ENERGY ENGINEERING AND CONTROL SYSTEMS

Volume 4, Number 1, 2018

Energy Saving from Tap Water Home Treatment Devices

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Received: February 20, 2018. Revised: March 30, 2018. Accepted: April 06, 2018

Abstract

Water is the only liquid used in human eating which presents different production and transportation processes. All the alimentary liquids, in fact, need production and sanification processes in controlled environments and transportation on carriers. On the other hand, besides more simple production processes, water can rely both on distribution networks and transportation on carriers. In the last years, bottled water consumption greatly increased not only for healthy needs but also for non-essential ones. In fact, only in few cases bottled water is used for a real need of specific characteristics and more and more its use is due to the perceived poor quality of tap water. Recent studies demonstrated that energy consumption related to bottled water can be up to 2000 times bigger than the ones related to tap water. In fact, energy consumptions for bottled waters come out mainly from the production of PET bottles, from the bottling process and, finally, from transport/distribution. In this paper, avoiding a comparison between bottled and tap water about the chemical-physical, microbiological and gustative characteristics, the authors present the results of an experimental study aimed to measure energy consumption of tap water domestic treatment devices. Moreover, the potential energy savings coming from the use of treated tap water are focused.

Keywords: tap water; bottled water; energy saving; water treatment.

1. Introduction

Despite the actual economic crisis, in recent years bottled water consumption greatly increased not only for healthy needs but also for non-essential ones. The unjustified increase of bottled water consumption can be ascribed to the perception of a poor quality of tap water rather than to the demand of water with specific mineral characteristics. On the other hand, recent studies in Italy [1, 2], Germany and Brazil [3, 4] demonstrated that the quality of bottled water not always is clearly higher than the one distributed in the city networks.

Bottled waters present worldwide a yearly global market over 100 billion USD, higher than the market of milk and fruit juice and lower only to the market of soft drinks and beer [5, 6]. Despite this, a part of the public opinion show an increasing resistance against bottled water due to: i) the large amount of plastic waste deriving from them; ii) the privatization and impoverishment of a public good; iii) the potential decrease of attention regarding water networks.

From the data in Table 1 published by the Beverage Marketing Corporation [6] it is clear that the increase of bottled water consumption is not justified by a lack of potable water. In fact, the more developed countries rank the top ten for bottled water consumption (see Table 1). From the same research, it was pointed out that in 2007 bottled water consumption worldwide summed about 190,000 million liters. Thus, a very close attention must be paid both to the energy consumption and to the environmental impacts that comes from such large amount of bottled water produced and consumed.

In Italy, a recent study developed by ISTAT [7] showed that in the last decade yearly consumptions of bottled water increased with a constant trend of about 3–4 %. Only in the last years this trend slightly decreased, (probably?) because of the economic crisis.

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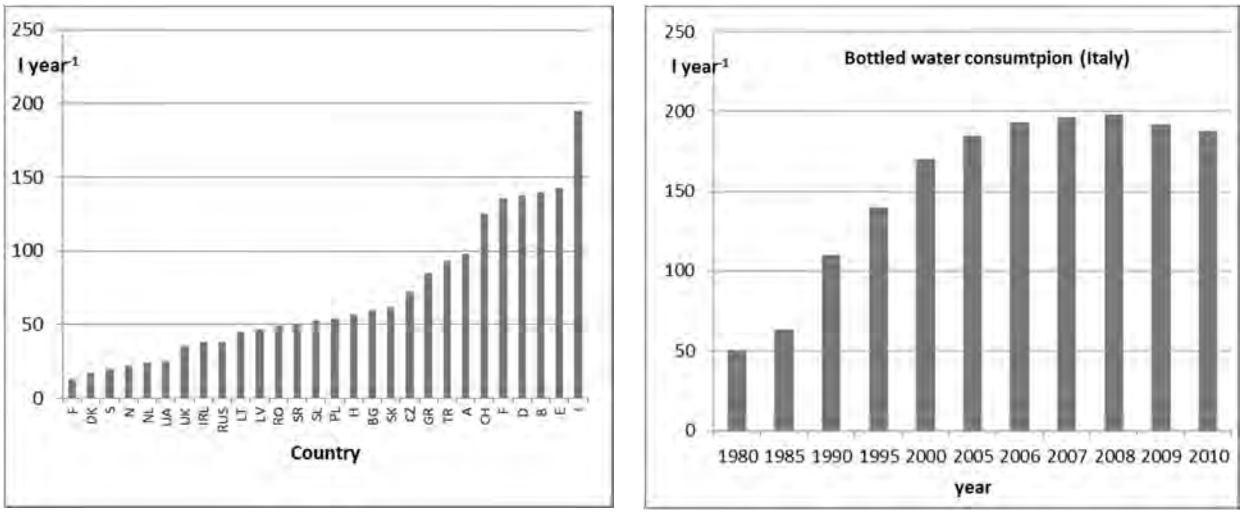
This paper should be cited as: L. Canale, G. Cortellessa, G. Ficco, A. Russi, F. Zuena. Energy saving from tap water home treatment devices. Energy Eng. Control Syst., 2018, Vol. 4, No. 1, pp. 17–26. https://doi.org/10.23939/jeecs2018.01.017

Table 1. World market of bottled water. Consumptions and trends in 2002–2007

Country	Bottled water yearly consumption ($L\ 10^6$)		Average Yearly Increasing trend (%)
	2002	2007	
United States	21,938.70	33,398.70	8.80 %
Mexico	14,757.80	22,277.90	8.60 %
China	8,094.70	18,123.80	17.50 %
Brazil	9,621.80	13,707.40	7.30 %
Italy	9,683.80	11,738.20	3.90 %
Germany	8,674.30	10,384.10	3.70 %
Indonesia	6,141.80	9,087.30	8.20 %
France	8,424.80	8,642.90	0.50 %
Thailand	4,833.90	5,803.40	3.70 %
Spain	4,509.90	4 860.50	1.50 %
total of first 10 countries	98,683.50	140,031.20	7.40 %
Other countries	34,273.90	50,752.20	8.20 %
Overall world total	132,957.40	190,783.40	7.60 %

NB: Data from Beverage Marketing Corporation.

The Italian market of bottled water is still one of the most important worldwide. In fact, it is the third market in Europe for volumes (about 12 billion liters per year) whereas, as shown in Fig. 1, it is the first market for per capita consumption with about 200 liters per year, which is about the double of the European average.



a *b*

Fig. 1. Per capita consumption of bottled water:
a – European consumption; b – trend of Italian consumption

Despite the actual economic crisis, market operators foresee a further increase of bottled water consumption because of the same causes that up to nowadays favored its growth: i) the spreading pollution of groundwater; ii) the perception of a poor quality of city water distribution networks; iii) the unevenness of potable water supply; iv) the emergence of healthy consumption models and discretionary ones linked to taste; v) the availability of low cost bottled waters.

In 2010 the average price of a bottled water decreased up to 20 c€ (in comparison with 21.3 c€ in 2009) and often the price is sometimes lower. The significance of the bottled water market in Italy is also confirmed by ISTAT, which states that 88.6 % of people says to drink bottled water usually.

Bottled water sector can be divided into different lines. In recent years natural water are spreading despite sparkling ones. On the other hand, lightly sparkling waters and natural effervescent ones are now becoming more and more relevant. These latter combine healthy characteristics with the more discretional ones linked to taste. It derives an industrial sector very relevant for people daily life, but, at the same time, it becomes necessary to deal with the energetic issues to join the actual sustainable energy policies [8].

A recent marketing trend concerns mineral waters treated and sanitized. Some large-scale distribution companies recently presented cost effective bottled waters covered by their own house brand. In this sector also other big industrial competitors are interested in higher price range, aiming to create a separate market niche out of the normal price competitions.

Nowadays, in US over 40 % of bottled waters is represented by purified waters, that is waters obtained through processes such as distillation, deionization, microfiltration, reverse osmosis, ozonation, treatment to ultraviolet radiation or other treatments of tap water [9].

However, such a large use of bottled water involves serious questions about the impact on the environment not only for the large number of bottles to be disposed of, but also about energy consumptions and CO_2 emitted as a consequence [10].

The polyethylene terephthalate (commonly known by the acronym PET) is the most common material used by the bottling companies (about 80 % of the total market and almost 99 % of the volumes in large-scale distribution), whereas glass is heavily disadvantaged both in terms of costs and management of the returnable bottles. As a consequence, the environmental impact of bottled water is not only related to packaging (material and production process), but also to transportation (more than 80 % of bottled waters is road transported), disposal and/or reuse. In fact, for 1 kg of PET (with which it is possible to produce about 25 bottles of 1.5 l capacity) about 17 l of water and 2 kg of oil are needed. Furthermore, a truck at full load enters into the environment about 1,300 kg km^{-1} of CO_2 [10].

The indiscriminate use of bottled water could be limited by the spreading of home water treatment and purification devices [11]. These devices have been designed to purify tap water and to provide a higher quality water in many respects similar to the bottled one by microfiltration, carbonation, refrigeration, etc. While these systems are widely available in restaurants, they are still not very common at home level. Their undoubted advantage is the possibility of obtaining purified water and carbonated with energy costs significantly lower than the bottled water ones. On the other hand, water treatment home devices are not easily standardized, as they are based on a wide variety of chemical and physical purifying processes (each one specific for certain contaminants). This often produces confusion and caution among potential users and, sometimes, a suspicion for its purchase and use.

In this paper, the authors highlight the environmental, economic and social issues related to the consumption of bottled water. Furthermore, the authors compare the energy consumption related to bottled water with the one related to the home treated waters. To this aim, data available in technical literature and experimental ones are presented and analysed.

Finally, the possibility to promote energy efficiency certificates for water treatment home devices (including the microfiltration, UV antibacterial treatment, cooling and addition of carbon dioxide) is evaluated according to DM n. 443 12/21/1990 [12]. In the authors' opinion, with these certificates, the misuse of bottled water could be reduced and, at the same time, energy consumption resulting from their use should be strongly reduced.

2. Energy consumption of bottled water

Figure 2 shows the typical supply chain of bottled waters and their main processes: i) production (extraction and treatment), ii) bottling (bottle production, filling, labeling, sealing and packaging), iii) transport iv) use (cooling), v) recycling and reuse.

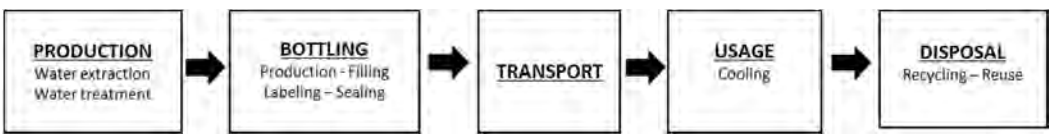


Fig. 2. Bottled water industrial chain

A recent study of the Pacific Institute (Gleick and Cooley, 2009) [13] carries out an interesting assessment of energy consumptions in the above processes, highlighting the main parameters that can affect the amount of consumption themselves. Energy consumptions can be in fact very different depending on the type and size of the bottle, the material used, the distance and type of transport, the final use of the water (at room temperature or cooled).

More interesting studies on the environmental impact of PET bottles packaging and on the life cycle of bottled water are analysed in [14–17].

Table 2 shows the total energy demand of the bottled water industry for the following aims: i) use of PET bottles ii) bottling plant (neglecting the energy needed to pump water in the pipes); iii) road transport; iv) cooling in the final use. On the **basis** of these assumptions, Gleick and Cooley [13] estimated that the total energy required for the whole chain of bottled water industry typically ranges from about 5.6 to 10.2 MJ l^{-1}.

Table 2. Energy consumptions in bottled water production, transport and use

Process	Energy need [MJ l^{-1}]	
	(Gleick e Cooley)	Authors' estimate
PET and plastic bottles production	4.0	1.8÷4.9
Treatment at bottling	0.0001÷0.02	0.009÷0.014
Filling, labelling and sealing	0.01	
Transport	1.4÷5.8	0.1÷0.6
Cooling	0.2÷0.4	0.1÷0.2
Total	5.6÷10.2	2.0÷5.7

Note: In the calculation 1 $kWh_{el.}$ has been supposed equal to about 3 kWh_{term}.

From the data in Table 2, clearly emerges that PET bottles production process is the prevailing one in terms of energy consumptions (about 4 MJ l^{-1}). On the other hand, transportation, especially for long distances, can lead to energy costs similar or even higher than those required to produce PET bottles (up to 5.8 MJ l^{-1}). Finally, a significant cost is represented by the energy needed for cooling purposes at final use. Other energy consumptions can be considered practically negligible.

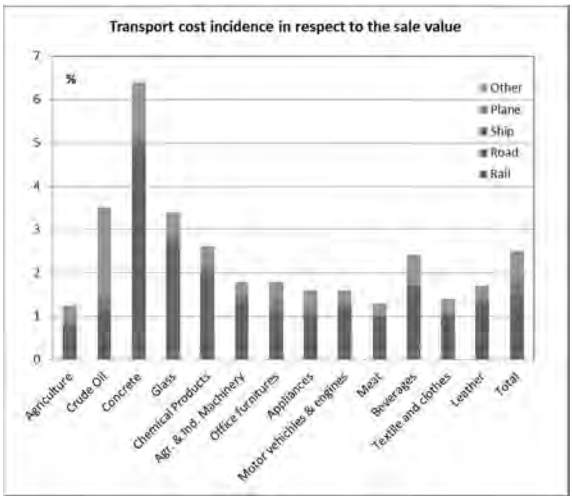


Fig. 3. Industrial transport costs (beverage sector) [20]

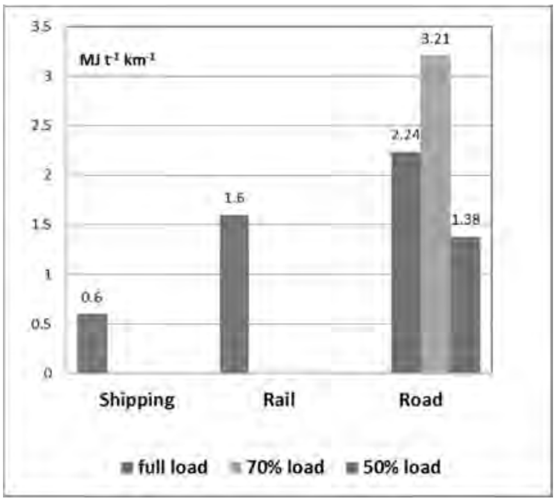


Fig. 4. Specific average Energy consumptions for different types of transportation in Europe [20]

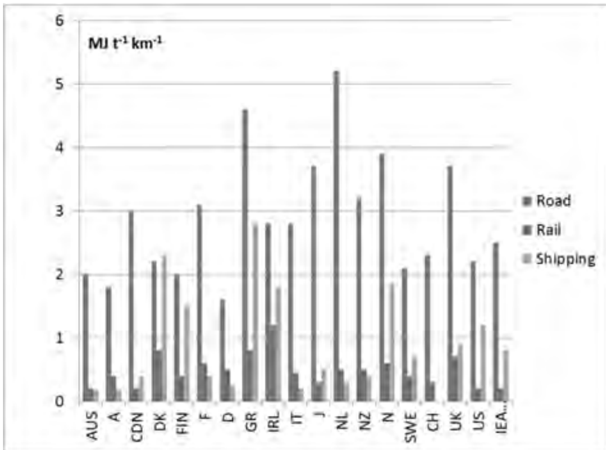


Fig. 5. Specific energy consumptions for road transport in Europe [23]

Energy consumption for PET bottles production has been deeply focused in literature [18–19]. It can be pointed out that average oil equivalent consumptions: i) range 65 to 73 $MJ \cdot kg^{-1}$ for the production of PET [18]; are about 24.9 $MJ \cdot kg^{-1}$ for the production of PET bottles [19]. Since very different shapes and sizes of the bottles are available, it can be estimated for PET bottles that the volume/weight ratio ranges 20 to 50 $l \cdot kg^{-1}$. Therefore, the authors estimated a specific energy consumption per liter ranging 1.8 to 9.4 $MJ \cdot l^{-1}$.

On the other hand, specific studies conducted on bottled water transport show that: i) road transportation is prevailing in respect to air, rail and sea ones; ii) costs for beverage transportation are among the highest in the entire industry sector and sum to about 2–3 % of the final cost of the product (see Fig. 4) [20]; iii) average distance in heavy road transportation in Italy is about 130 km [21]; iv) in Italy, because of geographical configuration and demographic distribution, very high average energy consumptions in road transport are needed (approximately equal to 2.8 $MJ \cdot t^{-1}$). In fact, energy consumptions are highly dependent on the operating conditions of transport both in terms of the means used and of the geographic and demographic characteristics of the territory (see Fig. 5) [22]. Thus, an average energy consumption intensity ranging 0.5 to 2.2 $MJ \cdot t^{-1}$ km^{-1} has been estimated in Europe [23]. From the above data, considering a specific energy consumption intensity ranging 1 to 3 $MJ \cdot t^{-1}$ km^{-1} and an average distance ranging from 100 to 200 km, the authors estimated that energy consumption for bottled water due to the transport ranges 0.1 to 0.6 $MJ \cdot l^{-1}$. This latter estimation doesn't consider the transport made by the consumer after purchase.

Finally, it can be definitely estimated that average energy consumption in Italy of bottled water is approximately equal to 4.4 $MJ \cdot l^{-1}$, that is about half of that estimated for the United States by Gleick and Cooley [13].

3. Energy consumptions of water treatment home devices

Burton (1996) [24] estimated typical energy consumption of approximately 0.005 MJ l^{-1} due to tap water treatment and distribution through city networks. This value is extremely low if compared with the corresponding one of bottled water. Despite this, energy consumptions related to the use of tap water is in average about 80 % of the total management cost of the distribution companies [25].

The term "watenergy" [26] effectively highlights the closeness between water and energy, not only because they are the most important natural resources, but also for the interconnection in the use and production of energy and potable water. In fact, in a potable water distribution network, energy is needed at each stage: extraction, processing, treatment, transport, distribution, use and discharge/reuse. From recent studies, potential energy savings in the industry sector emerge [27], but network companies are often discouraged by too long investment paybacks.

In reality, energy consumption for tap water are significantly lower than the corresponding ones of bottled water, but they strongly depend on the type of treatment and on the characteristics of the network. Santa Clara Valley Water District [28] estimated energy consumption between 0.002 and 0.005 MJ l^{-1} as a function of the water source (e.g. surface, groundwater, recycled, imported) as shown in Fig. 7. Mo et al. estimated similar values of energy intensity for surface water and slightly more in the case of recycled and treated one [29].

As discussed above, the use of water "safe" on a quality basis and "pleasant to the taste" is perceived as an important element for the quality of human life. To promote the concept of "short chain", tap water home treatment devices should be installed directly "to tap" in situ.

Recently, in fact, water home treatment devices appeared on the market and this could improve the characteristics of tap water. A wide variety of these devices is nowadays available, such as ion exchange softeners, mechanical filters, chemical dispensers, reverse osmosis systems, activated carbon filters, and other physical systems (e.g. electromagnetic) whose action is carried out both on hardness and on organoleptic properties of water. Some of these devices are specifically devoted to the purification of water and to the addition of gas. Thus, they are alternative to bottled waters. In Italy, the Ministry of Health fixed strict technical requirements for these devices to avoid the risk of pollution or deterioration of the original water quality [12].

These devices could combine some benefits (i.e. low energy consumption) of tap water with some peculiarities of mineral waters treatments. Therefore, the authors designed and performed a measurement campaign, which results are below described, in order to estimate energy consumptions due to water treatment home devices. To this aim, an experimental bench for the measurement of the electrical energy consumed by a commercial home treatment device for tap water (Fig.7) has been assembled. Figure 9 shows the test layout at LAMI, the mechanical measurement laboratory of the University of Cassino and Southern Lazio, accredited lab n.105 by Accredia.

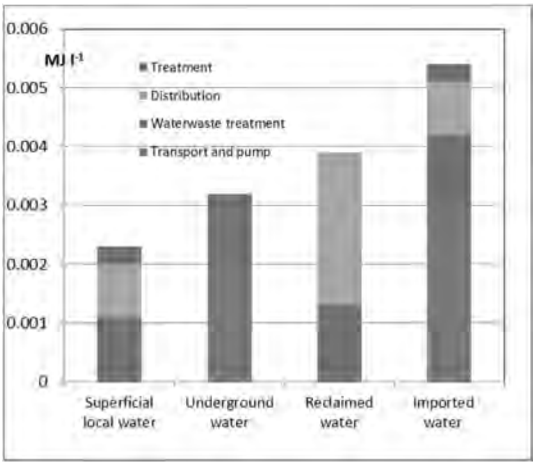


Fig. 6. Energy intensity of tap water [28]

Fig. 7. Experimental test bench for the measurements of electrical consumptions of home treatment devices

The authors measured energy consumption at different regimes: i) cooling system off and at low/full regime), ii) water consumption zeroed (0 $l \cdot h^{-1}$) and maximum (1 $l \cdot h^{-1}$). To this aim, a model for the estimation of energy consumption has been defined. The model is described in the following equation:

$$C = C_t + C_{dis}\vartheta_{on}\Delta T_a + V_w\left(C_{ref}\Delta T_w + C_{er}\right), \quad (1)$$

where:

- C, is the total energy consumed, kJ;
- C_t, is the energy consumed in the transient period, kJ;
- C_{dis}, is the scattered energy, kW K^{-1};
- ϑ_{on}, is the operating time of the refrigerator, s;
- ΔT_a, is the temperature difference between ambient and cool water, K;
- V_w, is the water consumed, l;
- C_{ref}, is the energy needed for refrigerating water, kJ l^{-1} K^{-1};
- ΔT_w, is the temperature difference between tap water and cool water, °C;
- C_{er}, is the Energy needed to supply water, kJ l^{-1}.

The different terms in eq.(1) are described in the following equations (2) and (3), at different operative conditions of the refrigerating system (i.e. at low regime and full speed, respectively):

$$\begin{gathered} C_t = m_s c(t_i - t_u)/COP_{min} = 146.5\ kJ \\ C_{dis} = \frac{U_A}{COP_{min}} = 0.47\ 10^{-3}\ kWK^{-1} \\ C_{ref} = \frac{\rho c}{[(t_i - t_u)COP_{min}]} = 7.6\ kJl^{-1}K^{-1} \\ C_{er} = 7.1\ kJl^{-1} \end{gathered} \quad (2)$$

$$\begin{gathered} C_t = m_s c(t_i - t_u)/COP_{max} = 366.3\ kJ \\ C_{dis} = \frac{U_A}{COP_{max}} = 0.70\ 10^{-3}\ kWK^{-1} \\ C_{ref} = \frac{\rho c}{[(t_i - t_u)COP_{max}]} = 8.7\ kJl^{-1}K^{-1} \\ C_{er} = 7.1\ kJl^{-1} \end{gathered} \quad (3)$$

where:

- m_s, is the mass of water stored in the device, kg;
- c, is the specific heat of the water, kJ kg^{-1} K^{-1};
- t_i, t_u are respectively the inlet and outlet water temperatures, K;
- COP_{min}, COP_{max} are the minimum and maximum coefficients of performance of the refrigerating system, dimensionless;
- U_A, is the thermal conductance of the storage tank of the device, $kW \cdot K^{-1}$;
- ρ, is the density of the water, $kg \cdot m^{-3}$.

In Table 3 the measured average consumptions at ambient temperature of 21 °C are reported. During the measurement campaign, the inlet water temperature was 20 °C and the final one with cooling system at low regime was 14 °C (8 °C at full speed).

Table 3. Energy consumed by the investigated home water treatment device

Refrigerating System regime	Water feeding regime	Average consumption [kJ h^{-1}]
Off	Zero	0
Low regime	Zero	11.9
Full speed	Zero	15.8
Off	Maximum	7.1
Low regime	Maximum	91.1

As for example, in Fig. 8 the absorption curves in the experimental conditions at low regime conditions are reported. Ultimately, avoiding to consider energy consumptions for cooling (that is comparable with the one of bottled water), average energy consumptions of tap water treated by means of the investigated device is approximately equal to 0.007 $MJ \cdot l^{-1}$. Thus, considering an amount of 0.005 $MJ \cdot l^{-1}$ due to distribution in the city networks, total energy consumption for the whole chain of treated tap waters sums 0.012 $MJ \cdot l^{-1}$, which is approximately two orders of magnitude less energy-consuming than bottled water.

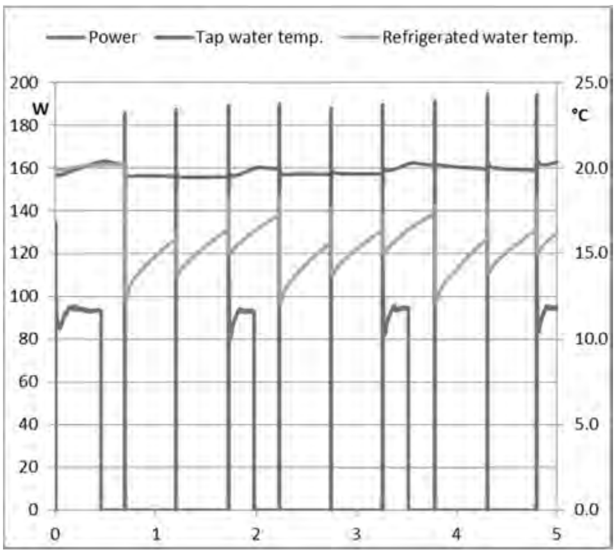


Fig. 8. Experimental analysis of the energy consumptions at not intensive regime

4. Energy savings and energy efficiency certificates

In Table 4, the comparison among the different energy contribution (loads) of tap waters and bottled ones is reported, considering the main processes. From the available data, it is clear that energy consumption is approximately equivalent in phases 1, 3, 4, 7 and 9, whereas in phases 2, 5, 6 and 8 bottled waters are more energy-consuming than the distributed ones.

Table 4. Comparison between the city network distributed and bottled water

Phase	Distributed	Bottled
1	Extraction	
2	Transport (network)	Carrying
3	Storage	
4	Treatment	
5	(Absent)	Bottle production Filling Sealing Labeling Packaging Plant management
6	Distribution (network)	Transport
7	Final Use	
8	(Absent)	Solid Waste
9	Drainage into sewer	

In order to compare annual energy consumption of bottled water with the tap water one, the authors considered a person weighing 70 kg requires a total water intake (from food and drinks) of about 2–2.5 l per day (i.e. approximately 30–35 ml per kg of body weight). In this balance, about 1 l is generally assumed indirectly from food and the remaining directly from water and soft drinks. Considering that bottled water consumptions per capita in Italy are approximately equal to 200 $l \cdot year^{-1}$, it is clear that on average more than a quarter of the water consumed in Italy is represented by bottled one. Thus, an average energy saving of 4.4 $MJ \cdot l^{-1}$could generate for a family of 4 presenting a bottled water consumption of 2000 $l \cdot year^{-1}$, a potential energy saving from the spreading of such systems of about 8800 $M \cdot J\ year^{-1}$. It follows that the potential energy saving is extremely high, even without considering the significant increasing trend of bottled waters foreseen for the next few years by market operators.

4.1. Proposal of energy efficiency certificates for the use of home treatment devices

An energy efficiency certificate (EEC) or white certificates derives from an activity or product that produces primary energy savings, reliable and quantifiable. This tool was introduced in Italy by the Ministerial Decrees April 24, 2001, later replaced by the Ministerial Decrees 20 July 2004 and updated by the Ministerial Decree of 21 December 2007 and supplemented by Legislative Decree 30 May 2008, n. 115, as amended, and by the legislative decree of 3 March 2011, no. 28.

The Resolution 103/2003 of the Italian Authority for Energy (AEEG) identifies three methods for the evaluation of proposals for EEC (Table 5): i) standardized evaluation, ii) analytical evaluation, and iii) assessment on completion. As an example, it should be possible to: i) replace an electric water heater water with a gas one (standardized approach); ii) install a small cogeneration plant for air conditioning analytically estimating savings (analytical method); iii) recover heat from a production process by measuring the fuel economy (final balance).

Table 5. Evaluation method as a function of the customer numerousness

Number of customers	Homogeneous estimation methods			Heterogeneous rating methods
	Standard	Analytical	Final balance	
One customer	Standard project	Analytical project	Final Project	Final Project
Many customers	Standard project	Analytical project	Final Project	Not allowed

For water treatment home devices, a standard approach could be adopted developing specific standard sheets for the installation and use of such devices at several customers premises located throughout the country.

For each water treatment home device sold, the company could obtain from 0.1 EEC (that is 41.868 divided by 4.49 GJ) to 1 TEE corresponding respectively to the savings achieved in five years from a family with a consumption of 200 and 2000 l $year^{-1}$, respectively. Alternatively, a more complex and more precise method, is represented by the actual balance with an energy meter installed directly on the device.

5. Conclusion

Energy consumption related to the use of bottled water are extremely high and more and more increasing. The analysis presented in this work shows that:

– the specific energy consumptions of bottled water range from 2.0 to 5.7 $MJ \cdot l^{-1}$ and most part of it is due to the production of PET bottles and to transport;

– the specific energy consumptions of tap water range from 0.002 to 0.005 $MJ \cdot l^{-1}$ as a function of the type of source, treatment and distribution network;

– the specific energy consumption of the water treated by the investigated home water treatment device is about 0.007 $MJ \cdot l^{-1}$.

From this study emerges that the use of home water treatment device in situ should limit the increase in energy consumption resulting from the use of bottled water and very important energy savings can rise from their spreading. In order to facilitate and encourage this process energy efficiency certificates should be attributed. The authors estimated that for an average family of 4 (2 adults and 2 children) that uses only bottled water with average consumptions of 2000 $l \cdot year^{-1}$ the potential energy savings could be about 4 500 $MJ \cdot year^{-1}$. The authors therefore propose that, for each treatment device sold, the company can obtain from 0.1 to 1 EEC.

Acknowledgements

This work was performed under a specific contract between the Department of Civil and Mechanical Engineering of the University of Cassino and Southern Lazio and Sidea King's Water Sas. The authors thank Ing. Marcello CUNI for his helpful technical suggestions and availability during the experimental campaign.

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Економія енергії завдяки побутовим пристроям очищення водопровідної води

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Анотація

Вода – єдина рідина, що використовується в їжі людини, яка представляє різні процеси виробництва та транспортування. Усі харчові рідини фактично потребують процесів виробництва та очищення в контрольованих середовищах, а також транспортування перевізниками. А воду, крім того, що процес її виробництва простіший, можна постачати як розподільними мережами, так і шляхом транспортування перевізниками. В останні роки споживання пляшкової води значно зросло не тільки для потреб здоров’я, але й для інших потреб. На практиці, лише в деяких випадках воду в пляшках використовують для реальної потреби в особливих умовах, а все більше її використовують через погану якість водопровідної води. Недавні дослідження показали, що споживання енергії, пов’язаної з пляшковою водою, може бути в 2000 разів більшим, ніж споживання енергії, пов’язане з водопровідною водою. Споживання енергії для пляшкової води головним чином зумовлене виробництвом пластикових пляшок, процесом розливу та транспортуванням / дистрибуцією. У цій праці, уникаючи порівняння між пляшковою та водопровідною водою щодо хіміко-фізичних, мікробіологічних та смакових характеристик, автори подають результати експериментального дослідження, спрямованого на вимірювання енергоспоживання пристроїв побутового очищення водопровідної води. Крім цього, зосереджено увагу на можливих способах економії енергії під час використання очищеної води з-під крана.

Ключові слова: водопровідна вода; пляшкова вода; економія енергії; очищення води.