System Controls and Building Types on the Building Energy Demand	2008	S. P. Corgnati, E. Fabrizio, M. Filippi	Elsevier
70	Experimental Investigation of Utilizing TLD with Baffles in a Scaled down 5-story Benchmark Building	2011	S. M. Zahrai, S. Abbasi, B. Samali, Z. Vrcely	Elsevier
71	Energy Efficiency Benchmarks and the Performance of LEED Rated Buildings for Information Technology Facilities in Bangalore, India	2010	A. Sabaphaty, S. K. V. Ragavan, M. Vijendra, A. G. Nataraja	Elsevier
72	Energy Benchmarking in Commercial Office Buildings	1996	T. Sharp	ACEEE
73	Benchmark Energy Use in Schools	1998	T. Sharp	ACEEE
74	Development of a California Commercial Building Benchmarking Database	2002	S. Kinney, M. A. Piette	ACEEE
75	Building Performance Analysis (Energy Benchmarking of New York State Schools)	2004	G. Coleman, C. Afshar	ACEEE
76	Empirical Benchmarking of Building Performance	2006	P. Bannister, A. Hinge	ACEEE
77	Energy Efficiency Indicators in the Residential Sector. What do we Know and what has to be Ensured?	1997	R. Haas	Elsevier
78	Energy Use in Commercial Buildings in Hong Kong	2001	P. C. H. Yu, W. K. Chow	Elsevier
79	A Study of Energy Performance of Hotel Buildings in Hong Kong	2000	S. M. Deng, J. Burnett	Elsevier
80	Energy Analysis of Commercial Buildings in Subtropical Climates	2000	J. C. Lam	Elsevier
81	Energy Performance Criteria in the Hong Kong Nuilding Environmetal Assessment Method	1998	F. W. H. Yik, J. Burnett, W. L. Lee	Elsevier
82	Benchmarking the Energy Efficiency and Greenhouse Gases Emissions of School Buildings in Central Argentina	2000	C. Filippìn	Elsevier
83	Simulation of Ventilated Facades in Hot and Humid Climates	2009	M. Haase, F. M. da Silva, A. Amato	Elsevier
84	What is Energy Efficiency ? Concepts, Indicators and Methodological Issues	1996	M. G. Patterson	Elsevier

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N°	Title	Year	Authors	Editor
85	Energy Efficiency - A Critical Review	2006	H. Herring	Elsevier

2.1.1 A study of energy efficiency of private office buildings in Hong Kong

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At the beginning of this article, the authors show that the previous works made to study the energy efficiency of buildings were not able to establish an objective and normalized consumption value, such as to be considered as a comparable reference. Meaning that all these studies did not consider enough variables, even though they were able to establish the Energy Use Intensity, a parameter measured in MJ/m^2, normalized only by the extension of the area. Chung and Hui wanted to include a lot more variables in order to establish an energy consumption value well normalized and easy to understand and use.

In order to reduce the operating field and make the data collection easier, they chose to consider only office buildings.

Some of these variables are easy to determinate (degree-day of the region, building age, user number, type of technology, operation hours of the heating/cooling system) while others need to be monitored in order to be measured. In this second group, the users' behavior and the maintenance factor are considered the most important but even the most difficult to measure; for this reason it was established a rating score to be assigned when the following 'good occupants' operations or maintenance practices were observed:

* Turn off lighting when not in use;

* Turn off air-conditioning when not in use;

* Turn off other equipment, not mentioned above, when not in use;

* Have an effective energy-monitoring and targeting system in order to save energy;

* Perform a proper energy audit, and implement energy conservation measures for the purpose of saving energy;

* Plan a regular maintenance program, and supply an easy-to follow inspection manual for maintaining the efficiency of the lighting system;

* Plan a regular maintenance program, and supply an easy-to follow inspection manual for maintaining the efficiency of the HVAC system;

* Plan a regular maintenance program, and supply an easy-to follow inspection manual for maintaining the efficiency of other building services system not mentioned above;

* Have an easy-to-follow manual detailing operation methods, instructions and standard control settings for the HVAC system.

Since the benchmarking study concentrated on private offices and possible improvement targets of energy efficiency, the construction factors were not considered.

As the base for their work, the authors used a benchmark study of the energy efficiency of private office buildings that was conducted in Hong Kong in 2002 because energy efficiency was declining. In the study, private office buildings were divided into five user groups. For each group, a multiple regression model was developed to find the relationship between Energy Use Intensities (EUIs) and other factors, such as operating hours, for normalization and benchmarking purposes. The model was the following:

$$EUI_{net} = a + \sum_{i=1}^{n} b_i \times \left(\frac{x_i - \bar{x}_i}{S_i}\right) + \varepsilon$$

Where a is the EUI measured, $b_i, \ldots b_n$, are the regression coefficients, x are the different variables and ε is the random error.

The authors of the article made use of the regression results to study the energy efficiency of private office buildings by different grades. In Hong Kong, office buildings are divided into three grades (A, B, and C) based on the quality of the facility, which is reflected in rental values; a Grade A building denotes expensive luxury, while a Grade C building denotes base services and consumption. Different management systems are also at work in the different grade buildings. For example, Grade A office buildings normally hire building management teams to take complete care of their buildings, while the owners of Grade C office buildings may provide adequate management by hiring building management agents who manage other Grade C or B buildings at the same time. Hence, the authors established that it is necessary to study the energy efficiency by office grades.

The bench-marking study of 2002 divided the private offices into five user groups: A1(CS/AC),A2(Tenant/AC),A3(CS/noAC),A4(Tenant/noAC), and A5(Whole).

- A1(CS/AC) denotes an air-conditioned building whose common services are looked after by a building management team;
- A2(Tenant/AC) denotes an individual tenant unit in a building with central air-conditioning provided by the common services;
- A3(CS/no AC) and A4(Tenant/no AC) denote the common service and the individual tenant unit in an office building without central air-conditioning respectively;
- A5(Whole) denotes a building with central air-conditioning used entirely by its owner.

Roughly, A3(CS/no AC) and A4(Tenant/no AC) belongs to Grade C. A1(CS/AC) and A2(Tenant/AC) may belong to either Grade A or Grade B. Obviously, A5(Whole) must belong to Grade A offices. With the results of this matching the authors used the normalization and regression results of the benchmarking study to study the energy efficiency by different grades.

The results of this work are shown in Figure 1, which shows the summary of the normalized EUI for each user group and in Figure 2, which shows the increasing trend of the usage of different grades of building offices. Overall, the authors found that the EUI of Grade A buildings is the highest, indicating that Grade A office buildings use more energy than the other grades per meter square. It is also clear (Figure 2) that the floor area of Grades A, B and C is increased by about 70%, 70%, and 32% respectively, which suggests that the increasing energy consumption of office buildings is due to the increasing usage of Grade A and B offices.

Moreover, the floor area of Grade A office is approximately equal to the sum of the floor area of Grades B and C. Usage data also suggests that Grade A offices consume over half of the total energy use in office buildings annually.

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Summary of the normalized EUI for each user group.

	Normalized EUI (MJ/m^2)				
	Grade A/B		Grade C		Grade A
	A1 (CS/AC)	A2(Tenant/ AC)	A3 (CS/no AC)	A4(Tenant/ no AC)	A5 (Whole)
Min.	361.02	278.57	109.68	271.43	547.98
Average	786.89	450.13	159.02	561.39	1129.68
Max.	1377.63	726.61	258.45	1090.61	1633.68
a	924.90	450.00	130.00	560.00	1131.60

Figure 1: Stock of office floor area of Grades A, B, and C.

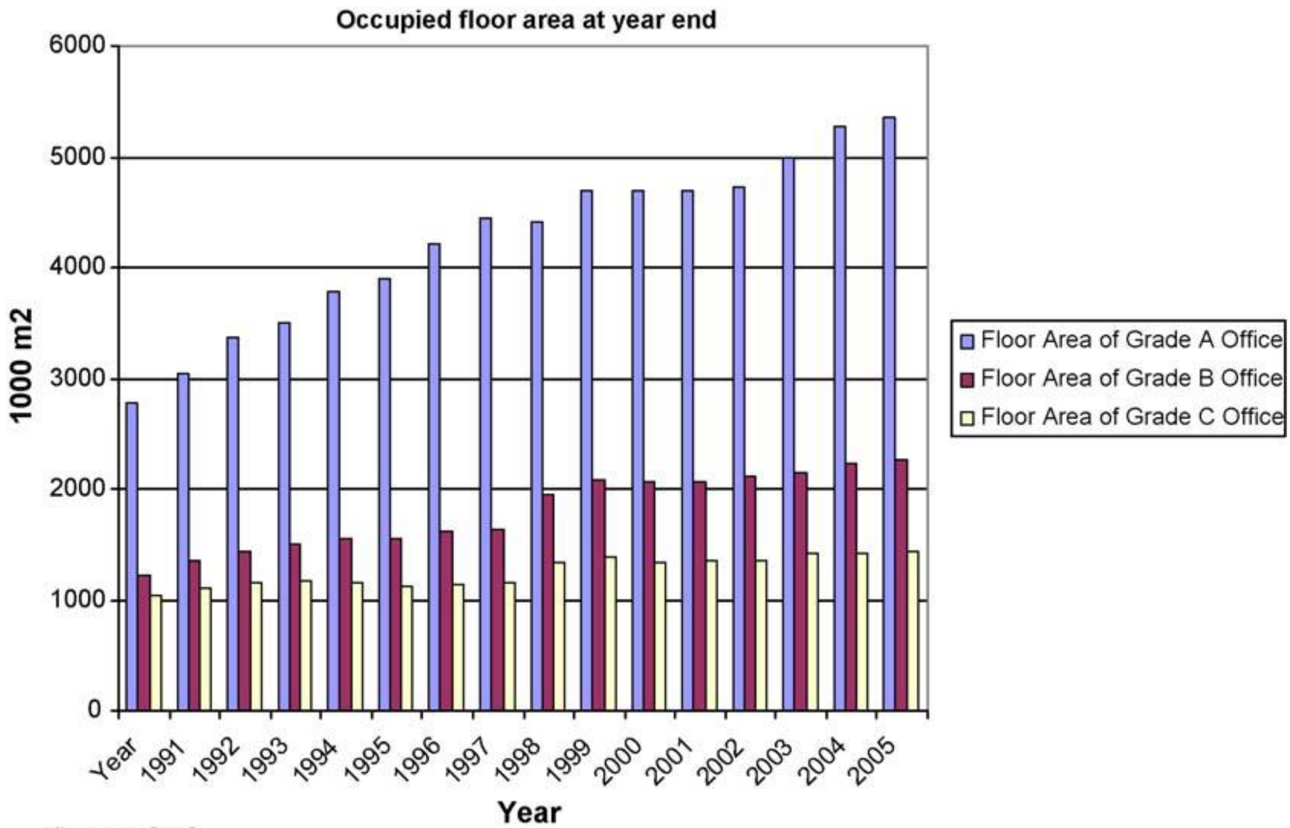

Figure 2: Trend of the usage of different grades of building offices

The most important results are shown in Table 3, which shows the summary of the observed EUI. Compared with the normalized EUI in Figure 1 they did not find any significant differences in the average levels of all the user groups. However, the interval of the normalized EUIs is smaller than that of the observed one. This result was expected while the normalization process was being used to find the average normal energy consumption level for each observation.

	Observed EUI (MJ/m^2)				
	Grade A/B		Grade C		Grade A
	A1(CS/AC)	A2(Tenant/AC)	A3(CS/no AC)	A4(Tenant/no AC)	A5(Whole)
Min.	373.44	185.37	65.95	209.83	506.49
Average	837.34	450.61	154.59	560.84	1131.57
Max.	1813.26	943.50	300.60	1138.56	1689.92
Median	719.84	425.16	139.93	517.28	1271.57
Std. Dev.	400.18	170.76	64.57	233.01	367.21

Table 3: Summary of the observed EUI for each group

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		Grade A/B		Grade C		Grade A
	R-square	0.3710	0.3628	0.5082	0.4669	0.7387
Factor Type	Significant factors	A1 (CS/AC)	A2 (Tenant/AC)	A3 (CS/no AC)	A4 (Tenant/no AC)	A5 (Whole)
People	Occupants behaviour and Maintenance factor	NS	−54.3 (26.7)	NS	−47.6* (41.2)	NS
	Indoor temperature set point	NS	NS	−43.9* (13.4)	NS	NS
Energy end-use	Chiller equipment type	−122.8 (63.1)	NA	52.6*,B (17.5)	NS	NS
	Air side distribution type	NS	NS	NS	NS	NS
	Air side control[B]	NS	NS	NS	NS	−385.0* (140.5)
	Water side distribution type	NS	NA	NA	NA	NS
	Water side distribution control[B]	−205.0* (67.703)	NA	NA	NA	NS
	Lighting equipment	NS	NS	−18.1 (8.9)	−100.4* (35.8)	NS
	Lighting control[B]	NA	NS	NS	NS	−292.0* (103.9)
	Office equipment	NA	67.7* (26.7)	NS	137.6* (39.6)	532.9* (204.9)

NS = not significant in the stepwise multiple regression model; NA = not applicable; B = binary measure; the value in parenthesis( ) = standard error.
* Significant at the 5% level.

Table 4: Regression results of each user group.

Table 4 reports the results of the stepwise regression models for each subgroup. The authors only reported two types of factors, people and energy end-use, because the other types of factors, along with the office equipment factor, are the inputs of daily business operations in an office. They consider the people factors to be behavioural, and energy end-use factors to be based on building engineering. It is expected that there is no single significant explanatory factor influencing all the user groups.

This study allowed the authors to make some useful conclusions: improving the energy efficiency of Hong Kong office buildings depends primarily on energy usage in Grade A office buildings, where the use of air side and lighting control should be promoted; the second statement is based on the regression results.

For Grade A/B rentals, the efficiency of their energy technologies should be addressed and there is no need to do anything in Grade C office, because they will improve energy efficiency based on the

fact that they pay their own utility bills.

Some main analogies could be find in this paper with our purpose:

1) The construction features of the building were not taken in consideration;
2) The variable measurement and the relative data collection is normalized and exhaustive;
3) The stepwise regression models demonstrates to be suitable.

On the other hand the main difference is the fact that the study was made to offer a method to forecast building consumption instead of create a benchmark to compare with. For this reason some variables considered will not apply on iSERV benchmark calculation method (e.g.: type of maintenance contract).

2.1.2 Benchmarking the energy efficiency of commercial buildings

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The theoretical base of this work is the same of the previous article, in fact it is made by the same authors and it is located in the same place, Hong Kong. The subject of the study are the commercial buildings, specifically supermarkets, in particular those which have an area bigger than 75 m², in order to analyze similar buildings.

The comparison model is the same of the previous article but this time the authors are concentrating on the aspects not well clarified, as the method to choose the factors influencing the EUI, their graphical representation and the practical realization of benchmarking. This paper describes a benchmarking process for energy efficiency by means of multiple regression analysis, where the relationship between energy-use intensities (EUIs) and the explanatory factors (e.g., operating hours) is developed. Using the resulting regression model, these EUIs are then normalized by removing the effect of deviance in the significant explanatory factors.

After the data-collection exercise, actuated as explained in the previous article, the benchmarking process have been divided in three steps: (1) climate adjustment of EUI (MJ/m^2) by degree–day normalization; (2) regression model building for discovering the relationship between the climate adjusted EUI and the significant factors corresponding to building characteristics; and (3) normalization of the climate-adjusted EUIs for the significant factors to form a benchmark table. In step 3, the bootstrapping technique is applied to provide an efficient percentile-estimation for small samples.

Subsequently the authors chose nine significant factors among those of the benchmark table, preferring the most significant ones. This step, which is very important to make a real and valid analysis, involves the analysis of the determination coefficient (R^2): a value that can change from 0 to 1, which represents the proportion between the data variability and correctness of the model.

After this analysis the authors were able to choose the nine factors listed in Figure 3.

Factor	Exogenous variable	Exogenous variable name
Age	X_1	Building age
Occupancy	X_2	Internal floor area
	X_3	Operational schedule
	X_4	Number of customers/year
People	X_5	Occupants' behaviour and maintenance factor
	X_6	Indoor temperature set-point (summer)
Energy system	X_7	Chiller type of equipment
	X_8	Lighting equipment
	X_9	Lighting control

Figure 3: Significant factors for normalization of energy consumption

For each of these factors the authors calculated and measured the minimum, maximum and medium EUI and the SD as shown in Figure 4.

Summary statistics of survey result

Xi	Min	Max	Mean ($\bar{X}_i$)	SD (S_i)
X_1	3	42	21.133	11.292
X_2	76	640	219.37	175.76
X_3	4380	8760	7071.9	1777.9
X_4	36500	912500	441.350	229.057
X_5	0	6	1.9667	1.7317
X_6	20	26	22.938	1.5713
X_7	2.3	2.5	2.42	0.0714
X_8	49.279	100	72.101	8.057
X_9	0	0.2	0.034	0.0627

Figure 4: Summary statistics of survey results

The authors used these factors in the regression model, similar to the previous study, as follow:

$$\text{EUI} = a + b_1 x_1^* + \ldots + b_9 x_9^* + \varepsilon = a + \sum_{i=1}^{9} b_i \left(\frac{x_i - \bar{x}_i}{S_i} \right) + \varepsilon,$$

The minimum, maximum, average and the SD of the supermarket EUIs (MJ/m^2/year) are 1802, 12442, 5852.6 and 2591.2, respectively, for 30 observed supermarkets with degree-days normalization. Comparing with other survey results, the average value was much greater than that of the UK Energy Benchmark with 3960 MJ/ m^2/year (based on 207 supermarkets with degree–days normalization only), and Energy Star with 3526 MJ/m^2/year (based on 88 supermarkets calculated with Sharp method). The big differences should be due to the compact size of Hong Kong supermarkets and different operating conditions.

The prediction error of the regression model, coming from the statistical analysis on 30 commercial buildings, is shown in Figure 5.

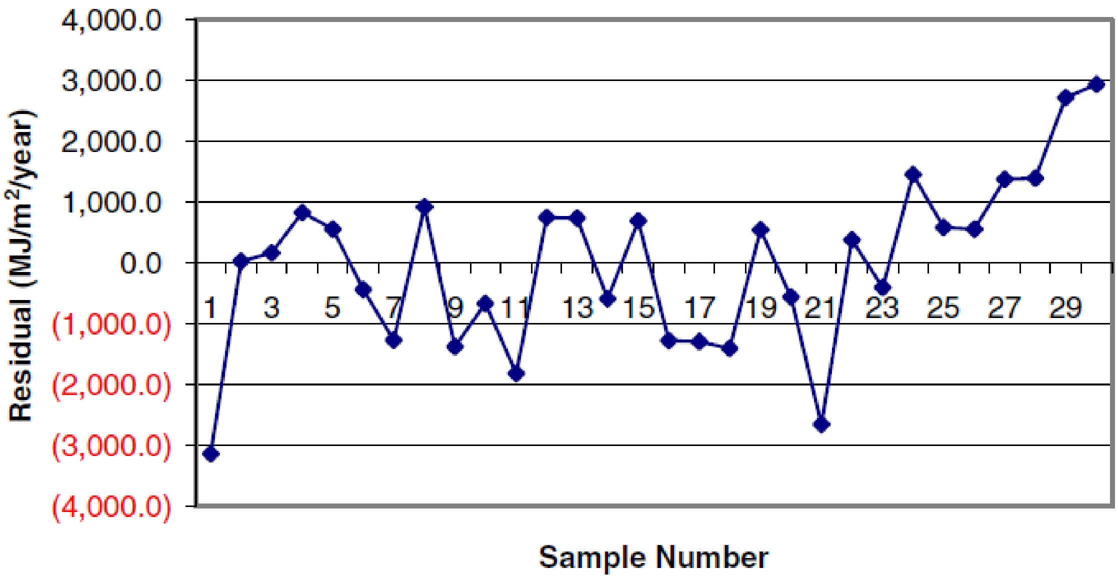

Figure 5: Graph of the prediction error

By using a bootstrap method applied operated by a software, the authors were able to calculate the percentile distribution estimation, as shown in Figure 6.

Percentile	EUI_{norm} (from bootstrapping results)[a]	EUI_{norm} (from sample data)[b]
10	3949	4045
20	4584	4571
30	5035	5193
40	5474	5421
50	5943	6026
60	6313	6415
70	6526	6548
80	6771	6687
90	7305	7253

[a] EUI_{norm} (from bootstrapping results) is calculated from the observed EUI_{norm} using the bootstrapping function in S-plus.
[b] EUI_{norm} (from sample data) is obtained by ranking the observed EUI_{norm}.

Figure 6: Percentile distribution estimation

At the end of the article the authors analyse the difference between manageable and unmanageable factors. Manageable factors, such as occupant behaviour, are the ones that can be modified through better energy-management practices or increased efficiency in energy systems. On the other hand, unmanageable factors are physical indicators that are not readily amenable to energy-management practices or the systems efficiency-improvements.

They consider a regression model including only the unmanageable variables in order to benchmark the subgroup's energy-consumption accordingly if we set all the manageable variables to be equal to their average value. For example, the subgroup benchmarking score can be obtained by setting the occupants' behaviour value at 1.97. Hence, by making use of the regression model, with only the unmanageable variables, the Government can set improvement targets for significant explanatory factors in each energy-consuming group. The discussed approach has been adopted to develop the on-line benchmarking system.

The main point of this article is the definition and analysis of manageable and unmanageable factors. The iSERV methodology for benchmark calculation need to take into consideration almost only unmanageable factor, to create a set of maximum consumption target for different activities and components.

2.1.3 Establishment of energy management tools for facilities managers in the tropical region

Majid Haji-Sapar and Siew Eang Lee

Department of Building, School of Design and Environment, National University of Singapore

This work explained how it was developed a model of *benchmark* in Singapore, with the ultimate aim of establishing a classification of energy efficiency in commercial offices within the same country. This project follows the recent world trend (the article dates back to 2005) that seeks to minimize energy consumption through multiple possible routes.

The authors have found it necessary to draw up a database, initially composed of only sixteen commercial buildings, and use it to extrapolate the energy consumption, either general or particular, based on individual facilities, including air conditioning, lighting, elevators, escalators, ventilation systems and heating systems.

In the article the importance of data collection have been stressed, specially from the private companies point of view. In fact, for the success of the benchmark, it is required an energy audit in which the company and the research team collaborate to analyze and catalogue all strategic points, to ensure a detailed study of consumption and to detect every critical issue. This study can be implemented with questionnaires, measurements, evaluations of experts. The sequence of steps required to implement this phase is represented in

Figure 7.

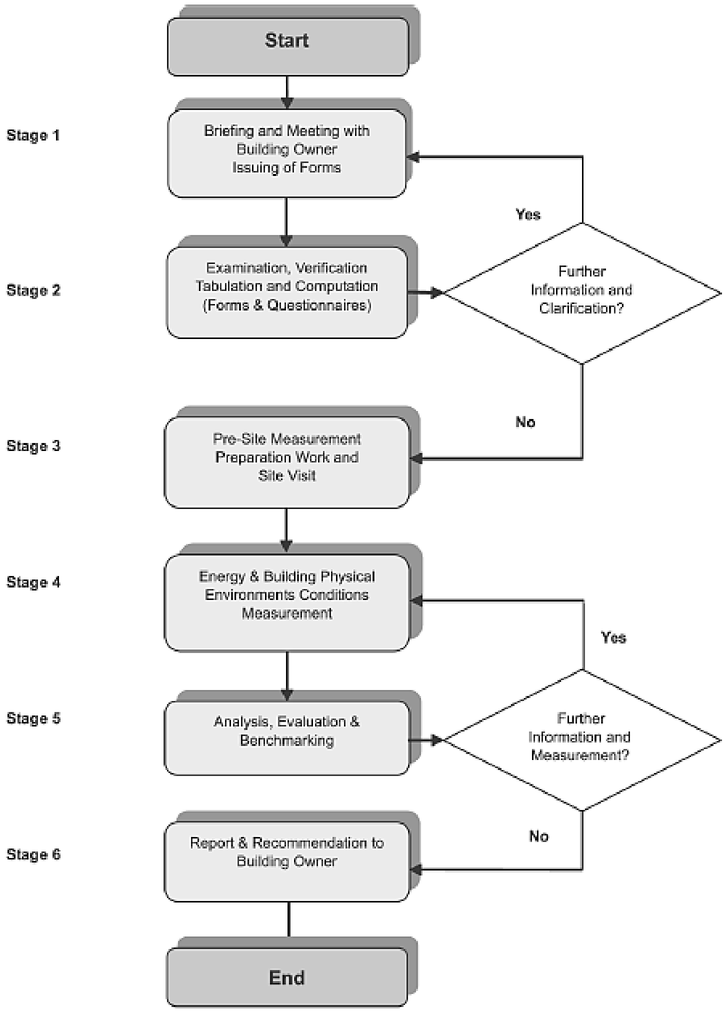

Figure 7: Energy audit methodology flowchart

Once the database was built and implemented, it has been possible to put the benchmark model created on a government national website, suitable for all office buildings, both private and public. Basically, by entering the values required from the graphical interface (which were collected by the internal energy audit), the user of the software will see a chart divided into three classes and he will see the point related to his consumption in the chart. The three classes are very simple and correspond to low, average and high level of energy efficiency. Moreover the software can produce detailed charts on total specific consumption, cooling and heating consumption, electricity consumption, and water consumption for cooling towers.

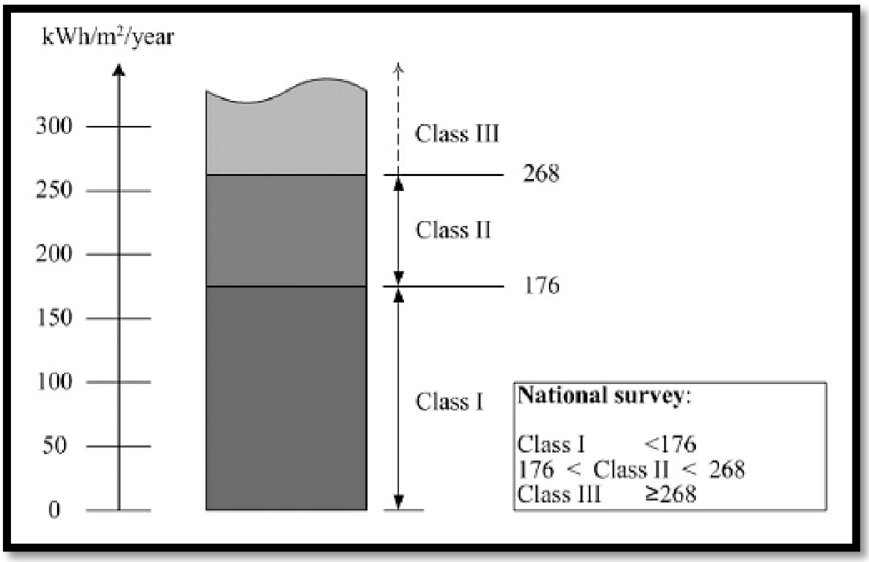

Figure 8: General consumption benchmark

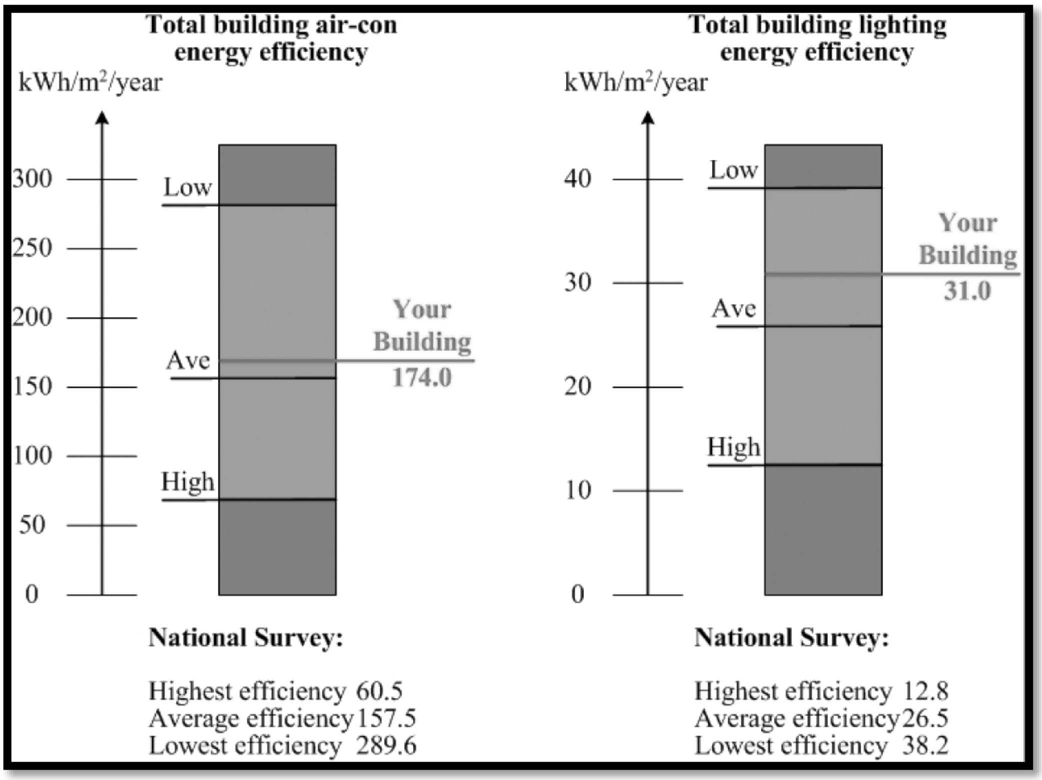

Figure 9: Specific consumption benchmark

In case of a proposed building, a developer can use the software to set targets for his design team. This verifiable target may be checked during the commissioning test stage. This ensures professionalism on the part of the design consultants to exercise design control and the final delivery of a set of performance targets. For further detailed design, the consultants may refer to specific consumption benchmarks. From the benchmark created, a facilities manager is able to set the energy design budget for the entire air-conditioning system and the lighting system, as well as other systems. This allows them to control system design and ensure that equipment and system selection are compatible with the target set. As for existing buildings, the system benchmarks shows clearly where the building has failed in relation to various classes of building and with particular reference to a services system. The energy services engineer can develop energy retrofitting strategies to optimize investment return and, if there are budget constraints, can handle the retrofitting work in stages to demonstrate the effectiveness of energy retrofitting project. A simple flow diagram describing the potential application of this management tool is shown in Figure 10.

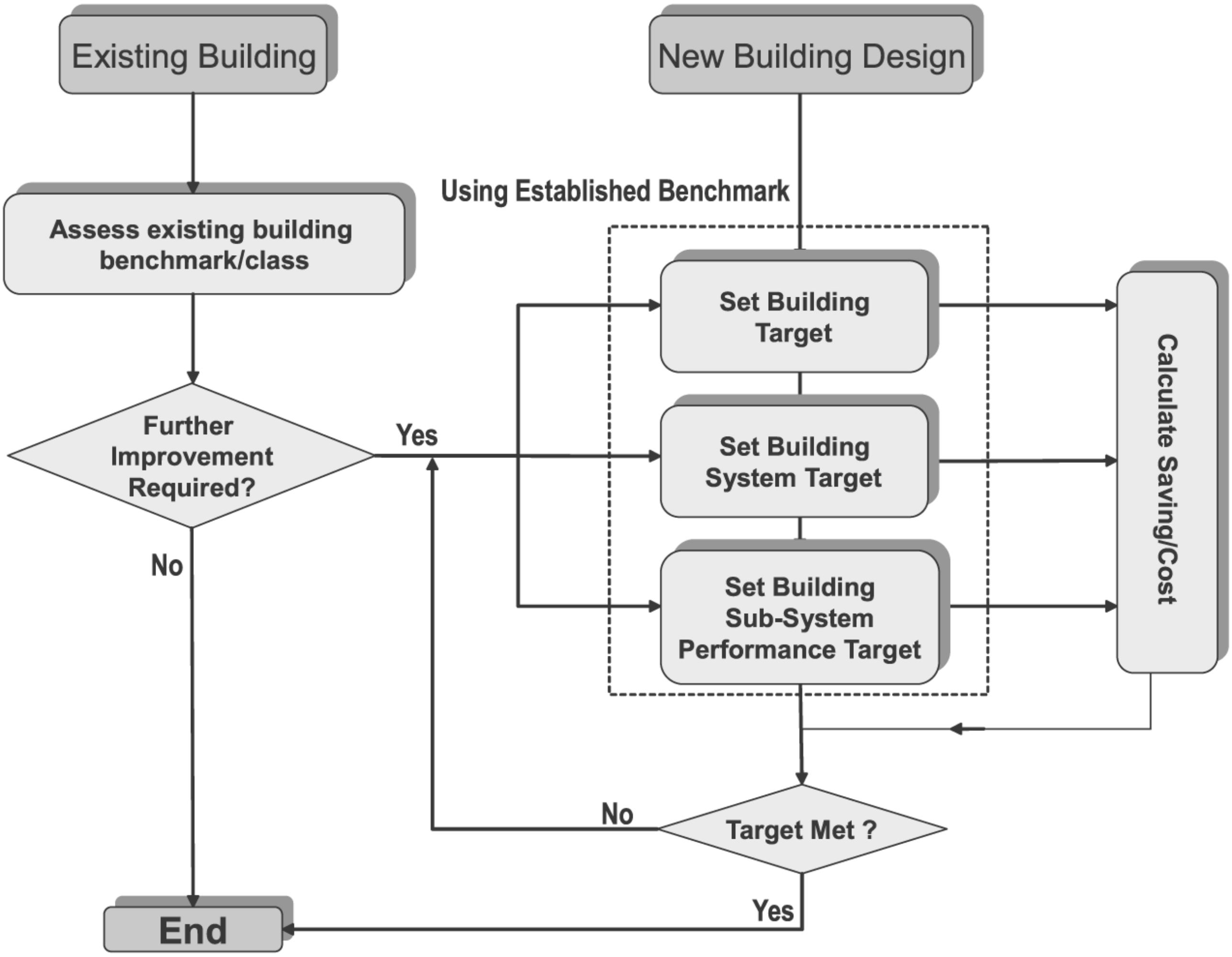

Figure 10: Flow diagram of management tool

The authors devote a paragraph to the economic benefits of the users of this model, noting that investments on innovative technologies are not financial return free; in fact, the payback period of this benchmark model is estimated between two and five years, with a minimum gain of 50% reinvested in energy management programs or new plants. Furthermore, in the last years the costs of an energetically efficient building are not far from those of any other building; therefore the convenience grows further.

Establishing this type of local energy management tool can help building professionals in estimating the saving potential of an existing building, cost recovery and financing requirements using the total/landlord/tenant energy performance benchmarking curves and using appropriate energy assessment and audit procedures to achieve the desired outcome. A performance target may be set for a short- or long-term performance of the building. If the services system energy data is available, the saving achievable from each of the systems can be determined using system benchmarking curves. Once the system's saving potential has been established, a building owner can prioritize an energy retrofitting project according to the extent of saving each system can achieve, and the return of investment may be calculated.

This study has the same aim of iSERV benchmark definition, nevertheless there are some major difference that make this methodology unsuitable to be applied directly. The most difficult stage is represented by the energy audit carried out by the same team or at least with the same methodology. Project iSERV define a brief methodology to fill a spreadsheet with the unique values that can be used in benchmark definition (in addition to energy metering and sensor logging), but it is not intended to be an energy audit. In addition, generally the energy audit are carried out by different professional workers so it will be really difficult to have standard results. Moreover, even if European and national project has defined a standard inspection methodology (as the HARMONAC IEE project) it resulted expensive and time consuming. iSERV benchmark definition was intended exactly to avoid the inspection in case of good performance of the HVAC system.

The financial analysis is a good point to stress out the importance of monitoring and benchmarking.

2.1.4 Model-based benchmarking with application to laboratory buildings

Clifford Federspiel, Qiang Zhang, Edward Arens

Center for environmental design research, University of California, Berkley CA, U.S.A.

In this work the authors created a coherent comparison model between similar buildings: laboratories. These buildings differ from the others on the high energy intensity, due mostly to the operation of special machines and HVAC systems, which must be more powerful than in normal buildings. Due to the particular sample selected, it was decided to develop a new benchmark model, mostly theoretical, that represents the minimum energy input necessary for the basic operation of the plant building.

At the beginning of the article the authors analyze some previous benchmarking studies on building energy efficiency. In particular they take into consideration the Sharp's method which, although does account for some functional requirements, many of the functional requirements that have a significant impact on energy use are not included (like temperature control, humidity control, ventilation rate, filtration efficiency). Another problem with existing benchmarking methods is that all current benchmarks are based on the performance of other buildings. They do not reflect the extent to which the energy efficiency could be improved because the entire population can make ineffective use of energy.

At the beginning of the article the authors consider two different approaches: the efficiency approach and effectiveness approach. The first, which is usually used to compare input and output, is not applicable to the development of a whole building energy consumption benchmark, because it is difficult to quantify the output, even if it can be defined. The output is not the energy consumption. It might be the comfort provided to the occupants or the work output of the occupants. The effectiveness approach involves a comparison with the benchmark and is, therefore, relevant to develop a whole building energy consumption benchmark. The key difference between the two approaches is that efficiency is a comparison of input and output, while effectiveness is a comparison of a key system variable (not necessary the output) with a well-defined calculable and, often, theoretically ideal benchmark.

The most used effectiveness approach is the E.U.I. but the authors refuse to use this metric for their study, because they think that it can be too variable for laboratory buildings. Part of the reason of this large variation is that because some of the buildings are not air-conditioned, because lightning efficiency varies, because plug and process loads vary and because the design of the air distribution system vary.

The authors preferred to study a benchmark that compensates for weather differences, design differences and usage differences. The objective was for the benchmark to be the energy consumption of an "ideal" building that consumes the minimum amount of energy required to achieve the same indoor temperature, humidity, lightning and ventilation conditions as the actual building. The energy consumption benchmark derived from the "ideal" is determined using mathematical models, so the method is called model-based benchmarking. This method has two parts. First the benchmark is computed and the actual energy consumption is compared with the benchmark. Then ratio of the benchmark to the actual consumption is an effectiveness metric analogous with other engineering effectiveness metrics such as heat exchanger effectiveness. The second part of the model involves a comparison of effectiveness of a particular building with that of a set of buildings and with the past performance of that same building. This part involves statistical comparisons. Since the benchmarking calculations compensate for functional requirements, it is possible to use model-based benchmarking to compare the performance of buildings with dissimilar features and functional requirements.

Basically all the real consumptions are compared with a dummy value of an ideal building where the efficiency is at the maximum level, energy consumption is minimal, but all other variables (internal temperature, humidity, lighting, ventilation, water) are identical to the real case. Therefore the model can optimize the energy consumption for the same final conditions of work, the same type of buildings and the same areas. This approach stems from the fact that in a laboratory, unlike residential buildings or offices, we can not expect to consume less energy, since the largest percentage of the energy is absorbed by working machines that have a constant power when full loaded.

To construct an ideal model of laboratory building they must necessarily make some approximations: the energy stored is zero, there is no input of energy from the sun, the use of sunlight needs to be maximized, the processing power of the machinery is set to the value of 0.11 W/m^2, the means of transportation (escalators, elevators) have a negligible contribution. The process produces two main outputs: effectiveness of the electric consumption and effectiveness of the fuel consumption, as reported in Figure 12.

No.	Initial calculations	Properties calculated hourly	Load-related calculations
1	Indoor pressure	Outdoor humidity ratio	Minimum outdoor air flow rate
2	Indoor vapor pressure	Outdoor specific enthalpy	Maximum outdoor air flow rate
3	Indoor humidity ratio	Outdoor air density	Cooling loads (lab and non-lab)
4	Indoor enthalpy	System status (on or off)	Fan power (lab and non-lab)
5	Indoor density		Pump power (lab and non-lab)
6	Fume hood flow rate		Heating load (lab and non-lab)
7	Exhaust flow rate of lab		
8	Occupant loads		

Figure 11: Calculated variables and constant

Once the method has given the two factors, calculated with the approximation assumptions, the authors refer to a statistical study, according to which, if the difference between the actual consumption and those calculated by the model is normally distributed, then a realistic comparison is possible. The authors used a

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set of parametric and non-parametric statistical methods to analyze the performance of the model-based benchmarking and compare it with existing benchmarking methods. For each method, two different correlation coefficients were computed. They were the Pearson product- moment correlation coefficient and the Spearman rank-order correlation coefficient. Figure 12 shows the square of the coefficients for each of the three methods when applied to 19 laboratory buildings on the UC Berkley Campus.

	Pearson coefficient, R^2 (%)	Spearman coefficient, R_s^2 (%)
Model-based method	41	55
Sharp's method	46	63
EUI method	40	52

Table 5
Comparison with outlier removed

	Pearson coefficient, R^2 (%)	Spearman coefficient, R_s^2 (%)
Model-based method	73	53
Sharp's method	54	58
EUI method	51	45

Table 6
Comparison with dissimilar building types

	Pearson coefficient, R^2 (%)	Spearman coefficient, R_s^2 (%)
Model-based method	43	41
Sharp's method	16	19
EUI method	22	18

Figure 12: Comparison of methods

This kind of model-based benchmarking will penalize buildings that use inefficient systems for energy consuming functional requirements or buildings that do not have laboratory space or that have very little laboratory space, because conduction and transmission heat transfer is a larger fraction of the heating and cooling load in those buildings. From the analytical point of view this method is very complex, but in extreme cases may be the only way to reach satisfactory results, even if in the article there is no reference to concrete uses the model. The model based benchmarking is definitely not suitable for simple comparisons between residential and commercial common buildings, even if the conclusions of the article refer to a less complex approach, suitable for any type of construction, but this statement comes without any concrete examples or explanations. It is an innovative method and far from simple comparison of energy intensity, but requires more research and maybe a simplified analytical approach.

The approach developed in this article will be useful for the iSERV benchmark definition for some specific reasons:

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1. effectiveness concept
2. objective method.

The effectiveness could be analyzed through a comparison between monitored components schedule and declared schedule. The benchmarks have to be calculated on effectively controlled HVAC system.

The objective method guarantees that the method minimize potential errors.

2.1.5 Benchmarking Energy Use in Schools

Terry R. Sharp

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The author of this work expresses his doubts towards a benchmarking implemented using an average between the consumption of a building typology derived from a government database, since he claims to be a superficial analysis that does not correspond to the real situation. For this reason he tried to implement a statistical model able to give, as output, a numerical value of the consumption related to many factors, such as gross area, degree-day, year of construction and others, in order to have as a more realistic result. The theory behind this method is similar to other articles analyzed but we must consider that Sharp has developed this model in 1998, eight years before Chung Hui, and it became the base to several subsequent works.

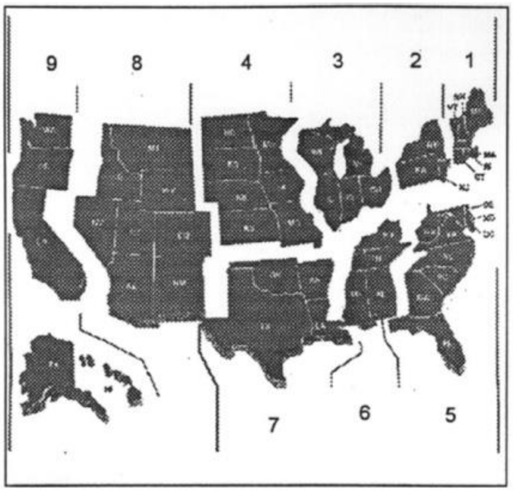

Figure 13: Territorial splitting defined by CBECS

The American author began his study taking data from a national database (the CBECS, *Commercial Buildings Energy Consumption Survey*): he analyzed the performance and energy consumption of 449 schools with a minimum gross area of 1000 internal square feet (about 93 m^2). These were chosen among 163000 schools in the United States as a sample for the statistical analysis. The United States' territory has been divided in nine different areas, from east to west; for each area it has been defined the number of schools belonging to the CBECS, the number of general buildings really present on the ground, the numerical value of the median of EUI and the average of EUI (Figure 14).

Census division	1	2	3	4	5	6	7	8	9
Number of buildings in CBECS database	21	55	69	21	74	29	75	22	83
Number of buildings in census division	5792	11907	17777	9777	22377	12012	29524	6613	46722
Median EUI (kWh/sf/yr)	4.8	4.9	4.7	4.4	7.5	8.7	7.4	7.7	7.3
Average EUI (kWh/sf/yr)	5.3	5.1	6.8	6.0	11.0	9.7	10.5	12.8	8.8
Location on distribution where average occurs, %	72	66	73	79	66	75	83	86	60

Figure 14: Electric use statistics for local government owned schools in the CBECS (medians and average are weighted values)

Also, a cumulative distribution of EUI schools has been built for each zone, defined starting from the government database. The second step concerned the definition of expected variables, useful to normalize the consumption value, in order to make it more objective and comparable: to do this, the author started from a shortlist of 32 elements (shown in Figure 15Figure 14), and then he determined six variables, which correspond to the most common ones present in the nine statistical distributions constructed previously. The elimination of the remaining variables was performed with the same analytical principle used, years after, by Hui and Chung, meaning that for each termination of a variable, the determination coefficient R2 has been analyzed. These are the six most common variables: the roof typology, the use of electricity for cooling, the amount of natural gas used, the behavior of the team responsible for HVAC systems, the year of construction and the presence of any cold rooms in the building. The last two have been defined as the most important.

Variable	Definition	Variable	Definition
CLIMATE5	Climate zone	NGHT15	Natural gas used for main heating
YRCON5	Year construction was completed	NGHT25	Natural gas used for secondary heating
HT25	Secondary energy used for heating	HWWATR5	District hot water for water heating
COOLP5	Percent cooled in 1992	RFGWI5	Refrig./freezer walk-in units in bldg.
WKHRS5	Total weekly hours open	FLUORP5	Percent lit by fluorescent lights
RFCNS3	Roof is shingles (not wood) [defined]	WIN5	Exterior wall insulation
NGBTUSE	Annual natural gas use-mBtu/sf [defined]	RDOTNF5	Reduction in other equipment off-hours
FDRMP5	Pct. floorspace commercial food prep.	EMCSCL5	EMCS controls cooling
CMPRMP5	Pct. floorspace computer rooms	EMCSLT5	EMCS controls lighting
PORVAC5	Space vacant for at least 3 months	DAYCTL5	Daylighting controls
LTHRS5	No. extra hours lighting equip. used	DEMMTR5	Electricity demand-metering
CDD655	Cooling Degree-Days (Base 65 F)	FKSUPL5	Fuel oil supplied
HTPHP5	Pct. heated by the heat pump	NWKER5	Number of workers
SLFCNP5	Pct. heated by individual space heaters	LTOHRP5	Percent lit during operating hours
BOILP5	Pct. heated by boilers	OPHVAC1	Person responsible for HVAC equipment is owner/manager [defined]
ELCOOL5	Electricity used for cooling		
ELWATR5	Electricity used for water heating		

Figure 15: Significant variable if related to the EUI

There are common characteristics that consistently cause a building's energy use to be higher than

in other similar buildings. Typical examples for office buildings are a high occupant density (the number of people per square foot), large amounts of electronic equipment such as computers, and long operating hours. A large database of individual buildings containing both energy use and characteristics data, such as the CBECS, can be used to identify the building characteristics that are the most common and significant

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drivers of building energy use. This has been done for office buildings using the CBECS database (Sharp 1996). This work performed a similar analysis for schools. In simple distributional benchmarking, energy use is normalized for floor area to get energy use per square foot and then the ranking (ordering by increasing EUI) is performed. By identifying the most important secondary drivers through analysis of energy performance data from existing buildings, it is possible to normalize for additional energy use drivers and improve upon our benchmarking ability.

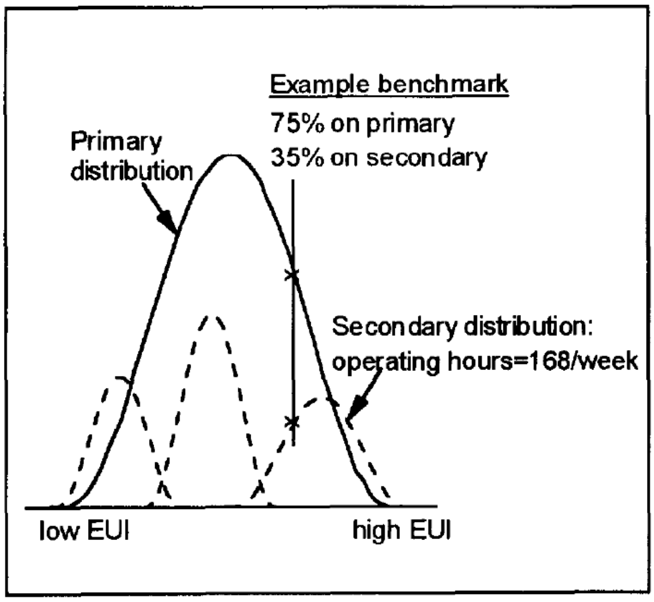

Figure 16: A distribution of buildings EUIs is made up of multiple secondary distributions

This concept of secondary drivers and their associated distributions is illustrated in Figure 16, which shows that a simple EUI distribution actually consists of multiple smaller, secondary distributions that can be created by grouping buildings by additional building characteristics beyond floor area. A building that may benchmark high in the primary distribution may actually be energy efficient if it happens to have a characteristic that increases energy use when present. By normalizing for the most important secondary characteristics, potential errors are further reduced and there is more confidence in the benchmarking results. The example benchmark shown in Figure 16 represents a building benchmarking at approximately 75% on the primary (floor area normalization) distribution. In this case, the buildings appear to be an excessive energy user. Thus, an owner or manager of a large number of properties trying to reduce a huge energy budget would want to make this building a higher priority in their efforts. If it turned out, however, that this building was operated 168 hours per week, the answer could be completely different.

Moving horizontally onto the secondary distribution for buildings with 168-hour operating weeks, the building is found to benchmark at around 30%. As a result, this building would likely no longer even be a priority for the owner's or managers' initial efforts.

The next step was the mathematical definition of the value of EUI normalized on the 6 most significant variables previously identified:

$$EUI_{norm} = a + b * YRCON + c * RFGWI + d * ELCOOL + e * NGBTUS + f * OPHVAC + g * RFCNS$$

CBECS definitions for the variables in the model are defined in Figure 15: RFGWI, ELCOOL, OPHVAC and RFCNS have a value of 1 when they are either true for or present within the building, and 0 otherwise. Coefficients and associated statistics for each census division model are given in figure 17. Note that individual census division EUI models are modelled on only two or three building characteristics. Yet, model R**2s, which are statistics related to how well a model can predict variations in the dependent variable, EUI, range from between 0.35 and 0.89. Expanding models to include other building characteristics did little to improve these R **2s. These results indicate that these simple 2- and 3-parameter models can explain most of the variation in electric EUIs that can be explained by all CBECS variables investigated.

Along with a statistical model, regression analysis produces equations that describe the confidence levels for predicted values that would result from applying the regression model. These equations can be used to determine the distribution of predicted EUIs that would result from applying the model. For a specific building, distributions of predicted EUIs will differ based on the model used (which census division) and the values of the building characteristics. Because of the wide variation in values of the important building characteristics identified, many different predictive distributions will result from applying the electric energy use models, and thus computational ability is needed. A spreadsheet-based benchmarking tool was developed for this purpose.

Census division	Model R**2	Model f stat.	Coeff. a	t stat.	Coeff. b	t stat.	Coeff. c	t stat.	Coeff. d	t stat.
1	0.47	2586	-8.714	-46.4	0.0106	53.7	0.271	28.3	0	
2	0.35	3234	-4.952	-39.3	0.0067	50.4	0.344	65.0	0	
3	0.42	4303	-7.027	-43.6	0.0088	51.8	0		0.318	46.9
4	0.76	10253	0.325	33.2	0		1.120	86.2	0.955	87.3
5	0.89	85590	0.000		0		0		2.433	402.94
6	0.35	3219	-11.684	-58.7	0.0143	68.7	0.206	21.5	0	
7	0.45	12211	-5.296	-35.7	0.0074	48.3			0	
8	0.64	3867	40.648	92.2	-0.0390	-86.9	-1.241	-70.2	0	
9	0.36	8362	1.757	351.2	0		0		0	

Census division	Coeff. e	t stat.	Coeff. f	t stat.	Coeff. g	t stat.
1-2	0		0		0	
3	0.00176	88.0	0		0	
4	0		0		1.52	117.4
5	-0.01422	-119.6	0		0	
6	0		0		0	
7	0		1.15	140.4	0	
8	0		-2.11	-97.4	0	
9	0.00543	71.3	0.44	50.1	-1.22	-120.9

Figure 17: Regression models and associated statistics by census division.

The distributional benchmarking, as defined by the Sharp is better than any other simple comparison between energy intensities of different buildings and, due to its construction it can be useful in the construction industry for a variety of reasons. Thanks to this method it is possible to identify the schools with serious plant problems, to ensure opportunities for cost reduction and technological improvements, to determinate the best efficiency and fuel consumption for a building, which becomes the target for other schools, to establish which is the minimum acceptable level for new school building. This tool can be downloaded from the University of Oak Ridge.

The analyzed method will represent a start point for the benchmarks definition, due to some similarity to our case:

1. Number of buildings analyzed
2. Normalization of data
3. Statistical method to define the key variables (not suitable to be discussed)
4. Applicable to other type of activity, changing the weight of the variables

The main difference are represented by the purpose of the analysis, Sharp created a model to evaluate energy consumption. Nevertheless the statistical model is suitable for benchmark definition.

2.1.5 Energy use in Ministry of Defence establishments

BRECSU

Department of the Environment, Transport and the Regions, U.K.

This work is not a real article but a booklet-study commissioned by the Ministry of Defence to analyze their internal consumption and, through a comparison, consider the critical points on which act to increase energy efficiency, to reduce consumption at the minimum target imposed by the government and to reduce emissions of pollutants. Furthermore, as shown so far, a careful and sustainable energy policy means, usually, to lower costs of operation and maintenance. The goals of this book are to show how to reduce power consumption and costs and to create an internal benchmark tool.

First of all it was required to make an internal comparison of consumption, as general as possible, since there were several types of buildings different in structure, function and size: offices, sports and recreational facilities, dormitories, shops, warehouses, hangars, gymnasiums, kitchens, canteens, garages.

The authors of this study have chosen a more analytical way, compared to the previous models analyzed: through nine numerical steps it is possible to determine two performance absolute indicators of energy, one for electricity and one for fuel, by which to compare the various types of existing buildings in the district of the British Ministry of Defence.

• First step: convert all types of measure units of the energy in kWh through the following table, in order to use in subsequent calculations a common unit of measurement.

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Fuel	Measured units	To get to kWh, multiply by
Electricity	kWh	1.0
Natural gas	m^3 kWh 100 ft^3	10.7 1.0 30.3
Gas oil (35 sec)	litres	10.6
Light fuel oil (290 sec)	litres	11.2
Medium fuel oil (950 sec)	litres	11.3
Heavy fuel oil (3500 sec)	litres	11.4
LPG/propane	tonnes	13 780
Coal	kg	9.0

Figure 18: Conversion factors for fuels

• Second step: divide the energy required for space heating by a factor (usually considered 0.76) with which it is possible to take into account the heat losses and leaks (if the technology include a boiler far from the heated point), and conversion between electricity and heat, (if the tecnology use an electrical system for heating or cooling).

• Third step: if possible it is recommended the division between energy used for the heating environment and the one used for the ACS.

• Fourth step: to determine the so-called "weather correction factor", which is a factor that takes into account the weather. This factor concerns only the energy for space heating, assuming the energy for the ACS is constant throughout the year. This factor is calculated as the ratio between the DD standard, calculated as the average of degree days in the last 20 years, and DD of this year, taken from any national or international site where there are regulations on this topic.

• Fifth step: to define an exposure factor, by using the table shown Figure 19.

Exposure factors	
Description of location	**Factor**
Sheltered The building is in a built-up area with other buildings of a similar height or greater surrounding it	1.1
Normal The building is on level ground in urban or rural surroundings. It would be usual to have some trees or adjacent buildings	1.0
Exposed Coastal and hilly sites with little or no adjacent screening	0.9

Figure 19: Exposure correction factors

• Sixth step: to add to total all of that energy is not used for heating or electricity.

• Seventh step: to determine the factor of occupation of the building, calculated as hours per year (or per month) in which the HVAC systems, and other technologies involved in the calculations, are operating in the building.

• Eighth step: to determine the gross area heated or cooled.

• Ninth step: to multiply or divide the energy consumed, both electrical and fuel, by the various factors specified or defined in the previous steps; then divide the value for the gross area in order to have two performance indicators measured in kWh/m^2 y.

After the description of the nine steps, the authors showed the worked examples: they divide the public buildings belonging to the Ministry in nine groups, depending on the activity implement in each group. For some group they identified several categories, depending on different factors. For example the office buildings have been divided in 3 categories depending on the ventilation system, while the sports buildings have been divided depending on their dimension and the presence of a swimming pool. Figure 20 shows the fossil-fuel benchmark for each group and each category.

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Category		Fossil-fuel benchmark (kWh/m²/annum)	Treated floor area (m²)	Calculated benchmark for annual fossil-fuel usage (kWh)
Offices	Category 1	110		
	Category 2	95		
	Category 3	143		
Sports	Category 1	133		
	Category 2	250		
	Category 3	360		
	Category 4	775		
Multi occupancy accommodation		225		
Workshops		175		
Motor transport facilities		317		
Stores/ warehouses	Category 1	187		
	Category 2	54		
Hangars	Category 1	444		
	Category 2	315		
	Category 3	220		
	Category 4	100		
	Category 5	Nil		
Messes with integral accommodation		235		
Training/education facilities	Category 1	114		
	Category 2	334		
	Category 3	123		
Sub-total using benchmarks				A

Electrically heated buildings

In the case of electrically heated buildings, the fossil-fuel benchmarks shown above need to be adjusted. Typically the benchmark would need to be multiplied by 0.76 or appropriate figure to take into account that there will be no flue gas or other heat losses from boilers in an electrically heated building.

Figure 20: Calculation for building-based fossil-fuel benchmark consumption

The problem, however, lies in the fact that for each building it is needed to calculate the factors with the same theoretical model and with the same hypo-thesis simplifying.

2.2 Conclusions on bibliography research

Generally authors intend benchmarks as indirect simulation to forecast energy consumption of buildings. Other authors defined benchmark for national legislation: those are the most similar benchmark to our purpose. One of the main outputs of the iSERV project is the creation of benchmark to provide end users with. Additionally, setting a maximum amount of energy that could be used for cooling could be a way to avoid a mandatory HVAC system inspection in those buildings which demonstrate sufficient performance. If we take this into account some normalization on data, proposed by different authors, are not suitable to create appropriate benchmarks. Those normalizations, needed for an indirect simulation, but not for our purpose, are typically:

1. Building age
2. HVAC system type
3. HVAC system maintenance contract

On the other hand stepwise regression models are valid and suitable to be used for our purpose and will represent the first method to create benchmark from iSERV collected buildings. Those buildings need to pass through an effectiveness analysis prior to populate the statistical sample. This analysis is somehow related to ECOs, but regards only the HVAC system schedule and control.

Effectiveness analysis

Due to the consideration written above, creation of representative benchmarks pass through a statistical analysis on a consistent sample of buildings. The consistent sample need to be validated: the aim is to find the right effectiveness for the right activity. For those reasons the system consumption will be firstly analyzed to verify if they are able to represent a good state of the art of effectiveness, with a minimum amount of efficiency (to be decided on the medium age of HVAC systems in the European Union).

These will be evaluated for different HVAC system aspect as:

A. Correct schedule and internal set points (effectiveness)
B. Overall consumption of the generation system VS energy delivered to the system (efficiency)

Those sections have votes in respect of statistical sample distribution for each considered aspect. On the beginning the mean will represent a vote = 5, while the upper quartile will represent 7.5 and the lower quartile 2.5.

The main idea is that just the buildings which have good votes in the two fields will be used to produce the baseline benchmark. A possible way is to put a correction factor, depending on the votes, to use also the data provided by all the buildings.

3.1 Calendar and work hours managing

Schedule is the first indicator of a well operated HVAC system. To allows analysis on different schedule profile it will be necessary to define the calendar and the hours (or sub-hours) in a unique and clear way.

The iSERV database allow the definition of different schedules for different days.

The hours are defined as:

- **O: Occupation hours** (effective work hours)
- **NO: Non occupation hours** (before the start time of work and after the end time)

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Days definition, similarly, are defined as working days and non working days, a specific analysis is made on the first working days after the weekend, because in some activities HVAC schedule has to be defined with some grade of pre-cooling or pre-heating.

3.2 Effectiveness analysis algorithms

The two main points of this section will be:

1) Which values will be used to calculate effectiveness parameter?
2) How to confront effectiveness parameters of different systems/buildings?

Effectiveness of a single system

This chapter will describe analysis on a single system, defined to get information on possible system wrong management. Those analysis are based on comparison with the declared/measured working hours: this will not apply to those activities that are h24 (e.g.: hospitals, data centers, etc…).

Due to the large amount of data, all values will be treated in statistical form. In general for all the values the monthly value will be calculated and then the yearly value will be shown as mean (weighted) and standard deviation. The system will display just the yearly value, while the monthly values are shown under request (2^{nd} level of report).

HVAC system, schedule analysis

The first set of output will allow end users to have consumption values on a specific basis (square meters, persons, square meters*working hours, etc...).

The system will made some calculation on the different values, considering occupation schedule, to show if schedules of HVAC sub-systems and of the HVAC system as a whole are correct.

Working hours consumption compared to non working hours consumption

This analysis will take into account the correct schedule of the system in respect of non working time.

The hourly consumption during non working hours will be summed on a monthly basis, and this value will be compared, on the same period of time, with the sum of all the working hours. The raito between those two values will be calculated for each month.

$$SOh_{m,j} = \sum_{i=1}^{n} [Oh_i(s_j)]$$

$$SNOh_{m,j} = \sum_{i=1}^{n} [NOh_i(s_j)]$$

$$NOratio_{m,j} = \frac{SNOh_{m,j}}{Oh_{m,j}}$$

$$NOratio, summarized(j) = \overline{NOratio} \pm sdev(NOratio)$$

The NOratio,summarized[1] will be a single value (with its standard deviation) which represents, for each subsystem, the behavior of the system related to non working hours. This ratio should be with a mean centered in 5-10% and possibye a high standard deviation, due to warm up time in some seasons. A small standard deviation will possibly represent an inaccurate schedule (no changin in warm up schedule with different seasons).

Warm-up, shut off and lunch time

This analysis is set up to understand how much the HVAC system consumes on a hourly basis in a day:

- First day warm up: Average hour of system start on Monday – average hour of occupation start
- WDe warm up: Average hour of system start on WDe – average hour of occupation start
- Last day shut off: Average hour of system shut off on last day of the week– average hour of occupation finish
- WDe shut off: Average hour of system shut off on Wde– average hour of occupation finish

Percentage values:

- Average first day warm up consumption/ Average first day consumption
- Average Wde warm up consumption/ Average Wde consumption
- Average last day shut off consumption/ Average last day consumption
- Average Wde shut off consumption/ Average Wde consumption

These calculations allow the user to understand how much energy intensive is the warm up time.

The analysis on the shut off time will give an advice on some misused or bad scheduled systems.

Depending on building and system, this will account for 3-8% of daily HVAC consumption.

Other analyses will be done on lunch-time HVAC system consumption, if applicable, with the purposes already described.

HVAC system, control diagnosis

Those analysis aim at verify if the system maintains the temperature/relative humidity set points and in how much time it need to reach the set points during warm up.

[1] J represent the sub system j, while m represent the month

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Efficiency of a system

Efficiency of the chiller

The distribution analysis during working hours will give useful information about the actual cooling needing of building/zone(s).

Generally a normal distribution is not a good evaluator to fit the experimental data about electric load of chiller and other variable loads; nevertheless more specific distribution fit will be needed for specific sub system.

$$\frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sigma\sqrt{\nu\pi}\,\Gamma\left(\frac{\nu}{2}\right)}\left[\frac{\nu+\left(\frac{x-\mu}{\sigma}\right)^2}{\nu}\right]^{-\left(\frac{\nu+1}{2}\right)}$$

Equation 1: density function of the t location-scale distribution

As seen in Figure 21, the input power for an electric chiller generally has a few peak points of probability density. In this case it has two clear peak points: a normal distribution does not fit accurately the real one. A t location-scale distribution appears to be more adequate: it does not identify the smaller peak, but clearly indicates the bigger one.

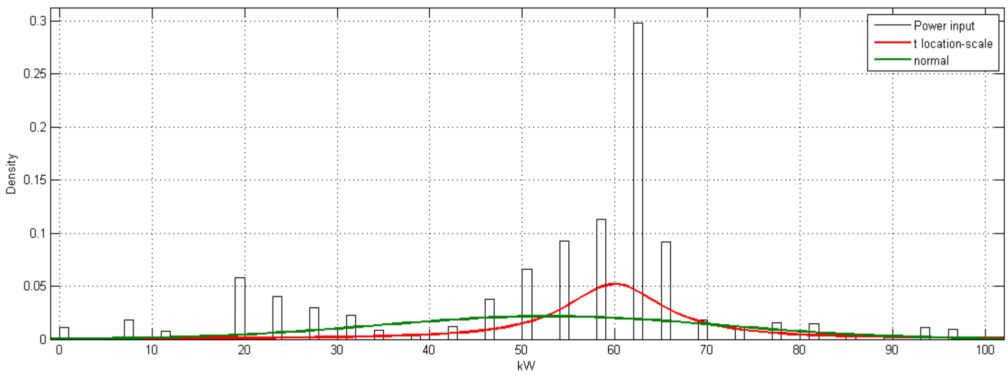

Figure 21: distribution fits for electric input of a Chiller

Mean: 59.9718

Parameter Estimate Std. Err.

mu 59.9718 0.0899609

sigma 6.21237 0.125072

nu 1.11212 0.0237817

The example figure shows that this system works for the most part of time at 60-65 kW, while its nominal power is 100 kW.

Depending on the number of chiller it will be get a vote in respect of the the difference between the nominal power of the smallest unit and the peak load class (in Figure 21 the class 55-65 kW represent the 50% of the total load). This will give a number about the possible efficiency of the system.

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