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Comparative Analysis of primary configurations of residential building systems with individual cold water metering

Análise comparativa das principais configurações de sistemas prediais residenciais com medição individualizada de água fria

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ABSTRACT: Given the global scenario of seeking to reduce water consumption, the adoption of individualized metering systems in residential buildings emerges as a promising solution. Although there are comparative studies on collective and individual metering systems—with collective systems still predominating in Brazil—there is a gap in specific analyses of the technical aspects of individualized metering. This study aims to compare two configurations for positioning water meters in individualized systems: distributed by floor and concentrated on the ground floor. The analysis considered technical criteria such as hydraulic pressure, operation, costs, quantities of materials, and impacts on project execution, based on modeling performed using QIBuilder software. The results indicate that the arrangement of water meters by floor is more efficient, with reduced use of materials and smaller diameter pipes, as well as greater feasibility in buildings with many floors. It was also found that, in both configurations, the use of toilets with flush valves is not feasible.
Keywords: Individualized water metering, hydraulic installation, individual meters, consumption, QiBuilder.

Resumo: *Diante do cenário global de busca pela redução do consumo de água, a adoção de sistemas de medição individualizada em edifícios residenciais surge como uma solução promissora. Embora existam estudos comparativos sobre os sistemas de medição coletiva e individual — sendo o coletivo ainda predominante no Brasil —, há uma lacuna quanto a análises específicas sobre os aspectos técnicos da medição individualizada. Este trabalho tem como objetivo comparar duas configurações de posicionamento de hidrômetros em sistemas individualizados: distribuídos por pavimento e concentrados no térreo. A análise considerou critérios técnicos, como pressão hidráulica, operação, custos, quantitativos de materiais e impactos na execução dos projetos, com base em modelagens realizadas no software QIBuilder. Os resultados indicam que a disposição dos hidrômetros por pavimento apresenta maior eficiência, com uso reduzido de materiais e tubulações de menor diâmetro, além de maior viabilidade em edificações com muitos andares. Verificou-se ainda que, em ambas as configurações, é inviável a utilização de bacias sanitárias com válvula de descarga.*
Palavras-chave: *Medição individualizada de água, instalação hidráulica, hidrômetros individuais, consumo, QiBuilder*.

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1. Introduction

It is evident that due to population growth and the consequent increase in water demand, the topic of conscious water use has become increasingly prevalent today. According to Albuquerque, Ribeiro and Vieira (2008), the disparity between water demand and supply is highlighted by the low availability of basins to meet the growing water demand and the lack of investment in supply systems, combined with losses in the supply process and the high rate of waste by the end consumer. This concern opens the door for viable solutions to be increasingly sought for social application.

According to Albuquerque, Ribeiro and Vieira (2008), some solutions can contribute to more efficient and rational water use, such as rainwater harvesting, residential water reuse, the use of water-saving devices, and the adoption of an individual water metering system in building complexes. Carvalho (2010) points out that one possible solution, combined with public awareness, would be the adoption of sanitary equipment such as faucets with flow restrictors, the use of aerators, and low-volume toilets, which can control the adequate volume for use, directly contributing to the rational use of water. Furthermore, he also highlights individual water metering in building complexes as an ally in reducing water waste.

From this perspective, it is clear that in the field of civil construction, the implementation of an Individual Water Metering System (IWMS) for cold water in building complexes can be an applicable solution to help reduce water consumption. This system implements individual meters for each autonomous unit in the building, allowing separate billing for each unit, which promotes greater user awareness, as they are more likely to pay attention to rational water use when paying for their own consumption. Carvalho (2010) indicates a reduction of up to 25% in savings, potentially leading to an overall water bill reduction of up to 50%, according to Bezerra and Oliveira (2016).

To this day in Brazil, the prevailing cold water metering system is the so-called Collective Water Metering System (CWMS), where users, in theory, do not need to worry about uneconomic water consumption, as billing in this metering method is done collectively for the entire building, with no differentiation of consumption between apartments. This is unfair and detrimental to residents compared to the individual metering system. However, in 2016, Federal Law No. 13,312 was enacted, making individual water metering mandatory in new building complexes. This law came into effect in 2021, which means the conventionality of implementing the collective metering system will have to be obligatorily changed.

Many studies directly analyze and compare collective and individual metering systems, especially regarding financial comparisons, their advantages and disadvantages, and the feasibility of construction methods. Examples of these studies include Barbosa (2017), Bussolo (2010), Carvalho (2010), Dantas (2003), Guedes and Athayde Júnior (2015), Lima *et al.* (2016), Rosa (2021), and Yamada (2001). However, the central point of analysis in these studies is precisely the differentiation between the conventional collective metering system and the individual metering system. Therefore, more specific analyses for the individual system itself are not identified, which constitutes a problem, as this lack of analysis prevents a more in-depth study of application feasibility, such as differences in system configuration.

The individual metering system can present different ways of positioning the water meters. The installation location is one of the key points in a project that adopts the system. Bussolo (2010) analyzes the main distribution forms as: one column for each apartment with meters positioned by floor, meters positioned on an intermediate floor, located on the roof, distributed by floor with a single supply column, and positioned on the ground floor. For the preparation of this work, the distribution of meters by floor and positioned on the ground floor were comparatively analyzed, as these alternatives are theoretically the most recommended and present the greatest feasibility compared to other possible alternatives.

Therefore, this study evaluated, in a comparative manner, the application of the two main distribution systems for meters within the individual cold water metering system in a residential building. These systems consist of positioning the meters by floor or positioning them on the ground floor. The analysis focused on comparing the results of calculation and sizing, differences in implementation costs, executive feasibility, and possible impacts and limitations on the building's architecture and structure between the distribution forms. The results of this analysis were obtained through the computational modeling of both systems using the Qibuilder software.

2. Literature Review

A cold water supply system essentially consists of a set of pipes, reservoirs, equipment, and devices responsible for supplying water at ambient temperature to the points of use and appliances present in a building, with the same quality as that provided by the supply system (Carvalho Júnior, 2017).

In Brazil, the current standard regulating the requirements for the design, execution, operation, and maintenance of cold water building systems is ABNT NBR 5626: 2020. This standard defines the standards that must be established for the proper functioning of the system throughout the building's life.

The current standard also refers to the sizing and installation of water meters, which are responsible for the measurement and systematic control of water consumed in residential units for subsequent billing by utility companies (Barbosa, 2017).

In condominium buildings, metering systems can be classified according to their positioning and the number of meters: the Collective Metering System (CMS) and the Individualized Metering System (IMS) (Dantas, 2003).

2.1 Collective Metering

In the Brazilian context, the collective metering system has traditionally been applied. In this method, the water meter is positioned at the building's entrance for periodic measurements. The system provides for the total measurement of the volume of water consumed by both the residential units and the common areas of the development. At the end of the process, the values are measured by the responsible utility company and passed on to the consumers.

After passing through the main water meter, the water goes to the building's reserve systems, which may consist of a lower and an upper reservoir, or, in the case of smaller buildings, there may be only one reservoir. From the reservoir, the water is distributed to horizontal pipes called "barriletes," which in turn distribute it to various columns that usually supply the different hydraulic areas of the apartments, making it impossible to measure separately for each apartment (Carvalho, 2010).

In the CMS, billing can be done in three basic ways: dividing the values equally among the apartments, billing proportionally to the apartment areas, or based on the number of residents. All these alternatives have drawbacks that make them unfair for billing among residents. In equal division, the unfairness lies in not considering the apartment area and the number of residents. In proportional billing to apartment area, the number of residents is disregarded, meaning a smaller apartment with more residents could potentially consume more water. Finally, billing by the number of residents is inefficient due to the lack of analysis regarding the residents' time spent in the apartment, as well as their habits and customs, which are directly linked to water consumption (Bussolo, 2010).

2.2 Individual Metering

In this metering system, individual water meters are adopted for each residential unit, in addition to a possible main meter responsible for collectively measuring the common areas of the development. This primary characteristic of the system makes it fairer, as consumers pay for what they actually consume (Dantas, 2003).

Besides the primary advantage of fair billing, generated by the system's implementation, several other benefits are identified when compared to the conventional system. According to Barbosa (2017), the user will never risk having their water cut off if other users fail to pay their bills. Another advantage for the utility company is the reduced local consumption demand, explained by the reduction in consumption by the end user. For the utility, there is also the advantage of reduced delinquency rates, as individual billing pressures users to pay due to the risk of individual water cut-off rather than a collective cut-off for the entire building. For developers, selling apartments with an already installed individual metering system becomes easier. According to Lima *et al.* (2016), the system allows for easier maintenance without interrupting much of the water distribution system and facilitates the identification and control of post-operation issues.

The system may include, optionally, a collective usage meter for buildings with common areas or demands, allowing collective billing and subsequent division among users. Bezerra and Oliveira (2016) define the individualized metering system as the sectorization of water consumption, using one or more meters per apartment to allow individual billing.

Regarding the configuration of the IMS, it differs from the conventional system in several aspects. Generally, the configuration consists of one or more columns that, from the upper reservoir, feed the individual meters, regardless of their position in the building. The next stage in the individual system is the horizontal distribution, responsible for delivering water from the columns through the individual meters to each unit, necessitating the provision of drops in plasterboard, for example, to allow tracing inside the apartments.

2.3 System Configurations Based on Meter Positioning

The positioning of meters is a crucial point for developing a project using the individualized metering system, and this positioning defines the distribution form to be implemented. Various solutions are identified for this system; however, not all solutions are applicable from an executive and sizing calculation perspective, as discussed below.

Bussolo (2010) points out one possible solution as positioning meters on typical floors, adopting a specific column that individually serves one unit. According to Barbosa (2017), this alternative is unfeasible from a financial perspective, as the material quantity significantly increases implementation costs. Additionally, the difficulty of implementing multiple columns is magnified by executive issues and potential architectural interferences, such as the difficulty of allocating a large amount of piping in already limited spaces.

Another distribution alternative, according to Bussolo (2010), is positioning the meters on the roof. However, this solution is also unfeasible from a construction perspective, as it requires one column per apartment, as pointed out by Barbosa (2017).

There is also a less widespread distribution method that involves positioning meters on intermediate floors, using one or several distribution columns. This method benefits from better pressure distribution. Conversely, it requires a reserved space on the floor where the meters are installed, reducing the useful area compared to others (Bussolo, 2010).

All these cited distribution alternatives have points that make them unfeasible. However, technically more viable solutions from an executive perspective exist and are theoretically most recommended. These alternatives include distributing meters per floor and positioning them on the ground floor.

Bussolo (2010) and Dantas (2003) highlight that meters positioned on the ground floor allow for consumption reading by the water utility employee. This configuration requires each apartment to have a specific water distribution column, with a branch supplying the other consumption points. In contrast, Rosa (2021) states that the system's inconveniences include increased costs due to the need for individual columns and significant pressure loss in this configuration, necessitating special attention and further analysis.

Finally, the other viable alternative for the individualized metering system involves placing meters in common areas on typical floors. Carvalho (2010) notes that this solution is frequently adopted by developments opting for individual metering due to its simplified hydraulic installation and potential cost savings. This configuration consists of a distribution column supplying meters positioned on the floors of the respective apartments. From the meter, a set of horizontal pipes runs through the ceiling or floor of the apartment, supplying the consumption points of the unit. According to Carvalho (2010), this system requires special attention to the measurement method, as meters installed on typical floors complicate access for reading, with remote reading implementation as a solution.

3. Metodological Procedures

To facilitate the analysis of the systems, the base architectural and structural projects were initially defined. The choice of the project was motivated by the demand for building hydraulic installation projects, which form part of the internship activities of the first author. The premises were the availability of architectural and structural files with designs and characteristics that allow a comprehensive observation of the possible interferences and limitations of this type of system. Based on the initial project, SMI (Individual Metering System) projects were developed for both configurations: the alternative with water meters positioned throughout the typical floors and the alternative with meters grouped on the ground floor.

For the project execution, the QIBuilder Hidrossanitário computational software, developed by the Brazilian platform AltoQI (AltoQI, 2024), was used. This software can size the installations, including various analyses according to the standards established by Brazilian norms. It also allows interoperability with other existing software in the market through open-standard files *.IFC (OpenBIM), which is a current trend in civil construction projects. The software can also generate the executive detailing and necessary documentation in an integrated manner, ensuring greater security for the installation designer. Additionally, it generates a complete installation quantity after its launch, allowing direct project budgeting, which was utilized in this study. All these functionalities were considered when choosing the software. It provided the necessary sizing values for the analyses discussed in the results.

With the results provided by the software, it is possible to comparatively analyze the two alternatives for the individual metering system configuration and subsequently address their advantages and disadvantages. Following this, an analysis was conducted regarding the executive process, execution costs, and possible architectural and structural interferences, relating this information to the sizing criteria results. This approach aimed to provide a more comprehensive comparison of the feasibility and applicability of the two configuration systems.

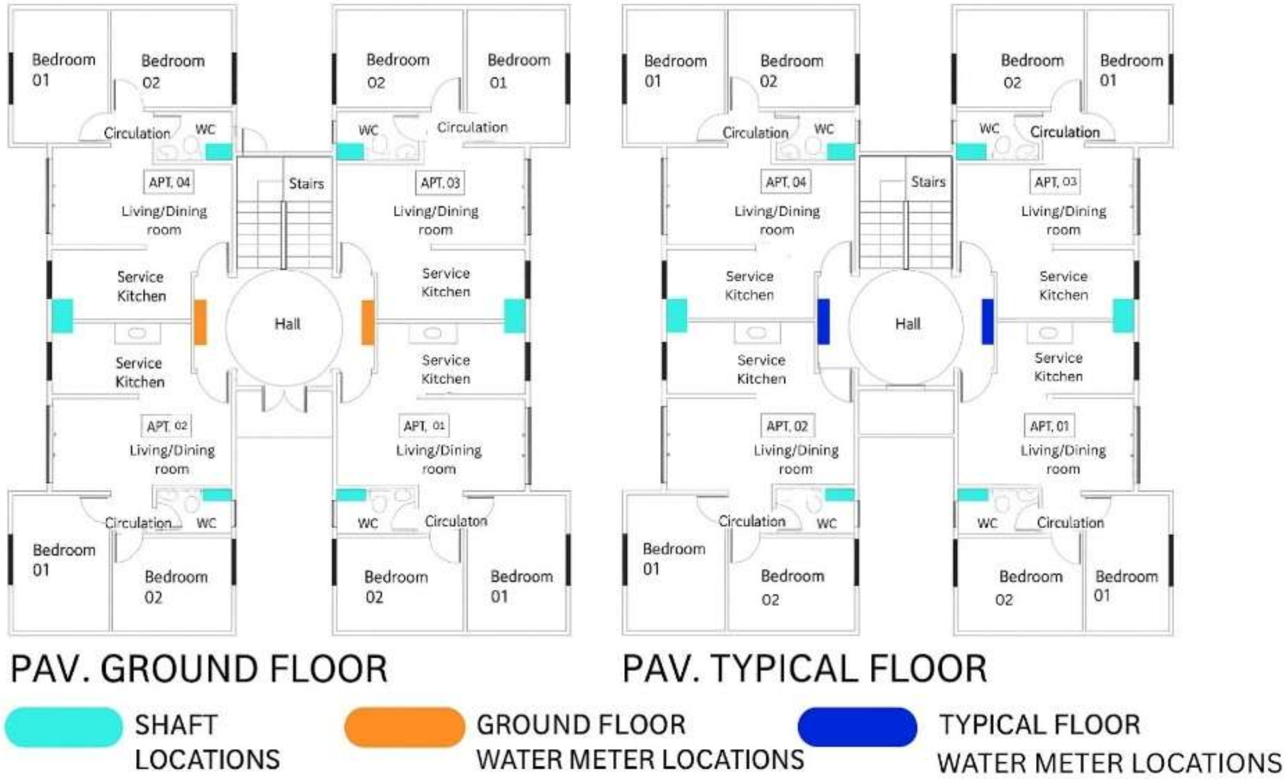
To facilitate subsequent writing, the project involving the installation of meters per floor will be referred to as Project 1, while the project involving the arrangement of meters on the ground floor will be referred to as Project 2.

3.1 Characterization of the Analyzed Building

For the study, the chosen project is a building to be constructed in the municipality of Ananindeua, in the state of Pará. The construction system adopted in the structure of the development is the concrete wall system, which directly influences how the cold water pipes are arranged in the building. The building has six floors, consisting of a ground floor, four typical floors, and a roof. The ground floor and the four typical floors have four identical apartments, totaling 20 consumer units.

The apartments to be supplied have a private area of 42.48 m², consisting of a living/dining room, a kitchen/laundry area, two bedrooms, a social bathroom, and a small circulation area. It is worth noting that the concrete wall construction method requires the implementation of shafts. Thus, the apartment includes these elements in its wet areas (kitchen/laundry area and bathroom), allowing an efficient and identical layout for both projects within the apartments. The architectural floor plans of the ground floor and typical floors are represented in Figure 1.

Figure 1– Architetural floor plans of ground floor and typical floors.



Source: Author, 2024

3.2 Design Criteria for the Hydraulic Project

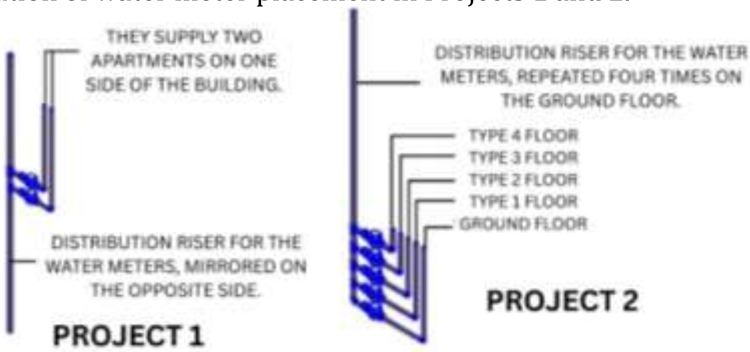
To implement the two projects using the QiBuilder software, several primary hydraulic design criteria were defined and applied identically to both Project 1 and Project 2. The rooms to be supplied in each apartment include the bathroom, kitchen, and laundry area. The bathroom includes a residential shower, a washbasin, a toilet with a flush tank, and a bidet spray. The kitchen has water points for a sink and a water dispenser, while the laundry area includes a water point for a laundry sink. The ceiling height of the apartments is set at 2.50 meters, with floor slabs having a thickness of 10 cm, resulting in a floor-to-floor height of 2.60 meters and a total building height of 13 meters to the roof level. Additionally, gypsum plasterboard ceilings are used in the apartments, with internal plumbing running above them.

Regarding the water tanks, both an underground and an overhead tank made of concrete were adopted. According to ABNT NBR 5626: 2020, the total volume of water storage must meet at least 24 hours of normal consumption in the building and consider an additional fire reserve if stored together. These parameters were considered in the tank sizing. The daily water consumption for the building was calculated based on the assumption that each apartment houses 5 occupants, each using 200 liters of cold water per day, an estimated consumption parameter for the locality, resulting in a total daily consumption of 20 m^3 for the building. As an economic criterion for consumption presented by Macintyre (1996), the underground tank was designed to hold 60% of the estimated total storage volume, including the required fire reserve. The overhead tank was designed to hold 40% of the total daily consumption, necessitating a volume of 8 m^3 for it. Based on this requirement, the concrete overhead tank was dimensioned internally, excluding the tank walls, to 245.9 cm in width, 289.15 cm in length, and 1.43 m in total height. With a freeboard of 0.3 m for operational purposes, the effective height of the tank was 1.13 m, meeting the 8 m^3 volume requirement.

Both projects adhered to a consistent design pattern, except where the configurations differed in meter placement or where pipeline diameters had to be altered due to sizing requirements. Therefore, the main differences between the projects occurred where the meters were positioned either in the ground floor hall in one project or in the apartment floor halls in the other. Additionally, the layout of the supply columns differed according to each project's needs, as previously discussed, and there were differences in the diameter of the riser pipes, as will be detailed later, to meet sizing criteria.

For the meter placement, in Project 1, two meters were installed one above the other, supplying two apartments on one side of the building, and this arrangement was symmetrically replicated on the other side, serving the other two units on the floor. This configuration was repeated on all floors. In Project 2, the meters were arranged in four groups of five meters aligned vertically. These groups were supplied by four different riser pipes from the main distribution pipe, with each meter in the group supplying the apartments vertically aligned in that direction, thus supplying all 20 units. In this configuration, the lowest meter in the group supplies the ground floor apartment, the next one supplies the first floor, and so on. These configurations are illustrated in Figure 2.

Figura 2 – Representation of water meter placement in Projects 1 and 2.



Source: Author, 2024

Except for the aforementioned differences, it was possible to follow the same piping layout for both projects, both in the riser pipe and within the consumer units. It is worth mentioning that the layout was carried out from the water tank downwards, as the rising main pipe to the reservoir and the building supply pipe would have identical dimensions for both projects.

3.3 Head Loss and Available Pressure

To calculate distributed head loss, the software employs the universal head loss formula for dimensioning, as recommended by ABNT NBR 5626:2020. Local head losses must be expressed in terms of equivalent lengths, with these values being entered into the software's calculation criteria.

To determine the downstream available pressure at a specific segment, the program first identifies the upstream pressure at that segment's entry point. To this value, the software adds/subtracts the corresponding elevation difference between the entry and exit points of the segment. A positive value indicates a pressure gain (descent), while a negative value indicates a pressure loss (ascent). Next, to ascertain the downstream pressure, the distributed and localized head losses associated with the pathway are subtracted, as expressed in Equation 1.

$$P_d = P_u + \Delta z - hf \quad (1)$$

Where P_{d} and P_{u} are respectively the downstream and upstream pressures of the analyzed segment, hf represents the head loss of the segment, expressed in meters of water column (m.w.c), and Δz is the elevation difference in meters between the entry and exit points of the segment.

For the calculation of head loss through individual water meters, the software utilizes Equation 2 as mandated by ABNT NBR 5626:2020.

$$\Delta h = (36Q)^2 \times (Q_{max})^2 \quad (2)$$

Where $\Delta \boldsymbol{h}$ is the head loss across the water meter, in kPa; Q is the estimated flow rate at the considered section, in l/s; and Q_{max} is the maximum flow rate specified for the water meter, in m^3/h.

As explicitly stated by the equation, the head loss across the water meter is directly related to the flow rate passing through it, as well as the maximum flow rate it can handle, which can be selected based on the components registered in the software.

In both cases, it was found that the flow rate passing through the water meter reached 0.51 l/s, or 1.84 m^3/h, leading to the selection of water meters with a nominal flow rate of 2.5 m^3/h, capable of handling a maximum flow rate of 5 m^3/h.

The adopted water meters are identical in their characteristics, including their type of reading, specified as remote reading for both configurations of water meter placement, despite theoretical concerns indicating that the greatest difficulties for reading occur in the system with water meters per floor. This decision was based on the observation by Bussolo (2010) that visual reading in buildings with individualized metering tends to be phased out due to the challenge of reading a large number of meters. Thus, since the quantity of water meters is the same, the difficulty for the reader would be high in both projects.

4. Results and discussion

After completing all the pipe layout entries up to the supply of hydraulic components, the software performs relevant checks according to regulations. ABNT NBR 5626:2020 specifies that the dynamic water pressure at any point of use must not be less than 10 kPa (1 m.w.c). Additionally, at any point in the distribution system, the dynamic water pressure must not be less than 5 kPa (0.5 m.w.c), except for vertical sections corresponding to intakes from elevated reservoirs.

Initially, both projects identified pressure issues at some points of use on the top floor, where they did not reach the minimum 1 m.w.c pressure required by the norm.

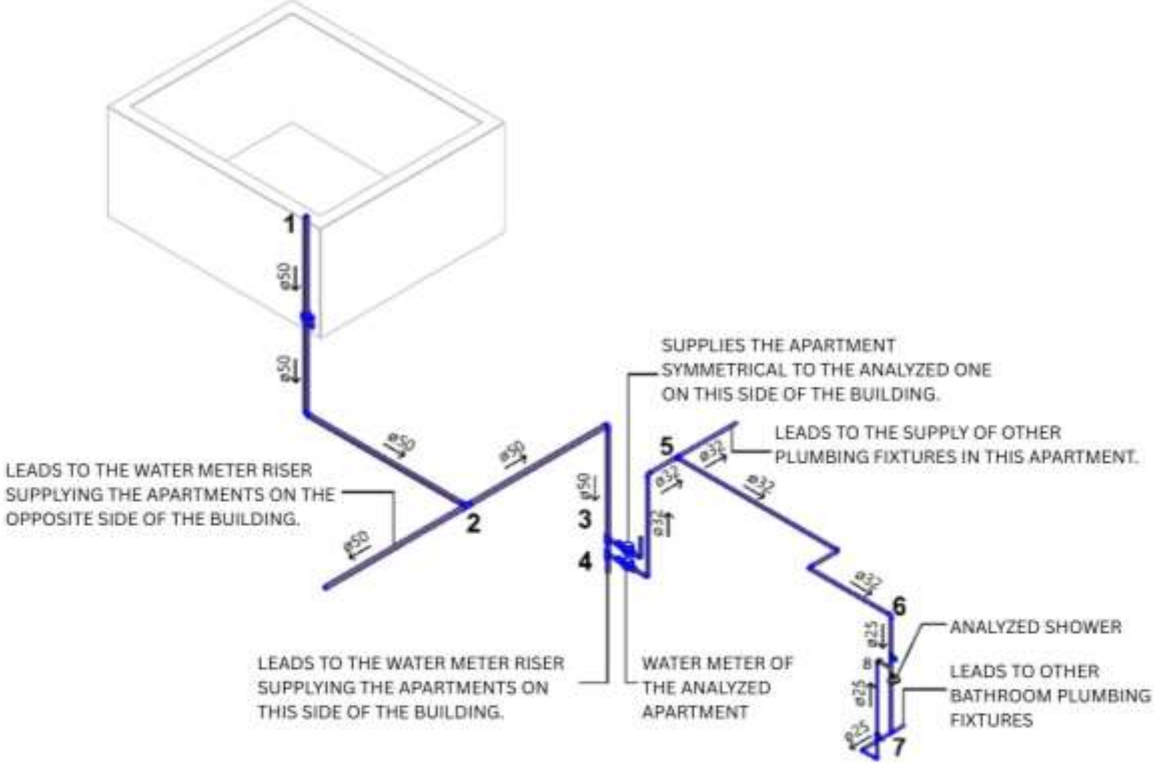
To resolve this issue, structural measures by gravity can be adopted, namely: raising the water tank to increase the head relative to the point of use and consequently increase the available pressure at the point; and increasing the diameter of the pipes upstream of the point with pressure issues to reduce unit pipe friction losses and thereby increase the available pressure downstream of the problematic point.

Given this information, for both projects, initially, the water tank was raised by 70 cm from the initial height of 2 meters relative to the roof level. It was found that even with this adjustment, some hydraulic points in the apartments on the top floor still did not reach the required pressure, with showers being the most critical points. Therefore, it was necessary to increase the pipe diameters. In Project 1, increasing one diameter above the previously launched size was sufficient to meet the minimum available pressure criterion. In Project 2, the first three sections of the pipe from the distribution header were increased by two diameters above what had initially been launched to meet the same criterion. This adjustment ensured that all points of use met the verification criteria for necessary pressure.

Regarding the option of positioning the water meters on the ground floor, as mentioned earlier, existing theoretical literature suggests that this configuration has disadvantages, such as increased costs due to the need for individualized column installations and significant pressure losses compared to the configuration where water meters are positioned per floor. Therefore, the software's dimensioning results were analyzed to verify these theoretical findings.

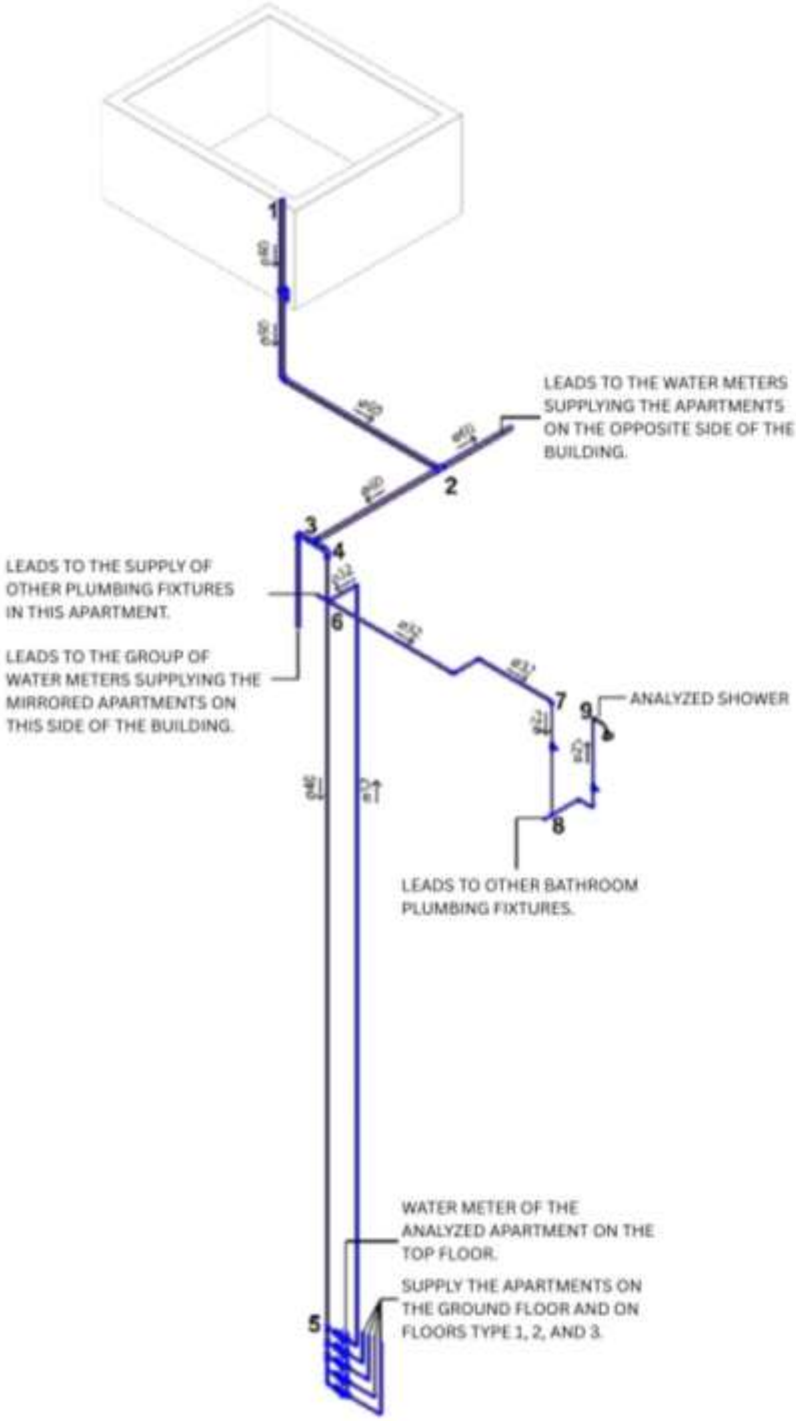
For the analysis of pressure loss, the supposedly most critical points were checked in both projects, considering aspects such as head and longer travel distances. It is observed that the available pressure at the showers on the top floor is directly affected by the pressure losses in the system. Figure 3 presents the results of the sections for Project 1, and Figure 4 shows the analyzed sections for Project 2.

Figure 3. Analyzed section from the project with water meters per floor (Project 1).



Source: Author, 2024

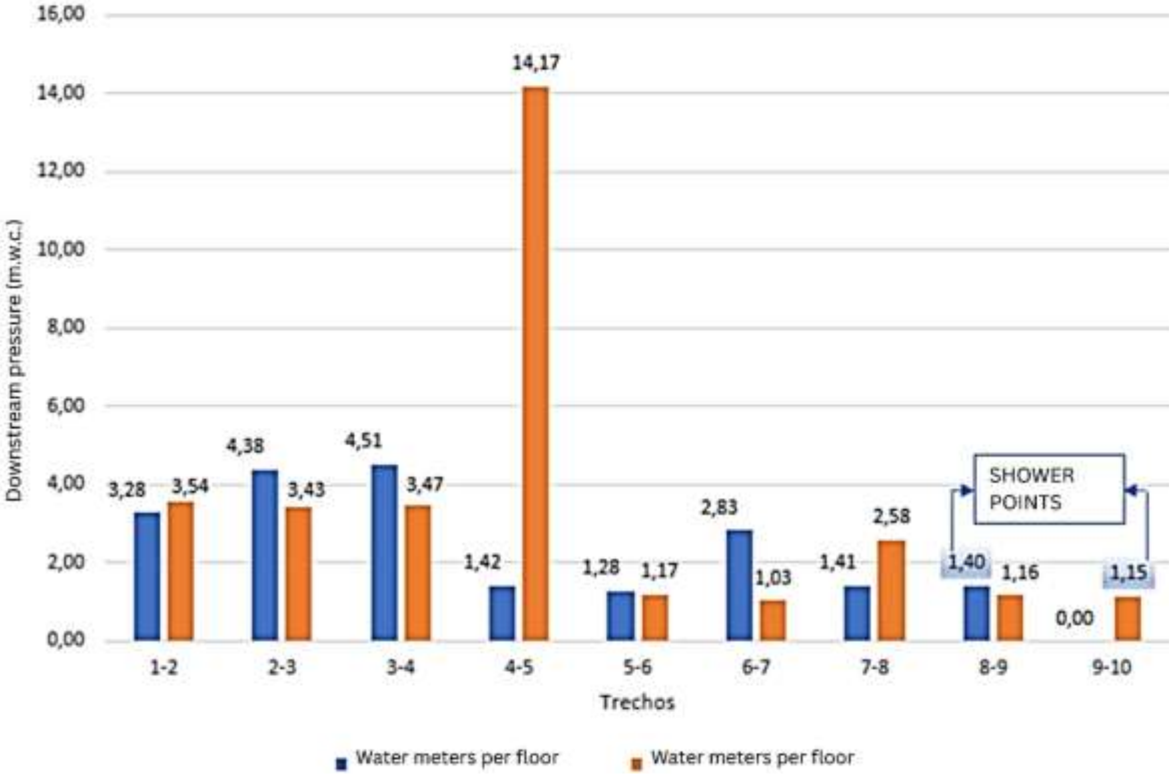
Figure 4. Analyzed section from the project with water meters on the ground floor (Project 2).



Source: Author, 2024

For both configurations, the software generates a spreadsheet of available pressures for each section, with the spreadsheets generated for each project used to construct the comparison graph shown in Figure 5.

Figure 5. Comparison of available pressure along the sections up to the showers.



Source: Author, 2024

In the project with meters positioned per floor (Project 1), represented by the blue color in the graph, sections 1-2 and 2-3, with a pipe diameter of 50mm, are the sections from the riser to the branch for the first meter on the top floor type, and section 3-4 is the section between the meters, with a pipe diameter of 40mm. From this point, the pipe, including the one passing through the meter, continues at 32mm until section 6-7, which is the column supplying the bathroom, where the pipe then reduces to 25mm until it reaches the shower. For the project with meters on the ground floor (Project 2), represented by the orange color in the graph, sections 1-2 and 2-3 have a pipe diameter of 60mm, which are the sections from the riser to the column feeding the meters on the ground floor. The column descending to the meters is represented by section 4-5 and has pipes with a nominal diameter of 40mm. From the first branch to the first meter supplying one of the apartments on the top floor type, the pipe diameter becomes 32mm. Only in section 7-8, provided by the column supplying the shower, does the pipe diameter reduce to 25mm until it reaches the shower. All these differences between the sections of the projects are shown in Table 1.

Table 1. Comparison of sections between projects.

Project	Section	Section description	Pipe diameter (mm)
Project 1 Project 2	1 - 2	Water tank outlet and header section Water tank outlet and header section	50 60
Project 1 Project 2	2 - 3	Header and riser section up to the first water meter Header section	50 60
Project 1 Project 2	3 - 4	Section between the floor water meter Header section	40 40
Project 1 Project 2	4 - 5	Water meter passage and riser up to apartment entrance Water meter supply riser	32 32
Project 1 Project 2	5 - 6	Apartment piping up to the bathroom riser Water meter passage and riser up to apartment entrance	32 32
Project 1 Project 2	6 - 7	Bathroom riser Apartment piping up to the bathroom riser	25 32
Project 1 Project 2	7 - 8	Section supplying the analyzed shower Bathroom riser	25 25
Project 1 Project 2	8 - 9	Section not present in Project 1. The shower is supplied in the previous section. Section supplying the analyzed shower	- 25

Source: Author, 2024

From the analysis of the results shown in the graph in Figure 5, some comparisons can be made between the projects. Section 1-2 in both projects corresponds to essentially the same layout, differing only in the pipe diameter, as in Project 2 the diameter had to be increased in this section, explaining its higher available pressure at the end of the section.

In Project 1, sections 2-3 and 3-4 do not show a significant loss of available pressure, as they have a drop from the level of the riser to the least favorable floor in terms of pressure, as mentioned earlier, which compensates for the pressure loss along the way. In Project 2, sections 2-3 and 3-4 belong to the horizontal pipes of the riser, so there is no significant pressure loss between these sections.

The most significant difference between the projects is observed in section 4-5 in Project 2. This section corresponds to the column that carries water from the riser to the first downward meter, which is the one that feeds the apartment with critical pressure on the top floor. Thus, the layout imposed by this configuration requires a nearly building-height drop. In this section, due to the large drop, there is an excessive pressure gain compared to Project 1, where the drop between the riser and the meter of the least favorable floor in terms of pressure only needs to overcome one floor. However, it is observed that the significantly increased pressure in section 4-5 for Project 2 is not transferred to the downstream sections to the same extent seen in Project 1. In Project 2, for water to reach the top floor, the drop is significantly greater than in Project 1. For this reason, as highlighted earlier, the pressure gain obtained in section 4-5 for Project 2 is consumed in the uphill section, resulting in an available pressure of 1.17 m.w.c at the apartment entrance, below the value of 1.42 m.w.c for Project 1.

Sections 4-5 in Project 1 and 5-6 in Project 2 correspond to the section from the distribution column to the arrival at the apartment. These sections have the same pipe diameter and pass through meters with the same characteristics, including pressure loss, as the flow passing through them is the same, since this flow will ultimately supply the same number of hydraulic points in the consumer unit in both projects. In the subsequent sections, it becomes the layout within the apartments, which basically follow the same layout characteristics and have the same pipe diameters. It is worth noting that since the Project 2 layout has an extra section, sections 5-6, 6-7, and 7-8 in Project 1 correspond to sections 6-7, 7-8, and 8-9 in Project 2.

At the end of the paths, the available pressure effectively at the showers was 1.40 m.w.c for Project 1 and 1.15 m.w.c for Project 2, representing a percentage difference of 17.85% in available pressure values between the projects.

These results found in this study can contribute to reflections on the application of the metering systems analyzed here in medium and large buildings. As mentioned, the available pressure problem was apparent in both systems on the fifth and top floor of the building, requiring adjustments to the height of the water tank and pipe diameters. However, within the system where meters are arranged per floor type, the increase in floors would not have a direct influence on the top floor considered, since the drop to be overcome would continue to be between the point of capture from the elevated water tank to the floor type to be supplied. On the other hand, in the system where meters are located on the ground floor, the drop to be overcome would increase and consequently there would be greater pressure loss. Therefore, in buildings that exceed the fifth floor, for the system with meters on the ground floor, there is a tendency to present available pressure results that further complicate the sizing, and this tends to be aggravated as the number of floors increases. For this condition, Project 2 would be conditioned to implement water pressurizers, which would increase the system cost and represent a potential operational bottleneck for equipment replacement demands and interruptions in electricity supply.

Another important comparative analysis to be made between the projects is the materials used. For this, the complete materials lists generated by the software at the end of the layout were used, as shown in Table2. The materials analyzed were the pipes and fittings used in the layout, since other materials, such as meters and hydraulic components, remained identical in both projects.

Comparing the material quantities between the projects reveals that Project 2 incurs considerably higher material costs compared to Project 1. This aligns with findings in the literature, where the distribution approach of Project 2 requires the installation of individual columns to convey water from the water meter to each serviced apartment.

Analyzing a general parameter of the building, the most significant disparity in material costs lies in the total length of piping used. Project 1 utilized a total pipe length of 419.8 meters, whereas Project 2 used 540.73 meters, resulting in a percentage difference of 22.31%.

In addition to the aforementioned points, an important observation was made during the execution of the hydraulic projects regarding the difficulty of implementing flush toilets in individually metered systems, whether the meters are positioned per floor or on the ground floor. This challenge arises from regulatory requirements mandating a dedicated distribution column for these devices due to their high operating pressure. Therefore, to implement such a system with flush toilets, multiple meters per consumer unit would be necessary, which would be disadvantageous financially due to increased component and piping requirements. This characteristic would increase the material quantities in both projects, with Project 2 being more affected due to its feature of having individual columns for each apartment, further increasing materials with the implementation of an additional column for the flush toilets in addition to those servicing the apartments themselves.

Table 2. Lists of project materials.

WATER METERS PER FLOOR		WATER METERS ON THE GROUND FLOOR	
Rigid solvent-weld PVC		Rigid solvent-weld PVC	
Short solvent-weld adapter with female-threaded socket for valve		Short solvent-weld adapter with female-threaded socket for valve	
25 mm - 3/4"	120 pç	25 mm - 3/4"	120 pç
50 mm - 1.1/2"	2 pç	60 mm - 2"	2 pç
Short solvent-weld reducing bushing		Short solvent-weld reducing bushing	
32 mm - 25 mm	4 pç	32 mm - 25 mm	4 pç
50 mm - 40 mm	2 pç	Long solvent-weld reducing bushing	
Long solvent-weld reducing bushing		40 mm - 25 mm	12 pç
40 mm - 25 mm	14 pç	60 mm - 40 mm	4 pç
90° solvent-weld elbow		90° solvent-weld elbow	
25 mm	200 pç	25 mm	216 pç
32 mm	18 pç	32 mm	20 pç
50 mm	3 pç	60 mm	5 pç
90° solvent-weld reducing elbow		90° solvent-weld reducing elbow	
32 mm - 25 mm	4 pç	32 mm - 25 mm	8 pç
Solvent-weld reducing coupling		Solvent-weld reducing coupling	
32 mm - 25 mm	8 pç	32 mm - 25 mm	8 pç
Pressure valve with chrome escutcheon		Pressure valve with chrome escutcheon	
3/4"	20 pç	3/4"	20 pç
Pipes		Pipes	
25 mm	358,15 m	25 mm	416,29 m
32 mm	30,23 m	32 mm	68,82 m
40 mm	19,42 m	40 mm	46,47 m
50 mm	12 m	60 mm	9,68 m
90° solvent-weld tee		90° solvent-weld tee	
25 mm	114 pç	25 mm	112 pç
32 mm	4 pç	32 mm	4 pç
40 mm	12 pç	40 mm	8 pç
50 mm	1 pç	60 mm	3 pç
90° Solvent-weld reducing tee		90° Solvent-weld reducing tee	
32 mm - 25 mm	4 pç	32 mm - 25 mm	4 pç
40 mm - 32 mm	2 pç	40 mm - 32 mm	8 pç
50 mm - 32 mm	2 pç	Solvent-weld union	
Solvent-weld union		25 mm	24 pç
40 mm	8 pç	32 mm	16 pç
50 mm	2 pç	40 mm	16 pç

Source: Author, 2024

Finally, it is important to note the architectural and structural compatibility considerations in both projects. The base design used shafts strategically positioned to eliminate potential interferences. This measure, coupled with adequate floor-to-ceiling heights for false ceilings in various apartment spaces, facilitated the internal routing of the piping systems.

5. Conclusions

After comparing the results obtained, it is concluded that despite efforts to maintain the same application conditions in both studied projects, the system with water meters positioned on the ground floor proved more problematic in terms of meeting the minimum sizing criteria required by regulations. This system required the use of larger diameter pipes in a significant number of sections compared to the project with meters positioned per floor.

Given these conditions, it was expected that the project with meters on the ground floor would achieve higher available pressure results than the project with meters per floor, which was not effectively the case according to the results presented. In fact, when analyzing the most critical points of available pressure in both projects, which were the showers on the last typical floor, the project with meters per floor showed 17.85% higher available pressure. This percentage difference implies that the pressure loss results in the project with meters on the ground floor were more impactful, despite using larger diameter pipes in more sections compared to the per-floor metering system.

From the extracted sizing results, it was concluded that for medium and large-scale projects implementing a ground floor metering system, the trend is that as the number of floors increases, the available pressure results will deteriorate, further complicating implementation and increasing costs in these scenarios.

Regarding the quantity of materials, from the analysis of the material lists, it is concluded that the major disparity in material costs is due to the pipes, confirming theoretical analyses. The system with meters on the ground floor showed a 22.31% higher consumption of materials compared to the other studied system. This difference within the context of constructing a single building may not have significant impacts, but in developments where identical buildings are replicated multiple times by the same developer, as in the case of the building analyzed in this study, it can have a significant impact on budget planning. Since the meters adopted are identical for both projects studied, there was no cost difference in this regard.

Thus, it is concluded that for the configurations analyzed, the configuration with meters located in common areas of the floor proved more efficient, as it presented better sizing results using a lower quantity of materials and smaller diameter pipes. This study can contribute to decision-making regarding the placement of water meters within an individualized measurement system. Therefore, developers or those responsible for buildings to be constructed should anticipate ways to allocate this system in their developments, seeking architectural and structural solutions that facilitate its implementation.

Additionally, an analysis of the feasibility of installing flush toilets in individually metered projects was conducted, and it was found that, based on the collected results and analyses of layout and sizing, its application is impractical for both systems: with meters in common areas of typical floors and with meters located on the ground floor. Therefore, considering Federal Law No. 13,312, which mandates individual measurement of water consumption in new condominium buildings, this method of implementation is likely to become obsolete.

Finally, considering that the quantity of pipes and the complexity of layout represent a major challenge compared to traditional centralized metering systems, the insertion of shafts and adequate ceiling heights in new designs are critical measures to ensure the feasibility of projects under the new legislation in force.

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