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Buildings metabolism. Study of measures to save water consumption in three schools in Madrid

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Abstract: Recent research has studied the energy performance of buildings for educational use.However, the relationship between energy consumption and water consumption in this type of buildings does not seem to have been sufficiently explored. This paper presents results of an empirical research, based on the methodology of the operational energy audit, carried out in three buildings for educational use located in Madrid Community. Findings suggest that the water saving measures, such implant pearlizers, timers or double push buttons, are relevant in terms of improving energy efficiency, they suppose moderate investments and they obtain simple return periods of investment attractive to the managers of the buildings.New avenues of research are opened that aim to carry out the analysis of other flows of matter and information, so as to establish the relationship between these flows and the consumption of energy that they suppose.

Key words: water; energy efficiency; sustainability; energy audit; architectural metabolism; buildings for educational use; life cycle analysis; fuel poverty

1 Introduction

According to the *Dictionary of the Spanish Language*, the word "metabolism" is defined as "the set of chemical reactions carried out by the cells of living beings in order to synthesize or break down substances" [1].

The conceptualization of cities as natural systems and living organisms led Abel Colman in 1965 to define urban metabolism, or the metabolism of cities, as "all the materials and raw materials necessary to sustain a city's inhabitants, at home, at work, and at play" [2].

This definition has been enriched and has become more complex over time. In 2007, Kennedy, Cuddihy, and Engel-Yan defined urban metabolism as "the sum total of the technical and socioeconomic processes that occur in cities, resulting from growth, energy production, and waste disposal" [3].

Initially, cities were understood as organisms that exchange materials, with a focus on the flows of matter entering cities and the flows of waste leaving them. Subsequently, urban metabolism began to studies the exchanges of matter, energy, and information within cities and with the surrounding environment [4].

Continuing with the organic analogy, if the city is understood as an organism, buildings can be viewed as cells that form part of that organism. In fact, considering energy systems at the building or neighborhood scale, rather than at the city or regional scale, would increase urban resilience [5], which implies a greater capacity to adapt to adverse scenarios where

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the supply of such resources becomes more difficult.

Architecture that falls within the dominant production system follows the same process as other consumer goods: extraction, manufacturing, and use, ultimately becoming waste [6]. In the biosphere, these processes follow a different logic. In natural processes, the waste products of human activities constitute resources that are used to restart the cycle of production and use. In this way, nature operates through circular cycles, in contrast to the linear cycles characteristic of conventional human activity [7].

Material and energy flows in construction are studied through life cycle assessment (LCA). This methodology allows for a comprehensive evaluation of the environmental impact of buildings by providing a complete accounting of resource consumption and waste generation associated with the various phases of the life cycle [8].

Life cycle assessment is an appropriate criterion for quantifying the environmental performance of buildings throughout all their phases: construction, operation, maintenance, and demolition. To study the metabolism of the existing building stock, one must focus on the operation and maintenance phases, since construction has already taken place and demolition will depend on how the building was originally constructed.

Currently, efforts are being made to improve the energy efficiency of buildings with the goal of reducing greenhouse gas emissions. To this end, the focus is on highlighting the benefits of energy efficiency improvement measures, both in terms of return on investment and the reduction of operating costs [9].

The relationship between energy consumption within buildings and the economic situation of the people who use them is also being studied. The concept of a household in energy poverty—whose development is analyzed by Moore [10] based on the first known definition by Boardman [11]—is understood to refer to households whose expenditure on energy services exceeds 10% of their income. This establishes a link between energy use in the home, household income, and the cost of energy.

The concept of energy poverty includes expenses for heating, domestic hot water production, lighting, appliances, and cooking [12]. Expenditures on water consumption are excluded from this consideration. Even more recent approaches [13] attempt to adapt this concept to various contexts by taking into account regional factors such as climatic variations, building characteristics, and socioeconomic factors; however, they continue to overlook water use.

Critical voices are beginning to emerge, drawing attention to the limitations of the current model, which analyzes only energy-related aspects: "The energy assessment of buildings typically quantifies consumption, energy and economic savings, payback periods, CO_2 emissions, etc.; however, there are other factors—usually overlooked—that can be decisive in choosing solutions for optimal building performance and energy efficiency, as well as for the well-being and quality of life of their occupants, especially in residential buildings [14]."

The limitation of energy-based approaches is that they neglect other factors influencing metabolism that are indeed taken into account when studying the exchanges of matter, energy, and information that occur within buildings. It is possible to reduce greenhouse gas emissions by analyzing and improving the exchanges of matter and information within buildings, rather than merely analyzing and improving energy exchange processes. We must shift the paradigm from efficiency to ecology, by understanding the cycles that occur within architecture [15].

This study advances our understanding of building metabolism. It examines water use from the perspective of a material exchange that impacts energy consumption and explores the potential for reducing greenhouse gas emissions through the use of this resource. To this end, the study emphasizes the advantages in terms of return on investment and reduced operating costs.

In fact, some authors have already addressed the link between water and energy [16], the relationship between water

and energy and between water and greenhouse gas emissions, highlighting its importance at the urban scale [17], and the use of energy across the large infrastructure systems conventionally used for water collection, transportation, and distribution, as well as for wastewater treatment [18,19,20].

There are also authors who have studied the history of wastewater treatment plants not only as urban infrastructure but also from the perspective of their integration into the biological water cycle, examining the complex relationship between society and nature. Schneider introduces the concept of an industrial ecosystem as the metabolic process of an ecosystem that is exploited to extract resources such as food, fuels, raw materials, etc [21].

Furthermore, research has even examined how the metabolism of cities is capable of transforming and shaping the geography of the territory [22].

Within this framework, educational institutions were chosen as the specific setting for the study, primarily for three reasons: First, these are buildings with significant water consumption due to the high number of users, though not to the extent that they stand out from other buildings—as might be the case with a swimming pool; additionally, the property is owned by a single entity, which facilitates the implementation of measures deemed worthwhile; Finally, given the educational nature of the activities carried out in the building, any action taken to improve energy performance can transform the mindset of the people who use it daily, helping to raise social awareness of the environmental problems facing today's society and equipping it with effective tools to mitigate the adverse effects of climate change [23].

It is therefore considered that the need for this work is justified by the impact that harnessing and applying the knowledge generated by this research would have on society.

Many studies in schools focus on air quality, energy consumption to maintain adequate thermal conditions, and acoustic and lighting comfort. There are also studies on the quality and quantity of water consumed in schools. However, no articles have been found that investigate water use in schools (beyond water intended for human consumption). This is why the present article is relevant.

In fact, the average water consumption in schools is 4.7 liters per day per user, ranging from 2 to 11 liters per user per day [24]. This gives us an idea of the significant amount of water consumed and the potential for savings in schools with higher consumption.

2 Data and methodology

2.1 Methodology

The methodology of an operational energy audit is used [23]. This audit covers both the study of energy performance and water consumption in buildings. The methodology used to study water consumption consists of 5 steps:

Step one

First, data is collected from the water utility's billing records: water consumption and the cost of that consumption. Data spanning 5 years is collected to avoid errors that may arise from unforeseen causes such as water leaks, meter malfunctions, lost bills, etc.

Step two

Second, data is collected on-site at the building. An inventory of water-consuming equipment is compiled.

The instantaneous flow rate of each faucet is determined. To do this, use a one-liter container and time how long it takes to fill. Next, calculate the reciprocal of the measured time; the resulting value is the faucet's flow rate in liters per second.

Also, note the volume of the toilet tanks by measuring their dimensions to determine the water consumption per flush.

Step three

Next, analyze the data obtained in the previous two steps.

The following indicators are calculated to compare the data obtained with data from other buildings with similar characteristics:

- Daily water consumption per user (L/user)
- Annual CO_2 emissions per user (kg/user)
- Annual water bill per user (€/user)

The values of the indicators obtained are compared with the benchmark indicators.

The average water consumption in schools is 4.7 liters per day per user [24,25].

To calculate the CO_2 emissions associated with water consumption, the following procedure is used:

A conversion factor of 0.331 $kgCO_2/kWh$ is applied to convert the final electrical energy required for the collection, treatment, and transport of water to consumption points into CO_2 emissions. This conversion factor was taken from the document recognized for demonstrating compliance with Spanish regulations [26].

There is no comprehensive study determining the energy consumption of the water cycle in Spain [27]. Some authors claim that if the energy consumed in the wastewater treatment process is added to the energy used in the transport of this water, in distributing potable water from the source to the point of consumption, and in water collection, the average figure is 3 kWh/m^3 [28,29]. However, if the water for the supply comes from a desalination plant, the unit energy consumption reaches 7.74 kWh/m^3 [30].

Based on these values, the CO_2 emissions associated with water consumption are calculated as 0.331 $kgCO_2/kWh \times 3$ $kWh/m^3 = 0.993$ $kgCO_2/m^3$.

Step four

The total water consumption is allocated among the various water-using fixtures in the building. To do this, the following values are estimated: the number of daily uses of toilets and sinks per building occupant, the ratio of liters of water per m^2 of building area for cleaning, and the ratio of liters of water per meal.

Once these estimates have been made, the total water consumption in the building is calculated and compared with the data obtained from the water bills. The previous estimates are adjusted accordingly so that both values match.

Finally, for each group of water-consuming appliances, the economic cost associated with their consumption is quantified by applying the water rates listed on the bills collected from each school.

Step five

The improvement proposals identified for the building are analyzed. To do this, the reduction in consumption resulting from each proposal is quantified, along with its economic savings, CO_2 emissions savings, the investment required to implement it, and the simple payback period.

2.2 Case studies

- The study was conducted at three schools located in the Community of Madrid (Figure 1).

La Inmaculada Early Childhood Education Center (C.E.I.):

a. Year of construction: 2002

b. Built area: 870 m^2

c. Number of students: 180

d. Location: Madrid

e. Climate zone: D3

- Regina Assumpta Preschool and Elementary School (C.E.I.P.):

a. Year built: 1960

b. Built area: 2,030 m²

c. Number of students: 200

d. Location: Cercedilla

e. Climate zone: E1

- Cala-Sanz Primary and Secondary School (C.E.P.S.):

a. Year built: 1970

b. Built area: 6,300 m²

c. Number of students: 1,000 students

d. Location: Alcalá de Henares

e. Climate zone: D3

These schools were selected with the intention of covering a wide range of the characteristics listed (year of construction, floor area, number of students, location, and climate zone).

In terms of the type of education, the selected sample includes early childhood education centers, early childhood and elementary schools, and elementary and secondary schools. These schools account for 98% of the types of educational institutions existing in the Community of Madrid, as reported by the Community of Madrid's Department of Education [31]. The remaining 2% consists of specialized special education schools.

Regarding the year of construction, the sample includes schools built prior to the entry into force of the *1979 Basic Building Standard on Thermal Conditions*, as well as those built in accordance with that code. From this perspective, the sample covers 92% of the existing schools in the Community of Madrid [32].

In terms of floor area, schools ranging from 870 m² to 6,300m² were selected.

In terms of student enrollment, schools with between 180 and 1,000 students were selected.

In terms of locations, the capital was chosen, with 3,200,000 registered residents in 2011, a large city such as Alcalá de Henares with 200,000 residents, and a mountain village such as Cercedilla with 7,000 residents.

Finally, regarding climate zones, the study covers schools built in climate zones D3 and E1. This covers 97% of the climate zones where existing schools are located in the Community of Madrid.



Figure 1. La Inmaculada Early Childhood Education Center, Regina Assumpta Early Childhood and Elementary School, and Calasanz Elementary and Secondary School

2.3 Data collection

The billing data used in this study correspond to the period from 2009 to 2013.

Data collection for each building, as described in step two, was conducted on the following dates: La Inmaculada Early Childhood Education Center on May 13, 2015; Regina Assumpta Early Childhood and Elementary School on January 30, 2015; and Calasanz Elementary and Secondary School on June 3, 2015

2.4 Description of the improvement proposals and the calculation of the impact of their implementation

The following section describes the improvement proposals to be studied at each school and the method for calculating the impact of their implementation.

Improvement proposal 1: water eco-audit

Water consumption depends directly on the consumption habits of users at each school. Any efficiency measures considered will have a limited impact on water savings unless they are properly implemented by the school's users. For this reason, we are considering implementing a water eco-audit as the first improvement proposal for the rational use of water.

This measure involves the entire school community in gathering information about how water is being consumed within the building. It promotes a participatory process in decision-making regarding the measures to be implemented, the subsequent monitoring of the results achieved, and the search for resources to carry them out including the allocation of resources obtained through the savings generated by the implementation of the water eco-audit.

To calculate the impact of this proposal, a modest target is set to limit maximum water consumption in schools to 11 liters per user per day [24] in those schools that currently exceed this amount. In the remaining schools that are above the average consumption level, it is estimated that this measure can reduce their consumption by 20%.

Improvement proposal 2: counterweight for high-tank toilets

High-tank toilets are operated by a flush chain. When the chain is pulled, the entire volume of water stored in the elevated tank is flushed out.

The purpose of installing a counterweight is to stop the tank from emptying once the chain is released. In this way, the amount of water used can be adjusted according to what is needed each time, rather than necessarily consuming the maximum amount of water every time the toilet is flushed.

To calculate the impact of this proposal, the volume of water contained in existing high-tank cisterns is first measured. Next, the difference in consumption is estimated, based on the average consumption of high-tank toilets after the implementation of the 5-liter-per-flush standard. This is a conservative estimate, since a full flush uses 6 liters and a partial flush uses 3 liters.

Improvement proposal 3: dual-flush button on low-tank toilets

Low-tank toilets have a single flush button. When pressed, it empties the entire water supply stored in the cistern mounted above the toilet.

The purpose of installing a dual-flush button is to adjust the amount of water used according to need. One flush button empties the entire cistern, while the second flush button empties half of the cistern. As with the previous improvement proposal, the amount of water used can be adjusted based on what is needed at any given time, without necessarily having to use the maximum amount of water every time the toilet is flushed.

To calculate the impact of this proposal, the same procedure is followed as with the previous proposal. First, the volume of water contained in the existing low-tank cisterns is measured. Next, the difference in consumption is estimated, taking into account the average consumption of high-tank toilets after implementing the 5-liter-per-flush measure. This is also a conservative estimate, since 6 liters are used for a full flush and 3 liters for a partial flush.

Improvement proposal 4: timed faucets

Non-timed faucets are prone to being left running. This would result in significant water waste. Without taking this effect due to misuse into account, we quantify the savings from installing a timed faucet using current technology that includes an aerator at the water outlet, which reduces the flow rate without compromising comfort. In addition, we propose installing a faucet that can be set to shut off 6 seconds after being turned on, which reduces water consumption per use

compared to faucets that remain open for 20 seconds.

To calculate the impact of this proposal, it was assumed that non-timed faucets remain open for 20 seconds during each use. If the timed faucets shut off after 6 seconds, this would result in a 70% reduction in consumption.

Additionally, the new faucets incorporate aerators that reduce their flow rate to 2.5 liters per minute. The flow rate of the existing faucets is measured to determine the additional reduction in consumption due to the aerator.

Next, the combined effect of both measures, reduction in time and flow rate, is calculated.

Improvement proposal 5: aerators for sinks

The sink faucets currently installed have a water flow rate exceeding 10 liters per minute.

We propose installing an aerator that provides a flow rate of 4.6 liters per minute. This is a sink-specific aerator equipped with a swivel head and flexible hose, allowing the stream to be directed in all directions and providing convenience when cleaning kitchen utensils.

To calculate the impact of this proposal, the flow rate of the existing sink faucets is measured. The flow rate with the aerators under study is 4.6 liters per minute, which allows us to determine the reduction in water consumption achieved.

3 Results and discussion

3.1 Results

Water consumption data in m^3 collected from the bills of the different centres are presented in Table 1.

Table 1. Water consumption (m^3) of the different centres

WATER CONSUMPTION (m^3)						
MONTHS	2013	2012	2011	2010	2009	AVERAGE
C. E. I. LA INMACULADA						
JAN-FEB	129	164	138	174	201	161
MAR-APR	102	131	189	169	226	164
MAY-JUN	74	142	135	200	249	160
JUL-AUG	76	96	101	159	138	114
SEP-OCT	168	368	232	199	116	216
NOV-DEC	195	184	239	246	128	198
TOTAL	743	1084	1034	1148	1058	1013
C. E. I. P. REGINA ASSUMPTA						
JAN-FEB-MAR	113	120	117	140	106	119
APR-MAY-JUN	103	125	129	116	118	118
JUL-AUG-SEP	52	55	84	71	83	69
OCT-NOV-DEC	191	171	146	208	239	191
TOTAL	460	470	477	535	545	497
C. E. P. S. CALASANZ						
JAN-FEB	700	499	562	454	579	559
MAR-APR	321	672	547	511	502	511
MAY-JUN	338	695	502	530	420	497
JUL-AUG	231	231	242	242	239	237
SEP-OCT	500	390	322	305	112	326
NOV-DEC	312	534	402	500	388	427
TOTAL	2402	3021	2577	2542	2240	2556

The data on the economic cost associated with water consumption in € collected from the billing records of the different centres are shown in Figure 2.

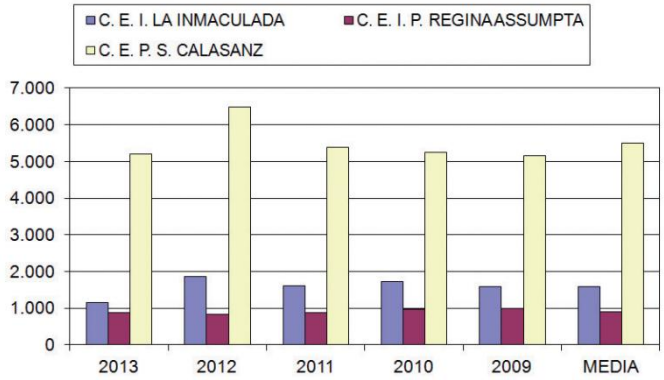

Figure 2. Economic cost associated with water consumption in € for the different centres

The indicators derived from the above data, which allow for a comparison of the performance of the different centres in terms of water consumption, are shown in Table 2.

Table 2. Water consumption performance indicators for the different centres

INDICATORS	C. E. I. LA INMACULADA	C. E. I. P. REGINA ASSUMPTA	C. E. P. S. CALASANZ
DAILY WATER CONSUMPTION PER USER (L/user)	14.8	7.9	6.2
ANNUAL CO_2 EMISSIONS PER USER (kg/user)	5.4	2.9	2.3
ANNUAL WATER BILL PER USER (€/user)	8.5	5.3	4.9

The inventory of water-consuming equipment or systems at each school is shown in Table 3.

Table 3. Inventory of water-consuming equipment at the different centres

	C. E. I. LA INMACULADA	C. E. I. P. REGINA ASSUMPTA	C. E. P. S. CALASANZ
Single tap	15	10	9
Timed tap	0	4	43
Single-lever mixer tap	0	1	2
High-tank toilet	12	20	66
Single push-button toilet	3	3	0
Dual push-button toilet	0	1	9
Sink (without aerator)	2	5	5
Wash trough	1	2	13
Urinal	0	0	2
Dishwasher	1	2	2
Shower	3	0	1
Laboratory sink	0	0	20

The breakdown of water consumption among the various water-consuming devices at each school, in m³ of annual water consumption and the associated cost in €, is calculated according to the methodology of the operational energy audit [23], which is explained below:

- The average water consumption of toilets per use is determined.
- The average flow rate of the faucets is determined.
- The number of daily toilet uses per building occupant is estimated, taking into account the number of hours they spend in the building.
- Estimate the number of daily sink uses per building occupant and the average duration of each use, taking into account the number of hours they spend in the building.
- The ratio of liters of water per square meter m² of the building is estimated for cleaning purposes.
- The ratio of liters of water per meal served in the school cafeteria is estimated.
- The daily consumption figures are multiplied by the number of days the school is open to determine the annual consumption for each system.
- Verify that the total result matches the average consumption obtained from the billing data. Make the corresponding adjustment to the previous estimates, considering any small difference that may exist as consumption resulting from other causes, such as laboratory sinks, small leaks in the plumbing system, etc.
- Each consumption figure is associated with its corresponding financial cost.

The results of the allocation are shown in Table 4. To determine the cost associated with each consumption figure in €, the water rates listed on the bills collected from each school were applied.

Table 4. Breakdown of water consumption and its associated cost among the different equipment of the centres

	C. E. I. LA INMACULADA		C. E. I. P. REGINA ASSUMPTA		C. E. P. S. CALASANZ	
	ANNUAL CONSUMPTION (m³)	ANNUAL BILL (€)	ANNUAL CONSUMPTION (m³)	ANNUAL BILL (€)	ANNUAL CONSUMPTION (m³)	ANNUAL BILL (€)
Toilets	499	783	311	570	1937	4165
Washbasins	191	300	75	137	406	872
Kitchen	166	261	77	141	80	171
Cleaning	10	16	23	43	72	155
Others	147	23	11	20	61	132
TOTAL	1013	1590	497	911	2556	5495

Figure 3 shows the distribution of water consumption among the various existing consumer units, expressed as a percentage of the total consumption at each school.

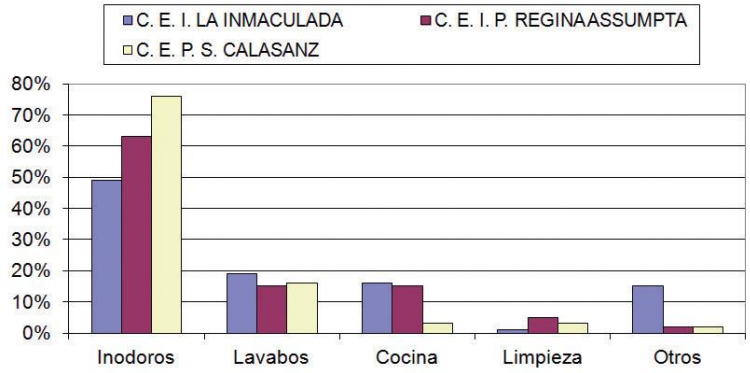

Figure 3. Distribution of water consumption among appliances, expressed as a percentage of the total consumption at each school

Table 5 below lists the indicators for the various improvement proposals (P.M.)

Table 5. Indicators for the different improvement proposals for the various educational centres

	C. E. I. LA INMACULADA	C. E. I. P. REGINA ASSUMPTA	C. E. P. S. CALASANZ
INDICATORS	P.M. 1: WATER ECO-AUDIT		
ANNUAL REDUCTION IN CONSUMPTION (m^3)	350	99	511
ANNUAL ECONOMIC SAVINGS (€)	542.5	945.06	1098.65
ANNUAL CO_2 EMISSION SAVINGS (t)	0.3	0.1	0.5
IMPLEMENTATION INVESTMENT (€)	0	0	0
SIMPLE PAYBACK PERIOD OF THE INVESTMENT (years)	-	-	-
INDICATORS	P.M. 2: COUNTERWEIGHT FOR HIGH-TANK TOILETS		
ANNUAL REDUCTION IN CONSUMPTION (m^3)	67	95	816
ANNUAL ECONOMIC SAVINGS (€)	103.16	180.5	1754.4
ANNUAL CO_2 EMISSION SAVINGS (t)	0.1	0.1	0.8
IMPLEMENTATION INVESTMENT (€)	174.24	304.92	958.32
SIMPLE PAYBACK PERIOD OF THE INVESTMENT (years)	1.7	1.7	0.5
INDICATORS	P.M. 3: DUAL PUSH-BUTTON FOR LOW-TANK TOILETS		
ANNUAL REDUCTION IN CONSUMPTION (m^3)	25	9	-
ANNUAL ECONOMIC SAVINGS (€)	38.68	17.1	-
ANNUAL CO_2 EMISSION SAVINGS (t)	0	0	-
IMPLEMENTATION INVESTMENT (€)	180.6	180.6	-
SIMPLE PAYBACK PERIOD OF THE	4.7	10.6	-

INVESTMENT (years)			
INDICATORS	P.M. 4: TIMED TAPS		
ANNUAL REDUCTION IN CONSUMPTION (m^3)	179	49	79
ANNUAL ECONOMIC SAVINGS (€)	277.45	93.1	169.85
ANNUAL CO_2 EMISSION SAVINGS (t)	0.2	0	0.1
IMPLEMENTATION INVESTMENT (€)	934.5	808.72	685.3
SIMPLE PAYBACK PERIOD OF THE INVESTMENT (years)	3.4	8.7	4
INDICATORS	P.M. 5: AERATORS FOR SINKS		
ANNUAL REDUCTION IN CONSUMPTION (m^3)	106	59	34
ANNUAL ECONOMIC SAVINGS (€)	388.27	112.1	73.1
ANNUAL CO_2 EMISSION SAVINGS (t)	0.3	0.1	0
IMPLEMENTATION INVESTMENT (€)	31.46	78.65	78.65
SIMPLE PAYBACK PERIOD OF THE INVESTMENT (years)	0.1	0.7	1.1

3.2 Discussion

When comparing the average water consumption per user at each school with the benchmark value of 4.7 liters per day per user [24,25], it is observed that all schools have a value higher than the benchmark, as shown in Figure 4.

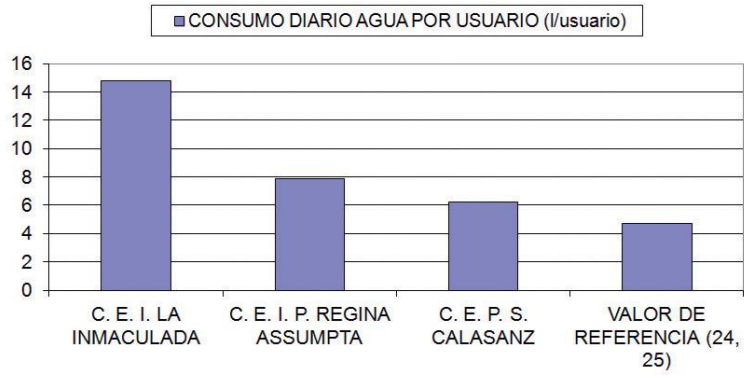

Figure 4. Breakdown of water consumption among facilities, expressed as a percentage of each school's total consumption

Given these results, it is reasonable to conclude that water use at the school can be optimized. However, it is observed that as the age of the school's users increases, their water consumption decreases. In particular, preschool students, especially in their early years, require a greater amount of water for personal hygiene.

Given that the water consumption values obtained exceed the reference value by 32%, 68%, and 215%, respectively. Therefore, it is considered a priority to adopt Improvement Proposal 1, which focuses on water use by users in the schools.

Regarding the distribution of water consumption among the various facilities, it is worth noting that the majority of consumption occurs in the toilets. These toilets account for between 65% and 75% of total water consumption, with the exception of the C.E.I. La Inmaculada, where this percentage is 50%. This is because at that school, water consumption in

the "other" category rises to 15%, while at the rest of the schools it remains at 2%, due to the water used in showers for the hygiene of children who are beginning to gain bladder control.

In this regard, investments made to reduce water consumption in toilets are expected to have a greater impact in terms of the amount of water saved.

Next, we find that water consumption in sinks and in the kitchen shows similar values, at around 15% of total water consumption, with the exception of the C.E.P.S. Calasanz, where kitchen consumption drops to 2% because it operates on a continuous schedule, meaning that the number of students using the cafeteria is much lower than in other cases.

For this reason, the measures proposed for sinks and the kitchen are expected to have a lesser impact in terms of water savings compared to the measures studied previously.

Since the percentage of water used for cleaning the schools and for other purposes is so negligible, ranging from 2% to 5%, the reductions that could be achieved in these areas are insignificant; therefore, they are excluded from this study.

Figure 5 shows the water savings in m³ achieved by implementing the various improvement proposals at the different facilities. The CO_2 emission savings and the financial savings resulting from these measures are linearly related to the water savings.

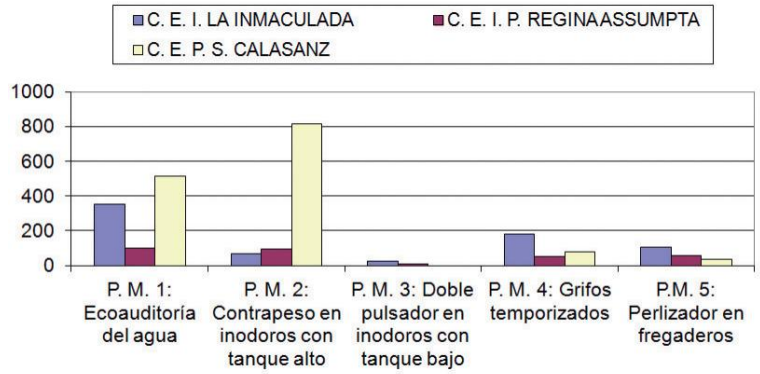

Figure 5. Water savings in m³ achieved by implementing the improvement proposals (P.M.) at the different centres

The results obtained differ from the expected results depending on the percentage of consumption that occurs in each water-consuming system.

At the La Inmaculada Preschool, the savings achieved at the sinks are double those achieved at the toilets. This is due to two reasons. The first is that the building was constructed in 2002, and the toilets installed there do not waste as much water as those found in older buildings. The second reason is that it has been found that 15% of the installed faucets have a flow rate six times that of the remaining faucets.

The C.E.I.P. Regina Assumpta shows results consistent with what would be expected based on the percentage of consumption for each water-using system.

At the Calasanz Elementary School, the savings achieved with the toilets are greater than what would be expected based on their consumption percentage. This is because the average capacity of the installed cisterns exceeds the water storage capacity of the current cisterns by 63%.

To compare the results of the investments required to implement the proposed improvements, the economic intensity indicator is used, defined as the investment in euros divided by the annual revenue in euros, expressed as a percentage, as shown in Figure 6.

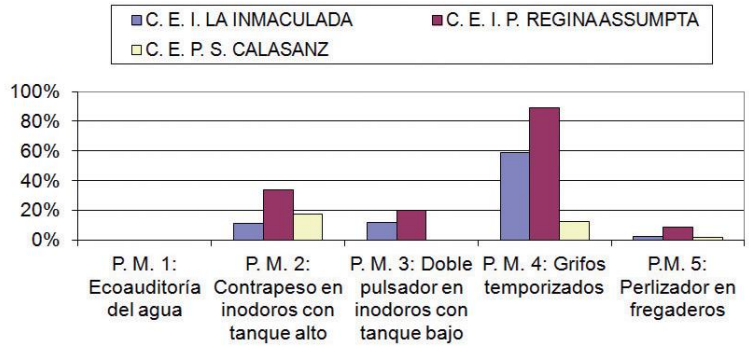

Figure 6. Economic intensity of the investment, expressed as a percentage of annual revenue, for the improvement proposals (P. M.) at the different centres

It can be seen that improvement proposal 1, a water eco-audit, has no economic cost, since it is carried out using the school's own staff as part of an educational activity.

Improvement proposals 2 and 3, regarding toilets, entail an expenditure of approximately 20% of annual revenue, except at the C.E.I.P. Regina Assumpta, where the figure reaches nearly 50%. This is because that school has a larger floor area per student and, consequently, a higher number of toilets per student than the other schools.

Improvement proposal 4, regarding sinks, shows greater variation, with values close to 60% at C.E.I. La Inmaculada, 90% at C.E.I.P. Regina Assumpta, and 10% at C.E.P.S. Calasanz. The higher value observed at C.E.I.P. Regina Assumpta has the same explanation as for the toilets: a higher number of sinks per student at the school.

Improvement proposal 5, installing aerators on sinks, requires an investment of less than 10% of revenue at all schools.

In general, C.E.P.S. Calasanz has the lowest economic intensity values in terms of the investments required to implement the measures, due to the scale factor: it has five times as many students as the other schools.

The results of the simple payback periods, expressed in years, for the various improvement proposals applied to the different schools are shown in Figure 7.

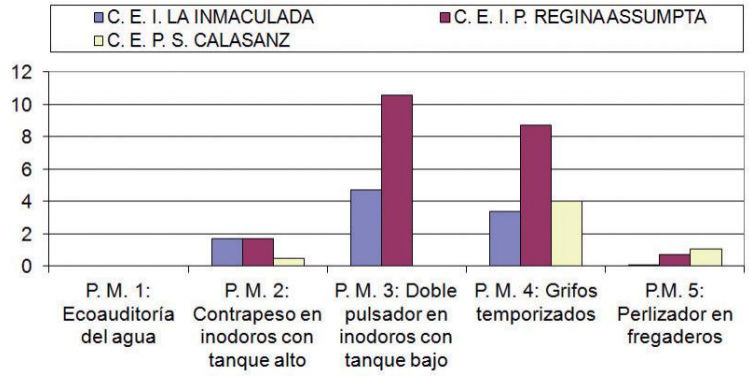

Figure 7. Simple payback period of the investment, expressed in years, for the different improvement proposals (P. M.) at the various centres

First, it should be noted that all the proposed improvements have a simple payback period of less than 5 years, which makes their implementation very attractive, with the exception of installing dual-flush toilets in low-tank models and timed faucets at the Regina Assumpta Elementary School. This is due, as noted in the previous results analysis, to the fact that this school has a larger floor area per student and, consequently, a greater number of toilets and sinks per student than the other schools.

Additionally, improvement proposals 2: Counterweights in high-tank toilets and 5: Aerators on sinks have a simple payback period of less than 2 years, making their implementation extremely attractive.

Finally, improvement proposal 1, Water eco-audit, does not have a simple payback period, since, as this is an educational institution, its implementation does not entail any additional cost. This does not mean that it does not involve a cost in terms of time, human resources, and materials; rather, these costs can be allocated to the educational activities carried out at the school. It does not entail an additional cost because if these resources are not used to carry out the suggested proposal, they will be used to carry out another educational activity. Its implementation depends solely on that decision being made, without the need to seek additional funding. User involvement is crucial in any effort to improve efficiency in the use of energy and resources such as water. Proposals based solely on technology that neglect user participation fail to take into account an important part of the process. Buildings do not consume energy (or water); people do [33].

Thus, if the criterion for implementing the improvement proposals were to start with those offering the greatest economic return, it would be advisable to implement P.M. 1 first, followed by P.M. 5 and 2, and concluding with P.M. 4 and 3.

4 Conclusion

Setting aside the study of water consumption while analyzing the energy performance of educational facilities represents a limitation in the approach, given that, as has been demonstrated, water consumption is inextricably linked to energy consumption. Therefore, incorporating the concept of building metabolism into the analysis yields a broader range of conclusions.

It is observed that the measures adopted to reduce water consumption are, first and foremost, necessary, given that consumption in the schools studied is far above the average values for buildings with the same use.

Furthermore, thanks to the operational energy audit methodology employed, results have been obtained regarding the distribution of water consumption among the various consumer systems, and it has been possible to quantify, for each proposed improvement, the reduction in consumption, the reduction in CO_2 emissions, the investment required for implementation, and the simple payback period.

The reduction in CO_2 emissions yields relatively insignificant figures, between 0.9 and 1.4 metric tons of CO_2, if all measures were implemented. Although every reduction counts, the reduction in emissions is less significant than that achieved through measures related to energy consumption for heating schools or electricity consumption within them.

The results obtained provide the school administrator with an informed basis to aid in the decision-making process regarding which measures to implement, how necessary they are, the investments they require, and the order in which to undertake them.

The greatest water savings are achieved through the work proposed to be carried out with school users via the water eco-audit, with savings ranging from 20% to 35%.

As for the fixtures that consume water in schools, the greatest water savings are achieved by upgrading toilets, with savings ranging from 10% to 30%. The next fixtures where the greatest water savings are achieved are sinks, with savings ranging from 5% to 20%.

As for the types of schools, it has been observed that the highest water consumption occurs in early childhood education centers, due to the greater need for personal hygiene among students, who are younger. In these centers, it is advisable to focus on users' consumption habits. In elementary schools and those with secondary education programs, water consumption from toilets accounts for the largest share. However, in elementary schools, where more students eat in

the school cafeteria, measures could also be taken regarding kitchen sinks; this proposed improvement has the lowest impact of all those studied.

Just as the relationship between water use and energy exchanges occurring in buildings has been analyzed, research can be further advanced by analyzing other material and information flows, thereby establishing the relationship between these flows and the energy consumption associated with them. In this way, measures can be studied to reduce greenhouse gas emissions by improving energy efficiency in the other metabolic processes that occur in the building beyond direct energy exchanges.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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