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COMPARATIVE ANALYSIS OF FINANCIAL COSTS AND ENVIRONMENTAL IMPACTS OF INDIVIDUAL AND COLLECTIVE COLD WATER DISTRIBUTION SYSTEMS

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ABSTRACT

Sustainable development is an essential concept for businesses, governments and people today. Construction is one of the largest economic sectors in the world and directly affects nature. Therefore, it is important to understand how construction and sustainable development interact. This work aims to analyze this interaction through a comparative feasibility study between collective or individualized cold water distribution systems in enterprises. The main objective is to find a model that optimizes the environmental costs with the financial costs, something that has not been much explored in the literature. The method used to achieve the objective is a case study conducted with buildings in the neighborhood of Icaraí, in the city of Niterói/RJ. First, to study the environmental impact, the Life Cycle Analysis of the polyvinyl chloride (PVC) tubes used in the installation of each distribution type is performed. Then through simulations based on TCPO software and real water consumption data in buildings, the financial analysis of each type of distribution is performed. It can be concluded that the collective distribution system is generally cheaper to install and use. However, the environmental impact generated by the use of PVC in this type of distribution is greater. Therefore, the engineer is subject to a trade-off between sustainable development and financial costs when choosing which distribution to deploy. However, for middle-class enterprises, the results are clearer and suggest that individual distribution is more efficient, both financially and environmentally.

Keywords: sustainable development; construction; water distribution systems; environmental impact.

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1. INTRODUCTION

The way society has been conducting its development is causing the degradation of ecosystems and the depletion of natural resources. Adhya et al. (2010) point out that the modern world consumes more and more resources, produces more pollutants, and seeks more space and energy. On the other hand, the world has been through more natural disasters than a few decades ago. These disasters are the result of growing market demands; however, society naturally wants protection from these disasters. So, there is a clear contradiction between the development model and the yearning for a healthy environment.

The search for more space is particularly related to construction, which is the sector responsible for meeting this demand. Buildings affect nature in a variety of ways, either during the construction process, which is the use of too much energy, forest devastation or changing course of rivers or after the project is completed, because if the project is not done efficiently, buildings may use more water or electricity than necessary, for example.

Therefore, there is a direct relationship between construction and environmental degradation, which should be studied. In this context there is an important concept to be addressed, which is sustainable development. There are several definitions for sustainable development, but generally speaking, the concept suggests that development must reconcile economic growth with the reduction of environmental impacts.

This paper will explore the concept of sustainable development from the point of view of reconciling the construction of a building with the reduction of the environmental impact and the financial costs involved in this process.

In particular, this paper uses data on the installation and use of individual and collective cold water distribution systems in different types of buildings, and tests which of the two types is most financially efficient as well as environmentally sound.

The case study uses the Life Cycle Analysis (LCA) technique, taking polyvinyl chloride (PVC) tubes as a base, to estimate the environmental impacts of each type of water distribution. It is also studied which of the distributions is related to a higher water consumption after the building is built. For the financial analysis, the TCPO program is used to calculate the installation cost of each distribution and actual water consumption data in buildings, to see which distribution generates the most expenses later, in Niterói/RJ.

This approach is important in practice, as companies ultimately seek profit. So it is no use finding the most sustainable way to construct a building if companies will not be able to invest in it. We need to study how to make this reconciliation.

In addition to this introduction, the article has four more sections. The first section makes a brief bibliographical review about the studied subject. The second describes and presents the LCA for PVC in the construction of the buildings. The third focuses on the financial calculations of each type of distribution. Finally, the last section presents the final considerations of the study.

2. LITERATURE REVISION

The literature related to environmental and financial impacts is large, but has no consensus. The results do not indicate whether sustainable development practices are compatible with healthier finances or not. Alberton (2003), for example, analyzes finance in the period before and after the NBR ISO 14001:96 certification of companies. In the overall result, certification seems to help in many, but not all, financial indicators.

The literature compared to environmental costs of cold water distribution methods is small. In fact, this is one of the motivations for this study.

In international literature, it is difficult to find articles dealing with the topic. A study that is marginally related to this article is that of Arbués and Barberan (2004). The authors do not address the type of distribution (collective or individual), but they do address the impacts of changes in price on the demand for water in buildings. The authors found that the price is reasonably effective in controlling water demand. In other words, if the price of water goes up, demand will reduce reasonably.

It is possible to draw a parallel between this result and the present study. By finding out which distribution system is most financially efficient, i.e. which is the cheapest for the client/resident, it can be inferred that this system would generate a higher demand for water. That is, a cheaper water cost can be interpreted as a relative price reduction, which would stimulate higher water consumption, according to Arbués and Barberan (2004).

It is therefore important to consider this effect in our analysis. This is because the analysis is done both in the dimension of environmental impact reduction and in the financial cost reduction in construction. However, if this cost reduction causes residents to consume more, the reduction in environmental impact may be less than expected.

In terms of national literature, there are some specific studies analyzing collective and individual water distribution. The study by Matos (2003) gives a good description of the process of implementing individual water distribution in buildings. The text addresses various dimensions of deployment, from customer engagement to system change challenges. The article also reviews current legislation and highlights that there are deficiencies in water regulation.

Carvalho (2010) presents a perspective that can mitigate the possible negative effect of the results of Arbués and Barberan (2004). Carvalho (2010) points out that individual measurement in buildings can lead to a reduction in consumption. In addition, Carvalho (2010) discusses the solutions available to deploy the individualized system. Like Matos (2003), Carvalho also presents an overview of the laws that regulate water distribution in Brazil.

About LCA, specifically PVC (which is also the object of study in this paper), there is the work of Lima (2007) that gives a detailed description of the PVC inventory. His research shows the environmental impacts of PVC pipes from resin manufacturing to pipe disposal after use. This study will serve as the basis for the LCA made here.

Another important article is that of Junqueira (2005), whose study is similar to the one proposed in this article. The author studied a building that changed the system from collective to individual distribution. The difference is that here the results will be simulated and more detailed. However, the results found by Junqueira (2005) may serve as a basis for comparison. The author's main conclusion is that the investment in switching to the individualized system pays back quickly (one month after deployment) and that there is a reduction in water consumption and environmental impact.

It is important to highlight that many of the studies cited are postgraduate dissertations, but few papers have been effectively published. Therefore, in addition to contributing to the specific point of a cost benefit analysis between sustainability and financial cost, in the case of water distribution systems, this article also seeks to consolidate some of the themes addressed in these unpublished works.

3. ENVIRONMENTAL IMPACT ANALYSIS AND FINANCIAL COSTS

The research aims to reconcile LCA with a financial cost analysis, in case of installation and use of collective or individual water distribution in residential buildings. As a sample, projects of buildings of the city of Niterói/RJ were used. In the LCA part, the research objects are PVC pipes and it is calculated how much environmental impact is generated according to the different projects – low/medium, medium and upper middle class buildings, divided into collective and individual distribution. It should be remembered that Law No. 13,312, of July 12, 2016 makes the individual measurement mandatory.

To calculate the financial costs, TCPO software was used to estimate the cost of installing a collective and individual cold water system in the three different types of project. In addition to the installation cost, the cost of use was simulated through a water consumption base, which was provided by a building manager in Niterói/RJ, in six different buildings. The objective was to answer the following questions:

- Which of the two types of systems has the lowest installation cost?
- Which of the two systems has the lowest operating cost?
- Which of the two systems consume more material, and therefore, generates more waste?
- Which of the two types of systems generates less water consumption over its lifetime?

4. LIFE CYCLE ANALYSIS

LCA is a technique for "compiling and assessing the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (ABNT, 2009). The life cycle of a product includes the extraction of raw materials through their transportation, processing, distribution, use, maintenance and disposal after use.

The result of LCA is the quantitative and systematic identification of incoming and outgoing flows of material, energy, waste and other emissions produced throughout the life stream, making it possible to estimate the environmental impact of a given product.

In this study, the LCA methodology was used in accordance with ISO 14040 and ISO 14044 normative documents. The steps are shown in Figure 1 and are divided into four main steps: goal and scope definition, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Assessment (AICV), and interpretation as shown below.

5. LIFECYCLE ANALYSIS OBJECTIVE

LCA's main objective is to measure the potential environmental impacts of the life cycle between two cold water distribution systems (collective vs. individual) in residential developments. Consequently, it is also possible to measure the costs involved in each type of distribution and discuss which one provides the most cost-effective environmental

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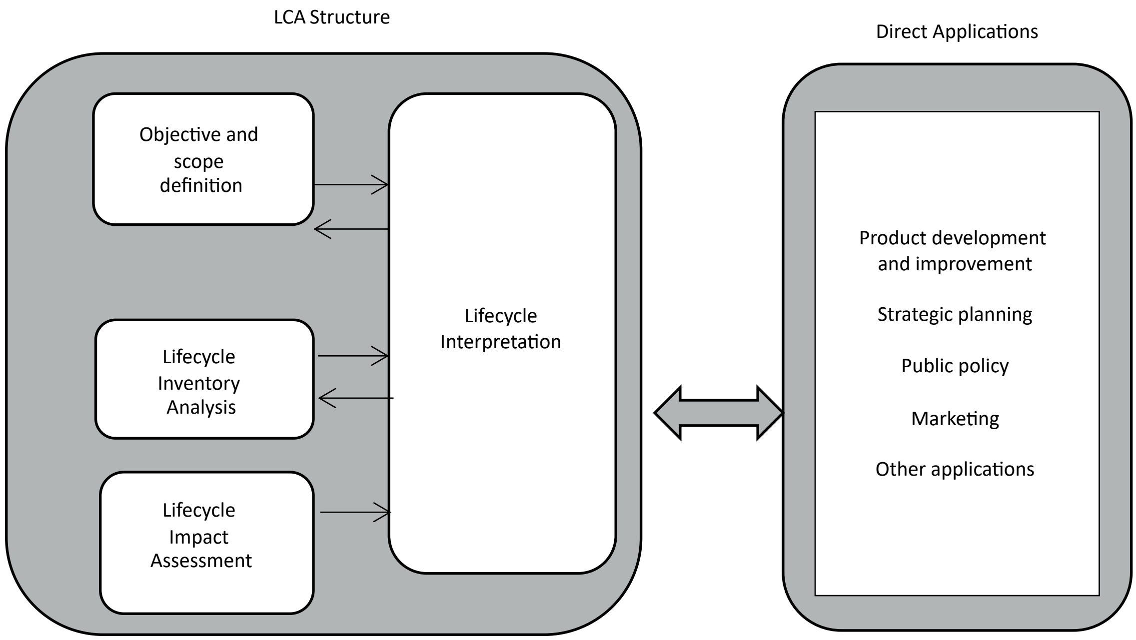

Figure 1. Life Cycle Analysis Framework
Source: Espitia et al. (2015)

and financial terms.

The study involved the analysis of three enterprises (projects) of different typologies, as follows:

- Residential A (Table 1.1)

High-income multi-family building, characterized by: four units of 250m^2 per floor (totaling 52), four elevators and four suites in each apartment.

- Residential B (Table 1.2)

Medium-income multi-family building, characterized by: eight units of 135m^2 per floor (totaling 102), four elevators, and each apartment with three bedrooms (one suite).

- Residential C (Table 1.3)

Medium/low income multifamily building with: eleven units of 74m^2 per floor (totaling 114), four elevators, and each apartment with three bedrooms (one suite).

For the preparation of this study the original projects with individual distribution were used and in parallel new projects of collective distribution were developed. The study was conducted taking into account the norms NBR5648:1997 – "Cold water building systems" and NBR5626:1998 – "Cold water building installation".

The results obtained can be used in the debate on sustainability within the construction industry. In addition, it is intended to contribute to the dissemination of this tool, serving as a basis for decision-making processes in choosing options from various projects.

6. PROJECT ANALYSIS

For the project analysis three different typologies of three residential buildings were selected: one of class A, medium/high (52 units of 250 m2); one of class B, medium (102 units of 135 m2); and one with a medium/low class C typology (114 units of 74m2).

In all projects obtained from the construction companies, the hydraulic installations were individually distributed, according to Law No. 13.312, of July 12, 2016, which requires the individual measurement of water consumption in the new condominium buildings. All designs were analyzed using Autocad software, which made it possible to survey the linear quantity of pipes with different diameters and the number of connections in each one.

Through the floor plan it was possible to raise the entire horizontal quantitative and with the cuts it was possible to raise the vertical quantitative, both expressed in the three tables: 1.1, 1.2 and 1.3. It was also feasible to analyze how the quality of the architectural design contributes to the reduction of material expenses.

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Some information of the individual distribution project was parameterized for comparison with the collective distribution, such as the height of the dishes and metals, slab thickness and right foot, so that some distortions between the two projects were minimized.

For the collective distribution project a new project was created taking into account some variables already parameterized in the individual distribution project, indicated in the observations of tables 1.1, 1.2 and 1.3, in addition to the consultation with NBR 5626 - "Cold water building installation" and Creder (6th Edition/2006).

The collective facilities design was also developed in Autocad software as well as the original designs. The quantities that are also indicated in Tables 1.1, 1.2 and 1.3 were taken from the archive.

With the quantities of each material it was possible to use the TCPO software to arrive at the cost of each of the two different systems in each of the three typologies, as well as the PVC consumption in each of the design options, which made it possible to trace a comparative table between them.

7. SCOPE

Product system

The product system defines what the analyzed product life cycle is like. For this study, a system similar to Figure 2 was considered.

According to Espitia et al. (2015), "the product system has six elementary processes: obtaining raw materials; transportation of raw materials; manufacture; product distribution; use (transportation of the product used); and after use (final disposal, recycling)".

Primary data were obtained from the company Tigre/SA, manufacturer of PVC pipes and consumption data were provided by a building manager in Icaraí (buildings were selected to suit the study typology: upper, middle and lower class). Data regarding extraction, transportation and manufacturing inventory were obtained from Lima (2007). The inclusion of labor costs was made from the TCPO program.

Functional unit, reference flow and system boundary

To analyze the impact of different types of water distribution, we consider the number of PVC pipes (with different sizes) used. The PVC pipe serves, for the purposes of this study, to store and transport water in residential buildings. As for the functional unit, this was defined as the water consumption per inhabitant. The reference flow for the described functional unit was the manufacture of 1kg of PVC tubing.

The system boundary was initially established through the function of the product and the choice of material used, which was PVC. According to Lima (2007), the direct impact of the use of tubes was not considered, but the impact of post-consumer disposal was. Also, according to Lima (2007), authors Darbello (2008) and Matos (2003) consider that only 9% of the pipes go to recycling after use, while the rest goes to landfills.

Life Cycle Inventory (LCI)

After defining the product system, functional unit, and reference flow, the next step involved data collection and calculation procedures to quantify product system inputs and outputs. Thus, the consumption of material resources, energy and emissions to air, water and soil associated with the system were quantified, which is the stage of LCI. In order to simplify the analysis, the focus will be on system outputs, i.e. the focus will be on environmental impact.

To organize the study, the product system was subdivided into five singular processes; thus, the subsystems were delimited as follows: (i) resin manufacturing; (ii) resin transport; (iii) tube manufacturing; (iv) transportation of pipes to stores; (v) transportation of tubes for disposal. Note that the usage phase was not included due to lack of data. The database used was Lima (2007), which was based on studies and on the data collected by Borges (2004).

PVC Resin Manufacturing

Resin manufacturing generates several inputs and outputs; therefore, to simplify the study, focus is given to the fossil carbon dioxide outlets, but not on fossil and sulfur. According to the studies cited above, the impact generated by resin manufacturing for each amount of PVC (see Table 2 for the quantities of each type of enterprise) is:

This step (as you will see later) is one of the most impacting the environment in terms of toxic gases. Even the transport phases where diesel is widely used do not come close to the impact of resin manufacturing.

It is possible to notice that the enterprises in which collective distribution is used generate more gas emissions, due to the greater need for PVC, which is resin.

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Table 1.1. Class A - Calculation of installation cost and quantity of material used for the project

High class enterprises					
TIPOLOGY					
Pattern				High class	
Number of apartments per floor				4	
Number of rooms per apartment				4 suites	
Average square footage of the apartment				250 m^2	
Square footage of slab type					
OBSERVATIONS					
The roof columns - 12 are pressurized					
Columns 12 - 6 and 6 - 2 are not pressurized					
Common areas were neglected, both in terms of survey and water consumption					
The distribution of cold water to the apartment is done through the ceiling					
The distribution of cold water inside the apartment is done by the ceiling					
The right foot considered was 2.5 m + 0.10 m x 2 slabs					
The toilet is 0.30 m from the floor (Ø 20)					
Washbasins are 0.60 m from the floor (Ø 20)					
Washing machine 0.90 m from the floor (Ø 25)					
Tank 0.90 m from the floor (Ø 25)					
Sink 0.70 m from the floor (Ø 20)					
Filter 1.20 m from the floor (Ø 20)					
The showers are 1.80 meters from the floor (Ø 25)					
INDIVIDUAL					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters	0	0	0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	145.80	168	128.55
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	992.81	1142	344.42
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1758.51	2022	384.23
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	1560.00	1794	242.19
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 “depth 15 cm	Units	228.00		
14.006.000057. MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 “flow 5 m³ / h	Units	60.00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 “	Units	60.00		
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 “	Units	0		
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 “	Units	2.00		
Total PVC Consumption (Kg)	1099.39				
Total Linear Footage	5126				
Total labor, without taxes (R$):	R$ 28,705.60				
Total other items, excluding taxes (R$):	R$ 30,609.65				

Grand total, excluding taxes (R$):	R$ 59,315.25				
Grand total, with tax (R$):	R$ 30,198.15				
COLLECTIVE					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters			0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	324.00	373	571.32
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	992.81	1142	344.42
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1766.91	2032	386.07
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	696.00	800	108.05
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 "depth 15 cm	Units	0.00		
14.006.000057. MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 "flow 5 m³ / h	Units	0.00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 "	Units	480.00		
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 "	Units			
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 "	Units	32.00		
Total PVC Consumption (Kg)	1409.86				
Total Linear Footage	4347				
Total labor, without taxes (R$):	R$ 26,513.20				
Total other items, excluding taxes (R$):	R$ 24,972.79				
Grand total, excluding taxes (R$):	R$ 51,485.98				
Grand total, with tax (R$):	R$ 115,800.51				
COMPARATIVE BOARD					
Description	**Individual**	**Collective**	**Difference**	**Percent**	
Total cost	R$ 130.198,15	R$ 115.800,51	R$ 14.397,65	12%	
MDO cost	R$ 28.705,60	R$ 26.513,20	R$ 2.192,40	8%	
Total Linear Footage	5126	4347	779	18%	
Total PVC consumption (Kg)	1099,39	1409,86	-310,47	-22%	

Source: Own elaboration based on the TCPO program

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Table 1.2. Class B - Calculation of installation cost and quantity of material used for the project

Upper-middle class enterprises					
TIPOLOGY					
Pattern				**Upper middle class**	
Number of apartments per floor				8	
Number of rooms per apartment				3 bedrooms (1 suite)	
Average square footage of the apartment				$135m^2$	
Square footage of slab type					
OBSERVATIONS					
The roof columns - 12 are pressurized					
Columns 12 - 6 and 6 - 2 are not pressurized					
Common areas were neglected, both in terms of survey and water consumption					
The distribution of cold water to the apartment is done through the ceiling					
The distribution of cold water inside the apartment is done by the ceiling					
The right foot considered was 2.5 m + 0.10 m x 2 slabs					
The toilet is 0.30 m from the floor (Ø 20)					
Washbasins are 0.60 m from the floor (Ø 20)					
Washing machine 0.90 m from the floor (Ø 25)					
Tank 0.90 m from the floor (Ø 25)					
Sink 0.70 m from the floor (Ø 20)					
Filter 1.20 m from the floor (Ø 20)					
The showers are 1.80 meters from the floor (Ø 25)					
INDIVIDUAL					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters	0	0	0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	145.80	168	128.55
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	992.81	1142	344.42
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1758.51	2022	384.23
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	1560.00	1794	242.19
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 “depth 15 cm	Units	228.00		
14.006.000057.MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 “flow 5 m^3 / h	Units	120.00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 “	Units	120.00		
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 “	Units	0		
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 “	Units	2.00		
Total PVC Consumption (Kg)	1099.39				
Total Linear Footage	5126				
Total labor, without taxes (R$):	R$ 29,959.94				
Total other items, excluding taxes (R$):	R$ 39,834.91				

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Grand total, excluding taxes (R$):	R$ 69,794.84				
Grand total, with tax (R$):	R$ 146,535.79				
COLLECTIVE					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters			0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	648,00	745	571,32
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	992,81	1142	344,42
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1766,91	2032	386,07
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	696,00	800	108,05
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 “depth 15 cm	Units	0,00		
14.006.000057.MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 “flow 5 m³ / h	Units	0,00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 “	Units	1664,00		
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 “	Units			
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 “	Units	32,00		
Total PVC Consumption (Kg)	1409.86				
Total Linear Footage	4719				
Total labor, without taxes (R $):	R$ 39,052.95				
Total other items, excluding taxes (R $):	R$ 29,011.67				
Grand total, excluding taxes (R $):	R$ 68,064.62				
Grand total, with tax (R $):	R$ 160,077.20				
COMPARATIVE BOARD					
Description	**Individual**	**Collective**	**Difference**	**Percent**	
Total cost	R$ 146.535,79	R$ 160.077,20	-R$ 13.541,41	-8%	
MDO cost	R$ 29.959,94	R$ 39.052,95	-R$ 9.093,01	-23%	
Total Linear Footage	5126	4719	406	9%	
Total PVC consumption (Kg)	1099,39	1409,86	-310,47	-22%	

Source: Own elaboration based on the TCPO program.

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Table 1.3. Class C - Calculation of installation cost and quantity of material used for the project

Low-middle class enterprises					
TIPOLOGY					
Pattern				**Upper middle class**	
Number of apartments per floor				11	
Number of rooms per apartment				3 rooms (1 suite)	
Average square footage of the apartment				74m²	
Square footage of slab type					
OBSERVATIONS					
The 12-9 columns are pressurized					
The 9-2 columns are not pressurized					
Common areas were neglected, both in terms of survey and water consumption					
The distribution of cold water to the apartment is done through the ceiling					
The distribution of cold water inside the apartment is done by the floor					
The distribution of hot water inside the apartment is done by the ceiling					
The right foot considered was 2.5 m + 0.10 m x 2 slabs					
The toilet is 0.30 m from the floor (Ø 20)					
Washbasins are 0.60 m from the floor (Ø 20)					
Washing machine 0.90 m from the floor (Ø 25)					
Tank 0.90 m from the floor (Ø 25)					
Sink 0.70 m from the floor (Ø 20)					
Filter 1.20 m from the floor (Ø 20)					
The showers are 1.80 meters from the floor (Ø 25)					
INDIVIDUAL					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters	0	0	0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	118.80	137	104.74
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	2304.50	2650	799.47
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1373.35	1579	300.08
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	643.50	740	99.9
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 “depth 15 cm	Units	275.00		
14.006.000057.MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 “flow 5 m³ / h	Units	121.00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 “	Units	121.00		
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 “	Units	0		
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 “	Units	4.00		
Total PVC Consumption (Kg)	1304.19				
Total Linear Footage	5106				
Total labor, without taxes (R$):	R$ 31,020.86				
Total other items, excluding taxes (R$):	R$ 47,819.11				

Grand total, excluding taxes (R$):	R$ 78,839.96				
Grand total, with tax (R$):	R$ 160,599.16				
COLLECTIVE					
Code	**Description**	**Un**	**Quantity**	**Consumption in Linear Meters**	**Weight**
13.008.000095.SER	Weldable PVC pipe, with Ø 60 mm connections	meters	980.10		0
13.008.000094.SER	Weldable PVC pipe, with Ø 50 mm connections	meters	0.00	1127	864.12
13.008.000092.SER	Weldable PVC pipe, with Ø 32 mm connections	meters	1399.67	0	0
13.008.000091.SER	Weldable PVC pipe, with Ø 25 mm connections	meters	1174.36	1610	305.83
13.008.000090.SER	Weldable PVC pipe, with Ø 20 mm connections	meters	0.00	1351	182.32
05.009.000033.SER	Hole in concrete with widia drill, using electric hammer Ø 1 1/2 “depth 15 cm	Units	0.00		
14.006.000057.MAT	Multi-jet hydrometer for measurement in residential water inlet Ø 1 “flow 5 m³ / h	Units	363.00		
13.004.000024.SER	Crude drawer register Ø 25 mm - 1 “	Units			
13.004.000025.SER	Crude drawer register Ø 32 mm - 1 1/4 “	Units	33.00		
13.004.000025.SER	Pressure reducing valve Ø 50 mm - 2 “	Units	980.10		
Total PVC Consumption (Kg)	1352.27				
Total Linear Footage	4087				
Total labor, without taxes (R $):	R $ 26,008.02				
Total other items, excluding taxes (R $):	R $ 24,399.79				
Grand total, excluding taxes (R $):	R $ 50,407.81				
Grand total, with tax (R $):	R $ 113,462.89				
COMPARATIVE BOARD					
Description	Individual	Collective	Difference	Percent	
Total cost	R$ 160,599.16	R$ 113,462.89	R $ 47,136.27	42%	
MDO cost	R$ 31,020.86	R$ 26,008.02	R $ 5,012.83	19%	
Total Linear Footage	5106	4087	1019	25%	
Total PVC consumption (Kg)	1304.19	1352.27	-48.08	-4%	

Source: Own elaboration based on the TCPO program.

8. RESIN TRANSPORT

Lima (2007) considers the transportation from the Solvay resin factory to the Tigre factory in Rio Claro (SP), totaling 530 km. However, they consider a quantity of 27 tons of resin. To make the analysis compatible, the outputs were recalculated for the resin quantities in each case.

9. PVC PIPE MANUFACTURING

In manufacturing, Lima (2007) considered the information of the companies Tigre S.A and Absoluto Ltda. and data from the Ministry of Mines and Energy. Following the authors, the proportions considered in the manufacture were 82% of PVC resin and 12% of calcium carbonate load (12%).

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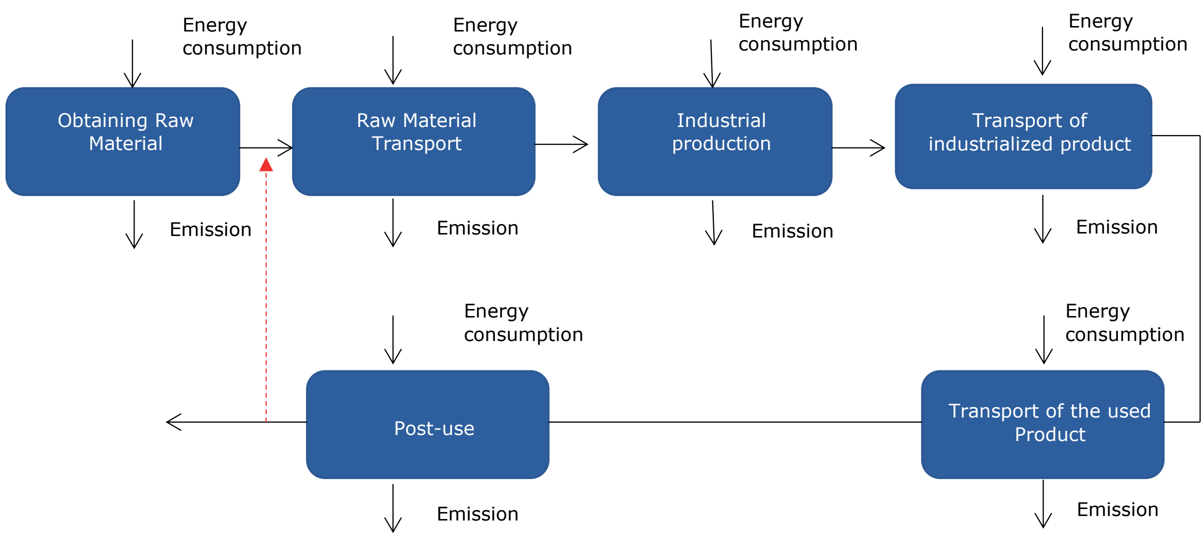

Figure 2. LCA Product System
Source: Epitia, Gondak and Silva (2015)

Loss of water in pipe cooling was not considered. Table 4 shows the amount of heat generated in each case.

Once again collective distribution is associated with more environmental impact, suggesting that it is worse in terms of sustainable development.

10. PVC SHIPPING

Lima (2007) considered the transport of 11.4 tons for a distance of 100 km from the factory in Rio Claro/SP. In this work the weights in each type of project were recalculated and the distance of 600 km were used, as this is the approximate mileage from the factory to Niterói/RJ.

The results again indicate that collective distribution emits more toxic gases and other harmful substances to the environment.

Transport for disposal

For disposal, the weights provided in Lima (2007) were recalculated and the distance was placed at 35 km, which is from Niterói to the nearest landfill, Jardim Gramacho.

The results are repeated suggesting that the collective water distribution generates more impact on the environment in terms of the amount of PVC used in its installation.

Inventory Interpretation

By using the TCPO program, it was possible to calculate the number (in kilograms) of PVC pipes used in each project, such as middle/low, medium and medium/high class buildings, with collective or individual distribution. These quantities are the ones that were used to make the LCA output calculations by distribution type and enterprise type. These quantities are in Table 7.

Table 2. Toxic outputs of resin manufacturing by collective or individual distribution and by type of undertaking (kg/total amount of PVC)

	Resin Manufacturing					
	Individual			Collective		
	A	B	C	A	B	C
CO2 f	177,46	177,46	210,51	181,46	227,57	218,27
CO2 nf	951,55	951,55	1128,81	973,03	1220,28	1170,42
SO2	31,81	31,81	37,73	32,52	40,79	39,12

Source: Own elaboration based on Lima (2007)

Comparing by type of enterprise, it can be observed that the amount of PVC required to set up the collective distribution is greater than for the individual in all cases. This is why all LCA accounts have pointed to collective distribution, in case it is more environmentally harmful in terms of toxic outlets.

The most striking case is for the middle class building, where the collective distribution uses 22% more PVC than in the individual case. For the middle/low and upper middle class enterprises, the difference is only 3.5% and 2.2%, respectively.

This implies that collective distribution generates carbon dioxide and sulfur in resin production, more heat in pipe production, and more components such as ammonia, benzene, particulate matter, among others, at all transport times.

Interestingly, there is no linear relationship between the number of units and the difference in the amount of PVC required per distribution. The number of apartments is decreasing in relation to the increase in class, while the difference in the amount of PVC for collective distribution is 3.5%, 22% and 2.2%, respectively, with the increase in the class. This finding is important because it shows that each designer must do his calculations and not consider that increasing units necessarily increases the amount of PVC and thus the environmental impact.

The result that points out that collective distribution spends more PVC pipes is somewhat surprising from a common sense point of view. One would think that a system that distributes water directly individually would spend more material (PVC) than a central system. However, the numbers show that this is not the case.

Given this result, from the perspective of environmental impact analysis, the collective water distribution is worse than the individual. This means that by installing the collective cold water distribution, more toxic waste is generated for the environment.

In addition, the financial analysis will assess whether any of the distribution types induces more water consumption, which would be harmful to the environment. This fact must be taken into account.

Table 3. Impact of resin transport by collective or individual distribution and by type of undertaking (kg / total amount of PVC)

	Resin Transport					
	Individual			Collective		
	A	B	C	A	B	C
Ammonia	8,87E-10	8,87E-10	1,05E-09	9,07E-10	1,14E-09	1,09E-09
CO2	1,80E-04	1,80E-04	2,14E-04	1,84E-04	2,31E-04	2,22E-04
CO	3,31E-07	3,31E-07	3,93E-07	3,38E-07	4,24E-07	4,07E-07
NOx	1,82E-06	1,82E-06	2,16E-06	1,87E-06	2,34E-06	2,24E-06
N2O	1,95E-09	1,95E-09	2,31E-09	1,99E-09	2,50E-09	2,39E-09
SO2	5,66E-08	5,66E-08	6,72E-08	5,79E-08	7,26E-08	6,96E-08
Benzene	1,88E-09	1,88E-09	2,23E-09	1,92E-09	2,41E-09	2,31E-09
NMVOC	1,07E-07	1,07E-07	1,27E-07	1,09E-07	1,37E-07	1,32E-07
Toluene	3,62E-10	3,62E-10	4,29E-10	3,70E-10	4,64E-10	4,45E-10
Xilene	9,04E-10	9,04E-10	1,07E-09	9,24E-10	1,16E-09	1,11E-09
CH4	2,70E-09	2,70E-09	3,21E-09	2,77E-09	3,47E-09	3,33E-09
Particulate matter	6,55E-08	6,55E-08	7,77E-08	6,70E-08	8,40E-08	8,06E-08

Source: Lima-based Own Preparation (2007)

Table 4. Impact of PVC pipe fabrication by collective or individual distribution and by type of undertaking (kg / total amount of PVC)

	Tube Manufacturing					
	Individual			Collective		
	A	B	C	A	B	C
Heat	3,39E+06	0,00E+00	4,02E+06	3,47E+06	0,00E+00	4,17E+06

Source: Lima-based Own Preparation (2007)

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Table 5. Impact of transportation by collective or individual distribution and by type of undertaking (kg/total amount of PVC)

	PVC shipping					
	Individual			Collective		
	A	B	C	A	B	C
Ammonia	2,99E-05	0,00E+00	3,55E-05	3,06E-05	3,83E-05	3,68E-05
CO2	5,34E+00	0,00E+00	6,34E+00	5,46E+00	6,85E+00	6,57E+00
CO	1,59E-02	0,00E+00	1,89E-02	1,63E-02	2,04E-02	1,96E-02
NOx	5,37E-02	0,00E+00	6,36E-02	5,49E-02	6,88E-02	6,60E-02
N2O	9,49E-05	0,00E+00	1,13E-04	9,70E-05	1,22E-04	1,17E-04
SO2	1,68E-03	0,00E+00	2,00E-03	1,72E-03	2,16E-03	2,07E-03
Benzene	1,02E-04	0,00E+00	1,22E-04	1,05E-04	1,31E-04	1,26E-04
NMVOC	5,78E-03	0,00E+00	6,86E-03	5,91E-03	7,42E-03	7,11E-03
Toluene	1,96E-05	0,00E+00	2,32E-05	2,00E-05	2,51E-05	2,41E-05
Xilene	4,89E-05	0,00E+00	5,80E-05	5,00E-05	6,27E-05	6,02E-05
CH4	1,47E-04	0,00E+00	1,75E-04	1,51E-04	1,89E-04	1,81E-04
Particulate matter	2,99E-03	0,00E+00	3,55E-03	3,06E-03	3,83E-03	3,68E-03

Source: Own Preparation based on Lima (2007)

Table 6. Impact of transporting pipes to landfill (kg/total PVC)

	Transport Disposal					
	Individual			Collective		
	A	B	C	A	B	C
Ammonia	3,98E-04	3,98E-04	4,72E-04	4,07E-04	5,10E-04	4,90E-04
CO2	4,77E-07	4,77E-07	5,66E-07	4,88E-07	6,12E-07	5,87E-07
CO	1,57E-12	1,57E-12	1,86E-12	1,61E-12	2,02E-12	1,93E-12
NOx	1,90E-17	1,90E-17	2,26E-17	1,94E-17	2,44E-17	2,34E-17
N2O	6,19E-25	6,19E-25	7,34E-25	6,33E-25	7,94E-25	7,61E-25
SO2	2,34E-31	2,34E-31	2,78E-31	2,39E-31	3,00E-31	2,88E-31
Benzene	4,76E-39	4,76E-39	5,65E-39	4,87E-39	6,10E-39	5,86E-39
NMVOC	5,51E-45	5,51E-45	6,53E-45	5,63E-45	7,06E-45	6,77E-45
Toluene	2,15E-53	2,15E-53	2,56E-53	2,20E-53	2,76E-53	2,65E-53
Xilene	2,09E-61	2,09E-61	2,48E-61	2,14E-61	2,68E-61	2,57E-61
CH4	6,13E-69	6,13E-69	7,28E-69	6,27E-69	7,87E-69	7,55E-69
Particulate matter	3,80E-75	3,80E-75	4,51E-75	3,89E-75	4,88E-75	4,68E-75

Source: Own Preparation based on Lima (2007)

It is noteworthy that the comparison between the three types of enterprise cannot be made. This is because unit sizes and floor sizes are not the same for all buildings.

In general terms, it is also interesting to note that although transport is present in several phases, its impact is not very significant. The emission of carbon dioxide, for example, accumulated in all transports is 0.005024, but this is only about 1% of what is generated in resin manufacturing.

11. FINANCIAL ANALYSIS

The differential of this study is to consider not only the environmental impact, but also the costs involved in each type of water distribution. For this, it was first analyzed the cost of installing each type and then the cost of using each one.

In the installation part, in addition to the costs of PVC pipes, the following were also considered: concrete hole with widia drill, using electric hammer Ø 1 1/2 ", depth 15 cm; multi-jet water meter for residential water inlet Ø 1",

Table 7. Quantity (kg) of PVC pipe spent on each type of distribution and undertaking.

Undertaking	**A**		**B**		**C**	
Distribution	Individual	Collective	Individual	Collective	Individual	Collective
kg de PVC	1099,39	1124,21	1099,39	1409,87	1304,19	1352,27

Source: Own elaboration with data from TCPO software and studied projects.

with flow rate 5 m³/h; rough drawer register Ø 25 mm - 1 "; rough drawer register Ø 32 mm - 1 1/4"; pressure reducing valve Ø 50 mm - 2 "; and labor costs. Details of calculations are given in the appendix of this study.

Table 8 presents the installation costs of each type of distribution (collective and individual) and for each type of project (class A, B and C).

For each type of enterprise, the cost is separated into total distribution installation cost (which includes inputs and labor) and labor cost only. For A and C projects, both labor costs and total costs are more expensive for individual distribution. On the other hand, in the case of venture B, the costs are cheaper for individual distribution. Here you can see a trade-off to which the designer is subject: In general, the individual system has a higher financial cost, but affects the environment less.

However, based on installation costs alone it is not possible to say which type of distribution is most financially advantageous. This is because in the examples of buildings A and B, the difference is very small compared to the total costs of a building construction, which suggests that small savings over time may mean a change in the choice of the cheapest system. Even in the case of venture C, the difference does not seem to be very high. Therefore, it is necessary to analyze how costs behave over time in each case.

To make this analysis of the dynamics of water consumption in each distribution type and the respective cost, data were collected during 21 months of consumption in six different enterprises in the central region of Niterói (Icaraí, Ingá and City Center). It was sought to respect the definitions of middle/lower, middle and upper/middle classes wherever possible.

The calculation strategy was to use the actual values of water bills to calculate simulated values for the projects studied in the TCPO program. Specifically, from the water bill, it was calculated how much would be the consumption per inhabitant in each type of enterprise, then multiplied by 2.5 (average inhabitants according to the Brazilian Institute of Geography and Statistics - IBGE) and by the number of units of each project. Thus, it was possible to make use of all available data and extract as much information as possible. The results of the 21-month averages are presented in Table 9.

Table 9. Average monthly water cost and consumption per inhabitant per month of buildings surveyed

	Individual		**collective**	
	m³	**R$**	**m³**	**R$**
A	10,94	29,91	10,38	28,40
B	17,90	53,65	32,23	113,91
C	10,38	30,37	17,10	46,00

Source: Own elaboration with data provided by Lumarj (condominium administrator)

The results regarding the installation cost are corroborated: Class A and C buildings have a higher cost when the cold water distribution is done individually for each unit. Again, in the case of class B, collective distribution is more expensive; therefore, the individual distribution in this particular case is more financially advantageous.

Because the results are aligned for installation and use, it is possible to analyze whether there is a break-even point where, after one period of use, one type of distribution would become more advantageous than the other. That is, collective distribution tends to be cheaper at installation, but the average monthly water consumption is higher.

Financial costs clearly relate directly to consumption. Therefore, from an environmental point of view, collective distribution impacts the environment more than individual distribution in terms of water consumption (the same is true of the impacts generated by PVC).

A possible interesting point of analysis is the number of months in which the water consumption was at the minimum threshold, that is, the months when only the minimum fee required by the water distributor was paid. Table 10 shows these numbers.

Table 10. Number of months with minimum water consumption

	Number of Months with Minimum Water Consumption	
	Individual	**Collective**
A	0	1
B	9	2
C	6	5

Source: Own elaboration with data provided by Lumarj (condominium administrator)

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Table 8. Installation costs for collective and individual distribution in each type of enterprise and percentage (%) in relation to the costs of collective installation.

Costs	Individual	Collective	Difference	% of collective costs
Class A				
Total Cost	R $ 130,198.15	R$ 115,800.51	R$ 14,397.64	12%
MDO Cost	R$ 28,705.60	R$ 26,513.20	R$ 2.192,40	8%
Class B				
Total Cost	R$ 146,535.79	R$ 160,077.20	-R$ 13,541.41	-8%
MDO Cost	R$ 29,959.94	R$ 39,052.95	-R$ 9,093.01	-23%
Class C				
Total Cost	R$ 160,599.16	R$ 113,462.89	R$ 47,136.27	42%
MDO Cost	R$ 31,020.86	R$ 26,008.02	R$ 5,012.84	19%

Source: Own elaboration with data from TCPO software and studied projects.

There is a clear relationship between the project typology and water consumption. In the case of class A, with individual distribution, the minimum was not consumed in any month; with the collective distribution the minimum consumed in one month was consumed. In the case of class B, individual distribution generated minimum consumption in nine of 21 months; and, for collective distribution, in two months. For the Class C building, with individual distribution, the water bill was at the minimum rate in six of the 21 months analyzed; with the individual distribution it was five months.

Overall, individual distribution seems to generate a slight tendency towards minimum consumption (two of the three cases). However, the results are very close in class A and C buildings. Only in class B buildings does this difference appear to be most significant.

12. CONCLUSION

The analysis of environmental impacts was done through LCA, PVC pipes for each distribution type and for three different types of enterprise (Class A, high; Class B, medium/high; Class C, medium/low). Projects compatible with the types of enterprise were used through quantitative surveys, through which it was possible to calculate the number of pipes (in kg) used for each type of distribution.

The results showed that individual distribution is, in most cases, better for the environment. That is, to perform the installation of the individual system less amount of PVC pipes is used, which results in less environmental impact.

The financial analysis was based on the TCPO for the installation with real consumption data of projects with similar class A, B and C typologies. From the value of the account the consumption per inhabitant and the average expenditure per cubic meter of water were calculated.

The results showed that individual distribution costs more to install, although it uses fewer pipes, which can be explained by other materials needed for installation. However, individual distribution is related to lower consumption, which generates lower water bill costs. This result is intuitive because, in general, one expects to know exactly how much each person spent, generating the tendency to save.

In general, the study concludes that the engineer/designer is subject to a trade-off, since collective distribution has a greater impact on the environment but is cheaper in financial terms. As the evidence is not indisputable, the importance of taking this cost-benefit ratio into account is even greater.

The results found in this research suggest that factors such as the project typology, number of floors, slab size, number of units per floor and right foot influence the results obtained, and it is not possible to identify a formula to determine which system has the lowest impact per type of venture. This is a point to be studied in future research.

It is also understood that the evaluation of updated projects does not fully cover the implications of the law, as the cost of renovating an old condominium adaptation may make trade-offs unfeasible and is a point of interest for further studies.

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