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Energy Efficiency Indicators for Water Pumping Systems in Multifamily Buildings

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Abstract: With the current concerns about sustainable development and energy consumption in buildings, water pumping systems have become essential for reducing energy consumption. This research aims to develop guidelines for the energy assessment of water pumping systems in multifamily buildings. The methodological procedures are: (i) definition of the efficiencies of electric motors; (ii) definition of pump efficiency levels; (iii) determination of energy consumption; and (iv) construction of the efficiency scale and guidelines for projects and assessments. The results obtained were that centrifugal pumps with 40% efficiency have higher energy consumption, regardless of the efficiency class of the electric motors, showing a 20% increase in electrical energy consumption. Lower efficiencies directly impact the energy efficiency rating of the water pumping system. Thus the 40% efficiency obtained energy efficiency rating "Very Low—VL" for all motor efficiency classes (between IE1 and IE5). At 60% efficiency, the energy efficiency level of the system was "Average—A", gradually increasing to "Very High—VH", as the energy consumption in the pumps decreased and the motors' energy efficiency classes increased. It is concluded that designers and professionals in the area must consider the efficiency of the pumps, as they play a fundamental role in the classification of the system's energy efficiency. It is also recommended to verify the energy efficiency of the water pumping system and implement design guidelines so that the pumping system achieves lower energy consumption, contributing to the building's energy efficiency and sustainability.

Keywords: motor efficiency level; pump efficiency; MEPS; guidelines

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1. Introduction

Access to water and energy is something necessary for the quality of life of a population and the economic growth of a region [1]. As a consequence, the energy demand has been increasing to allow this access. In the Brazilian context, commercial buildings, public agencies, and residences represented in 2019 approximately 52% of total electricity consumption [2].

In vertical buildings, one of the sources of energy consumption is water pumping systems. Urban water supply systems typically consume between 1% and 4% of a municipality's electricity and are typically the largest single consumer of electricity. From collection to final use by users in large cities, urban pumping systems can consume 3.3 kWh/m^3 [3]. In water distribution concessionaires, the expenditure on electricity in pumping systems contributes to about 90% of the electricity consumed in this sector [4].

Currently, 55% of the world population is concentrated in cities in urban areas, according to a report by the United Nations (UN) [5]. It is estimated that 2.5 billion people will be added to the urban population by 2050, leading to more than half an increase in the number of people living in urban areas today. Thus, it is observed that the expansion of water supply infrastructure should be expanded, as those related to water pumping will intensify. Currently, the internal demand for domestic water—excluding garden irrigation and other external uses—represents 30% to 70% of the total urban water demand in developed countries [6].

In this context, the trend of continuous urbanization will increase the number of megacities with more than 10 million inhabitants, which may also increase the number of vertical multifamily housing buildings, making this building an attractive option [7,8]. It is observed that the higher the building and the denser its occupation, the higher the energy demand will be, including the energy consumption of the water pumping systems.

Electric motors are responsible for about 70% of the electricity consumed worldwide in industry and 46% of the world's electricity. Pumping systems alone consume almost 22% of all electrical energy consumed in electric motors in the world [9]. Electric motors are considered highly efficient equipment. The energy efficiency of centrifugal pumps is not considered high when compared to the efficiency of electric motors. Overall, pumps with 50% or even fewer efficiencies are typical depending on design and horsepower, and efficiency decreases over the pump lifecycle [10].

Aiming to advance the efficiency of electrical equipment, the minimum standard entitled the Minimum Energy Performance Standard (MEPS) and energy labels were defined, which is seen as one of the main ways to support energy efficiency directly at the product level. Using MEPS and energy product labels is a way to support rational consumer choice and overcome information barriers. These efforts are often mandatory, but they can also be voluntary [11], being updated over the years, according to improvements in construction materials and equipment designs, thus aiming to manufacture increasingly efficient equipment commercially.

In electric motors, MEPS is based on efficiency classes, enabling different levels, which increase according to technological advances and market acceptance. Efficiency classes for motors internationally are harmonized with the IE code in IEC 60034-30-1 [12], widely accepted as the global standard, making efficiency classes comparable worldwide. The standard defines efficiency classes IE1 to IE4, where IE1 is the least efficient and IE4 is the motor efficiency class with the highest efficiency. Similarly, in the United States, the efficiency classes IE1 to IE4 are called Standard, High Efficiency, Premium Efficiency, Super-Premium Efficiency, according to NEMA [13]. The new IE5 class has not yet been defined in detail but is planned for potential products in a future edition of the standard. For IE5 electric motors called Ultra-Premium Efficiency, the goal is to reduce losses by about 20% compared to the IE4 class [14,15]. Some manufacturers already offer IE5 class electric motors.

Efficiency classes are specified by the shaft power of the electric motor and by the number of poles on which the motor is built, responsible for speed. Most motors are 4-pole, representing between 50 and 70% of total electric motors. In motors that drive centrifugal pumps, most are 2-pole, which are the fastest alternating current electric motors, representing between 15 and 35% of the total number of motors [16].

A pumping system has several types of equipment besides the electric motor and the centrifugal pump that form the motor unit. Figure 1 shows the equipment/components presented for a typical system.

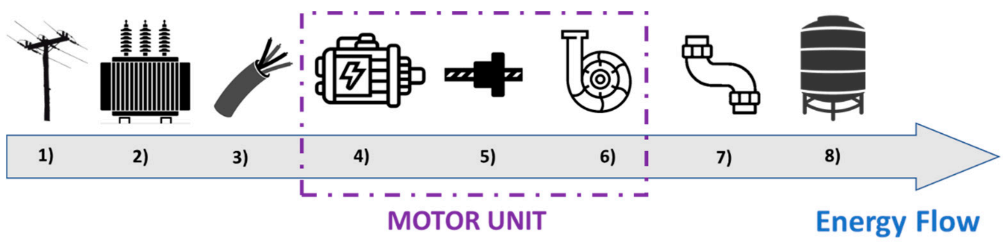


Figure 1. Equipment/components of a building pumping system.

The equipment/components with the most significant possibility of intervention in order to reduce energy losses are the electric motor and the centrifugal pump [17], as they are the equipment that presents the highest losses in a pumping system. Table 1 presents the description of the components in Figure 1 and the approximate typical efficiency of each one of them.

Table 1. Losses in the building's water pumping system.

#	Component in Pumping System	Efficiency Level (%)	Comments	Authors
1	Electric power distribution system	-	There are losses in the electricity distribution system. However, this analysis is restricted to the pumping system.	-
2	Electrical transformer	~98	There is no direct energy conversion. The input and output are electrical energy, and the transformer is naturally high-efficiency equipment.	Krishnamoorthy and Jayabal [18]; Kazakbaev et al. [19]
3	Electric cables	~98	For short distances, electrical cable losses are low.	Krishnamoorthy and Jayabal [18]; Kazakbaev et al. [20]
4	Electric motor	>80	The electric motor converts electrical energy to mechanical energy. It presents electrical losses, magnetic losses, and mechanical losses.	Almeida et al. [14]
5	Coupling	~99	It performs the coupling between the electric motor and the centrifugal pump.	Kalaiselvan et al. [17]
6	Centrifugal pump	35–70	Centrifugal pumps have mechanical and hydraulic losses. They are dependent on the flow and pressure of the piping system.	Mitrovic et al. [21]
7	Piping system	~73	High pressures in the piping system cause vibrations and wear. However, they are difficult to measure.	WSU Energy Program [22]
8	Upper reservoir	-	Losses in the upper reservoir occur due to water evaporation. If not, effectively energy loss.	-

Labels and MEPS for these devices tend to be stabilized by the theoretical limits of the dominant technologies so that the following improvements will come through new technologies in the case of electric motors [14,19], replacing the traditional three-phase Induction Motors with Squirrel Cage Rotor (SCIMs), by Permanent Magnet Synchronous Motors (PMSM), and by Motors Synchronous Reluctance (SynRM), to achieve the highest levels of IE4 and the future IE5 [20,21].

Improvements between IE1 and IE4 classes using SCIMs technology were promoted by using more copper in the stator windings, improvement in the quality of ferromagnetic materials, optimization of electrical designs, and the aerodynamics of the ventilation system [23–25]. However, it is easier to increase the efficiency of the motor system with the application of other technologies, such as PMSM and SynRM, where joule losses in the motor rotor do not exist, as they operate synchronously, thus increasing efficiency [14].

Several works in the literature analyze the impact of IE classes on the electrical system, discussing the economic and environmental impacts.

Andrade and Thé Pontes [26] simulated the replacement of IE2 motors for IE3 in the Brazilian case. They concluded that the energy efficiency measure could generate approximately 164 GWh/year savings if fully adopted from 2020. About 2600 GWh accumulated until 2030, reducing 0.64% of the total electricity consumption of the Brazilian industry until 2030, which represents 5.3% of the total electricity savings expected by the Brazilian government.

Mahlia and Yanti [27] simulated the advancement of MEPS in Malaysia for electric motors, demonstrating the reduction of the country's electricity consumption, the indirect reduction of emissions, and the reduction in electricity bills. The study proved the remarkable benefit to consumers, manufacturers, government, and the environment by implementing energy efficiency standards for electric motors. Mahlia and Yanti [27] also noted that improving the efficiency of electric motors in the industrial sector is a valuable strategy for reducing the impacts of electricity generation in Malaysia. Energy efficiency standards benefit the consumer, national economy, natural environment, and local manufacturing.

Bortoni et al. [28] estimated the amount of energy saved in SCIM due to Brazil's energy efficiency labeling program and its contribution to reducing peak demand, analyzing the replacement of IE1 class motors by IE2 class motors. Bortoni et al. [28] observed that efficiency increases in motors in the range of 1–10 HP are significant for the labeling program because, in absolute numbers, they represent 76% of induction motors installed in Brazil.

Safin et al. [29] compared the energy consumption in a water pumping system using SCIM class IE2 starting directly from the electrical network with a SynRM class IE5 starting with Electronic Speed Variator (VSD) with a power of 0.75 kW. They achieved savings of 13.9% using the IE5 class electric motor compared to the IE2 class.

Goman et al. [30] analyzed the energy consumption of 8 electric motors from different manufacturers, with a shaft power of 2.2 kW, with 3 SCIM class IE3, 2 SCIM class IE4, and 3 PMSM class IE4 being in the electrical drive of a pumping unit with variable speed for a water supply system. Goman et al. [30] simulated the energy consumption by a pump unit in four typical work cycles, considering 25%, 50%, 75%, and 100% electric motor loading, and concluded that for the IE4 standard, the PMSM do not provide significant advantages over peer SCIM.

Kazakbaev et al. [20] compared SCIMs class IE2 and IE3 fed directly from the network with PMSM and SynRM class IE4, fed through an Electronic Speed Variator (VSD), evaluating the energy savings over the life cycle of the motor-pump set and the payback period when replacing an IE2 class SCIM motor with an IE4 class motor. Kazakbaev et al. [18] concluded that the IE4 electric motor, in addition to saving more energy due to its higher efficiency class, with the higher power factor, losses in the cable and the transformer were also reduced, recording a payback time of less than one year.

The efficiency of the centrifugal pump is a determining element in the efficiency of the pumping system. Thus, another way to improve energy efficiency is in the optimal sizing of the installation, seeking to operate the centrifugal pump in the region where efficiency is maximum, also known as the Best Efficiency Point (BEP) [31].

According to Wong et al. [32], from studies carried out in Hong Kong, approximately half of energy losses in the water supply is reserved for pumping systems, as well as aging systems and misuse. In many cases, the centrifugal pump is used at low or medium loads, despite having higher efficiency values at loads close to the nominal. Glover and Lukaszczyk [33] estimated that 75% of centrifugal pumps are oversized by more than 20% and that 80% of electric motors driving centrifugal pumps are operating outside the region of maximum efficiency.

In the Brazilian case, there are still no standards or regulations to establish the minimum efficiency of centrifugal pumps. In the European case, positive experiences such as the Minimum Efficiency Index (MEI) that limits circulation pumps and centrifugal pumps with lower efficiency in the market have already shown good results [32,33].

Buildings are known to account for more than 30% of global energy demand and global greenhouse gas emissions [34,35] and improving energy efficiency in building pumping systems is a strategy to reduce Greenhouse Gases (GHG) [36,37]. Therefore, the adoption of design strategies to promote energy efficiency is fundamental.

Low efficiency in building water pumping systems is common, as it is generally not visible to residents, and most often, the pumping systems are installed by builders, who are not users of the building, nor do they pay the bills for the low system efficiency. With this, the barriers to the energy efficiency of these systems are higher [11,38].

In the context of energy consumption in multi-family buildings, attention to energy efficiency is normally directed towards systems that consume the most energy, such as heat pumps, lighting, refrigeration, and cooking. Thus, environmental certifications for sustainable buildings usually focus credits on these energy consumptions.

The energy efficiency of the building's water pumping system is usually not assessed by environmental certifications for sustainable buildings. For this reason, means of advancing energy efficiency in these systems for multifamily buildings is a research potential. As building water pumping systems are essential for multifamily buildings, considering the growing energy consumption of buildings, the improvement in the energy efficiency of these systems is essential in the context of building certifications and on the path to sustainable buildings.

Thus, research aims to develop project guidelines for evaluating water pumping systems in multifamily buildings.

2. Materials and Methods

The focus of this research is to develop design guidelines for water pumping systems to serve vertical multifamily buildings. Thus, the methodological process consists of five steps, namely: (i) definition of the object of study; (ii) definition of the efficiencies of two-pole electric motors; (iii) definition of pump efficiency levels; (iv) determination of energy consumption; and (v) construction of the efficiency scale and design guidelines, as shown in Figure 2.

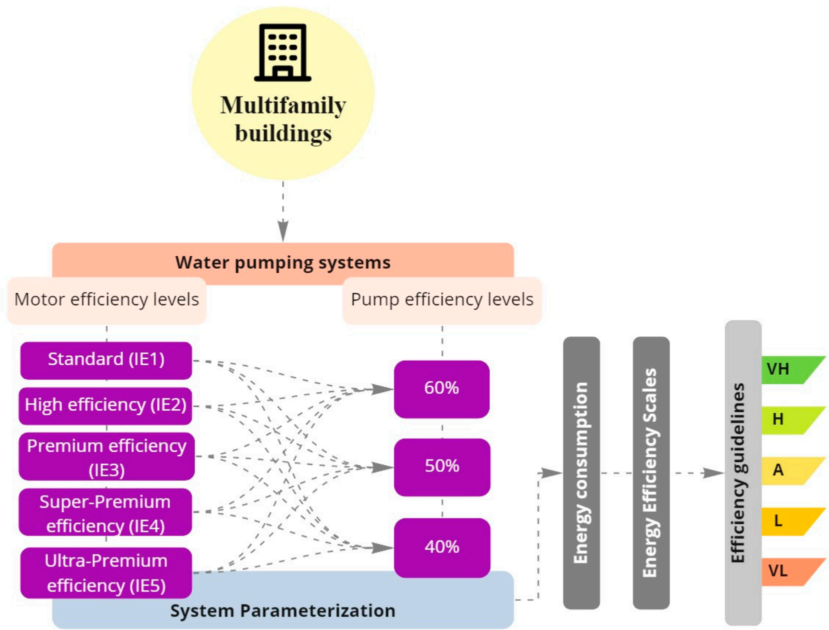


Figure 2. Methodological process flowchart.

2.1. Study Object

The object of study was a vertical multifamily building (Figure 3) for the design of the water pumping system. The building has 16 floors, distributed into a ground floor and 15 intermediate floors, featuring four housing units per floor, elevators, emergency exits, and entrance halls, totaling 60 m in height. In the housing units, an occupation of four people was considered, totaling 240 people in the building.

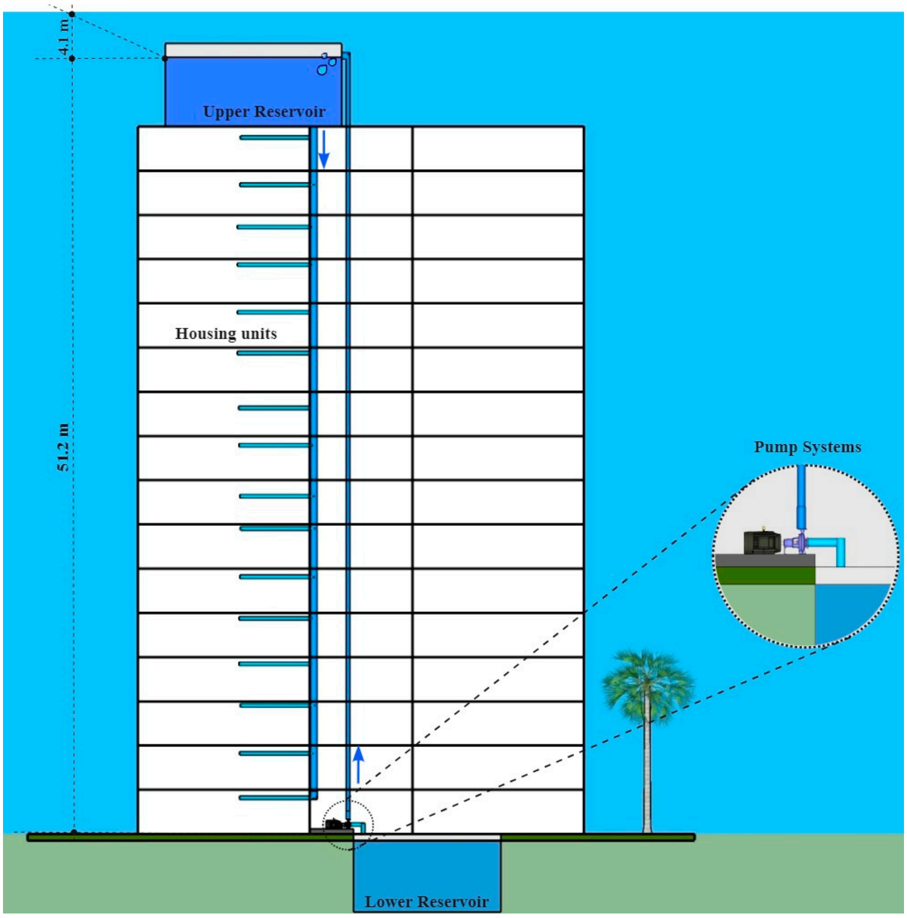


Figure 3. Representation of the building object of study.

On the building's roof, there is an upper water reservoir, which distributes to the housing units, and on the ground floor, there is a lower reservoir that receives and stores the water from the municipal sanitation concessionaire. Thus, in this study, a water consumption of 200 L per person per day was considered, totaling 48 m^3 per day in the building. Thus, the capacities considered in the reservoirs are less than 2/3 of the daily volume (32 m^3) and greater than 1/3 of the daily volume (16 m^3).

In this context, the sizing of head losses [39] was given by the difference in level between the lower and upper reservoir of 51.2 m and head losses due to pipes, bends, special hydraulic parts, and others in 4.1 m, the losses of total loads being considered in 55.3 m. Suction and discharge hydraulic piping materials are in accordance with Brazilian standards [40].

In view of the daily consumption and the losses of distributed loads, the sizing of the centrifugal pump is obtained, given by the power of the equipment (kW), according to Equation (1). The operation of the pump system was considered for four hours a day, the flow of 12 m^3/h, and three different efficiencies, being 40%, 50%, and 60%. The power increase was not considered.

$$P_{pump} = \left(\frac{\gamma \times Q \times H_{total}}{270 \times n_{pump}} \right) * 0.736 \tag{1}$$

where:

P_{pump} = pump power (kW);
γ = specific water weight (1 kg/L);
Q = flow (m^3/h);
H_{total} = total height including head losses (m);

n_{pump} = Pump efficiency (%).

In addition to the pumps, it is necessary to dimension the electric motors, which are responsible for the mechanical drive of the centrifugal pump to lift water. For this, the power of the motors was considered to be the same as that of the pumps, determined by Equation (1), as well as only two-pole motors, as they are the most used in pumping systems. As the operating power of the electric motor is very close to the nominal power of the motor, polynomial interpolation will not be necessary to find a new efficiency value for the electric motor, considering the nominal efficiency for the analysis.

Thus, to identify the efficiency of two-pole electric motors for each calculated power, the Brazilian Decree number 4508 of 2002 [41] was considered for classes IE1 and IE2; the Interministerial Ordinance number 1 of 2017 [42] for class IE3. Standard IEC 60034-30-1 [12] was applied for class IE4. For class IE5 motors called Ultra-Premium Efficiency, a 20% reduction in losses was considered in relation to class IE4 [14].

2.2. Estimation of Energy Consumption and Energy Efficiency Scales

Energy consumption was defined based on the power of the motor-pump set, defined in Equation (1), by the efficiency of the electric motor at full load and by the hours and days of use, according to Equation (2). In addition, 0.736 was used to convert the power of electric motors in kW.

$$E = \left(\frac{P_{motor} \times 0.736}{n_{motor}}\right) \times \left(h \times N_{days}\right) \quad (2)$$

where:

E = electricity consumption (kWh);
P_{motor} = motor power (kW);
n_{motor} = engine efficiency (%);
h = daily hours of use;
N_{days} = number of days of use.

The energy consumption and energy efficiency scale was elaborated based on the efficiency classes of the motors and on the efficiency range of the pumps of 40%, 50%, and 60% considered in this study. This scale was created with the objective of classifying building water pumping systems, mainly for vertical multifamily buildings, classifying as Very High (VH), High (H), Average (A), Low (L), or Very Low (VL).

The definition of the intermediate classes results in the division of the difference between the highest and lowest energy consumption with the scale efficiency intervals, in five parts, according to Equation (3), with the value of the consumption difference and the coefficient "E", the scale according to Table 2.

$$E = \frac{(H_E - L_E)}{5} \quad (3)$$

where:

E = coefficient representing the intervals between classifications;
H_E = highest energy consumption obtained (kWh/year);
L_E = lowest energy consumption obtained (kWh/year).

Table 2. Range limits of energy efficiency ratings for the water pump system.

Efficiency Class	VH	H	A	L	VL
	$< H_E - (5 \times E)$	$< H_E - (4 \times E)$	$< H_E - (3 \times E)$	$< H_E - (2 \times E)$	$> H_E$

Finally, with the help of a scale, guidelines for projects for water pumping systems for vertical multifamily buildings of up to 16 floors were elaborated in order to help designers and researchers achieve energy efficiency in these systems.

3. Results and Discussion

3.1. Analysis of Energy Consumption of the Water Pump System

Through pump efficiency of 40%, 50%, and 60%, the respective powers were obtained, resulting in 3.01 kW, 4.91 kW, and 6.14 kW. In this way, the powers of the electric motors were defined by means of the powers of the pumps, being 3.0 kW, 3.7 kW, and 5.5 kW, respectively, for each pump efficiency. Thus, using the procedure described in item 3.1, the efficiency classes of electric motors were obtained (Table 3).

Table 3. The efficiency of two-pole electric motors for different classes.

Pump Efficiency	60%	50%	40%
Pump power	3.01 kW	4.91 kW	6.14 kW
Rated power of electric motors (2 poles)	3.0 kW	3.7 kW	4.5 kW
IE1	82.5%	84.5%	85.0%
IE2	85.0%	87.5%	88.0%
IE3	88.5%	88.5%	88.5%
IE4	89.1%	90.0%	90.9%
IE5	92.1%	92.0%	92.7%

From these results, the energy consumption of the pumping system was obtained. It is noteworthy that the energy consumption of the building was not considered, with only the consumption of pumps and motors with different efficiencies being considered. Thus, the highest energy consumptions were from the pump with 40% efficiency of pumps and from the efficiency classes of motors IE1 to IE4, which obtained values above 7000 kWh/year. In this scenario, IE5 presented lower values, with a difference of 626 kWh/year in relation to IE1 (Figure 4). It is noteworthy that using the 40% efficiency pump, it is possible to obtain energy efficiency in the system of up to 4% with IE2 and IE3, up to 7% with IE4, and up to 5% with IE5 in relation to IE1.

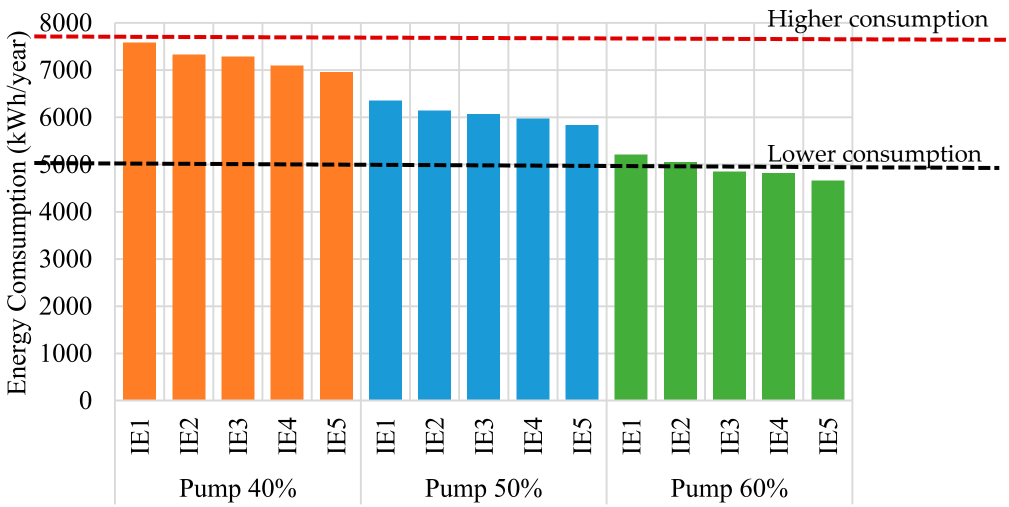


Figure 4. Energy consumption by pump efficiency range and electric motor classes.

It was observed that in the scenario of 50% pump efficiency, it presented median energy consumption values ranging from 6959 kWh to 5970 kWh from IE1 to IE5. The level of efficiency increased gradually according to the class of electric motors, obtaining a difference of 4% with IE2, 5% with IE3, 7% with IE4, and 9% with IE5 (Figure 4). However, comparing the efficiency of 50% (IE5) with 40% (IE5), I obtained smaller reductions in energy consumption, 518 kWh/year, compared to IE1 and difference between the scenarios of up to 108 kWh/year.

The scenario using a pump operating at 60% efficiency presented lower energy consumption with the same reduction profile as the other scenarios, gradually increasing according to the classes of electric motors. In this way, better energy efficiency levels were obtained up to 3% with IE2, up to 7% with IE3, up to 8% with IE4, and up to 12% with IE5. Thus, this scenario presented better efficiency levels from IE4 on compared to other scenarios. Thus, the difference in energy consumption between IE5 and IE1 was 543 kWh (Figure 4).

It was observed that the 40% scenario obtained greater energy consumption reductions with efficiency class IE5, followed by the 60% scenario and the 50% scenario. However, the highest energy consumptions were obtained in the 40% scenario; that is, the lower the pump efficiency, the greater the energy consumption of the system, so that the efficiency classes of electric motors had little influence on consumption when compared to savings with different pump efficiencies. Thus, in multifamily buildings that use pumps with an efficiency of approximately 40%, it is recommended to use class IE4 to IE5 motors so that the average consumption of the pumping system is around 7000 kWh/year.

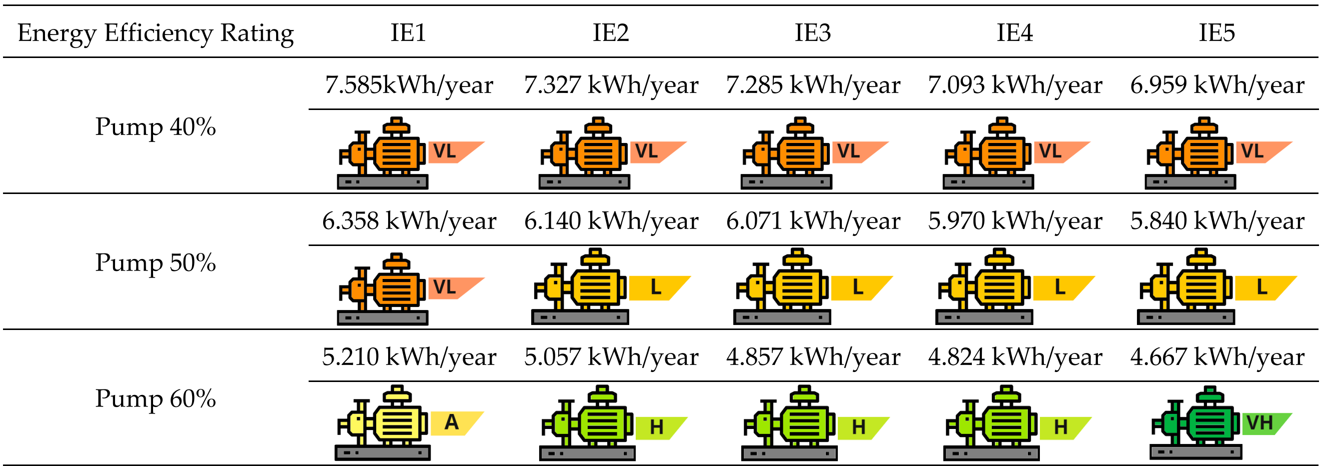
3.2. Classification of the Energy Efficiency of the Water Pumping System of the Object of Study

The classification of energy efficiency of the water pumping system in the three pump efficiency scenarios was performed based on energy consumption. Thus, the intermediate classes were defined through the difference between the highest and lowest energy consumption, being 7585 kWh/year and 4667 kWh/year, respectively, and the coefficient "E"—Equation (3) and Table 2. Table 4 presents the 5 resulting energy efficiency classes.

Table 4. Energy efficiency ratings for the water pumping system of the object of study.

Energy Efficiency Rating	VH	H	A	L	VL
	≤4.667 kWh/year	4.667 < 5.251	5.251 < 5.834	5.834 < 6.418	≥7.585

Thus, the energy efficiency rating "VL" was obtained for all efficiency classes of electric motors using the pump with 40% efficiency. Thus, water pumping systems that present these scenarios may present less energy efficiency, contributing to the increase in the energy demand of the building under analysis (Figure 5).



Energy Efficiency Rating	IE1	IE2	IE3	IE4	IE5
Pump 40%	7.585kWh/year	7.327 kWh/year	7.285 kWh/year	7.093 kWh/year	6.959 kWh/year
	VL	VL	VL	VL	VL
Pump 50%	6.358 kWh/year	6.140 kWh/year	6.071 kWh/year	5.970 kWh/year	5.840 kWh/year
	VL	L	L	L	L
Pump 60%	5.210 kWh/year	5.057 kWh/year	4.857 kWh/year	4.824 kWh/year	4.667 kWh/year
	A	H	H	H	VH

Figure 5. Energy efficiency rating of the analyzed water pumping system.

In the 50% scenario, the electric motor class IE1 presented an efficiency rating of "VL", changing to "L" in the other classes (IE2 to IE5) (Figure 5). However, it is noteworthy that the lowest consumption was observed in the scenario 50% (IE5) and 50% (IE4). Thus, to achieve better levels of energy efficiency, it is recommended to use these scenarios. It was also observed that the difference in the efficiency levels of these scenarios was only 136 kWh/year to become "A" efficiency level; that is, reducing energy consumption, consequently increasing the energy efficiency of the system as a whole including the building under analysis.

In the 60% scenario, the energy efficiency level of the system was "A", gradually increasing to "VH", according to the reduction in energy consumption and increase in the energy efficiency classes of electric motors (Figure 5). It is noteworthy that this scenario is the most optimistic in terms of energy efficiency, which presented the best levels achieved through water pumping systems in multifamily buildings.

Thus, it was observed that the efficiency of pumps played a preponderant role in a pumping system, regardless of the efficiency classes of electric motors. Thus, comparing the efficiency of the pumps, considering the 40% pump and the IE1 class motor, 15.6%, and 35.0% were obtained in relation to the use of 50% and 60% efficiency pumps. These differences show a similar behavior if we consider the other efficiency classes of electric motors.

In this context, in order to assist designers in building water pumping systems for vertical multifamily buildings, project guidelines are presented. Thus, through the ratings obtained, it was observed that with the efficiency of pumps above 60% from the IE3 efficiency class, it is possible to obtain the energy efficiency rating "VH". As for pumps with efficiency between 60% and 50% for all classes of electric motors, it is possible to obtain an energy efficiency rating of "H" and a lower increase in energy consumption of the water pumping systems in the building (Figure 6).

	Guidelines				
Pump Efficiency	≤60%	60% < 50%	50% < 40%	<40%	≥40%
Motor Efficiency	<IE3	IE5 < IE1	IE5 < IE1	IE4 < IE2	≥IE2

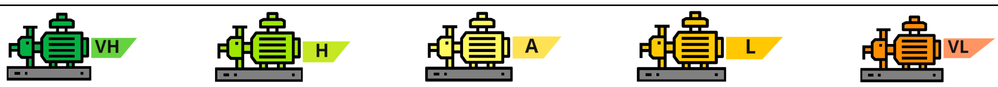


Figure 6. Guidelines for designing water pumping systems for multi-family buildings.

In the pump efficiency range between 40% and 50% for all motor energy efficiency classes, it is possible to obtain energy efficiency level "A". Thus, it is observed that without major difficulties, it is possible to reach average levels of energy efficiency, which can help in total energy efficiency when considering the complete building, especially in cases of retrofit. Finally, centrifugal water pumps with efficiency greater than 40%, considering efficiency classes IE2, IE3, and IE4 of electric motors, it is possible to obtain efficiency level "L". For pump efficiency and motor efficiency class less than 40% and IE2, respectively, it is only possible to obtain a "VL" efficiency level, being the worst energy efficiency rating.

Thus, it is observed that to have better levels of energy efficiency in pumping systems, it is necessary to apply higher pump efficiencies, while with classes above IE3, it is possible to achieve high levels of efficiency. Thus, it is recommended that designers and professionals in the area use pumps with greater efficiency and ensure that they are operating in the region where they have the best performance, as well as verifying the energy efficiency of the system as a whole, so that it achieves better levels of efficiency and reduces the energy consumption of the system, helping both in environmental sustainability and in the energy classification of the building under construction.

4. Conclusions

Given the results presented, it is concluded that the efficiency of pumps is preponderant in the efficiency of the pumping system. The highest energy efficiency classes of electric motors IE4 and IE5 showed significant gains compared to the lower classes IE1 and IE2. However, the efficiency of the pumps played a fundamental role in the energy consumption of the system.

Pumps with efficiency of 50% and 60% presented better levels of energy efficiency in the system, depending on the efficiency class of the motors used. Thus, for the 50% scenario (IE1), it presented an efficiency class "VL", changing to "L" in the other classes (IE2 to IE5). In the 60% scenario, the energy efficiency level of the system was "A", gradually increasing to "VH", according to the reduction in energy consumption and increase in the energy efficiency classes of electric motors. Thus, it is observed that to have better levels of energy efficiency in the systems, it is necessary to apply higher pump efficiencies. In the efficiency range between 40% and 50% for all motor energy efficiency classes, it is possible to obtain an average energy efficiency level "A".

It is concluded that the designers and professionals in the area must consider the efficiency of the pumps, as they play a fundamental role in the classification of the system's energy efficiency. In addition, in old buildings, the energy efficiency of pumping systems can be improved without changing the envelope or other equipment, thus reducing energy consumption.

In addition, it is recommended to verify the energy efficiency of the water pumping system and implement design guidelines to achieve lower energy consumption, contributing to the building's energy efficiency and sustainability. For future research, it is recommended to investigate other efficiency levels of pumps and motors and use other case studies of vertical multifamily buildings.

Usually, energy efficiency in water pumping systems in buildings is not evaluated by sustainable certifiers. Therefore, the proposed efficiency assessment guideline presents an initial and original contribution to increasing the energy efficiency of buildings.

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