ENERGY ASSESSMENT OF WATER NETWORKS, A CASE STUDY

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Abstract

The complete urban water cycle requires large amounts of energy and so, there is an increasing motivation to optimize its consumption. In addition, the periodic energy crises (the last one, July 2008, brought the price of the oil barrel to 150 USD), the acute worldwide commitments to reduce greenhouse gas emissions and, last but not least, the need to minimise economic losses linked to leaks (including the energy costs) place water-energy issues on the front page of the portfolio's research. A fact highlighted by the report "California's Water-Energy Relationship" (CEC, 2005). According to this study, up to 19% of the total California's energy consumption is related to water cycle, 6.5% associated to water distribution step, the one analysed here.

Cabrera et al. (2010) developed a methodology to perform energy audits in pressurized water distribution systems obtained from the integral energy equation and its integration in extended period. Input energy (pumps, reservoirs) is equal to the energy consumed by users (through demanded water) plus leakage and friction energy losses in pipes. Energy audit requires the previous water audit as well as the mathematical model of the distribution network. From the energy audit, context and performance indicators (Cabrera et al., 2010) are calculated in order to assess the energy performances of the system. Furthermore, these indicators will help to identify future actions devoted to improve the network's energy efficiency. Cost-benefit analysis is required to decide the best strategy to implement in practice.

The paper is organised as follows. The fundamentals are firstly outlined and then, a case study to assess a real network from an energetic point of view is presented. The real network supplies Denia city (Alicante, Spain) and the surrounding areas. The whole distribution system supplies water in a very touristic area, close to 100000 people, which is an interesting case study because of current water scarcity and high energy consumption. Both facts explain the high fees paid by the final consumer, compared with those paid in the rest of Spain. Being Denia a hilly city at the east Mediterranean coast of Spain, the energy assessment is an interesting academic exercise although for the utility company (Aqualia) is much more than that –improving water-energy performances is a key objective to be competitive.

Keywords: Energy audit, water networks assessment, performance indicators

1 INTRODUCTION

Energy assessment of water distribution networks is a key goal for utilities. In a permanent energy crisis scenario, its importance can be justified in different ways, as sustainable water management is becoming very energy consuming. But, in a few words, wasting significant amounts of water and energy through leaks is, simply, unacceptable. Energy is commonly wasted as a result of network leakage, and such energy loss results not only from the energy leaving the system through leaks (which can be quite relevant depending on the energy footprint of the previous steps of the urban water cycle, mainly when water comes from desalination plants) but also from the extra energy needed to overcome additional friction losses created by higher flow rates in pipes.

The audit presented in Cabrera et al. (2010) allows to identify the final uses of the energy that enters the system, and thus to perform an assessment that characterizes the network behaviour from an energy perspective. Context information and energy indicators summarise the energetic performance of the whole system. The energy audit can be used to evaluate the GHG impacts, which depend on the sources of water and energy (Cabrera et al., 2009). In order to have a more holistic point of view, a cost-benefit analysis including environmental costs can be performed. As a matter of fact, these tools could easily be used from a regulatory or administrative perspective to create incentives for a more sustainable urban energy management in water distribution systems. The energy audit, like related indicators, requires a previous water audit and a calibrated model. Both audits must be applied to similar boundaries (either to the whole network or a sector).

In this paper this methodology is applied to a real network, Denia (a coastal hilly city between Valencia and Alicante, Spain). For such purpose an agreement between Aqualia, the water utility responsible of the network and the Universidad Politécnica de Valencia was established. Up to now, this methodology was only applied to synthetic networks. Among many candidates, Denia was selected because it is mainly supplied from desalination (which uses brackish water from Racons River) and groundwater. Although this paper only focuses on the influence of the energy losses at the distribution stage, this kind of water source (really energy consuming) involves high values of energy water footprint, and performing a global assessment of the whole urban water cycle becomes essential.

2 REVISION OF THE STRUCTURE AND ENERGY AUDIT CALCULATION

This section describes how to evaluate the amount of energy consumed in water distribution networks. Further details can be found in Cabrera et al. (2010).

2.1 Input Energy Supplied By The Reservoir (Natural Energy)

The external energy supplied by reservoirs is:

$$E_N(t_p) = \gamma \cdot \sum_{i=1}^{i=n_N} \left(\sum_{t_k=t_1}^{t_k=t_p} Q_{Ni}(t_k) \cdot H_{Ni}(t_k) \right) \cdot \Delta t \qquad (1)$$

Where γ is the specific weight of water, $Q_{Ni}(t_k)$ and $H_{Ni}(t_k)$ are, respectively, the flow rate supplied from the reservoir i (being n_N the number of reservoirs) and its piezometric head at time t_k. Since the analysis in extended time corresponds to a given period $t_p = k \cdot \Delta t$, the k time intervals Δt of the analysis must be added to totalise this period.

2.2 Incoming Energy to the Network Supplied by the Pumping Station (Shaft Work)

The shaft work supplied by the pump is:

$$E_P(t_p) = \gamma \cdot \sum_{i=1}^{i=n_P} \left(\sum_{t_k=t_1}^{t_k=t_p} Q_{Pi}(t_k) \cdot H_{Pi}(t_k) \right) \cdot \Delta t \qquad (2)$$

Where $Q_{Pi}(t_k)$ and $H_{Pi}(t_k)$ are respectively the flow rate pumped by the station and the pump head at time t_k. This calculation needs to be done for the n_p pumping stations that supply shaft work to the system at the k different time instants. In this balance, and because pumps do not belong to the system, their efficiencies (an essential parameter for the energy optimization) are not considered. In any case, they can be easily included dividing, for each time interval, this shaft energy term by the corresponding pump's efficiency. In this paper and since the focus is on new concepts, these energy losses are not included in the analysis.

2.3 Energy Delivered to Users at Consumption Nodes

The useful energy delivered is:

$$E_U(t_p) = \gamma \cdot \sum_{i=1}^{i=n} \left(\sum_{t_k=t_1}^{t_k=t_p} q_{ui}(t_k) \cdot H_i(t_k) \right) \cdot \Delta t \tag{3}$$

Where n is the number of demand nodes of the network, $q_{ui}(t_k)$ and $H_i(t_k)$ are respectively the flow rate delivered to users and the piezometric head at node i and time t_k.

2.4 Outgoing Energy Through Leaks

Leaks represent energy leaving the system, formally analogous to the energy delivered to users, although from the point of view of the audit it is lost energy. This term is:

$$E_L(t_p) = \gamma \cdot \sum_{i=1}^{i=n} \left(\sum_{t_k=t_1}^{t_k=t_p} q_{li}(t_k) \cdot H_i(t_k) \right) \cdot \Delta t \tag{4}$$

With n the number of leaking nodes in the network, $q_{li}(t_k)$ the leaked flow rate in the pipes adjacent to node i (and therefore associated to this node) at time t_k, while $H_i(t_k)$ is the piezometric head at time t_k in the node where the leak $q_{li}(t_k)$ has been concentrated.

2.5 Friction Dissipated Energy

The energy dissipated due to friction in pipes is:

$$E_F(t_p) = \gamma \cdot \sum_{j=1}^{j=n_l} \left(\sum_{t_k=t_1}^{t_k=t_p} q_j(t_k) \cdot \Delta h_j(t_k) \right) \cdot \Delta t \tag{5}$$

Where n_l is the number of lines of the network, $\Delta h_j(t_k)$ are friction losses in line j at time t_k (this term is in pipe j the difference in piezometric heads between the initial and final nodes, a value known from the mathematical model of the system), $q_{uj}(t_k)$ and $q_{lj}(t_k)$ are, in line j, the flow rate necessary to satisfy the users demand and the flow rate that finally is lost through breaks, respectively. Therefore, the total flow rate in line j, $q_j(t_k)$, is the sum of the two previous values. Local losses may be added to this term by calculating their equivalent piping length.

The energy dissipated due to friction in valves is:

$$E_V(t_p) = \gamma \cdot \sum_{j=1}^{j=n_V} \left(\sum_{t_k=t_1}^{t_k=t_p} q_j(t_k) \cdot \Delta h_j(t_k) \right) \cdot \Delta t \qquad (6)$$

Where n_v is the number of valves of the network, $\Delta h_j(t_k)$ and $q_j(t_k)$ are friction losses and flow rate in valve j at time t_k .

2.6 Energy Compensation of the Downstream Tank

Many networks have a compensation tank to accumulate water during low consumption hours while releasing it in peak ones. However, the net flow of water and energy in one of these tanks, when integrated through a long enough period, is zero, and so it is their contribution to the analysis as well. Short term would then be the period of time after which the energy stored in a tank is below a threshold, while the long term would just be the opposite case.

The variation of potential energy stored in tanks of constant section for a given period of time is:

$$\Delta E_C(t_p) = \sum_{i=1}^{i=n_C} \left(E_{C_i}(t_p) - E_{C_i}(t_1) \right) = \gamma \cdot \sum_{i=1}^{i=n_C} \left(A_i \cdot \left(z_i^2(t_p) - z_i^2(t_1) \right) / 2 \right) \qquad (7)$$

With A_i the section of compensation tank i and $z_i(t_p)$, $z_i(t_1)$ the levels of the free surface of water of tank i at the initial and final times. The maximum variation of this energy, $\Delta E_{C\max}$, obviously corresponds to total oscillation between empty and full tanks of the whole system. This last term will be necessary to conclude the type of analysis (short or long term) performed.

2.7 Final Balance

From the preceding terms, being t_p the period of calculation of the previous expressions (as is the case of a water audit, commonly one year), the following final balance results:

$$\begin{aligned} E_{input}(t_p) &= E_N(t_p) + E_P(t_p) = E_U(t_p) + E_L(t_p) + E_F(t_p) + E_v(t_p) + \Delta E_C(t_p) = \\ &= E_{Output}(t_p) + E_{Dissipated}(t_p) + \Delta E_{Compensation}(t_p) \end{aligned} \qquad (8)$$

Equation (8) states that the energy (natural and shaft) supplied to the water coming into the network is equal to the energy delivered to the users (throughout the water supplied) plus the losses (leakage and friction) and the variation of energy at the compensation tank. From this balance, energy losses can be evaluated and its knowledge allows outlining efficient actions aimed to improve system's efficiency.

3 ENERGY AUDIT OVERVIEW. CONTEXT INFORMATION AND EFFICIENCY INDICATORS

Each system is, from an energetic point of view, different. The network topography is not modifiable and of course it can result in a high or low interest energy analysis. For instance, a hilly city with numerous intermediate pumping stations, with water coming from deep wells or desalination plants would require significant amounts of energy, and consequently, a great interest study. The opposite case is a plain city, fed by surface water and without any pumping stations.

The difference in context between these two situations is summarised by the context information (Table 1). The first one, C_1, shows which portion of energy delivered to the system is natural. It ranges from 0 to 1 (best value, the whole amount of energy is natural), whereas the second one, C_2, takes into account how energy demanding the network is. In particular, it is the ratio between the minimum useful energy, $E_{min,useful}$ (defined in each node from the minimum required head, $h_{Mín,i} = z_i + P_{Mín} / \gamma$) and a theoretical minimum required energy (for a flat, leak free and frictionless network) $E_{min,flat}$. Since this ideal network corresponds to a flat layout with all nodes located at the same maximum height zmax, the best possible value of C_2 is one.

Table 1. Context information

C_1 Energy nature	C_2 Network energy requirement
$C_1 = \dfrac{E_N(t_p)}{E_{Input}(t_p)}$	$C_2 = \dfrac{E_{\min,useful}}{E_{\min,flat}} = \dfrac{\gamma \cdot \sum_{k=t_1}^{k=t_p} \sum_{i=1}^{n} q_{ui}(t_k) \cdot (h_{Min})_i \cdot \Delta t}{\gamma \cdot \dfrac{P_{\min}}{\gamma} \cdot \forall_U(t_p)} = \dfrac{\sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}{\dfrac{P_{\min}}{\gamma} \cdot \forall_U(t_p)}$

To perform the analysis and assessment, five performance indicators were proposed and reviewed herein (Table 2):

Table 2. Energy efficiency indicators

I_1 Excess of supplied energy	I_2 Network energy efficiency	I_3 Energy dissipated through friction
$I_1 = \dfrac{E_{input}(t_p)}{E_{min,useful}} = \dfrac{E_{input}(t_p)}{\gamma \cdot \sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{min,i}}$	$I_2 = \dfrac{E_U(t_p)}{E_{Input}(t_p)}$	$I_3 = \dfrac{E_{Dissipated}(t_p)}{E_{Input}(t_p)}$

I_4 Leakage Energy	I_5 Standards compliance
$I_4 = \dfrac{E_L(t_p) + E_{Dissipated}(t_p) - E'_{Dissipated}(t_p)}{E_{Input}(t_p)}$	$I_5 = \dfrac{E_U(t_p)}{\gamma \cdot \sum_{i=1}^{n} \vartheta_{u,i}(t_p) \cdot h_{\min,i}}$

Further information on these indicators can be found in Cabrera et al. (2010). Their values range as follows:

- $I_1 \geq 1$. It shows that the head at the nodes is close (but always above) to minimum required head. The closer to one, the better.
- $0 \leq I_2 \leq 1$. It represents which fraction of the total energy input is useful. The closer to one, the better.
- $0 \leq I_3 \leq 1$. It represents which fraction of the total energy input is dissipated in pipes and valves. The closer to zero, the better.
- $0 \leq I_4 \leq 1$. It shows energy losses due to leakage (including the additional energy required to overcome friction in pipes and valves with the extra flow rate). It is desirable to reach low values of this indicator.
- $I_5 \geq 1$. Better as closer to one. This is the direct ratio between the energy delivered to users and the minimum required useful energy. A value close to 1 indicates greater efficiency in meeting the pressure service above standards (condition required in our analysis). Values below one (unacceptable) would show that pressure at some junctions is below standards.

4 CASE STUDY

4.1 Problem Description

The case study here is based on the Denia water distribution network (Figure 1). The network contains approximately 434 km of pipes supplying water to a population of 100,000 inhabitants (which includes Denia and the surrounding areas), 11,500 connections (27 connections/km). The original hydraulic model was provided by Aqualia in EPANET 2 software. The model contains 6,296 nodes, 3 reservoirs, 9 tanks, 6,562 pipes, 14 pumps and 16 valves. Pipe diameters range between 600 and 12 mm.

EPANET2 is a well known demand-driven water distribution network modelling software that uses temporal demand pattern multipliers (DPMs) to represent a diurnal curve, i.e. the temporal variation of demand, typically for 24 hrs (although EPANET 2 simulator repeats a pattern where the duration of an extended period simulation exceeds the duration of the pattern). In the case study here, the network nodes are assumed to follow two different diurnal curves (i.e., two sets of DPMs). The first covers 28% of the average demand (57.2 l/s); while the other covers the demand left (147.5 l/s, 72%). The duration of the extended period may be 24 hours (short term simulation) or 1 month (long term one). Pattern time step was set to 1 hour at every simulation and the hydraulic time step was set to 5 minutes.

Figure 1. Denia network layout

Leakage was not originally modelled as pressure driven demand, and so, the first step was to model it using an orifice function as (Rossman 2000):

$$q_{li}(t_k) = C_{E,i} \cdot \Delta H_i(t_k)^{\alpha} \quad (9)$$

Where $\Delta H_j(t_k)$ is the head difference across the leak (at our case, $\Delta H_i(t_k) = H_i(t_k) - H_{GW}$, and $H_i(t_k)$ and H_{GW} heads in the pipe and in the surrounding groundwater at line i and time t_k. It is assumed that $H_{GW} = 0$ and so, $\Delta H_j(t_k) = H_{ij}(t_k)$), $C_{E,i}$ is the coefficient assigned to each node (named emitter coefficient), being their units, $m^{3-\alpha}/s$, while α =1.1 is the emitter exponent that models the characteristics of the pipe material.

Another hypothesis relies on the spatial distribution of leaks, which in Denia is assumed to be homogeneous with a uniform distribution of leaks, only taking into account the lengths of the lines and the time variation of pressure at nodes. So, leakage is simulated as an emitter assigned to a node that considers the weighted length of the lines connected to it (Almandoz et al., 2005). The sum of all nodal leakages rates should equal the total leakage of the system (in Denia represents around 23% of the total injected volume).

5 ENERGY AUDIT RESULTS

Four cases are presented. They correspond to daily and monthly simulations for both ideal (leak free) and real networks. These can be summarized as follow:

- Case A. Daily simulation, real network
- Case B. Monthly simulation, real network
- Case C. Daily simulation, ideal network
- Case D. Monthly simulation, ideal network

The aforementioned compensation term is only relevant in short-term simulations. The threshold value, $t_{p,B}$, boundary between the short and the long term is calculated imposing a threshold value (i.e. 1%), from the maximum compensation energy ($\Delta E_{c,max}$) and the daily system energy input (E_{Input}). The simulation can be considered as long term one if the maximum compensation energy is lower than this small percentage of the system energy input. The equation used to calculate $t_{p,B}$ is, then:

$$t_{p,T}(days) = \frac{\Delta E_{c,\max}}{\frac{1}{100} \cdot E_{Input}(daily)} \quad (10)$$

As the input energy is $E_{input}(t_p) =$ 13,699.91 kWh/day and the maximum variation in the 9 compensation tanks is $\Delta E_{c,\max} =$ 2,467.47 kWh. The threshold value is $t_{p,T} = 18$ days (equation 10) and so, the daily simulation can be considered as short term, but not the monthly one that qualifies as long-term.

5.1 Results

Prior to perform the energy audit, it is compulsory to solve the hydraulic problem. The hydraulic model of the network and its water audit (apparent losses are considered as additional demand) is required. Table 3 presents the water audit results:

Table 3. Water balance in Denia network.

	Case A (m^3)	Case B (Hm^3)	Case C (m^3)	Case D (Hm^3)
Injected water	42,272.50	1.2206	35,294.40	0.9384
Delivered water	31,490.00	0.9327	31,090.00	0.9327
Real losses	7,363.72	0.2842	0	0
Volume stored in tanks	3,796.10	0.0035	4,191.40	0.0042

In case B, water losses per unit of length and time are equal to 0.91 m^3/kmh. This indicator tends to range between 0.1 m^3/kmh and 2 m^3/kmh, so the attained value corresponds to the mean value of the range and to a relevant leakage level. Table 4 shows the energy audit. Theoretical energies, defined as $E_{\min,useful}$ and $E_{\min,flat}$, are equal to 2,197.26 kWh/day (65.92 MWh/month) and 1,061.28 kWh/day (31.84 MWh/month) respectively.

Table 4. Energy balance in Denia network

Energy		Real network		Ideal network (no leaks)	
		Case A	**Case B**	**Case C**	**Case D**
		Short Term $t_p < t_{p,T}$ (kWh/day)	Long Term $t_p > t_{p,T}$ (MWh/month)	Short Term $t_p < t_{p,T}$ (kWh/day)	Long Term $t_p > t_{p,T}$ (MWh/month)
$E_{Input}(t_p)$	$E_N(t_p)$	2,213.21 (16.2%)	67.15 (18.5%)	2,137.22 (19.7%)	64.84 (22.4%)
	$E_P(t_p)$	11,486.70 (83.8%)	296.53 (81.5%)	8,689.90 (80.3%)	224.33 (77.6%)
$E_{Output}(t_p)$	$E_U(t_p)$	3,862.12 (28.3%)	120.62 (33.2%)	4,746.70 (43.9%)	168.79 (58.3%)
	$E_L(t_p)$	2,095.23 (15.3%)	64.43 (17.7%)	- (0%)	- (0%)
	$\Delta E_C(t_p)$	1,362.56 (10.0%)	2.03 (0.6%)	1,264.19 (11.7%)	1.88 (0.7%)
$E_{Dissipated}(t_p)$	$E_F(t_p)$	6,132.51 (44.9%)	169.94 (46.7%)	4,639.68 (42.9%)	113.57 (39.2%)
	$E_V(t_p)$	201.14 (1.5 %)	6.49 (1.8%)	164.54 (1.5%)	5.31 (1.8%)

Additionally, results in Table 4 show that:

- The energy required at the distribution step is very high. In particular, for case B, the energy intensity per unit of water injected is as high as 0.32 kWh/m^3. In fact, it is equal to the upper limit for the distribution step provided by CEC (2005).
- The input energy savings in a leak-free network are significant. At the daily simulation, it is given by the difference between 13,699.91 kWh/day and 10,827.12 kWh/day whereas at the monthly one it can be calculated from the difference between 363.68 MWh/month and 289.17 MWh/month.
- The energy delivered to users is higher in a leak-free network than a real one (respectively 168.79 MWh/month and 120.62 MWh/month). This increase shows improvement at the network performance. Accordingly to this, the partial or total recovery of these energy surpluses requires the optimization of the operating conditions of the network. So, it increases potential energy savings.
- The energy losses linked to leaks (outgoing energy through breaks plus additional friction losses) is 2,095.23+6,132.51+201.14-4,639.68-164.54 = 3,624.66 kWh/day for the short term simulation. This value is 121.98 MWh/month for the monthly case. This potential savings represents 26.45% and 33.54% respectively of the total energy in use. A significant figure, indeed.
- The energy dissipated in valves is not a high value, which implies a low percentage figure compared to energy dissipated due to friction in pipes.

5.2 Energy Assessment of the Denia Network

The results obtained with the long term simulation are now used (Cases B and D) to calculate both context and efficiency indicators. Table 5 shows them all. Context indicators remark the relevance of the analysis, while energy indicators show that, with an adequate system management, there is a huge room for improvements. As expected, it is easy to notice that all the indicators improve in a non leaky network.

Table 5. Energy Indicators

	C_1	C_2	I_1	I_2	I_3	I_4	I_5
Real network	0.18	2.07	5.52	0.33	0.47	0.34	1.83
Ideal network	0.22	2.07	4.39	0.58	0.39	-	2.56

The first context information shows that less than 20% of the input energy is natural. The slight variation of this value between the real and ideal networks is negligible, since it is supposed to be independent of the state of the network (Alegre et al., 2006). This is due to the fact that C_1 is not strictly a context indicator because it depends on the percentage of energy supplied by the reservoirs, and, in turn, it varies according to the system behaviour. C_2, shows that Denia's network is rather hilly, as it is highlighted by the difference between the highest and lowest node (180 m).

The first efficiency indicator, I_1, shows that the input energy of the network is more than 5 times the minimum amount of energy necessary to supply the service. As a matter of fact, when leakage disappears, this indicator is brought down to 4.4. The second indicator shows the percentage of energy delivered to users, 33% in the real network compared to the input energy. This leaves 67% of the energy lost through either leakage or friction. In a leakage-free scenario, the value goes up to 58%, representing a relevant improvement. I_3 shows how much energy is used to overcome friction in pipes and valves. In this case, a value this high (47%) indicates high length of the network, or tight pipe diameters, or both. In a leak-free situation, this value is 39%, high enough to trigger the substitution of key mains with larger ones, although a cost-benefit analysis is required to explore other options (i.e., demand management policies). The fourth indicator evaluates total energy lost due to leaks. Its high value (34%) means a lot of energy wasted, 180 MWh/month. At the distribution step, this energy can represent economic losses of approximately 20,000 €/month (according to the Spanish electric tariff).

Finally, as expected, I_5 increases in a free-leak network. So, there is more surplus of energy delivered to users. It means that, in absence of leaks, the level of pressure increases, and network's performance can be improved by means of regulation (valves or variable-speed pumps).

Anyway, performance indicators show that it is worth to explore different ways to improve performances and, throughout the corresponding cost-benefit analysis, to decide the order and the time to implement them. And this is, indeed, the second step of the study. To this regard, next section outlines the ways to be explored.

6 THE WAY FORWARD

Due to the fact that water sources in Denia (groundwater and desalination) are very energy consuming, the operator is interested in an overall energy assesment, that will include all the steps of the urban cycle, and not just the distribution phase up to now described. In any case, this paper will only focus on the energy assessment of the distribution stage.

The strategies can be divided into two groups. Those that improve the system operation (i.e., variable speed pumps) and those that minimize the flows through the network, either reducing leaks or demands. The first ones can only be faced by the utility, whereas the second ones can be undertakaen by both, utility and users. This last option is the ond finally adopted to outline the way forward.

1. From the utility side
   - A better system operation, mainly through pressure management.
     Pressure control can reduce leakage, as well as other pressure driven demands (i.e. garden watering) and the frequency of bursts. Also, it provides a more steady service to costumers. That pressure control must requires to implement district metering areas (DMA), pressure management areas (PMA) or both. It is very convenient that both areas will coincide because, in that case, water and energy audits can be particularly applied and energy indicators identified. Depending on the improvements achived for each particular DMAs, the subsequent actions can be scheduled. Obviously, the technique used to reduce the pressure might differ according to each PMA's particularities. Typical options range from the installation of pressure reducing valves to the replacement of constant speed pumps by variable speed ones.
   - A better network management, through a more active leakage control.
     There are two ways to reduce leaks. The first, pipe renovation and the second one a more active leakage control. A pipe renovation policy will, indeed, improve Denia´s network performance. Pardo (2010) dealt with the influence of water and energy costs in pipe renovation periods. On the other hand, areas where the number of bursts per km and year presents a reasonable figure and, hence, pipe renovation is not fully justified, a more active leakage control should be promoted.

2. From the users side

   - Water demand reduction. It is quite clear that water use reduction would lead into energy savings. CEC (2005) showed that although water efficiency programs and conservation efforts exist in that state, there are many missed opportunities to save energy, and the achievable benefit could be higher than the one obtained with energy efficiency measures. It is shown (Table 3) that in Case A, the consumed volume is 31,490 m^3/day which results in 321.32 l/cap/day, a rather high value compared to the spanish average (157 l/cap/day). So, high water demand reduction possibilities rely behind.

This project of Denia's network energy assessment tries to improve the sustainability by promoting a more efficient use of water and energy. Hydraulic and energy efficiency are inextrincably coupled and so, every assessment decision has a double synergetic effect. Now, the project overcame this first step, the energy audit highlighted the current state of the network and showed huge potential savings which are now under study. Cost benefit analyses (depending on the water and energy costs) should be performed to evaluate different potential actions, and once more, the energy audit herein plays a crucial role.

7 CONCLUSIONS

This paper shows the first application of the energy audit to a real water network. Results demonstrate that it is a powerful tool to provide key information to ease operator's decisions. Now, the strengths and weaknesses from an energetic point of view are well known.

This case study shows huge amounts of energy losses due to leakage and dissipation. Moreover it helps to clarify the relationship between water and energy. It is obvious that the leakage reduction leads to energy savings and the results show huge potential savings because of the complex topography, the lack of specific assessment, etc.

The energy assessment policy will have to address all this info in order to evaluate properly the benefits of each individual decision, as well as all the plans considered simultaneously (observing the synergy amongst all of them). The energy audit supports all these facts in numbers, not just words. Undoubtely, energy is a key factor in order to take decissions.

As aforementioned, this paper does not consider the energy water footprint of previous steps of the urban water cycle. In Denia, water comes from very energy consuming sources i) desalination, at 3.5 kWh/m^3 (NRC, 2008), and ii) groundwater at 0.35 kWh/m^3 per 100 m of elevation. So, improving the network efficiency is crucial for the water utility, mainly if environmental costs (as those derived from the GHG emission) are considered.

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