Research Article

The influence of different water efficiency ratings of taps and mixers on energy and water consumption in buildings

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Abstract

This paper analyses two different models (methods) used for determination of water consumption in residential buildings. For this purpose, some basic sanitation facilities were implemented in the models as typical household equipment. As there is a big variety of sanitary solutions available, in order to achieve a significant reduction in water consumption, a novel classification of faucets (taps and mixers) is proposed. This classification also allows for the assessment of energy efficiency ratings of sanitary appliances. On the basis of this classification, water savings resulting from the use of faucets with different water efficiency ratios were determined. Depending on the type of faucet, it is possible to achieve more than 50% water savings, as well as a significant reduction in energy demand for heating and pumping water to customers. The paper also discusses the equations used to determine the energy demand for domestic hot-water preparation and its pumping to consumers. The results of the energy consumption calculations for the above-mentioned purposes were determined per person.

Keywords Water consumption levels · Water saving · Model consumption · Energy demand

1 Introduction

Increasing economic growth, the development of industrialized countries and introduction of modern technologies have contributed to more and more attention paid to the efficient management of renewable natural resources. One example of such resources is water, which circulates and is constantly renewed in the so-called hydrological cycle. It should be noted, however, that despite the hydrological cycle, fresh drinking water resources may not be sufficient in the near future. Increasing demand for water caused, for example, by population growth and industrial development, results in changes in the world water balance. In addition, climate changes can reduce freshwater resources. These processes increase, inter alia, the costs of obtaining freshwater and the problem of drinking water shortage. Water is also an indispensable medium in buildings. However, before water reaches specific customers, it is necessary to: determine the water demand in the building, design the necessary number of sanitary facilities, assume the appropriate number of faucets and taps, plan the proper distribution of pipes, select the proper pipe size, determine the pressure drops in the water supply system, select the appropriate control-testing unit, shut-off valves, pressure boosters and devices to prevent uncontrolled pressure increase.

Successful handling of these tasks is based on the standards and guidelines for designing water supply systems in buildings [1–3]. Unfortunately, such documents contain data and equations that clearly differ from the current state of the art. As a result, it often happens that designed sanitary installations can be considerably oversized [4–7].

Such problems have been identified by many researchers. Franieczek and Jedlikowski [4] analysed and compared various methods of calculating water flow rate in

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preschool facilities. In a further paper, the authors [5] analysed the water consumption in these buildings, examining the nature of water demand variability observed over the last few decades in urban households. Englart and Jedlikowski [6] compared the methods of gas demand calculation in a gas installation equipped with combi boilers used for domestic hot-water preparation, while Englart and Dudkiewicz [7] compared various methods of water meters selection in water supply systems.

Apart from oversized installations, the main reason for the differences between the design water flow rate and the actual water flow rate is the increase in water savings in the buildings [5, 7–11]. In his paper, Nowakowski [8] paid particular attention to the obligation to measure the consumption of cold and hot water in buildings, which influenced water consumption indicators in residential and public buildings. Puszkarewicz [9] analysed water consumption in residential buildings according to present regulations. Hotloś et al. [10] discussed the variations in water demand for the city of Wrocław, observed over the period of 1990–2011. They observed a clear decrease in water consumption. Heidrich and Jędrzejkiewicz [11] analysed the water consumption in Polish cities in the years 1995–2005. These authors also stated that water consumption in Polish cities and towns follows a time-related pattern with a visible downward trend.

Proper management of water demand is increasingly perceived by governments, agencies and public utility companies not only as a potential means of supporting the security of the future water supplies, but also as an important tool to limit the resulting environmental consequences [12]. Reduced water consumption saves energy directly in the household or outside the household, at water abstraction, treatment and distribution points. For example, lower water consumption in a household is associated with a reduction in the energy required for water abstraction, processing in a wastewater treatment plant, pumping and heating in the home. In addition, it also significantly reduces the cost of wastewater treatment at the treatment plant [13]. Willis et al. [14] stressed the need to ensure the sustainable urban water consumption. The authors claim that households have great potential for water saving, especially in case of discretionary end-uses such as showering. Moreover, the authors express the claim that equipping bathrooms with high-resolution smart meters and data recorders and equipping showers with alarm visual display monitors locked at 40 l resulted in significant savings in water consumption. Beal et al. [15] demonstrated that that householders' prediction of their water use is not correctly aligned with their actual water use. The authors presented the results of the measurements taking into account a group of factors which have a significant impact on the value of water consumption, including the age, income, percentage of water-efficient stock (e.g. low-flow faucets), family size, as well as the intentions and attitudes of the end-users regarding their behaviour during hygienic activities. Willis et al. [16] focused on the relationship between a range of socio-demographic variables, household stock efficiency variables and water end-use consumption levels. Similar issues were analysed by Makki et al. [17], who presented the determinants of shower water end-use consumption. They used an eight-way independent factorial ANOVA extended into a three-tier hierarchical linear multiple regression model to create a novel model for forecasting the end-use of the shower. Jack et al. [18] presented an overview of the water supply and drainage systems for buildings. For this purpose, the authors analysed the results of numerical simulations conducted with the use of different prediction models. The authors presented three different examples of the design where the main emphasis is on providing sustainability.

Barberán et al. [19] analysed the possibilities of water saving in hotel buildings. The hotel in Zaragoza (Spain) was used for this purpose. This building was equipped with water-saving technologies to reduce the amount of water consumption. The authors analysed the impact of such modernization (retrofitting) on the consumption, and its financial and economic profitability. Moreover, they stated that a small investment can lead to a very significant reduction in water consumption and the related costs (in particular energy costs). Horsburgh et al. [20] presented technologies which allow for achieving water savings in two high-traffic, public toilets. For this purpose, the authors installed high-efficient automatic faucets and flushing valves for the toilet. In addition, these facilities were also equipped with a user-counting system. This made it possible to identify equipment failures, average water consumption per person and variability in the use of fixtures compared to the manufacturer's specification. Moreover, this measurement system can help institutions to measure and record trends and behaviours related to water use, identify leaks and malfunctions, and provide maintenance or upgrades of sanitary facilities. All these actions can ultimately contribute to the achievement of sustainable water use. Wong et al. [21] analysed the possibilities of recovering heat from showers in bathrooms equipped with instantaneous water heaters. A simple single-pass counter-flow heat exchanger installed horizontally under the shower drain was used for this purpose. The heat exchange took place between the cold water and the water in the sewer drain. As a result, the cold water was preheated.

As can be seen, the faucets and taps which are the last part of the water installation are the key element of water saving. In this way, users of the water supply system can directly or indirectly reduce water consumption. The indirect factors include: high water prices, water bills based on readings from individual (residential) water meters (also known as sub-meters) for domestic drinking water supply, rational use of water. On the other hand, the direct factors are as follows: the replacement of traditional faucets and taps with modern technology or innovative products with a high level of water saving, replacement of baths with showers, the installation of toilet bowls equipped with tanks with smaller capacities, the sale of more economical household appliances such as washing machines and dishwashers [5, 22]. Each of these examples is directly related to the type of water connection. The only exceptions are modern household appliances and toilet bowls, the operation of which results in some water savings. However, it is worth noting that the vast majority of all sanitary facilities are equipped with faucets and taps. Depending on the type of these elements, some significant differences in the amount of water consumption are possible.

For this reason, several important issues are worth considering. What impact will modern mixing valves have on total water consumption? Is there a classification of mixing valves based on different water consumption levels? How much can water consumption be reduced in this way? In order to answer these questions, it is necessary to conduct a detailed analysis of the solutions available on the sanitary-ware market.

2 Methodology

The building regulations (BRs) applicable in England and Wales, Part G, require that the daily potable water consumption per person in a new dwelling does not exceed 125 l [23–25]. This condition results in the guidelines presented in the Code for Sustainable Homes (CSH) [27], in which different levels of water efficiency have been specified. They form the part of the environmental performance criteria that are taken into account in sustainable design [26, 27]. Based on the guidelines [23, 27, 28], the required levels of daily water consumption per person can be determined (Table 1).

In order to achieve a relatively high level indicated in Table 1, it is required to significantly reduce water consumption in households. Appropriate allocation of water consumption to a given level depends on the characteristics of water consumption of the installed faucets (microcomponents). There are a lot of types of mixing valves available on the market. Each of them is characterized by its shape, structure, construction and flow rate depending on the water pressure. In addition, there are many accessories available to control the volume of water flow such as aerators, flow limiters (eco-buttons), flow regulators and pressure regulators [22, 29]. Based on literature studies, regulations and standards [22, 30–37], a general classification of faucets (mixing valves) used in sanitary facilities has been proposed: mechanical, double handle (the water flow rate is controlled by two handle knobs), of cold and hot water; mechanical, single handle (the water flow rate is controlled by a single handle), which allows setting the temperature of mixed water; thermostatic (allowing the outflow of water at a preset temperature); automatic shut-off (equipped with push button allowing the set volume of water to flow out); electronic or touchless (water flow rate is controlled by bringing hands closer to the spout).

Table 1 Water consumption levels

Performance target	Maximum consumption of potable water
–	Litres/person/day
Level 0 (BR part G)	125
Levels 1 and 2 (CHS)	120
Levels 3 and 4 (CHS)	105
Levels 5 and 6 (CHS)	80

Reducing water pressure can be one of the methods of limiting the water flow rate. In a multi-storey building, the water pressure directly before the spout can differ considerably. The reason for this is the need to ensure appropriate pressure conditions at the furthest water draw-off points. According to the applicable Polish standard PN-92/B-01706 [3], the minimum water pressure should be higher than 0.1 MPa. In multi-storey buildings, pressure values in the range of 0.3–0.4 MPa [22] and even higher can be observed at some points in the cold- and hot-water installation. It may, therefore, result in an increased water flow rate in other draw-off points. There are many literature studies presenting the characteristics of mixing valves operation determined as the variability of water flow rate in the function of pressure [38]. Moreover, some studies present a different classification of water flow rate during the operation of these appliances [39, 40]. Reducing the pipe diameter can be another way of reducing the water flow rate [29]. The effect of all these measures is the introduction of indexes of water efficiency rating [39–44]. Over the past few years, a lot of attention has been paid to water-saving issues. Fidar et al. [13] attempted to evaluate the performance of conventional and electronic mixing valves. The authors claim that faucets with a lower water flow rate can reduce water consumption per person. For this purpose, they carried out a number of measurements of water flow rate in toilets in higher education buildings. The obtained results allowed them to determine the trends in cold- and hot-water consumption, as well as to estimate the energy required for water heating. Meireles et al. [45] carried out a study on water savings for washbasin mixers equipped with different aerators. The authors also analysed how the preferences of users influence the level of water consumption savings and whether the application of water-saving faucets is fully utilized. Fidar et al. [24, 25] evaluated the economic potential of using different micro-components (baths, taps, showers, WCs, washing machines, dishwashers). They also proposed a methodology for assessing the cost-effectiveness of a given solution. According to Kalbusch and Ghisi [46], replacing ordinary taps with water-saving ones in order to reduce water consumption is a regular practice in existing buildings. Replacing conventional faucets with water-saving solutions can reduce water consumption by 26.2% and energy consumption by 13.6%.

Despite many studies on water saving, a number of discrepancies in the classification of faucets were found. The authors of this paper have therefore decided to develop a more general classification, which will be used to analyse the impact of faucets on energy demand and water consumption in buildings. For this purpose, the data presented in papers [24, 39, 41, 47] and information provided by various producers of faucets were used. The proposed classification of mixing valves based on different levels of water consumption is shown in Table 2.

In Table 2, the classification into three main levels and one non-class level has been made. In addition, it has been assumed that the maximum water flow rate can occur for pressure-independent mixing valves or for taps operating at 3 bar.

3 Results and discussion

The principles discussed in the previous papers [23, 28] and [48] can be used to estimate the water consumption in a residential building. On this basis, it is also possible to estimate the water savings, resulting from the use of taps with coefficients of efficiency in accordance with Table 2. The results of water consumption calculations for different faucets and taps are presented in Tables 3 and 4.

Table 2 Water efficiency rating

Water efficiency rating	Fitting/appliance	
	Taps	Shower
Level	l/min	l/min
0	> 8	> 12
1	> 6 but not ≥ 8	> 9 but not ≥ 12
2	> 4 but not ≥ 6	> 6 but not ≥ 9
3	≤ 4	≤ 6

In the calculations, the following basic sanitary appliances designed for a typical household were used: a washbasin mixer (tap) for basic sanitary activities, a shower for bathing and a sink mixer (sink tap) used in the preparation of meals. The analyses focused on the above-mentioned groups of sanitary appliances because they are characterized by significant differences in the level of water consumption. In other household sanitary appliances such as toilet bowls, washing machines and dishwashers, the water flow rate depends mainly on their water capacity and technical and economic solutions.

As can be seen, depending on the assumed level of water efficiency rating, correspondingly lower values of water flow rate were observed. The analysed models are characterized by the identical tap water flow rates for different use factors per day.

The comparison of water consumption of these two models shows slight discrepancies. Model 2 calculation procedure results in higher average water consumption. Analysing the data of both models (Tables 3, 4) obtained for level 0, it is possible to have the impression that model 2 (129 l/person/day) shows very high level of accuracy with the guidelines for daily water consumption (125 l/person/day) (Table 1). However, it is worth noting that these data also take into account toilets that are flushed several times a day. Assuming a toilet water use ratio of 6–7 times per day and an average water flow rate per flush of ~ 3.4 l (for 1 large flush 6 l and for 6 small flushes 3 l), a water consumption of about 24 l/person/day can be obtained. Taking into account the flushing water used for the toilet in relation to the total water consumption, it is possible to obtain for the model 1 → ~ 126 l/person/day and for the model 2 → 154 l/person/day. Therefore, the model 1 will have a much better accuracy for level 0. The highest levels of water efficiency rating for both models are close to (slightly lower than) the 80 l/person/day from maximum water consumption guidelines (model 1 → ~ 46 + 24 l/person/day, model 2 → 48 + 24 l/person/day). The values obtained from the models for the different levels are sufficiently compatible with the actual water consumption in buildings. On the basis of reports of water consumption for 252 households, Beal et al. [15] found that the consumption for taps was 22.7–30.6 l/person/day and for showers 29.6–52.4 l/person/day. Willis et al. [14] reported that in 151 households 50% used less than 40 l/person/day of water for showering, 37% of households used between 41 and 80 l/person/day, 13% consumed on average more than 80 l/person/day in the shower. These studies did not specify the water efficiency rating for installation type.

The use of these models can be helpful in the design stage of new buildings. Estimation of water consumption at the preliminary design phase allows to apply the appropriate water-saving solutions (e.g. selection of faucets with

Table 3 Water consumption of different faucets and taps determined by the water efficiency calculator used for new dwellings—model 1 [23]

Installation type	Capacity/flow rate	Use factor	Fixed use	Water consumption
–	Litres/min	–	Litres/person/day	Litres/person/day
Level 0				
Taps (excluding kitchen/utility room taps)	12	1.58	1.58	20.54
Shower (where bath also present)	15	4.37	0.00	65.55
Kitchen/utility room sink taps	12	0.44	10.36	15.64
	Total water consumption			101.73
Level 1				
Taps (excluding kitchen/utility room taps)	8	1.58	1.58	14.22
Shower (where bath also present)	12	4.37	0.00	52.44
Kitchen/utility room sink taps	8	0.44	10.36	13.88
	Total water consumption			80.54
Level 2				
Taps (excluding kitchen/utility room taps)	6	1.58	1.58	11.06
Shower (where bath also present)	9	4.37	0.00	39.33
Kitchen/utility room sink taps	6	0.44	10.36	13.00
	Total water consumption			63.39
Level 3				
Taps (excluding kitchen/utility room taps)	4	1.58	1.58	7.90
Shower (where bath also present)	6	4.37	0.00	26.22
Kitchen/utility room sink taps	4	0.44	10.36	12.12
	Total water consumption			46.24

high water efficiency rating). It should be emphasized that during the application of both models special attention should be given not only to the results of the calculations but also to the total water consumption in the household.

Based on the results obtained from two different water consumption models (Tables 3, 4) and (Fig. 1a, b), it can be concluded that the assumption of specific efficiency levels 1–3 for individual faucets allows for significant savings in water consumption in households.

As can be seen in Fig. 1, depending on selection of the model, different percentages of water savings have been achieved. The differences are in the range of 5–8%. This was caused by different results obtained from the models (Tables 3, 4) of the total water consumption. Furthermore, it should be noted that in the above considerations 100% of the value refers to the total water consumption for level 0, which is the model 1 → ~ 102 l/person/day and for the model 2 → 129 l/person/day, respectively. This gives the incorrect assumption that the model 2 has the highest level of savings despite the use of the same mixing valves. A quantifiable assessment of the effect of using faucets with a higher water efficiency rating should be carried out in conjunction with an in-depth analysis of previously developed data (Tables 3, 4).

A lot of manufacturers of sanitary appliances inform the customers about the efficiency of faucets providing incomplete data concerning the water flow. In practice, the value of water consumption reduction rates for which a percentage savings are determined is never completely clear. Sometimes, this percentage is determined on the basis of assumed value of the reduced water flow rate from a single tap with reference also to the assumed maximum value.

In conclusion, it should be noted that these two models are characterized by a clearly visible reduction in water flow rate in relation to level 0. Depending on the faucets and taps used, it is therefore possible to achieve water savings of more than 50%.

The next step of the analysis is to determine the energy demand on the basis of the data from the developed models (for water heating and pumping purposes, i.e. supply to customers).

The energy consumption (in kWh) of the showers, internal taps and baths is calculated using Eq. (1) [26]:

$$E = \frac{m \cdot c_w \cdot \Delta T}{3.6 \cdot 10^6 \cdot \eta} \qquad (1)$$

where E energy requirement, kWh, m mass of the water used, kg, c_w specific heat capacity of water, 4190 J/(kg K), ΔT change in water temperature, K, η the efficiency of the

Table 4 Water consumption of different faucets determined on the basis of the benchmarks for estimating residential end-uses of water—model 2 [48]

Installation type	Capacity/flow rate	Likely range of average values	Unit	Water consumption		
				Minimum	Maximum	Average
–	Litres/min	–	–	Litres/person/day	Litres/person/day	Litres/person/day
Level 0						
Bathroom faucet use	12	0.5–3.0	Minutes/person/day	6	36	21
Kitchen faucet use	12	0.5–5.0	Minutes/person/day	6	60	33
Showering frequency	15	0.0–1.0	Showers/person/day	75	225	75
Duration of average shower		5–15	Minutes			
	Total water consumption			87	321	129
Level 1						
Bathroom faucet use	8	0.5–3.0	Minutes/person/day	4	24	14
Kitchen faucet use	8	0.5–5.0	Minutes/person/day	4	40	22
Showering frequency	12	0.0–1.0	Showers/person/day	60	180	60
Duration of average shower		5–15	Minutes			
	Total water consumption			68	244	96
Level 2						
Bathroom faucet use	6	0.5–3.0	Minutes/person/day	3	18	10.5
Kitchen faucet use	6	0.5–5.0	Minutes/person/day	3	30	16.5
Showering frequency	9	0.0–1.0	Showers/person/day	45	135	45
Duration of average shower		5–15	Minutes			
	Total water consumption			51	183	72
Level 3						
Bathroom faucet use	4	0.5–3.0	Minutes/person/day	2	12	7
Kitchen faucet use	4	0.5–5.0	Minutes/person/day	2	20	11
Showering frequency	6	0.0–1.0	Showers/person/day	30	90	30
Duration of average shower		5–15	Minutes			
	Total water consumption			34	122	48

heating system, dimensionless, the constant is a conversion factor from Joules to kWh.

For taps and faucets, it has been assumed that the ratio of domestic hot water to cold water is 1:1, i.e. its consumption will constitute 50% of cold water and 50% of hot water, respectively. The other components of equation were taken as follows: $\Delta T = 50$K (domestic hot-water preparation from 10 to 60 °C) and average efficiency of the heating system $\eta = 0.7$ according to [49]. Then, the energy requirements of the pumps should be analysed.

The following equation is used for this purpose:

$$E_p = \frac{m \cdot g \cdot H}{10^3 \eta_p} \cdot \tau \quad (2)$$

where m mass of the pumped water, kg, g acceleration due to gravity, m/s^2, H head (the hydraulic energy of water in metres), m, τ time of pump operation per day, h, η_p the efficiency of the pumping system, dimensionless.

The following assumptions are made in Eq. (2):

- hydraulic energy of water in metres equal to $H = 1$m,

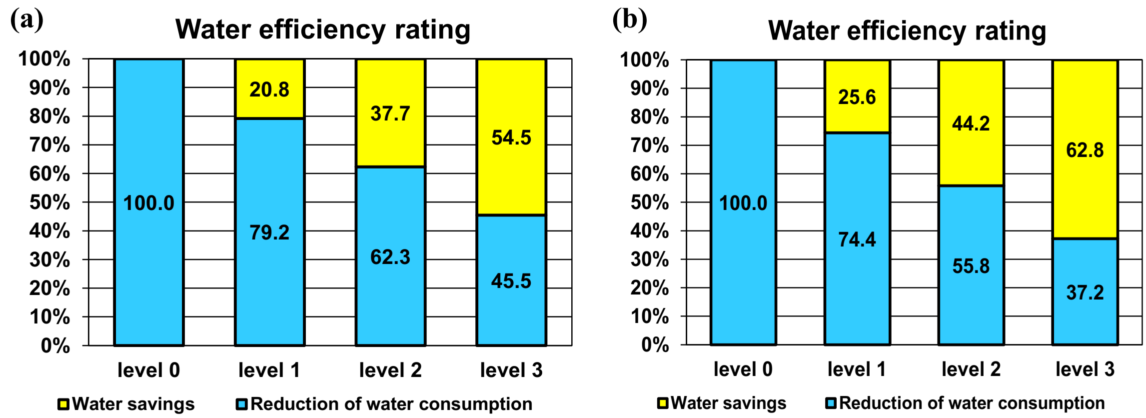

Fig. 1 Comparison of different levels of water efficiency rating of water consumption determined on the basis of: **a** results of model 1 (Table 3) and **b** average values of model 2 (Table 4)

- efficiency of the pumping system $\eta_p = 0.8$ [50],
- time of pump operation per day $\tau = 20$ h.

Properly selected pumping system should operate within the range of high efficiency. Pumps in multi-family buildings operate at different performances depending mainly on the pressure and required water flow rate. For this reason, the average efficiency of the pumping system available in the literature $\left(\eta_p = 0.8\right)$ has been used to calculate the energy demand [50].

Both Eqs. (1) and (2) were supplemented with the data from the two models (Tables 3, 4). The results of energy consumption per person are shown in the charts (Fig. 2a, b).

As can be seen (Fig. 2), the use of high-level taps and faucets results in significant energy savings both for domestic hot-water preparation (Fig. 2a) and pumping water to consumers (Fig. 2b). Particular attention should also be paid to the fact that the energy consumption of both models is almost the same in the case of level 3 of water efficiency rating. This is mainly due to the fact that in this case, these two models have similar water demand data: model 1 (46.24 l/ (person day)) and model 2 (48 l/ (person day)).

The highest energy demand for hot-water preparation and water pumping is at level 0. The reason for this is the highest water flow rate for the two analysed models. In addition, there are also significant differences in the results of the models due to different values of total water consumption. This confirms that similar results are achieved as the level of water efficiency rating increases. The energy demand for hot-water preparation obtained from the analysed models is comparable to the demand reported by Fidar et al. [26].

In summary, it is worth noting that the issue of saving water in households facilitates the implementation of modern technologies introduced by manufacturers of sanitary appliances and faucets. The problem is that there

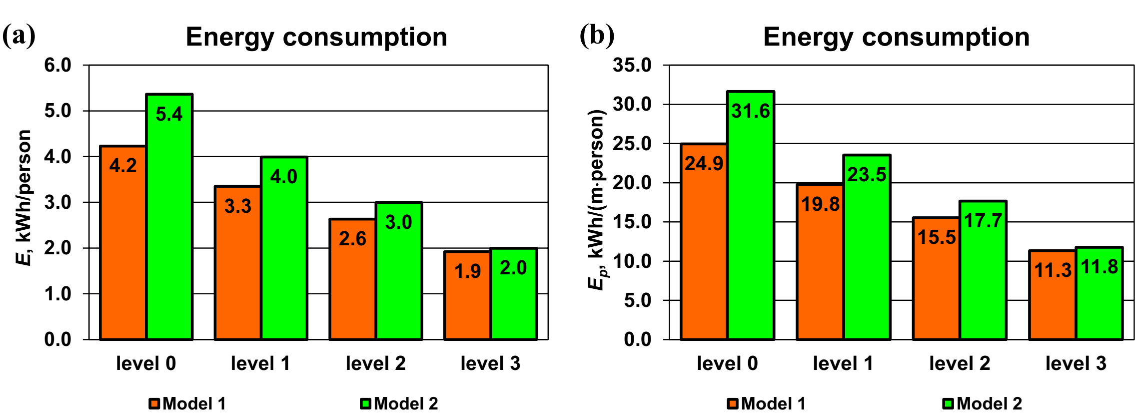

Fig. 2 Comparison of energy consumption for different levels of two models of water efficiency rating determined for the purposes: **a** domestic hot-water preparation and **b** pumping water

is currently no unification of technologies reducing water consumption and assigning to them precise indicators or efficiency rating classes. The technical solutions mentioned in this paper are mainly based on the reduction in the water flow rate directly before the draw-off point. It is worth noting that the authors of this paper only consider single-handle faucets. As a continuation of the research, it would be useful to make similar analyses based on the application of modern solutions for households and public sanitary fittings in commercial, service and industrial buildings. A good example may be the application of thermostatic mixer faucets for showers. The replacement of traditional shower heads with modern overhead showers characterized by different modes of economic operation can also bring measurable profits. Similarly, automatic flow regulators that react to changes in water pressure reduce the water flow rates to approximately 4 l/min. The same procedure should be used when analysing the equipment of washbasins with special mixers with electronic control that reacts to the appearance of hands. It is worth noting that time, non-contact (electronic) and thermostatic systems can be used in all types of faucets. All the above-mentioned solutions can be implemented without restrictions in newly designed buildings or during the modernization of existing buildings. In addition, consideration should be given to using leak detection devices which have a water shut-off function and also notify the user of any leakage. It is very important because such failures, in addition to generating damage, also cause the irretrievable loss of significant amounts of water. Moreover, water consumption monitoring devices should be equipped with motion sensors, which in cooperation with electromagnetic valves control the flow rate of water, eliminating leaks and leakages. Attempts to implement such solutions should ideally be made at the design or early construction stage. This will allow for the proper installation of monitoring equipment in the piping system.

The above proposals for the study of water use are important in view of the constantly diminishing water resources and for this reason should be in focus of further research.

4 Conclusions

Currently, there are many solutions available to significantly reduce the demand for water and energy in residential buildings, which is not always reflected in the applicable regulations and design requirements. As a result, considerably lower total water consumption has contributed to the introduction of new classifications for the assessment of the energy efficiency of the equipment used. It is worth noting that currently there is no harmonized classification of levels of water efficiency rating for taps and faucets used in sanitary installations. Moreover, the application of normative water flow rate designing sanitary systems in buildings will result in the selection of sanitary appliances with significantly higher performance and electricity demand. The use of modern technologies to reduce the water consumption household must take into account the different number of efficiency levels reported by the manufacturers and the corresponding reduced water flow rates. Regardless of the model of water efficiency rating used to calculate the total water consumption, a significant reduction in the energy demand is possible.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

References

1. Obwieszczenie Ministra Infrastruktury i Rozwoju z dnia 18 września 2015 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Ministra Infrastruktury: w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie/The Notice of the Polish Minister for Infrastructure and Regional Development of 18 September 2015, on publication of the consolidated text of the Regulation of the Polish Minister for Infrastructure: on technical conditions which must be fulfilled by buildings and their location. Dz. U. nr 0, poz. 1422/Dz. U. No. 0, item 1422 (Poland)
2. Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie/Regulation of the Polish Minister for Infrastructure of 12 April 2002: on technical conditions which must be fulfilled by buildings and their location. Dz. U. nr 75, poz. 690/Dz. U. No. 75, item 690 (Poland)
3. PN-92/B-01706 (1992) Instalacje wodociągowe w budynkach. Wymagania w projektowaniu/Water supply systems in buildings. Design requirements (Poland)
4. Franieczek I, Jedlikowski A (2018) Porównanie metod do wyznaczania przepływu obliczeniowego wody w obiektach przedszkolnych/The comparison of calculation methods for determining the water flow rate for pre-school facilities. Gaz Woda i Technika Sanitarna/Gas Water Sanitary Eng 7:252–258. https://doi.org/10.15199/17.2018.7.3
5. Franieczek I, Jedlikowski A (2018) Zużycie wody w obiektach przedszkolnych na podstawie kilkudziesięcioletniej zmienności

zapotrzebowania na wodę dla budynków mieszkalnych/The water consumption in pre-school facilities on the basis of water demand variability over the past several decades in residential buildings. Gaz Woda i Technika Sanitarna/Gas Water Sanitary Eng 8:289–293. https://doi.org/10.15199/17.2018.8.3
6. Englart S, Jedlikowski A (2017) Porównanie metod obliczeń zapotrzebowania na gaz w instalacjach gazowych z kotłami dwufunkcyjnymi/The comparison of calculation methods of gas demand in the gas installation with combi boilers. Gaz Woda i Technika Sanitarna/Gas Water Sanitary Eng 9:350–354. https://doi.org/10.15199/17.2017.9.1
7. Englart S, Dudkiewicz E (2016) Porównanie metod doboru wodomierza głównego w budynku mieszkalnym wielorodzinnym/Comparison of main water meter selection methods in residential building. Gaz Woda i Technika Sanitarna/Gas Water Sanitary Eng 10:364–369. https://doi.org/10.15199/17.2016.10.2
8. Nowakowski E (2012) Wskaźniki zużycia wody w budynkach mieszkalnych i użyteczności publicznej. Rynek Instalacyjny 7–8:80–82
9. Puszkarewicz A (2010) Analiza zużycia wody w osiedlach miejskich o zróżnicowanym wyposażeniu mieszkań/Water consumption analysis in urban settlements with varied apartments' equipment. Gaz Woda i Technika sanitarna/Gas Water Sanitary Eng 5:16–17
10. Hotloś H, Głowacka J, Kołodziej A (2012) Zmienność poboru wody w systemie wodociągowym Wrocławia/Water demand variations in the water distribution system of Wroclaw. Ochrona Środowiska/Environ Pollut Control 34(4):23–28
11. Heidrich Z, Jędrzejkiewicz J (2007) Analiza zużycia wody w miastach polskich w latach 1995–2005/Analysis of water consumption in Polish cities in the time span of 1995–2005. Ochrona Środowiska/Environ Pollut Control 29(4):29–34
12. Beal CD, Stewart RA (2013) Identifying residential water end uses underpinning peak day and peak hour demand. J Water Resour Plan Manag https://dx.doi.org/10.1061/(ASCE)WR.1943-5452.0000357. Accessed 12 Nov 2018
13. Fidar AM, Memon FA, Butler D (2016) Performance evaluation of conventional and water saving taps. Sci Total Environ 541:815–824
14. Willis RM, Stewart RA, Panuwatwanich K, Jones S, Kyriakides A (2010) Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. Resour Conserv Recycl 54:1117–1127
15. Beal CD, Stewart RA, Fielding K (2013) A novel mixed method smart metering approach to reconciling differences between perceived and actual residential end use water consumption. J Clean Prod 60:116–128
16. Willis RM, Stewart RA, Giurco DP, Talebpour MR, Mousavinejad A (2013) End use water consumption in households: impact of socio-demographic factors and efficient devices. J Clean Prod 60:107–115
17. Makki AA, Stewart RA, Panuwatwanich K, Beal C (2013) Revealing the determinants of shower water end use consumption: enabling better targeted urban water conservation strategies. J Clean Prod 60:129–146
18. Jack LB, Swaffield JA (2009) Embedding sustainability in the design of water supply and drainage systems for buildings. Renew Energy 34:2061–2066
19. Barberán R, Egea P, Gracia-de-Rentería P, Salvador M (2013) Evaluation of water saving measures in hotels: a Spanish case study. Int J Hosp Manag 34:181–191
20. Horsburgh JS, Leonardo ME, Abdallah AM, Rosenberg DE (2017) Measuring water use, conservation, and differences by gender using an inexpensive, high frequency metering system. Environ Model Softw 96:83–94
21. Wong LT, Mui KW, Guan Y (2010) Shower water heat recovery in high-rise residential buildings of Hong Kong. Appl Energy 87:703–709
22. Chudzicki J (2011) Techniczne możliwości oszczędzania wody i energii w budynkach użyteczności publicznej—wnioski ze STEP-u. Energia i Budynek. https://www.ogrzewnictwo.pl/artykuly/systemy-i-instalacje/ciepla-woda-uzytkowa/techniczne-mozliwosci-oszczedzania-wody-i-energii-w-budynkach-uzytecznosci-publicznej-wnioski-ze-step-u. Accessed 5 Nov 2018
23. The Building Regulations (2010) Sanitation, hot water safety and water efficiency. 2015 edition with 2016 amendments. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/504207/BR_PDF_AD_G_2015_with_2016_amendments.pdf. Accessed 21 Dec 2018
24. Fidar AM, Memon FA, Butler D (2017) Economic implications of water efficiency measures i: assessment methodology and cost-effectiveness of micro-components. Urban Water J 14(5):522–530. https://doi.org/10.1080/1573062X.2016.1223859
25. Fidar A, Memon FA, Butler D (2017) Economic implications of water efficiency measures II: cost-effectiveness of composite strategies. Urban Water J 14(5):531–538. https://doi.org/10.1080/1573062X.2016.1224361
26. Fidar A, Memon FA, Butler D (2010) Environmental implications of water efficient microcomponents in residential buildings. Sci Total Environ 408:583–828
27. Communities and Local Government (2010) Code for sustainable homes: technical guide, November 2010. Department for Communities and Local Government, London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/5976/code_for_sustainable_homes_techguide.pdf. Accessed 24 Dec 2018
28. Communities and Local Government (2009) The water efficiency calculator for new dwellings, Department for Communities and Local Government, September 2009. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/529172/The_Water_Efficiency_Calculator_for_new_dwellings_archived.pdf. Accessed 24 Dec 2018
29. Guidance Leaflet, Reducing water use—pressure, pipework and hoses. http://www.wrap.org.uk/sites/files/wrap/guidance_doc_4_pressure_pipework_hoses.pdf. Accessed 5 Nov 2018
30. Wiśniowicz A (2008) Badanie baterii wodociągowych w świetle aktualnych norm/Examining water supply systems batteries in the light of current standards. Gaz Woda i Technika Sanitarna/Gas Water Sanitary Eng 7–8:13–16
31. PN EN 200:2008 Armatura sanitarna. Zawory wypływowe i baterie mieszające do systemów zasilania wodą typu 1 i typu 2. Ogólne wymagania techniczne/Sanitary tapware. Single taps and combination taps for water supply systems of type 1 and type 2. General technical
32. PN EN 817:2008 Armatura sanitarna. Baterie mechaniczne (PN10). Ogólne wymagania techniczne/Sanitary tapware. Mechanical mixing valves (PN 10). General technical specifications
33. PN-EN 1111:2017 Armatura sanitarna. Baterie termostatyczne (PN 10). Ogólna specyfikacja techniczna/Sanitary tapware. Thermostatic mixing valves (PN 10). General technical specification
34. PN EN 1286:2004 Armatura sanitarna. Baterie mechaniczne niskociśnieniowe. Ogólne wymagania techniczne/Sanitary tapware. Low pressure mechanical mixing valves. General technical specification
35. PN EN 1287:2017 Armatura sanitarna. Niskociśnieniowe termostatyczne baterie mieszające. Ogólna specyfikacja techniczna/Sanitary tapware. Low pressure thermostatic mixing valves. General technical specification

36. PN EN 816:2017 Armatura sanitarna. Armatura samoczynnie zamykana PN 10/Sanitary tapware. Automatic shut-off valves PN 10
37. PN EN 15091:2014 Armatura sanitarna. Armatura sanitarna otwierana i zamykana elektronicznie/Sanitary tapware. Electronic opening and closing sanitary tapware
38. Test Report No. S08MEC07709-1-CLC (2009) Testing of Tap/Mixers Fittings. https://en.vola.com/files/accreditation/1562-500T1%202471%20590%20HV4%20TUV%20SINGAPORE.pdf. Accessed 5 Nov 2018
39. Kaps R, Wolf O (2011) Development of European Ecolabel and Green Public Procurement Criteria for Sanitary Tapware—Taps and Showerheads, Background Report Including Draft Criteria Proposal Working Document For First Ahwg-Meeting For The Development Of Ecological Criteria For Sanitary Tapware—Taps And Showerheads. http://susproc.jrc.ec.europa.eu/ecotapware/docs/1st%20draft_Technical_background_report_Criteria_for_taps_and_showerheads.pdf. Accessed 5 Nov 2018
40. Information Sheet Template—Wrap, Achieving water efficiency on projects. http://www.wrap.org.uk/sites/files/wrap/Achieving%20water%20efficiency%20on%20projects_0.pdf. Accessed 5 Nov 2018
41. PUB Singapore's National Water Agency (2018) Water efficiency labelling scheme (WELS) Guidebook. https://www.pub.gov.sg/Documents/WELS_Guidebook.pdf. Accessed 8 Nov 2018
42. Roberts P (2004), Yarra valley water 2004 residential end use measurement study. http://www.manuelectronics.com.au/pdfs/YarraValleyWater2004REUMS.pdf. Accessed 12 Nov 2018
43. Joint Research Center Technical Reports (2014) MEErP preparatory study on taps and showers, tasks 1 report: introduction and scope (version 2). http://susproc.jrc.ec.europa.eu/taps_and_showers/docs/Task1_2ndTWG_v2.4.pdf. Accessed 12 Nov 2018
44. Joint Research Center, MEErP preparatory study on taps and showers, 1st TWG meeting—Seville, 29 October 2013. http://susproc.jrc.ec.europa.eu/taps_and_showers/docs/1stTWG_presentation_part2.pdf. Accessed 12 Nov 2018
45. Meireles I, Sousa V, Adeyeye K, Silva-Afonso A (2018) User preferences and water use savings owing to washbasin taps retrofit: a case study of the DECivil building of the University of Aveiro. Environ Sci Pollut Res 25(20):19217–19227
46. Kalbusch A, Ghisi E (2016) Comparative life-cycle assessment of ordinary and water-saving taps. J Clean Prod 112:4585–4593. https://doi.org/10.1016/j.jclepro.2015.06.075
47. Allen A, Hayes C, Mactavish A, Lawson R, Ryan S, Hammond C, Moon D (2010) Guidance for new building projects, refurbishment and facilities management. Procurement requirements for water efficiency. WRAP, https://www.waterwise.org.uk/wp-content/uploads/2018/02/WRAP-2010_Procurement-Requirements-for-Water-Efficiency.pdf. Accessed 24 Dec 2018
48. US Environmental Protection Agency (1998) Water conservation plan guidelines, Appendix B: benchmarks used in conservation planning. https://www.epa.gov/watersense/water-conservation-plan-guidelines, https://www.epa.gov/sites/production/files/2017-03/documents/appendix-b-benchmarks-used-in-conservation-planning.pdf. Accessed 21 Dec 2018
49. Cholewa T, Siuta-Olcha A, Anasiewicz R (2016) Sprawność i koszty eksploatacyjne wybranych systemów c.o. i c.w.u. w budynkach wielorodzinnych/Efficiency and operating costs of heating and hot water preparation systems commonly used in multifamily buildings. Rynek Instalacyjny 4:69–71
50. Jędral W (2007) Efektywność energetyczna pomp i instalacji pompowych. Krajowa Agencja Poszanowania Energii, Warszawa