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Comparative study of the costs of flexible and rigid pipes used in cold water and hot water building hydraulic systems

Estudo comparativo dos custos de tubos flexíveis e rígidos utilizados em sistemas hidráulicos prediais de água fria e água quente

Estudio comparativo de costos de tuberías flexibles y rígidas utilizadas en sistemas hidráulicos prediales de agua fría y agua caliente

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Abstract

This work aims to compare the use of cross-linked polyethylene (PEX) for building hydraulic installations instead of traditional systems built with PVC and CPVC rigid pipes. This flexible system is very widespread overseas and shows great potential in reducing costs and building time, however it is still underutilized in the country when compared to rigid pipe systems, mainly due to the lack of studies on cost indicators and experienced professionals who work with that technology. As such, this work aims to analyze and compare both systems - rigid systems with PVC and CPVC and flexible systems with PEX – in budget, quantity of materials and head loss in order to accentuate the characteristics of flexible systems. Three different layouts were constructed and simulated using hydro sanitary software in a standard apartment: two of the conventional PEX (type and partial point-to-point), and the other using a rigid system. The estimated cost per meter was BRL 34.57 for the rigid system, BRL 37.91 for the conventional PEX, and BRL 26.57 for the point-to-point PEX. Therefore, for this case study, the partial point-to-point PEX system achieved the best cost indicator, representing 23.4% less than the rigid system.

Keywords: Cross-linked Polyethylene; PVC; CPVC; Hydraulic Building Systems; Building piping.

Resumo

Este trabalho apresenta os resultados da comparação da utilização nos sistemas prediais hidráulicos de tubulações em polietileno reticulado (PEX) frente a sistemas tradicionais com a tubulação rígida em PVC e CPVC. O tipo PEX é bem conhecido internacionalmente e apresenta potencial para diminuição de custos e tempo de execução de obras. No Brasil, atualmente não é tão utilizado quando comparado com os sistemas em tubulação rígida. Pode-se apontar como causas os poucos estudos sobre indicadores de custo, bem como a falta de profissionais com experiência sobre esta tecnologia. Desta forma, este estudo realizou uma comparação entre os sistemas rígidos e os sistemas flexíveis em PEX, tendo como parâmetros os custos, as quantidades de materiais e as perdas de carga. Para tanto, foram modelados e simulados, em softwares hidrossanitários, três traçados diferentes em um apartamento, sendo dois do tipo PEX (convencional e ponto a ponto parcial); e um com o sistema rígido. O custo estimado por metro foi de R$ 34,57 para o sistema rígido, R$ 37,91 para o PEX convencional e R$ 26,57 para o ponto a ponto. Portanto, para esse estudo de caso, o sistema PEX ponto a ponto parcial atingiu melhor indicador de custo representando 23,4% menor que o sistema rígido.

Palavras-Chave: Polietileno Reticulado; PVC; CPVC; Instalações hidráulicas; Tubulações prediais.

Resumen

Este estudio comparó el uso de instalaciones hidráulicas de polietileno reticulado (PEX) en comparación con sistemas tradicionales de tuberías rígidas de PVC y CPVC. El sistema flexible de PEX está bien establecido en el extranjero y tiene un gran potencial para reducir costos y tiempos en proyectos de construcción. Sin embargo, actualmente no se utiliza tanto en el país como los sistemas de tuberías rígidas, principalmente debido pocos estudios sobre indicadores de costos y profesionales con experiencia en la tecnología. Por lo tanto, este estudio realizó un análisis comparativo de ambos sistemas rígidos y sistemas flexibles de PEX en términos de costos, cantidad de material y pérdida de presión para demostrar las características del sistema flexible. Se construyeron y simularon en software hidrosanitario tres trazados diferentes en un apartamento tipo: dos del tipo PEX (convencional y punto a punto parcial), y el otro en sistema rígido. El costo estimado por metro fue de R$ 34,57 para el sistema rígido, R$ 37,91 para el PEX convencional y R$ 26,57 para el punto a punto. Por lo tanto, para este estudio de caso el, sistema PEX punto a punto parcial alcanzó el mejor indicador de costo, representando un 23,4% menos que el sistema rígido.

Palavras Clave: Polietileno Reticulado; PVC; CPVC; Sistemas de Plomería; Tuberías de Edificio.

1 Introduction

The supply and distribution of water for consumption has always been a crucial issue for the development of society from its early stages to the present day. Considering this context, several systems have been developed to ensure an adequate water supply. Thus, in order to address the water needs of residential buildings, cold and hot water building systems are operational, and the NBR 5626 (ABNT, 2020) are followed to create their design, implementation and maintenance. These NBR standards aim to ensure the fulfillment of hygiene, safety and comfort criteria, as well as to guarantee the provision of quality water.

Currently, the most used material for the installation of cold-water systems is the polyvinyl chloride (PVC), a rigid thermoplastic material with several contexts of use, including the production of packages and electrical cable insulation, however, approximately 65% of its production is allocated to the civil engineering sector (Souza, 2011). According to the Brazilian PVC Institute (2024), 70% of the material's demand is destined to the construction industry, with the primary application being in piping and fittings.

The chlorinated polyvinyl chloride (CPVC), a material used for hot water building systems, is characterized by presenting all the inherent properties of PVC, while also offering a high resistance to the conduction of liquids at elevated temperatures (Brandão, 2010). This material can withstand a working pressure of up to 60 meters water column (m.w.c.) and water temperature of 80ºC, with the ability to endure occasional temperatures up to 95ºC. It also presents an elevated capacity for heat retention, and the use of thermal coating in indoor areas is not necessary (Tigre, 2021).

Another material which has been used in cold and hot water building systems is the cross-linked polyethylene, known as PEX. This material is obtained through the cross-linking of thermoplastic polyethylene, resulting in a more pressure - and temperature - resistant material (Lourenço, 2020). The PEX system, which includes piping and fittings, can be used for both cold and hot water distribution, and its main characteristic is the flexibility of application. It allows bending, and eliminates the need for pipe elbows, tees and bend fittings, reducing installation time. It is also possible to observe that this material results in lower head loss when compared to the conventional system, also offering ease of maintenance due to the use of shafts in order to access the pipes (Dos Santos; Modolo, 2019).

The design and installation of a hydraulic system with PEX can be performed in two ways: as a conventional system, similar to the rigid systems, or as a point-to-point system, where the pipping is distributed from a fixed point to other usage points. The conventional system is implemented in the same way as traditional rigid PVC systems, as the environments are supplied by branches deriving from a specific piping system, requiring the use of some "T type" pipe connection for its implementation- eliminating the need for bends or pipe elbows. The point-to-point system, on the other hand, consists of a system where the PEX piping originates from a manifold (Dos Santos; Modolo, 2019).

In 2011, technical standards considering the use of PEX were elaborated regarding its use in some types of buildings. The regulation was adjusted and divided into three parts: NBR 15939-1 (ABNT, 2023a); NBR 15939-2 (ABNT, 2023b); and NBR 15939-3 (ABNT, 2023c).

PEX pipes present an important potential for reducing the assembly time and costs in the civil construction field, a fact which is highlighted by studies such as those by Brandão (2010), Lourenço (2020) and Nóbrega (2021). Anselmo and Oneda (2023) identified that PEX pipes were a 19,17% cheaper alternative when compared to PVC due to the lower labor costs. In agreement, Lourenço e Rodrigues (2020) observed that PEX has a cost 58,9% lower when compared to rigid CPVC piping.

Comparative studies that considered PEX and traditional systems were developed by Nóbrega (2019) and Santos (2022). Based on the data obtained by Nóbrega (2019), it was possible to observe that the cost per linear meter of the PVC system was BRL 58,18, while the PEX system costs were BRL54,77. Data from Santos (2022) presented that the combination of PVC (cold water) and PEX (hot water) resulted in BRL21,87 per linear meter, while for the PEX system (both cold and hot water), the cost was BRL 23,28. These values suggest that the use of PEX can be competitive when compared to the PVC and CPVC systems.

Despite the characteristics presented by the PEX system and its widespread use abroad, the system still faces difficulties in being adopted in Brazil, where it is overshadowed by the use of traditional PVC systems for residential buildings and low- to mid- standard constructions. According to Lourenço and Rodrigues (2020), the use of PEX is still in its early stages compared to the use of traditional rigid systems such as PVC, CPVC and metal piping.

In this context, it is possible to observe that several factors may contribute to the limited use of PEX systems, such as the lack of data on cost indicators; the limited number of qualified professionals with experience in using this technology; the higher cost of the material when compared to PVC; and the conservatism of the civil engineering market in the country (Lourenço; Rodrigues, 2020).

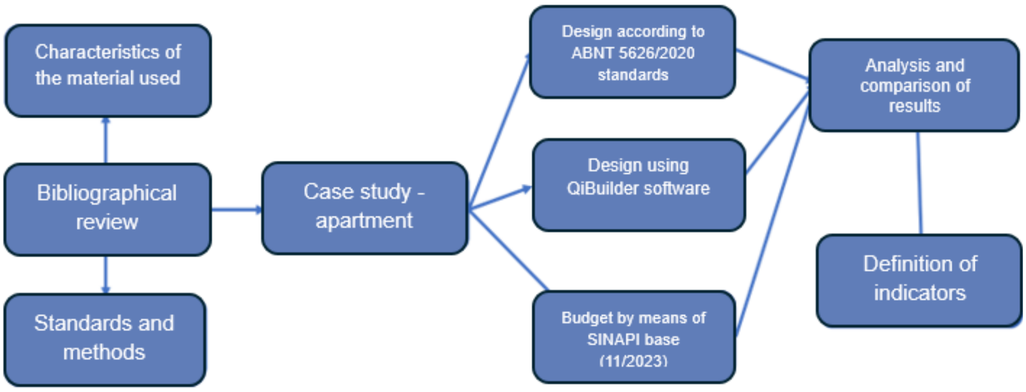
Therefore, this research aims to provide information, data and indicators comparing the PEX system and traditional systems, in terms of costs, quantity of material used and head loss, with the goal of presenting the characteristics of the PEX system and encouraging its greater use in the civil engineering sector.

In this way, this work presents the results of the comparison from both technical and economic perspectives, of flexible systems (PEX), conventional and partial point-to-point systems, compared to traditional rigid piping systems (PVC and CPVC), which are applied in multi-story buildings, with the aim of expanding knowledge about the application of PEX, filling gaps in the academic understanding about new technologies for the installation of hydraulic building systems, and encouraging its use through the understanding of economic indicators.

2 Material and Methods

To develop this research, a bibliographic study was performed, considering the materials, characteristics of the pipping systems and current standards. Subsequently, a case study was developed based on a medium-standard apartment project, with an area of 100m^2 and an already completed hydraulic design using PEX system. Based on this project, new layouts were created for systems using rigid pipes (PVC and CPVC), and for a new PEX layout with the same routing adopted in the rigid system. Finally, small adjustments were made to the existing partial point-to-point PEX layout from the original project. These layouts were created by means of the modeling software AutoCAD and the calculations for the hydraulic system were performed by the software QiBuilder. Based on the specifications of NBR 5626 (ABNT, 2020), the design and calculation of head losses for the systems were performed, as well as the corresponding material quantities and budget were obtained, from which the comparative analyses were made, and the performance indicators were defined for each system and their respective costs and compared to other studies. The flowchart in Figure 1 summarizes the methodology used in this research.

Figure 1: Flowchart of the study methodology.



2.1 Case Study

The base of the project consists of a medium-standard building, located in the state of São Paulo, with one garage floor, one ground floor and 23 typical floors. For this study, apartment 02 on the typical floor was selected, as it is the representative of most of the apartments in the building. The apartment contains three bedrooms, one living room, two bathrooms, one powder room and one kitchen/ laundry area with a gourmet balcony.

In each apartment, the measurement of the water consumed by the systems is performed using individual water meters located in accessible cabinets in the common circulation area. Table 1 presents the appliances and points of (cold and hot) water usage in the apartment.

Table 1: Sanitary areas, appliances and points of water usage in the apartment.

Sanitary areas	Sanitary appliances and points of usage
Bathrooms 1 and 2	1 washbasin – CW/HW; 1 toilet bowl - CW and 1 shower – CW and HW
Powder room	1 washbasin – CW;1 toilet bowl – CW
Kitchen	1 sink – CW/HW
Gourmet balcony	1 sink – CW
Laundry area	1 gas heater – CW/HW; 1 sink – CW and 1 washing machine - CW

CW – Cold Water point; HW – Hot Water point.

2.2 Design of the plumbing system

The design of the building system was carried out in two stages: First, the pipe routing was designed on the ground plant of the typical floor of the building using the AutoCAD software from Autdesk. This layout connects the plumb of the water meter to each apartment, in a way that it is possible to supply all the areas of usage. Next, a three-dimensional model of the pipping system was created by means of the QiBuilder software, 2023-11 version (AltoQi, 2023), in which data from each system were included and were used as guides for implementing the system.

For this study, three different systems were analyzed, each implemented in its own 3D model within the software.

- System 1 (S1): installation using rigid PVC and CPVC pipping as the standard system, with proper valves for each room.
- System 2 (S2): installation with flexible PEX pipping in the conventional system, considering the same layout and routing used on S1.
- System 3 (S3): installation with flexible PEX in a partial point-to-point system, where each room is individually supplied by pipes connected to a manifold located in the laundry area (Dos Santos e Modolo, 2019), with a single main valve.

For all three systems, the hot water supply was conducted by means of a conventional layout starting at the water heater to serve the bathrooms and the kitchen. The quantity of components and the length of the piping used were obtained through the QiBuilder software (Building > Sheets > Materials list). This information was considered in order to analyze the costs and to generate costs indicators per linear meter for each system.

2.3 Cost survey of the project

The estimate cost of the hydraulic system materials was calculated by means of an electronic spreadsheet, with inputs from the SINAPI 11/2023 (CAIXA, 2023) base, applied to buildings located in the State of São Paulo.

The quantity of components used in each model was obtained from the modelling of hydraulic building systems in the Revit software from Autodesk and material lists for edifications using PVC and PEX were generated. These data were allocated into specific spreadsheets for each, and data from SINAPI 11/2023 (CAIXA, 2023), considering the unit cost of the materials, were also inserted. Social charges for non-exempt services were considered and an arbitrary value of 25% was adopted for the BDI (Benefits and Indirect Costs), due to it being an intermediate value among the values observed in the study by Nóbrega (2021).

2.4 Sizing and calculation of head loss

In order to perform the sizing of the pipping in the water distribution system, the NBR 5626 (ABNT, 2020) requirements for pressure and velocity were considered. A maximum velocity of 2,5 m/s was adopted in the QiBuilder software, and the allowable pressure in the piping was set within the range of 5 to 400kPa.

The method of weighing was considered to estimate the flow rates of the pipping system. This method is mainly adopted due to its practicality and its common use among engineers, assigning relative weights to each consumption point based on the flow rate.

The flow rates, relative weights and head loss in the adopted water meters were obtained from recommendations present in the previous version of NBR 5626, as outlined in the book *Instalações Hidráulicas e Sanitárias* (Creder, 2006).

The head loss in the piping was calculated considering the distributed head loss, which varies according to the length of the piping system, its material, diameter and the flow rate inside it. The calculation of the unit head loss was performed using the Universal Head Loss Equation, as this method is recommended by NBR 5626 (ABNT, 2020).

The universal head loss coefficient was obtained based on the Reynolds number, the kinematic viscosity of the fluid and the pipe roughness. These parameters were calculated using the QiBuilder software. The total length of the conduit used for calculation is composed of the length of the piping along with the sum of the equivalent lengths of the components used in the system, which were defined by the software.

The calculation of head loss in systems using PEX piping, performed by the QiBuilder software, generally considers the same procedures used in hydraulics for rigid piping. However, this system presents a particularity due to the curvature formed by the pipe itself (Souza, 2011), in which the determination of the head loss may vary (AltoQi, 2022). In this context, an equivalent length of the curvature is considered for the calculation and is defined based on the ratio between the curvature radius r and the internal diameter of the pipe, D, both in meters (m).

- If r/D > 8, the equivalent length of the curvature is discarded and therefore the value is zero.
- If r/D ≤ 8, the software must calculate the value of the equivalent length of the curvature at the intermediate point.

For all points that meet the second criterion, the value of the friction factor (K) of the curve is calculated using Equation 1 (AltoQi, 2022):

$$K = \left[0{,}13 + 0{,}16.\left(\frac{r}{D}\right)^{-3{,}5}\right].\sqrt{\alpha°/180°} \tag{1}$$

In which:
K = friction factor;
D = internal diameter of the pipe (m);
r = radius of the curvature;
α° = angle of the curvature (degrees).

As the friction factor K is determined, the localized head loss of the curvature is obtained from Equation 2 (AltoQi, 2022, adapted):

$$H = K.\frac{\left(\frac{Q}{\pi.\left(\frac{D}{2}\right)^{2}}\right)^{2}}{2.g} \tag{2}$$

In which:
Q = flow rate of the pipe section (m^3/s);
D = internal diameter of the pipe (m);
K = friction factor;
g= gravity (m/s^2);
H = Head loss (m).

To obtain the value of the localized head loss H, the equivalent length of the curvature is calculated using Equation 3:

$$CE = \frac{H}{J} \tag{3}$$

In which:
CE = Equivalent length of the curvature (m);
H = Localized head loss of the curvature (m);
J = Unit head loss of the pipe (m/m).

The equivalent lengths obtained for each curvature are added to the length of the piping to reach the total length. This process was performed for all systems in the standard apartment.

Regarding the available pressure for supplying the standard apartment, the pressure of the most hydraulically distant unit from the main distribution pipe was considered. This approach ensures adequate network pressure to account for head losses within the system and to maintain a minimum pressure of 10 kPa or 1 m.w.c. at the points of use. An arbitrary value of 15 m.w.c. was assumed immediately after the water meter. It is important to note that this study aimed to analyze the branch lines and sub-branches lines within a single apartment unit under various layouts and material configurations (PEX, PVC and CPVC), excluding the hydraulic and economic analysis of the entire building.

2.5 Definition of cost indicators

At the end of the project, after executing the layouts and entering the hydraulic systems S1 (conventional PVC and CPVC), S2 (conventional PEX), and S3 (PEX point-to-point) into Ravit, the cost estimates provided by the construction company completed in 2023 and the values of head loss in the systems were inserted into spreadsheets, and a cost analysis of the materials used in the three systems was conducted. Indicators were defined by relating the costs of the system execution per linear meter of piping used as reference for future value estimates or for professionals in the market who aim to plan construction projects. Thus, comparative tables were created, considering:

- Cost per linear meter of piping obtained for the three systems;
- Percentage ratio between the costs of the PEX system and the PVC and CPVC systems;
- Comparative analysis of the costs of executing the hydraulic systems in the studied apartment using weldable PVC and CPVC and PEX, quantifying the percentage difference among the values obtained for the systems.

A total of 2 workers were considered in this study – one plumber and one assistant- to assemble the pipes and fittings. Regarding the time required to assemble the systems, one and a half days (12 hours) were considered for the PVC and CPVC system, and one day (8 hours) was considered for the PEX system. The reduction in the execution time is due to the use of specific material kits, which facilitates the assembly on-site.

3 Results and discussion

3.1 Piping layouts of systems S1, S2 and S3

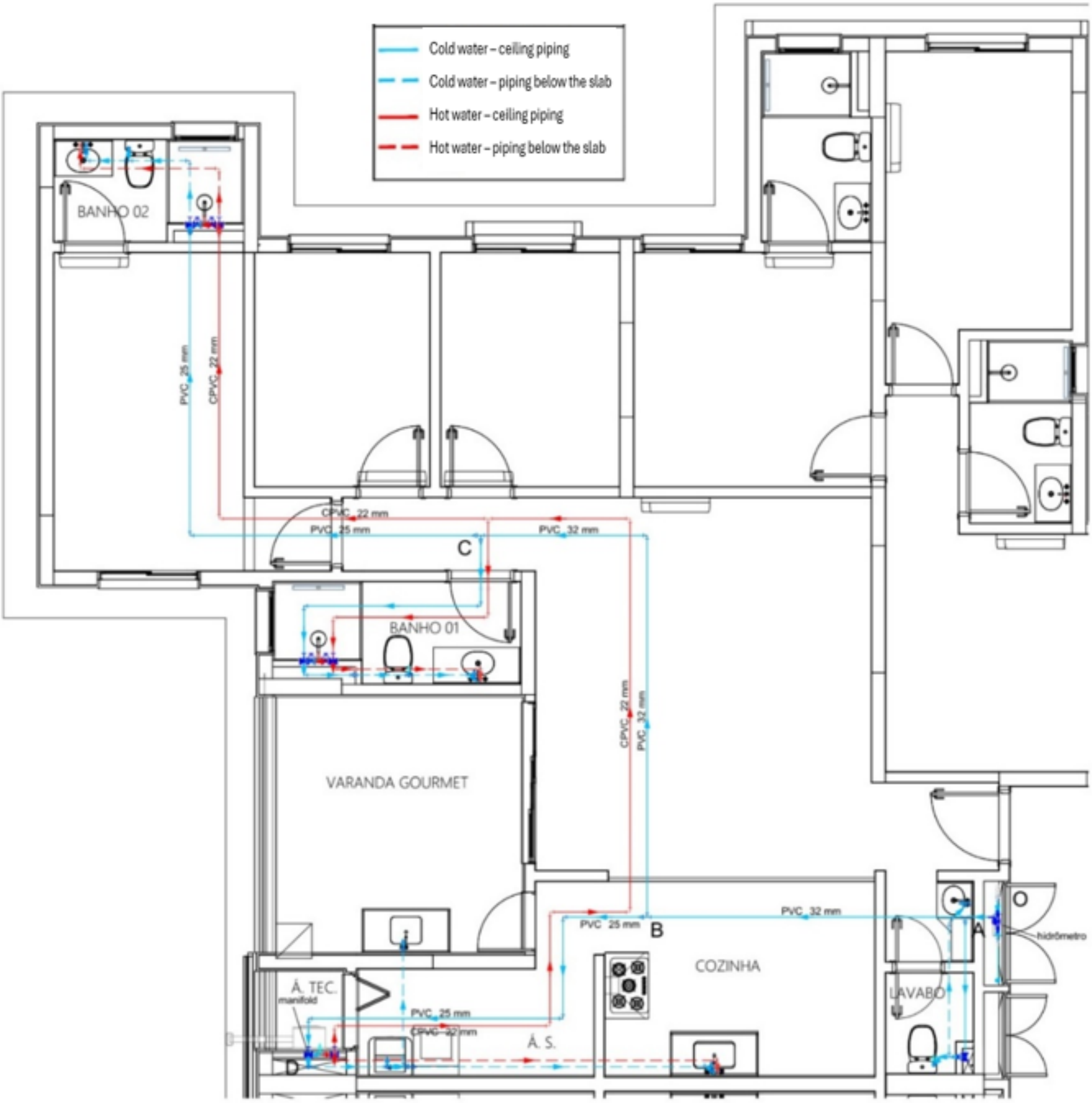
The project considered for this case study was provided by a construction company specialized in the development of engineering and architecture projects, with the client's identification data removed.

Based on the different systems, the original layout was created using rigid pipes (S1). The layout designated as S2 followed the same path as S1 but utilized PEX material. Finally, the S3 system employed PEX with a different layout configuration compared to S1 and S2, incorporating the use of a "manifold" system.

The routes of the layouts were designed considering the position of structural elements in order to avoid beams, slabs and columns. The branches originate from the cabinet where the water meter is located and run through the ceiling (solid line) to the shafts of the rooms, from where they descend and continue under the floor slab (dashed line) to supply the sub-branches and the points of use, following the original design of the company's project.

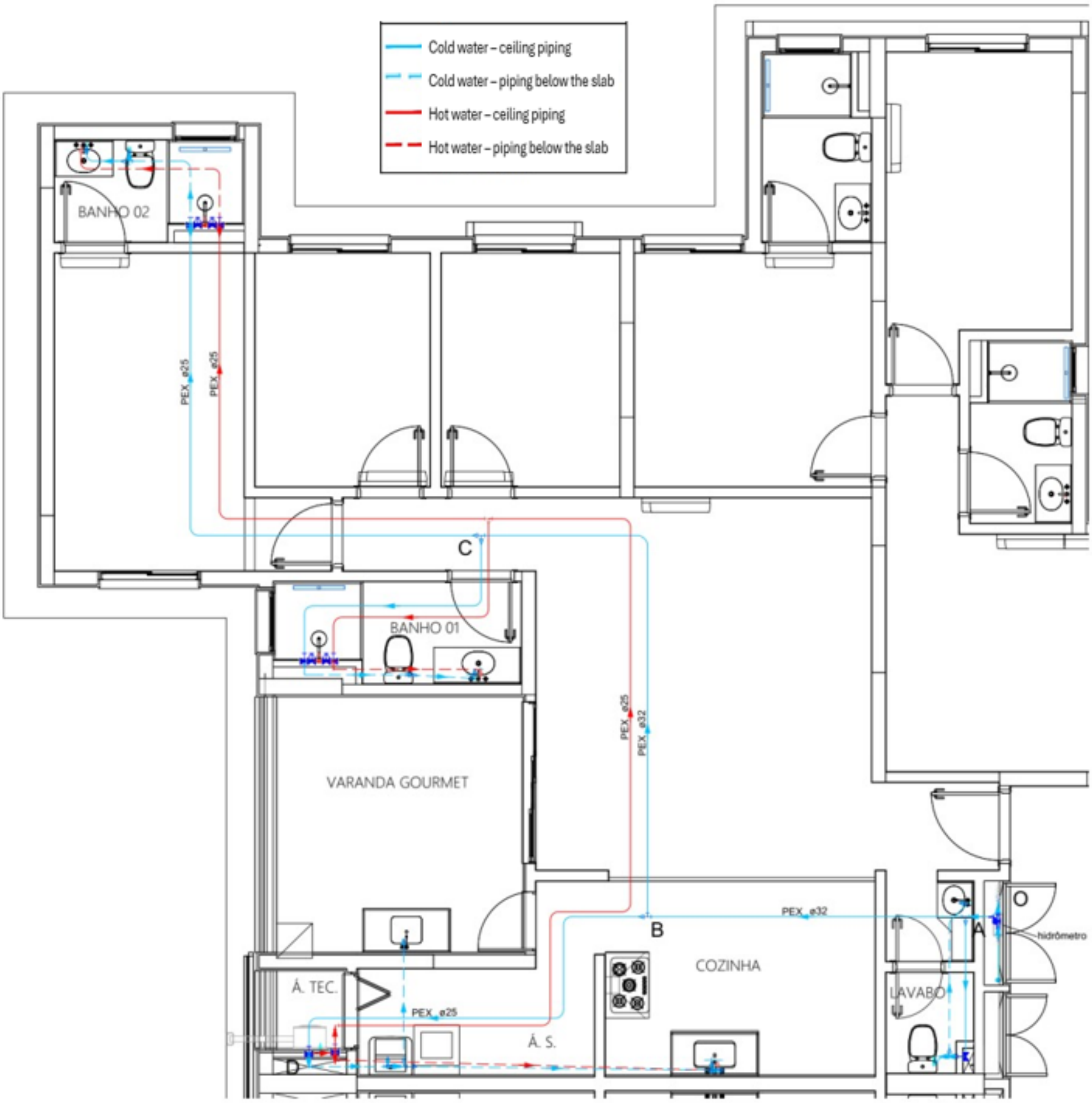
The results of these layouts, respectively for layouts (S1), (S2) and (S3) are presented in Figures 2, 3 and 4.

Figure 2: Layout of the S1 System (conventional PVC and CPVC).



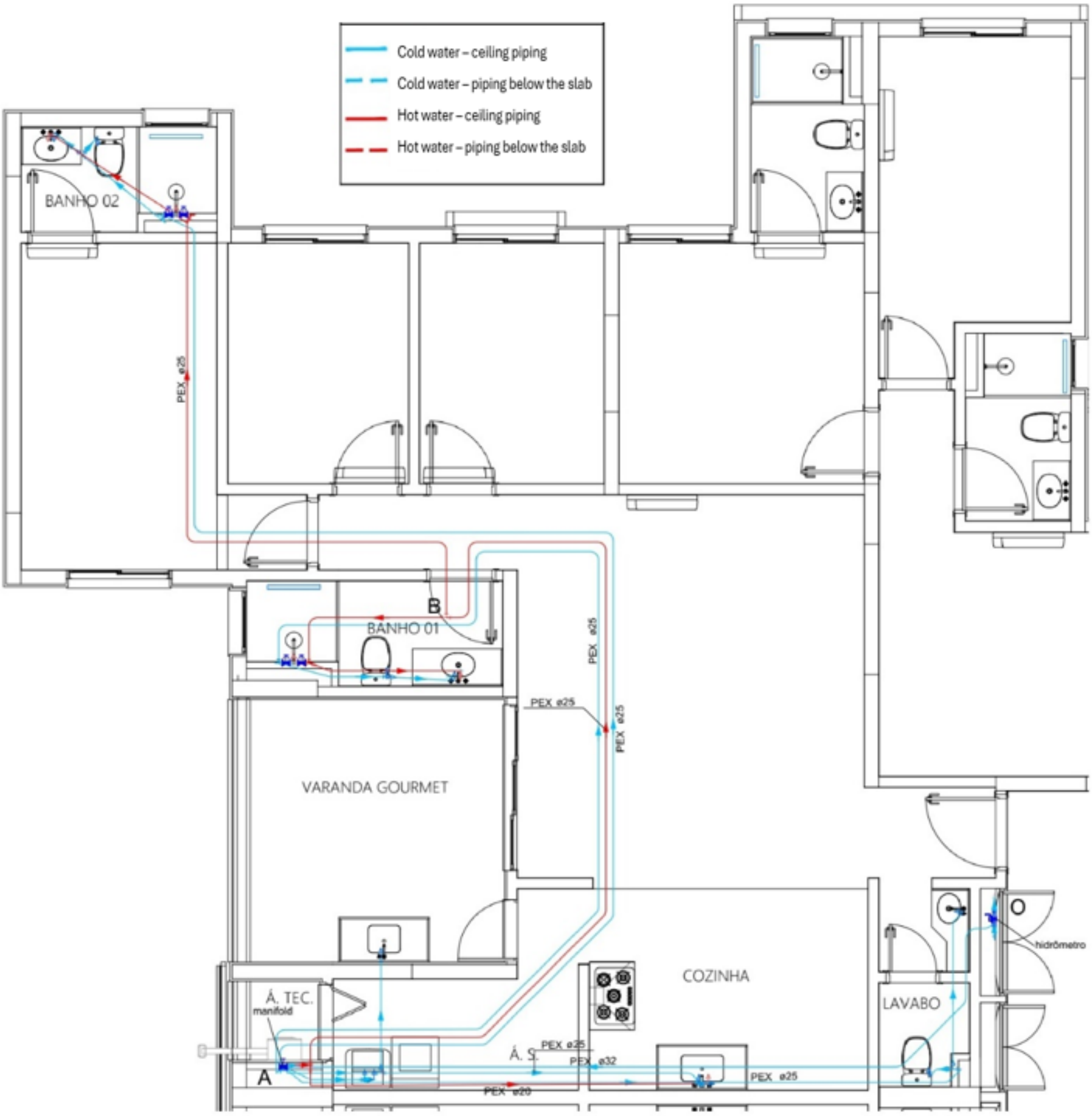
Source: Company specialized in engineering and architecture (2024), adapted by the authors (2024).

Figure 3: Layout of the S2 System (conventional PEX)



Source: Company specialized in engineering and architecture (2024), adapted by the authors (2024)

Figure 4: Layout of the S3 System (partial point-to-point PEX).



Source: Company specialized in engineering and architecture (2024), adapted by the authors (2024).

In Figure 2, it is possible to observe the straight layout of the rigid piping (S1) passing through the ceiling, with direction changes made by means of 90º elbows. In the mentioned figure, the branches for the sanitary rooms were routed below the slab, as can be perceived by the dashed lines.

In Figure 3, it was presented the same straight layout utilized in S1, however the changes in direction occurred due to the curvature of the PEX piping, rather than by using fittings.

In Figure 4, the S3 system presents a configuration that is completely different from S1 and S2, as the 32 mm PEX piping runs directly from the water meter to the technical area, where there is a specific shaft containing valves and a manifold that distributes the PEX piping to each sanitary room.

It is important to highlight that the diameters presented in the designs of Figures 2, 3 and 4 were obtained through calculations performed using the QiBuilder software and are approximated to the nearest commercially available diameter values.

Table 1 presents the quantitative summary of piping and fittings used for the different systems studied. The results correspond to the materials of a standard apartment on the typical floor, including the quantity of pipes, lengths, fittings, and accessories used in the kitchen, laundry area, bathrooms and powder room.

Table 1: Quantitative summary of systems S1, S2 and S3.

Quantity/Length	System S1		Total S1	System S2		Total S2	System S3		Total S3
	CW	HW		CW	HW		CW	HW	
Fittings and valves (units)	81	50	131	44	34	78	30	15	45
Piping (m)	65,6	49,38	115,0	66,67	50,07	116,8	95,55	48,87	144,3

It is observed that the quantity of fittings used decreases when S1, S2 and S3 are compared, respectively, as each PEX system reduced the quantity of curvature components such as elbows and bends (**S2** and **S3**), and branching components as “t” (S3). However, system **S3** has a greater total piping length because it covers longer distances, as all sections that supply the rooms originate from the manifold in the laundry area. Systems **S1** and **S2** have virtually identical piping lengths, as they present the same layout.

3.2 Comparison regarding head loss in the systems

The values of head losses from the water meter and the available pressure at the points of systems **S1, S2 and S3** are presented in Tables 2, 3 and 4, respectively.

Table 2: Head loss from the water meter (H) outlet to the supplied points – S1 System.

Room	**Section**	**Pressures (m.w.c.)**				
		Initial point	**Elevation difference**	**Initial static pressure**	**Total head loss**	**Available pressure**
POWDER ROOM	**H to LV**	15,00	0,60	15,60	2,19	13,41
	H to BS	15,00	1,20	16,20	2,13	14,07
BATHROOM 01	**H to LV-CW**	15,00	0,60	15,60	2,95	12,65
	H to LV-HW	15,00	0,60	15,60	10,79	4,81
	H to BS	15,00	1,20	16,20	2,93	13,27
	H to CH	15,00	-0,95	14,05	11,24	2,81
BATHROOM 02	**H to LV-CW**	15,00	0,60	15,60	3,06	12,54
	H to LV-HW	15,00	0,60	15,60	10,88	4,72
	H to BS	15,00	1,20	16,20	3,05	13,15
	H to CH	15,00	-0,95	14,05	11,30	2,75
LAUNDRY AREA/ KITCHEN	**H to TLR**	15,00	0,60	15,60	7,26	8,34
	H to MLR	15,00	0,60	15,60	7,41	8,19
	H to MLL	15,00	0,80	15,80	7,67	8,13
	H to SINK-CW	15,00	0,60	15,60	7,64	7,96
	H to SINK-HW	15,00	0,60	15,60	7,75	7,85
	H to SINK-VAR	15,00	0,60	15,60	7,30	8,30

H: Water meter; LV: Powder room; BS: Toilet bowl; CH: shower; TLR: Laundry sink;
MLR: Washing machine; MLL: Dishwasher; VAR: Balcony sink.

Table 3: Head loss from the water meter (H) outlet to the supplied points - S2 System.

Room	Section	Pressures (m.w.c.)				
		Initial point	Elevation difference	Initial static pressure	Total head loss	Available pressure
POWDER ROOM	**H to LV**	15,00	0,60	15,60	1,75	13,85
	H to BS	15,00	1,20	16,20	1,60	14,60
BATHROOM 01	**H to LV-CW**	15,00	0,60	15,60	2,44	13,16
	H to LV-HW	15,00	0,60	15,60	5,17	10,43
	H to BS	15,00	1,20	16,20	2,36	13,84
	H to CH	15,00	-0,95	14,05	5,02	9,03
BATHROOM 02	**H to LV-CW**	15,00	0,60	15,60	2,62	12,98
	H to LV-HW	15,00	0,60	15,60	5,31	10,29
	H to BS	15,00	1,20	16,20	2,55	13,65
	H to CH	15,00	-0,95	14,05	5,11	8,94
LAUNDRY AREA/ KITCHEN	**H to TLR**	15,00	0,60	15,60	4,69	10,91
	H to MLR	15,00	0,60	15,60	4,78	10,82
	H to MLL	15,00	0,80	15,80	5,06	10,74
	H to SINK-CW	15,00	0,60	15,60	5,07	10,53
	H to SINK-HW	15,00	0,60	15,60	4,45	11,15
	H to SINK-VAR	15,00	0,60	15,60	4,95	10,65

H: Water meter; LV: powder room; BS: Toilet bowl; CH: Shower; TLR: Laundry sink;
MLR: Washing machine; MLL: Dishwasher; VAR: Balcony sink.

Table 4: Head loss from the water meter (H) outlet to the supplied points – S3 System.

Room	Section	Pressures (m.w.c.)				
		Initial point	Elevation difference	Initial static pressure	Total head loss	Available pressure
POWDER ROOM	**H to LV**	15,00	0,60	15,60	3,52	12,08
	H to BS	15,00	1,20	16,20	3,38	12,82
BATHROOM 01	**H to LV-CW**	15,00	0,60	15,60	3,58	12,02
	H to LV-HW	15,00	0,60	15,60	3,92	11,68
	H to BS	15,00	1,20	16,20	3,49	12,71
	H to CH	15,00	-1,00	14,00	3,78	10,22
BATHROOM 02	**H to LV-CW**	15,00	0,60	15,60	3,84	11,76
	H to LV-HW	15,00	0,60	15,60	4,09	11,51
	H to BS	15,00	1,20	16,20	3,80	12,40
	H to CH	15,00	-1,00	14,00	3,94	10,06
LAUNDRY AREA/ KITCHEN	**H to TLR**	15,00	0,60	15,60	3,22	12,38
	H to MLR	15,00	0,60	15,60	3,27	12,33
	H to MLL	15,00	0,80	15,80	3,74	12,06
	H to SINK-CW	15,00	0,60	15,60	3,75	11,85
	H to SINK-HW	15,00	0,60	15,60	3,99	11,61
	H to SINK-VAR	15,00	0,60	15,60	3,54	12,06

H: Water meter; LV: Powder room; BS: Toilet bowl; CH: shower; TLR: Laundry sink;
MLR: Washing machine; MLL: Dishwasher; VAR: Balcony sink.

The **S1** system, which was implemented with PVC, presented the worst performance in terms of head loss, particularly at the hot water outlets in the bathrooms, where the head loss from the water meter to the outlet exceeded 11 m.w.c.

The **S2 and S3** systems demonstrated superior performance when compared to **S1**. In showers, which represent the most critical points in the **S1** system, **S2** achieved head loss values approximately 53.3% to 54.8% lower than those of **S1**. Similarly, **S3** exhibited values 73.7% to 75.0% lower than **S1**. This improved performance is attributed to the reduced number of fittings required for bends, as these were executed using the PEX tubing itself.

The **S3** system presents consistent results when compared to all connections, with slightly inferior performance in the powder room compared to **S2**, but achieving lower head losses in the sections serving other areas. As a point-to-point system, **S3** employs individual pipes branching from the manifold to supply each area separately, thereby reducing head loss for each specific environment.

Regarding the available pressure at the outlets, considering an initial pressure of 15 m.w.c. immediately downstream of the water meters, all outlets achieved available pressure exceeding the minimum standard requirement of 1 m.w.c. (ABNT,2020). The most critical outlets were the showers in the **S1** system, with available pressures of 2.81 m.w.c. for bathroom 01 and 2,75 m.w.c. for bathroom 02. For the same outlets, the other systems achieved approximately 9 m.w.c. (S2) and 10 m.w.c. (S3).

The S2 system presented an average available pressure of 11.60 m.w.c. across all system outlets, while the **S3** system showed an average of approximately 11.85 m.w.c. In contrast, the **S1** system had an average value of 8.93 m.w.c., with greater variation between the outlets.

The analysis shows that the PEX systems (**S2 and S3**) outperformed the rigid PVC and CPVC piping system (**S1**) in terms of head loss.

3.3 Cost analysis

Table 5 shows the cost values for the materials used in the cold-water distribution in the three systems, while Table 6 presents the cost values for the materials used in the hot water distribution of the same systems.

Table 5: Total cost of the cold-water subsystems (including B.D.I.).

Material	System	Cost (BRL)[1]		
		Piping	Fittings	Total
PVC and CPVC	**S1**	421,80	745,08	1.166,88
PEX	**S2**	837,12	1.422,18	2.259,30
	S3	1.165,52	997,95	2.163,47

[1] SINAPI Base 11/2023 (CEF, 2023).

Tabela 6: Total cost of the hot water subsystems (including B.D.I).

Material	System	Cost (BRL)[1]		
		Piping	Fittings	Total
PVC and CPVC	**S1**	949,46	915,72	1.865,18
PEX	**S2**	537,97	993,86	1.531,83
	S3	495,96	537,89	1.033,85

[1] SINAPI Base 11/2023 (CEF, 2023).

Considering the cold-water system, it is observed that the **S2** system (conventional PEX) and the **S3** system (point-to-point PEX) present significantly higher costs than the **S1** system (PVC and CPVC), with costs 93,6% and 85,4% higher, respectively. The **S2** system incurred the highest expenses related to fittings, while **S3** had higher costs for piping, due to the longer length required for this system. For hot water, the **S1** system had higher cost than the other two systems, with an expense 21.8% higher than the **S2** and 80.4% higher than **S3**.

The CPVC material has higher unit costs in the SINAPI base 11/2023 (CEF, 2023) when compared to PEX, resulting in the reversal of the results in relation to the cold-water systems. Table 7 presents the difference in unit costs for the piping of the three types of materials. The **S1** system had the highest expenses for piping, 76.5% higher than the second highest (**S2**), while **S2** incurred slightly higher costs for fittings, and **S3** had the lowest costs for both piping and fittings, resulting in the lowest total subsystem cost. Regarding labor, Table 8 presents the unit cost of the professional involved.

Table 7: Unit cost of the piping material used (including B.D.I.).

Material	D (mm)	Cost (BRL)[1]
PVC	25	5,17
CPVC	22	19,22
PEX	25	11,53

[1] SINAPI Base 11/2023 (CEF, 2023).

Table 8: Time and unit cost of labor.

Material	System	Working time (h)		Cost (BRL)[1]			
				Unit (BRL/h)		Total (BRL)	
		Plumber	Assistant	Plumber	Assistant	Without B.D.I.	With B.D.I.
PVC and CPVC	**S1**	12,00	12,00	34,68	28,97	763,80	954,75
PEX	**S2**	8,00	8,00	34,68	28,97	509,20	636,50
	S3	8,00	8,00	34,68	28,97	509,20	636,50

[1] SINAPI Base 11/2023 (CEF, 2023).

The reduction in the execution time for the PEX systems results in lower labor costs, which impacts the total cost of the project, as shown in Table 9. It can be observed in Table 9 that, when considering labor costs, the **S3** system (**partial point-to-point PEX**) has a slightly lower total cost compared to the rigid piping **S1** system, with a value 3.8% lower.

Table 9: Total cost of the systems (including B.D.I.).

Material	System	Cost (BRL)[1]				
		Materials			Labor	Total
		Cold water	Hot water	Total		
PVC and CPVC	**S1**	1.166,88	1.865,18	3.032,06	954,75	3.986,81
PEX	**S2**	2.259,30	1.531,83	3.791,13	636,50	4.427,63
	S3	2.163,47	1.033,85	3.197,32	636,50	3.833,82

[1] SINAPI Base 11/2023 (CEF, 2023).

Regarding material costs, it is observed that when purchasing materials for the **S1** and **S3** systems, the total costs of PEX are 85% higher when compared to PVC and 44% lower when compared to CPVC. Lourenço and Rodrigues (2020) also reported that PEX showed a cost reduction of approximately 58.9% when compared to rigid CPVC piping.

When taking into account only the materials, the **S3** system had a cost 5% higher than **S1**. In both cases, the difference between the values obtained is small, considering an acceptable margin of error- a difference of BRL100,00 to BRL150,00 between the two systems – meaning the costs for both systems may be considered pratically identical. The **S2** system was identified as the most expensive of the three evaluated systems, with a total cost of approximately BRL440,00 to BRL590,00 higher than the other two, which represents a cost difference of 11% to 15%.

Thus, it is possible to observe that PEX material presents a significantly higher cost than PVC material, especially when utilized in the same layout as the rigid piping, as occurred for **S2**. Additionally, it can be observed that the layout of a partial point-to-point system results in fewer connections, lower costs in the hot water subsystem when compared toCPVC, and a reduction in labor costs. These attributes enable the PEX system to be competitive with the **S1** system in terms of costs.

3.4 Indicators

The **S2** system presented the higher cost among the three systems, with a value 9.3% higher than **S1**. The difference between the pipe lenghts of the two systems is small, as they share the same overall layout, and the higher cost of the PEX material resulted in this increase in the value of the indicator. Table 10 presents a percentage comparison between the costs of each system.

Table 10: Cost comparison of the three systems (in BRL).

Cost comparison[1]	PVC and CPVC	PEX		PEX and PVC/CPVC Relation	
	S1	S2	S3	S2-S1	S3-S1
Materials	3.032,06	3.791,13	3.197,32	25,03%	5,45%
Labor	954,75	636,50	636,50	-33,33%	-33,33%
Total	3.986,81	4.427,63	3.833,82	11,06%	-3,84%

[1] SINAPI Base 11/2023 (CEF, 2023).

In relation to the rigid piping system **S1**, both PEX systems presented a reduction in labor costs of approximately one-third or 33,33%. In agreement, Anselmo and Oneda (2023) also identified that the PEX system proved to be 19,79% more economical compared to the use of PVC, with the lower labor cost being a significant factor.

The **S2** system (conventional PEX) presented an increase in material cost and the total value, while the **S3** system (partial point-to-point PEX) presented a small difference in material costs – 5,45% higher – and in total cost – 3,84% lower, so the total costs of both systems may be considered practically identical. The point-to-point PEX system (**S3**) proves to be competitive compared to the conventional rigid piping system (**S1**).

Given the quantity of materials used, the lenghts of the piping in each system, and the costs from the project's synthetic budget, several indicators related to the costs of each system were defined. Table 11 provides the values obtained for the cost per linear meter of piping for each system.

Table 11: Cost per linear meter of piping for the systems.

Material	System	Total cost[1] (BRL)	Piping length (m)	Cost per linear meter (BRL/m)
PVC and CPVC	**S1**	3.986,81	115,00	34,67
PEX	**S2**	4.427,63	116,80	37,91
	S3	3.833,82	144,30	26,57

[1] SINAPI Base 11/2023 (CEF, 2023).

It is observed that the **S3** system (partial point-to-point PEX), with the lowest total cost and the longest piping length, achieved the lowest value of the indicator, showing a 23,4% difference when compared to **S1** with PVC and CPVC, and 29,9% difference when compared to the **S2** system, with conventional PEX.

To conclude this section of analysis, the cost indicator values defined in this study were compared with those from other studies. Considering the inflation, the cost values from these studies were adjusted based on the IPCA index from IBGE (Brazilian Institute of Geography and Statistics), which is the official inflation index of Brazil, as recongnized by the Federal Government. Table 12 provides a comparison of the values related to the cost per linear meter of piping, between this study and the studies by Nóbrega (2019) and Santos (2022).

Table 12: Comparison of the values obtained and the values from other studies regarding the cost per linear meter.

Source	Material	Cost (BRL		Piping length (m)	Cost per linear meter (BRL/m)
		Total	Updated by the IPCA		
Nóbrega (09/2019)	**PVC**	279.440,10	320.314,29	5505,50	58,18
	PEX	320.352,10	367.210,56	6705,00	54,77
Santos (07/2022)	**PVC AND PEX**	559,25	652,84	29,85	21,87
	PEX	622,69	726,89	31,22	23,28
This research (11/2023)	**PVC AND CPVC (S1)**	3.986,81	3.986,81	115,00	34,67
	PEX (S2)	4.427,63	4.427,63	116,80	37,91
	PEX (S3)	3.833,82	3.833,82	144,30	26,57

Based on the comparison of the cost indicators per linear meter of the PEX systems obtained in this study with the indicators from the works by Nóbrega (2019) and Santos (2022), it may be observed that the cost per linear meter ranges from BRL54,77 to BRL23,28. A significant variation is noted between the values obtained from each study, which was expected given the substantial differences in the objects of study of each work. The standard layout of the apartments considered vary between cases, the amount of labor and their work hours are defined by different criteria and some of the systems evaluated by authors such as Nóbrega (2019) and Santos (2022) consists of mixed systems with both rigid and flexible piping.

However, upon reviewing the values obtained for their respective systems, it may be observed that, in general, the systems executed with PEX tend to present higher costs compared to rigid piping systems (whether mixed or not). At the same time, flexible systems with PEX tend to exhibit a lower cost per linear meter of piping used when compared to rigid piping systems in most cases.

4 Conclusion

This research confirmed, specifically for this case study, that the PEX S3 system performed better in terms of head loss in its layout and also presented a 23,4% lower cost relative to the length of piping used. This system has not proven to be much more complex in its design and modeling compared to the conventional layout, despite requiring the architecture to include shafts for the manifolds and main valves, something that is becoming increasingly common for mid- to high- standard apartments.

In relation to the use of a point-to-point layout, even partial, executed with PEX material, as it was performed for S3 system, it was possible to obtain total costs – considering material and labor- equivalent to the cost of a system built with rigid PVC and CPVC, as S1 system.

It was found that, among the evaluated systems, the PVC/CPVC system presented the lowest material cost while the PEX system had the lowest labor cost. The cost per meter indicator for the rigid system was BRL34,57, while for the conventional and point-to-point PEX systems, it was BRL 37,91/m and BRL 26,57/m, respectively.

Considering the limited scope of this study, which involves a single apartment layout configuration and simulation in floors with an initial branch pressure of 15 m.w.c., it was possible to demonstrate the effectiveness of the partial point-to-point PEX system as a technical and economic alternative to the conventional PVC and CPVC system.

It should be emphasized that the results obtained in this study are valid only for this specific case study, and are not necessarily applicable to any construction project, serving purely to academic purposes.

As for future works, it is suggested to compare traditional systems using PVC and CPVC with the use of prefabricated kits; explore the challenges related to the acquisition of PEX piping and fittings; compare the use of different systems in apartments located on the top floor and in areas near the operating limits of pressure reducing valves, as well as consider methods to standardize the development of cost indicators per linear meter for PEX systems.

References

ABNT – ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 15939-1:** Sistemas de tubulações plásticas para instalações prediais de água quente e fria – Polietileno reticulado (PE-X). Parte 1 - Requisitos e métodos de ensaio. Rio de Janeiro, 2023. 41 p.

ABNT – ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 15939-2:** Sistemas de tubulações plásticas para instalações prediais de água quente e fria – Polietileno reticulado (PE-X). Parte 2 - Procedimentos para projeto. Rio de Janeiro, 2023. 10 p.

ABNT – ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 15939-3:** Sistemas de tubulações plásticas para instalações prediais de água quente e fria – Polietileno reticulado (PE-X). Parte 3 - Procedimentos para instalação. Rio de Janeiro, 2023. 10 p.

ABNT – ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 5626:** Instalação predial de água fria. Rio de Janeiro, 2020. 64 p.

ALTOQI. **Como são calculadas as perdas de cargas em condutos PEX na disciplina Hidráulico do AltoQi Builder?**. 2022. Available at: https://suporte.altoqi.com.br/hc/pt-br/articles/8454925135639-Como-s%C3%A3o-calculadas-as-perdas-de-cargas-em-condutos-PEX-na-disciplina-Hidr%C3%A1ulico-do-AltoQi-Builder. Accessed: February, 2024.

ALTOQI.. **Software para projetos de instalações prediais**. Versão atualização 2023-11 [*S.l.*] 11 nov. 2023. Available at: https://www.altoqi.com.br/builder. Accessed: December, 2023.

ANSELMO, Mariana Silva; ONEDA, Tânia Mara Sebben. In: XV SIMPÓSIO NACIONAL DE SISTEMAS PREDIAIS (SISPRED 2023), nº XV, 2023, Joinville -SC. **Aspectos técnicos e econômicos de diferentes tipos de materiais nos sisteas prediais hidráulicos: análise comparativa entre PEX E PVC**. Joinville -SC 20/08/2023. 127-135. Available at: https://eventos.antac.org.br/index.php/sispred/article/view/2982/3674. Accessed: July, 2024

BRANDÃO, Rosana Gouveia. **Estudo da viabilidade da utilização de PVC, PEX e PPR em empreendimentos familiares**. 2010. Projeto de graduação (Graduação em Estruturas e Engenharia Civil) – Curso de Engenharia Civil, Escola Politécnica da Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2010.

CAIXA ECONÔMICA FEDERAL. **Referências de preços e custos**. In: https://www.caixa.gov.br/Downloads/sinapi-a-partir-jul-2009-sp/SINAPI_ref_Insumos_Composicoes_SP_202311_Desonerado.zip. Accessed: November 2023

CAVALCANTE, Felipe Martins. **Aplicação de inovações tecnológicas e de novos sistemas construtivos nas instalações hidráulicas e sanitárias: um ganho na produtividade**. 2019. Monografia (Graduação em Engenharia Civil) – Curso de Engenharia Civil, Universidade Federal do Ceará, Fortaleza, 2019.

CREDER, H. **Instalações Hidráulicas e Sanitárias**. 6ª. Ed. Livros Técnicos e Científicos, Rio de Janeiro: Guanabara, 2006. 423p

DOS SANTOS, Vitor Manuel; MODOLO, Marcelo Romano. **Sistema PEX e as inovações nas instalações prediais**. Revista Científica Semana Acadêmica, ed. 000183, v. 1, 2019. Available at: https://semanaacademica.org.br/artigo/sistema-pex-e-inovacoes-nas-instalacoes-prediais. Accessed: February, 2022.

FREITAS, Walace; BRASIL, Luiz; PALÁCIO, Humberto. **Vantagens do uso do BIM para a modelagem de instalações prediais**. In: CONGRESSO DE CONSTRUÇÃO CIVIL – CONSTRUÇÃO 2020, 12., 2020, Brasília-DF. Anais [...] Brasília: Universidade de Brasília, 2020. p. 205-215.

INSTITUTO BRASILEIRO DO PVC. **Arquitetura e construção**. 2024. Available at: https://pvc.org.br/arquitetura-e-construcao. Accessed: July, 2024.

LOURENÇO Arthur, Ferreira; RODRIGUES, Rafael Felipe Teixeira. **Sistema de tubulações flexível como solução eficaz para instalações hidráulicas**. Revista Boletim de Gerenciamento, ed. 21, 2020. Available at: www.nppg.org.br/revistas/boletimdogerenciamento. Accessed: February, 2022.

NÓBREGA, Karen Tayna Fernandes De Almeida Nóbrega. **Análise da viabilidade econômica da utilização do PEX como alternativa ao PVC em projeto hidráulico de uma edificação multifamiliar**. 2021. Projeto de Trabalho de Conclusão de Curso (Bacharelado em Engenharia Civil) – Curso de Engenharia Civil, Instituto Federal de Educação, Ciência e Tecnologia da Paraíba, Campus Cajazeiras, Paraíba, 2021.

SANTOS, Adriano Lucas Luna dos. **Análise comparativa entre instalações prediais de água fria com utilização de PEX e PVC-estudos de caso: condomínios praia de Ponta Negra e praia de Pipa em Natal/RN**. 2022. Trabalho de Conclusão de Curso. Universidade Federal do Rio Grande do Norte. 2022.

SOUZA, Carolina Corrêa. **Aspectos econômicos e hidráulicos da utilização do PEX como alternativa em projetos de instalações hidráulicas prediai**s. 2011. Trabalho de Conclusão de Curso (Graduação em Engenharia Sanitária e Ambiental) – Curso de Engenharia Sanitária e Ambiental, Universidade Federal de Santa Catarina, Santa Catarina, 2011.

TIGRE. **Orientações técnicas sobre instalações de água quente**. 2021 Available at: https://www.tigre.com.br/catalogos-tecnicos. Accessed: March, 2022.