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Energy benchmarking for buildings and plant engineering

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ABSTRACT

Benchmarking is the continuous activity of identifying, understanding and adapting best practice and processes that will lead to superior performance. It is becoming a key methodology for the assessment of energy efficiency opportunity. The process of energy benchmarking is very useful not only to building operation and management, but also to plant engineering and maintenance. By benchmarking the energy use, it is possible to set targets for promoting best practices and achieving better energy efficiency in buildings and industrial facilities.

This research paper describes the basic principles of energy benchmarking and explains its significance to building facility management and plant engineering. As energy is important to every society and organization, it is believed that the benchmarking process can help evaluate performance, support decisions and facilitate improvements. The important issues and considerations for the implementation are discussed. It is hoped that more people can understand and make use of the benchmarking techniques to achieve sustainable facilities and plant engineering.

Keywords: Energy benchmarking, buildings, plant engineering, Hong Kong.

1. Introduction

Benchmarking is a continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as best practices for the purpose of organizational improvement (Spendolini, 1992). It is a business tool that has blossomed in the 1980s and is now widely used in total quality management (TQM) for comparing performance and identifying improvement opportunities (Stapenhurst, 2009).

Basically, a "benchmark" is a reference or measurement standard used for comparison. "Benchmarking" is the continuous activity of identifying, understanding and adapting best practice and processes that will lead to superior performance (Wireman, 2004). It is the process of comparing one's business processes and performance metrics to industry bests and/or best practices from other industries. Figure 1 shows a typical benchmarking process.

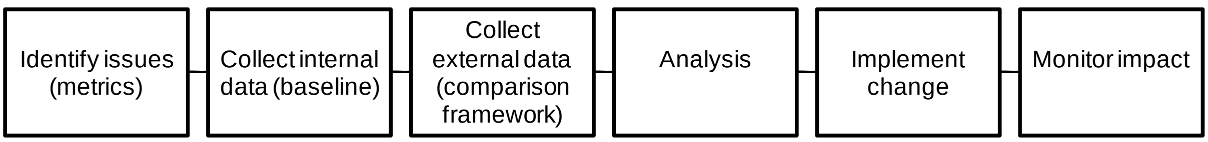

Figure 1. Typical benchmarking process

For building and facility management professionals, benchmarking is a strategic management tool which allows operating costs or other metrics to be assessed against similar properties, so as to determine how a given property or portfolio performs relative to its peers (Padavano, 2004). Through detailed comparative analysis, the benchmarking process can identify areas for improving operations and management by trimming costs or adjusting service levels. It can also provide essential information and data to enable preparation of an operating budget for energy management and building maintenance (Mull, 2001).

Since operating costs and expenses are a significant concern to building and facility managers, buildings can be benchmarked against themselves to indicate the status and performance of energy efficiency (Energy Star, 2007). This method can verify whether an energy reduction project has indeed met its goal and then quantify the actual savings. This feature is also helpful for validating the outcomes and effectiveness of energy performance contract projects (Haji-Sapar and Lee, 2005; Hui, 2002).

With the growing importance of building energy codes and green building rating systems, energy benchmarking has been adopted as an important method to demonstrate code compliance (Lee and Chen, 2008) and for obtaining energy performance credits (Chang, 2010). The performance indicators and process of energy benchmarking are very useful not only to building operation and management, but also to plant engineering and maintenance (Bovankovich, 2008; Price, 2008; Snow, 2002; Vavra, 2009). By benchmarking plant energy use with suitable energy performance indicators, it is possible to set targets for promoting best practices and achieving better energy efficiency in buildings and industrial facilities.

This research paper describes the basic principles of energy benchmarking and explains its significance to building facility management and plant engineering. As energy is important to every society and organization, it is believed that the benchmarking process can help evaluate performance, support decisions and facilitate improvements. The important issues and considerations for the implementation of energy benchmark are discussed. It is hoped that more people can understand and make use of the benchmarking techniques to achieve sustainable facilities and plant engineering.

2. Energy Benchmarking

Benchmarking is becoming a key methodology for the assessment of energy efficiency opportunity (Field, *et al.*, 2008). A benchmarking tool allows users and operators to compare their energy consumption levels with others in the same group, set future targets and identify measures to reduce energy consumption (CIBSE, 2004, Chps. 19 & 20). Building managers can improve the energy performance of buildings by examining the what, why, when, where and how of the building energy use (Energy Star, 2007).

2.1 Basic Principles

Benchmarking is a quantitative process for tracking performance and identifying opportunities for improvement (Field, *et al.*, 2008). It can help to compare an organisation's current performance to past performance and evaluate against both industry and competitor standards (IBLF and WWF-UK, 2005). Nowadays, benchmarking has become a commonly used management practice for performance measurement and improvement and is applied by leading companies across all sectors (Hui and Wong, 2010). It is considered a key tool in strategic business development activities. Table 1 shows the major benefits of energy benchmarking.

Table 1. Major benefits of energy benchmarking

1)	Determine how well a building is performing
2)	Compare energy consumption to similar buildings
3)	Set targets for improved performance
4)	Facilitate assessment of property value
5)	Gain recognition for exemplary achievement
6)	Identify actions for energy savings
7)	Facilitate energy audit and energy efficiency campaign
8)	Act as a standard for energy performance contracts
9)	Demonstrate compliance with building energy codes
10)	Obtain energy performance credits in green building assessment

Energy benchmarking involves the development of quantitative and qualitative indicators through the collection and analysis of energy-related data and energy management practices (CDM, 2002). The energy benchmarks can be derived from distributions of metric values obtained from facilities having similar functionality or characteristics, from engineering analysis or building simulation modeling, or from expert knowledge of standard and best practices. Table 2 shows three general approaches to benchmarking which are commonly used for the evaluation of building energy consumption.

Table 2. Three general approaches to benchmarking

Approach	**Description**
"Tracking" or "baseline" approach	Comparing a building to itself
Target finder approach	Empirical model from a sample of other similar buildings in a population (e.g. EnergyStar)
Simulation model approach	Results of an energy simulation model with certain pre-defined baseline characteristics, such as meeting an energy code or standard

Depending on the purpose and requirements of the exercise, the benchmarking results will provide information for performance management to establish how the building compares with typical and best practice buildings. In general, the comparison of energy benchmarks could be made in four different ways (Stapenhurst, 2009):

- Relative to previous performance (trending)
- Relative to portfolio (target setting and trending)
- Relative to national average
- Relative to a standard ("best practices")

2.2 Benchmarking Methods

Liddiard, Wright and Marjanovic-Halburd (2008) have studied and identified five basic types of benchmarking methods for commercial buildings as indicated below.

- Ranking systems

- Distribution models, using medians and percentiles
- Regression models
- Regression models using standard regression errors or mean energy use intensity
- Prototypical models

The benchmarking methods have different degrees of complexity and their effectiveness is significantly influenced by the quantity and quality of the benchmark's source base data. The criteria for a good benchmarking system usually focus on the following aspects:

- Easy to use and understand
- Accurate and consistent
- Comprehensive for the type of buildings or applications concerned
- Can account for the specific criteria unique to each building or application

When studying the strategies for energy benchmarking in cleanrooms and laboratory-type facilities, Sartor, *et al.* (2000) have described five types of benchmarking techniques.

(a) Statistical analysis: compare energy-use intensities
(b) Point-based rating: assign ratings by building characteristics
(c) Model-based rating: develop "effectiveness metric"
(d) Hierarchical end-use performance metrics: develop hierarchical performance metrics
(e) Hybrid: combination of the above

CIBSE (2004, Chps. 19 & 20) describes systematically the benchmarking process and techniques. Three levels of benchmarks were suggested for analysis of building energy use.

- Overall building benchmarks
- Detailed component benchmarks
- Detailed end-use benchmarks

When assessing the energy performance of existing buildings, CIBSE (2006) describes the main procedure based on metered energy use. It is necessary to consider carefully the building types and allow for different use and occupancy, in order to understand their consumption trends and characteristics.

3. Building Energy Performance

Building energy benchmarking is a valuable tool to manage energy usage. It allows comparison of whole-building energy use relative to a set of similar buildings and is useful for individual energy audits and for targeting buildings for energy saving measures. The building's energy performance based on its annual energy use is often expressed as an energy index (per sq.m) or a score (percentile). The physical efficiency (building, equipment) as well as operational efficiency (operation, maintenance) can be evaluated.

When assessing the building energy performance, one must also take into consideration weather normalization and occupancy or usage level. In general, normalization allows us to compare or combine data that we could not otherwise compare or combine. While the energy utilization index (EUI) represents actual energy use with no adjustments or correction factors for site or source energy, the normalised performance indicator (NPI) considers the effects of weather, operating hours, etc. and enables comparison of buildings of a similar type. NPI can be used for total energy, specific energy types (electricity, gas, oil) or by use (air-conditioning, light, heat). Table 3 shows examples of building energy benchmarks for typical practice and good practice in UK.

Table 3. Examples of building energy benchmarks [extracted from CIBSE (2004, Chp. 20)]

Building type	Energy consumption benchmarks for existing buildings (kWh per m^2 per year)				Basis of benchmark
	Good practice		Typical practice		
	Fossil fuels	Electricity	Fossil fuels	Electricity	
Offices:					
- air conditioned, standard	97	128	178	226	Treated floor area
- air conditioned, prestige	114	234	210	358	Treated floor area
- naturally ventilated, cellular	79	33	151	54	Treated floor area
- naturally ventilated, open plan	79	54	151	85	Treated floor area
Hotels:					
- holiday	260	80	400	140	Treated floor area
- luxury	300	90	460	150	Treated floor area
- small	240	80	360	120	Treated floor area
Retails:					
- clothes stores	65	234	108	287	Sales floor area
- department stores	194	237	248	294	Sales floor area
- small food shops	80	400	100	500	Sales floor area
- supermarket	200	915	261	1026	Sales floor area

Table 4. Selected examples of building energy benchmarking tools

Tool	**Description**
Energy Star Benchmarking in USA	- Energy Star Label for Buildings, developed by US-EPA and US-DOE - Based on the USA's Commercial Building Energy Consumption Survey (CBECS) data - Applied across the nation in USA - Using regression models, normalized for climate, schedules, occupancy, etc. - Score between 1-100 (at least 75 is required for an Energy Star Label for Buildings) - Further information: www.energystar.gov/ benchmark
Building energy benchmarks in Singapore (e-Energy)	- Developed by BCA-NUS Building Energy & Research Information Centre - Applied to offices, shopping centres and hotels - Divided into 3 parts: Total, Landlord and Tenant - Energy audit online and questionnaires are also available - Further information: www.bdg.nus.edu.sg/buildingEnergy
Energy Consumption Indicators and Benchmarks in Hong Kong	- Developed by the Electrical & Mechanical Services Department (EMSD) - Online tool and guidelines - Building types include: private offices, commercial outlets, hotels and boarding houses, universities, post-secondary colleges and schools, hospitals and clinics - Further information: www.emsd.gov.hk/emsd/eng/pee/ecib.shtml
APEC Energy Benchmark System	- Initiated by the Asia-Pacific Economic Cooperation (APEC) Energy Working Group - Contains metered energy use of each fuel and other building characteristics - Building types include: office, hotel and hospital - Industrial facilities include: paper mill, ferrous metal casting and cement - Further information: http://eber.ed.ornl.gov/apec/

At present, some countries have developed useful tools for building energy benchmarking. A list of the selected examples is given in Table 4. However, it should be noted that the benchmark number in itself is meaningless, unless there is an understanding of how the benchmark is derived (Wireman, 2004). Understanding the enablers and success factors behind the benchmark is the most important.

4. Plant Engineering and Maintenance

Energy management for plant engineering includes both industrial and non-industrial sectors. For the non-industrial applications such as commercial and public buildings, the strategies for energy benchmarking are similar to the building energy benchmark described in the previous sections. In both sectors, major building services systems and equipment are often involved, like chillers, cooling towers, fans and pumps, lighting and vertical transportation systems (Snow, 2002). Management of the operation and maintenance (O&M) of these systems, and sometimes their retrofitting and upgrading, is the key factor affecting the performance (CIBSE, 2008).

4.1 Maintenance Function and Energy Conservation

The focus of the maintenance function is to ensure that all company assets meet and continue to meet the design function of the asset (Wireman, 2004). This implies that the best practices of the maintenance process will enable a company to achieve a competitive advantage over its competitors. Ineffective maintenance adversely affects energy consumption and improved maintenance practices can contribute to significant energy reduction (Bannister, 1999).

Many operations managers are now facing the challenges for energy optimization (Price, 2008). To recognize the savings potential, they must consider and implement best practices designed specifically for energy savings. This means a strategy that keeps equipment operating at maximum efficiency, whereas the processes stay online, productivity increases and costs decrease. In summary, planned maintenance for productivity and energy conservation is the goal of the maintenance management (Criswell, 1990). To achieve this, Price (2008) suggested the following key areas for facility maintenance.

- Allocate staff time to do regularly scheduled inspections of key equipment and systems.
- Establish thresholds for performance below which maintenance and repairs are required.
- Keeps equipment operating at peak efficiency so it uses less energy and consumes less staff time than troubleshooting problems or replacing failed equipment.

In fact, maintenance benchmarking is accomplished in two ways, internally and externally (Rosaler, 2002). Internal benchmarking is established within the company, usually against other similar facilities. External benchmarking is achieved by benchmarking against another company in a similar area.

4.2 Benchmarking Techniques

Benchmarking takes many forms, but in plant engineering and maintenance the benchmarking techniques are often similar (Rosaler, 2002). In most cases, benchmarking begins by defining the goal. The second phase is the data collection method. The third phase is deciding where the data is going to be collected, externally or internally. The fourth phase is deciding how you are going to use the results. Figure 2 shows the typical steps of benchmarking techniques.

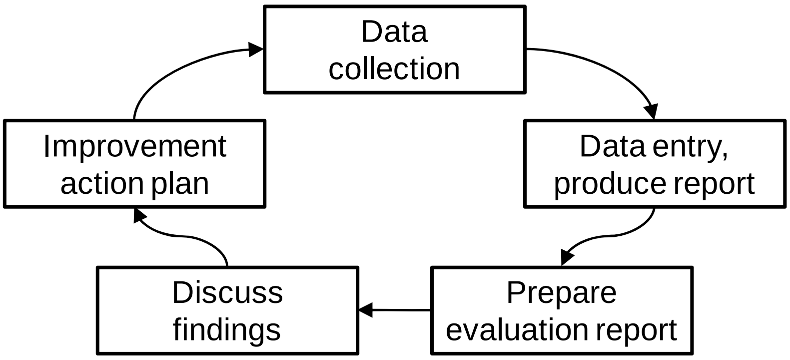

Figure 2. Typical steps of benchmarking techniques

Energy efficiency in both industrial and non-industrial sectors should start with knowing how the facility is using its power (Bovankovich, 2008). As a first step, detailed energy audits by energy management professionals are used for identifying potential energy conservation measures and savings opportunities in the facility. Based on what is learned about a particular plant's inefficiencies and potential cost savings, improvement measures such as lighting retrofits, infrared scanning of heavy equipment and advanced sub-metering can then be implemented.

From the past experiences, the ability to turn the energy information into results is found to be a key for managing energy costs (Bannister, 1999; Criswell, 1990; Rosaler, 2002). However, it is not an easy task to allocate energy consumption and determine an optimum benchmark for an industrial facility (Hu, *et al.*, 2008) because the system components and design requirements vary significantly. In order to study and develop energy benchmark for plant engineering in the industrial sector, the following websites could provide some useful guidelines and information.

- Energy Benchmarking for Buildings and Industries, by Lawrence Berkeley National Lab, USA (http://energybenchmarking.lbl.gov/)
- Benchmarking Guides for Industries, by Office of Energy Efficiency (OEE), National Resources Canada (http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/)

5. Implementation Issues

The nature of benchmarking is about learning how to improve business activity, processes and management. It is an integral tool within the management process that assesses performance and helps to identify and prioritise areas to manage. Spendolini (1992) suggested five stages of benchmarking:

- Stage 1: determine what to benchmark
- Stage 2: forming a benchmarking team
- Stage 3: identifying benchmarking partners
- Stage 4: collecting and analyzing benchmarking information
- Stage 5: taking action

5.1 Major Hurdles

Garris (2008) has discussed 8 energy benchmarking hurdles and how to get over them.

1) Upper management doesn’t understand the results of energy benchmarking enough to support it.
2) The motivation behind energy benchmarking at your facility isn’t clear.
3) You don’t know what exactly to benchmark your energy use against because there are so many options.
4) You don’t know what data you’ll need to make accurate comparisons.
5) You don’t know what features to look for in a benchmarking tool.
6) You don’t know what to do with the benchmarking data once you have it.
7) Numbers can be very misleading.
8) You don’t know what exactly to benchmark when it comes to energy use.

5.2 Key Success Factors

The key success factors for benchmarking are summarized as follows.

- Top management’s commitment, involvement & support
- Well preparation
- Open-minded, accept new & innovative matters
- Clear understanding on organizations’ critical success factors & processes
- Provide benchmarking training to relevant employees
- Areas for benchmarking should not be too board for each single time
- Clear self understanding before doing comparison
- Find the best practice business process if possible
- Follow the predetermined standard
- Share information with partners voluntarily
- Focus on processes improvement

5.3 Avoid Copycat Benchmarking

Benchmarking is a concept, attitude, tool or management system (Stapenhurst, 2009). It provides a deep understanding of the processes and skills that create superior performance. Without this understanding, little benefit is achieved from benchmarking. By using a best organization as a reference, it can improve an organization's processes and performance in an effective and efficient way. Benchmarking emphasize proper transfer and adoption (according to own situation), but not “totally transfer”. Therefore, copycat benchmarking should be avoided. But useful reference can be drawn from energy benchmarking guidances on common building types, such as offices (NBI, 2005), hotels (IBLF and WWF-UK, 2005), hospitals (Singer, *et al.*, 2009) and laboratory-type facilities (Sartor, *et al.*, 2000).

5.4 Mandatory Energy Benchmarking

In recent years, some cities and states in USA have passed ordinances mandating that existing buildings benchmark their energy usage and disclose the consumption information. These ordinances push green building one step further by not only enforcing standards on new construction, but regulating existing buildings which constitute the major portion of the building stock. It is believed that this trend will have significant implications to the energy management activities.

In some Asian cities such as Hong Kong (Environment Bureau, 2009) and Singapore (Lee and Rajagopalan, 2008) there are already proposals to implement mandatory requirements on building energy audits and building energy labels. The benchmarking tool and information are essential to these initiatives and will form the basis of the related laws. Further development of the energy benchmarking law is expected.

6. Conclusions

The spirit of benchmarking could be represented by the old Chinese saying 「他山之石，可以攻玉」which means "stones from other hills may serve to polish jade". In conclusion, the key elements of benchmarking can be summarized by three points.

(a) Continuous systematic search for and identifying best practices.
(b) Careful study to find the reasons of success.
(c) Develop recommendations and implementation for improvement.

Energy benchmarking is a useful tool for the long-term management of energy use, but it is not the destination, just the mile marker. Energy benchmark only hints at potential for improvement. A benchmark performance does not remain a standard for long. Continuous improvement must be the goal. It is important to properly select and define the metrics for energy benchmarking, apply expertise to investigate systems and devise changes for promoting better energy effectiveness.

If we could learn from the best practices and make use of the benchmarking process to "plan, analyse, act, review and repeat", it is possible to transform existing buildings and achieve sustainable facilities and plant engineering for the whole society.

References

Bannister, K. E., 1999. *Energy Reduction Through Improved Maintenance Practices*, Industrial Press, New York.

Bovankovich, D., 2008. Optimizing energy conservation in today's plants, *EC&M Magazine*, Feb 1, 2008. (at http://ecmweb.com/mag/electric_optimizing_energy_conservation/)

CDM, 2002. *Consultancy Study on the Development of Energy Consumption Indicators and Benchmarks for Selected Energy-consuming Groups in Hong Kong: Executive Summary for Principal Groups A & B (Final)*, prepared by Camp Dresser & McKee International Inc. (CDM), Electrical and Mechanical Services Dept., Hong Kong.

Chang, R., 2010. More than a single percentage energy benchmarking, *ASHRAE Journal*, 52 (2): 74-77.

CIBSE, 2008. *Maintenance Engineering and Management: A Guide for Designers, Maintainers, Building Owners and Operators, and Facilities Managers*, CIBSE Guide M, Chartered Institution of Building Services Engineers (CIBSE), London.

CIBSE, 2006. *Energy Assessment and Reporting Methodology*, CIBSE TM 22: 2006, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.

CIBSE, 2004. *Energy Efficiency in Buildings*, CIBSE Guide F, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.

Criswell, J. W., 1990. *Planned Maintenance for Productivity and Energy Conservation*, 3rd ed., Fairmont Press, Lilburn, GA.

Energy Star, 2007. *Benchmarking to Save Energy: Protect Our Environment Through Energy Efficiency*, U.S. Environmental Protection Agency, Washington, DC. (available at www.energystar.gov)

Environment Bureau, 2009. *Legislative Council Brief: Building Energy Efficiency Bill*, ENB 24/26/22, Legislative Council, Hong Kong SAR. (available at www.legco.gov.hk)

Field, J., *et al.*, 2008. *Energy Benchmarks*, CIBSE Technical Memoranda TM46, Chartered Institution of Building Services Engineers, London.

Garris, L. B., 2008. 8 energy benchmarking hurdles (and how to get over them), *Buildings*, July 2008. (available at www.buildings.com)

Haji-Sapar, M. and Lee, S. E., 2005. Establishment of energy management tools for facilities managers in the tropical region, *Facilities,* 23 (9/10): 416-425.

Hu, S.-C., *et al.*, 2008. Power consumption benchmark for a semiconductor cleanroom facility system, *Energy and Buildings*, 40 (9): 1765–1770.

Hui, S. C. M. and Wong, M. K. F., 2010. Benchmarking the energy performance of hotel buildings in Hong Kong, Paper submitted to the *Dalian-Hong Kong Joint Symposium 2010*, 2-3 July 2010, Dalian, China. (in English with a Chinese abstract)

Hui, S. C. M., 2002. Opportunities and challenges of energy performance contracting to improve existing buildings in Hong Kong, In *Proceedings of the Joint Symposium 2002: Achieving Sustainable Performance in Built Environment*, 19 November 2002, Shangri-la Hotel, Kowloon, Hong Kong, pp. 8-1 to 8-10.

IBLF and WWF-UK, 2005. *Why Environmental Benchmarking Will Help Your Hotel*, The International Business Leaders Forum (IBLF) Tourism Partnership and World Wildlife Fund (WWF) UK, London. (available at www.iblf.org)

Lee, W. L., Chen, H., 2008. Benchmarking Hong Kong and China energy codes for residential buildings, *Energy and Buildings*, 40 (9): 1628-1636.

Lee, S. E. and Rajagopalan, P., 2008. Building energy efficiency labeling programme in Singapore, *Energy Policy*, 36 (2008): 3982-3992.

Liddiard, R., Wright, A. and Marjanovic-Halburd, L., 2008. A review of non-domestic energy benchmarks and benchmarking methodologies, In *Proceedings of the IEECB Focus 2008 Improving Energy Efficiency in Commercial Buildings Conference*, 10-11 April 2008, Congress Center Messe Frankfurt (CMF), Frankfurt am Main, Germany, 11 pp. (http://re.jrc.ec.europa.eu/energyefficiency/html/Proceedings_IEECB2008.htm)

Mull, T. E., 2001. *Practical Guide to Energy Management for Facilities Engineers and Managers*, ASME Press, New York.

NBI, 2005. *Benchmark: Energy Benchmark for High Performance Buildings*, Version 1.1, New Building Institute (NBI), Inc., White Salmon, WA. (available at www.newbuildings.org)

Padavano, K. R., 2004. Benchmarking: Strategies for gauging operational performance, *Journal of Facilities Management*, 3 (2): 145-160.

Price, M., 2008. The basics of energy optimization, *Plant Engineering*, 62 (12): 55.

Rosaler, R. C. (ed.), 2002. *Standard Handbook of Plant Engineering*, 3rd ed., McGraw-Hill, New York.

Sartor, D., *et al.*, 2000. Strategies for energy benchmarking in cleanrooms and laboratory-type facilities, In *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings*, August 20-25, 2000, Pacific Grove, California, 13 pages.

Singer, B. C., *et al.*, 2009. *Hospital Energy Benchmarking Guidance - Version 1.0*, LBNL Report LBNL-2738E, Lawrence Berkeley National Laboratory, Berkeley CA.

Snow, D. A. (ed.), 2002. *Plant Engineers' Reference Book*, 2nd ed., Butterworth-Heinemann, London & Boston.

Spendolini, M. J., 1992. *The Benchmarking Book*, AMACOM Books and American Management Association, New York.

Stapenhurst, T., 2009. *The Benchmarking Book: A How-to-guide to Best Practice for Managers and Practitioners*, Elsevier/Butterworth-Heinemann, Amsterdam & London.

Vavra, B., 2009. Sustaining an energy plan, *Plant Engineering*, 63 (1): 23.

Wireman, T., 2004. *Benchmarking Best Practices in Maintenance Management*, Industrial Press, New York.