

Article



Energy Efficiency of Water Heating Systems in Single-Family Dwellings in Brazil

Juliana May Sangoi and Enedir Ghisi *D

Laboratory of Energy Efficiency in Buildings, Department of Civil Engineering, Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil; julimaysangoi@hotmail.com

* Correspondence: enedir.ghisi@ufsc.br; Tel.: +55-48-3721-2115

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Abstract: The objective of this paper was to compare primary energy consumption and energy efficiency during the operation phase of different types and combinations of water heating systems in single-family dwellings. Systems with an electric shower, liquefied petroleum gas heater, and solar heater with electric backup were analysed. The analysis was performed by means of computer simulation using EnergyPlus. Three Brazilian cities with different climates were assessed, i.e., Curitiba, Brasília and Belém. The systems were compared in terms of final energy and primary energy consumption. Results showed that systems with an electric shower, which have a lower water flow rate, led to lower primary energy consumption. The solar heating system combined with an electric shower was the option with the lowest energy consumption, and the solar heating system with a heating element in the storage tank was the option that consumed more energy. The systems were sized according to the requirements of the Brazilian energy efficiency labelling for residential buildings, and the efficiency level was compared to the results of primary energy consumption. The electric shower was found to be the third lowest energy consumer, but it was ranked the least energy efficient by Brazilian labelling, while systems with high energy consumption, such as gas heaters and solar heaters with a heating element in the storage tank, were ranked the most energy efficient. Therefore, a review of the requirements and methodology of the Brazilian energy efficiency labelling for residential buildings is recommended in order to encourage the use of truly efficient systems. Public policies that encourage solar heating systems should establish requirements regarding the configuration and sizing both the solar heating system and the backup system.

Keywords: water heating; energy efficiency; residential buildings; computer simulation

1. Introduction

Residential buildings account for 25.1% of the electricity consumption in Brazil [1]. Almost a quarter of this consumption corresponds to water heating for a shower, and 73% of Brazilian households have an electric shower [2], which is mainly due to its low installation cost. In Southeast, South and Centre-West regions of Brazil, 81%, 90% and 92% of households use electric showers to heat water, respectively [3]. In addition, according to Ghisi et al. [4], electric showers account for 20% of the energy consumption in the residential sector in Brazil.

In addition to representing a high portion of energy consumption to dwellers, electric showers are also a concern for the energy utilities as it is mainly used in the early morning and mainly in the evenings [2]. The energy consumption is high in early mornings and mainly in the evenings when lights and household appliances are turned on while some people are still working in commercial buildings. Since electric showers use energy to heat water for shower, there is a high demand for electricity in the mornings and evenings [5]. However, since 2010, a change in the electricity-peak hours to the middle of the afternoon during summer months has been observed; on the other hand,

in winter months, when the energy demand to heat water increases, electricity-peak hours still occur in the evenings [6].

In addition to electric showers, there are many types of water heating systems, such as gas heaters, heat pumps and solar heaters. The choice of a system for a building should account for parameters such as energy consumption, environmental impacts, operational costs and initial investment. Parameters such as local climate, energy source, type of system and layout affect the performance of the system [7].

Aiming to reduce energy consumption and promote the use of renewable energy sources, several policies have promoted the use of renewable energy and more efficient systems to heat water. Countries such as China, Israel, New Zealand, and many European countries have established public policies in order to promote the use of solar heating in residential buildings—financial subsidy policies, tax credits, and even mandatory policies are some examples [8]. According to Reference [9], investing in solar energy is economically viable to the energy utilities, more than to the individual consumer. Such a conclusion is related to the fact that replacing electric showers with solar heating has a significant impact on reducing energy demand at peak times. On the other hand, for low-income consumers, the savings generated by this system may not be enough to compensate for its high investment.

According to Brazil's National Energy Plan 2050, an increase in the number of buildings with solar water heating is expected until 2050, mainly due to a Brazilian low-income housing programme, which requires the use of solar water heating in single-family households [10]. Thus, it is likely that the use of electric showers, which is currently the most widely used system in Brazil, will suffer a significant reduction in the following years, corresponding to only 38% of water heating systems in 2050.

Energy efficiency labelling programmes are also important tools to promote more efficient buildings. The Brazilian Labelling Programme classifies residential and commercial buildings according to their energy efficiency, enabling consumers to choose systems that are more efficient. The programme is not mandatory for residential buildings. For dwellings, according to the Brazilian regulation for energy efficiency levels in residential buildings, the use of solar energy, natural gas, liquefied petroleum gas or heat pumps leads to the highest efficiency levels [11]. On the other hand, electric heaters and oil boilers are not encouraged.

Consider a system more efficient than another by only comparing their energy consumption can lead to inaccurate analysis of the use of primary energy and natural resources. Conversion factors, calculated based on the energy matrix of each country, considerable losses in the generation, storage and transportation to transform primary energy into final energy [12]. Studies as those developed by Gustavsson et al. [13], Santos [14] and Maguire et al. [15] show that the source of energy has a strong influence on primary energy efficiency. Systems that consume the same amount of final energy than others, or even less, can be less efficient in terms of primary energy.

In addition to the energy source, parameters such as weather conditions, usage patterns, type of hot water storage and distribution also affect the performance of the system. Computer simulation is an important tool that allows for the analysis of such parameters and the selection of the most appropriate system, even at the design phase. Altoé et al. [16] compared the energy consumption of a solar water heating system with electric showers for a household in Brazil, using the EnergyPlus computer programme. EnergyPlus was also used by Vieira et al. [17], who compared the performance of solar water heating systems, electric heaters and heat pumps in dwellings in Australia. Comparisons among different water heating systems in homes located in different cities in the United State were performed by Maguire et al. [15], Cassard et al. [18], Karki et al. [19] and Balke et al. [20]; in South Africa by Hohne et al. [21]; in Australia by Kumar and Mathew [22]; in Canada by Leidl and Lubitz [23]. Simulations of water heating systems in single-family dwellings were also conducted by (i) Biaou and Bernier [24], considering the climate of Montreal (Canada) and Los Angeles (United States), (ii) Hobbi and Siddiqui [25], for the climate of Montreal, and (iii) Kalogirou [26], in Nicosia, Cyprus. Most studies confirmed that solar heating contributes to energy savings, but such savings depend mainly on where the building is located.

Hence, the main objective of this paper is to compare the primary energy consumption and energy efficiency during the operation phase for different types and combinations of water heating systems in single-family dwellings in three cities of Brazil.

2. Methods

2.1. Cities and Climate Conditions

The performance of the water heating systems was analysed considering three cities with different climates in Brazil: Curitiba (latitude—25°25′), Brasília (latitude—15°46′) and Belém (latitude—01°27′). Belém is the city with the highest temperatures, i.e., the monthly average maximum temperature in the hottest month is 32.3 °C. Curitiba is the coldest city, reaching a monthly average minimum temperature in the coldest month equal to 8.1 °C [27]. Figure 1 shows the location of the cities, and Figure 2 shows the monthly average temperatures of each city during the year.



Figure 1. Location of the cities considered in this study.



Figure 2. Monthly average temperatures for the three cities. Based on [22].

This study considered water heating systems in single-family residential buildings. The same type of house was adopted for the three cities, with about 60 m², one bathroom and two bedrooms (Figure 3), with three residents. This study considered the use of hot water only for showers, as is usual in Brazilian homes.



Figure 3. Floor plan of the house.

Among many types of water heating systems, the four most common in Brazilian single-family buildings were analysed, i.e., electric shower, instantaneous gas heater, solar heater with electric shower, and solar heater with a heating element in the boiler.

Each system was sized as described by Sangoi [28], aiming to comply with the requirements of the Brazilian Energy Efficiency Labelling for Residential Buildings (RTQ-R) [11] and Brazilian standards. Solar heating systems were sized according to the RTQ-R methodology to yield an annual solar fraction equal to 70%.

The water flow rates varied according to each type of shower. For electric showers, the flow rate considered was 3 L/min, according to electric showers available on the market. For a solar heating system with a heating element in the storage tank, and for a gas heater, the type of shower used had a higher flow rate, so 12 L/min was considered in this work, complying with NBR 5626 [29]. Table 1 shows the characteristics of each instantaneous system.

Table 2 shows the characteristics of solar heating systems. The required solar panel area for systems with electric shower (3.0 L/min) was smaller than for solar systems with a boiler (12.0 L/min) to reach the same solar fraction. For solar systems with a heating element in the boiler, the heating element adopted had power equal to 3500 W, as indicated by the boiler manufacturer.

Heater	City	Flow Rate (L/min)	Nominal Power Rate (kW)	Efficiency (%)
	Curitiba	3	6.5	95
Electric Shower	Brasília	3	5.2	95
	Belém	3	3.2	95
	Curitiba	12	30.9	85
Gas Heater	Brasília	12	25.1	84
	Belém	12	17.9	84

Table 1. Characteristics of each instantaneous system.

Parameters	Solar + Electric Shower			Solar + Boiler		
	Curitiba	Brasília	Belém	Curitiba	Brasília	Belém
Shower flow rate (L/min)	3.0	3.0	3.0	12.0	12.0	12.0
Solar panel inclination	35°	25°	11°	35°	25°	11°
Optical efficiency factor (dimensionless)	0.77	0.76	0.74	0.77	0.76	0.74
Overall loss coefficient (kW/(m ² K))	4.20	6.62	4.42	4.20	6.62	4.42
Solar panel area (m ²)	1.00	1.59	1.00	1.00	1.59	1.00
Number of panels	2	1	1	4	2	2
Total solar panel area (m ²)	2.00	1.59	1.00	4.00	3.18	2.00

Table 2. Solar water heating systems characteristics.

For hot water distribution, polypropylene (PPR) pipes with thermal insulation made of expanded polyethylene, 1 cm thick and thermal conductivity equal to 0.035 W/mK were considered, as required by RTQ-R [11]. Pipes connecting the solar panels and boiler were made of copper, with the same thermal insulation used on PPR pipes.

2.3. Computer Simulation

Energy consumption and performance of the systems were analysed using the EnergyPlus computer programme, version 8.2. Weather data for each city were obtained from the SWERA database, available at the EnergyPlus website. The simulations were performed for a one-year period (from 1 January to 31 December).

Table 3 shows the hot water temperature for a shower. It was considered a variation on temperature according to the season because it is usual that shower temperatures are lower during summer months and higher in winter months. As for cold water, the temperature was calculated for each month, considering the monthly average air temperature minus 2 °C, according to the RTQ-R method.

City	Months	Shower Temperature (°C)
	January, February and March (summer)	35
Curitiba and Brasília	April, May, June (autumn) October, November and December (spring)	38
	July, August and September (winter)	40
Belém	Every month of the year	35

Table 3. Hot water temperatures along the year for the three cities.

As for the hot water usage pattern, three showers per day (one 10-min shower per resident per day) were considered. For instantaneous heaters, the time the shower takes place does not influence energy consumption because cold and hot water temperatures were considered constant during the month. Thus, for systems with electric shower and gas heater, showers were considered to take place at 6:30 a.m., 7:30 a.m. and 8:30 a.m.

As the solar heating systems use energy from the sun to heat water, the time that the user takes a shower influences the performance of the system. Thus, two scenarios were simulated: one with three showers in the morning (6:30 a.m., 7:30 a.m. and 8:30 a.m.), and another with three showers in the evening (6:30 p.m., 7:30 p.m. and 8:30 p.m.).

Table 4 shows the two models considered for solar water heating systems. For the first model, there was no heating element inside the boiler; the water outlet was an electric shower. That way, solar panels pre-heat the water and, when necessary, the heating element of the shower supplements the heat.

The second model had a heating element inside the boiler. Temperature set points controlled the heating element, i.e., when the water temperature was lower than the set point, the heating element

turned on; when the water temperature was greater than the set point, the heating element turned off. For this second model, two scenarios were considered for set point temperatures: one scenario of a storage temperature equal to 60 °C to avoid the proliferation of *Legionella* bacteria, and another with a storage temperature close to the outlet temperature as indicated in the RTQ-R (Table 4).

Backup Heater	Set Point Temperature to Turn the Heating Element on (°C)	Set Point Temperature to Turn the Heating Element off (°C)	Boiler Capacity (L)
Electric shower	-	-	200
Heating element in the boiler—scenario 1	40	60	200
Heating element in the boiler—scenario 2	40 (winter) 38 (autumn and spring) 35 (summer)	45 (winter) 43 (autumn and spring) 40 (summer)	300

	Table 4.	Solar water	heating	systems	simulated.
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Note 1: For Belém, in scenario 2, the same set point temperature was considered along the year, i.e., 35 °C to turn the heating element on, and 40 °C to turn it off. Note 2: Set point temperatures for scenario 1 were the same for the three cities.

2.4. Primary Energy Consumption

To compare the energy efficiency of systems that use different energy sources, the annual primary energy consumption was calculated using Equation (1).

$$E_P = E_F \times F_C \tag{1}$$

where E_P is the annual primary energy consumption (kWh), E_F is the annual final energy consumption (kWh), and F_C is the primary energy conversion factor (dimensionless).

For liquefied petroleum gas, the conversion factor calculated by Santos [14] was adopted. For electricity, this factor varied as a function of the energy matrix. The factor calculated by Santos [14] considered data prior to 2009. In the last few years, the Brazilian energy scenario went through many changes, especially due to a water crisis and greater use of thermal energy. For that reason, for the current scenario of the Brazilian energy matrix, it was adopted the conversion factor calculated by Santos [30] using the same method described by Santos [14] but using data for 2013 published by EPE [31].

In the study of Santos [14], primary energy conversion factors for electricity were calculated considering different future scenarios for the Brazilian energy matrix, resulting ifigures ranging from 1.49 to 1.75. In order to analyse the influence of variations in the energy matrix on the primary energy consumption for water heating, the primary energy consumption considering the most critical scenario presented by Santos [14] was also calculated.

Thus, the results of the primary energy consumption of systems that use electricity were calculated considering the current scenario and a critical scenario. For liquefied petroleum gas, the same conversion factor was considered in all simulations. Table 5 shows the primary energy conversion factors adopted in this study.

Table 5.	Primary energy conversion factors for Brazil.	

Energy Source	Conversion Factor				
<i>a</i> , <i>b</i>	Current Scenario	Critical Scenario			
Electricity	1.46	1.75			
Liquefied petroleum gas	1.10	1.10			

2.5. Comparison of Results

In the Brazilian energy efficiency labelling programme for residential buildings, the water heating system of a household can be classified from level A (more efficient) to level E (less efficient). The energy efficiency level is calculated according to requirements and prerequisites defined in the Brazilian regulation RTQ-R [11].

The water heating systems considered in the computer simulations were sized to comply with level A of RTQ-R, except for the electric shower because the best classification it can get is level D. The efficiency level of each system was compared to the annual primary energy consumption, obtained by means of computer simulation.

2.6. Water Consumption

EnergyPlus calculates monthly water consumption of each system based on the water flow rates specified for the showers. However, the results of simulations refer only to the consumption of water for the duration of the shower. EnergyPlus does not calculate the volume of cold water that is discarded up to the moment hot water reaches the showerhead.

In order to estimate the volume of water wasted at the beginning of a shower, the amount of water in the pipes between the heater and the showerhead was estimated assuming that all inert water in the pipes was cold. The volume of water in the pipeline was calculated using Equation (2).

$$V = l \times \pi \times \left(\frac{d}{2}\right)^2 \tag{2}$$

where *V* is the volume of water in the pipeline (m^3) ; *l* is the length of the pipeline (m); *d* is the internal diameter of the pipeline (m).

This estimate was made only for one shower. The results were not extrapolated to the other showers to verify the increase in annual water consumption because such waste does not necessarily occur in all showers. For example, when one shower is taken just after the other, the water may already be at a temperature close to the desired temperature and will not be wasted.

3. Results and Discussion

3.1. Final Energy Analysis

3.1.1. Systems with Electric Shower (Flow Rate Equal to 3.0 L/min)

This section presents monthly final energy consumption of systems that have showers with a flow rate equal to 3.0 L/min, i.e., electric shower and solar system with electric shower (Figures 4–6). For these systems, the final energy consumption corresponds to electricity consumption.

For Curitiba and Brasília, where there is significant air temperature variation during the year, and different hot water temperatures were considered according to the season, higher energy consumption in winter months can be noticed. For Belém, where there is low air temperature variation along the year, there is no significant energy consumption variation during the year.

Solar water heating systems resulted in lower energy consumption when showers were used in the evening in all three cities. In these cases, solar panels heated the water during the day, and then the hot water was used in the evening. When showers took place in the morning, the water in the boiler lost heat to the environment during the night, and got to the electric shower with a lower temperature. The water therefore needed more energy to reach the desired temperature.

In Belém, where there are high temperatures along the year, it can be observed that solar heating system can supply almost all the hot water demand due to higher cold water temperatures, reduced heat losses in the boiler because of higher air temperatures, and because the hot water temperature determined for the simulation was lower.



Figure 4. Electricity consumption in Curitiba.









Table 6 shows the annual energy consumption and energy savings obtained when using a solar water heating system to pre-heat the water in comparison to a house that has only has an electric shower. It can be observed that, when showers were taken in the evening, the annual energy savings in Belém were greater than the annual solar fraction calculated (70%). A solar heater could supply almost all the hot water demand in Belém, especially if showers were taken in the evening.

Electric		Solar System with Electric Shower				
City	Shower	Showers in the Morning		Showers in the	Evening	
	Annual Consumption (kWh)	Annual Consumption (kWh)	Energy Savings (%)	Annual Consumption (kWh)	Energy Savings (%)	
Curitiba	919.6	298.8	68	191.8	79	
Brasília	766.4	177.0	77	66.2	91	
Belém	442.1	43.4	90	9.2	98	

Table 6. Comparison of electricity consumption to heat water using either electric shower or solar water heating system with an electric shower.

3.1.2. Systems with Electric Shower (Flow Rate Equal to 12.0 L/min)

Figure 7 shows the monthly final electricity consumption of instantaneous gas heater for the three cities. Simulations considering gas heater resulted in greater electricity consumption during winter months in Curitiba and Brasília, and a small variation along the year in Belém, as also observed for an electric shower.

Figures 8–10 show the results of solar water heating systems with a boiler. For each city, showers in the morning and in the evening were simulated considering either a water storage temperature equal to the water temperature for showering (indicated as "T_{storage} 40 °C") or a water storage temperature equal to 60 °C.

The electricity consumption was lower when the showers take place in the evening because the water heated during the day was used after a short time, avoiding heat losses during the night. The electricity consumption was also lower for water storage temperature equal to 40 °C (close to the water temperature for showering) when compared to water storage temperature equal to 60 °C.

Results showed a significantly higher electricity consumption when the backup was done by a heating element instead of an electric shower. Although the water flow rates, and consequently the volume of water to be heated, were different, such a great difference in electricity consumption was mainly due to the type of system. The electric shower was an instantaneous system; therefore there was electricity consumption only while the shower was turned on. In systems with a heating element in the boiler, the heating element turned on every time the water temperature in the boiler reached a certain minimum value. That is, at certain times, there was an electricity consumption to heat a volume of water that may not be used. For example, late at night, when the air temperature gets lower than the setpoint temperature, the water in the boiler may reach a temperature lower than that set on the thermostat, therefore the heating element will be turned on to heat the water when it is not being used.

Programming the system to a water storage temperatures equal to 60 °C in order to avoid the proliferation of *Legionella* bacteria led to electricity consumption even greater (from 1.6 to 3 times greater than that for the water storage temperature similar to the water temperature for showering, depending on the city). Although it is an important strategy for health issues, the system was oversized and led to energy consumption greater than necessary to meet the water temperature for showering. Contamination by *Legionella* is a risk in open systems (direct), but an alternative to avoid such a problem and have a lower energy consumption is to use a closed system (indirect), wherein the stored hot water is not used; it only heats the cold water through a heat exchanger.



Figure 7. Final electricity consumption using instantaneous gas heater system.





Figure 8. Electricity consumption using solar heating systems with a boiler in Curitiba.

Figure 9. Electricity consumption using solar heating systems with a boiler in Brasília.



Figure 10. Electricity consumption using solar heating systems with a boiler in Belém.

3.2. Primary Energy Analysis

This section presents the annual primary energy consumption for the different systems considered for the three cities analysed (Figures 11–13). The green bars represent systems with showers of 3 L/min, and purple bars represent showers of 12 L/min.



(b)

Figure 11. Annual primary energy consumption for water heating in Curitiba. (**a**) Current scenario; (**b**) critical scenario.



Solar + electric shower (evening) Solar + electric shower (morning) Electric shower



(b)

Figure 12. Annual primary energy consumption for water heating in Brasília. (a) Current scenario; (b) critical scenario.

Systems with showers of 12 L/min, led to higher comfort levels but also led to higher primary energy consumption. Many public policies encourage the replacement of the electric shower by other systems. It was noticed, however, that the electric shower led to one of the lowest primary energy consumptions among the systems evaluated. However, it is important to note that, as evidenced by Reference [9], the electric shower leads to higher electricity consumption at peak times, as the consumption of energy occurs at the time of the shower. It was also shown by Reference [32] that electric showers are responsible for the highest emission of CO₂ over their life cycle.

Solar heating, encouraged by public policies due to its low energy consumption, is a very advantageous alternative when combined with electric showers. On the other hand, when the backup heating is inside the boiler and is set to very high water temperatures, a solar system becomes a less efficient alternative. If the water storage temperature was close to the water temperature for showering, considering the current scenario for electricity generation in Brazil, solar heating was the most efficient option for showers with a flow rate equal to 12 L/min.

Although the gas system had a conversion factor for primary energy lower than for electricity, it had a high final energy consumption since the shower flow rate was greater and this demanded more energy to achieve the desired temperature. Thus, in the current scenario, the gas heater was among the systems that consumed more primary energy. However, considering the most critical scenario for the generation of electricity, with a higher conversion factor for electricity, gas can be a more efficient alternative. For the cities of Curitiba and Brasília, considering the current scenario, the instantaneous gas heater consumed more primary energy than the solar system with a heating element in the boiler, with water storage temperature close to the water temperature for showering. Considering the most

critical scenario for electricity, the gas heater presented energy consumption similar to that of the solar heating system when showers occurred in the morning, and for Curitiba, the gas heater energy consumption was lower.



(b)

Figure 13. Annual primary energy consumption for water heating in Belém. (a) Current scenario; (b) critical scenario.

3.3. Comparison of Primary Energy Consumption with Energy Efficiency Level

Table 7 shows the primary energy consumption for each system evaluated in ascending order, and the efficiency level according to the RTQ-R. The electricity conversion factor considered for primary energy was 1.46 (current scenario).

From the analysis and comparison of primary energy consumption, one can see that there was an inconsistency in the method proposed by RTQ-R. The electric shower, which reached the worst level according to RTQ-R, presented the third lowest energy consumption according to the analyses performed for the three cities.

Some parameters that were not addressed in the RTQ-R proved to had a major impact on energy consumption, such as the type of backup of the solar heating system, flow rate of showers and water storage temperature. Storage systems programmed to high water storage temperatures consumed a lot of energy, even being a backup for solar energy. Some designs considered storing water at 60 °C as a way of avoiding the spread of *Legionella* bacteria. RTQ-R does not refer to means of preventing *Legionella* and, therefore, does not recommend such a high storage temperature. However, it neither limits the water temperature for showering nor the water storage temperature.

System	Annual Prima	ry Energy Consu	Efficiency Level	
System	Curitiba	Brasília	Belém	
Solar and electric shower (evening)	280	97	13	А
Solar and electric shower (morning)	436	258	63	А
Electric shower	1343	1119	645	E (Curitiba and Brasília); D (Belém)
Solar and boiler, T _{storage} 40 °C (evening)	3685	2599	997	A
Solar and boiler, T _{storage} 40 °C (morning)	4040	3121	1170	А
Gas heater	4495	3791	2186	А

4912

5697

3034

3703

Table 7. Comparison of primary energy consumption and energy efficiency according to KIC	iption and energy efficiency according to $KTQ-K$.
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The instantaneous gas heater is rated level A according to RTQ-R, but compared to other systems it leads to higher primary energy consumption in most cases. Gas is encouraged by RTQ-R because it has a primary energy conversion factor lower than that for electricity. However, primary energy consumption is also related to the final energy consumption, which is significant in this system with high water flow rate showers, and without the contribution of solar energy. On the other hand, if the scenario of electricity generation leads to higher conversion factors for electricity, gas can be an interesting alternative, as it is in other countries.

5989

6445

3.4. Water Consumption Analysis

Solar and boiler, Tstorage 60 °C (evening)

Solar and boiler, T_{storage} 60 °C (morning)

The water consumption was 30 L per shower when considering a 10-min shower and an electric shower with a flow rate equal to 3 L/min. Such water consumption increased to 120 L per shower for showers with 12 L/min, i.e., four times more.

Table 8 shows the annual primary energy consumption and water consumption for the systems analysed herein. The water consumption considers only the duration of the shower, which is the same for all cities.

System	Annual Prima	Annual Water		
-)	Curitiba	Brasília	Belém	Consumption (m ³)
Solar and electric shower (evening)	280	97	13	32.85
Solar and electric shower (morning)	436	258	63	32.85
Electric shower	1343	1119	645	32.85
Solar and boiler, T _{storage} 40 °C (evening)	3685	2599	997	131.40
Solar and boiler, T _{storage} 40 °C (morning)	4040	3121	1170	131.40
Gas heater	4495	3791	2186	131.40
Solar and boiler, T _{storage} 60 °C (evening)	5989	4912	3034	131.40
Solar and boiler, T _{storage} 60 °C (morning)	6445	5697	3703	131.40

Table 8. Comparison of primary energy consumption and water consumption.

The use of showers with lower water flow rates contributed not only to reducing water consumption but also primary energy consumption. The lower the flow rate, the less power was required to heat the water and reach the desired temperature. For solar heating, the lower the daily consumption of hot water, the smaller the area of solar panels needed to reach the same solar fraction.

For households that have only electric showers, in addition to the lower consumption of water due to the low flow rate, there was no waste of cold water since the water was heated instantly in the shower. For solar heating systems with an electric shower, the water can be heated by the electric shower at the beginning of the shower, and then when hot water comes from the boiler the heating element power can be reduced or even turned off. This system helps avoid the waste of water, although there may be unnecessary energy consumption in days when the solar system could fully meet the demand for water heating.

А

А

For centralized heating systems, there was a waste of the cold water that was in the pipes up to the moment hot water reaches the showerhead. We calculated the amount of water wasted in showers with instantaneous gas heater and solar heaters with a heating element in the boiler (Table 9). The amount of water wasted reached 1% of the water consumed in a 10-min shower for the gas heater system, which had a pipeline longer than that for the solar system. If the time between the showers was too long, or if the pipes were not insulated, the cold water waste occurred for all showers and impacted the annual water consumption.

Parameter	Gas Heater	Solar Heater with a Heating Element in the Boiler
Water consumption (L)	120	120
Amount of water wasted (L)	1.16	0.49
Increase in water consumption (%)	1.0	0.4

Table 9. Water consumption and water wasted per shower.

The longer the pipeline, the higher the volume of water wasted. Therefore, one recommends that the distance between the heater and the showerhead be as short as possible. Water recirculation is an alternative to keep the water in the pipes at the desired temperature, avoiding the waste of water and reducing the time until the hot water reaches the showerhead. On the other hand, this option leads to an increase in energy consumption due to the use of pumps for water circulation.

4. Conclusions

The efficiency of different water heating systems in single-family households, for three Brazilian cities of different climates, was analysed in this paper. The study compared the energy consumption of systems such as electric shower, instantaneous gas heater and solar heating systems, with different configurations and usage patterns.

The electric shower, known to be one of the systems with high energy consumption, had one of the lowest annual primary energy consumption mainly due to low water flow rate and no thermal losses in storage and distribution of hot water. Showers with higher water flow rates result in a higher volume of water to be heated and hence increased energy consumption. It is noteworthy that with the use of electric showers with greater water flow rates, or the use of gas or solar heaters with showers with low flow rate, there could be differences in the comparison of primary energy consumption. It is also important to note that the problem of the electric shower use was not only related to energy consumption, but also to increasing electricity demand at peak hours. Using other energy sources such as gas, or systems with hot water storage tank, electricity consumption at shower time—which usually coincides with the peak hours—can be avoided.

Solar water heating systems, encouraged in many pieces of research and public policies as an efficient and sustainable option, may not represent energy savings depending on the system configuration; for example, solar systems with the heating element inside the boiler led to high energy consumption. This was due to thermal losses and the need to maintain the water temperature in the boiler always within a predetermined temperature range, which led to energy consumption when there is no consumption of hot water.

In order to actually represent a reduction in energy consumption in Brazil, public policies that encourage solar heating systems should establish requirements regarding the configuration and sizing both the solar heating system and the backup system. In Brazil, the national housing programme requires the use of solar heating in single-family households, but prohibits backup heating by means of a heating element in the boiler; backup heating has to be by means of instantaneous gas heating or electric shower. This study showed that these backup systems (instantaneous gas heating and electric shower) result in primary energy consumption lower than that for systems with a heating element in the boiler. Other policies, however, do not consider the backup heating system. The Brazilian Labelling Programme for residential buildings considers the energy efficiency level of the backup system in the final classification of the water heating system only when the backup is done by gas heaters. When the backup system is electric, the system is classified according to the efficiency level of the solar heating system, even if the backup system leads to high electricity consumption.

The Brazilian Labelling Programme for residential buildings classifies electric shower with the worst efficiency level, however, the analysis performed herein showed that an electric shower led to low primary energy consumption. On the other hand, systems such as instantaneous gas heaters and solar heating with a heating element in the boiler, which showed high primary energy consumption, are ranked as level A. A review of the requirements and methodology of RTQ–R is recommended in order to encourage the use of truly efficient systems that provide financial savings for the user and reduce the energy consumption in Brazil.

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