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Water Supply and Energy in Residential Buildings: Potential Savings and Financial Profitability

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Abstract: This article examines the suitability of water supply installations in residential buildings for the pressure conditions of the main water network, and evaluates the energy saving possibilities associated with pumping water into homes. It assesses the situation and the options for renovation in a sample of 151 buildings in the city of Zaragoza (Spain), estimating the savings in electric power and the possible financial returns that could be obtained. The results show that in half the buildings, the installations are inadequate and lead to inefficient energy use, which could be avoided by renovation. However, they also show that in many cases, this type of retrofitting would not be profitable for the building owners, meaning that technically viable solutions may not necessarily be financially viable. To mitigate or avoid the energy inefficiency in question, the public sector could step in by informing and financing support for building owners and regulating in the areas of town planning and construction.

Keywords: water-energy nexus; residential buildings; pumping; tanks; financial profitability

1. Introduction

The so-called "water-energy nexus" refers to the interdependency between water and energy, the world's two most critical resources. In recent years, this issue has received more and more attention in the buildings field [1–3]. At a basic level, treating and transporting water requires energy, primarily electricity, and in many cases, generating energy requires large amounts of water [4]. Given that water and energy are strategic resources, planning them together is vital to ensure future economic, social, and political stability, and to avoid unwanted unsustainable scenarios [5]. Energy efficiency is the most profitable way for society to ensure energy supply and reduce greenhouse gas emissions and other pollutants, with existing buildings offering the greatest potential for improved efficiency [6,7]. According to the International Energy Agency (IEA), buildings currently account for more than 40% of primary energy consumption and, if no action is taken to improve energy efficiency, energy demand is expected to rise by 50% by 2050. Buildings are also responsible for approximately one-third of global carbon emissions [8,9]. For all these reasons, various institutions, including the IEA itself, the European Union (EU), and the United Nations have made energy efficiency in buildings a priority on their political agendas [10–12]. The EU [13] encourages energy building renovations and asks member states to promote them.

Water supply systems to provide drinking water consume a lot of energy, since it is needed at each stage of the process during water collection, treatment, and especially transport and distribution to consumers. Therefore, saving water will certainly result in saving energy. A number of works have been devoted to analyzing specific issues related to this topic, such as where storage tanks should be located [14], energy savings when altering system properties [15], and energy savings linked to water loss [16,17].

The energy intensity of residential end use is very high relative to other parts of the water supply cycle [18]. The literature focuses its attention on energy consumption for HVAC (Heating, Ventilation, and Air Conditioning) because in percentage terms, this consumes the most energy, and renovations to improve home insulation can produce significant savings [11,19–25]. Other studies analyze how much energy consumption can be reduced by decreasing household water consumption, whether this is thanks to water-saving mechanisms, alternative water sources, or changing consumption patterns [26–29]. A third line of research, less explored than those above, examines the energy used to treat water for human consumption and to transport it to urban users, and its subsequent treatment as wastewater [30–32]. Our work on the energy consumption required to raise the level of water in blocks of residential buildings forms part of this area of research.

Buildings have their own installations to supply water to households. These installations normally include a connection to the municipal distribution network, the stop tap, different input pipes, various meters, the internal network of pipes, and often a pressurization system which includes a pump unit and water tank [33]. The pump unit provides sufficient pressure to every point of use inside the building, using one or more pumps in series or parallel, which need electricity to work.

Most pressurization systems in buildings are originally installed by the owners to ensure adequate pressure for the water supply because they are not confident that the municipal network can provide this unassisted. The problem arises in those cases where the pressure in the municipal network is enough to supply water to all the households in a building, but the pressurization system is still working, leading to unnecessary use of power. This is also the case when the pressurization system is needed only to supply water to the upper floors but is used to pump water to all the homes in the building. The extent of the problem is not known because there are no statistics or reports about this situation, either at the national or at the local level.

The purpose of this paper is to establish how widespread this problem is and to try to explain why the owners continue to run unnecessary installations and pay higher electricity bills. The goal is to draw useful conclusions for drafting policies which will change this behavior and encourage the retrofitting of these installations. The most plausible explanations include, in some cases, a lack of information on the pressure guaranteed by the municipal network, and in others, the high costs which owners will have to pay to retrofit the installations in their buildings. Thus, in conditions of perfect information, the decision of whether to retrofit these installations depends on how profitable the required investment will be. Therefore, energy savings in themselves are a necessary condition, but not enough in themselves to drive the owner to retrofit.

This article analyzes: (i) the energy-saving potential which would be realized by retrofitting water supply installations in buildings according to efficiency criteria, and (ii) the financial obstacles to retrofitting. More specifically, it evaluates the situation of the water supply installations in residential buildings in the city of Zaragoza (Spain) and the energy-related and financial consequences of retrofitting them, to make better use of the existing pressure in the city's general distribution network. To our current knowledge, there has so far been no analysis of this type in the literature, not even in exhaustive reviews regarding ways to improve efficiency in water supply systems [34]. Our final purpose is to provide conclusions which can be useful for the design of public policies intended to reduce energy consumption in residential buildings.

The rest of the article is organized as follows. Section 2 presents the case study; Sections 3 and 4 show the date and methodology used to calculate the potential energy savings, costs, and benefits of retrofitting, and how profitable this would be; Section 5 presents the results obtained; and the last section presents the conclusions of the study and their implications for policy design.

2. Case Study

Zaragoza is the fifth largest city in Spain by number of inhabitants (661,108 in 2016), with a gross disposable income per capita of approximately 17,000 euros, an economy specializing in the service sector, and a large industrial sector [35]. The dominant housing type in Zaragoza, as in other large towns and cities in Spain, is blocks of flats, usually three to twelve stories high. To ensure the supply of water at adequate pressure to all floors, many buildings have a pump unit, usually associated with a storage tank located between the municipal network and the pump unit itself. This tank is usually atmospheric. That means that the water loses the pressure of the municipal network in the tank and must be pumped to supply the upper floors. Occasionally, there are pressurized tanks which maintain the pressure of the mains network, and therefore use less energy to raise the water.

In recent years, efficient water management to ensure sustainable development has been one of the priority goals of Zaragoza City Council. It has developed regulations to ensure access to services relating to the total water cycle in its municipality with criteria relating to quality, efficiency, savings, and environment-friendliness [36]. It has also executed various plans to improve the municipal water infrastructure and has encouraged lower consumption of potable water in public awareness-raising campaigns. Concerned that unnecessary pressurization systems and atmospheric tanks could lead to lower-quality water supplied to homes, losses from leaks, and wasted energy, the City Council has established new technical characteristics required of water supply systems in new buildings and has proposed eliminating existing atmospheric tanks. This was the context for the design and execution of the research project on which this article is based.

3. Data

The research was based on a sample of residential buildings obtained by random sampling, stratified by area, with proportional allocation. The strata were defined according to the location of the buildings, establishing 14 different strata depending on the characteristics of town planning and construction. The samples were extracted from the City Council's census of buildings, with information being supplied by the 2012 municipal census, which counted 42,957 buildings. After filtering this census to eliminate units outside the scope of study—including ruined or empty buildings; industrial, commercial, and administrative premises; cultural and sports facilities; and buildings outside the consolidated city—19,371 buildings met the conditions established for study, from which a sample of 151 was extracted. For each building in the main sample, two substitutes were extracted in case of difficulties in accessing or inspecting the installations.

The inspections to collect all the necessary information related to the characteristics of the buildings and their installations were performed by technicians of the company Aquagest (the company that gives services to the City Council of Zaragoza in the integral cycle of the water) over the first quarter of 2013. Half of the buildings in the sample had operating pump units (50.3%), and 39.1% had no pump units. The remaining 10.6% had pump units, but they were not in use. Over half the buildings in the sample (58.3%) did not have water tanks. Among buildings with water tanks, 31.8% had atmospheric tanks in use, 8.6% had atmospheric tanks not being used, and 1.3% had pressurized tanks in use. In most of the buildings with water tanks (91.1%), the tank was in a basement. The distribution of the buildings in the sample by number of floors (not including basements) is shown in Figure 1.

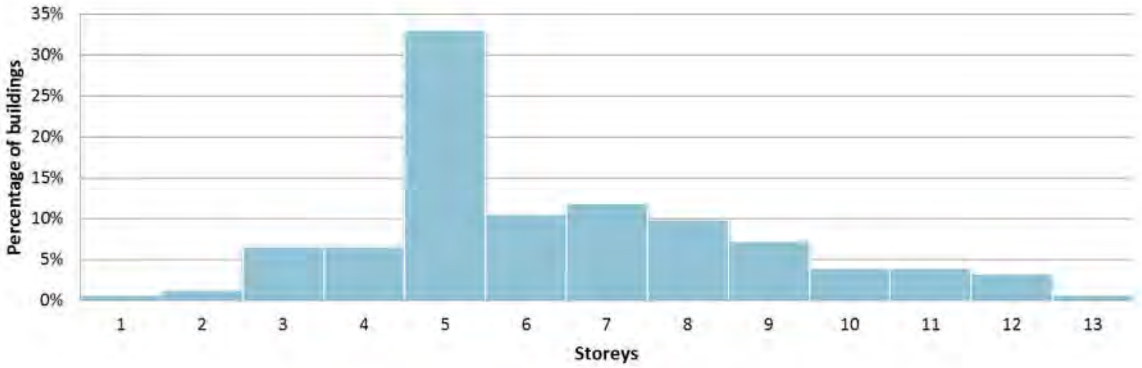

Figure 1. Distribution by the height of the buildings in the sample.

The City Council provided information on the pressure of the municipal network in the location of each building in the sample. This information was used to calculate, for each building, the number of floors that could have sufficient water pressure from a direct connection to the municipal network, shown in Figure 2. All the buildings in the sample could use the network pressure for at least some floors, and in nearly half of them, the pressure could supply the sixth floor or higher.

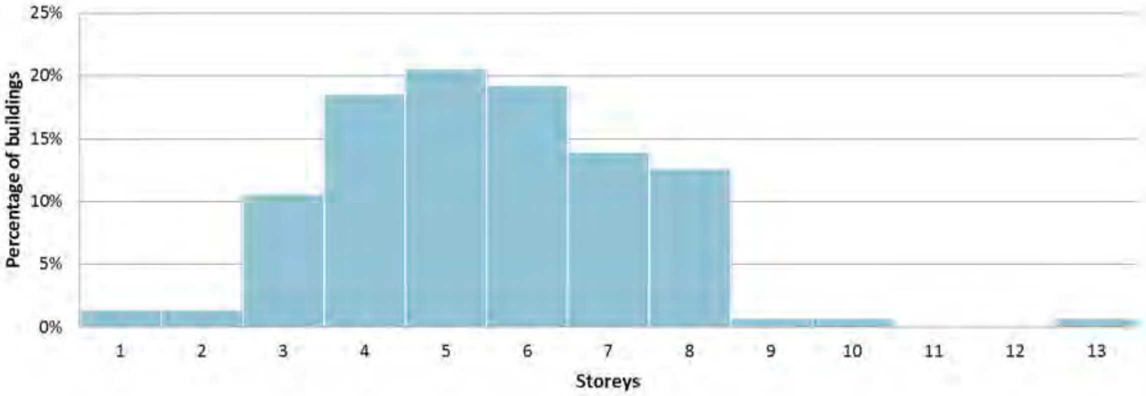

Figure 2. Distribution of the buildings in the sample by height with the natural network pressure.

Combining the characteristics of installations in the buildings and the network pressure allowed us to establish building types and to associate them with proposed retrofits designed to minimize energy consumption, as shown in Table 1. The goal was to establish which buildings could eliminate the pump unit, which should add a pressurized tank and an adapted pump unit to supply the upper floors only, and finally, to identify buildings where the current situation would not be improved by retrofits.

Table 1. Building types according to the characteristics of their water supply installations and retrofit options.

Building Type	Characteristics of the Type		Proposed Retrofit	% Buildings
	Network Pressure	Installations		
Type 1	Sufficient pressure for all floors	No pump unit or tank	No scope for improvement	39.1
Type 2	Sufficient pressure for all floors	Pump unit and tank not in use	No scope for improvement	10.6
Type 3	Sufficient pressure for all floors	Pump unit with or without tank	Eliminate the pump unit and connect directly to the mains network	15.2
Type 4	Sufficient pressure for the lower floors	Pump unit without tank	Connect lower floors directly to the network, and retrofit the pump unit to work with a pressurized tank for the upper floors	10.6
Type 5	Sufficient pressure for the lower floors	Pump unit with tank	Disconnect the atmospheric tank, connect lower floors directly to the network, and retrofit the pump unit to work with a pressurized tank for the upper floors	24.5

The percentage of buildings in the sample by type is shown in the last column of Table 1 above. In half of the sample (50.3%), changes could be made which would lower energy consumption. These buildings are: 15.2% type 3; 10.6% type 4; and 24.5% type 5. There is some relationship between building type and building age, as can be seen in Table 2.

Table 2. Building distribution by age and type (%).

Building Type	< 1960	1961–1970	1971–1980	1981–1990	1991–2000	> 2000
1	71.9	50.0	31.6	15.4	9.5	25.0
2	6.3	4.8	0.0	15.4	19.0	16.7
3	6.3	7.1	15.8	15.4	19.0	37.5
4	12.5	23.8	15.8	0.0	4.8	0.0
5	3.1	14.3	36.8	53.8	47.6	20.8
Total	100	100	100	100	100	100
No. of buildings	32	42	19	13	21	24

Among the oldest buildings (before 1970), type 1 prevails; between 1970 and 2000, it is more common to find type 5. From then on, almost half of the buildings are type 1 or 2 (they do not need retrofit); type 5 has decreased, but more than a third are type 3. In short, the percentage of buildings that require retrofit (type 3 to 5) increased over time until 2000. Since then, the tendency has changed, but more than half of the buildings still require retrofitting.

4. Methodology

4.1. Calculating Potential Energy Savings

To estimate the energy savings associated with pumping water which could be obtained by retrofitting the installations in the buildings, the first step is to calculate, for each building, the current energy consumption in kWh/m^3. This depends on the average height the water is raised to in the building and the operational design of its pump unit. The second step is to multiply this unitary energy consumption by the building's water consumption in 2012—information provided by Zaragoza

City Council from the water meters in homes and businesses—in order to obtain the annual pre-retrofit energy consumption values. To simplify the calculation, a constant and identical performance of the present and the alternative pump units was assumed. With this approach, energy savings are obtained only if the retrofit means reducing the need for pumping water; in other words, if all or some of the households (on the lower floors) will now be supplied directly from the mains network rather than via the pump unit. Thus, energy savings after the retrofit are estimated as a percentage of the previous energy consumption determined by the number of floors which will no longer be supplied by pumping. If the pump unit is eliminated and the building switches to the mains supply on all floors, this percentage will be 100%, with the savings obtained equal to the estimated pre-retrofit energy consumption.

In summary, to achieve any savings, the installations in the buildings must be retrofitted, removing the atmospheric tank and the pump unit in buildings where all the floors can be supplied using the existing pressure in the mains network, replacing the atmospheric tank with a pressurized tank and redesigning the pump unit when only the lower floors can be supplied without pumping.

4.2. Calculating Costs and Benefits

The starting point for financial analysis is identifying and quantifying the private costs and benefits arising from the retrofits, following the usual cost–benefit analysis methods for investment projects [37,38]. The calculation of the cost of the reforms is based on the data provided by two pilot studies carried out for each type (1 to 5) of the building. These pilot studies were made by technicians and engineers from the company Alfredo Sanjuan, specializing in the design, execution, and maintenance of water supply installations. These pilot studies provided information on the hours of work required, the type and amount of plumbing materials needed, and their respective market prices as of the first quarter of 2013. This information was used to calculate costs per building according to the building type and the type of retrofit. Table 3 summarizes these costs.

Table 3. Costs per building arising from retrofitting water supply installations by type of building (in 2013 euros).

Building Type	Labour	Materials
Type 1	-	-
Type 2	-	-
Type 3	1212.9	801.7
Type 4	12,129.0	13,380.5
Type 5	13,948.4	15,107.7

Returns on retrofitting come from savings on the electricity needed to pump water to the points of use in each building, and savings on maintenance and repair of pump units in buildings where they can be eliminated. The energy saved is priced according to the price of electricity and the energy used to run the pressurized systems. The price of electricity is established by the Ministry of Industry as the "Rate of Last Resort" (Directorate General for Energy Policy and Mining Resolution of 27 December 2012, establishing the cost of production of electricity and the rates of last resort to be applied from 1 January 2013). The corresponding taxes were added to this price: electricity tax (effectively 5.113%) plus general value-added tax (VAT) at 21%.

The savings arising from eliminating the need for maintenance and repair of the pump unit, if removed, were calculated based on the information supplied by companies in the sector on the average prices of maintenance (once a year) and repairs (every five years). This cost does not depend on the number of floors of the building. The estimated prices for calculating the returns of retrofitting were, for electricity, 0.1920 euros/kWh; for repairs, 133.1 euros/year; and for maintenance, 363 euros/year.

4.3. Calculating Profitability

The period during which the investment generates returns is taken to be 20 years, corresponding to the average lifespan of this type of installation, according to the consulted companies in the sector. All investment costs are assumed to be produced in the first year. The benefits arising from energy savings, and from eliminating the need for maintenance and repair on pump units when removed, are assumed to be obtained annually from the first year and to remain constant in real terms.

Profitability is calculated using the two indicators most commonly found in investment project valuations: The Net Present Value (NPV) and the Rate of Return (RR). To homogenize the values of the annual flows for aggregation in the calculated NPV, a 5% discount rate was adopted, as recommended by the European Commission for countries not receiving Cohesion Funds [38]. The results obtained for the sample, in terms of energy saved and NPV, were extrapolated to the entire city of Zaragoza for an approximation of the size of the problem. Extrapolation was done separately for each of the 14 strata into which the city's buildings were divided to obtain the sample. The extrapolation factor used was the ratio between the number of buildings in the population and the number of buildings in the sample in each stratum (this value varies between 111.2–140.1).

5. Results

5.1. Energy Saving

Table 4 shows the energy savings obtained for the buildings in the sample, grouped according to the building types established above. It also presents the total energy savings for Zaragoza after extrapolating the results of the sample to the whole city.

The Type 4 and Type 5 buildings in the sample have the greatest potential energy savings, which can be explained by their greater height, allowing them to make full use of the pressure of the mains network despite needing to keep the pump unit to supply the top floors. The least energy savings obtained are in Type 3 buildings because the height which can be supplied with the mains network pressure is greater than the height of the building, so not all the pressure can be used. The average energy saving per retrofitted building is 695 kWh/year. In most of the buildings, the savings range from 100 to 600 kWh/year, although there are cases where over 1000 or even 2000 kWh/year can be saved, as shown in Figure 3.

Table 4. Energy savings from retrofitting water supply installations in buildings.

Building Type	Sample *	City of Zaragoza	
	kWh/Building/Year	kWh/Year	TOE **/Year
Type 3	400.9 (228.8)	1,180,406.8	101.5
Type 4	768.0 (627.9)	1,576,976.3	135.6
Type 5	846.2 (516.3)	4,015,976.3	345.3
Total		6,773,337.5	582.4

* Standard deviation in brackets. ** TOE: Tonnes of Oil Equivalent.

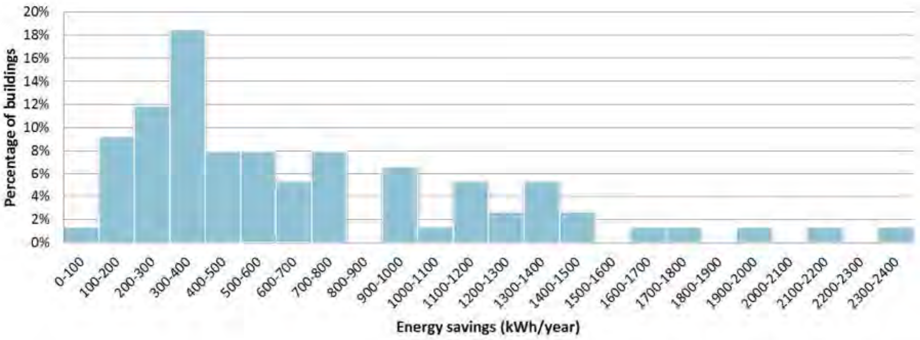

Figure 3. Distribution of the buildings by annual energy savings.

5.2. Financial Profitability

The financial analysis seeks to show the monetary profitability for building owners of retrofitting water supply installations. Table 5 shows the average NPV obtained for the buildings in the sample, grouped by type. It also shows the total NPV for Zaragoza as a whole, obtained by extrapolation of the above results. The NPV is positive in Type 3 buildings and negative in Types 4 and 5 (69.7% of the buildings which obtain energy savings). The profitability of Type 3 buildings is explained by the easy retrofit, which simply removes the pumping system. Finally, the lack of profitability in Types 4 and 5 is explained by the high cost of adapting the installations, and because the costs of pump unit maintenance and repair still apply. The NPV distribution function per building can be seen in Figure 4, which clearly shows the difference between the results for Type 3 buildings with positive profitability and the rest.

Table 5. Net Present Value (NPV) of retrofitting water supply installations in buildings (in 2013 euros).

Building Type	Sample *	City of Zaragoza
Type 3	6819.6 (777.2)	20,079,575.7
Type 4	−6204.2 (4884.9)	−12,739,245.2
Type 5	−6275.3 (4218.7)	−29,781,914.9
Total		−22,441,914.9

* Standard deviation in brackets.

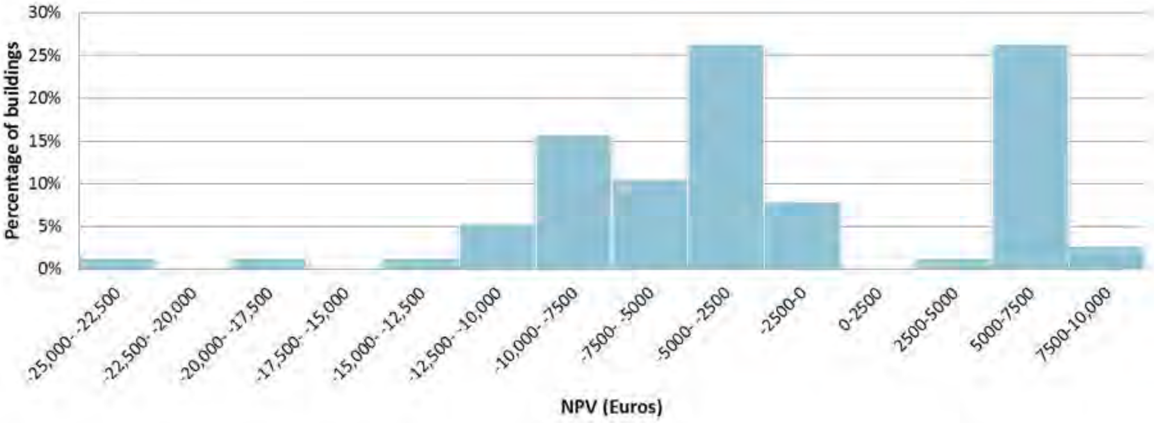

Figure 4. Distribution of buildings by the Net Present Value of their retrofit.

In discount rate sensitivity analysis, the sign of the results did not change (even when the discount rate was zero). The calculation of the RR (see Table 6) confirms the stability of the sign of the results, given that the rate of return on investments in retrofitting installations in Type 3 buildings is positive and extraordinarily high, while the rate of return on Types 4 and 5 is undeniably negative.

Table 6. The Rate of Return (RR) of retrofitting water supply installations in buildings (%).

Building Type	Sample *
Type 3	114.0 (53.0)
Type 4	−9.1 (2.7)
Type 5	−8.3 (2.9)

* Standard deviation in brackets.

6. Conclusions and Policy Implications

This article shows, through analysis of a sample of buildings in the city of Zaragoza (Spain), that there is a serious problem of water supply installations in residential buildings which do not make the best use of the pressure conditions in the municipal network. The main consequence of this is the unnecessary consumption of electricity to pump water into homes.

Avoiding this waste of energy, estimated at 6,773,337 kWh/year for the city of Zaragoza, would benefit both the owners of the buildings and society as a whole. However, executing the necessary retrofits would require owners to invest in the buildings and bear an initial cost, which is not always profitable for them. The data indicate that 50.3% of the buildings in Zaragoza have inadequate water installations and therefore consume more energy than necessary. Also, according to the calculations, retrofitting these installations provides positive returns in some buildings (15.2% of the total) where the pressure in the municipal network is enough to raise the water to every floor. In buildings where the network pressure is not enough to reach the upper floors (35.1%), modifying the installation would save energy, but it would not be financially profitable. In the buildings with positive financial profitability, the retrofit is extraordinarily profitable (114% RR) and the entire cost of investment can be recouped in the first year. Despite this, owners are not opting for this type of retrofit.

From an economic viewpoint, the existence of buildings with installations using energy inefficiently when retrofitting would be profitable for the owners indicates a market failure. The most probable reason for this is a lack of accurate and accessible information on the characteristics of the city's municipal water distribution network and the options it offers for the water supply of each building. Correcting this failure requires public intervention at the municipal level to provide the necessary information to the owners of each building showing how many floors could be supplied directly with the pressure of the municipal network. It would also be very useful to provide information, based on case studies like those in this article, on the cost of unnecessary installations and the net benefits of retrofitting. These are examples of interventions which are easy and inexpensive for municipal governments but highly beneficial for society.

Sometimes the lack of information is exacerbated by a problem of poverty when owners cannot access the funds required to retrofit the installations. Given the small average investment required in the type of building where retrofitting is profitable (2014.6 euros), this problem is unlikely in this case. However, if there should be owners whose income is below the poverty threshold, it would be advisable to set up a public support programme to help them access funding for the investment. Apart from such cases, there is no reason for a general public intervention in the form of subsidies to incentivize these retrofits, given that their private profitability is positive.

In the case of buildings with inefficient installations where retrofitting would not be financially profitable, the policy of supplying information would not be effective in the short term in convincing owners to retrofit. In this case, there could be justification for launching a line of financial support if the authorities consider all the potential social benefits of this type of retrofit, particularly the benefits of reducing the negative environmental externalities caused by these installations (benefits which would not be directly enjoyed by the owners). These benefits would include the elimination of water loss from old, badly maintained atmospheric tanks; the risks to public health of poor maintenance and cleaning in these tanks; and polluting gas emissions arising from the electricity consumed in unnecessary pumping.

In any case, both information and funding are crucial when the pump units in each building reach the end of their lifespan (which will inevitably happen at some point) and the owners have to decide whether and how to replace them. In these circumstances, if comparing the additional cost of retrofitting the installation (the difference between the cost of the retrofit and the cost of renewing the installation) with the benefits, they are very likely to obtain a positive NPV and RR. But if the information is lacking and the owners are not aware of the problem of inefficient installations or how they might benefit from a retrofit, they are unlikely to consider this option. The same applies if the owners cannot access the funding they need for this investment. Therefore, public intervention to supply information will again be needed, and if applicable, support for access to funding as well.

Meanwhile, to avoid energy-wasting installations being left in place for years to come (at least until the end of their useful lifespan) due to the high costs of retrofitting, it is vital to design them correctly at the construction stage, according to the pressure available in the municipal network, and using the best technology available. This means that building regulations must establish compulsory standards for the design of water supply installations in buildings, as Zaragoza's municipal ordinances have since 2011 [26]. It is also necessary for municipalities to make the necessary investments to guarantee the stability of the mains water supply network over both the short and the long term. Additionally, new urban developments could minimize the power used for pumping water in buildings through town planning, which would limit the height of buildings according to the pressure of the mains water network in each area of the city.

To summarize, the results of this case study allow us to draw conclusions of use for policy design in any city, both for existing buildings and for future construction—in existing buildings, to minimize inefficiency in energy use; and in new construction, to prevent this inefficiency from happening. These policies, which fall within the typical scope of responsibility of municipal governments, include various measures, such as providing information to building owners on the options the municipal water supply network offers them for retrofitting their water supply systems; providing subsidies to help pay for retrofits when justified by the positive externalities generated or the poverty of building owners; adopting compulsory standards for the design of water supply installations in new buildings to ensure they are suitable for the pressure available in the municipal network; and making the necessary investments in the municipal network itself to guarantee constant pressure levels in the water supply.

The possibility of replacing the remaining pumping units with smaller and more efficient ones has not been considered in this work. For this purpose, the size of the new unit would have to be calculated for building types 4 and 5. Then, the annual performance of the existing unit would have to be compared with the annual performance of the new unit. This analysis is beyond the scope of this project and would be suitable for future research.

Finally, in order to extrapolate the results and find out if there is some room to save energy in other cities, it would be necessary to analyze the state of the water supply facilities in their building stock. This is a costly task that would require public funds.

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