# HYDROUSA

H2020-CIRC-2-2017

Water in the context of circular economy

**Full project title:**

Demonstration of water loops with innovative regenerative business models for the Mediterranean region

**Deliverable: D13**

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# Demonstration of eco-tourist water loops

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# EXECUTIVE SUMMARY

HYDROUSA aims to offer a set of solutions to expand the application of circular economy principles to water use and reinforce the water-energy-food nexus in the Mediterranean area. These solutions are designed and implemented within demonstration sites in Greece and they are planned to be adaptable and replicable to other potential locations around the world. Under HYDRO6 demonstration site of Work Package 2 (WP2) the following specific objectives are accomplished:

- Demonstrate that circular and nature-based technologies can fully supply water from non-conventional water sources
- Support the demand of water through the utilization of non-conventional water resources in agriculture and for domestic use
- Reduce freshwater demand from the tourist sector by implementation of strategies according to circularity approach

In particular, under the HYDRO6 the following technologies have been set up:
1) Upgrade and renovation of existing rainwater collection systems (cistern, stable roofs)
2) Construction of a greenhouse for cultivation of vegetables and as additional surface (greenhouse roof) for rainwater collection
3) Development and installation of atmospheric water condensation systems (multifunctional roofs and water flower)
4) Installation of commercial condensation systems

HYDRO6 is a micro scale implementation site for a whole set of interacting nature-based solutions proposed and developed within the HYDROUSA Project. This report describes the implementation of developed atmospheric vapour capture prototypes and upgraded rainwater collection systems. The rainwater collection system already existing within the Tinos Eco lodge have been upgraded to include higher capture and storage capacity, as well as a better distribution system within the premises. The water loops in the Tinos Eco lodge are integrated within a permaculture project where a new greenhouse has been constructed within HYDRO6 to grow a variety of vegetables and fruits for local consumption. The greenhouse serves as controlled area for horticultural production as well as roof rainwater collection surface. The premises of Tinos Eco lodge are energy self-sufficient, powered by solar energy. The objective of the systems developed in this demonstration site are the following:

- Demonstrate that local organic food production is feasible and welcomed by customers contributing to a” Zero-Kilometre kitchen”, reducing overall energy and water demand in the tourist sector
- Show feasibility of provision of 100% renewable energy within a touristic facility
- Exhibit reduction of non-local inputs through holistic and sustainable land management
- Increase biodiversity, ecosystem services, human understanding and interaction within the system

The HYDRO6 foresees the achievement of the above-mentioned targets by accomplishing performance indicators (KPIs), such as: a) the amount of rainwater harvested is 50 $m^3$/year, and b) 30 $m^3$/year of water recovered from atmospheric vapour.

The HYDRO6 is located in Tinos at the Ecolodge, a remote tourist facility that is energy self-sufficient, being located off the grid. The Ecolodge is composed of a series of technologies to reclaim water and it uses renewable energy (solar). On the premises there is a rainwater collection system, a reedbed filtration system to treat wastewater, and an off-grid solar powered energy production system. In addition, vegetables are grown in the local garden according to the principles of permaculture and the produce is consumed locally.
In HYDRO6 the upgrade of the existing rainwater collection system consisted in renovating the structure to enlarge the water collection surface, maintaining at the same time the traditional structure and the integration within the local landscape. Details of the upgrade of the rainwater system are reported in chapter 4.

Within this approach of integration within the local landscape and maintenance of the traditional structure, a greenhouse has been built not only to facilitate gardening and small-scale vegetable production, which plays a vital role within the economy of the Ecolodge, but also to increase the rainwater collection surface using the roof of the greenhouse. Ecolodge has a history of organizing workshops for vegetable garden production and permaculture, offered to the tourists as a mean to contribute to environmental education of the visitors, which take great pleasure investigating all the beautiful, different edible treats at 0 kilometre from farm to plate. Having the greenhouse for vegetable production provides the opportunity to further diversify the income stream of the Ecolodge and complement the agricultural activities and the seminars. Details of the construction of the greenhouse are reported in chapter 5.

In HYDRO6 rainwater collection has been complemented with harvesting and collection of ambient air water. Rainwater collection is relatively simple, but in areas where rainfall patterns are irregular the supply is not constant. Ambient air water, in its liquid or gaseous state, is abundantly present and it is emerging as an important source of potable water, especially in areas with little rain but relatively high humidity or big temperature differences between day and night. In HYDRO6, atmospheric water harvesting has been another innovation implemented at Ecolodge, where it can play a key role in the water supply chain at off- grid situations.

Two atmospheric water condensation systems were developed in HYDRO6: 1) multifunctional roofs, and 2) water flower. The water flower is a hexagonal, flower- like funnel on legs that is light weight and mobile. The interior is painted with high emissivity coating and cools down for the purpose of condensation. The multifunctional roof is a structure with multiple functions: 1) condenses water vapour from the air, 2) gives shade, 3) protects from and collects rain, and 4) it is energy self-sufficient. In addition to this innovations, commercial condensation units that are powered by renewable energy are considered for the purpose of atmospheric water condensation. Details of the atmospheric water condensation systems are reported in chapter 6.

Currently, all the above-mentioned renovations, upgrades, and technologies have been developed and installed at Ecolodge in Tinos. Further optimization of the systems will take place in the next few months.

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# ABBREVIATIONS

| | |
|---|---|
| a | Active |
| AWG | Atmospheric water generators |
| ELT | Ecolodge Tinos |
| EPDM | Ethylene Propylene Diene Monomer |
| COP | Coefficient of Performance |
| CW | Constructed Wetlands |
| DC | Direct Current |
| IR | Infrared |
| OPUR | International Organization for Dew Utilization |
| p | Passive |
| PV | Photovoltaic |
| PVC | polyvinyl chloride |
| PVT | Photovoltaic thermal |
| TE | Thermoelectric |
| U.S EPA | United States Environmental Protection Agency |
| WHO | World Health Organization |

# 1. INTRODUCTION

HYDRO6 demonstration site within Work Package 2 (WP2) aims to demonstrate that: 1) water scarcity and unsustainable water consumption can be effectively addressed by the utilization of non-conventional water sources; 2) the supply of water from non-conventional water sources can be provided with circular nature-based technologies; 3) principles of circularity of freshwater use can lead to reduced consumption and therefore reduced demand of the resource.

HYDRO6 is a microscale site in the island of Tinos within a remote eco-tourist facility (Tinos Ecolodge) that is located off the grid. All activities will be powered using renewable energy. Within the eco-tourist facility vapour water, wastewater and rainwater will be recovered through nature-based technologies. The reclaimed water will be used to cover the needs of the tourist living in the eco-lodge and to support local organic food production (0.15 ha) including the cultivation of horticultural crops within a greenhouse (60 $m^2$).

The existing circular infrastructure of the tourism facility is further developed and upgraded to transition from eco-tourism to agro-eco-tourism. The water loops within the system are shown in **Figure 1.1**. The water is reclaimed within a system of loops that are interconnected and allow for increased business diversification where eco-tourism is integrated with agricultural production. The developed business model is less vulnerable to fluctuations within the tourisms sectors as it generates income diversification, reduces costs, and increases biodiversification of the natural environment without stressing the water provision system. To reduce the overall water withdrawal from the aquifer, the water used in the facility derives from: 1) surface water from rain captured through a rainwater harvesting-storage system and a stream, 2) vapour condensation unit for direct water production. These technologies are described below. The anthropogenic cultural landscape of Tinos and the natural habitat are carefully integrated and valorised into the design of the technology through technical measures (i.e., usage of local materials, building techniques, and traditional craftsmanship) and social adaptation (i.e., behavioural and cultural integration of changes toward alternative sanitation concepts).

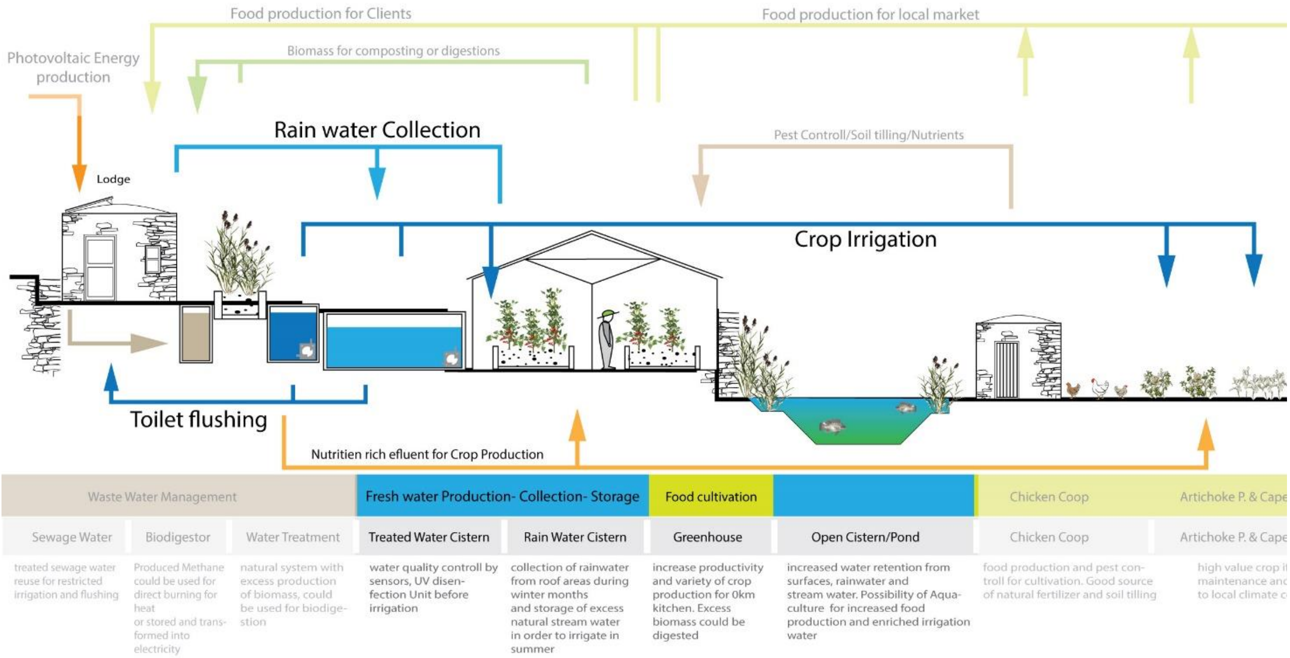


**Figure 1.1 Diagram of HYDROUSA nature-based solutions in the eco-tourist facility**

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# 2. ECOTOURIST FACILITY

## 2.1. Description of Tinos Ecolodge

Tinos Ecolodge is an eco-tourism facility that was built during the years 2014-2015. The Ecolodge plot covers an area of 6,000 $m^2$. The vegetation on the plot is composed of grasses and bushes and it partly connects with one of the oldest oak forest on the island (**Figure 2.1**). The Ecolodge bases its economic activities on sustainable ecotourism, recovery of natural resources (i.e., water), and permaculture. The following ecological concepts create the framework of the Ecolodge philosophy based on self-sufficiency and sustainable use of natural resources.

1. Collect, store and use water resources sustainably
2. Treat grey water, store it and use it for irrigation
3. Use renewable solar energy to the largest extent feasible
4. Build harmonically within the landscape and respect local architecture tradition
5. Produce food and agricultural products
6. Invest and design solutions beneficial to our natural habitat

The final design of the Ecolodge was carefully studied and formed by the owners taking into account the natural topography of the landscape, orientation and wind direction, solar simulation for optimal light distribution, traditional architecture, local building materials and environmental factors of the island.

The Ecolodge structure is composed of a series of technologies to reclaim water and use renewable energy (solar). On the premises, there is a rainwater collection system, a reedbed filtration system to treat wastewater, and an off-grid solar powered energy production system. In addition, vegetables are grown in the local garden according to the principles of permaculture and the produce is consumed locally.

The photovoltaic system (2.2 kWp energy production capacity) covers all basic needs for the residents and the energy needs for wastewater treatment and irrigation. The whole system is designed and optimized for ultra-low energy consumption (2.9 kWh).

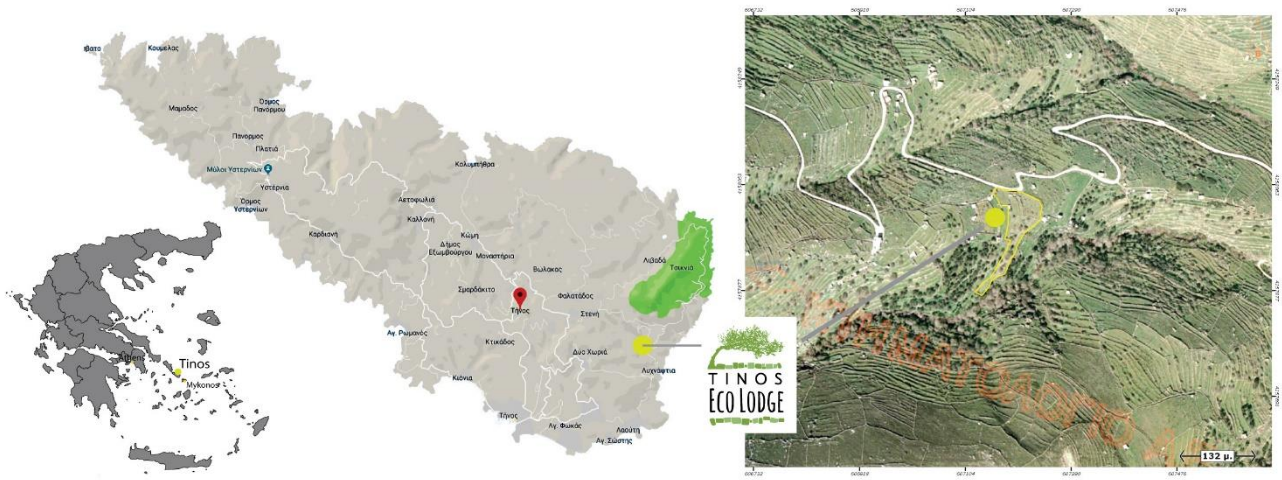


**Figure 2.1 Geographical position of ELT & Satellite picture (source Greek cadastre)**

A permaculture design course is offered every year at the Ecolodge. Professional teachers from the UK and Greece meet with approximately 20-25 participants for a few days to promote the philosophy of sustainable living and demonstrate practical solutions on-site.

## 2.2. Existing water loops at Ecolodge before HYDROUSA

At the Ecolodge, most of water needs are covered by non-conventional sources. Drinking water is provided by the public water grid, whereas the water used for all other activities (irrigation, cleaning, toilet flushing) is supplied through the system of rainwater catchment and storage, river water, and treated sewage water.

The rainwater is captured by all hard surface like roofs, stairs, and verandas which are then connected by a collection network of pipes and stored in an old cistern of 100 $m^3$ capacity from which the water is distributed by pumping to the various Ecolodge facilities. **Figure 2.2** shows the overview of the system and the houses with their according verandas and the underground cistern. Because of the strong slope of the plot it was possible to design the system to be gravity driven without the need for pumps, where the cistern is located at the lowest elevation and all collection surfaces are located uphill. The schematic section shows the elevation and flow direction from collection surfaces to the cistern. The total collection surface, taking into account only horizontal surfaces, is 297 $m^2$.

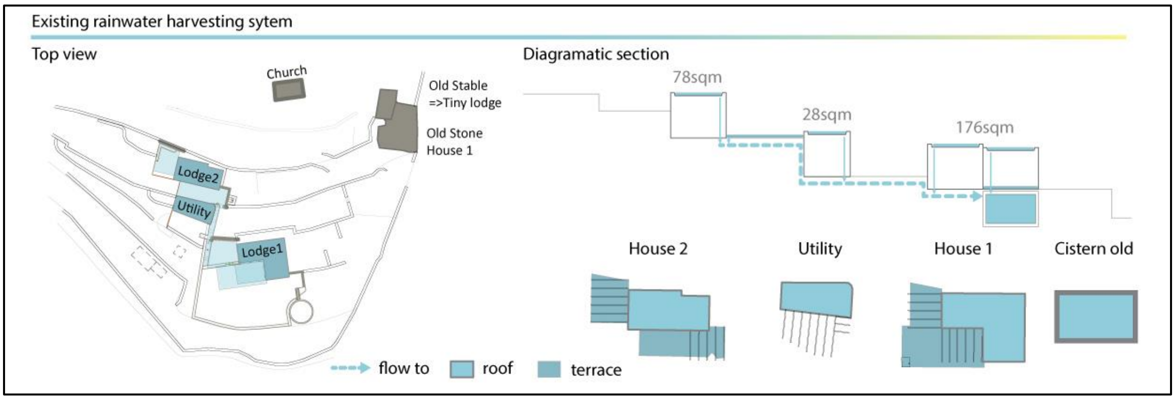


**Figure 2.2 Existing rainwater harvesting system at Tinos Ecolodge**

The sewage water which is transported through a split grey-black water canalization is treated by a CW-vf unit. The treated effluent is collected in a cistern and it can be utilized for irrigation of ornamental plants or for toilet flushing when rainwater reserves run low (**Figure 2.3**).

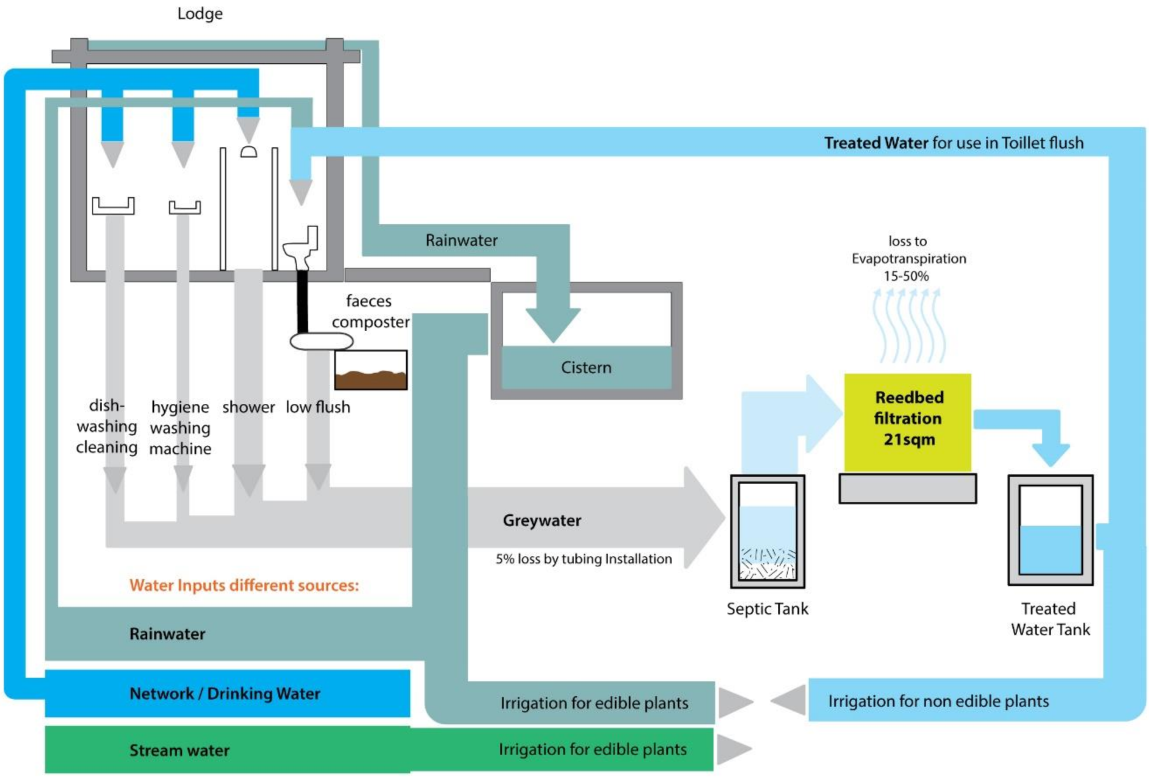


**Figure 2.3 Diagram of existing water loops at Tinos Ecolodge**

The river water is used to supplement the irrigation water for the agricultural production. In an off-the-grid situation, as applying to ELT, it is important to be able to react fast to upcoming malfunctions of different sub systems until the error is solved. This is described in the emergency row where in case of error or shortage, different bypasses can be made in order to keep the overall system running. These bypasses become crucial in the case of a malfunction, e.g. concerning the vegetable production where 2-3 days without water can lead to a total production loss.

# 3. UPGRADE OF EXISITING WATER LOOPS

Water harvesting potential of the rainwater collection system is addressed in HYDRO6. The goal is to have 95% catchment efficiency. We calculated that the current performance of the system was deficient (it did not fill up all the volume of the cistern, considering rainfall data from a nearby weather station).

If the rainwater system is the sole source of water, the collection surface must be oversized in order to meet the demand. This derives from the non-uniform yearly precipitation pattern. The ELT system has derived from a mixed approach, where water balance calculations within a maximum water conserving design have been combined into an overall build environment for tourism in warm climate. The initial design goal for the system was complete water self-sufficiency, which was later on discarded due to legislative issues. Water consumption at the Ecolodge has been estimated as 106 L/person per day.

About 52% of the total demand can be provided by rainwater. Within the whole water stream only 9%, consisting of the water for cooking and irrigation, is lost within the first usage cycle (indicated in orange). The remaining 91% is transported to the sewage treatment for reuse (indicated in black/grey). This, results in a rainwater demand of 55.3 $m^3$ for an operating season of 6 months and a 100% occupation by six customers. Hence, the minimum performance of the rainwater system is to collect and store at least 60 $m^3$ of water throughout the rainy season in order to satisfy the summer season demand. However, when we add the water needed for irrigation of vegetable garden the water demand is higher. The available surface space for rainwater collection at Ecolodge is around 300 $m^2$. This harvesting surface ensures the utility water demand even in very low precipitation periods. Taking the average rainfall for the decade, the system can harvest 112 $m^3$, which provides a good indication for the storage cistern volume. The cistern was sized to a 100 $m^3$ providing a reasonable ratio of under and over performance, leaving 46.7 $m^3$ of rainwater for irrigation.

Through the existing water loop present at Ecolodge, the reclaimed water from the sewage treatment process contributes to the total water demand. About 95.8 $m^3$ of the overall water consumed within the facilities enter the reedbed treatment. About 5% of this amount is lost due to pipe leaks and 30% is evapotranspired in the CW-vf. These assumptions fluctuate throughout time due to degradation of the piping network and weather conditions affecting the water uptake within the wetland. Throughout the season, 65% of reclaimed water is available for non-edible plant irrigation or in case of insufficient rainwater store for flushing.

The rainwater collection upgrade followed the logic of how much water can be harvested from all surfaces. According to the predicted water harvest, the storage cistern was then planned. This created a harvesting system consisting of:

1. The greenhouse (roof material: polycarbonate)
2. The old stable renovated into a new lodge (roof material: extensive green roof)
3. The Cistern (open)
4. Tube installation and pump for water distribution

The greenhouse, the roof of the renovated old stable and the verandas, and the cistern's surface, are surfaces that are used for rainwater collection within HYDRO6. The cistern was placed at the highest possible point within the premises of the Ecolodge to take advantage of the steep slope and minimize gravity fed flows and uphill pumping to the final consumption point. **Figure 3.1** shows the existing and upgraded rainwater system with all the new surfaces for catchment.

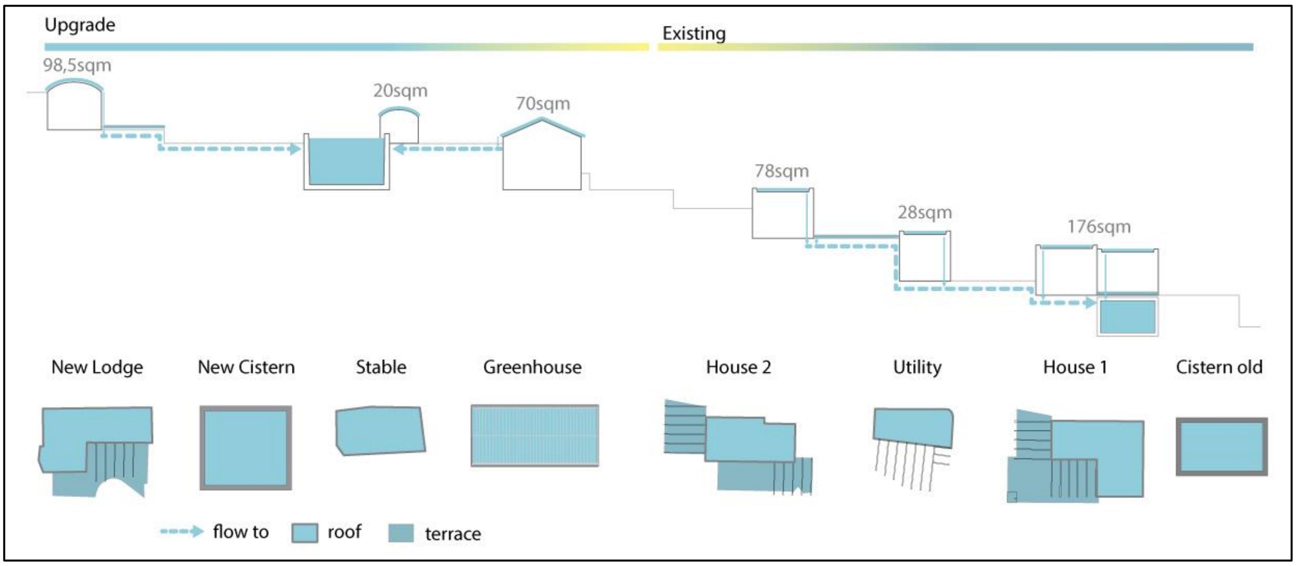


**Figure 3.1 Diagram of upgrade plan relative to the existing water loops**

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# 4. TECHNOLOGY APPLIED IN HYDRO6: CISTERN AND OLD STABLE

## 4.1. Cistern pond

In the mountainous steep terraced landscape of Tinos, it is difficult to integrate large utility buildings, like cisterns, harmonically into the terrain. In respect to the beauty of the cultural anthropogenic landscape, we decided to place the cistern underground, and design the cover as veranda area in front of the lodges. The increased agricultural plantations and the additional lodge within the HYDROUSA project create an increased demand of water that the old system could not provide on itself. The overall collection/storage system had to be redesigned and extended in order to meet the new demands.

In order to select the most suitable solution, we considered product data concerning price, price over lifespan, availability on local market and the footprint on ground that was crucial because the terraced landscape does not easily fit large utility facilities.

Even if the traditional cistern, carved into the bed rock, has a medium-high initial investment cost and has a medium-low performance of 2.0 € per $m^3$ over time, the licensing process is fast and fairly uncomplicated because it falls within the Greek building regulation in a category of light structures. The construction effort is low because it is embedded in the ground, hence the complicated shutter building for the casting process is omitted. Therefore, the implementation time is faster. Furthermore, an open water surfaces has high recreational and environmental quality, attractive for both humans and the local flora and fauna. Cisterns of this type exist on Tinos traditionally for a long period of time and are well situated into the cultural landscape.

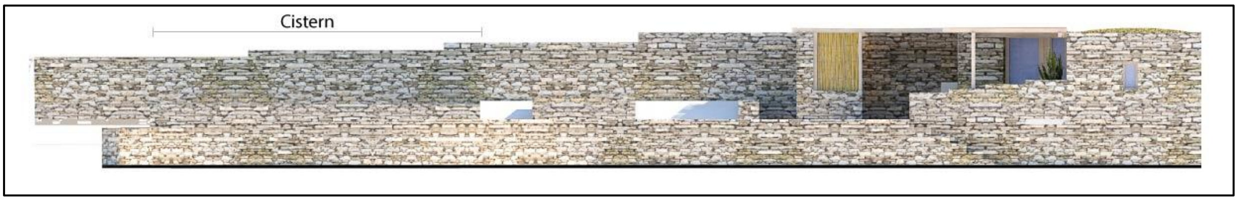


**Figure 4.1 Computer generated visual investigation of a traditional cistern design**

Within the visual investigation of the traditional cistern, we saw that it harmonizes very well with its surrounding landscape, where it reaches the point of being nearly invisible from most viewpoints (**Figure 4.21)**.

Due to its low height over ground, it keeps the analogies with the nearby buildings in a very smooth progression. The perimeter wall is kept in stone masonry, which creates the blending into the environment. Adding up all the beneficial characteristics of this typology, the decision was made to advance with this solution. During the excavation of the hole into the bedrock, good quality stone was extracted from the ground and used to construct the perimeter wall, the new lodge and other structures within WP4.

### 4.1.1. Placement and sizing of the cistern pond

It was important to design not only a technical water holding basin, but also to create an attractive water feature that combines a place of interest for relaxation and observation with the benefits of an open water surface for the local wildlife (**Figure 4.2** and **Figure 4.3**). The holistic approach of the HYDROUSA project makes it vital to consider also broader aspects to every intervention. In the dry summer months, typical to the Cycladic islands, open freshwater bodies become scarce but essential for bees, dragonflies, birds, frogs etc. On the other hand, these animals are essential to an agricultural site due to their ecosystem services like pollination, pest predation and an overall intact habitat with its complex interdependencies. The main down site of the open water body is the increased evaporation due to high exposure to direct sun radiation, following an increased water temperature, which leads to a higher vapour exchange to the atmosphere. This issue can be partially addressed by the introduction of water lilies (*Nymphaeaceae*) and duck weed (*Lemnoideae*) to the water body.

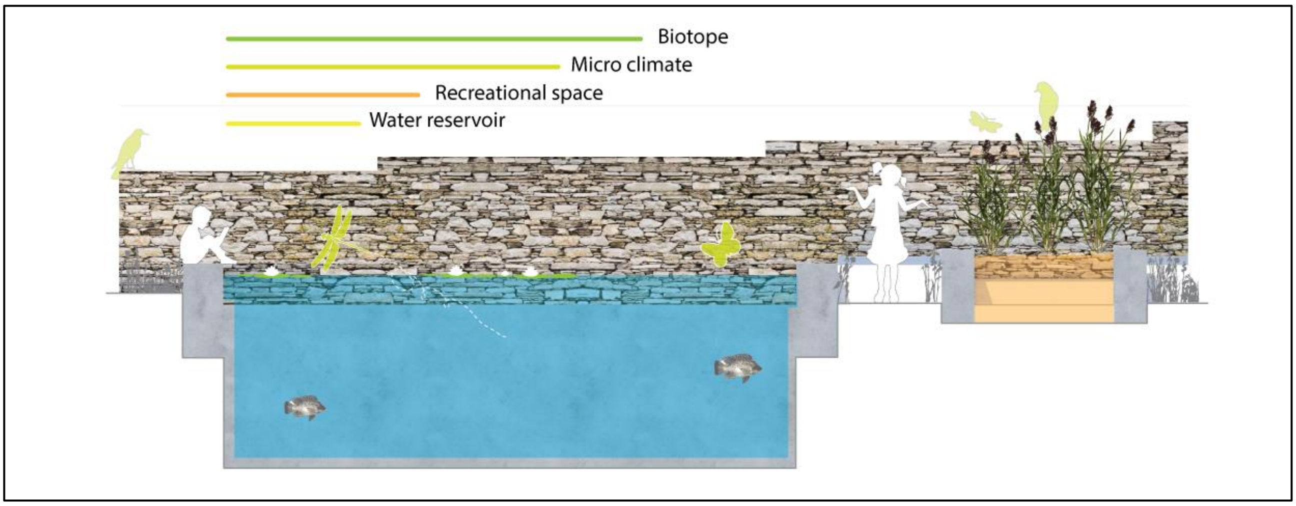


**Figure 4.2 Example of placement of cistern pond within the existing environment**

### 4.1.2. Cistern placement

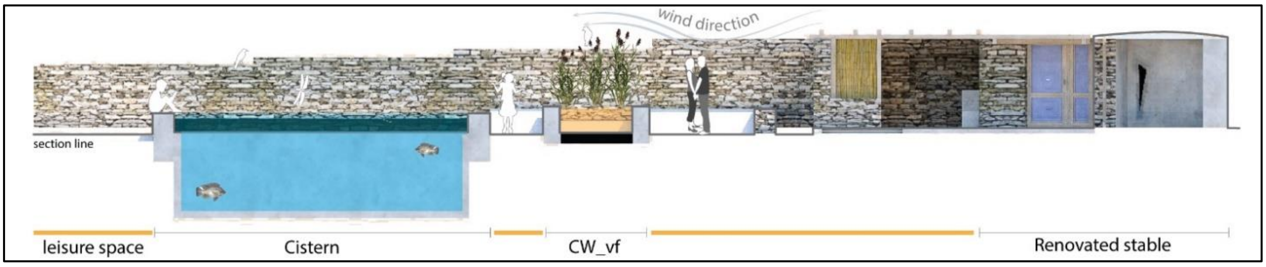


**Figure 4.3 Integration of the cistern into the surrounding space**

The cistern structure consists of an excavation into the bedrock of 5.8 m ×5.8 m with a depth of 1.8 m and a perimeter stone masonry wall of 7 m × 7 m with a height of around 1 m where only half is above ground level. The inner surfaces are plastered with an additional water proofing additive for mortars, suspended in water. The mortar is reinforced with a nylon net in order to add strength and avoid future cracking due to micro movement of the bed rock. The inlet and outlet pipes are placed during construction to avoid laborious later installation. The plastered surface is impregnated with a water impermeable cement slurry classified for drinking water quality.

After finalizing the excavation, the channels for the inflow pipe from the greenhouse roof were levelled, dug out and the tube work installed. At the same time, the group of stone masons began erecting the perimeter wall using the excavated rock. Building with natural stone is a physically heavy work which needs skilled craftsmanship with experience.

The plastering process (**Figure 4.4**) started with a very strong coarse mixture of cement, fine gravel and sand to achieve a sub layer capable of bearing the final load of plaster. On this rough surface another two layers of plaster were applied, reinforced with a nylon grid. From layer to layer the sand was selected less coarse so that the final texture could render as a smooth surface and fairly waterproof. Then, the “Kapakia” big stones were placed, especially selected for the final top row. The final waterproofing was achieved with a brushed-on cement slurry in two crossed layers.

**Figure 4.4 Plastering process**

### 4.1.3. Renovation of old stable and green roof

Inside the plot of ELT, there are 3 small stone stables dating probably from the $19^{th}$ century (**Figure 4.5**). These small buildings, that can be found all over the island, were the farmers shelter, where they kept their animals, their crops and one room usually for them to sleep in. The fields being far away from the villages, people had to walk for hours to reach them, so at the time of harvest they stayed on their fields, for the whole period. Their architecture is unique, built totally out of stone and earth, with huge stones placed on the roof and an oval structural shape inside. These buildings are a cultural and historical heritage of the island. Two of the small stables were decided to be fixed during the HYDROUSA project. Their position on the highest level of the plot was convenient to serve as a collection surface for rainwater harvesting. The challenge was to renovate these historical buildings, keeping their original structure as much as possible and transforming them to small lodges for tourists and volunteers.


**Figure 4.5 Picture of the stables, green roof and roof stone plates**

The traditional buildings have a green roof consisting of big stone plates and compacted earth in the shape in of a half cylinder for isolation against water and heat. When they were still in use, twice a year the soil was compacted with a special marble cylinder in order to keep water from infiltrating deep into the soil and into the stable. The green roof of the stables is part of the cultural heritage of the traditional agricultural stone buildings of Tinos and should be preserved as an architectural element. Therefore, the renovation was designed to keep the roof structure using modern building materials for green roofs ensuring total water proofing and long-term durability.

The medium stable collects the rainwater, which is then stored in the new cistern (**Figure 4.6**), while the small stable is connected to a drainage pipe (**Figure 4.7**) that flows under one of the herb plots of the facility. This water is stored underground, and it can be accessed by deep rooting plants.

The renovation of the old stable was designed to preserve the structure that is 120 years old (**Figure 4.8**). Skilled local craftsmanship was implied by artisanal workers, who implied this design.

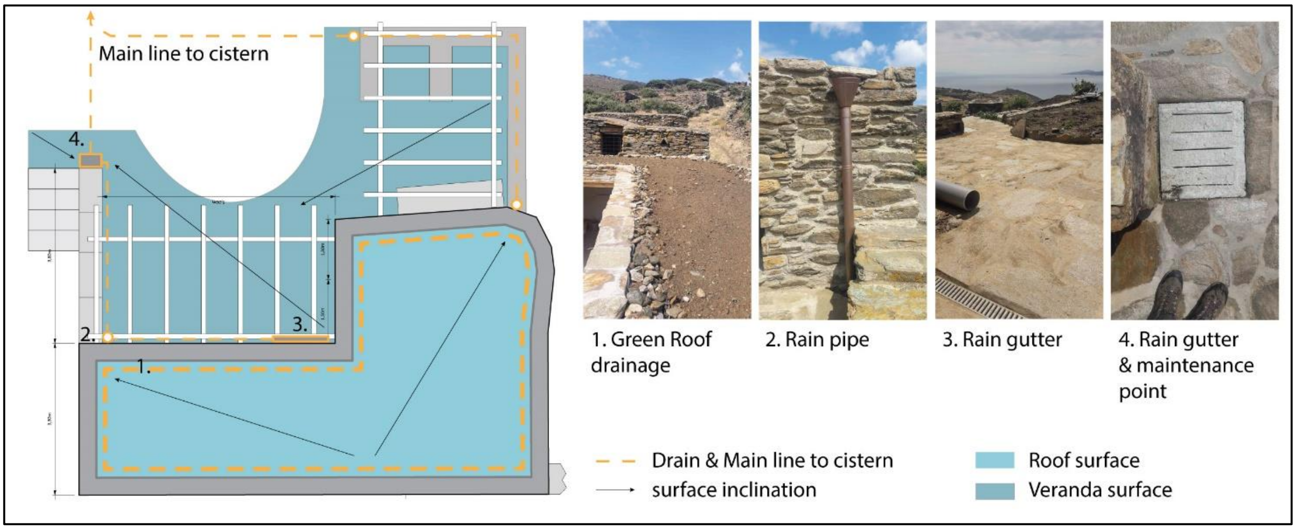


**Figure 4.6 Rainwater catchment, pipe flow, slopes and installation pictures**

**Figure 4.7 Rainwater pipes**

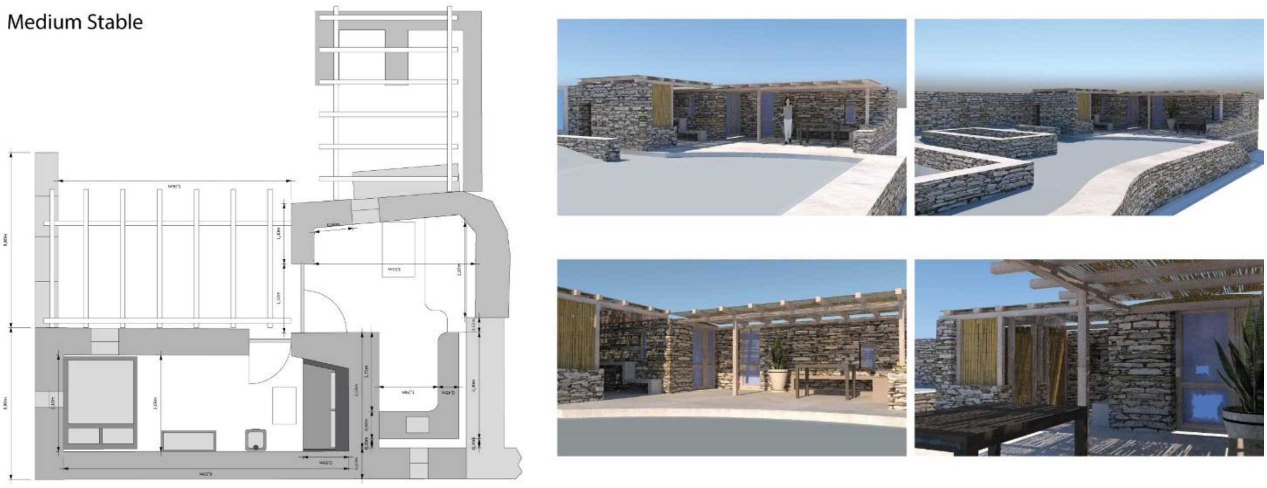


**Figure 4.8 Medium stable design**

**Figure 4.9 Construction of stable roof**

Material upcycling was utilized in the water proofing construction. Old PVC membranes from large print commercials, were easily accessible and have been used for that purpose (**Figure 4.9** and **Figure 4.10).**

**Figure 4.10 Installation of the upcycled PVC membrane**

The existing roof construction had a soil layer of around 60 cm at its highest point. This layer of soil created a lot of weight on the structure and it has been replaced with a strong mortar mix with a high content of extruded perlite rock. Perlite is used to create very light mortar mixes that can be well shaped. Mortar is not a good barrier to water because the material is subject to cracking from weathering and shifts within the structure, especially old stone buildings that continuously settle. A cement slurry was used to prevent steam condensation from within the building and a PVC membrane covered the slurry (**Figure 4.11**). The membrane can absorb heat expansion and is waterproof. The PVC membrane is then covered by a thick geo-textile that functions as a root barrier and drainage layer to protect the underlying construction from root intrusion. The top layer is formed by a special drainage and water retention foil. This system ensures that the roots have a water reservoir in dry periods while all excess water is drained away into the perimeter drainpipe. This water retention by the foil and the soil reduce run-off. The soil layer (8 cm thick) allows for extensive roof vegetation.

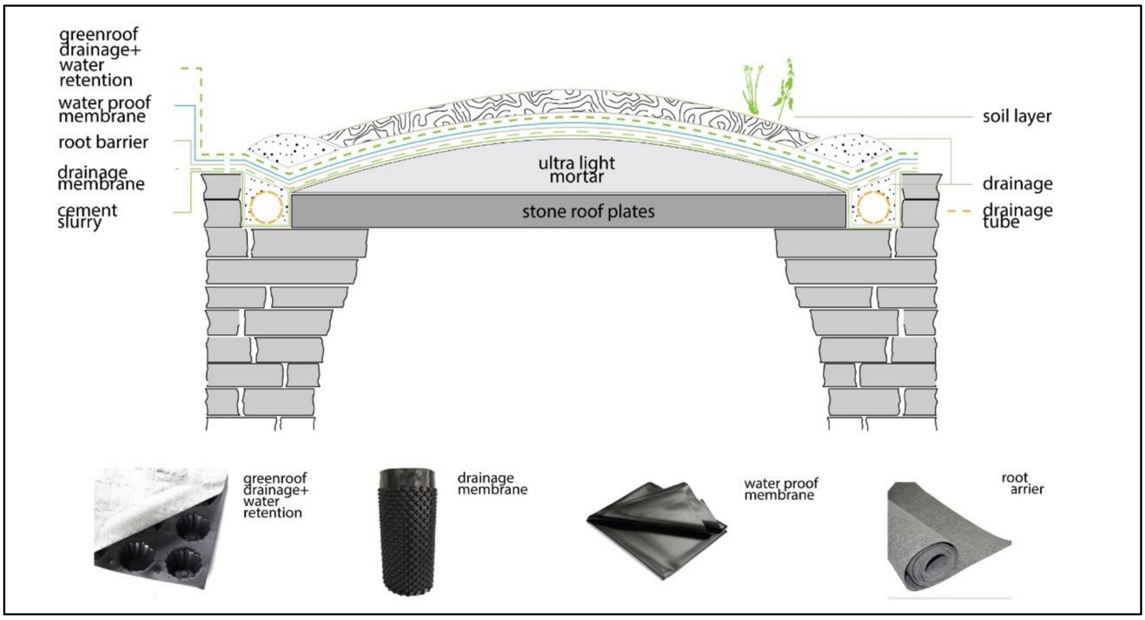


**Figure 4.11 Schematic construction drawing of the green roof installation and materials**

The vegetation will dry out through the summer months and re-establish with the first autumn rainfalls. This creates a natural looking surface with a very low environmental impact. The runoff coefficient is 0.9. The surface run off is planned with an inclination towards the rain gutters, which transport the water to the main rainwater pipe and further on into the cistern. The central gutter retains a certain amount of the sand and bigger particles that are flushed by the rain from the surfaces into the gutters. This, reduces the entry of bigger particles into the cistern. This gutter must be periodically cleaned out. It functions also as main service point, in case of pipe clogging. **Figure 4.12** shows the final state of renovation of the stables.

**Figure 4.12 Final state of renovation of the stables**

# 5. TECHNOLOGY APPLIED IN HYDRO6: GREENHOUSE

Gardening and small-scale vegetable production play a vital role within the economy of the Ecolodge. It complements the experience of the tourist with an ecological holistic approach to life. It provides organically grown heirloom varieties of fruit at 0 kilometre from farm to plate. It largely contributes to the environmental education of the visitors, which take great pleasure investigating all the beautiful different edible treats. Within the workshops organized by the Ecolodge the vegetable garden is a space for practicing and showcasing different approaches to food production. With this experience gained over the last years, the Ecolodge found it feasible to upscale and intensify certain parts of the agricultural production.

The construction of the greenhouse was chosen because it is a sheltered area for early seed propagation, propagation of local plants and an intensive cultivation area with increased crop yield per area. It prolongs the vegetation period into the winter and gives the possibility of early spring production for the upcoming tourist season. This improves greatly the early availability of crops to customers, that would otherwise be only productive much later in the season. It provides the opportunity to further diversify the income stream of the Ecolodge and complement the agricultural activities and the seminars.

The design and planning of the greenhouse were supported by knowledge transfer and co-creation with Kamarantho Project on Paros Island, with whom Ecolodge had a cooperation in the past. The greenhouse at the Ecolodge has a footprint of 80 $m^2$, which is larger than a hobby conservatory but rather small for a commercial production facility. Given the relatively small size, commercially manufactured greenhouses are not fitting. One of the requirements for the construction of the greenhouse was the integration of the structure within the landscape in Tinos. The local population was involved in a dialogue to make sure that the construction will impact with any of the cultural heritage of the site. The design was developed according to the local construction of a nearby church that dominates the site both for the position at the top of the hill and for style. Therefore, to account for impact with the surrounding landscape and architecture, the size of the greenhouse was reduced to 60 $m^2$ and to a lower height than that of the church. This was obtained by sinking the greenhouse 60 cm into the ground. Through this measure we gained a serious quantity of good soil for the other agricultural areas and could reduce the heat gain and loss. The space limitation on the terraces was addressed by integrating the structure into the stone wall of the laying behind terrace in order to visually blend both elements together (**Figure 5.1**).

**Figure 5.1 CG-Graphics of the Greenhouse building**

The internal space should not only be an agricultural production area but also an inviting space for the customers to experience a diverse culture. We designed raised beds, build out of wood that are well accessible also for older people and provide a nice warm atmosphere. The space becomes clearly structured and people can orientate easily where to walk and where to pick vegetables (**Figure 5.2** and **Figure 5.3**).

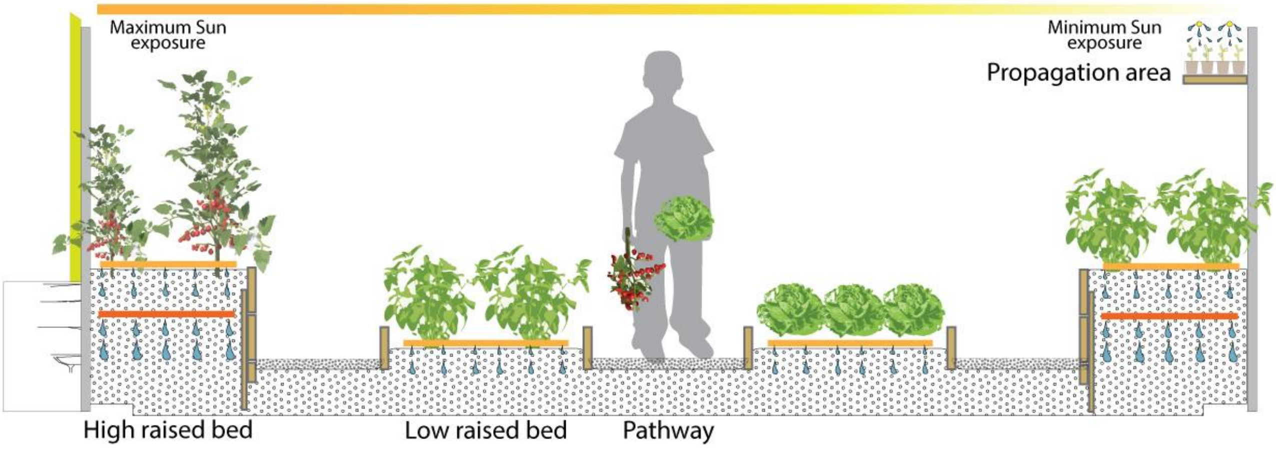


**Figure 5.2 Cross section greenhouse inner space**

**Figure 5.3 Greenhouse interior with first cultivation**

The area in front of the greenhouse is designed as a working and propagation area. With a small Pergola for shade and wind protection. In the lower area, three composting chambers were built for the organic material from the greenhouse (**Figure 5.4**).

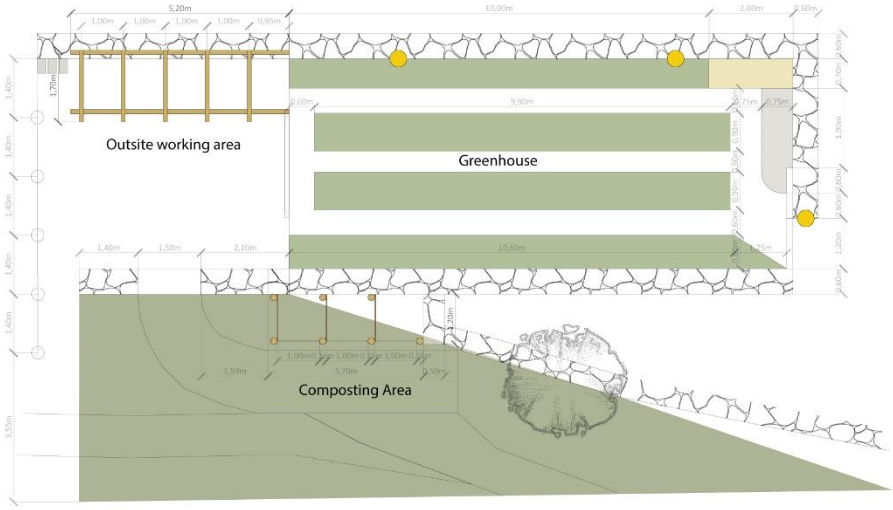


**Figure 5.4 Design of the outside greenhouse area**

The excavated soil and stones have been conserved for later use. Thereafter, the concrete shutter was built and the foundation tubes for the greenhouse structure were placed according to plan. Concrete was poured and the shutter removed. The dumper started to fill in a layer of rough stony material as drainage layer and a better ground level. Carpentry work started, following the installation of empty conduits and basic water tube installation. Steel tubes were painted with an anti-corrosion paint for protection. The raised beds were built on both sides, sanded down and oiled. At the inner site, a drainage layer was installed for wood protection against mould and fungus. Shelves for the propagation area were installed and painted (**Figure 5.5**).

The topsoil from the excavation was moved back in and improved with soil additives to create a mixture from local soil and additives obtaining a highly productive and water holding plant substrate.

**Figure 5.5 Construction of the greenhouse interior**

Figure 5.6 shows the crops in the greenhouse at different stages within the year.

**Figure 5.6 Cultivation within the greenhouse**

# 6. TECHNOLOGY APPLIED IN HYDRO6: ATMOSPHERIC WATER HARVESTING

The world's ever-increasing need for fresh water is a driver for investigations into new water sources, such as rain and fog harvesting. Rainwater collection is relatively simple, but the supply is usually very irregular. Water, in its liquid or gaseous state, is abundantly present in our ambient air and is emerging as an important source of potable water, especially in areas with little rain but relatively high humidity or big temperature differences between day and night. Hence, atmospheric water harvesting can play a key role in the water supply chain at off- grid situations, like the one at Ecolodge. The obtained water can be used for agricultural purposes, ecosystem services and potentially be re-mineralised to gain drinking water.

Compared to atmospheric water in its liquid form as fog, the occurrence of dew however is far more widespread, can be formed in most climates and geographic settings and shows high frequency and prevalence throughout the year. Therefore, atmospheric water condensation units went under intensive research, in order to design a system that can work under the local weather conditions with a satisfying degree of efficiency.

In terms of condensation, there are a few aspects which either hinder formation of liquid water or enhance it. These aspects can be broken down in water purity, surface material, geometry, surface temperature and -structure and meteorological conditions such as relative humidity, air temperature and air movement.

The variables that could be manipulated in our case are surface material, surface temperature and structure. Eventually, a condensing surface of any shape is being cooled down well below the dew point, thus water starts to condense. The cooling process hereby can be facilitated by two main principles: passive radiative cooling and active cooling, both contribute to decrease the temperature of the surface under ambient air temperature. Reaching a temperature below the dew point once is not sufficient, as there are constant influxes of heat to be expected through thermal conduction from warmer materials in the surrounding, IR radiation from warmer air layers and objects in the surrounding, convective heat transfer from warm winds, and last but not least the enthalpy of condensation from the water that condenses on the cool surface (**Figure 6.1**).

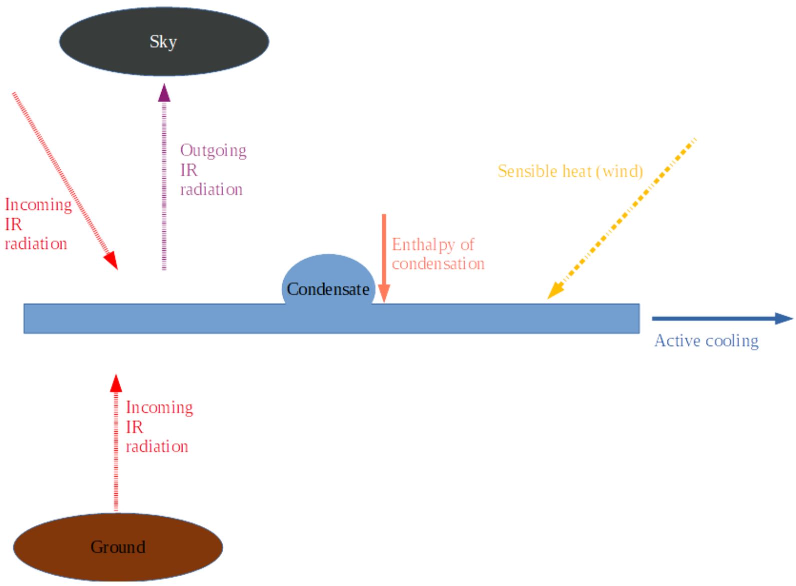


**Figure 6.1 Relevant energy fluxes in night-time operation**

The desired system for harvesting water from the ambient air in the absence of water in the liquid phase (rain, fog) should be suitable for an off-grid situation, reliable, efficient, easy to replicate and low cost.
Other criteria that influenced the design of the condensation systems were:

- Small footprint
- Small energy consumption
- Energy storage not needed or simple
- Affordable materials
- Affordable auxiliary components
- No disturbance of environment (visual, tonal)
- Multi-functionality
- Environmentally friendly

## 6.1. The water flower

The Water Flower is designed to be used in both passive and active operation. The model is that of a hexagonal, flower- like funnel on legs (d~1.6 m, h~1 m) that is light weight and mobile. The interior is painted with high emissivity coating and cools down for the purpose of condensation. The inclination is a compromise between proper radiation passage from the condenser surface, but at the same time provide a gradient for the water to trickle down. The outlet is located at the end of the funnel, being the lowest point, where the condensed water is diverted into a collecting container. All six sides of the funnel are isolated from the outside to shield the condensation surface from IR originating from the ground and surroundings. The structure is attached to the ground with three metal feet. For resistance against wind gusts, the whole structure is strapped down by the wooden frame and anchored into the ground.

The Water Flower is designed to adapt to local conditions and needs. It can be operated actively in times of energy surplus and will continue operating passively otherwise. If necessary, the construction can be removed without residues and rebuilt at another location. The longevity aspect is also a decisive factor in the choice of materials. The condenser surfaces have been painted with a water-based paint mixed with a high-infrared-emissivity additive based on 0.2–2 µm aluminosilicate powder (15% by weight), provided by OPUR- International Organisation for Dew Utilization (France). The water flower has a hexagonal funnel structure **(Figure 6.2** and **Figure 6.3**).

**Figure 6.2 Sketch of cooled, coated Water Flower (left) and picture of the setup of all 3 prototypes**

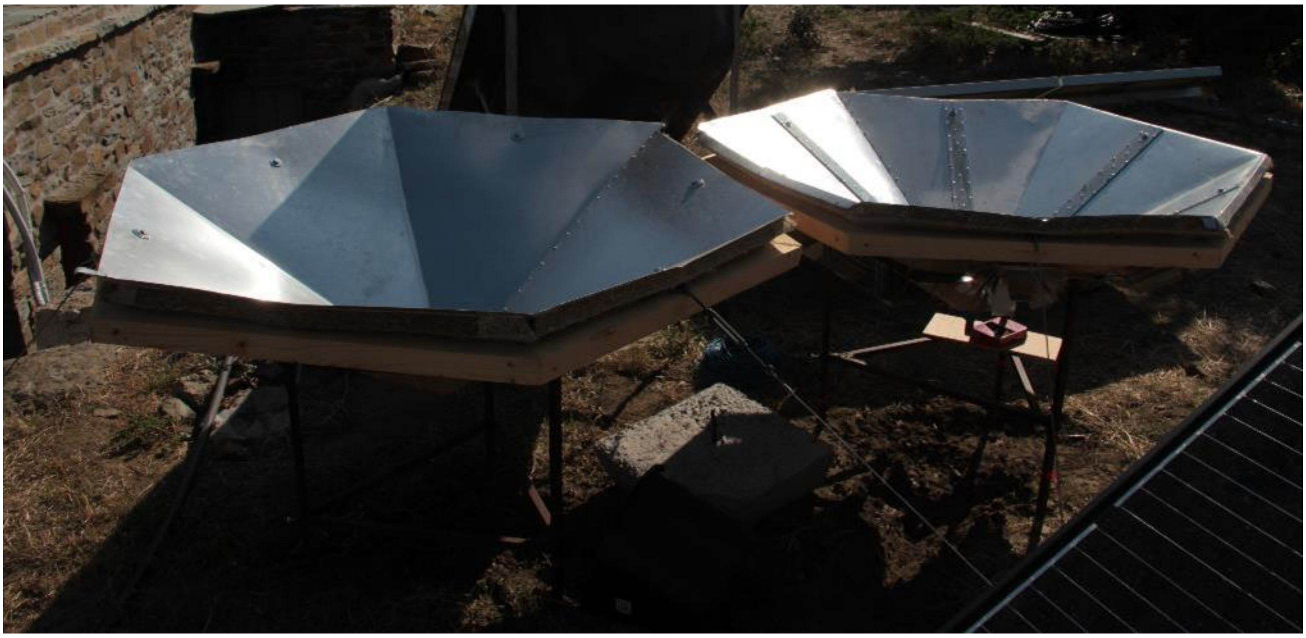

**Figure 6.3 Setup of the 2 Water Flowers at HYDRO6, passive (left) and active (right)**

## 6.2. Multifunctional roof

The multifunctional roof is a structure with the following functions: 1) condenses water vapour from the air, 2) gives shade, 3) protects from and collects rain, and 4) it is energy self-sufficient. To realise these functions, back-cooled PVs (PVTs) are used as energy providers and condensation surface at the same time. The cooling is provided by Peltier elements, which will directly consume the energy produced by two 300 W panels and cool down water that is pumped through a heat exchanger on the cold side (**Figure 6.4**). To transfer the cooling potential to the night, the cold water is stored in a tank and during the night pumped through the panels. The PV panels are oriented such to provide a good radiation passage from the condenser surface and at the same time provide a gradient that is big enough to facilitate runoff.

**Figure 6.4 Multifunctional roof**

The system facilitates condensation in passive operation and benefits from being cooled down further by the cold water. Due to the water being cooled over the day the system needs a very small electrical storage and is energy self-sufficient. The multifunctional roof is designed as a standalone unit, it is powered solely by its PVT panels.

The final setup of the multifunctional roof represents a downscaled shell of a house with PV Panels on top of the roof (**Figure 6.5**). The base is a semi-mobile foundation, a wooden frame filled with gravel. The base is firmly attached to the roof shell for stability against strong winds. As a stand-alone unit all the necessary electric equipment with following specifications is mounted within the multifunctional roof.

**Figure 6.5 Views of the finalised Multifunctional Roof**

## 6.3. Commercial vapour condensation systems

Beside the pilot trials of custom-developed vapour condensation systems, a review and selection of most promising commercially available technologies to be tested in HYDROUSA project has been done. The vapour water harvesting technologies can be divided into five types, including the nature structure, fog collection, underground condensation, atmospheric air water generators, and adsorption method. Approximately 50% of the costs in most commercial devices relate to energy consumption, and the performance is good for humidity higher than 30%. They also need to consider some general features such as safety, the simplicity of utilizing, flexibility in power source renewable (solar or wind energy) or conventional (from the electrical grid), efficiency and cost. A very limited number of commercialized technologies as atmospheric water generators (AWG) has been identified due to the constraint in weather conditions and low efficiency indicating that further technology development is still necessary. AWG generators range from home-based units that can produce 1 to 20 litres of water per day to commercial-scale units capable of 1,000 to over 10,000 litres per day. The three most commercially relevant AWG processes include:

- Cooling condensation (or mechanical refrigeration): air is then passed over a cooled surface or coil, that contains a refrigerant, which cools the water vapour below its dew point, causing condensation.

- Desiccants (i.e. hygroscopic materials): air is pulled in by a fan, but not cooled below the dew point of water vapor. Instead, water molecules adsorb to the surface of the sorbent until saturation (i.e. maximum adsorption capacity) is reached. To release the water, the desiccant is then heated or boiled (50-160°C depending on sorbent).
- Fog harvesting: large meshed nets made of a polymer are set up vertically and placed in areas where water droplets are captured and are collected in a reservoir through gravity.

The most commonly used AWG systems employ condenser and cooling coil technology to pull moisture from the air in the same way a household dehumidifier does. Although significant quantities of energy can be required to operate these condenser and fan systems, recent technological advancements have substantially improved the energy-water ratio—increasing the feasibility of using these systems.

**Table 6.1** shows a list of worldwide companies providing atmospheric water condensation solutions. From this list, two of most trending technologies have been selected to be tested in HYDROUSA project (marked in green): 1) ZeroMassWater Hydopanels, which provide an off-grid vapour condensation solution using renewable energy; and 2) Genaq, which provide a dispenser-like atmospheric water generation device which requires an external energy source.

**Table 6.1 Commercial vapour water condensation technologies**

| Company | Web Page |
|---|---|
| air to water harvest | http://www.a2wh.com |
| Air to Water Technologies | http://www.airtowatertech.com |
| Aqua Sciences, Inc. | http://www.aquasciences.com |
| Aquavolve, LLC | http://www.aquavolve.com |
| Zero Mass Water (Source) | https://www.source.co/ |
| Atlantis Solar and Wind LLC | http://www.atlantissolar.com |
| Eole Water S.A.S., | http://www.eolewater.com |
| Island Sky Corporation | http://islandsky.com |
| GENAQ | http://www.genaq.com/water/ |
| Rainmaker | http://dutchrainmaker.nl |
| SunToWater Technologies, LLC | http://www.suntowater.com |
| Uravu Labs | http://www.uravulabs.com |
| Water-Gen Ltd. | http://www.water-gen.com |

### 6.1.1. Zero Mass Water (SOURCE) Hydropanels

SOURCE is an off-grid vapour condensation technology, which is powered by renewable energy as an integral combination of solar photovoltaics and high efficiency solar thermal. The electrical and thermal power is used to efficiently produce water in a modified psychrometric cycle. The solution comes in the form of Hydropanels illustrated in **Figure 6.6**.

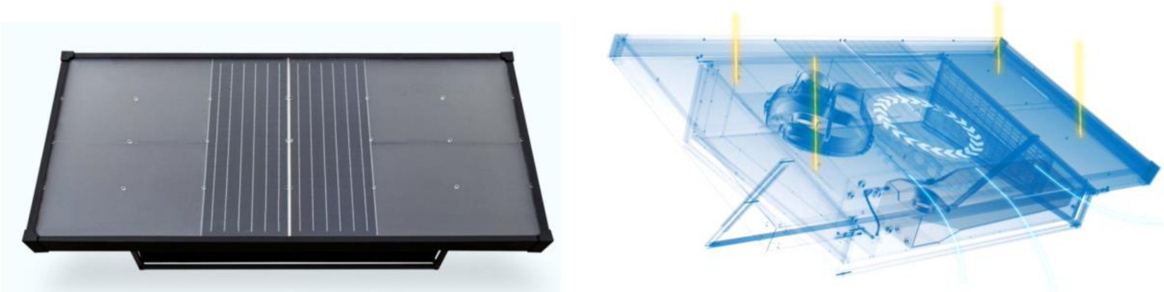

**Figure 6.6 Zero Mass Water Hydropanels**

The unit takes ambient air through a fan which is circulated through hygroscopic material that extracts the water vapour from the air and passively condenses it into liquid that is collected in the reservoir. Minerals are also added at the end of the process to make it suitable for drinking water purposes.

Although water production can vary depending on the weather in the chosen location, SOURCE technology is optimized for a wide range of conditions and can even produce water in low to medium sun and humidity. One unit is able to produce up to 4 litres day in optimal conditions (**Figure 6.7**).

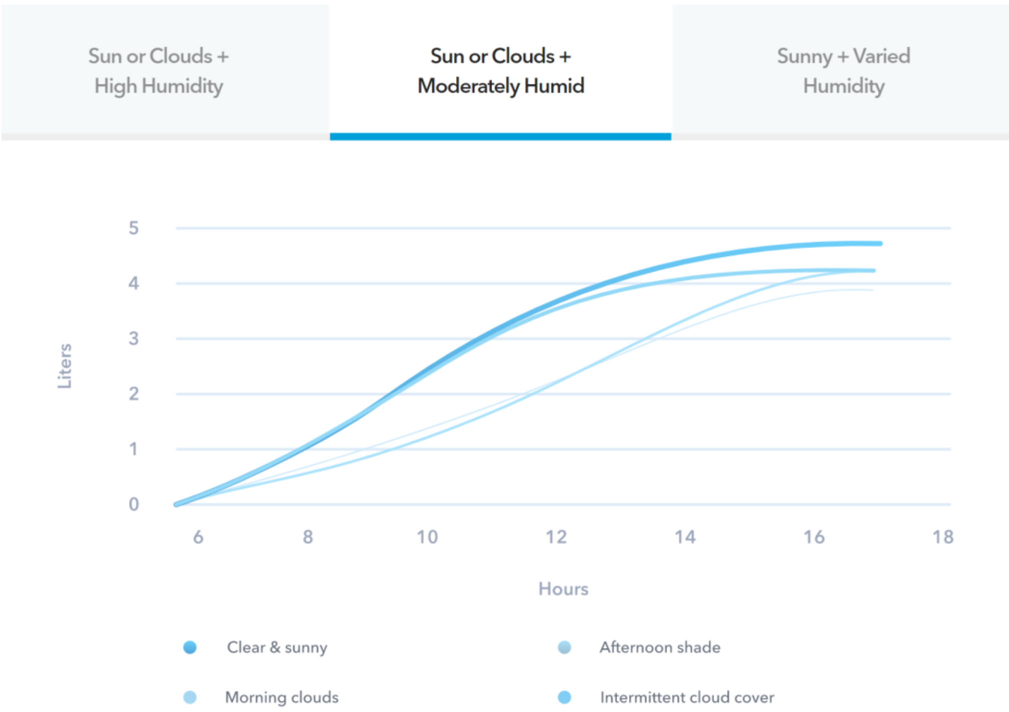


**Figure 6.7 Water production capacity of one Hydropanel in optimal conditions**

#### 6.1.2. GENAQ atmospheric water generators

The GENAQ atmospheric water generators obtain drinking water through the condensation of water vapor contained in the atmospheric air using a thermodynamic cycle with mechanical refrigeration technology with an advanced electronic control. The emphasis in this technology is to increase efficiency and, thereby, reduce energy consumption and maximize water generation. In order to ensure the highest quality of water, the process includes air and water treatments to eliminate suspended particles in the atmosphere and water soluble volatile organic compounds, to increase water mineralisation for drinking water, and to ensure proper conservation for stored water.

The units can operate in arid climates with temperature over 50ºC (122F) and relative humidity lower than 20%, and also industrial or polluted areas, where this technology ensures high quality drinking water. There is no need for installation and requires very low maintenance. The produced water is ideal for human consumption and for other purposes such as preparation of food, irrigation or water supply to animals. High quality is guaranteed even in industrial or polluted areas, because suspended particles in the atmosphere are retained through air and water filters, while water soluble volatile organic compounds are eliminated through active carbon filters. Produced water complies with World Health Organization (WHO), United States EPA and European Directive 98/83/EC parameters for drinking water. The working scheme of the GENAQ AWG is shown on **Figure 6.8**.

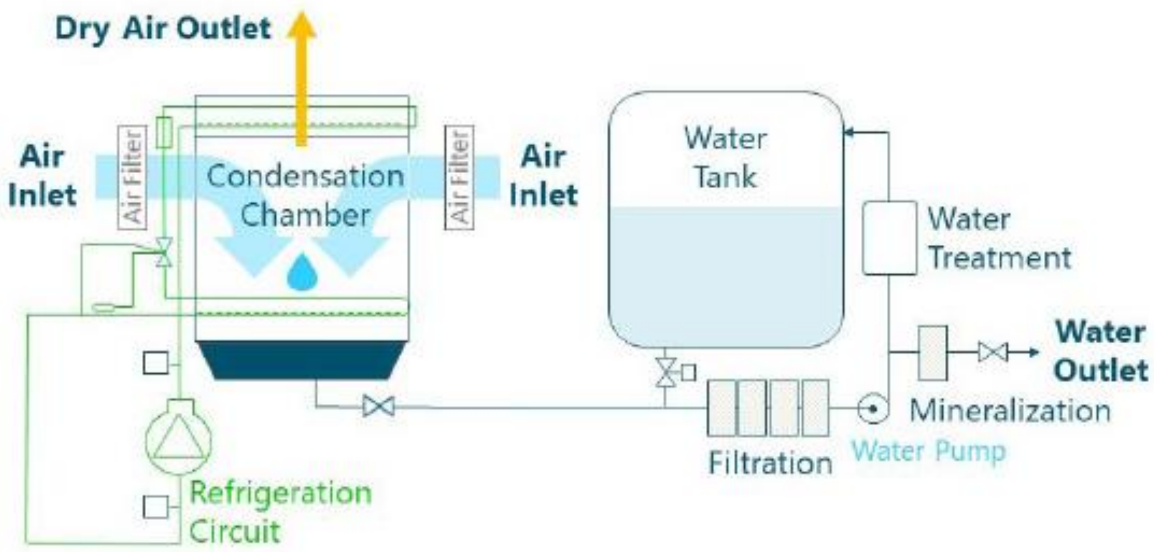


**Figure 6.8 Working Scheme of GENAQ AWG**

The main features that the GENAQ AWG provide comprise:

- 2-stage air filtration
- Condensation chamber in food-grade materials
- Efficient refrigeration components and heat exchangers
- Water filtration including sediment, activated carbon and
- ultrafiltration
- UV water purification
- Mineralization
- Software optimization control
- Internet of Things

In HYDROUSA project two models of GENAQ dispenser-like AWG have been selected to be tested. These are Stratus S50 with a nominal generation capacity of 52 litres/day and Stratus S200 with a nominal generation capacity of 201 litres/day. The key technical specifications of the two units are shown in **Table 6.2**.

**Table 6.2 Technical specifications of the GENAQ Stratus S50 and Stratus S200 AWG units**

<table>
<tr><th>Item</th><th>Stratus S50</th><th>Stratus S200</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Dimensions (Height x Width x Depth)</td><td>1500 x 400 x 515 mm</td><td>1765 x 595 x 710 mm</td></tr>
<tr><td>Weight</td><td>105 kg</td><td>185 kg</td></tr>
<tr><td>Nominal power</td><td>0.7 kW</td><td>2.5 kW</td></tr>
<tr><td>Nominal air flow</td><td>350 m3/h</td><td>1000 m3/h</td></tr>
<tr><td>Generation (liter per day)</td><td>
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<tr><th></th><th></th><th colspan="10">Temperature (ºC)</th></tr>
<tr><th></th><th></th><th>55</th><th>50</th><th>45</th><th>40</th><th>35</th><th>30</th><th>25</th><th>20</th><th>15</th><th>10</th></tr>
<tr><th rowspan="10">Relative Humidity (%)</th><th>100</th><td>-</td><td>-</td><td>67</td><td>64</td><td>61</td><td>55</td><td>45</td><td>34</td><td>22</td><td>13</td></tr>
<tr><th>90</th><td>-</td><td>-</td><td>67</td><td>64</td><td>61</td><td>54</td><td>45</td><td>34</td><td>21</td><td>12</td></tr>
<tr><th>80</th><td>-</td><td>71</td><td>66</td><td>63</td><td>59</td><td>52</td><td>43</td><td>32</td><td>20</td><td>12</td></tr>
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<tr><th>60</th><td>67</td><td>64</td><td>59</td><td>52</td><td>46</td><td>39</td><td>28</td><td>20</td><td>12</td><td>5.4</td></tr>
<tr><th>50</th><td>60</td><td>57</td><td>50</td><td>43</td><td>37</td><td>28</td><td>21</td><td>14</td><td>6.7</td><td>2.6</td></tr>
<tr><th>40</th><td>47</td><td>43</td><td>37</td><td>29</td><td>24</td><td>19</td><td>14</td><td>7.0</td><td>2.9</td><td>0.9</td></tr>
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<tr><th>50</th><td>281</td><td>270</td><td>242</td><td>204</td><td>159</td><td>109</td><td>71</td><td>20</td><td>8</td><td>3</td></tr>
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<tr><td>Consumption (kWh per liter)</td><td>
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<tr><th rowspan="10">Relative Humidity (%)</th><th>100</th><td>-</td><td>-</td><td>0.32</td><td>0.34</td><td>0.35</td><td>0.39</td><td>0.43</td><td>0.48</td><td>0.67</td><td>0.85</td></tr>
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<tr><th></th><th></th><th colspan="10">Temperature (ºC)</th></tr>
<tr><th></th><th></th><th>55</th><th>50</th><th>45</th><th>40</th><th>35</th><th>30</th><th>25</th><th>20</th><th>15</th><th>10</th></tr>
<tr><th rowspan="10">Relative Humidity (%)</th><th>100</th><td>-</td><td>-</td><td>0.24</td><td>0.26</td><td>0.28</td><td>0.34</td><td>0.42</td><td>0.56</td><td>0.88</td><td>2.47</td></tr>
<tr><th>90</th><td>-</td><td>-</td><td>0.24</td><td>0.26</td><td>0.28</td><td>0.34</td><td>0.43</td><td>0.56</td><td>0.89</td><td>2.48</td></tr>
<tr><th>80</th><td>-</td><td>0.24</td><td>0.25</td><td>0.26</td><td>0.29</td><td>0.36</td><td>0.44</td><td>0.58</td><td>0.92</td><td>2.56</td></tr>
<tr><th>70</th><td>0.24</td><td>0.24</td><td>0.25</td><td>0.27</td><td>0.31</td><td>0.39</td><td>0.47</td><td>0.67</td><td>2.06</td><td>2.83</td></tr>
<tr><th>60</th><td>0.24</td><td>0.25</td><td>0.26</td><td>0.30</td><td>0.36</td><td>0.42</td><td>0.59</td><td>0.85</td><td>2.38</td><td>4.22</td></tr>
<tr><th>50</th><td>0.26</td><td>0.27</td><td>0.30</td><td>0.35</td><td>0.41</td><td>0.55</td><td>0.69</td><td>2.06</td><td>3.65</td><td>6.72</td></tr>
<tr><th>40</th><td>0.31</td><td>0.33</td><td>0.38</td><td>0.46</td><td>0.56</td><td>0.67</td><td>0.96</td><td>3.32</td><td>6.06</td><td>11.88</td></tr>
<tr><th>30</th><td>0.44</td><td>0.46</td><td>0.54</td><td>0.62</td><td>0.81</td><td>1.00</td><td>3.41</td><td>6.02</td><td>11.46</td><td>15.70</td></tr>
<tr><th>20</th><td>0.63</td><td>0.66</td><td>0.83</td><td>1.23</td><td>3.13</td><td>4.92</td><td>7.34</td><td>14.35</td><td>-</td><td>-</td></tr>
<tr><th>10</th><td>2.64</td><td>2.81</td><td>3.99</td><td>5.22</td><td>7.51</td><td>12.31</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
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</table>

Both units come with IoT integration for internet remote control and measurement and additional water meters will be installed to monitor the total water produced.

The Stratus S50 will be installed at Ecolodge (HYDRO6) where it will valorise the excess renewable energy from the photovoltaics to produce water for drinking water purposes of Ecolodge customers. The larger unit (Stratus S200) will be installed at HYDRO3 site where there is access to electricity from the grid and will provide drinking water to the local community.

Unfortunately, due to COVID-19 situation the orders of the two units have been delayed and the actual shipment and installation is expected to be done by the end of January 2021. However, this will not impact the future activities and demonstration of these technologies within the project since there is sufficient time to evaluate their performance.

## 6.4. Installation

The Zero Mass Water Hydropanels have been installed at HYDRO6, where the generated water will be used to satisfy the drinking water needs of the Ecolodge customers. Photos from the installation of the Hydropanels are shown on **Figure 6.9** Installation of Zero Mass Water Hydropanels at HYDRO6.

**Figure 6.9 Installation of Zero Mass Water Hydropanels at HYDRO6**

The cooled coated water flower and the uncooled coated water flower were installed at the Ecolodge.
The water flowers are positioned next to each other occupying an area of about 2 m x 1.5 m. Anchors and buried feet give the water flowers stability against wind burst. For faster assembly and less impact, the anchors were realised as concrete blocks (40 cm x 40 cm x 15 cm) that can be withdrawn manually when the prototypes need to be moved. The active flower is powered by 2 solar panels with all infrastructure such as battery and charge controller mounted below the panels to be protected against inclement weather events. The water flower is a stand-alone unit which is electrically and mechanically disconnected from the utilities at the Ecolodge.

The operation of the cooling units is controlled by a relay that connects the batteries to the Peltier elements, once the PV panels' output drops after sunset, and a battery guard that breaks this circuit once the batteries are drained to a pre-set limit.

The water flower and the multifunctional roof were arranged to use little space and least impact on the surrounding. While standing side by side on an about 3 m x 4 m area, both are operated independently and self-sufficiently. The water collection takes place in separate storage tanks with water meters interposed between outlet and collection tank in order to automatically quantify the water output. The assessment of water yield is realised by self-developed tipping counters for each unit. For further correlation, the surface temperature of all three units is measured constantly and logged every 10 minutes coupled with natural conditions such as air temperature, relative humidity, absolute pressure, and illuminance. As back up, a weather station was mounted in the middle of the set-up for logging additionally wind speed and wind direction.

The vapour condensation unit will be compared to PV-driven water condensation unit with overall efficiency rates later on the project when both systems will be fully operational.

# 7. CONCLUSIONS

Increasing the application of circular economy for water and reinforcing the water-energy-food nexus in the Mediterranean area, are the main objectives of HYDROUSA. A set of innovative solutions are designed and implemented within the project in various demonstration sites in Greece. These solutions are low cost, energy efficient, and environmentally sound and as such, are easily adaptable and replicable to locations around the world with similar water scarcity issues as in the Mediterranean area. Under HYDRO6 demonstration site of Work Package 2 (WP2), Ecolodge in Tinos has been upgraded to improve the efficiency of the existing water collection systems (i.e., rainwater harvesting), and utilized to boost local production and consumption of organically grown vegetables and crops. Existing buildings have been renovated to enlarge the water collection structure maintaining the traditional structure and integration within the local landscape (**Figure 7.1**). In addition, innovative atmospheric water harvesting technologies have been implemented on site to increase water capture without stressing the withdrawal of groundwater and reducing the usage of water from the public grid.

Water is first collected and then reclaimed after usage within a system of loops that are interconnected and allow increased business diversification where eco-tourism is integrated with agricultural production. The business model developed within HYDRO6 is less vulnerable to fluctuations within the tourisms sectors as it generates income diversification, reduces costs, and increases biodiversification of the natural environment without stressing the water provision system from the public grid. To reduce the overall water withdrawal from the aquifer, the water used in the facility derives from: 1) surface water from rain captured through a rainwater harvesting-storage system and a stream, 2) vapour condensation unit for direct water production. These technologies are nature-based and rely on minimal use of energy that is provided though solar panels. The anthropogenic cultural landscape of the locality were HYDRO6 is being demonstrated (Tinos) and the natural habitat are carefully integrated and valorised into the design of the technology through technical measures (i.e., usage of local materials, building techniques, and traditional craftsmanship) and social adaptation (i.e., behavioural and cultural integration of changes toward alternative sanitation concepts).

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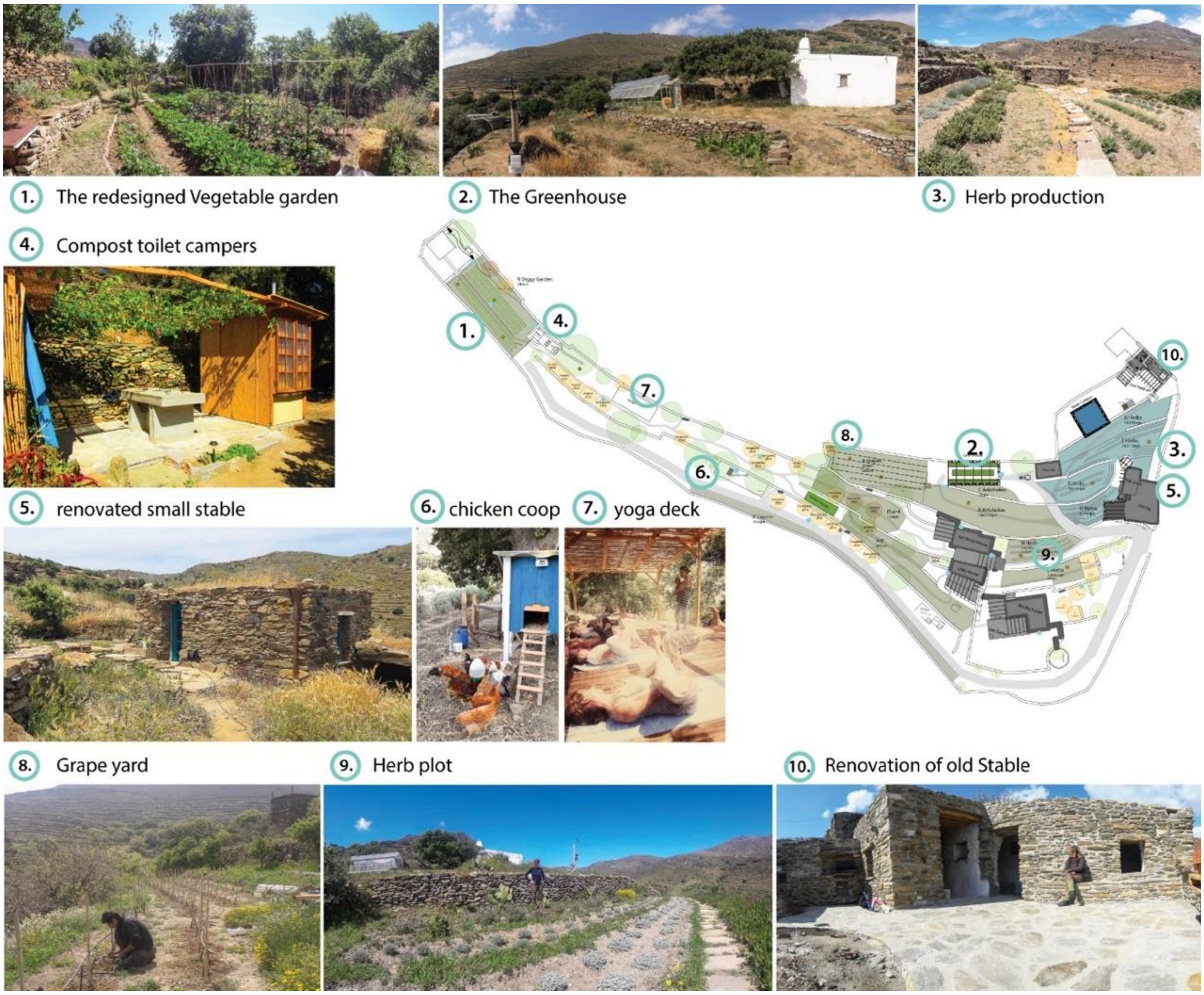


**Figure 7.1 Set of water loops at Tinos**