PROCEDURES AND SOLUTIONS FOR ENERGETICAL OPTIMIZATION OF WATER DISTRIBUTION SYSTEMS

SÂRBU, Ioan

Department of Building Services,
"Politehnica" University of Timisoara, Romania

1. INTRODUCTION

Water distribution to users by pumping is a process which consumes preponderantly electrical energy. It is estimated that in order to provide the service pressure, usual networks supplied exclusively by exterior pumping stations require an energy consumption of 60...70 % of the energy consumed by operation of the whole centralized supply system of large urban centres. This fact generates a great increase of the national energetic system load, during average consumption hours and especially in peak consumption hours. The present world's energy's situation rises the reconsideration of the structure and functioning principles of water distribution systems from the point of view of energetical optimization as a major, necessary and opportune problem, which can be solved by a new structural design.

Thus, the objective of this paper is to analyze some procedures and solutions for functional and energetic optimization of distribution systems by separation of water networks by pressure zones. The energetic and economic efficiency of zoning procedures is estimated and numerical examples are presented for studied solutions.

2. ZONING PROCEDURES

The separation of water distribution networks into pressure zones is technically necessary when available pressures in the network exceed the limit value H_{max} = 60 m H_2O, but it can be applied also for energetic and economic optimization of the system.

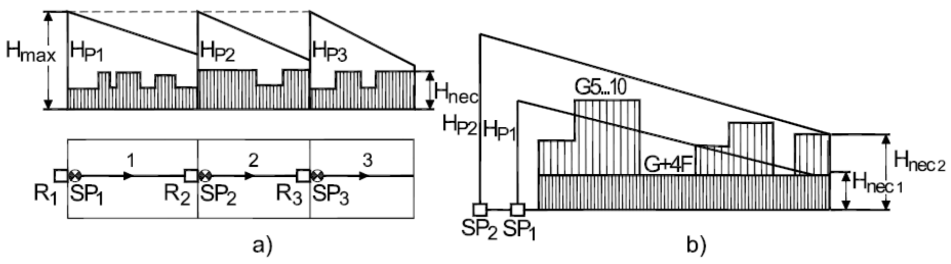

Fig. 1 Scheme of network separation into pressure zones
a) – *horizontal zoning*; b) – *vertical zoning*

As a rule, the separation of the networks into pressure zones can be realized by:

a) *Horizontal zoning*, which assumes successive repumping, imposed by the great length of the route at large networks situated in plains (fig.1-a). The pumping height is subdivided into several steps, providing the service pressure H_{nec}, while at the end of each zone k is installed a buffer reservoir R_k and a pumping station SP_k ;

b) *Vertical zoning* caused especially by tall buildings from a low extent area (fig.1-b). This assumes realization of a network for the users from ground levels to the fourth floor (G+4F) with a pumping head H_{p1}, and another network for users from the fifth levels to the tenth floor (F5...10) supplied from a pumping station SP_2 equipped with air-pressure tank. The horizontal, as well as the vertical zoning, at networks supplied by pumping can be realized in series or in parallel. Figures 2 and 3 present these two technic procedures for vertical zoning.

2.1. Features of series zoning

When zoning in series (fig. 2), the pumping stations are placed at the limits of zones, so that the maximum admitted pressure in the network would not be exceeded. The inferior pumping station SP_1 is pumping the water discharge (Q_1 + Q_2) necessary for the entire population center at a pumping head H_{p1} corresponding to zone I. The pumping station SP_2 provides from an intermediary reservoir the discharge Q_2 necessary for zone II, equipped with its own reservoir R_2.

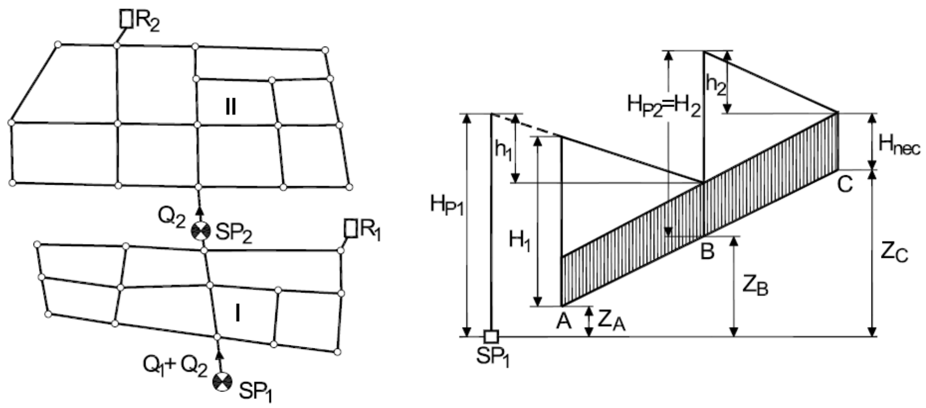

Fig. 2 Scheme of series zoning procedure

The maximum pressure in the inferior zone I (A-B) is given by the relation (1), while in the superior zone II (B-C) it is determined by relation (2):

$$H_1 = H_{\text{nec}} + (Z_B - Z_A) + h_1 \le H_{\max} \tag{1}$$

$$H_2 = H_{\text{nec}} + (Z_C - Z_B) + h_2 \le H_{\max} \tag{2}$$

where:

H_{nec} – the service pressure;
Z_A, Z_B, Z_C – geodesic elevations in the points A, B, C;
h_1, h_2 – pressure losses in zones I, II.

If each zone would have had their own compensation reservoirs, their volumes could have been calculated according the distribution, proportional to the daily maximum consumption of each zone. The damage reserve is stored only in the main reservoir of the inferior zone, while the fire-fighting water storage is recommended to be stored in the reservoirs of each pressure zone.

2.2. Features of parallel zoning

In a parallel zoning (fig. 3), each pumping station is delivering the discharge corresponding to the zone it serves Q_1 and Q_2, each of the network being provided with a reservoir (R_1, R_2), so having a greater independence than in the case of series zoning. The pressure pipe of the pumping station SP_2 passes the zone *I* with no service, distributing water only in zone II, unlimited pressure being available despise the functioning condition (2).

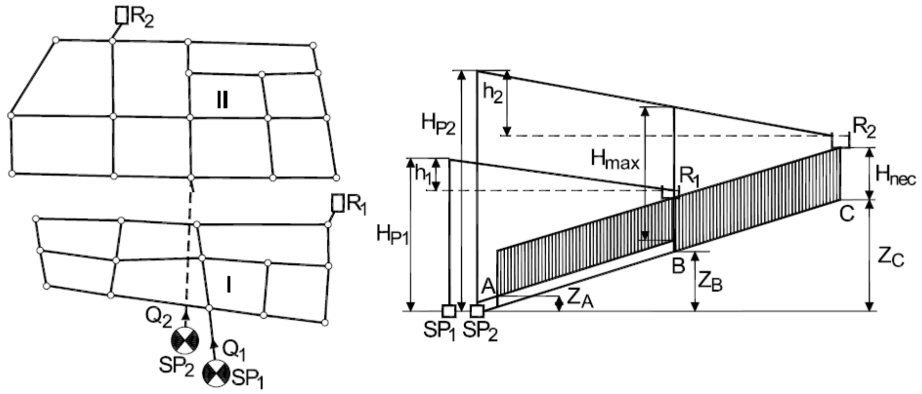

Fig. 3 Scheme of parallel zoning procedure

The damage reserve is common, while the compensation reserve and the fire-fighting storage are recommended to endow each zone separately.

3. ENERGETIC AND ECONOMIC EFFICIENCY OF ZONING PROCEDURES

Assuming, theoretically, that we are dealing with zones with equal height and equivalent functional intensity, the reduction of energy consumption in distribution system is justified and evaluated, at the separation of networks into pressure zones. The annual energy consumption for water pumping W_e, in an unzoned system is expressed by the following relation:

$$W_e = k\, V_a\, H_p \tag{3}$$

where:

V_a – the water volume distributed each year;
H_p – average pumping head;
k – a propor-tionality factor.

Assimilating the representation of real piezometric lines with quasi-triangular diagrams (fig. 4), the annual energy consumption for water pumping W_e in a zoned system is expressed by the equations:

– for systems zoned in series:

$$W_e = k\left(V_a \frac{H_p}{2} + \frac{V_a}{2}\frac{H_p}{2}\right) = \frac{3}{4} k V_a H_p \tag{4}$$

– for systems zoned in parallel:

$$W_e = k\left(\frac{V_a}{2} H_p + \frac{V_a}{2}\frac{H_p}{2}\right) = \frac{3}{4} k V_a H_p \tag{5}$$

It results that for both zoning procedures, the annual energy consumption in zoned systems represents only 75 % of the annual energy consumption of unzoned systems.

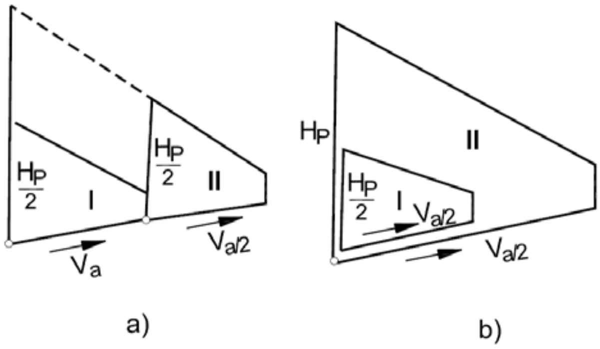

Fig. 4 Approximation of pressure lines
a) – *series zoning*; b) – *parallel zoning*

With respect to the ideal situation of subdivision of network in two zones of equal pressure, the actual zoning is usually even more advantageous from the point of view of electric energy consumption. The inferior zone is always more developed, representing approximately 90 % of the energetic consumption of the system, which means that, for practically equal zone pumping heads, even more than 35 % of electric energy could be saved. Though zoned networks are more expensive investments, because they require more pumping stations and reservoirs or recipients for pressure breaks, they are more economical in operation due to their reduced consumption of energy.

A comparative study is necessary, to compare the unzoned network with high pumping head, which require a small investment I_1, but high annual operating expenses C_1 and zoned network with reduced pressure heads at pumping stations, which imply a larger investment I_2 but reduced annual operating expenses C_2.

In order to determine the economical efficiency of the solution with zoned network, the equation for comparative recovery time T_r is applied:

$$T_r = \frac{I_1 - I_2}{C_2 - C_1} \leq T_n \tag{6}$$

where T_n is the normal amortization time.

4. NUMERICAL EXAMPLES OF ENERGETIC AND ECONOMIC EVALUATION OF ZONING PROCEDURES

4.1. Energetical evaluation of zoning of large circular networks

At networks of great extent and capacity, it is not possible to provide the necessary pressures and especially the highest pressure in the central zone, without adopting an optimization solution by zoning the network.

For example, let's consider the energetic evaluation of series zoning for a network of ideal equivalent circular design [5] (fig. 5-a) in the branched and looped alternative, considering the supply discharge of Q_p = 2.4 m^3/s and the service pressure H_{nec} = 15 m H_2O in marginal zones and H_{nec} = 30 m H_2O in central zone. The pipe routes pass through gravity centers of users area, which are considered punctiform in the peaks of the networks graph.

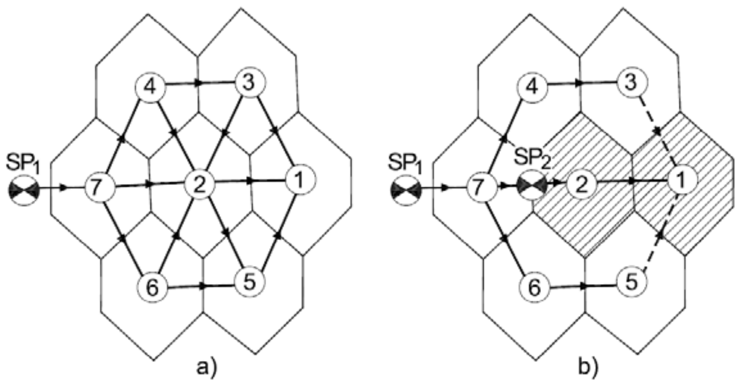

Fig. 5 Scheme of an ideal equivalent circular network
a) – *unzoned distribution*; b) – *zoned distribution*

The series zoning (fig. 5-b) assumes that the systems is equipped with a principal pumping station SP_1 for zones with reduced pressure, and a boosting station SP_2 for the central zone, which high service pressure.

Boosting station's units are assembled in series, under the protection of a pneumatic reservoir, in order not to waste the available pressure in upstream network.

No.	Distribution system	Network type	Pumping station SP_1			Pumping station SP_2			Consumed energy, W_e [MWh/yr]
			Q_1 [m^3/s]	H_p [m]	W_{e1} [MWh/yr]	Q_2 [m^3/s]	H_p [m]	W_{e2} [MWh/yr]	
0	1	2	3	4	5	6	7	8	9
1	Unzoned system	Branched	2.4	51.84	12172.9	–	–	–	12172.9
		Looped	2.4	50.80	11991.6	–	–	–	11991.6
2	Zoned system	Branched	2.4	39.12	9224.1	0.90	7.72	678.6	9902.7
		Looped	2.4	38.28	9051.1	0.89	7.52	646.2	9697.3
Energy saving, ΔW_e [%]		Branched	18.6						
		Looped	19.1						

Table 1. Comparative energetical characteristics of the circular distribution system

The numerical results of comparative energetical calculus for zoned and unzoned distribution systems are presented in table 1.

It results that by zoning of the circular distribution system with a single boosting station, 18...20 % of electrical energy can be saved.

4.2. Economic and energetic evaluation of zoning distribution networks in buildings assemblies with different construction regimes

In the case of dwellings assemblies with 3,000 apartments and about 11,000 inhabitants two pressure zones are considered, according to the two heights regimes of dwellings. In the first zone, water supply must be provided for dwellings with ground and four floors (G+4F) and garden hydrants. The second zone requires water supply for ground and 10 floors dwellings (G+10F).

The distribution of cold water in this dwelling assemble is realized through a single network of steel pipes (represented in figure 6 with continuous lines) supplied from a station for increasing pressure SP_1, corresponding to the maximum service pressure H_{nec} = 42 m H_2O.

As an energetic optimization alternative for the unzoned network, we used the parallel zoning, which supposes that each of the two pressure zones with service pressures H_{nec1} = 42 m H_2O and H_{nec2} = 21.5 m H_2O to be supplied from a pumping station with air-pressure tank (SP_1, SP_2) through a separate water distribution network (represented in figure 6 with dashed and, respectively, dotted lines).

The water distribution networks has been designing using computer program DIOPREDA [8]. The results of economic and energetic computations for the two considered solutions are presented in table 2.

No.	Distrib. system	Pumping station SP_1			Pumping station SP_2			W_e [kWh/yr]	I [mil €]	C [mil €/yr]
		Q_1 [dm^3/s]	H_p [m]	W_{e1} [kWh/yr]	Q_2 [dm^3/s]	H_p [m]	W_{e2} [kWh/yr]			
0	1	2	3	4	5	6	7	8	9	10
1	Unzoned network	43.98	42.66	70133	–	–	–	70133	22.7	1.83
2	Zoned network	23.50	42.69	37500	20.48	22.28	17,050	54550	23.9	1.60
Energy saving, ΔW_e		[kWh/a]	15583							
		[%]	22.2							
Redeeming time, T_r		[years]	5.2							

Table 2. Comparative economic and energetic characteristics of water distribution networks

The calculus show that the optimal solution with zoned distribution network leads to minimum annual operating expenses, as well as to savings of electrical energy for water pumping which raise to 15583 kWh/year, representing about 22 % of the energy consumption of the unzoned network solution, while the additional investment in pipes, pumping stations and air-pressure tanks is recuperated in 5 years, a shorter period than the normal redeeming time.

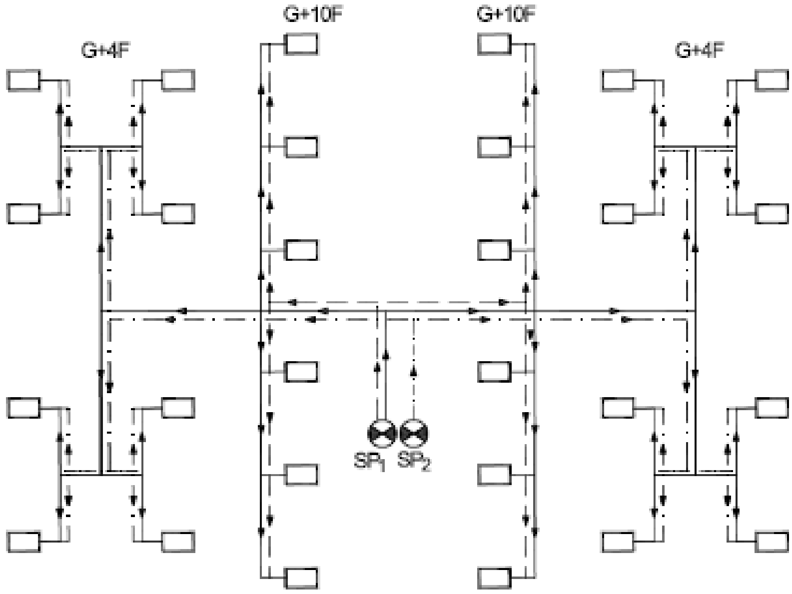

Fig. 6 Scheme of water distribution networks in a dwelling assembly

5. CONCLUSIONS

Though separation of water distribution systems in pressure zones is a more expensive investment because it requires more pumping stations, reservoirs or pressure breaks recipients, it is more economical in operation by reducing the energy consumption up to 35 % compared with unzoned networks, a fact of great importance in the general energetical juncture.

Indirectly, by operating networks at lower pressures, could be obtain important savings from smaller maintenance and repair works.

As well, water losses in zoned networks are reduced as a result of a lower pressure in pipes and especially in indoor installations.

REFERENCES

[1] BABITT, E.H. Water supply engineering, McGraw-Hill, New York, 1962.
[2] DUMITRESCU, L. Instalații sanitare pentru ansambluri de clădiri, Editura Tehnică, Bucureşti, 1980.
[3] HAESTAD METHODS, Computer Applications in Hydraulic Engineering, Haestad Press, Waterbury, 1999.
[4] MĂNESCU, AL. Alimentări cu apă, Editura Didactică şi Pedagogică, Bucureşti, 1994.
[5] SÂRBU, I. Energetical optimization of water distribution systems, Editura Academiei Române, Bucureşti, 1997.
[6] SÂRBU, I. BORZA, I. Energetic optimization of water pumping in distribution systems, Periodica Polytechnica Budapest, no. 42/2, 1998.
[7] SÂRBU, I. KALMAR, F. Optimization of looped water supply networks, Periodica Polytechnica Budapest, no. 46/1, 2002.

[8] SÂRBU, I. KALMAR, F. Proiectarea asistată de calculator a instalaţiilor, Editura Mirton, Timisoara, 2000.
[9] VINTILĂ, ŞT. ş.a., Probleme actuale privind instalaţiile de pompare cuplate cu recipiente de hidrofor şi rezervoare tampon deschise, Simpozionul „Instalaţii pentru Construcţii şi Confortul Ambiental”, Timişoara, vol. 1, 1994.

VÍZELLÁTÓ RENDSZEREK ENERGETIKAI OPTIMALIZÁLÁSI LEHETŐSÉGEI

Az ivóvíz eljuttatása a felhasználókhoz egy energiaigényes folyamat. A jelenlegi gazdasági és energetikai helyzetben a vízellátó rendszerekre vonatkozó tervezési elvek átgondolása szükséges. A cikk célja néhány optimalizálási megoldás vizsgálata elsősorban a vízellátó rendszer nyomászónákra történő felbontásával. Különböző megbontási lehetőségeket vizsgálunk energetikai és gazdaságossági szempontból. A megoldások egy rendszeren bemutatásra kerülnek.