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ScienceDirect

Procedia Engineering 119 (2015) 1088 – 1097

Procedia Engineering

www.elsevier.com/locate/procedia

13th Computer Control for Water Industry Conference, CCWI 2015

Direct and indirect water supply: an energy assessment

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Abstract

Tanks have always played a crucial role in urban water distribution systems. With well known advantages (as to guarantee reserves for emergencies) they are widely used. But they present, as well, inconveniences such as their contribution to a higher water age and are, as will be seen, energy-hungry. This paper introduces an indicator to assess energy savings of direct water supply (without head tanks) with regard to the traditional indirect one (throughout head tanks). Furthermore a case study is presented showing the reliability of this indicator. The paper concludes with an economic comparison of both strategies.

Peer-review under responsibility of the Scientific Committee of CCWI 2015

Keywords: Water and energy; energy savings; network layout; energy assessment

1. Introduction

Water tanks have been, and are, key elements in urban water distribution systems. Therefore, it should not be a surprise that still deserve the attention of hydraulic researchers mainly as far as theirs main parameters concern (e.g., location, elevation, volume, minimum and maximum operational level, diameter-height ratio and emergency volume–total volume). Those who are interested in all these aspects can find a good review of the state of the art in a recent paper [1], in which several formulations and models of resolution are analyzed. Another relevant issue linked to water tanks is the resilience concept [2]. Energy aspects, with their corresponding costs (linked to applicable electric tariffs) related with tank's characteristics has been deeply analyzed as well [3]. Last, energy consumption with their environmental implications (green house gas emissions) has been considered in more recent

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Peer-review under responsibility of the Scientific Committee of CCWI 2015
doi:10.1016/j.proeng.2015.08.941

multiobjective models, inside the global optimization process [4]. In all these models, tanks are included as part of the global system.

Our approach is much simpler. We just consider a water network in operation and evaluate its energy requirements with and without tank. In other words, we compare indirect and direct water supply from a strict energetic point of view. This comparison actually makes sense because the wide use of variable frequency drivers. These elements are gaining credibility due to a higher reliability and the energy savings achieved with their use. By the other hand, the main drawback of the direct supply, potential electric network failures, is rapidly losing room (actually are much more infrequent than some years ago) and, in any case, this problem can be overcome using emergency power generators. As a matter of fact, in new designs of pressurized water irrigation systems tanks are not included at all. Obviously reliability in urban uses must be much higher than in the irrigation use but in any case, few years ago tanks were very common in these systems as well.

Energy requirements are very much depending on network's topography [5]. To minimize this impact, a potential action is to divide the network into different areas, to be called District Supply Areas (DSAs). In the end this is the only way to reduce the topographic energy of the whole system and therefore to increase the global network efficiency. This option must be always considered in systems with irregular profile (a concept strongly linked to Pressure Reducing Valves, PRV, and Pumps working as Turbines, PATs). In any case this analysis, although collaterally discussed, is out of the scope of this paper focused on energy requirements of water networks with direct or indirect supply.

2. Energy assessment

2.1. Background

Three indicators to assess the energy efficiency of a pressurized water network have been introduced in a previous paper [5], two of them of particular interest to this paper. They show respectively the ideal (η_{ai}) and real (η_{ar}) efficiencies of the system, based on the minimum energy required by users—the minimum (because of its ideal behavior) amount of energy to be supplied to the system, the minimum energy needed by the system (provided its ideal behavior) and the energy really consumed. The gap between both efficiencies gives a clear idea on the margin of improvement the system has. In other words, the ideal efficiency, an upper limit impossible to achieve in real systems, is linked to the layout and independent on how it works. Therefore for a given configuration of the system is a constant value.

The ideal and real system efficiencies can be expressed as:

$$\eta_{ai} = \frac{E_{uo}}{E_{si}} = \frac{E_{uo}}{E_{uo} + E_{ti} + E_{ei}}; \qquad \eta_{ar} = \frac{E_{uo}}{E_{sr}} = \frac{E_{uo}}{E_{uo} + E_{tr} + E_{er} + E_{rg}} \tag{1}$$

Being E_{uo}, the minimum energy required, constant no matter the system should be real or ideal. It represents the minimum energy demanded by the users that depends on the required pressure (p_0), set by the standards, and the volume to be supplied to each generic node (v_j). This value will be extended along the space (to any junction) and time (along the considered period). E_{ti} and E_{tr}, are, respectively, the topographic energy required by the ideal and real system. Represents the energy required by the system because its topography and is very much depending on the highest and, therefore, the less favorable (from a hydraulic point of view) node (z_h). The more irregular the ground is, the more relevant this term becomes. Last E_{ei} and E_{er}, represent the excess (or surplus) of energy supplied to the system. On the contrary that the topographic energy, this surplus can be avoid because correspond to an overpressure (up the required standard) delivered to the highest node. Last E_{rg}, is the reducible global energy in real systems and, obviously, does not exist in ideal systems. Losses can be due to leaks, friction in pipes, inefficiencies in pumping stations and others. More details can be found in [5]. Table 1 shows their analytical expressions.

Table 1. Main energy terms of a pressurized system assessment [5]

Energetic Term	Concept
Minimum required energy by users (E_{uo}) (constant, no matter the system be real or ideal)	$E_{uo}=\gamma\sum v_j\left[(z_j-z_l)+\frac{p_0}{\gamma}\right]$
Topographic energy required by the ideal system (E_{ti})	$E_{ti}=\gamma\sum v_j(z_h-z_j)$
Supplied excess energy for the ideal system (E_{ei})	$E_{ei}=\gamma\sum v_j\frac{p_{ei}}{\gamma}$
Total supplied energy for the ideal system (E_{si})	$E_{si}=E_{uo}+E_{ti}+E_{ei}$
Total supplied energy for the real system (E_{sr})	$E_{sr}=E_{uo}+E_{tr}+E_{er}+E_{rg}=E_{sr,n}+E_{sr,p}$

Assuming an ideal behavior, the only difference between indirect and direct supplies lies on the excess of energy. Therefore the efficiency improvement of the direct supply can be easily estimated from the tank elevation H_t with regard to the energy requirements of the highest node (see Figure 1). The ideal efficiencies of both scenarios (indirect, $\eta_{ai,1}$, and direct $\eta_{ai,2}$) can be easily linked.

$$\eta_{ai,1}=\frac{E_{uo}}{E_{si,1}}=\frac{E_{uo}}{E_{uo}+E_{ti}+E_{ei}};\quad \eta_{ai,2}=\frac{E_{uo}}{E_{si,2}}=\frac{E_{uo}}{E_{uo}+E_{ti}}\quad\rightarrow\quad \eta_{ai,2}=\left(1+\frac{E_{ei}}{E_{si,2}}\right)\eta_{ai,1} \tag{2}$$

Where E_{ei} can be expressed as $E_{ei}=\gamma\sum v_j\frac{p_{ei}}{\gamma}=\gamma\sum v_j\left(Ht-\left(z_h+\frac{p_o}{\gamma}\right)\right)=\gamma\sum v_j\Delta H$,

Being ΔH the difference between the tank elevation, H_t, and the piezometric head required at the highest node.

Both ideal indicators are related by the equation:

$$\eta_{ai,2}=\left(1+\frac{\gamma\cdot V\cdot\Delta H}{E_{si,2}}\right)\eta_{ai,1}=I_{ds,i}\eta_{ai,1} \tag{3}$$

This equation clearly evidences that, in ideal systems, direct supply is, from an energetic point of view, always more efficient than the indirect one. The margin of improvement is given by the direct supply improvement indicator I_{ds} ($I_{ds,i}$ for the ideal case) always equal or greater than one. Just in case of ΔH equal to zero, I_{ds} will be one. But this case is impossible to find in practice because in that case the additional energy required when the behavior is real could not be provided. Figure 1 clarifies this concept. It can be seen that the higher the tank is, the more inefficient the system is (E_{ei} = $\gamma\cdot V\cdot\Delta H$). Last, it must be underlined that the other terms, E_{uo} and E_{ti} are, for the same network, independent on the tank elevation.

$$I_{ds,i}=1+\frac{\gamma\cdot V\cdot\Delta H}{E_{si,2}}=1+\frac{\gamma\cdot V\cdot\Delta H}{E_{uo}+E_{ti}} \tag{4}$$

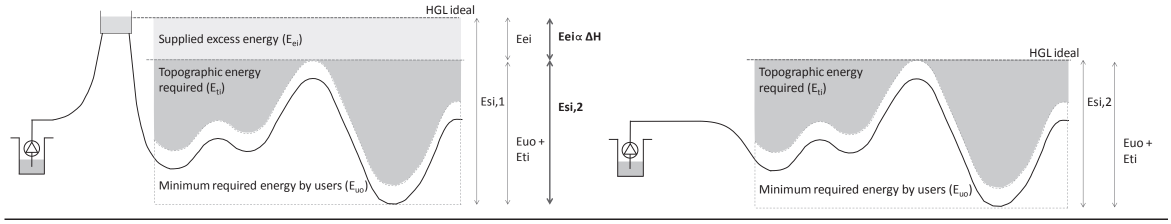

Fig. 1. (a) Scenario 1 (indirect supply); (b) Scenario 2 (direct supply).

All these concepts are applied to the numerical case study that follows. Table 5 depicts the different energy terms for the ideal case. From them, ideal efficiencies are calculated (0.519 for indirect supply and 0.679 for direct supply) while I_{ds} is equal to 1.31. This value indicates that direct supply has, in the ideal case, a higher efficiency than the indirect one. As will be seen later, in similar conditions (analogous pump efficiencies in both scenarios) in the real case, the improvements are of the same order of magnitude or even higher than the quoted for the ideal case.

2.2. Numerical example

The main purpose of this example is to analyze, from an energetic point of view, the same system (see Figure 2) with just one modification: the different supply (indirect or direct). For this second scenario, two pumps will run in parallel, one provided with a frequency variable speed driver. The other data (system layout, demands, pressure requirements, leaks and pumping efficiencies) are in both cases the same. EPANET is the hydraulic solver used. Leaks are pressure depending and therefore modeled in both scenarios with the same nodal coefficient emitters. In such conditions energy variations will be solely attributed to the different supply.

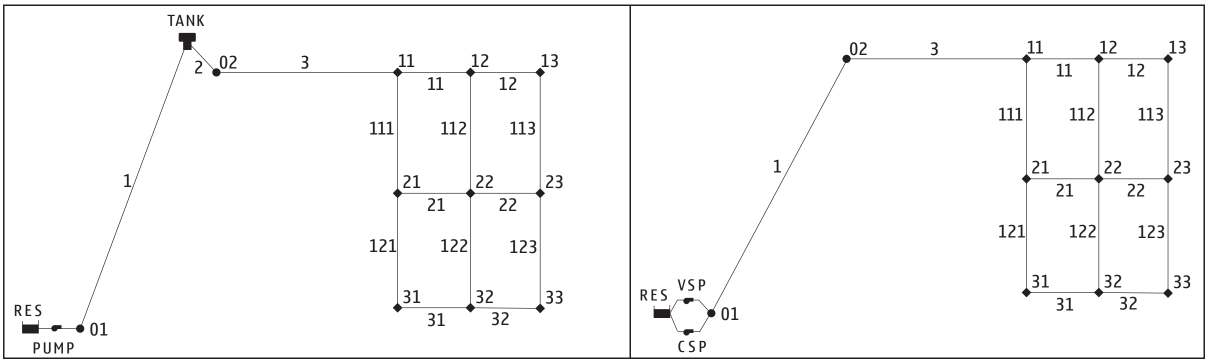

Fig. 2. Example's network (indirect supply, left side; direct supply right side)

2.3. Basic data

Table 2 depicts pipes and nodes characteristics, including the emitter's coefficients to model pressure depending leaks, according the equation $q_{li}(t_k) = C_{E,i} \cdot [p_i(t_k)]^{\gamma}$ [6], in which $C_{E,i}$ ($m^{3-\gamma}/s$) is the node's leak coefficient, $p_i(t_k)$ (m) the pressure at node and γ=1,1 the exponent that accounts for the average behavior of the pipe' material [7]. Pipe roughness coefficient is 0.1 mm.

Table 2. Pipe's and junction's characteristics of the analyzed system

PIPES	1	2	3	11	12	111	112	113	21	22	121	122	123	31	32
Lenght (m)	1000	10	2000	2000	2000	4000	4000	4000	2000	2000	4000	4000	4000	2000	2000
Diameter (mm)	350	350	350	250	200	200	200	150	150	150	150	150	150	100	100

JUNCTIONS	01	02	11	12	13	21	22	23	31	32	33	RES.	TANK
Elevation (m)	0	37	37	51	44	29	33	26	16	19	12	0	90
Base Demand (l/s)	0	0	3	5	3	2	5	5	7	2	6	-	-
Emitter ($m^{3-\gamma}/s$)	-	-	0.02889	0.05117	0.02887	0.04146	0.04475	0.04146	0.00987	0.02316	0.02087	-	-

Tank data are: diameter 20 m; maximum height = 5 m; maximum and minimum water levels 4 m and 2 m respectively; initial level 3 m and elevation 90 m. This value is the minimum required to achieve in the less favorable junction (node 12) at peak time the minimum pressure required, 20 m (p_0, the standard pressure). Daily pattern demand is the same for all nodes (Table 3).

Table 3. Hourly pattern demand

HOUR	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Multiplier	0.4	0.3	0.3	0.2	0.3	0.4	0.9	1.3	1.4	1.7	2.7	2.4
HOUR	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Multiplier	1.8	1.3	1.3	1.2	0.8	0.7	0.7	1.1	1.2	0.7	0.6	0.4

The two scenarios differ on the pumping station. In the first case (indirect supply), the pump is controlled by the tank's water level and, in order to avoid as much as possible pumping during on-peak hours, by the time as well. As the objective is to compare not only the energy consumption but also the economic costs, a three Times Of Use (TOU) electric tariff is assumed. The pump will work mainly on mid-peak and off-peak periods, avoiding when possible on-peak TOU. By the other hand direct supply is simulated with two parallel pumps, one running at a constant speed (CSP) while the second, a variable speed pump (VSP) is fed by a variable frequency driver that during the simulation is adjusted to provide 20 m at the less favorable node (node 12) avoiding over pressures at any time. Therefore, as can be seen in Table 4, the pump speed ($\alpha=N/N_o$) is strongly modulate in time, with its nominal value at the time that water demand coefficient is the highest. The CSP pump starts when the VSP is not able to attend all the requested flow (that happen, see Table 4, from 9 to 12). Head – flow and efficiency flow curves of the pump are as well included in Table 4. To assign the difference of the energy consumption to the type of supply, pump efficiencies are quite the same in both cases.

Table 4. Pump characteristic curves for both scenarios

	Head (H (m)) – flow (Q (l/s)) curve	Efficiency curve
SCENARIO 1		
	$H_1 = 140 - 0.0035\,Q^2$	$\eta_1 = -0.0026\,Q^2 + 0.6617\,Q + 35.358$
SCENARIO 2		
CSP	$H_{2\text{-}CSP} = 108 - 0.004219\,Q^2$	$\eta_{2\text{-}CSP} = -0.0023\,Q^2 + 0.5051\,Q + 53$
VSP	$H_{2\text{-}VSP} = 110 + 0.2165\,Q - 0.082\,Q^2$	$\eta_{2\text{-}VSP} = -0.017\,Q^2 + 1.9528\,Q + 24.687$

HOUR	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
CSP Status	-	-	-	-	-	-	-	-	-	1	1	1
VSP Rotation speed (α)	0.828	0.82	0.82	0.813	0.819	0.828	0.885	0.948	0.965	-	1	0.931

HOUR	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
CSP Status	1	-	-	-	-	-	-	-	-	-	-	-
VSP Rotation speed (α)	-	0.948	0.948	0.931	0.872	0.859	0.859	0.915	0.931	0.859	0.847	0.828

All these values have been obtained from a simulation extended to one year. For the second scenario, as the pattern demand is repeated every 24 hours, does not make sense a so long period. But this is not the case of the scenario 1 because the tank. So far, after one day work, the final water level can be different than the initial one. Therefore, for a better assessment of the economic analysis deeply dependent on the TOU, and in order to minimize the energetic impact of the tank in the energy balance, the calculation period has been extended up to one year. In any case it is important to remind that the energy analysis can be extended to shorter periods of time, to be determined imposing that the tank contribution (in terms of energy) is less than 1% of the total energy supplied. This period, $t_{p,T}$, currently is around 10 days [8]. Last, the hydraulic calculation period used in the simulation is, for both scenarios, one hour, the same than the interval of the pattern demand.

2.4. Energy assessment

Table 5 shows the energy assessment of this pressurized water system [5] for both scenarios (direct and indirect supply) and behaviors (ideal and real systems). The evaluation of the ideal behavior is performed from few basic data (node's elevation and demand with the minimum pressure required) while the real assessment requires, additionally, the energy (shaft and natural) supplied to the system. Shaft energy is well known from the invoice of the energy provider ($E_{sr,p}$) while natural energy is linked to system's topography. In this particular case the natural energy ($E_{sr,n}$) is zero because the water table elevation of the reservoir (where water is withdrawn) is the lowest of the whole system.

Table 5. Ideal and real system's efficiencies

	SCENARIO 1	**SCENARIO 2**
Minimum required energy by users (E_{uo}) (constant, no matter the system be real or ideal)	158176 kWh	158176 kWh
Topographic energy required by the ideal system (E_{ti})	74644 kWh	74644 kWh
Supplied excess energy for the ideal system (E_{ei})	72142 kWh	0.00 kWh
Total supplied energy for the ideal system (E_{si})	304962 kWh	232820 kWh
Ideal performance (η_{ai})	**0.519**	**0.679**
Total supplied energy for the real system (E_{sr})	661917 kWh	463867 kWh
Real performance (η_{ar})	**0.239**	**0.341**

Ideal values are those previously commented (0.519 and 0.679). Both are related by the direct supply improvement indicator, $I_{ds,i}$ that, in this particular case, is 1.31. Real efficiencies (0.239 and 0.341) are, obviously, lower because include all system's losses. As said before, the difference (no matter ideal or real behavior) is due to the excess of energy required by the tank. If the supply is direct the energy is always the minimum value needed to achieve the standards of pressure in the less favorable node while the tank imposes a constant head pump value. In other words, from an energetic point of view, the tank is a "rigid" element. Another different issue is how to improve real efficiencies (ideal values are unachievable upper limits) no matter the scenario considered. This can be done reducing any kind of system's losses (friction pipes, leaks, pumping station losses and others).

Last, another important aspect to be considered is the relation between real efficiencies throughout the direct supply improvement indicator, $I_{ds,r}$. In this case the relationship between real efficiencies is 1.43 (= 0.341/0.239) that, although higher, has the same order of magnitude than $I_{ds,i}$. Therefore the question to answer is if, as in this case, $I_{ds,i}$ constitutes a lowest reference of the improvement that can be expected with a direct supply with regard to the previous indirect supply. Table 6 provides, if similar conditions apply (e.g., same efficiency in both pumping stations), the reply. And this is yes, because all energy losses (that does not exist in the ideal case) are smaller in the direct supply. Because of that case $I_{ds,i}$ is a good reference of the margin of improvement.

The surplus of pressure supplied by the tank along the day (except for the peak time demand, when this surplus is nil because the tank elevation has been optimized) is usually eliminated by a Pressure Reduction Valve (PRV). Its presence does not modify the ideal results but real values are affected (and improved) because, as pressure is reduced along the day, leaks are smaller. In this particular case, with the installation of a PRV near node 2, the new real efficiency is 0.249 (before 0.239). Precise identification of the best cost/benefit actions to improve real efficiencies, no matter the scenario, requires an energy audit [8]. It will show where the main energy savings pouches are.

3. Energy audit

An energy audit based on the mathematical model of the network can be performed, provided the water audit has been previously done. The energy audit is a further step (that needs much more information than the assessment) in the way to reduce the energy requirements of a pressurized water system. Table 6 depicts the results for both scenarios. First rows are the results of the water audit. As can be seen the difference between both scenarios lies on the leaked volume, higher in the first scenario because pressures are higher. Water consumed are always the same.

Concerning the energy terms, Table 6 evidences that:

- Natural energy is zero because, as said previously, the reservoir has the lowest elevation of the system.
- The minimum energy required by users, E_{uo}, already estimated (Table 5) is, as explained, in both cases the same.
- The excess of energy delivered is different because it takes into account the topographic energy and the surplus of pressure delivered. In the first scenario both terms are present while in the second one, the surplus of energy is zero (the pump is adjusted to deliver at any time the minimum pressure required). Therefore, for this case, the result corresponds to the topographic energy.
- Embedded energy in leaks is smaller in the direct supply because the pressure is as well smaller.
- Friction losses are smaller in the direct supply because the circulating flows are, with fewer leaks, smaller.
- In the indirect supply, and after one year simulation, the energy compensation is practically zero. In the scenario 2, without tank, this term is nil.
- Last, although pumping efficiency is practically the same in both scenarios (around 0.76), losses are different because pumped volumes and heights are different.

Table 6. Energy audit results for both scenarios

			SCENARIO 1	SCENARIO 2
VOLUMES (m^3/year)				
$V_{injected}$ (m^3/year)			1939660	1654730
$V_{consumed}$ (m^3/year)			1203360	1203360
$V_{leakage}$ (m^3/year)			736300	451370
$\eta_{volumetric}$			**62.04%**	**72.72%**
ENERGIES (kWh/year)			SCENARIO 1	SCENARIO 2
ENERGY CONSUMED	Useful energy	Minimum required energy by users (E_{uo})	158176 (24.52%)	158176 (34.10%)
		Excess energy delivered to users ($E_{tr} + E_{er}$ / E_{tr}+0)	85907 (13.32%)	47440 (10.23%)

	Energy losses	Leakage energy losses (E_l)	151806 (23.54%)	82773 (17.85%)
		Friction energy losses (E_f)	95792 (14.85%)	71508 (15.42%)
		Wasted energy in pumping stations (E_{wp})	153287 (23.76%)	103945 (22.41%)
		Energy compensation (ΔE_c)	49.24 (<0.01%)	0
	Total Energy consumed		645018	463844
ENERGY SUPPLIED		Shaft energy (supplied by pumps) ($E_{sr,p}$)	661917	463867
		Natural energy (supplied by external sources) ($E_{sr,n}$)	0	0

It is important to underline that in the energy audit an appreciable error can be committed in the first scenario. This is because the tank water level can achieve the highest allowed elevation in the middle of the hydraulic interval of calculation (this is not a continuous process). In other words, the real physical step differs from hydraulic interval of calculation. In the direct supply both time intervals goes hand with hand during the simulation and therefore this error is almost inappreciable. This is evidenced comparing the energy consumed with the energy supplied (Table 6). In the second scenario the error is small (0.005%) while in the first one, although not significant from an engineering point of view, is rather appreciable (2.55%). In any case the value adopted to estimate the real performance (see Table 1) corresponds to the supplied energy, because in the real world this value is well known (from the energy bill). This error can be minimized reducing the hydraulic interval of calculation. In particular using fifteen, five and one minute as intervals, the error is reduced to 0.95%, 0.18% and 0.06% respectively. In any case, Table 6 results correspond to the more frequent interval (1 hour).

All in all, a global analysis of Table 6 results clearly evidences the energetic inefficiencies of the indirect supply. The energy consumption in the direct supply is 70% of the indirect one, the same relation existing between the real efficiencies (0.239/0.341 = 0.7). Obviously its inverse gives the “real” supply improvement indicator, $I_{ds,r}$.

By the other hand, to improve the real system´s performance, no matter the scenario considered, it is necessary to look at the energy audit breakdown. From these results it can be concluded that:

- The percentage that corresponds to the minimum energy required by users is the real efficiency of the system. In this case, and because the error committed, there is a small difference (0.239 in Table 5, 0.245 from Table 6) in the scenario 1.
- The excess of energy delivered to users is significant, although much less relevant than the losses linked to leaks and friction. In the scenario 2, the topographic energy is in the real case smaller than in the ideal one (47440 kWh/year and 74644 kWh/year respectively). This is because friction losses are relevant. The only way to recover this topographic energy is with Pumps working as Turbines (PATs). In what concerns to the excess of energy, the only way to make it zero is the direct supply.
- Topographic energy should be much higher in this network if node 12 (because its elevation, the less favorable one) should be located at the end of the network (that is to say, if node 33 was the highest one).
- The energy embedded in leaks is relevant. Higher in the indirect supply (the average pressure, in space and time, is 55.73 m) than in the direct supply (average pressure is 40.53 m). It seems clear that in this case the first action to take to improve the efficiency should be a leak reduction.
- The network is undersized because friction losses are important. Critical pipes should have bigger diameters.
- As already mentioned, a PRV in the indirect supply network is cost effective. It reduces the average pressure (from 55.73 to 51.75) with 79600 m^3 per year of leak reduction. Friction losses will be reduced as well because circulating pipe flows should be smaller. All in all, the installation of a PRV will result in an energy reduction of around 4%. In general, for indirect supplies PRV are actions with a very good trade off cost/benefit.

- As usually happens, the main losses are located at the pumping station, even when the efficiency is reasonable (76%). In absolute terms, because the difference of water volume to be pumped, losses are reduced.

4. Pros and cons of the direct and indirect supply. Economic analysis

Advantages and disadvantages of water tanks have been widely reported in the literature. On the positive side, it can be said that the reservoirs are designed with two main objectives [9], to supply reliable water to consumers at a reasonable cost and to provide an emergency volume for fire contingencies. The negative aspect, by the other hand very well documented as well [10], is the negative impact on the water quality due to longer water retention times and deficient mixing regimes. Another positive aspect of the indirect supply is its positive contribution to minimize energetic costs because allows the pumps to work on their Best Efficient Point.

It is not the objective of this paper to discuss pros and cons of the indirect supply although it seems clear that, with passing time, electric companies have increased dramatically service's reliability and, by the other hand, emergency power generators can help to overcome short (as in most of the cases happen) energetic failures. With regard to its role as emergency volume, there are alternative solutions to solve this problem. From compensation tanks (without the energetic inconveniences of the header tanks) to on site tanks placed in (or close to) strategic buildings or areas up to pumping stations ready to supply specific peak flows under emergencies circumstances. These drawbacks are obviously irrelevant in the agricultural use and, in fact, new pressurized irrigation systems never include tanks.

Last, an economic analysis follows. Its objective is to assess if the indirect supply minimizes the energetic costs, as frequently is argued. Its conclusion is clear, while the energy consumption is 30% lower (and therefore the corresponding indirect green house emissions, GHG) the economic savings are less, around 25%, but still important. Obviously this percentage is very much dependent on different factors (mainly the tank size, the pattern demand modulation and the tariff model, very much dependent on the country). To do the analysis the hypothesis are:

- The used tariff is the Spanish 3.1A. Applies to users requesting a maximum power of 450 kW (150 kW in our case) with 1 to 36 kV of voltage. This tariff is based on three different TOUs (off-peak, 8 hours, mid-peak, 12 hours, and on-peak, 4 hours). The kWh prices for each TOU are 0.090852€; 0.133798€ and 0.165604€.
- The power term is not considered because the peak power requested is in both cases almost the same. In the indirect supply the pump is working at any time practically (there are some tank level oscillations) at the same point (110.78 l/s; 97.04 m). Therefore, always requests the same power (137.41 kW). In the direct supply case the demanded power has wide variations. The maximum power is requested at peak time (10 a.m.) when both pumps (the CSP and the VSP) are running at its nominal speed. The requested power (136.43 kW) is almost the same.
- The volume of the tank (20 m diameter and 5 m high) is 1570 m^3, about 50% of the daily demand. Although to size the tank there are many, and very different, criteria all around the world, most of them more stringent [1], the size adopted in our case study is conventional.

From these hypothesis, the energetic costs are respectively 80150 €/year and 59948 €/year, very different. Mainly, taking into account that the cheapest energetic solution minimizes as well the needed capital costs (pumping stations requirements are slightly higher in the second scenario, because the variable frequency driver, but the main investment, the tank, is avoided). It is obvious that with other starting data, results should be different. For instance changing the size of the tank mid-peak and on-peak TOU could be avoided (in the scenario 1 the system works 1 hour at on-peak time), but a bigger tank should be required and therefore the capital costs will increase as well in a significant way. For such reason, with a global economic analysis (capital costs included), the economic advantages of the direct supply are evident.

5. Conclusions

Water energy nexus is an issue of increasing importance in all political portfolios, a trend born in this XXI century that seems clear that will follow in coming years. GHG must be avoided and natural resources wisely used in a world with a nonstop increasing population. As in the previous century these concerns did not exist, most of the actual urban water distribution systems have been designed without considering these environmental and economic aspects. Because of that, many of these designs based on indirect water supply, will be rethinking in coming years.

Using tools (energy assessments and audits) presented in previous works, this paper is a practical application to a standard case study: the energetic implications of the traditional indirect water supply throughout heading tanks. Furthermore, the assessment has been complemented with the direct supply improvement indicator $I_{ds,i}$ that allows to foresee the energy savings, with regard to the traditional set up (throughout a head tank), of the direct supply.

Leaving to one side the current debate about tanks (more reliability versus less water quality), from an energetic and economic point of view, the conclusions are clear: from both points of view, the direct supply is, by far, better.

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