Universidad de Oviedo

EPM ESCUELA POLITÉCNICA DE MIERES

FINAL DEGREE PROJECT

DEGREE IN CIVIL ENGINEERING

Mention in Hydrology

Sanitation System of a Single-Family Dwelling with Rainwater Harvesting and Greywater Recycling Using a Separate Sewer

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July, 2024

Statement of Originality of the Final Degree Project

I, Mr./Ms. Andrea Fernández Chavarría , a student of the Civil Engineering Degree at the Escuela Politécnica de Mieres, University of Oviedo, declare under my responsibility that:

The TFG presented here with the title "*Sanitation System of a Single-Family Dwelling with Rainwater Harvesting and Greywater Recycling Using a Separate Sewer*" has been carried out under my authorship, is original, and all sources used for its completion have been properly cited within it.

In witness thereof, I sign this statement.

Mieres, July 1, 2024.

Andrea Fernández Chavarría

Relationship of the Final Degree Project with the Sustainable Development Goals

SDG related to the TFG:

Justification:

SDG 6: Promote sustainable water management through rainwater and greywater harvesting and recycling.

SDG 11: Enhance urban sustainability through sanitation systems that optimize water use and reduce the burden on natural resources.

SDG 12: Promote responsible use of water resources and educate about conservation practices in the context of a sustainable dwelling.

SDG 13: Mitigate the environmental impact related to water through wastewater recycling and reuse to improve adaptation and resilience to climate change in a single-family home.

RESUMEN

En este **Trabajo Final de Grado,** se presenta una memoria técnica, compuesta por una memoria descriptiva y unos anexos, del diseño de la red de saneamiento de una vivienda unifamiliar aislada con un sistema de reciclaje de aguas grises y pluviales, ubicada en la ciudad de Gijón, en el Principado de Asturias. La finalidad de esta memoria es servir como base en el desarrollo futuro del proyecto de la vivienda.

A lo largo del trabajo, se analizarán detalladamente los componentes necesarios para la captación, almacenamiento, tratamiento y distribución del agua reciclada. El objetivo principal es diseñar e implementar un sistema de saneamiento que maximice la eficiencia en el uso del agua mediante la captación de aguas pluviales y el reciclaje de aguas grises. La integración de un sistema separativo permite una gestión diferenciada de las aguas según su origen y calidad, posibilitando su reutilización en aplicaciones específicas, como el riego de jardines, el uso en cisternas y lavadoras,

También se presentan ciertos aspectos constructivos de la vivienda desarrollados paralelamente en otro TFG titulado *“Diseño y Cálculo de una Vivienda Unifamiliar Aislada Bajo el Estándar Passivhaus”.*

Por último, se exploran las ventajas y los desafíos de implementar un sistema de este tipo, evaluando su viabilidad técnica, económica y ambiental en el contexto de una vivienda unifamiliar

Asimismo, el presente documento busca aumentar la conciencia ambiental entre la población. Más allá de los aspectos técnicos y económicos, se pretende enfatizar la importancia de adoptar una mentalidad sostenible en el uso diario del agua. Al mostrar cómo las prácticas de reutilización y conservación del agua pueden integrarse eficazmente en la vida cotidiana de una vivienda unifamiliar, el estudio aspira a inspirar un cambio en la percepción y el comportamiento de los individuos hacia un consumo más responsable.

De esta manera, se espera que la adopción de estos sistemas no solo optimice el uso del recurso hídrico, sino que también promueva una mayor sensibilización y compromiso hacia la protección del medio ambiente.

ABSTRACT

In this **Final Degree Project** (TFG), a technical report is presented, consisting of a descriptive report and annexes, on the design of the sanitation network of a detached single-family house with a greywater and rainwater recycling system, located in the city of Gijón, in the Principality of Asturias. The purpose of this report is to serve as a foundation for the future development of the housing project.

Throughout the work, the necessary components for the collection, storage, treatment, and distribution of recycled water will be analysed in detail. The main objective is to design and implement a sanitary system that maximizes water use efficiency through the collection of rainwater and the recycling of greywater. The integration of a separative system allows for differentiated management of water according to its origin and quality, enabling its reuse in specific applications such as garden irrigation, cisterns, and washing machines.

Certain construction aspects of the house, developed in parallel in another TFG titled *"Diseño y Cálculo de una Vivienda Unifamiliar Aislada Bajo el Estándar Passivhaus"* are also presented.

Lastly, the advantages and challenges of implementing such a system are explored, evaluating its technical, economic, and environmental viability in the context of a single-family house.

Additionally, this document aims to raise environmental awareness among the population. Beyond the technical and economic aspects, it seeks to emphasize the importance of adopting a sustainable mindset in the daily use of water. By demonstrating how water reuse and conservation practices can be effectively integrated into the daily life of a single-family home, the study aspires to inspire a change in individuals' perception and behaviour towards more responsible consumption.

In this way, it is expected that the adoption of these systems will not only optimize the use of water resources but also promote greater awareness and commitment towards environmental protection.

DESCRIPTIVE REPORT

Contents Index

Illustrations Index

Tables Index

1. Background

1.1. Water scarcity: An Increasingly prevalent problem

Water scarcity is defined as the point at which the consumption of users affects the supply or quality of water, in such a way that the demand cannot be fully satisfied.

The supply of drinking water is crucial for health, industry, and agriculture. Currently, the countries most affected by water scarcity are in the Middle East and North Africa, although countries like Spain are also experiencing high levels of water stress.

It is considered **water scarcity** when the water deficit is chronic due to meteorological causes such as droughts and climate change. On the other hand, **water stress** refers to situations where demographic pressure and pollution, rather than the decrease in available water resources, are the causes of the scarcity. [2]

The causes of water scarcity in the world are diverse, with the main ones being:

- **Pollution:** The pollution of freshwater, as well as the pollution of land and air, can infiltrate water bodies and affect their quality.
- **Drought:** Climate change has intensified droughts, causing prolonged periods without rain, resulting in a scarcity of water for human consumption, agriculture, and industry.
- **Uncontrolled Water Use:** Both on a large scale in factories and on a small scale in households, the excessive use of water contributes significantly to its scarcity.

Water scarcity can have devastating consequences, including:

- **Diseases:** The lack of access to clean drinking water and proper purification systems forces people to rely on contaminated sources, which can lead to illnesses.
- **Hunger:** Water scarcity affects agriculture, livestock, and industry, leading to food shortages and, subsequently, hunger.
- **Species Extinction:** Both plant and animal species depend on water to survive, so water scarcity threatens biodiversity.
- **Conflict:** The lack of water resources is the root of numerous conflicts and causes people to be displaced in search of safe places to live.

Although the total global supply of freshwater still exceeds demand, water problems are significant due to its uneven distribution. For example, South America has 26% of the world's water resources but only 6% of the global population, while Asia, with 60% of the global population, has only 36% of the available freshwater. Currently, 550 million people live in countries with water scarcity and water stress.

1.2. The importance of water reutilization

Given the problems associated with water, its consumption, unequal distribution, and immense importance for life, it is evident that water conservation, controlled consumption, and reuse are essential to maintaining our way of life.

According to *R.D. 1620/2007*, **reclaimed water** refers to water that has been used and then subjected to the necessary treatment processes to meet the quality requirements for a new private use, before being returned to the public water domain.

Water reuse is an essential strategy for the sustainable management of water resources. Through resource conservation, pollution reduction, economic savings, and adaptation to climate change, water reuse offers a comprehensive solution to the current and future challenges related to water scarcity. Promoting and adopting water reuse practices is fundamental to ensuring a future where water is available for all necessary uses without compromising the health of our planet.

This document highlights the urgent need to adopt sustainable water management practices and demonstrates how water reuse can significantly contribute to global water security [5].

1.2.1. Household reclaimed water

Regarding the reuse of urban water, two approaches can be considered: treating only greywater or treating all wastewater, which includes both greywater and blackwater.

Greywater: refers to the water from showers, bathtubs, and sinks, and sometimes also includes water from sinks, washing machines, and dishwashers. Greywater has a very low contaminant load and is practically free of human faecal matter. Its treatment is very simple and is typically used to feed the toilet cisterns. The volume of greywater is at least 40% of the total in domestic use (sink + shower) and the consumption of the toilet is estimated at 30%, so this expenditure is covered. With an average consumption of 144 litres per person per day in Spain, 43 litres per person per day could be saved.

Wastewater: includes both greywater and blackwater. Blackwater is contaminated liquid that contains faecal matter and urine. It requires piping and treatment systems to comply with current regulations. This water cannot be used for other activities unless it undergoes treatment, which requires more infrastructure and investment.

For this project, it has been decided to give use only to greywater, due to the amount of biodegradable organic matter contained in the blackwater.

1.3. Rainwater harvesting

Given the water scarcity situation mentioned previously, a rainwater harvesting process will also be implemented. Rainwater harvesting involves filtering the rainwater collected on a specific surface, such as a roof or terrace, and storing it in a tank. The treated water is then distributed through a hydraulic circuit independent of the drinking water network. With the installation of a rainwater harvesting system, up to 40% of drinking water consumption in the home can be easily saved.

Although not potable, rainwater is of high quality due to its low concentration of contaminants. This water is ideal for many domestic uses, such as toilet flushing and garden irrigation, where it can substitute for drinking water.

Rainwater harvesting is carried out using building roofs as collection surfaces. The water is collected through gutters or drains on the roof, conveyed through downpipes, and stored in a tank.

Incorporating rainwater into greywater provides an additional source of clean water, reducing the concentration of contaminants in the greywater through dilution. This facilitates the subsequent treatments necessary to reuse this water, expanding the possibilities for water savings and conservation.

1.4. Water quality

1.4.1. Reference parameters

The control of the quality of water intended for the supply of the population is a comprehensive process that begins at its source, such as reservoirs, rivers, and wells. This monitoring continues during its treatment at drinking water treatment plants (DWTP) and extends along its journey through the distribution network until it reaches the final consumer.

At each of these points, water samples are collected and subsequently analysed in the laboratory. Technicians, using appropriate techniques, evaluate the necessary parameters to determine if the water is suitable for human consumption. The parameters that must be controlled in the water reaching the consumer's tap include, at a minimum: Odor, taste, colour, turbidity, and conductivity.

Likewise, water intended for reuse in a single-family home must meet certain parameters to be considered suitable for its use. There are different parameters to determine water quality, ensuring that it meets the required standards for both consumption and reuse.

According to *Real Decreto 1620/2007*, the following parameters are established to evaluate water quality [9]:

Microbiological

- **Intestinal nematodes**: Parasites that can transmit pathogens and affect the quality of treated water.
- **Escherichia coli**: Its presence indicates failures in water disinfection or contamination after treatment.

Physicochemical

- **Suspended solids**: Small particles that indicate water quality, as they can transport contaminants.
- **Turbidity**: A measure of the loss of water transparency due to suspended particles. It influences the Odor, taste, and potential toxicity of the water.

Physical

- **Taste and Odor**: Subjective determinations important for drinking water.
- **Conductivity and resistivity**: A measure of the water's ability to conduct electricity, indicating the presence of impurities.

Chemical

- **pH**: Determines the acidity or alkalinity of the water.
- **Hardness**: Concentration of minerals such as calcium and magnesium.
- **Alkalinity**: Ability to neutralize acids, important to prevent corrosion and foaming.
- **Colloids**: Suspended material that requires specific treatments for its removal.
- **Total Kjeldahl nitrogen**: Indicates the amount of nitrogen, relevant for water quality.

Biological

- **BOD (Biological Oxygen Demand)**: Measures the oxygen consumed in the elimination of organic matter.
- **COD (Chemical Oxygen Demand)**: Measures the capacity of a chemical oxidant to consume oxidizable materials, providing a rapid measurement.

These parameters are used to ensure the water meets the required standards for both consumption and reuse.

To determine the reference parameters for rainwater and greywater, we will start from the indicative values provided by *Aqua España* (Spanish Association of Water Treatment and Control Companies).

Table 1 . Rainwater parameters. Source: AquaEspaña [8]

	PARAMETERS	VALUES FOR RAINWATER
PHYSICOCHEMICAL PARAMETERS	pH	4.4-5.7
	Electric conductivity	10-50 µS/cm
	Dissolved oxygen	2.8-5.4 mg/L
	Dissolved carbon dioxide	1-3.2 mg/L
	Total dissolved salts	4.9-12.9 mg/L
	Suspended solids	60 mg/L
	COD	30 mg/L
	BOD_5	5 mg/L
	N. total	1.6 mg/L

Table 2. Greywater parameters. Source: AquaEspaña [7]

	PARAMETERS	VALUES FOR GREYWATER
PHYSICOCHEMICAL PARAMETERS	Suspended solids	45-330 mg/L
	BOD_5	90-290 mg/L
	N Kjedahl	2.1-31.5 mg/L
	Turbidity	22-200 NTU
MICROBIOLOGICAL PARAMETERS	Total coliforms	10^{1} -10^{6} UFC/100ml
	Escherichia Coli	10^{1} -10^{5} UFC/100ml

The water quality is defined by the intended use R.D. 1620/2007 provides quality criteria for water reuse that the project will have to comply with:

Table 3. Permissible parameters of the output water. Source: RD 1620/2007[9]

Uses	***MAXIMUM ALLOWABLE VALUES***			
	INTESTINAL NEMATODES	ESCHERICHIA COLI	SUSPENDED SOLIDS	TURBIDITY
	1-Urban uses			
QUALITY 1.1: RESIDENTIAL *a) Private garden irrigation* *b) Sanitary appliance discharge*	1 egg/10L	0 UFC/1000mL	10 mg/L	2 UNT

1.5. Installations for the Reuse of Greywater and Rainwater

To achieve the values previously stated, the wastewater intended for reuse must undergo treatments to eliminate or reduce organic matter, turbidity, suspended solids, or intestinal nematodes. To this end, various treatments will be proposed.

Every water treatment facility, whether for rainwater or greywater, has a series of clearly identifiable components that make up its basic structure. The common parts of these facilities are described below:

1. **Harvesting network**:
    - Rainwater: Includes roofs and building covers, as well as gutters, drains, channels, and pipes that collect and channel rainwater.
    - Greywater: A set of pipes that collect greywater from various points of origin and channel it to the storage and subsequent treatment system. This network is independent of the sewage network.

2. **Primary filtration system:**
   Separation, through a mechanical or physical type of discriminating filter, of the larger particles or waste from the catchment network.

3. **Storage system**:
   Tanks that store the collected water, whether rainwater or greywater. In the case of greywater, storage initiates the treatment process using the appropriate equipment.

4. **Secondary treatment - Purification**:
   Application of one or more treatments responsible for reducing the pollutant load of the filtered water. These treatments may include different stages to reach the minimum water quality level sufficient for reuse at the authorized consumption points. They are carried out inside one or more tanks or containers and can be

done through aeration, chemical treatment, biological treatment, or a combination of these methods.

5. **Uses of treated water**:
   Reuse for garden irrigation, washing machines, and toilet tank refilling.

2. Purpose

The aim of this document is both the design and implementation of a greywater recirculation system from the kitchen and bathrooms of a single-family home, as well as the use of abundant rainwater in the area, to reduce the family unit's water consumption by more than 40%.

To this end, different alternatives for the treatment of water to be reused will be presented, guaranteeing its suitable quality for various uses such as toilet tank refilling and garden irrigation.

Furthermore, this work aims to raise awareness about the need for good water management in our cities, given the imminent scarcity of this essential resource in an increasing number of points on the planet.

3. Dwelling characteristics

3.1. Situation and location

The designed dwelling is located in the Somió neighbourhood (Gijón), in the Principality of Asturias.

The location provides the installation with a significant flow of rainwater to be managed, for its optimal use in the new applications to which it will be destined.

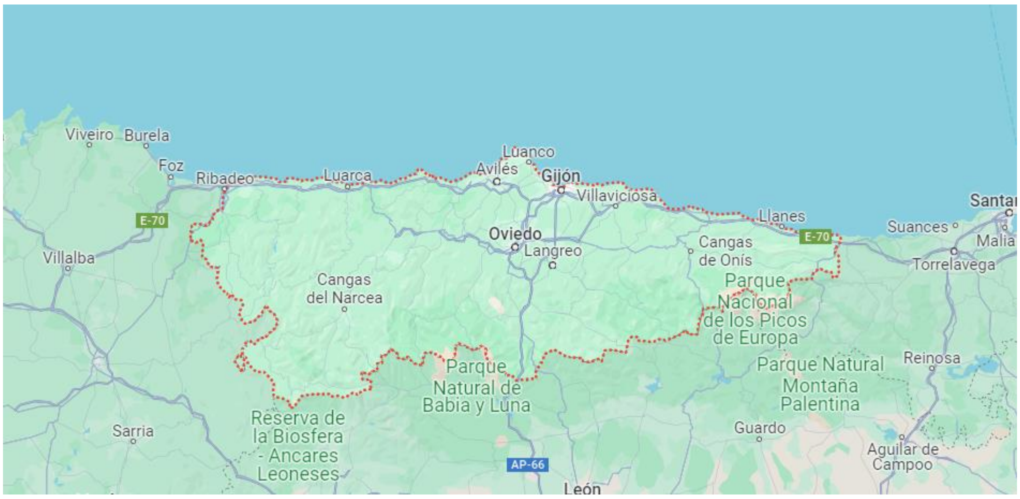

Illustration 1: Location of the Principality of Asturias. Source: Google Maps

Illustration 2: Location of the neighbourhood of Somió, in the locality of Gijón. Source: Google Maps

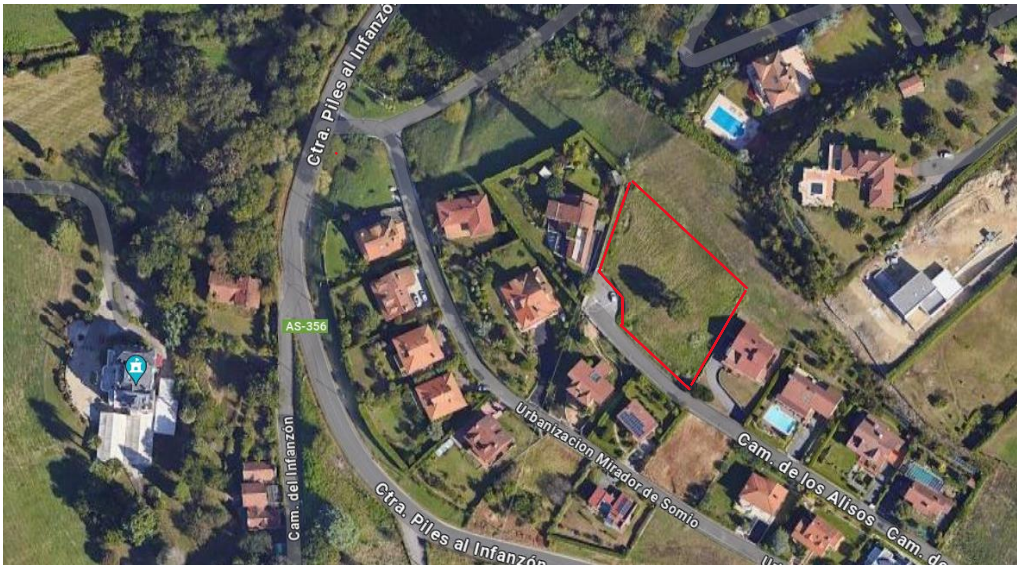

Illustration 3: Exact location of the dwelling. Fuente: Google Maps

3.2. Characteristic data

The dwelling has 3 bathrooms, 1 toilet, and 1 kitchen distributed over three floors of 3 meters each, as shown in ANNEX III. Therefore, for the calculation of greywater production, there will be 3 showers, 4 sinks, one sink, one washing machine, and one dishwasher. Illustration 4 and Illustration 5 show the main views of the designed house [1].

Illustration 4: View from the front (south) of the house. Source: Own Elaboration

Illustration 5: Northwest view of the house. Source: Own Elaboration

Regarding the rainwater supply, the catchment area consists of an extensive green roof and another flat roof without gravel of 95 m^2 and 65 m^2 respectively.

Illustration 6: Roof covers of the house. Fuente: Own Elaboration

As for the garden, no conditioning work has been carried out, so its extension is unknown. All the water available after its use in toilet tank refilling and washing machine, will be considered for irrigation of that area.

3.2.1. Foreseeable generated flows

ANNEX I specifies the calculation of the estimated annual flows of both rainwater and greywater, which are as follows:

Rainwater:**100,650L/year**
Greywater: **156,220 L/year**

Therefore, adding both flows, a total water generation of **257,000 L/year** is expected.

3.2.2. Demanded flows

The entire treated water will be used for garden irrigation, washing machine, and toilet tank refilling, as mentioned earlier. Extracting the data from ANNEX I, it can be concluded that the demanded flow is: **257,000 L/year.**

The demanded flow is equal to the generated flow, so the water needs for the chosen uses can be met.

4. Rainwater

4.1. Rainwater harvesting

As mentioned earlier, rainwater will be collected from two flat roofs of different composition. All the collected water will be derived from them, through small eaves, into a light well that will act as a filtering module for this water for reuse.

Each roof has its own filtration system that serves as a primary screening for leaves, branches, or other large objects that may reach the installation.

- **Green roof:**
  It consists of an extensive green roof of the "Sedum carpet" type from ZinCo. This system is an ecological alternative to conventional roofs with gravel layers. They are lightweight and low-profile, and once the vegetation is established, maintenance is limited to one or two inspections per year.

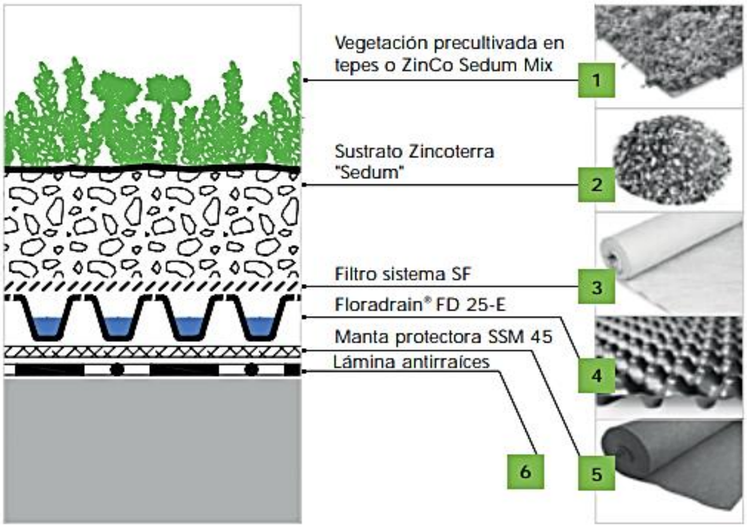

Illustration 7: Layer Distribution of the "Sedum Carpet" System. Source: ZinCo Green Roofs

The drainage and water retention element used in this system is the Floradrain FD 25-E, suitable for use under extensive landscaping, which has concavities for water retention, as well as a continuous channel system on the lower side that allows excess water to be safely drained.
To prevent the water from causing filtration problems on the facade, a small eave with a drip edge will be provided, through which the water will descend in a "waterfall" manner towards the light well.
The roof itself acts as a filter for large solids to facilitate the subsequent treatment stages.

- **<u>Inverted roof:</u>**
  The composition of this roof consists of an inverted flat roof with gravel. As with the green roof, eaves will be provided on the drainage facades, but in this case, aluminium TRP 80 profiles will be added, which will act as gravity stops and gravel retainers. The vertical part is perforated to allow the flow of water towards the evacuation area and to retain large solids that could interfere later.

Illustration 8: TRP 80 Eave Profile. Source: ZinCo Green Roofs

4.2. Treatment system: Filtration module

As mentioned earlier, the main treatment process for rainwater will be carried out in the enclosure formed by the light well, which can be seen in Illustration 4. This will consist only of a primary filtration system to achieve the necessary parameters for its reuse.

It has been decided to build a filtering module composed of various overlapping layers of materials. The main function of the filter is to purify the water that passes through it, removing small particles, solids, and dissolved chemicals or heavy metals that could be harmful, depending on the materials that make it up, the design, and the intended use of the water. The purification percentage provided by this instrument will depend on these factors.[4]

The layers that constitute it are as follows:

1. **Pebble stones:** The pebbles are placed on the surface of the rain garden. They help disperse the water flow, reduce the speed of rainwater, and prevent erosion. They will constitute a thickness of about *10 cm*. In this layer, a perforated horizontal pipe will be placed to control the water level in the rain garden, allowing drainage when the water reaches a certain level.

2. **Filter layer:** The main purpose is to allow water drainage and therefore contain less than 3% silt and clay. It is clearly appropriate to create a substrate to maintain the expansion of plant roots, and to promote a rich microbiological environment. Considering the root system of the chosen plant variety, the thickness of this layer should not exceed *40 to 60 cm*.

3. **Transition layer:** This area pretends to be a filter to prevent the vertical migration of the materials that make up the biofilter in the drainage area. This area must be composed of well-calibrated sand with less than 2% fine particles. To speed up drainage, each lower layer must have greater hydraulic conductivity compared to the upper ones. The minimum thickness of this layer should be *10 cm.*

4. **Activated carbon:** Activated carbon is effective for filtering contaminants and improving the quality of water that infiltrates the soil. The thickness of this layer will also be about *10 cm*.

5. **Drainage system:** made up of fine aggregates (gravel size from 2 to 7 mm). The main function of this area is to collect and transport the treated rainwater and, finally, in this particular layered design, maintain and store a reserve of water accessible to the vegetation during dry periods. The thickness of this area should be between *45 and 50 cm*.

   Integrated into this layer is the drainage system that helps direct excess water out of the rain garden, preventing waterlogging and ensuring a constant water flow.

6. **Impermeable layer:** The impermeable layer prevents water from penetrating the underlying soil, directing it towards the drainage system or specific infiltration areas.

7. **Concrete lining:** It will serve as a structural base for the rain garden, providing stability and support.

Table 4. Water Quality of the Effluent. Source: TFG Filter Module [2]

PARAMETERS	VALUES
Permeate SS [mg/L]	*0,1*
Permeate Turbidity [UNT]	*0,2*
Permeate BDO_5 [mg/L]	*5*
Escherichia coli UFC/100ml (with chlorination)	*Absence*
Intestinal nematodes [eggs/L]	*Absence*

4.3. Storage tank

The drains will divert the treated water to a common storage tank along with the treated greywater.
The chosen tank will be underground (the location can be seen in ANNEX III in order to maintain a low aesthetic profile and be able to use the area above the tank for other purposes. In addition, the soil will provide thermal insulation and protection against sunlight and extreme environmental conditions.
Given the generated and demanded flows, the estimated necessary volume for the tank, calculated in ANNEX I, will be **4,224 L.**
For this reason, the 5,000 L capacity horizontal polyethylene tank commercialized by the company Depurpack SL, suitable for underground installation and wastewater storage, has been chosen. This tank has high physical and mechanical resistance, lightweight handling, and excellent corrosion behaviour.

Illustration 9: Treated Water Storage Tank. Source: DKDepurPack

5. Greywater

5.1. Greywater harvesting

It is essential to perform the necessary calculations to properly size the greywater collection network. This system must connect the drains of sinks, showers, washing machines, dishwashers, and sinks to the treatment system in a simple and efficient manner.

In the case of greywater, the network must link the drainage of the appliances that generate this water with the set of pipes and fittings that will transport it to the discharge and storage points of the treatment equipment.

Within the possibilities of configuring sanitation networks, the following options are available [10]:

1. Unitary: The water treatment is performed jointly, meaning that the rainwater and greywater intended for reuse are collected and treated together.

2. Separative: The treatment is performed separately, where the rainwater is given certain treatments to achieve the minimum required quality; and the greywater is given the treatments it needs to achieve the same quality.

3. Pseudo-separative: They have a single pipe for the rainwater and wastewater from the building, and another pipe for the runoff from the public road.

4. Doubly separative: It evacuates domestic, industrial, and rainwater separately.

For this project, a **separative** sanitation network has been chosen, as it offers multiple advantages:

- **Efficiency in Wastewater Treatment:** By separating greywater from rainwater, it can be ensured that greywater is treated properly and efficiently. This is crucial for complying with local water treatment regulations and protecting the environment.
- **Reduced Flood Risk:** Separating rainwater and directing it to an independent drainage system (such as a rain garden, infiltration well, or rainwater collection system) can help prevent saturation of the home's sewage system and reduce the risk of flooding in the yard or adjacent areas.
- **Rainwater Reuse:** A separative network allows the collection and use of rainwater for non-potable purposes, such as garden irrigation, car washing, or use in toilets. This can significantly reduce potable water consumption and associated costs.
- **Simplified Maintenance:** Maintaining separate treatment and drainage systems can simplify maintenance. Problems in the rainwater system (such as blockages or leaks) will not affect the wastewater system and vice versa. This facilitates the identification and resolution of issues.
- **Protection of the Septic System:** For single-family homes using septic tanks, separating rainwater reduces the load on the septic system. Septic tanks are designed to handle a specific amount of wastewater, and the infiltration of rainwater can overload the system, leading to failures and high maintenance costs.
- **Compliance with Regulations:** In many areas, local construction and sanitation regulations require the separation of wastewater and rainwater. Implementing a separative network from the beginning ensures compliance with these regulations and avoids legal and public health issues.
- **Environmental Benefits:** Proper rainwater management helps reduce soil erosion and pollution of nearby water bodies. By allowing rainwater to infiltrate the soil, aquifers are recharged, and groundwater quality is improved.

The plan view of the greywater sanitation network, calculated in ANNEX II, can be seen in ANNEX III.

Regarding the ventilation system, only a primary ventilation system will be necessary. Its objective is to ensure a minimum air circulation to facilitate the evacuation of gases, prevent odors, and avoid water backflows in the users' network through the appliances.

5.2. Treatment system: Compact systems

Compact water treatment systems are designed to occupy a minimum of space and are particularly useful in environments where space is limited, such as small towns, individual residences, and buildings. Although they require less space, these systems generally involve higher energy costs and require constant control and specialized personnel for efficient operation.

Compared to extensive and semi-intensive systems, compact systems are more suitable for urban environments and areas with space constraints, providing advanced and efficient treatment in a reduced format, and therefore are the most suitable for this project [11].

There are mainly two types:

- **Biological Treatment Plant:**

Within the biological treatment systems for homes, there are compact biological filters, commonly known as "filter septic tanks". These systems stand out for their simplicity, low cost, and minimal maintenance needs. An additional advantage is that they do not depend on electricity and do not require highly qualified personnel for their maintenance.

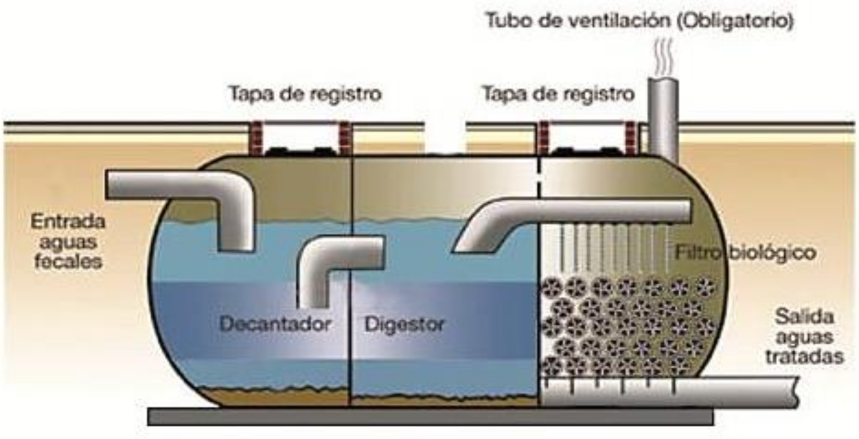

Illustration 10: Biological Treatment Plant "Filter Tank". Source: DepósitosparaLíquidos

- **Total Oxidation Treatment Plant:**

Total oxidation treatment plants have a first tank where a set of diffusers injects air, keeping the water in permanent oxygenation, which favours the elimination of organic matter through the action of aerobic bacteria.
Within this group, there is a wide variety of typologies such as *Sequential Sludge Reactors, Membrane Bioreactors.*

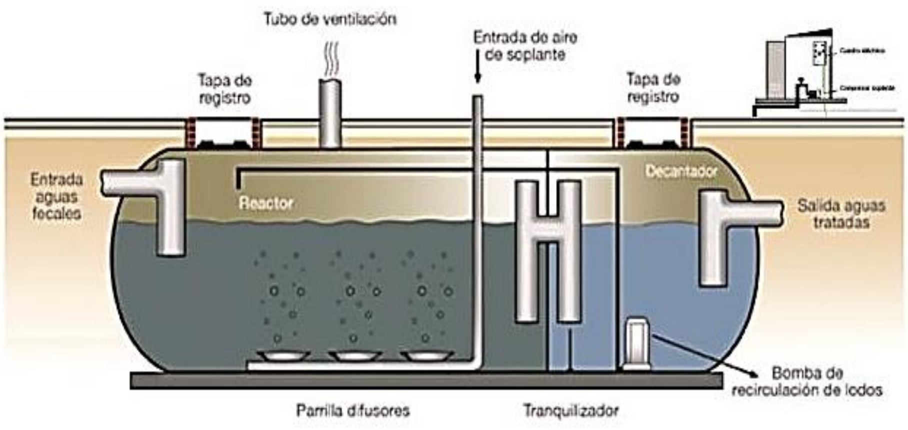

Illustration 11: Complete Oxidation Treatment Plant. Source: DepósitosparaLíquidos

The following provides a more extensive presentation of each of the compact treatment systems, for their subsequent comparison and selection of the most suitable for the project.

5.2.1. Presentation of alternatives

1. Biological Treatment Plant (Compact Biological Systems)

Compact biological treatment plants use natural processes, such as microorganisms and plants, to decompose contaminants in a controlled environment. These systems are designed to integrate natural and technological components in a reduced space.

Main Components:

1. Biological Reactor: Where the degradation of organic matter takes place through the action of microorganisms
2. Natural Components: Such as aquatic plants, which help in the absorption and treatment of pollutants.

Advantages:

- High efficiency in the elimination of organic matter and suspended solids.
- Low operating cost due to natural processes
- Moderate maintenance, focused on the health of plants and microorganisms.
- Positive environmental impact, with integration of natural processes.

Disadvantages:

- Requires more space compared to some complete mix systems.
- Initial cost can be high due to the complexity of the design.
- Less adaptability in extreme climates or very limited spaces.

2. Sequential Batch Reactors (SBR)

Sequential Batch Reactor (SBR) systems are a type of wastewater treatment system that operates in cycles. Unlike continuous flow systems, SBRs operate in sequential phases in a single tank. Each cycle includes filling, aeration, settling, and decanting phases, allowing for biological treatment and solids separation in the same reactor.

Cycle Phases:

- Filling: The tank is filled with wastewater.
- Aeration: Air is introduced to promote microbial activity and the degradation of organic matter.
- Settling: Aeration is stopped to allow solids to settle.
- Decanting: The treated effluent is discharged.

Advantages:

- High efficiency in the removal of organic matter and nutrients.
- Ability to handle variations in load and flow.
- Smaller space required compared to other traditional systems.

Disadvantages:

- Requires precise cycle control and trained personnel.
- Moderate initial and operating cost due to control technology**.**

3. Membrane Bioreactors (MBR)

Membrane bioreactors (MBR) combine biological processes with membrane filtration. In these systems, the wastewater is biologically treated and then passes through membranes that retain solids, microorganisms, and some dissolved contaminants, producing a very high-quality effluent.

Main Components:

1. Biological Reactor Tank: Where the degradation of organic matter takes place.
2. Filtration Membranes: Can be microfiltration or ultrafiltration, located inside the biological tank or in a separate tank.

Advantages:

- Very high efficiency in the removal of organic matter, suspended solids, and pathogens.

- Production of high-quality effluent, suitable for reuse.
- Very compact space required.

Disadvantages:

- High initial and operating costs due to advanced technology and membrane replacement.
- Requires intensive maintenance and specialized personnel.

4. Rotating Biological Contactors (RBC)

Rotating Biological Contactors (RBC), are biological treatment systems where a series of large, rotating discs are partially submerged in the wastewater. The rotation of the discs allows a biofilm of microorganisms to form, alternating its exposure to water and air, facilitating biological treatment.

Main Components:

1. Rotating Discs: Large plastic or similar material discs, mounted on a horizontal shaft.
2. Treatment Tank: Where the wastewater is placed, and the discs rotate slowly.

Advantages:

- High efficiency in the removal of organic matter.
- Low energy consumption.
- Relatively simple operation and maintenance.

Disadvantages:

- May require more space than some other compact systems.
- Less adaptable to large variations in contaminant load.
- Moderate initial cost

5. Extended Aeration

Extended Aeration is a variant of the activated sludge system that operates with longer hydraulic retention times and solids retention times. This allows for greater sludge stabilization and a reduction in the production of biological sludge.

Main components:

1. Aeration tank: Where the biological treatment takes place with prolonged aeration.
2. Secondary clarifier: Separates the treated effluent from the activated sludge.
3. Sludge recirculation system: Recycles a portion of the settled sludge back to the aeration tank.

Advantages:

- Excellent removal of organic matter, nutrients, and suspended solids.
- Reduced sludge production due to the extended aeration and stabilization.
- Simpler operation and maintenance compared to other activated sludge variants.
- Ability to handle fluctuations in flow and load.

Disadvantages:

- Larger tank volume required due to the longer hydraulic and solids retention times.
- Higher energy consumption due to the prolonged aeration.
- Potential for foaming and bulking issues if not properly managed.
- Moderate initial and operating costs compared to other biological treatment systems.

5.2.2. General comparative

Table 5. Comparative of different compact treatment systems. Source: Own elaboration

CRITERIA	BIOLOGICAL TREATMENT	SBR	MBR	RBC	EXTENDED AERATION
Efficiency	*High*	*Very high*	*Very high*	*High*	*High*
Initial cost	*Moderate to high*	*Moderate*	*High*	*Moderate*	*Moderate to high*
Operative cost	*Low*	*Moderate*	*High*	*Moderate*	*Moderate*
Maintenance	*Moderate*	*Moderate*	*High*	*Moderate*	*Moderate*
Space requirement	*Larger*	*Compact*	*Very compact*	*Moderate*	*Larger*
Environmental impact	*Positive*	*Neutral to positive*	*Neutral to negative*	*Neutral*	*Neutral*
Technical complexity	*Low to moderate*	*Moderate to high*	*High*	*Low to moderate*	*Moderate*
Sludge production	*Low*	*Moderate*	*High*	*Moderate*	*Low*

After considering all the available options, the decision has been made to implement a total oxidation treatment plant. This choice is based on the fact that its smaller size will facilitate the installation and allow more efficient control of flow fluctuations throughout the day. It will also offer greater ease in monitoring its operation.

Within the range of total oxidation treatment plants, the **SBR treatment plant** has been chosen. This decision is because SBR systems use a single tank, which significantly reduces the necessary investment and associated construction costs. Additionally, SBR systems are easy to control and require a lower level of technical knowledge. They also demonstrate a good capacity to adapt to variations in the incoming flow throughout the day.

The estimated quality of the water obtained at the outlet of the treatment is:

Table 6. Water Quality of the Effluent. Source: Aqualia

PARAMETERS	VALUES
Permeate Suspended Solids [mg/L]	*0,8*
Permeate Turbidity [NTU]	*0,3*
BOD_5 of the Permeate [mg/L]	*7*
Escherichia coli CFU/100ml (with chlorination)	*Absence*
Intestinal Nematodes [eggs/L]	*Absence*

5.2.3. Equipment selection

After an exhaustive selection process, it has been decided to implement the BIOX system, marketed by the company *Depurpack SL*. This decision is based on the advanced treatment technology offered by the system, its efficiency in greywater reuse, and its compatibility with the specific requirements of the project. In addition, the reputation and experience of Depurpack SL in the water treatment sector have been decisive factors in the choice.

The BIOX system treats greywater through an efficient and safe process. Initially, the water passes through a settling tank to retain coarse solids, then it is directed to an SBR (Sequencing Batch Reactor) biological reactor that operates with activated sludge in a medium load regime. The clarified effluent is pumped to a filtration and disinfection module, where sodium hypochlorite is added to eliminate pathogens.

The treated water is pressurized for the secondary network, being used in toilet flushing, irrigation systems, and pavement washing. The system includes the SBR biological reactor and the WATER SMART BOX control module, equipped with programmable clocks to manage the treatment cycles.

According to the manufacturer, it has the following advantages:

- **Easy Installation:** Requires minimal human intervention and is suitable for underground installation.

- **Simple Maintenance:** Automatic operation that minimizes human intervention.
- **Reduced Costs:** Low initial investment and operating costs.
- **Modern Design:** State-of-the-art equipment without noise, odors, or visual impact.
- **High Safety**: High hydraulic and sanitary functional safety.
- **Regulatory Compliance:** The system complies with all the requirements of *Real Decreto 1620/2007*, which establishes the legal regime for the reuse of treated water.

The BIOX system provides an advanced and practical solution for the reuse of greywater in single-family houses.

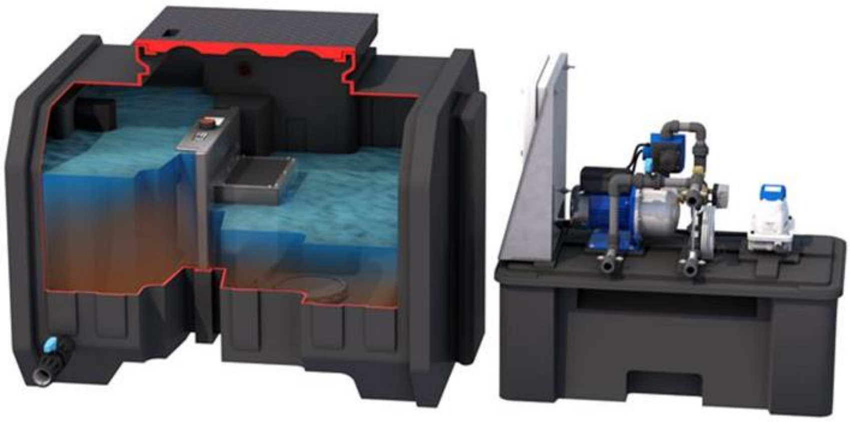

Illustration 12: SBR BIOX6 Wastewater Treatment Plant. Source: DKDepurPack

Similar to the treated water tank, the equipment will be installed underground to maintain a low aesthetic profile and allow the area above the tank to be used for other purposes.

Since the generated greywater flow is **428 L/day**, the BIOX6 model for flows up to 1,325 L/day will be sufficient.

5.3. Storage tank

As mentioned in section 4.3, the same tank will be used to discharge both the treated greywater and the rainwater.

6. Return installation

6.1. Pumping system

Since this project requires pumping and lifting water from an underground tank, the use of submersible pumps is recommended. These are particularly suitable for applications where the water is at a considerable depth and needs to be pumped to the surface. Some of their advantages are:

- **Design:** These pumps are designed to operate underwater, making them ideal for extracting water from buried tanks or other underground sources.
- **Efficiency:** By being submerged directly in the water, submersible pumps have higher efficiency compared to surface pumps, as they do not have to suck the water through long suction pipes.
- **Cavitation Prevention:** When submerged, submersible pumps avoid cavitation, a phenomenon that can occur in surface pumps when there is a significant difference between the suction height and the discharge height.
- **Lower Risk of Damage:** Submersible pumps are protected from the external environment, reducing the risk of damage from adverse weather conditions or vandalism.
- **Variety of Applications:** They are versatile and can be used in a wide range of applications, including potable water systems, wastewater drainage, agricultural irrigation, among others.
- **Ease of Installation:** Although the initial installation may require some effort, once installed, submersible pumps are relatively easy to operate and maintain.

The pump chosen, according to ANNEX II, is the **Shurflo 9300 24V Submersible Pump**, capable of supplying up to 413 L/h at a height of 12.2 meters:

Illustration 13: Submersible Pump Shurflo. Source: AutoSolar.

7. Analysis of results and conclusions

For the water consumption of each device defined in ANNEX I, a total household consumption of 394,110 L/year is calculated.

With the recirculation flow of 256,870 L/year, calculated previously, a notable reduction in potable water consumption of **65% per year** has been observed.

This achievement not only represents substantial **economic savings** by reducing the costs associated with water supply, but it also stands out for its positive environmental impact. By decreasing demand, pressure on local natural resources is reduced, and the home's water footprint is minimized. This is crucial in a context where sustainable water management is increasingly relevant for ecosystem conservation and climate change mitigation.

Furthermore, the implementation of these practices not only benefits the individual household but also serves as an inspiring example for other communities and homes seeking to adopt similar measures. The replication of greywater and rainwater recycling and reuse systems can have a multiplier effect on water security at the local and global level, promoting a more **sustainable** and **resilient** environment.

To further **improve** the percentage of water savings, several additional strategies could be considered, especially to reduce the use of potable water for direct consumption, such as in showers, sinks, and for ingestion, through advanced filtration and purification technologies. However, in this case, this alternative has not been chosen due to the higher costs associated with the treatments necessary to ensure the quality of drinking water. Instead, focusing on the use of recycled water for applications such as irrigation, cisterns, and washing machines offers an effective balance between savings and economic viability.

In **conclusion**, this case study illustrates how relatively simple measures can generate significant impacts on environmental sustainability and the reduction of vital resource consumption, such as water, highlighting the importance of technological innovation and individual responsibility in the efficient management of resources.

8. Budget

Budget summary

Component	***Percentage (%)***	***Total cost (€)***
Preliminary Actions	1	143.35
Trench Execution	10	1,592
Sanitation Network	28	4,200
Treatment Equipment	37	5,635
Storage Equipment	12	1,820.67
Pumping Equipment	6	911.88
Health and Safety Plan	3	460
Waste Management	2	308
Quality Control	2	308

Material Execution Budget (PEM) **15,378.9 €**

- **General Expenses (13%)**: 1,999 €
- **Industrial Profit (6%)**: 922.8 €
- **VAT (21%)**: 3,229.6 €

Contract Execution Budget (PEC) **21,530 €**

The estimated total cost of the project, including general expenses, industrial profit, and VAT, is **TWENTY-ONE THOUSAND FIVE HUNDRED AND THIRTY** euros.

It is important to note that this budget is **indicative** and aims to provide a general idea of the expected costs, but it should not be considered as a formal offer. It is necessary to work with a more detailed and precise budget for the future development of the project.

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ANNEX I: WATER FLOWS

Contents Index

Tables Index

1. Generated Flows

1.1. Rainwater

Rainwater, being an additional source of water, can significantly influence the required capacity of the treatment system and the overall water management in a household.

To obtain accurate data on precipitation at the location of the home, it is important to refer to local rainfall records. This data provides valuable information on the average amount of rain that falls in the area during different periods of the year.

In the specific case of the home project, the rainfall data for Gijón was collected, which provides the characteristic annual average precipitation, equal to:

$$h=1059 \text{ mm}$$

The volume of available rainwater that can potentially be generated for a given temporal frequency in different areas is defined by the following formula:

$$\boxed{\mathbf{Q_{rainwater}=\sum A_i \cdot h_i \cdot e_i \cdot n_i}}$$

Where:

- **Yr**: rainwater production by temporal frequency t, expressed in litres (L)
- **A:** horizontal projection of the collection surface, expressed in square meters (m^2)
- **h:** total precipitation for the given temporal frequency t, expressed in millimetres (mm or l/m^2)
- **e:** performance coefficient of the surface.
- **n:** hydraulic treatment efficiency coefficient (0.9)

Table 1. Performance Coefficients. Source: UNE-EN 16941-1:2019

ROOF OR COVER COMPOSITION	PERFORMANCE COEFFICIENT (e)
Smooth-surface sloped roof	*0.9*
Rough-surface sloped roof	*0.8*
Flat roof without gravel	*0.8*
Flat roof with gravel	*0.7*
Intensive green roof (garden)	*0.3*
Extensive green roof	*0.5*
Sealed areas (e.g., asphalt)	*0.8*
Unsealed areas (e.g., pavers)	*0.5*

The hydraulic treatment efficiency coefficient (n) is defined as the ratio between the rainwater flow entering the equipment (collection tank) and the output flow of water after the planned treatments have been applied within the equipment, if any type of treatment is implemented. This relationship considers the inevitable loss of flow that occurs between these two points. Generally, a value of 0.9 is established for this coefficient.

Since there are several surfaces for rainwater collection, the corresponding calculations for each type of "cover" will be made separately, and then they will be added together to obtain the total rainwater flow.

$$\mathbf{Q_{green\ roof} = 95 \cdot 1{,}059 \cdot 0.9 \cdot 0.5 = 45{,}270\ L/year}$$

$$\mathbf{Q_{gravel\ roof\ I} = 65 \cdot 1{,}059 \cdot 0.9 \cdot 0.7 = 43{,}370\ L/year}$$

$$\mathbf{Q_{gravel\ roof\ II} = 18 \cdot 1{,}059 \cdot 0.9 \cdot 0.7 = 12{,}010\ L/year}$$

$$\mathbf{Q_{rainwater} = Q_{green\ roof} + Q_{gravel\ roof\ I} + Q_{gravel\ roof\ II} = 45{,}270+43{,}370+12{,}010 = 100{,}650\ L/year}$$

1.2. Greywater

To perform a detailed analysis of the contribution of greywater to the system, several factors will be considered, including the number of residents in the home, the frequency of use of showers or bathtubs by each resident, and the amount of water consumed in each use. With this information, a calculation will be made to determine if the generated greywater is sufficient to meet the needs of the home, such as refilling cisterns and watering gardens.

The following devices are identified in the home that generate greywater:

- Bathroom: showers and sinks.
- Kitchen: dishwashers, washing machines, and sinks.

The number of residents in the home for which consumption will be calculated from now on is 4.

Next, in Table 2, the calculation of the amount of greywater generated by each of these devices will be carried out:

Table 2. Consumption of Greywater Devices I. Source: Reuse and Use of Greywater and Rainwater in Buildings

DEVICES	AVERAGE DEVICES CONSUMPTION [L/hab/day]	ANUAL CONSUMPTION [L/year]
Shower	*65*	*94,900*
Sink	*10*	*14,600*
Dishwasher	*9*	*13,140*
Washing machine	*13*	*18,980*
Kitchen sink	*10*	*14,600*

$$Q_{greywater} = \mathbf{94{,}900 + 14{,}600 + 13{,}140 + 18{,}980 + 14{,}600 = 156{,}220\ L/year}$$

1.3. Total water

Therefore, the total captured water will be the sum of the previously calculated values:

$$Q_{GENERATED} = Q_{greywater} + Q_{rainwater} = \mathbf{156{,}220 + 100{,}650 = 256{,}870\ L/year}$$

2. Demand Flow

The uses for which the treated water will be used, and their corresponding flows are shown in Table 3.

Table 3. Consumption of Greywater Devices II. Source: Reuse and Use of Greywater and Rainwater in Buildings

DEVICES	AVERAGE DEVICES CONSUMPTION [L/hab/day]	ANUAL CONSUMPTION [L/year]
Cisterns	*31.5*	*45,990*
Washing machine	*13*	*18,980*
DEVICES	**AVERAGE DEVICES CONSUMPTION [L/hab/day]**	**ANUAL CONSUMPTION [L/year]**
Irrigation	*4*	*191,900*

As mentioned earlier, the number of residents considered in the calculation is equal to 4.

For the calculation of water demanded for irrigation, all the surplus water generated will be used, which allows for the irrigation of an area of 131.41 m^2.

$$\mathbf{Q_{DEMANDED} = 45{,}990 + 18{,}980 + 191{,}900 = 256{,}870\ L/year}$$

ANNEX II: SANITATION SYSTEM DESIGN

Contents Index

Tables Index

1. Drainage network sizing

A sanitation system for a single-family home is essential for the safe management and disposal of wastewater. This system is responsible for collecting, transporting, treating, and properly disposing of the wastewater generated in the home. A typical sanitation system for a single-family home is described below [6]:

1. **Branches:** They conduct the wastewater from toilets, sinks, showers, bathtubs, and other sanitary fixtures to the exit of the dwelling.
2. **Traps:** They collect and channel the wastewater from various sanitary fixtures, while at the same time ensuring that no odors are produced inside the dwelling.
3. **Downpipes:** Vertical ducts that transport wastewater from the different levels of the dwelling to the main collector. Their design must prevent leaks and minimize noise.
4. **Collectors:**
    - **Collector branches:** Pipes that connect the different drains and downpipes to the main collector.
    - **Horizontal collectors:** Horizontal pipe that collects the wastewater from the downpipes and transports it to the public sewerage network or to the septic tank.
5. **Ventilation pipes:**
    - **Primary ventilation:** Allows the exit of gases from the sanitation system to the atmosphere, preventing negative pressures in the pipes that could suck the water from the traps.
    - **Secondary ventilation:** Complements the primary ventilation in more complex or larger systems.

The sanitation system must comply with the requirements of the Technical Building Code (CTE), particularly with the *Documento Básico HS "Salubridad"*

For greywater, the number of Drainage Units (DU) must be established for each fixture connected to the network and its corresponding minimum diameter, depending on the use (public or private). To perform the sizing calculations, it is necessary to know a series of specific parameters.

In this case, the following are considered:

- **Building use:** The building is used for housing, so it will be considered private use.
- **Slope of the collectors:** The slope of the collectors has been estimated at 2%.
- **Number of floors:** The house has 3 floors.

1.1. Individual branches

To properly size the greywater pipes, Drainage Units (DU) are assigned to each sanitary fixture, and the minimum diameters of the branches are determined. The following is Table 1, with the typical values for a single-family dwelling:

Table 1. DUs corresponding to different sanitary devices. Source: CTE/DB-HS-.5

SANITARY DEVICE	DRAINAGE UNITS (DU)	MINIMUM DIAMETERS (mm)
Sink	*1*	*32*
Kitchen sink	*3*	*40*
Shower	*2*	*40*
Washing machine	*3*	*40*
Dishwasher	*3*	*40*

The DU and diameters for each downpipe are the followings:

DOWNPIPE 1

Floor 3:

- **Bathroom ppl.**:
  - 1 sink: 1 DU   Ø40 mm
  - 1 shower: 2 DU   Ø40 mm

Floor 2:

- **Bathroom 1**:
  - 1 sink: 1 DU   Ø40 mm
  - 1 shower: 2 DU   Ø40 mm

Floor 1:

- **Kitchen**:
  - 1 sink: 3 DU   Ø40 mm
  - 1 washing machine: 3 DU   Ø40 mm
  - 1 dishwasher: 3 DU   Ø40mm

DOWNPIPE 2

Floor 2:

- **Bathroom 2**:
  - 1 sink: 1 DU   Ø40 mm
  - 1 shower: 2 DU   Ø40 mm

Floor 1:

- **Restroom**:
  - 1 sink: 1 DU Ø40 mm

1.2. Traps

The outlet diameter of the traps is obtained from the discharge units and the slope of the pipe, although the most common diameter for the outlet of the collectors is **50 mm** with a slope of 2%.

1.3. Collector branches

The derivations or collector branches, as explained above, have the function of connecting the drains of the different sanitary fixtures to the downpipes. The diameter of these horizontal pipes will depend on the number and type of sanitary fixtures connected to them, as shown in Table 2.

With a slope of 2%, it is ensured that the wastewater flows properly by gravity without stagnation.

Table 2. Diameters of collector branches between sanitary fixtures and downpipe. Source: CTE/DB-HS-5

MAXIMUM NUMBER OF DU			DIAMETER (mm)
SLOPE			
1%	*2%*	*3%*	
-	*1*	*1*	*32*
-	*2*	*3*	*40*
-	*6*	*8*	*50*
-	*11*	*14*	*63*
-	*21*	*28*	*75*
47	*60*	*75*	*90*

To optimize the design and construction, as well as to reduce costs, the same pipe diameters will be used for all branches, corresponding to the one that collects the largest number of units.

Therefore, the diameter of the collector branches will be **75 mm.**

1.4. Downpipes

The diameter of the downpipes is determined, as shown in Table 3, considering the largest of the values obtained between the maximum number of Drainage Units (DU) in the downpipe and the maximum number of DU in each branch that connects to the downpipe, depending on the number of floors.

Table 3. Diameter of the downpipes according to the number of building floors and the number of DU. Source: CTE/DB-HS-5

MAXIMUM NUMBER OF FIXTURE UNITS FOR A DOWNPIPE HEIGHT OF:		MAXIMUM NUMBER OF FIXTURE UNITS PER BRANCH FOR A DOWNPIPE HEIGHT OF:		DIAMETER (mm)
Up to 3 floors	More than 3 floors	Up to 3 floors	More than 3 floors	
10	*25*	*6*	*6*	*50*
19	*38*	*11*	*9*	*63*
27	*53*	*21*	*13*	*75*
135	*280*	*70*	*53*	*90*
360	*740*	*181*	*134*	*110*
540	*1100*	*280*	*200*	*125*

In this case, a downpipe diameter of **110 mm** is established, since it must always be greater than that of the upstream sections and thus using the same as for the downpipes that serve toilets.

1.5. Horizontal collectors

In this section, the buried horizontal collectors for wastewater only will be sized for a separate system, based on the maximum number of DU and the slope, according to Table 4.

Table 4. Diameter of horizontal collectors based on the maximum number of DU and the adopted slope1. Source: CTE/DB-HS-5

MAXIMUM NUMBER OF DU			DIAMETER (mm)
SLOPE			
1%	*2%*	*4%*	
-	*20*	*25*	*50*
-	*24*	*29*	*63*
-	*38*	*57*	*75*
96	*130*	*160*	*90*
264	*321*	*382*	*110*
390	*480*	*580*	*125*

The chosen diameter will be **125 mm** since it is the minimum recommended for a buried collector network.

2. Size of the pumping and lifting systems

2.1. Pumping flow

To calculate the flow rate of a pump, several factors related to the specific application and the characteristics of the system must be considered. The flow rate (Q) is the amount of liquid that the pump can move per unit of time, usually measured in litres per second (l/s), cubic meters per hour (m^3/h).

According to the consumption values of each sanitary fixture estimated in Table x, we have a total daily flow rate for cisterns, washing machines, and irrigation of:

Total daily for cisterns: 4 people · 31.5 litres/person = 126 litres/day

Total daily for irrigation: 131.44 m^2 · 4 litres/m^2 = 525.76 litres/day

Total daily for washing machines: 2 uses per week · 45.5 litres/use = 13 litres/day

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Total daily: 126 litres + 525.76 litres + 13 litres ≈ 664.76 litres/day

Assuming that the pump operates for 2 hours a day to cover all needs, the necessary flow rate will be:

Necessary flow: $\frac{673.19\ \text{litres/day}}{2\ \text{hours}}$ = 336.60 litres/hour ≈ **0.0923 L/s**

2.2. Manometric pressure

The manometric pressure of the pump must be obtained as a result of adding the geometric height between the highest point to which the pump must lift the water and the minimum level of the water in the tank. In the case of submersible pumps, this height is equal to zero, and the pressure loss produced along the pipe, from the pump outlet to the highest point.

The expression that summarizes the concept is:

$$\boxed{H_{MT} = H_{TA} + H_{TI} + A_t}$$

Where:

- **H_{MT}:** Total manometric head (m.c.a or its equivalent value in bar or kPa)
- **H_{TA}:** Total suction head (m.c.a or its equivalent value in bar or kPa)
- **H_{TI}:** Total discharge head (m.c.a or its equivalent value in bar or kPa)
- **A_t**: Total head loss in the section

The HMT, in this case, is equal to the total suction head, which is 9 meters, since the minimum water level in the tank, in the case of submersible pumps, is equal to zero.

2.3. Diameters of the discharge pipelines

We use the flow continuity formula to relate the flow rate with the cross-sectional area of the pipe and the flow velocity:

$$\boxed{Q = A \cdot \upsilon}$$

Where:

- **Q:** flow rate (m^3/s)
- **A:** cross-sectional area of the pipe (m^2)
- **υ:** flow velocity (m/s)

The minimum velocity will be 0.6 m/s, and the maximum will be 2.5 m/s, so the intermediate value of 1.5 m/s will be chosen.

$$A = \frac{\mathbf{0.0000923\ m^3/s}}{\mathbf{1.5\ m/s}} = 0.00006153\ m^2$$

The cross-sectional area of the pipe is a circle, so we use the formula for the area of a circle to find the diameter:

$$\boxed{A = \pi \cdot \left(\frac{d}{4}\right)^2}$$

We rearrange the formula to solve for the diameter:

$$\mathbf{d} = 2 \cdot \sqrt{\frac{0.00006153\ \text{m2}}{\pi}} = 0.00885\ \text{m} \approx \mathbf{8.85\ mm}$$

The closest commercial diameter to 8.85 mm would be a **10 mm** pipe.

2.4. Pump selection

The selected pump must handle a flow rate of **0.0923 l/s** at an HMT of **9 meters**, with a pipe diameter of **10 mm.**

For these characteristics, the most suitable pump is the **Shurflo 9300 24V Submersible Pump,** capable of supplying up to 413 l/h at a height of 12.2 meters.

Table 5. Pump characteristics according to the manufacturer. Source: AutoSolar

DEPTH METERS	LITRES PER HOUR	POWER USE BY SOLAR PANELS	USED AMPS
6.1	*420*	*52*	*1.7*
12.2	*413*	*65*	*2.0*
18.3	*398*	*78*	*2.3*
24.4	*390*	*89*	*2.6*
30.5	*379*	*99*	*2.9*
36.6	*360*	*104*	*3.2*
42.7	*352*	*115*	*3.5*

ANNEX III: PLANS

Plans Index

Plan 1: *Ground floor distribution of the house*

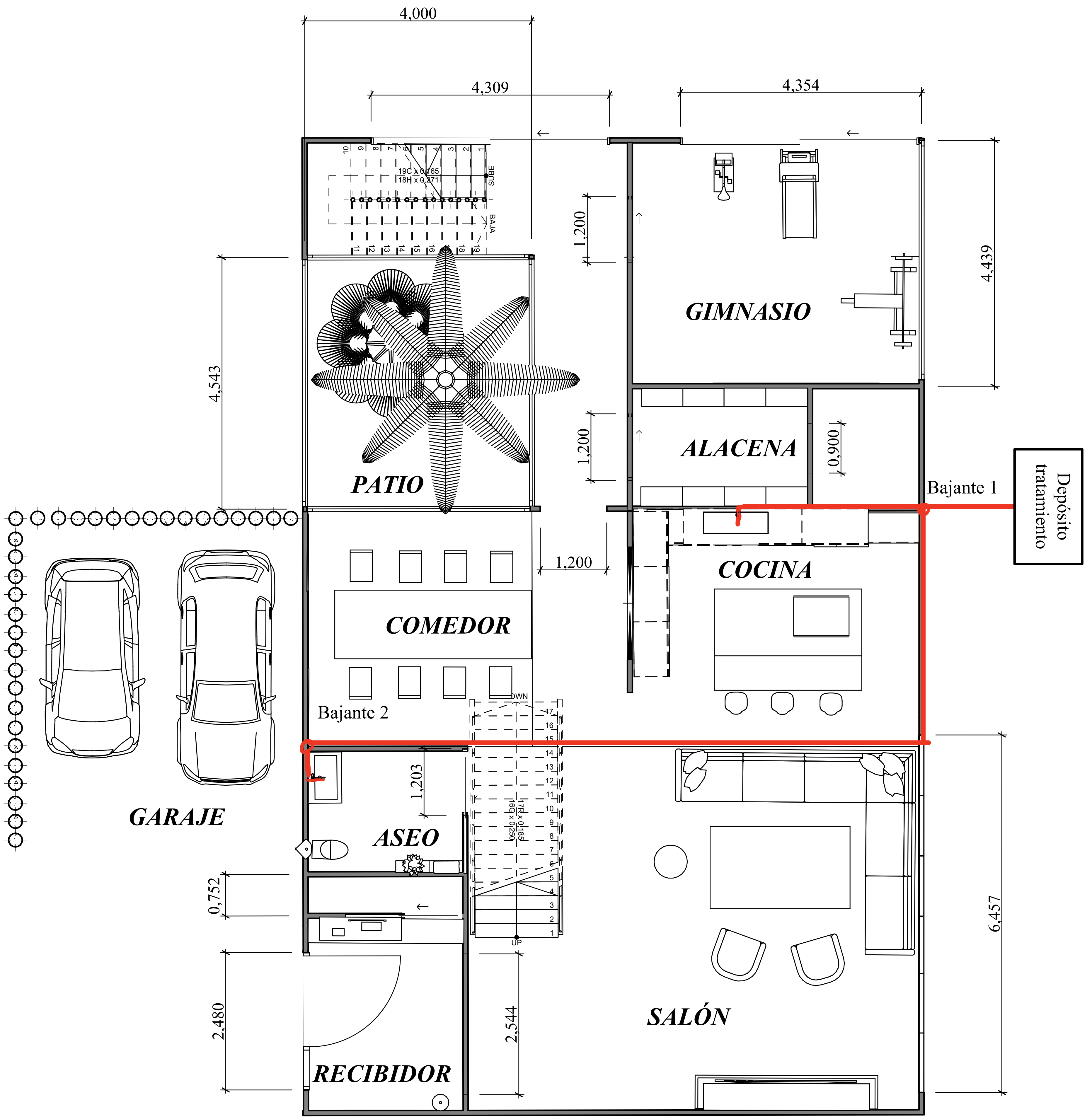
Plan 2: *First floor distribution of the house*

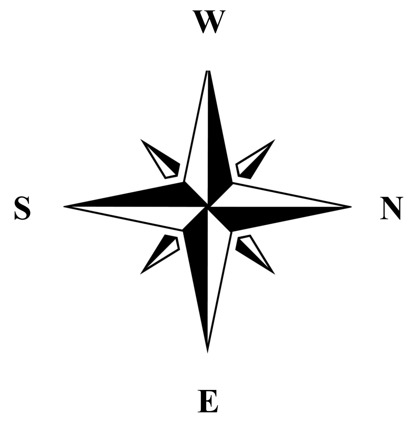
Plan 3: *Attic distribution of the house*

Plan 4: *South elevation of the house*

Plan 5: *West elevation of the house*

Plan 6: *North elevation of the house*





Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

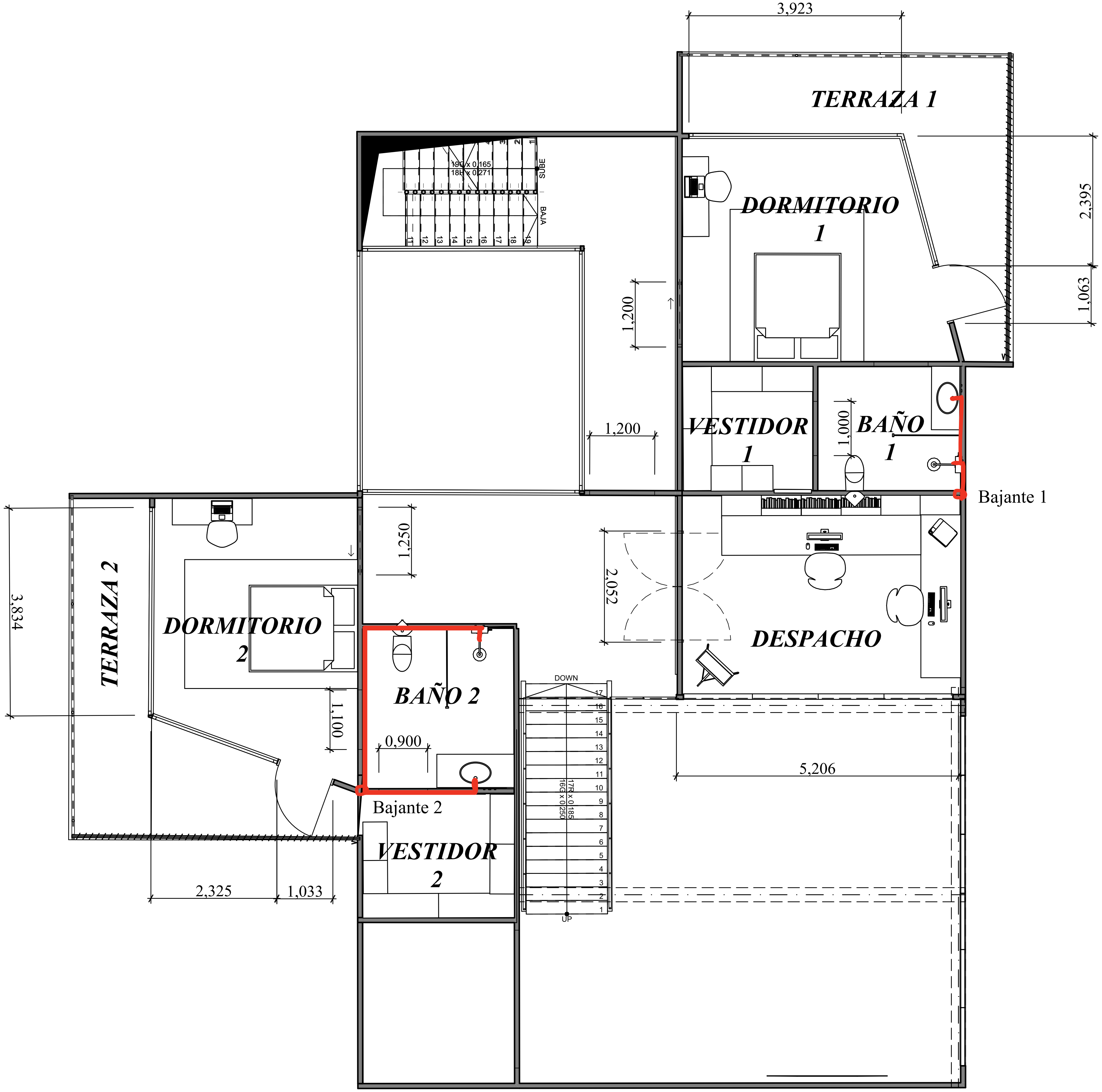
Distribución planta baja de la vivienda

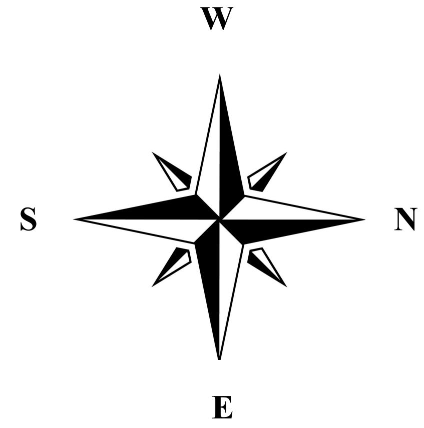
Autor:

Andrea Fernández Chavarría

Escala:	**Fecha:**	**Nº:**
1:80	29/06/2024	**01** /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA





Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

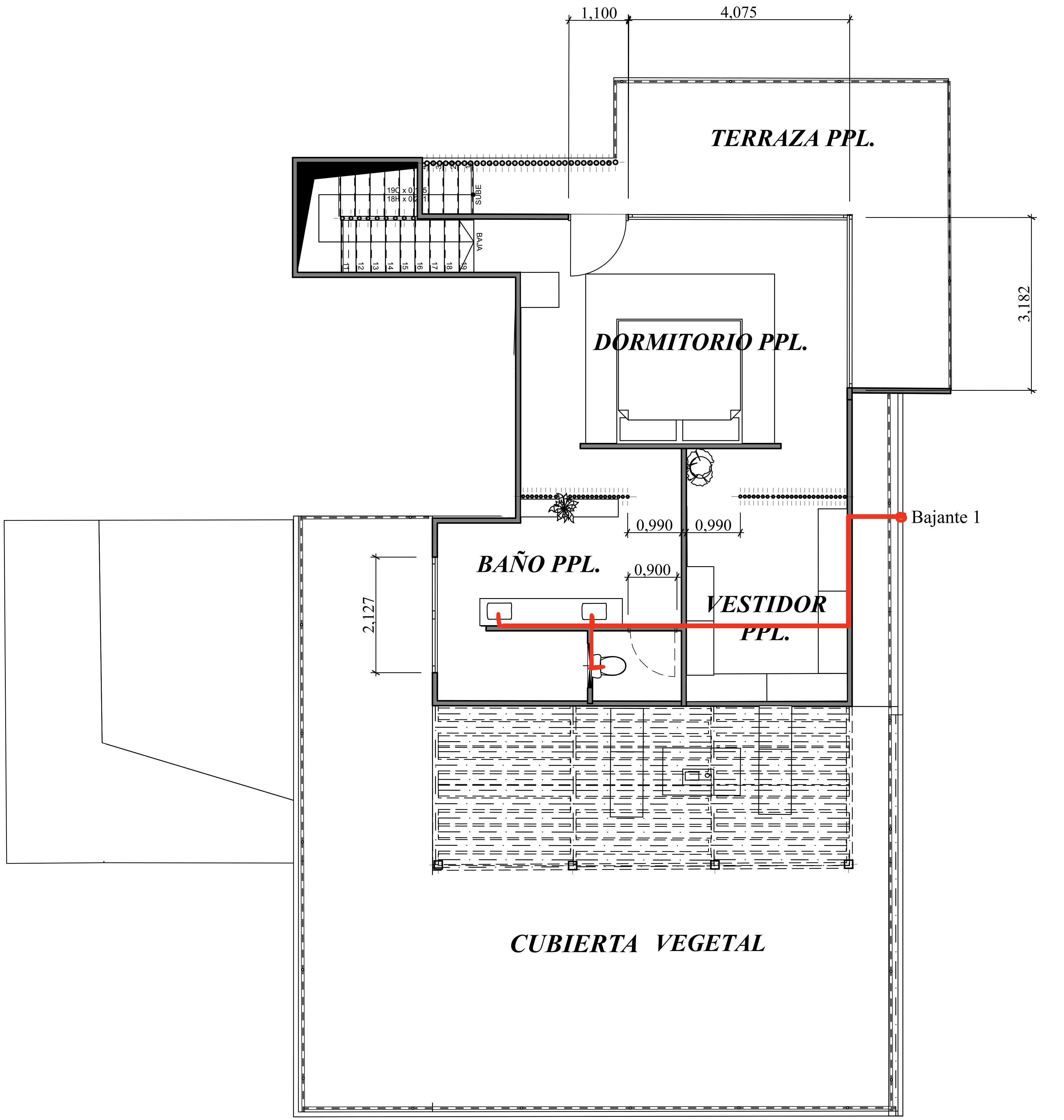
Distribución primera planta de la vivienda

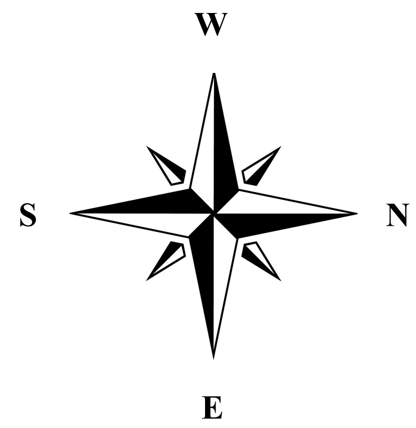
Autor:

Andrea Fernández Chavarría

Escala:	**Fecha:**	**Nº:**
1:80	29/06/2024	**02** /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA





Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

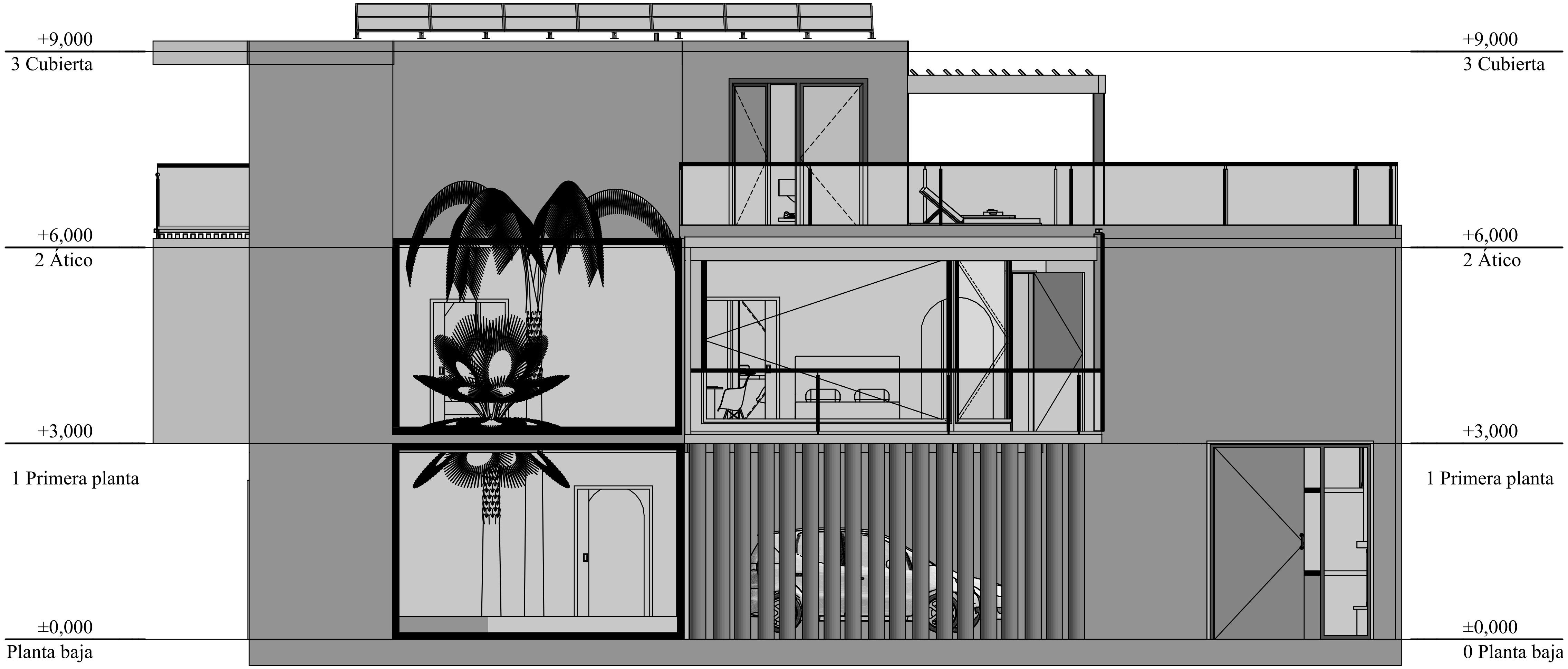
Distribución planta ático de la vivienda

Autor:

Andrea Fernández Chavarría

Escala:	Fecha:	Nº:
1:80	29/06/2024	03 /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA



Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

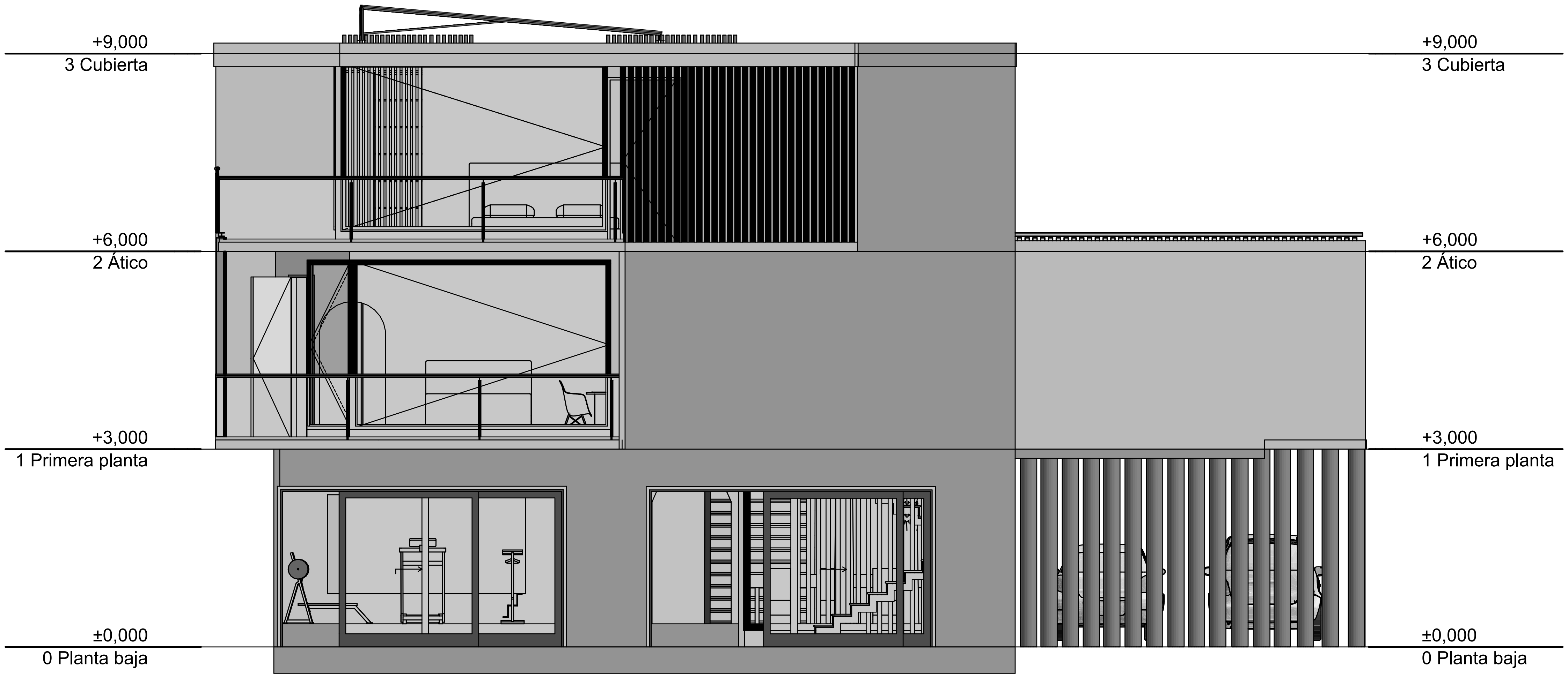
Alzado sur de la vivienda

Autor:

Andrea Fernández Chavarría

Escala:	**Fecha:**	**Nº:**
1:80	29/06/2024	**04** /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA



Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

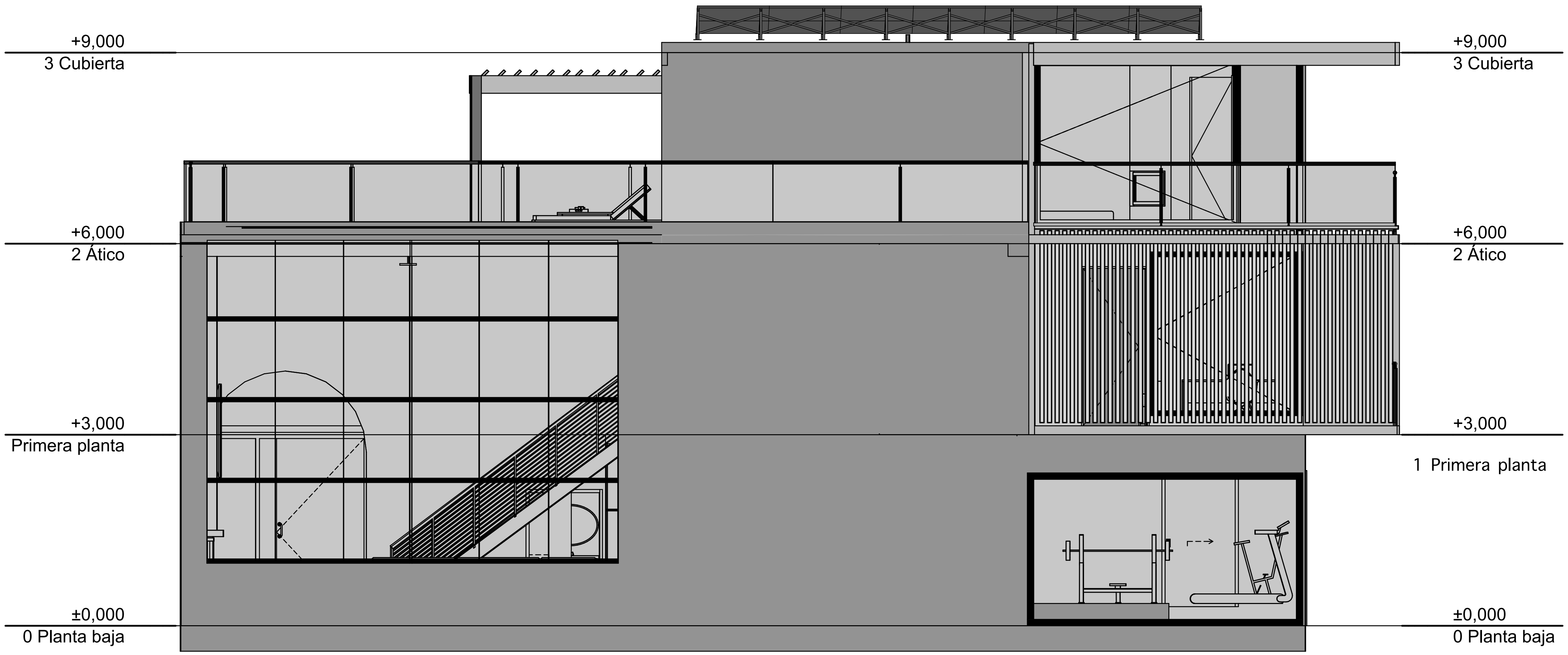
Alzado oeste de la vivienda

Autor:

Andrea Fernández Chavarría

Escala:	**Fecha:**	**Nº:**
1:80	29/06/2024	**05** /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA



Proyecto:

Saneamiento de una Vivienda Unifamiliar con Captación de Aguas Pluviales y Reciclaje de Aguas Empleando Sistema Separativo

Plano:

Alzado norte de la vivienda

Autor:

Andrea Fernández Chavarría

Escala:	Fecha:	Nº:
1:80	29/06/2024	**06** /06

CHAVARRÍA INGENIERÍA Y ARQUITECTURA