REVIEW OF METHODS FOR HYDRAULIC AND ENERGETIC PERFORMANCE MEASUREMENT SYSTEMS IN WATER SUPPLY UTILITIES

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Abstract. *Performance measurement systems (PMSs) are frequently used in the corporate sector as an instrument of strategic planning and management, allowing quantifying, analyzing and disseminating efficiency information about various areas of a company - from the use of raw materials to the satisfaction of consumers. Much of the theoretical framework for the design and implementation of PMSs has its origin in the areas of production engineering, business and economics, aimed for use in a competitive market environment. While efficiency is a key to survival and growth of private enterprises, the Brazilian public sector - in particular the water supply services, the object of study - lacks of initiatives aimed at measuring and increasing performance, particularly as refers to the rational use and conservation of water and electricity, that are fundamental to the sustainability of this activity. Proof of this inefficiency is the high rate of water loss in national systems, with high value-added energy, whose average is over 40%. In this sense, this article presents a review of methods and tools available for the design and implementation of PMSs, paying attention to their use in hydraulic and energetic analysis of water supply systems. Initially, the theoretical basis for PMSs development are presented; some specific tools such as benchmarking and data envelopment analysis are examined in more detail, given its relevance and applicability in the workplace. Then, a comparison table is drawn between the measurement of business performance and analysis of hydraulic and energy efficiency, from which adaptations and usage guidelines are proposed for this kind of application. The paper concludes that despite the existence of several opportunities for improvement of water supply systems relative to the use of water and electricity, there is little technical basis for measuring and managing their hydraulic and energy efficiency. The adaptation of methodologies from the business sector is, at first, a viable alternative for analysis of hydraulic and energy efficiency in water supply systems.*

Keywords*: water supply systems, hydraulic efficiency, energy efficiency, performance measurement systems.*

1. INTRODUCTION

The need to implement performance measurement systems for the water supply sector, although technically indisputable, finds predominantly political nature obstacles in Brazil. In 2008, 571 water and sewer national services were public (municipalities, departments and municipal secretaries), 16 private (joint stock companies, public enterprises and social organizations) and 41 private companies (MCIDADES, 2010). This scenario, according to Byrnes *et al*. (2010), is similar to Australia, and differs the UK (mostly private) and U.S. (balance between public and private systems), for example. Janson and Ehrhardt (2010) indicate that the regulation used in conventional water services has no commercial motivation, preventing the profits maximization. For the authors, such legislation should be adapted to allow citizens to assess the performance of services, forcing the government to consider the issue of efficiency in the management of systems. The lack of competition in the sector in which there are monopolies in production and supply is indicated by Abbott and Cohen (2009) and Tupper and Resende (2004) as a key factor on the low efficiency of national water supply systems (WSSs). Several studies (Walter *et al*. 2009; Saal and Parker, 2001; Nauges and van den Berg, 2008; Abbott and Cohen, 2009; Byrnes *et al*. 2010; Tupper and Resende, 2004) indicate that the regulation is the main factor to influence the efficiency of WSSs, surpassing even the question of ownership (public or private). Rogers (2005 *apud* Rogers and Louis, 2009) argues that the approaches to assessment and evaluation of performance used in the public water supply is inadequate, since it does not provide a consistent view, based on efficiency, referring to uniform quality standards. The most relevant example of the inefficiency of WSSs in Brazil is the average water losses, exceeding 40% (MCIDADES, 2010). Given that energy consumption is directly proportional to the volume of pumped water, the waste of energy in these systems is at least of the same magnitude. Araujo *et al.* (2006) indicate that, worldwide, rates of water losses in WSSs range from 30% to 40%, while Colombo and Karney (2002), quoting other authors, quantify the volumes of water unaccounted in Europe between 9% and 30%. Leaks increase operating costs related to water loss and extra energy consumption for all systems, also resulting in economic losses (Colombo and Karney, 2005). This consumption refers to the extra energy that must be supplied by pumping to maintain the same level of service of a system without losses; leaks waste energy due to the aggregated content in the missing volumes, and also by further increasing power for such volumes would not compromise meeting the demand. Besides the quantitative question, leaks in water distribution networks may compromise the quality of the product, through the intrusion of pathogenic microorganisms, especially in the occurrence of hydraulic transients, during which the pressures become low and even negative (Colombo and Karney, 2002, 2005; Besné *et al.*, 2011; McInnis, 2004).

For Carrijo and Kings (2006), the cost of electricity is the most important parameter in operational optimization of WSSs in terms of minimizing production costs. Despite that, "[...] the operational rules used looks to guarantee the continuity of public supply, without concern for energy-saving in the operation of electric motors" (Costa *et al.*, 2010). According to Colombo and Karney (2002), in many communities, the power consumption resulting from the pumping of water is the largest component of supply operational costs, and wasted energy to leak compensation is linked to several environmental impacts such as greenhouse gas emissions, acid rain and depletion of resources.

Based on these questions, this study aims to evaluate the development and implementation of performance measurement systems (PMSs), typically applied in the business sector, with a view to its use in the measurement of hydraulic and energy efficiency of water supply systems. Initially, the theoretical bases related to PMSs are presented and the application of some traditional tools used for performance measurement in corporative sector - as benchmarking and data envelopment analysis – is discussed in hydraulic and energy efficiency studies and illustrated by case studies reported in the literature. Next, a panel which proposes adaptations and analogies between the business and the thermodynamics performance measurement is established, by which one could envisage applications of the corporative tools in the context of measuring hydraulic and energy efficiency, the object of the study.

2. PERFORMANCE MEASUREMENT SYSTEMS

In an extensive literature review aimed to identify the state of the art of performance measurement, Nudurupati *et al.* (2011) defines performance measurement, based on the work of Neely *et al.* (1995), as "[...] the process of quantifying the effectiveness and efficiency of actions.". A PMS is defined by the same authors as the set of measures used to quantify the effectiveness and efficiency of these actions. Nudurupati *et al.* (2011) also states that the period between 1994 and 1996 can be considered revolutionary in terms of academic research on performance measurement, been identified over 3600 publications between those years. During this period, the financial outlook of efficiency - referring to the past performance of the organization - used mainly by Western companies, have been transcended by the aggregation of components aimed at strategic planning and foresight, such as customer satisfaction, internal processes, learning and growth. According Tezza *et al.* (2010), the transition from purely financial to nonfinancial occurred from the year 1980. Some of the first studies on efficiency measurement in the water industry was developed between the 1960s and 1970s, all based on econometrics, in which performance was measured by means of cost and production functions (Abbott and Cohen, 2009).

In Brazil, the policies established by the National Sanitation Plan (PLANASA), 1971, aimed mainly at financial sustainability of the sector, and its universalization goals led to a system of cross subsidies between different classes of consumers - large consumers paid higher values than the production costs to cover the deficits from low-income consumers - was conducive to the establishment of inefficiencies in the water supply sector (Tupper and Resende, 2004). Walter *et al.* (2009) states that the efficiency analysis in the form of benchmarking has been used in the water supply sector primarily to the establishment of policies and prices. According to Abbott and Cohen (2009), from the 1990s, there was an expansion in the use of analytical techniques for measuring performance and efficiency in various industries in the United States. Initially these techniques were applied to rail transport and electricity sectors companies, and later expanded to water supply and wastewater systems, given its strategic importance for the urban and economic development. Such initiatives were encouraged by the discussions in the 1970s on the optimal sizing of water supply systems and the savings from this, and the effects of mergers and relative performance of public and private water (Abbott and Cohen, 2009). The authors further state that reforms occurred in the water sector in the UK, since 1990, also urged researchers to develop studies on the efficiency and productivity in this sector in many countries.

Also according to Abbott and Cohen (2009), until the 1990s, the focus of performance measurement systems for water supply lay in the identification of economies of scale[1] and the performance difference between public and private system. Nauges and van den Berg (2008) suggest that returns to scale in water and sewage services in Brazil are constant, varying in proportion to the increase or decrease in production. As a complement, Abbott and Cohen (2009), Walter *et al.* (2009) and Nauges and van den Berg (2008) presented a study indicating the existence of economies of scope[2] in the sector of water supply, especially in the joint provision of water and sewage services - as is the case of

[1] Economy of scale results of a increase in the size of a production or distribution unit of some product. This increase in size (scale) is responsible for reducing the cost of production or distribution (Vinholis and Brandão, 2009). Abbott and Cohen (2009), citing 26 authors, demonstrate that there is no consensus on the existence of economies of scale in the water supply sector; the heterogeneity of the findings of these studies can be attributed to the great diversity of characteristics presented by WWSs, influenced by hydraulic / hydrologic, topographic, geographic, market and regulation issues, as well by the segments of the systems analyzed (treatment, distribution, etc). Walter *et al.* (2009) corroborates this conclusion, saying there was evidence of the presence of economies of scale in the sector, however, variable depending on the characteristics of the systems reviewed.

[2] Economy of scope is that obtained by the combination of processes for simultaneous production of more than one product (Abbott and Cohen, 2009).

most Brazilians WSSs -; in addition, companies that jointly operate the production / processing and distribution of water tend to have economies of scope in terms of reduction of water losses in the networks.

A third category of economy, addressed by Nauges and van den Berg (2008) and Walter *et al.* (2009), is the economy of density, which can be production economy - reducing costs through higher volumes of produced and/or treated water and sewage, holding constant the number of connections and length of the network - or consumers economy - consider the savings from the simultaneous increase of the volume produced/processed and the number of connections/consumers. The analysis of economies of density of consumers is important in countries with deficient supply of sanitation services, where there is a large contingent of people to be covered with these services, in addition to economic growth. The economics of density seems to be present in most WSSs worldwide, based on literature (Walter *et al.* 2009; Nauges and van den Berg, 2008; Byrnes *et al.*, 2010), although the cases studied by Nauges and van den Berg (2008), in Brazil, show the opposite, as regards the economy of the density of consumers. Through a case study, Filion (2008) illustrates that a 10% reduction in energy consumption per capita in SAAs (including the energy consumed to manufacture and repair pipes, pumping water and install water mains) can be achieved by increasing the density population of 10 inhabitants.ha^{-1} to 275 inhabitants.ha^{-1}.

Despite the existence of several initiatives aimed at performance measurement for water supply systems, little attention is paid to the formalization of methods for measuring hydraulic and energy performance from a thermodynamic approach of efficiency; the essence of these PMS is predominantly accounting and operational, using indicators to assess the use of financial, personnel and operational resources (e.g. number of connections, length of distribution networks, micro-measurement rates), with these components not tied to efficiency goals or optimal values of reference. The hydraulic efficiency, itself, is covered almost exclusively by means of indicators/indices of water losses (Lamberts *et al.*, 1999), while energy efficiency is evaluated through specific energy consumption (the main indicator is the kWh.m^{-3}), not sufficiently descriptive in terms of peculiarities and conditions of the systems.

For Tanaka (2008), classical methods for measuring energy efficiency are based on physical and thermodynamic indicators, namely:

- Thermal energy efficiency: expressed by the classic relationship between energy consumed and produced useful energy, suitable for end use technologies and energy conversion. As an example, cite the conversion ratio of electric power in power in an engine shaft;
- Energy consumption intensity (of energy intensity or specific energy consumption per unit): energy consumption is divided by a value of physical output, for example, energy consumption required to pump a cubic meter of water from a pumping station (kWh.m^{-3}). This kind of indicator is not influenced by economic fluctuations, and may be related to processes and operations. While providing an overview of energy use in water supply systems, energy intensity related to the volume produced/distributed not provide information about how energy is used throughout the proceedings, distancing the possibility of such an index in energy audits processes (Cabrera *et al.*, 2010);
- Absolute energy consumption rate: is the total amount of energy consumed by a production unit in a given period of time, being an absolute value for which a comparison is only possible between identical systems, which operate on the same production rates. This approach becomes not so relevant in terms of efficiency analysis, since it is not associated with rates of production. When dealing, for example, the absolute rate of energy consumption of a country, with its gross domestic product (GDP), the energy intensity index is obtained (MME and EPE, 2007a);
- Diffusion rate of energy-efficient equipments and technologies: measures the utilization rate of equipment of high efficiency. The percentage of high performance engines to total engine of an industrial plant and the proportion of energy-saving bulbs compared with the amount of incandescent exemplify the method and can serve as an indicator for energy efficiency / energy conservation projects.

According to Bor (2008), indicators of physical and thermodynamic efficiency are those associated with the products volume index, mainly related to thermal efficiency. Patterson (1996), in turn, classifies the energy efficiency indicators such thermodynamic indicators, physical-thermodynamic indicators, economic-thermodynamic and economic indicators. Extending the analysis of Patterson (1996), Tanaka (2008) indicates that energy efficiency indicators of economic-thermodynamic beyond purely economic are the latest approaches to the topic. It is perceived to be a convergence in definitions between the work of Tanaka (2008), Bor (2008) and Patterson (1996). The latter author, in turn, adds that no thermodynamic efficiency indicator, although numerically consistent, measures the amount of output in terms of the adequacy of useful service delivered. A similar observation is made by Schaumann (2007), whereby the coefficient of thermodynamic efficiency does not take into account the quality of energy, which could be quantified by exergetic analysis. The analysis of exergy or availability, allows the measurement of quality of energy flows, according to the Brazilian Ministry of Mines and Energy and the Energy Research Company (MME and EPE, 2007b). According to these institutions, the classical thermodynamic energy balances can be substituted for exergy balances, which obtains information not only about the losses in the system, but also the irreversibility of its various processes. With this, you can define which of these processes have greater potential to increase the capacity of producing work.

3. PERFORMANCE MEASUREMENT METHODS

In this section, two widely used tools for measuring business performance - benchmarking and data envelopment analysis - are described. Examples of application of such techniques in the water supply and energy sectors, extracted from the literature, are also presented, allowing the connection between its classical context of use and the hydraulic/energetic vision proposed in the article.

3.1. Benchmarking

Benchmarking is a methodology aimed at increasing the performance of processes in organizations, through the use of experiences gained in similar organizations and processes. It is a way to identify the gap between the level of current and possible performance, and make changes to achieve the highest standard of performance (Malano *et al*., 2004). For Stapenhurst (2009), benchmarking is a method of measuring and improving organizational performance by comparing its performance with the best there is in the same industry. There are two types of benchmarking (Kingdom, 1998):

- Metric benchmarking: it is a comparative quantitative analysis that allows companies to monitor its internal performance over time and compare it to similar companies. Through these comparisons, the target levels of performance can be defined;
- Process benchmarking: involves the identification of specific work processes to be improved, through a step-by-step mapping, and subsequent location of external examples of excellence in the same process for determining the standard to be achieved.

In general, metric benchmarking is preliminarily applied, giving the manager an indication of where are the missing points. Subsequently, process benchmarking will inform what should be done to improve these points. Kingdom (1998) highlights the importance of using metric benchmarking sparingly, especially in water supply systems, in which the operating environment can influence the values of the indicators. Several explanatory factors - such as local terrain and raw water quality - which cannot be changed through the management system influence directly production costs and availability.

The American Water Works Association Research Foundation (AWWARF, 1996) states that an effective performance measurement system, based on the benchmarking process, should be composed of the following structure:

- A set of performance indicators that capture the most fundamental characteristics of the process;
- Understanding the explanatory factors that cannot be controlled by the system manager, but that influence their performance in a direct way;
- Generation of accurate, consistent and time associated internal data, to quantify all the factors that influence the process and at the same time, allow the identification of trends in its variability;
- External data to allow comparisons of the performance of the other similar organization;
- Techniques for data analysis.

Several companies and managers of water supply systems have used benchmarking as a tool for performance analysis. The AWWARF has developed the project Performance Benchmarking for Water Utilities (AWWARF, 1996; Kingdom, 1998; Parena and Smeets, 2001), in which were developed several performance rates, uni and multivariate cost models and metric through benchmarking process. The Water Environment Research Foundation (WERF) gathered technical managerial information of 100 companies from sewage treatment and wastes, which were analyzed using multivariable cost models, resulting in the publication called Benchmarking Wastewater Operations - Collection, Treatment and Management Biosolids. Walter *et al*. (2009) presented in Fig. 1, a world map of studies on performance measurement and benchmarking in the water supply sector.

Parena and Smeets (2001) present an overview of several international experiences in benchmarking in the water industry, as summarized below:

- New South Wales, Australia: the Benchmarking Syndicate spent seven local governments, to assess the benefits of a union of benchmarking for local government councils in the preparation of guidelines and recommendations on efficiency analysis;
- UK: the Severn Trent Water has developed a benchmarking study focused on evaluating the best opportunities to maximize benefits from a budget of 4.5 million pounds, in a review period of ten years and associated with a privatization process. The study was directed to the measurement of efficiency in project management, expertise, resources and returns of investments;

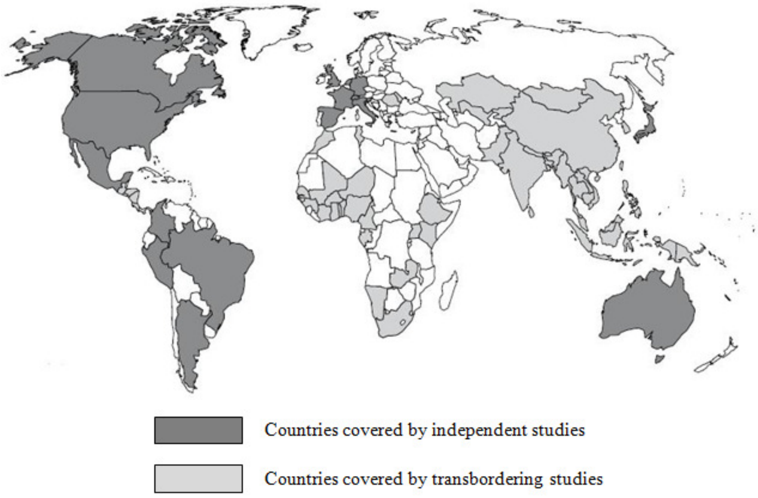

Figure 1. Countries with benchmarking studies applied to the water supply sector (adapted from Walter *et al.*, 2009)

- England and Wales: the OFWAT, the regulator of water services, conducted a comparative assessment of efficiency in determining tariff values between 2000 and 2005. International comparative studies were also developed allowing the independent comparison of performance between privatized water companies in England and Wales and Sydney and Perth firms that operated under different regulatory regimes;
- Netherlands: the New Benchmarking System (formerly COCLUWA) involved 85% of water services in Dutch. The performance indicators used to bring transparency to the sector in the Netherlands, from a government request, and provided information for management control and the pricing of water;
- Poland: the European Bank for Reconstruction and Development named the Water Research Centre of the United Kingdom to conduct a benchmarking study focused on investigating the goal levels and performance measures in enterprises of selected water exploration in Western Europe, and compare them with water and sewerage companies in Poland. The study provided to the Bank a comparative reference data base to determine the operating efficiency and performance relative to potential borrowers of the Bank, and set performance targets for borrowers with better practices in the industry;
- United States, American Water Works Association: this association has developed QualServe voluntary program aimed at helping American utilities to meet the requirements of total quality. How self-assessment and peer review were used to examine 15 areas of institutional performance, and develop an agenda of possibilities for improving quality, while the Benchmarking Clearinghouse provides information, tools and services specific to water systems and sewage;
- United States, Regional Water Utilities Benchmarking Group: created in early 1996 by a group of 14 organizations of water services, the group researched structures and practices that could make benchmarking meaningful to you and to other utilities companies. Using the benchmarking framework developed by the American Center for Productivity and Quality (APQC), Houston - Texas, 12 business processes were described for each utility, data were collected, identified best practices, performance indicators, and the comparison made practices documented in order to identify improvement opportunities for each of the active components of the distribution systems;
- Italy, the Italian Federation of Public Water: promoted in 1998, the Benchmarking project aimed to analyze the functioning of key processes and activities, identify benchmarks of performance and, possibly, identify best practices. Benchmarking Club, as it was called, was implemented by 14 member companies and an independent consultant to collect data. The main results of the project were to identify areas with greatest potential to improve performance, suggested organizational structures and control systems' abilities to overcome the performance limitations and validity of benchmarking in driving the renewed discussion of roles, functions and operational procedures.

One of the main, if not the world's main benchmarking initiative in the water sector worldwide, is the International Benchmarking Network for Water and Wastewater Utilities the (IBNET). The network maintains a database of performance information of WSSs from different countries, allowing comparison between them and the dissemination of industry best practices. In Brazil, the Ministry of Cities (MCIDADES, 2010) is responsible for the National Sanitation Information System (SNIS), which maintains a database similar to IBNET and publishes an annual diagnosis of water and sewage services in Brazil, held by indicators.

3.2. Data envelopment analysis (DEA)

The theoretical framework for the formalization of techniques for measuring efficiency through input/output relations was presented originally by Debreu (1951), Farrel (1957) and Koopmans (1965) studies. The generalization of the Farrell's proposal (Farrel, 1957) for applications with multiple inputs and outputs, developed by Charnes *et al.* (1978), originated the technique of data envelopment analysis (DEA). In the classical definition elaborated by these authors, DEA is presented as a mathematical programming model applied to observational data that provides a new way of obtaining empirical estimates of relations between inputs and outputs - such as production functions and/or frontiers of possible and efficient production - which are pillars of modern economy.

The DEA technique allows one to determine the relative performance of decision making units (DMUs) that use multiple resources of the same nature (inputs) to produce the same goods or services (outputs). These inputs and outputs may represent continuous variables, ordinal or categorical, with different dimensions (units of measure) (Peña, 2008). In this case, the DEA technique is based on weighted combinations of inputs of products, called virtual inputs and outputs (Zhou *et al.*, 2008). Its main advantage is that it does not require any prior assumption about the functional relationships between inputs and outputs, thus constituting a non-parametric and data-oriented approach (Zhou *et al.*, 2008). Mathematically, the technical efficiency of a DMU is defined by Eq. (1) (Omid *et al.*, 2011):

$$\theta = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} = \frac{\sum_{r=1}^{s} u_r . y_{rj}}{\sum_{r=1}^{m} v_i . x_{ij}} \qquad (1)$$

been θ the technical efficiency of DMU_j [1], s is the number of outputs, m is the number of inputs, u_r is the weight of output y_r, v_i is the weight of the input x_i, y_{rj} and x_{ij} are the values of outputs and inputs of DMU_j. The basic model of DEA is the CCR, which considers constant returns to scale. During the DEA-CCR, the efficiency of DMU_o (unit under analysis) of a set of n units is obtained by assigning weights that maximize their individual effectiveness, according to Eq. (2), and subject to the restrictions of Eq. (3) and (4):

$$\max_{u,v} \theta = \frac{\sum_{r=1}^{s} u_r . y_{ro}}{\sum_{r=1}^{m} v_i . x_{io}} \qquad (2)$$

$$\frac{\sum_{r=1}^{s} u_r . y_{rj}}{\sum_{r=1}^{m} v_i . x_{ij}} \leq 1 \text{ with } j = 1, 2, 3, ..., n \qquad (3)$$

$$u_r,\ v_i \geq 0 \qquad (4)$$

This fractional maximization problem can be converted into a linear programming problem, as Eq. (5), subject to the restrictions of Eq. (6), (7) and (8):

$$\max_{u,v} \theta = \sum_{r=1}^{s} u_r . y_{ro} \qquad (5)$$

$$\sum_{i=1}^{m} v_i . x_{io} = 1 \qquad (6)$$

$$\sum_{r=1}^{s} u_r . y_{rj} \leq \sum_{i=1}^{m} v_i . x_{ij} \text{ with } j = 1, 2, 3, ..., n \qquad (7)$$

$$u_r,\ v_i \geq 0 \qquad (8)$$

After calculating the individual efficiencies, the DMUs with higher efficiencies (the highest possible efficiency is numerically equal to 1) establish a production possibilities frontier (envelope). In other words, the distance of each

DMU to the efficient frontier corresponds to its inefficiency. In addition, the DEA indicates the key factors for improving performance through the discretization of the weighted share of each output and input regarding the overall efficiency.

The DEA has been accepted as the main frontier technique for benchmarking for the energy sector in several countries (Zhou *et al*., 2008), and also for assessing efficiency in water consumer/producer systems, as demonstrated by the work of Abbott and Cohen (2009), Alsharif *et al.* (2008), Byrnes *et al.* (2010), Cubbin and Tzanidakis (1998), De Witte and Marques (2010), Grosche (2009), Lee (2008), Lee and Lee (2009), Asmild and Lilienfeld (2007), Nassiri Shingh (2009), Omid *et al*. (2011), Pessanha *et al*. (2007), Raju and Kumar (2006), Sarica and Or (2007), Srdjevic *et al*. (2005), Thanassoulis (2000) and Wang (2010). The use of DEA for efficiency analysis in water supply systems is suggested, for example, by the Brazilian National Sanitation Information System (MCIDADES, 2010).

3. CONCLUSIONS AND SUGGESTIONS ON HYDRAULIC AND ENERGY PERFORMANCE MEASUREMENT IN WSS

Despite its direct and intense influence on water supply system´s levels of service and corporate finance, water use and electricity in WSS is still approached in a superficial way with regard to performance measurement, with prioritization of information relating to accounting and operational matters of another nature. Some examples, based on two major databases, are presented below. In energy terms, the SNIS (MCIDADES, 2010) includes in its list of indicators the participation of electricity in operating costs [%], rate of spending by energy consumption in water and sewage systems [R$. kWh^{-1}], electricity consumption rate in the water supply [$kWh.m^{-3}$]; in turn, Alegre *et al.* (2004) uses the indicators of normalized energy consumption [$kWh.m^{-3}$. 100 m^{-1}], reactive power consumption [%], energy recovery [%] plus the cost of electricity [%]. Regarding the efficiency of water use, both the SNIS (MCIDADES, 2010) and Alegre *et al.* (2004) give special attention to the losses rates, by type (real, apparent, billing, distribution) and per capita consumption rates, among others. Examples of other hydraulic indicators considered by the two sources are: storage capacity of treated water [days], density of valves in [$units.km^{-1}$], density of flow meters in districted metered zones [units.1000 $connections^{-1}$], micro and macro-measurement rates [%].

Based on the examples from literature and on the nature of the databases referenced above, it is clear that performance measurement systems for water supply has been conducted with a view to the relative efficiency by using global indicators aimed at comparing WSSs, which explains the predominant use of techniques such as benchmarking and DEA in this industry.

In hydraulic and energetic terms, this type of analysis should be conducted with care, given that specific energy consumption and/or water loss rates, the way they are commonly available, are not ideal for benchmarking /relative efficiency analysis. This is because these ratios are affected by individual conditions of each system. An example of this dependence in terms of energy consumption refers to the various topographical conditions which WSS are subject to; systems installed in flat regions tend to require lower total height of elevation for pumping water, compared to others located in mountainous regions. In relative comparisons, the system that requires a smaller pump head due to smaller gaps to be overcome, may have a lower specific energy consumption to one installed in the region with bigger topographic gradient, and be considered a benchmark, even though its facilities, equipment and operation are less energy efficient than those for the second system. Examples of other factors that influence the analysis of hydraulic and energy efficiency in WSS are: shape and distribution of the urban population, location of water sources (allowing gravity adduction or not), groundwater levels (in the case of groundwater abstraction.) A possible alternative to this problem is the normalization of the indicators, through mathematical manipulations based on the physical components of the systems, which eliminate the influence of individual characteristics on indicators calculated.

As mentioned above, the review of the literature revealed a gap in the measurement of absolute hydraulic and energy efficiency of a thermodynamic nature, as regards the determination of optimum conditions of each system and compared their situation. In this sense, techniques such as benchmarking and DEA can be used to define target values (Andersen and Fagerhaug, 2002) on analysis in which it is not possible to be obtained this values through simulation and optimization techniques, or through theoretical references. Examples of this application are the identification of more efficient equipment (e.g. motor-pump sets) available for installation on the WSS from the query to databases of labeling programs, or to define optimal levels of water losses technically achievable, considering that, in theory, these levels would be 0%.

Despite the efficiency measurement techniques applied on the WSS be useful for an initial analysis of hydraulic and energetic performance, only through absolute thermodynamic efficiency analysis is it possible to effectively manage the efficiency of systems by identifying missing points and prospecting alternatives improvement. Whereas the modeling, simulation and optimization techniques for water supply systems demands large amounts of data, it is necessary to introduce in Brazil a culture of measurement and monitoring systems, associated with information management.

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