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## Estimation of water consumption in multifamily residential buildings

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**ABSTRACT.** This article shows an estimation of water expenditure in multifamily residential buildings in the city of Joinville, located in south Brazil. The proposed method includes an investigation of the water expenditure and an evaluation of the particularities of each building. The investigation was accomplished in thirty buildings and the collected data allowed a classification of the buildings and a measurement of the water consumption rate. The water consumption in buildings with individualized and collective water measurement systems was analyzed. Furthermore, a comparative study was done between the water consumption in buildings that have at least one pool and buildings without any pools. Some buildings in the sample have an alternative water supply system; however there is no measurement of the water consumption in none of the cases analyzed in this study. The *per capita* consumption was 224 liters per person per day. The buildings with individualized water measurement had smaller consumption per capita than the buildings with collective measurement, showing a reduction of about 34%. The buildings with pools had consumption per capita nearly 48% more than the per capita consumption in buildings without pools.

**Keywords:** consumption indicator, water measurement systems.

### Estimativa do consumo de água em edifícios multifamiliares

**RESUMO.** O presente artigo apresenta a estimativa de consumo de água em edifícios residenciais multifamiliares na cidade de Joinville-SC, localizada na região Sul do Brasil. O método proposto inclui a investigação do consumo de água e avaliação de particularidades de cada edificação. A investigação foi realizada em 30 edifícios localizados na região central da cidade e os dados coletados permitiram classificar os edifícios e quantificar o indicador de consumo de água. Foi analisado o consumo de água em edifícios com medição individualizada e com medição coletiva do consumo de água. Além disso, foi realizado um estudo comparativo entre o consumo de água em edifícios que possuem pelo menos uma piscina e edifícios em que não há piscinas. Alguns edifícios da amostra possuem sistema alternativo de abastecimento de água, porém não há medição de consumo de água em nenhum dos casos analisados neste estudo. O consumo *per capita* calculado foi de 224 litros/habitante por dia. Os edifícios com medição individualizada de água apresentaram menor consumo *per capita* que os edifícios com medição coletiva de água, com uma redução de aproximadamente 34%. Os edifícios com piscina apresentaram um consumo *per capita* aproximadamente 48% maior que o consumo *per capita* de edifícios sem piscinas.

**Palavras-chave:** indicador de consumo, sistema de medição de água.

### Introduction

For designers of building water distribution systems and for engineers and technicians that work with supply of drinking water services, data acquisition of monthly and daily water consumption is essential. In order to avoid incorrect evaluations, it is necessary to perform a survey on the *per capita* consumption indicator (CI), which is defined as the relation between the volume of water consumed in a determined period, called the historical period, and the number of consumer agents in this same period (Fernandes Neto, Naghettini, Von Sperling, & Libânio, 2005). The water consumption determination is also important to

estimate other related parameters. The water-energy nexus has been studied by Vieira and Ghisi (2016). The authors state that information regarding water-energy nexus can improve management practices for both water and energy conservation. Hamiche, Stambouli and Flazi (2016) presented a review of water-energy nexus studies and conclude that water and electricity are inextricably linked. Athayde Junior, Onofre and Beserra (2014) also found that residential solid waste generation was highly correlated with water consumption.

The water consumption in the buildings is influenced by several factors like the temperature

(Breyer, Chang, & Parandvash, 2012), family income (Domene & Sauri, 2006; Willis, Stewart, Giurco, Talebpour, & Mousavinejad, 2013), the number of people in the residence (Domene & Sauri, 2006; Willis et al., 2013), lot size (Willis et al., 2013), the presence of garden and the kind of species planted in the garden (Domene & Sauri, 2006), the presence of swimming pools (Domene & Sauri, 2006), cultural and behavioral aspects (Willis, Stewart, Panuwatwanich, Williams, & Hollingsworth, 2011). The presence of technological features as water-saving appliances or rainwater harvesting systems can also influence water consumption (Willis et al., 2013).

According to Wong and Mui (2007; 2008) water demand is also influenced by user's behavior, installed water appliances and system commissioning. In the survey developed by Fernandes Neto et al. (2005), in which a study was done in 96 municipalities in Minas Gerais (Southeastern Brazil), it was proved that the *per capita* income and the Municipal Human Development Index (MHDI) are factors that have high influence on water *per capita* demand. Hoque (2014) states that changing the amount of the water tax to be effective in water consumption reduction, the consumption should be individually metered and the users should be informed about their water consumption periodically.

From a sample of residential consumers, Narchi (1989) specified the factors that have a relation with the domestic demand of water in the city of São Paulo (Southeastern Brazil), and stressed correlations between the domestic water demand and certain variables. These variables are: the number of inhabitants per residence, the built area, the land area, market value of the property and family income. Among them, the most relevant are the number of inhabitants per residence and the built area.

Von Sperlling (1995) correlated the *per capita* water consumption according to the number of residents serviced by the public supply system. For cities that have more than 250,000 inhabitants, the *per capita* consumption shown is from 150 to 300 liters per person per day. Feil and Haetinger (2014) calculated the effective *per capita* consumption of Lageado (Southern Brazil) during the period from 2000 to 2007. The average consumption *per capita* calculated was of 143.25 liters per person per day. The authors found that intervening variables in *per capita* consumption were relative humidity, average water taxes, and the total population.

The general purpose of this article is the quantification of the *per capita* water consumption in multifamily residential buildings in the city of Joinville, Southern Brazil. To achieve this, the data on water

consumption in buildings with individualized and collective water consumption measurement and the method of averaging the water consumption in buildings with collective measurement are analyzed. In addition, the data on water consumption in buildings with and without pools and the relation of water consumption per capita to the average condominium fee of the buildings are also analyzed.

## Material and methods

The method used considers the evaluation of *per capita* water consumption in 30 residential buildings in downtown Joinville, in the northern part of the state of Santa Catarina, in southern Brazil. Joinville is an industrial city (Cabral et al., 2016) with 562,151 inhabitants and is the biggest city of the state, with a MHDI equal to 0.809 (Instituto Brasileiro de Geografia e Estatística [IBGE], 2016). The climate can be classified as of warm temperature, completely humid, with hot summer (Rubel & Kottek, 2010). The buildings analyzed in the case study are located in the central area of the city.

The survey involves the analysis from the monthly water consumption of each building. The data were supplied by the municipal water supply company, based on the year 2011. A questionnaire was also applied to the building representative of each one of the 30 buildings. The data were collected to enable the analysis of variables that can influence the water consumption from the buildings in the period.

In the questionnaire, the data collected included the number of residents in the building in 2011, type of water consumption measurement system in the housing units (individualized or collective), the age of the building, presence of pools, and the use of alternative supply systems (wells, water reuse, use of storm water).

The buildings studied were named as E1 to E30 for reasons of confidentiality. The buildings have varied ages. In the oldest building, the occupation began in 1982, while in the youngest building the conclusion of construction was 2010. The building with the largest built area is E27 with 23,605.32 m<sup>2</sup>, and the one with smallest built area is E30 with 1,031.52 m<sup>2</sup>. Table 1 shows the particulars of the studied buildings like built area, floor numbers, number of apartments, year of conclusion and measuring system for water consumption.

In the buildings with an alternative water supply system, the existence of a water measurement system and the destination of this water (potable or not potable) were verified. For the analysis of the studied buildings, it was also established a rating to connect the condominium fee with the water consumption in the building. The rating was based on the following criterion: buildings with condominium fees up to R\$

399.99; buildings with condominium fees from R\$ 400.00 to R\$ 899.99; and buildings with condominium fees greater than or equal to R\$ 900.00. This classification evaluates, indirectly, the consumption of water through the purchasing power of residents.

**Table 1.** Features of studied buildings.

Building	Built area (m <sup>2</sup> )	Number of floors	Number of Apartments	Year of occupation	Measuring System
E1	2,442.24	5	24	1982	Collective
E2	2,798.46	7	22	1983	Collective
E3	9,289.42	12	40	1985	Collective
E4	3,526.42	8	28	1985	Individualized
E5	5,808.90	13	22	1987	Collective
E6	2,563.32	9	13	1987	Collective
E7	5,323.96	12	11	1991	Collective
E8	4,415.90	13	11	1991	Collective
E9	3,336.79	9	24	1992	Collective
E10	5,147.66	11	29	1994	Collective
E11	3,914.63	12	10	1995	Collective
E12	7,511.50	13	48	1997	Collective
E13	6,976.77	12	44	1999	Collective
E14	9,550.35	13	44	2000	Collective
E15	8,185.01	14	44	2000	Collective
E16	6,175.68	12	22	2001	Individualized
E17	2,720.76	19	68	2009	Individualized
E18	6,473.85	13	12	1985	Collective
E19	7,502.22	13	22	1998	Collective
E20	3,149.43	8	24	1982	Collective
E21	3,209.99	9	8	1993	Collective
E22	3,373.55	7	24	1989	Collective
E23	6,493.62	13	22	1988	Collective
E24	4,885.16	10	36	1990	Collective
E25	2,367.84	9	8	1996	Collective
E26	3,381.44	6	25	2003	Individualized
E27	23,605.32	Tower A: 17 Tower B: 17	69	2010	Individualized
E28	7,891.98	17	60	2001	Collective
E29	6,112.73	13	22	1995	Collective
E30	1,031.52	5	12	1983	Collective

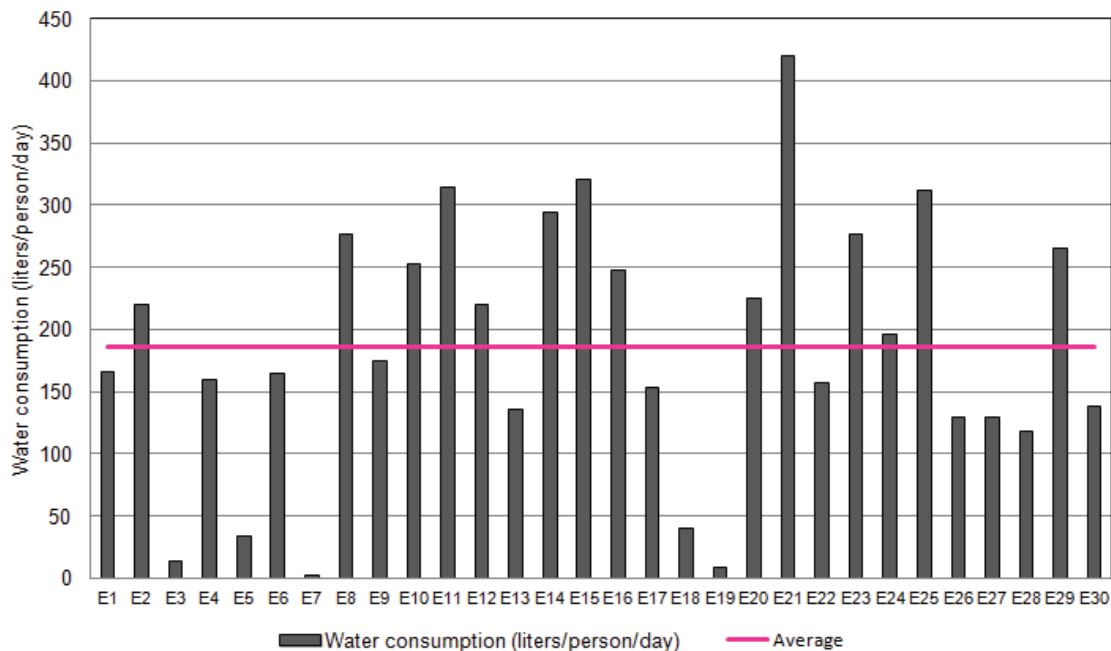
It is also important to mention that the age of the water meters installed in the buildings supply systems can influence the meter accuracy (Couvelis & Zyl, 2015). The age of the meters installed in the building under analysis range from 1-7 years, and 10% (n = 3) of the studied buildings have water meters over 5 years of age.

**Results and discussion**

Data collection described in the methodology section allowed the calculation of the *per capita* water consumption indicator in the buildings of the case study. Figure 1 shows the average *per capita* consumption of each building analyzing the general average from the buildings.

Buildings E3, E5, E7, E18 and E19 showed greatly reduced consumption because these buildings use wells as an alternative water supply system. Through the analysis of the *per capita* consumption curve from these buildings, consumption peaks can be seen when, for any reason, the well water was not used and the piped water was used instead. In none of these buildings there was a measurement system for the water consumed from the well.

Buildings E1 and E4 also have an alternative water supply system using well water, however they show a considerable consumption of piped water as it is possible to observe in the *per capita* monthly consumption line graph for these buildings.



**Figure 1.** *Per capita* water consumption average of the studied buildings.

Among the buildings that do not have alternative water supply, in other words, those that consume exclusively piped water, the building with the smallest *per capita* consumption is E28, with a *per capita* consumption average of 118 liters per person per day. The building with the greatest *per capita* consumption average is E21 with 420 liters per person per day. Building E21 is considered a high standard building, with 8 apartments in a total built area of 3209.99 m<sup>2</sup>. In turn, building E28 has 60 apartments in a total built area of 7891.98 m<sup>2</sup>. This is one possible explanation for the disparate patterns of consumption of these two buildings.

As there is not a measurement of the consumed water from the wells, a calculation was made to verify the average water consumption in the other analyzed buildings. In this calculation the data

collected in the buildings E1, E3, E4, E5, E7, E18 and E19 which use water from the wells were eliminated. This way, the *per capita* consumption average resulting from the data of the 23 remaining buildings is 224 liters per person per day, as presented in Figure 2.

Concerning the comparison of the water consumption in buildings with collective and individualized measurement systems, for the calculation of the *per capita* average consumption, the data collected in the buildings that have an alternative water supply system were not considered. For comparison, the per capita consumption monthly average and the overall average of the buildings with collective and individualized water measurement systems are presented (Figure 3).

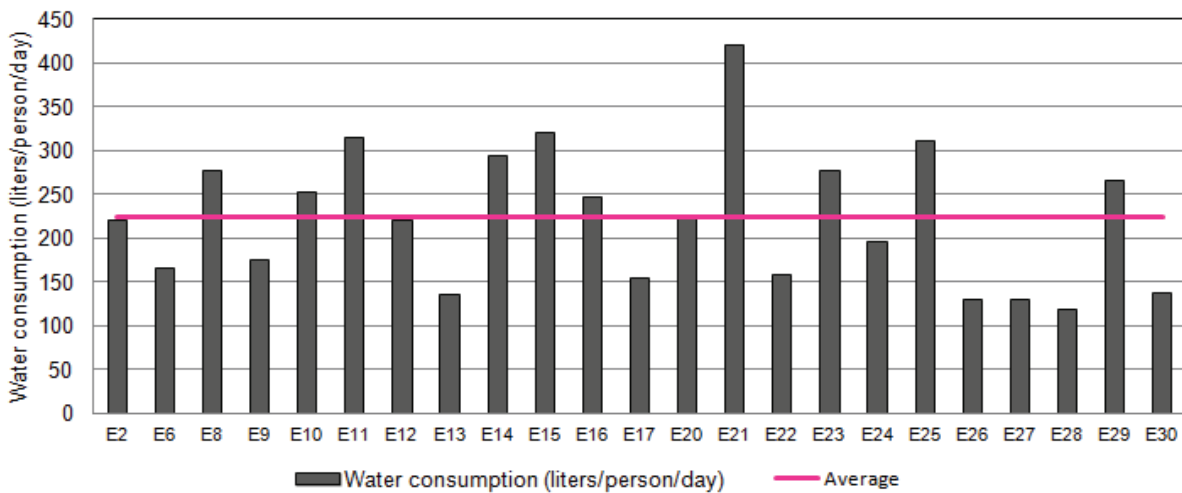


Figure 2. *Per capita* consumption average of the buildings without alternative water supply.

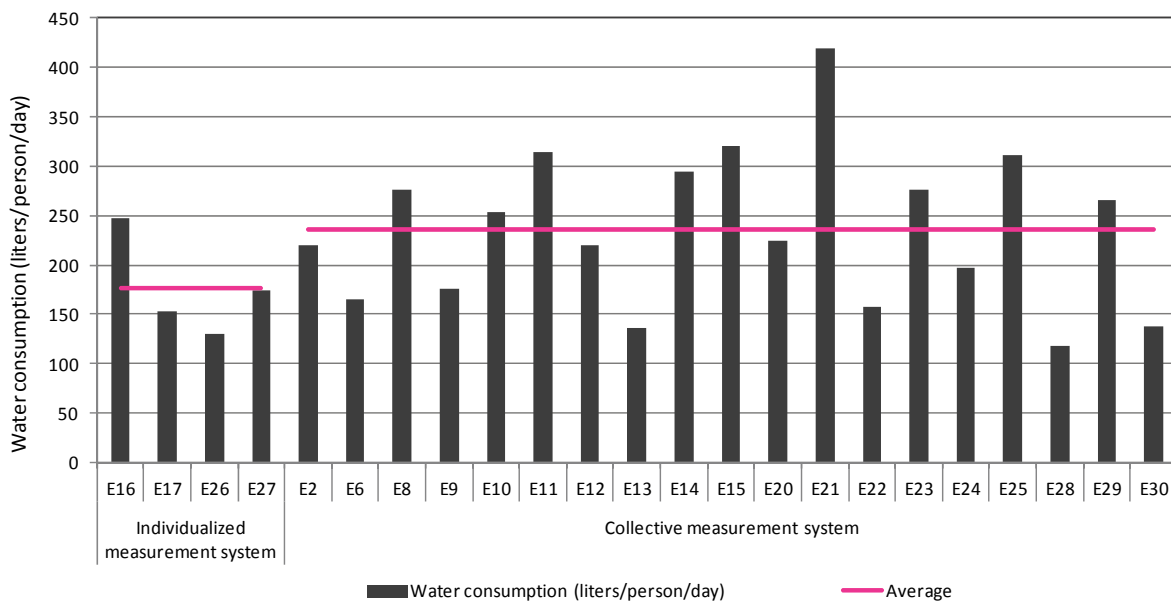


Figure 3. *Per capita* consumption average of the buildings without alternative water supply according to consumption measurement system.

The buildings with individualized water measurement system showed less consumption, with a *per capita* consumption average of 176 liters per person per day, while the average of the buildings with collective water measurement system was 236 liters per person per day. This result was expected given that the individualized measurement results in the payment for the water actually consumed.

Regarding the method of averaging the water consumption among the residents of the buildings with collective water measurement systems, Figure 4 shows the way of averaging for this measurement system, which most often uses the number of residents in the apartment in the calculation of water consumption.

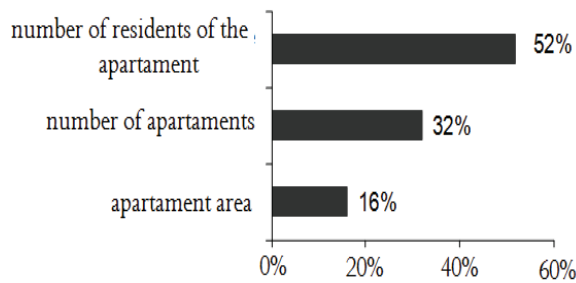


Figure 4. Way of averaging water consumption for buildings with collective measurement systems

In the majority (n = 13) of analyzed buildings with collective measurement system, the averaging of water consumption is based on the number of residents. In the remaining buildings, the division is performed by number of apartments (n = 8) or apartment area (n = 4).

To analyze the water expenditure according to the condominium fee, the classification described in the method was used. From the buildings with only piped water, 48% had average values of monthly condominium fee above R\$ 900.00, 26% had fees between R\$ 400.00 and R\$ 899.99 and 26% had fees up to R\$ 399.99. Figure 5 shows the *per capita* consumption of the buildings according to this classification.

Figures 6-9 show the *per capita* consumption of the buildings according to the number of floors of the buildings, the number of apartments, the age of the buildings and the built area.

The data collected do not allow setting a trend of increase or decrease in water consumption in buildings according to the number of floors. Regarding the number of apartments, there is a tendency to reduce consumption with the increase in the number of apartments.

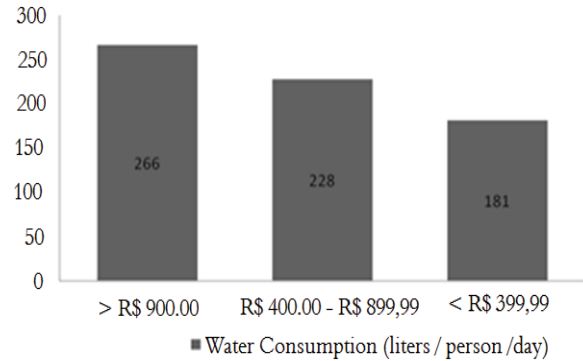


Figure 5. *Per capita* consumption according to the condominium fees.

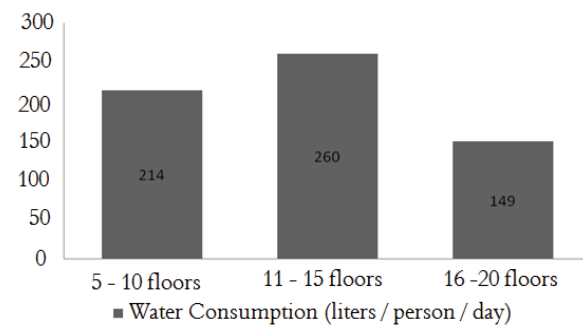


Figure 6. *Per capita* consumption according to the number of floors.

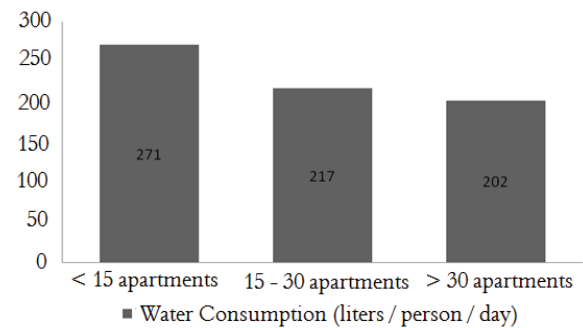


Figure 7. *Per capita* consumption according to the number of apartments.

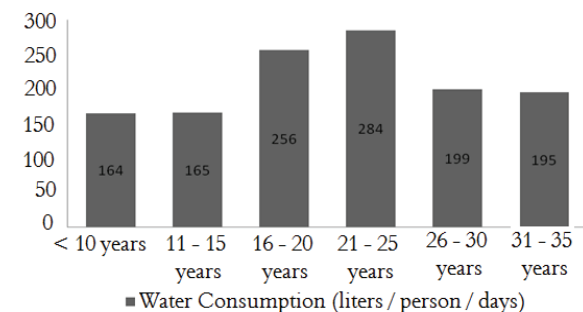


Figure 8. *Per capita* consumption according to the age of buildings.

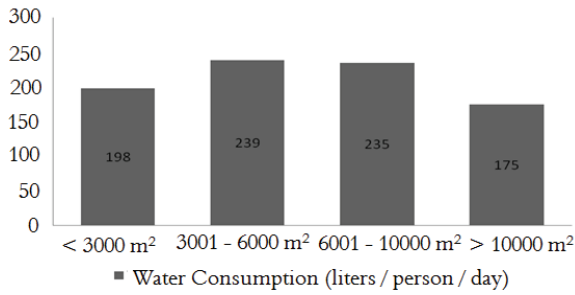


Figure 9. Per capita consumption according to the building area.

Regarding the age of the buildings, it is noted that buildings with less than 15 years have per capita water consumption of up to 165 liters person<sup>-1</sup> day<sup>-1</sup>. Buildings 15-25 years old have higher consumption pattern compared to buildings older than 25 years. This could be explained by renovation procedures in the hydraulic systems of older buildings.

Regarding the built area, data collected do not allow setting a trend for water consumption. Buildings with an area up to 3,000 m<sup>2</sup> and more than 10,000 m<sup>2</sup> had average water consumption below the average of the buildings with area 3,000-10,000 m<sup>2</sup>. However, when comparing per capita consumption with the total area and number of apartment ratio, there is a trend of increasing water consumption when increasing the area per apartment (Figure 10).

In relation to the existence of pools in the building, 77% of the buildings with only piped water have at least one pool. However in none of the cases

is there a specific measurement of pool's water consumption. The per capita consumption average of the buildings with and without pools, disregarding the buildings with alternative water supply systems, is shown in Figure 11. The analyzed buildings that have at least one pool had an average per capita consumption of 235 liters per person per day, and the buildings with no pools had a per capita consumption average of 159 liters per person per day.

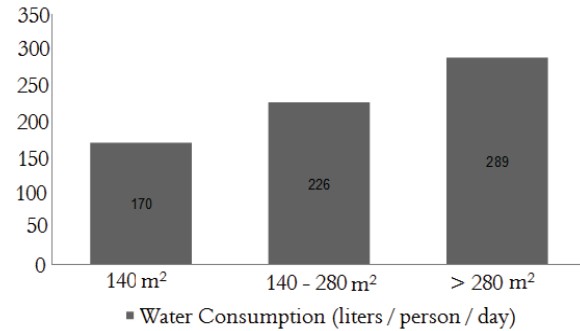


Figure 10. Per capita consumption according to the total area and number of apartment ratio.

In relation to alternative water supply systems, buildings E1, E3, E4, E5, E7 E18 and E19 had well water as an alternative supply system (23% of the initial sample). In all the mentioned buildings, the water from wells is used for potable purposes, but in 43% of the cases there is not any kind of treatment for this water before it is consumed.

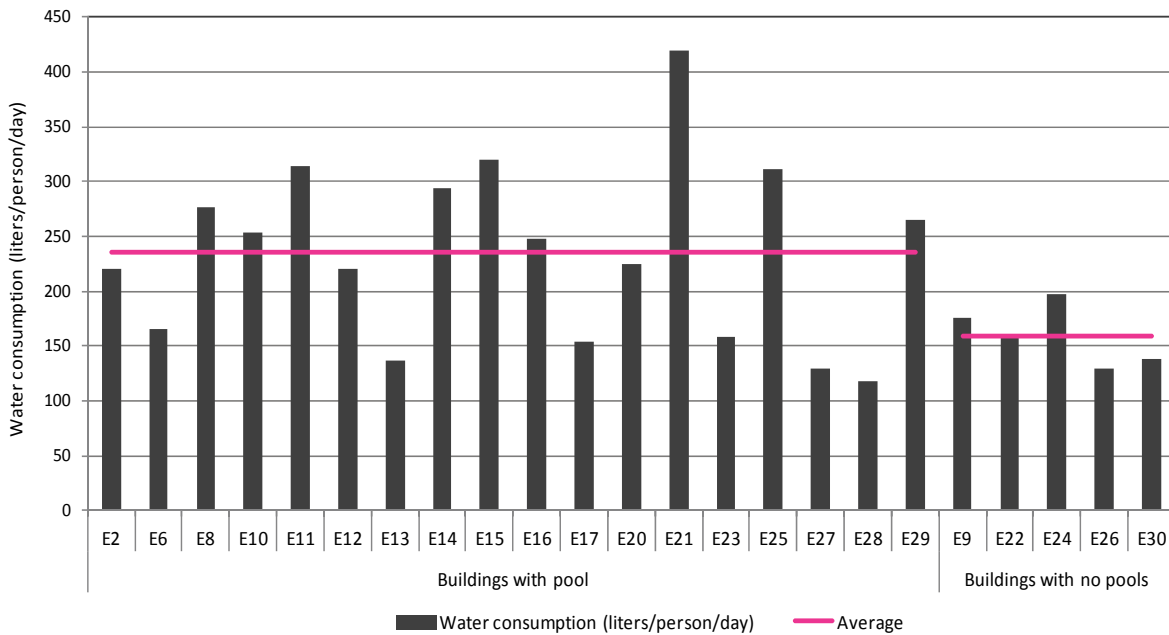


Figure 11. Per capita consumption in the buildings with and without pools.

## Conclusion

The *per capita* water consumption average of the initial sample of 30 buildings was 186 liters per person per day. Disregarding the buildings that have alternative water supply system, the *per capita* consumption assessed becomes 224 liters per person per day.

In relation to the *per capita* water consumption of the buildings with individualized and collective measurement systems, the *per capita* consumption of the buildings with individualized measurement was about 34% under the *per capita* consumption of buildings with collective water measurement.

It is also possible to observe that in buildings with pools, the *per capita* consumption calculated was 48% above the *per capita* consumption in buildings without pools. Approximately 23% of the initial sample of buildings has an alternative water supply, namely wells.

This article shows the variation in the water consumption when there are changes in given design variables. For the planning of water distribution systems, the understanding of parameters such as the *per capita* consumption is very important. However it should be pointed out that the variation in the water consumption can happen for different reasons, as it is directly related to the habits of the residents of the building. In this case study, the average *per capita* water consumption decreased when the number of apartments in the building increased. The water expenditure increased according to condominium fees and also according to total area and number of apartment ratio. Still, the average *per capita* water consumption was lower in buildings with no pools. The results also show that buildings with individualized water measurement system presented less consumption when compared to buildings with collective water measurement system.

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