



Energy and hydraulic efficiency in conventional water supply systems



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ABSTRACT

This paper presents the state-of-the-art approaches to energy (electricity) and hydraulic efficiency and conservation in conventional water supply systems, providing an overview of energy efficiency and conservation alternatives from the analysis of selected research literature. These alternatives vary from leakage management to state-of-the-art real-time optimization techniques, and can be classified into three dimensions according to their natures: project and design dimension, operational dimension and physical dimension. The potential energy savings and the impact of these alternatives over the water supply systems' energy efficiency are highly variable. All the energy efficiency and conservation alternatives analyzed in this work may contribute with the promotion of sustainability of conventional water supply systems.

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1. Introduction

Water and energy resources are fundamental to human existence, and are regularly subject to economic, technological, demographic and social pressures. It is estimated that 2–3% of the

worldwide electricity consumption is used for pumping in water supply systems (WSSs) [1], while 80–90% of this consumption is absorbed by motor-pump sets [2,3]. This cost represents one of the major operational costs associated with WSSs.

Water pumping in WSSs and the other inter-relationships between water and energy (i.e., hydroelectric and thermoelectric generation, fuel and biofuel production, water supply, pumping and water treatment, desalination) will intensify if predictions regarding global climate change are confirmed. In this sense, while the production and use of energy from fossil fuels is considered the main cause of global warming, the most drastic consequences

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of climate change, such as floods, storms, droughts, and water-borne diseases, have been attributed to water.

Shrestha et al. [4] states that considering the critical links between water and energy during water planning and policy making can lead to significant energy savings. In turn, these savings have the potential to reduce the associated CO₂ emissions. The availability of drinking water in the near future will also require adaptations in several regions of the world in response to changes in precipitation and runoff patterns, salinization and alterations in water source quality as a result of climate variability [5]. However, most of the adaptive technological alternatives to these issues are energy-intensive (e.g., desalination and water reuse) [6].

According to Gude et al. [7], the electricity consumed (described by the energy intensity) by the desalination process varies from 1.5 kWh m^{−3} in multi-effect distillation and multi-effect distillation with thermal vapor compression processes to 12.0 kWh m^{−3} when mechanical vapor compression processes are engaged. Based on a literature review, Plappally and Lienhard [8] reported electrical intensities in the range of 0.27 kWh m^{−3} to 3.8 kWh m^{−3} for urban wastewater reuse and recycling plants. The same authors reported the medium specific energy intensity (energy intensity divided by the elevation head) of groundwater pumping in California to be 0.004 kWh m^{−3} m^{−1}. Table 1 presents the energy intensities associated with conventional water supply systems (CWSSs) as reported in literature, which vary from 0.25 kWh m^{−3} to 4.5 kWh m^{−3} depending on the source type (i.e., surface or groundwater).

Promotion of the efficient and rational use of water and electricity in WSSs plays a strategic role in the quest for the sustainable development of nations as well as in the mitigation of and adaptation to the causes/consequences of climate change. The high potential for the application of water and electricity rational use actions in WSSs has been attributed to poor infrastructure and operational procedures, particularly in developing countries. Moreover, according to the Millennium Development Goals (MDGs) [14], there is a need for more sustainable alternatives in the expansion and implementation of new systems by the year 2015; further, according to the MDGs, there is a target to halve the proportion of people without sustainable access to safe water and basic sanitation.

Given the relevance of this theme, the present work presents a review of the alternatives and opportunities to promote water and electricity efficiency and conservation in CWSSs. CWSSs are systems in which the treatment is carried out by conventional coagulation, flocculation, settling and filtration; additionally, in CWSSs, the majority

of electricity consumed is generally attributed to the power demand associated with pumping (for water catchment, adduction and distribution). The use of this delimitation in our study was defined based on the widespread use of such systems around the world in addition to the great potential for efficiency improvement, which typically can be identified in pumping systems, a fact which assigns an applied nature to this research.

This paper is focused on the supply side of management and alternatives and does not consider the opportunities and technologies available for energy and water conservation on the demand side of water management. Only the direct electricity consumption in CWSSs is considered, disregarding the energy consumption implicit in the various inputs (e.g., chemicals, materials) used in these systems; the energy consumed by the inputs is usually evaluated through life cycle analysis. We also disregard other energy flows beyond hydraulic and electrical; for example, the thermal energy embodied in the water masses flowing through the system is not considered here.

This paper is organized as follows: Section 2 presents the energetic and hydraulic model considered in this work, which summarizes the energy and mass flows in CWSSs. Section 3 presents a general approach to energy efficiency (EE) and energy conservation (EC) interventions and actions. As proposed by Dias [15], this general approach involves the classification of EE and EC actions in intervention classes, which allows both the impact of each measure on the EE of the system as well as the complexity of the measure's implementation to be inferred. Subsequently, these actions and interventions are contextualized to CWSSs, for which we identified three dimensions to evaluate the use and possibilities of energy conservation, including (1) the project and design dimension, (2) the operational dimension and (3) the physical dimension. The subsections of Section 3 detail the main opportunities for energy conservation applied to the CWSSs identified in the literature. In Section 4, we evaluate the opportunities described in Section 3; additionally, we evaluate some theoretical and empirical results of the applications of these opportunities. This evaluation includes the classification of EE and EC actions and opportunities in accordance with their impact on the energy efficiency of the system; this evaluation also explores their associated level of intervention, as described in Section 2.

2. The energy and hydraulic model of CWSSs

A water supply system is a set of structures, facilities and services that produces and distributes water to consumers;

Table 1
The energy intensities and indicators associated with CWSSs.

Authors	Region	Indicator description	Indicator values
Racoviceanu et al. [9]	Canada, Toronto	Energy intensity in the operation phase of water supply and treatment	0.68 kWh m ^{−3}
Mo et al. [10]	USA, Florida	Energy intensity in the operation and maintenance phases of surface water supply due to direct energy use	1.33 kWh m ^{−3}
	USA, Michigan	Energy intensity in the operation and maintenance phases of groundwater supply due to direct energy use	1.69 kWh m ^{−3}
Scott et al. [11]	USA, Arizona	Energy intensity of water pumping in the Central Arizona Project	1.24 to 2.55 kWh m ^{−3}
Venkatesh and Brattebø [12]	Norway, Oslo	Energy intensity in the operation and maintenance phases of water supply	0.39 to 0.44 kWh m ^{−3}
Brasil [13] (indicators calculated by the authors with data from Brazilian National Sanitation Information System)	Brazil	Medium energy intensity of the Brazilian largest regional water companies	0.69 kWh m ^{−3}
Plappally and Lienhard [8] (the authors presented values of indicators based on a literature review)	Canada, Ontario	Energy intensity of water extraction from wells	0.25 to 3.02 kWh m ^{−3}
	USA, Northern Caroline	Energy intensity of surface water pumping	2.4 kWh m ^{−3}
	Australia, Sydney	Energy intensity of water conveyance	1.6 to 2.6 kWh m ^{−3}
	USA, California		
	Mexico, Tijuana	Energy intensity of water conveyance	4.5 kWh m ^{−3}

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