Sustainable cellar architecture and design: concept, application and examples

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Summary. The construction of a winery, as well as its renovation, requires that sustainable development be taken into account. This is particularly important for cellars, which are built for a very long time and support the image of the structure. Bioclimatic architecture is an approach designed to make the most of the conditions of a site and its environment, for a design that is naturally comfortable for its users while optimising water and energy management in particular. The optimisation of energy and the reduction of the impact on the greenhouse effect combine the use of the thermal inertia of the subsoil and of renewable energy (solar, ground source heat pump, geothermal, etc.). With regard to effluents, ecological treatment aims to reduce energy consumption, better integrate into the landscape and possibly contribute to the development of biodiversity. This is often based on the principle of phytoremediation by plants with a view to the circular economy. These treatments also aim to progressively recycle water for irrigation or possibly for the cellar's cooling systems. The aim of the communication is to present the main operational approaches and avenues that can be applied to wineries with labels and feedback from different regions of the world.

1 Basics of a sustainable cellar

+ Objectives

Whether traditional or modern in design [1], beyond their wine-making functions, cellars (from the Latin cavita "hollow place") and wineries (a term of Celtic origin) are emblematic showcases for the winegrower, the winery or the merchant. Thus, the architecture of these places of wine production constitutes the support of aesthetic and sometimes artistic identities of the wines, which are increasingly valued by wine tourism (and notably eco-wine tourism). Beyond image, regulations and possibly financial aid are progressively integrating sustainable prerequisites, which will very probably increase, an important development to be taken into consideration for the future. Eco-construction or sustainable construction is the creation, restoration, renovation or rehabilitation of a building by

This concept, which appeared at the end of the 1940s, also seeks to integrate the building as respectfully as possible into the natural environment by making the best possible use of local resources. This concept, which appeared at the end of the 1940s, also seeks to integrate the building as respectfully as possible into the natural environment by making the best use of local resources. The eco-design of a cellar integrates both concepts developed in the past in traditional cellars (high inertia of walls, local construction and insulation materials, buried area, etc.) and modern technologies linked in particular to alternative energy sources (solar, geothermal) and regulation systems (ventilation, lighting).

Thus, beyond the oenological aspects, cellars and wineries must take into account a certain number of sustainable operational aspects (Fig. 1) [2] :

+ Management of **waste and by-products**, which can impact on effluent treatment and represent potential sources to be used as

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renewable energy source in a circular economy.

+ **Water management**, which combines technologies for water conservation and optimal effluent treatment [3].

+ **Limiting energy consumption**, especially fossil fuels, by using insulation and renewable energy.

+ **Landscape integration**, so that the winery finds its place in the farm (in the same way as the other farm buildings), in terms of aesthetics and heritage.

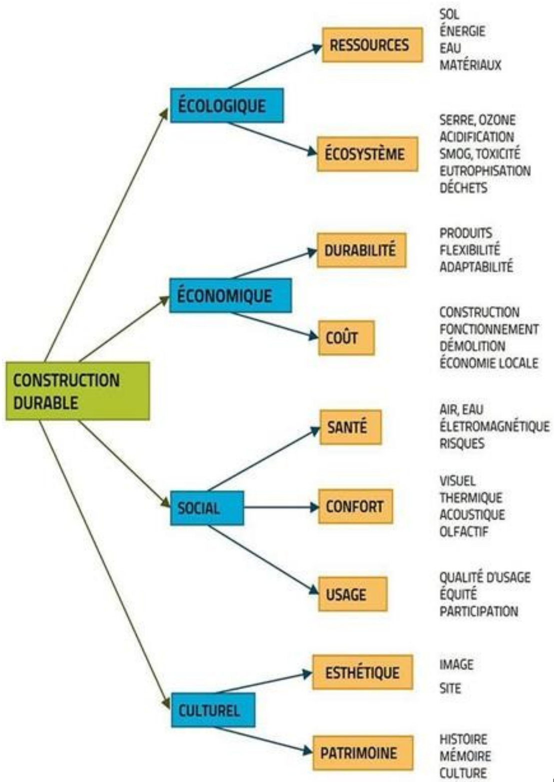

Figure 1: Main objectives of sustainable construction, after B Peuportier [4].

CELLAR TRADITIONAL FR DESIGN

The old cellars, built before the use of air-conditioning, incorporated traditional architectural forms that naturally allowed for coolness in summer and warmth in winter, thanks in particular to the use of the thermal inertia of the subsoil and very thick stone walls that attenuated the internal thermal variability (Fig. 2 and Photo 1). Thus, each wine-growing region, depending on the local climate and the materials available, was able to develop wine-growing habitats that combined optimal thermal conditions for both wine production and possibly other agricultural production and the living area.

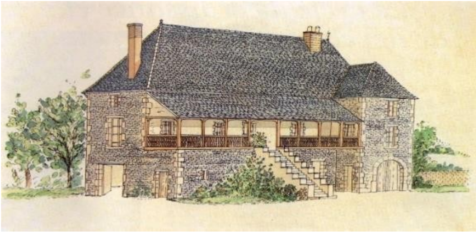

Figure 2: Traditional house in the Mâconnais region, French wine tourist encyclopaedia, Hachette 1994 Drawing by D. Duplantier.

Photo 1: Traditional Moldavian cellar with a green roof, photo J. Rochard.

Bioclimatic architecture is a know-how to make the most of the conditions of a site and its environment, with a comfortable design for its users, while optimising water and energy management in particular. It involves many strategies, techniques and systems for cooling and ventilating the indoor environment of a building. The context of the site (climate, microclimate, geology, relief, etc.) plays a major role in the study and implementation of the project. A thorough study of the site allows us to take advantage of it and to identify the constraints. Moreover, bioclimatic design is accompanied by broader reflections and approaches on respect for the environment, both locally and globally (Figs. 5 and 6).

BIOSOURCE AND GEOSOURCE MATERIALS

In the 20th century, with the growth of transport and the standardisation of architecture, construction often abandoned the use of local resources and favoured non-renewable materials (sand, aggregates, metals, etc.). But the earth's resources are not infinite. Gradually, the construction sector is becoming aware of the importance of reverting to the use of materials available close to the site and of using materials with a low or even negative carbon impact. Several types of materials can be considered:

+ Biobased materials (Fig. 3) which contain mostly material from living organisms (animal or plant). This material is considered renewable, but must be the result of sustainable management. (Example: wood, straw, hemp, cellulose wadding, wood wool, sheep wool, etc.).

+ Geo-sourced (Fig. 4) based on natural mineral elements (stone) or earth (adobe, raw earth brick, earth plaster, site concrete, etc.).

These materials have several advantages:

+ Hygrometry regulation quality: They store moisture and release it.

+ Temporary carbon storage: Biobased materials participate in the sequestration of carbon, absorbed by plants during their growth, throughout their processing.

+ Low emissions of Volatile Organic Compounds (VOCs), which are harmful to the health of occupants and which generally have a good air quality rating.

+ Good thermal phase shift, due to their density.

Figure 3. Main bio-based materials, www.envirobatbdm.eu

Figure 4. Main geosourced materials, www.envirobatbdm.eu.

These approaches, which concern both new construction projects and renovations, combine consideration of a building's impact on the environment with the means implemented to reduce it. In France, an HQE certified building integrates environmental requirements right from the construction or renovation project. This approach, managed in France by www.hqegbc.org, is part of a dynamic

international of construction construction
supported by World Green.

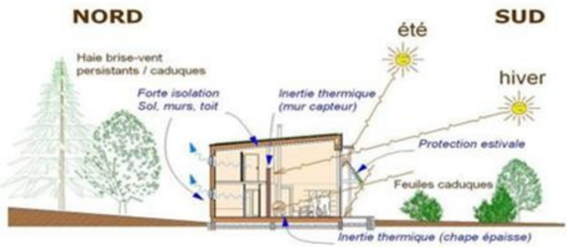

Figure 5. Logos of green building certification in the international network www.worldgbc.org.

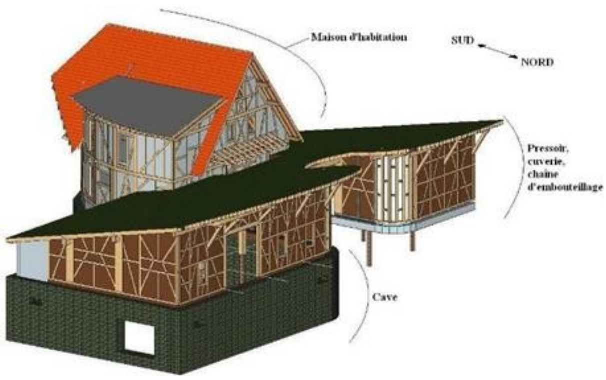

Figure 6. An example of a bioclimatic winery with bioclimatic architecture (Domaine Léon Boesch in Alsace). Designed by the architect Mathieu Winter, the winery is an outstanding example of a bioclimatic cellar. It is built from a wooden frame, a traditional construction method in Alsace. The construction combines dry stone foundations, a green roof, straw bale wall insulation, etc. The raw materials come from the surroundings of the wine village. The foundations are made of limestone rocks to guarantee the hygrometry and the "breathing" of the cellar. The production area, located to the north, benefits from the coolness, while the living quarters, positioned to the south, benefit from the sunshine. The framework is made up of half-timbering (a traditional construction method in Alsace), from local forests. www.domaineboesch.fr.

Building Council (WorldGBC) www.worldgbc.org (Fig. 8). According to this organisation, a sustainable building, in its design, construction or operation, reduces or eliminates negative impacts and can create positive impacts on our climate and natural environment.

https://doi.org/10.1051/bioconf/20235602002

LANDSCAPE INTEGRATION OF THE BUILDING
A good analysis of the visual impact of the buildings in the near and distant view is essential given the often large volumes of buildings to be built on a very marked relief (Fig. 7 and Photo 2).

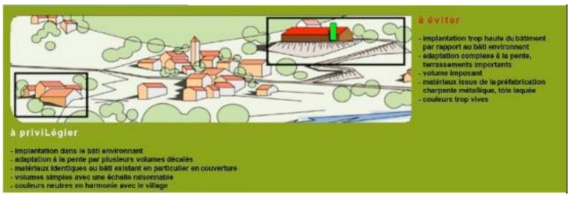

Figure 7. Some key points for successful integration landscape of a building, www.parc- monts-ardeche.fr.

Photo 2. Antinori "la Mortelle" winery in Tuscany. It was designed to limit the impact on the environment with optimal integration into the surrounding hills. The cellar has a semi-buried hemispherical shape, hidden for the most part in a hillside and vegetation in the unburied areas. A skylight provides natural lighting inside the cellar. Photos www.antinori.it.

Green buildings conserve valuable natural resources and improve our quality of life, including the following aspects

- Efficient use of **energy,** water and other resources
- Use of **renewable energy,** such as solar energy
- Measures to reduce **pollution and waste**, and the possibility of reuse and recycling
- Good indoor **air quality**
- Use of **non-toxic**, ethical and sustainable **materials**
- **Environmental** considerations in design, construction and operation
- Taking into account the **quality of life** of occupants in design, construction and operation The HQE approach, which initially concerned the housing sector, is now being extended to industrial production with
- the gradual integration of various French wineries into the process (Fig. 8 and Photo 3).

Figure 8. Objectives of an HQE approach, www.hqegbc.org.

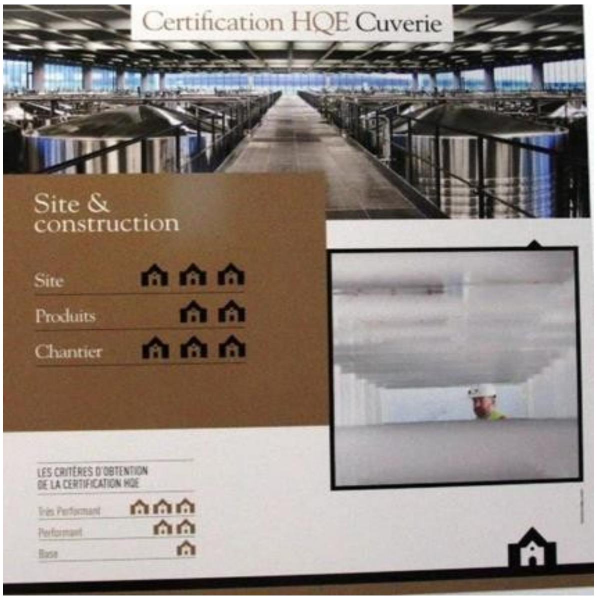

Photo 3. Example of the application of the HQE approach for the Moët et Chandon Champagne winery, photo J. Rochard.

2 Thermal optimisation

+ Strategy

Winegrowers often knew empirically the importance of thermal aspects during wine making [5]. All the means that made it possible to benefit from the coolness or heat

In addition, the cold winter months were used to ensure the tartaric stabilisation of the wines. In addition, winter cold was favoured to ensure the tartaric stabilisation of the wines.

However, vinification remained very dependent on the immutable cycle of the seasons and the weather conditions of the year. For several decades now, quality requirements, the need to ensure perfect biological and physical-chemical stability of the wines, the reduction of vinification cycles and the establishment of above-ground cellars have tended to generalise thermal applications throughout the wine-making process. To design an ecological winery, a clear architectural framework must be drawn up, setting out the objectives to be achieved, which implies a strong involvement of the winery's responsible and operational staff in liaison with the architect, the project manager and possibly a landscape architect, while integrating the materials, techniques and know-how available in the region. In addition to the choice of building structure, it is possible to optimise energy consumption through the use of insulating materials, if possible environmentally friendly, and plant structures (Fig. 9).

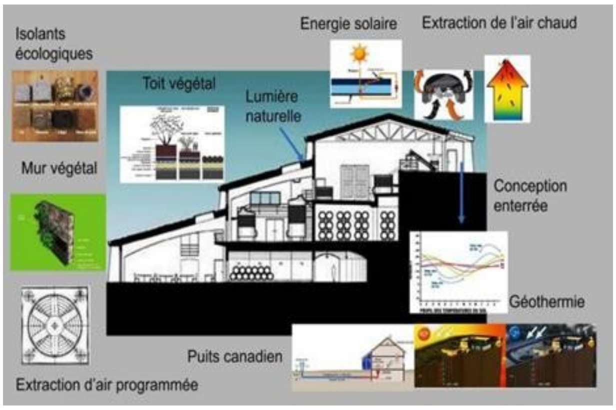

Figure 9. Main avenues for thermal optimisation of a cellar, according to J. Rochard.

+ Thermal inertia

By limiting the overheating of the building in summer and its cooling in winter, thermal inertia has a direct impact on the comfort of the staff, the quality of the wines and the energy consumption necessary to air-condition or heat the building. Applied to the thermal field, the notion of inertia designates the capacity of a material (or a structure) subjected to external changes (heat input or, on the contrary, cooling) to preserve its temperature, initially; then to restore the thermal flow, in a second time. The thermal phase shift refers to the capacity of a material to defer temperature variations. It is therefore the time lag between the restitution of the heat flow and the storage period. The subsoil, whose temperature is practically constant at a depth of 5 to 7 metres (i.e. 10 to 16 °C for most wine-growing regions), provides thermal inertia for buried buildings [6] (Figs. 10 and 11).

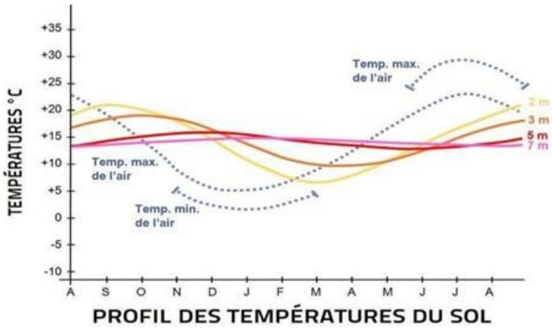

Figure 10: Example of a temperature profile as a function of depth in the Vaucluse. It can be seen that the amplitude of fluctuations decreases with depth. At 6 or 7 metres below ground, the temperature stabilises around the annual average air temperature of 15 or 16 °C. At shallower depths, there is a phase shift between minima and maxima. This phase shift increases with depth. In July, at a depth of 2 metres, the ground temperature is 16-17°C, while the maximum air temperature is 30°C. This data underlines the natural air-conditioning role of the earth. www.archi.climatic.free.fr.

In addition to temperature variations over the year, it is also important to take into account the thermal variation between day and night and from day to day during the week. The thermal inertia of a material represents its resistance to temperature change when a disturbance to its thermal balance occurs. A good thermal inertia of the building (without internal insulation) can be achieved by using dense materials (stone, concrete). The "monomur alveolar" type brick, with a large thickness (40 to 50 cm), is also interesting.

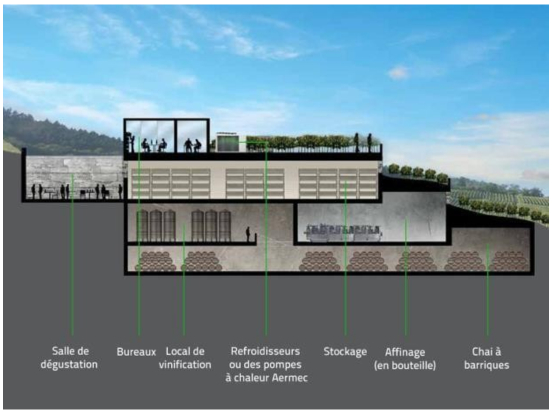

Figure 11. Optimal use of the thermal inertia of the soil and basement in the design of a cellar. Part of the cellar is underground and the upper area has a green roof. www.produits.xpair.com.

+ Architectural sun protection

For above-ground areas, for staff comfort and to save energy from artificial lighting, it is usually worthwhile to incorporate natural light sources. However, these increase the interface between the building and the exterior, with the risk of heat transfer. In addition to insulation, these light openings can be protected by pergolas (Photo 4) or slatted systems of the type "It is also possible to provide skylights which, like many religious monuments, allow natural lighting to be diffused with little heat transfer. It is also possible to provide skylights which, like many religious monuments, allow natural lighting to be diffused with little heat transfer. For underground areas, where artificial lighting is essential, LED systems should be used to reduce power consumption and limit the risk of light tastes due to ultraviolet radiation. Lighting should not represent an unnecessary energy loss, hence the interest in implementing individual or centralised automated control systems.

Photo 4. Vineyard pergola near the administrative buildings, which filters light in the summer and retains natural light in the winter, Photo J. Rochard.

Photo 5. Sun breaker" device at La Grajera, a Gobierno winery in the Rioja region of Spain, photo J. Rochard.

+ Ecological insulation

The insulation of a building is one of the most important points in eco-design.

In recent years, building owners have sought to improve the ecobalances of insulation with less toxic, recycled or recyclable, low energy-consuming materials, while maintaining equivalent (and sometimes superior) performance to conventional insulation. They are building materials that meet both the usual technical criteria for construction and environmental criteria throughout their life cycle. Ecological insulation materials are generally of mineral, vegetable or animal origin (Fig. 12). In addition to the insulating properties, it is important that the material is adapted to the environmental conditions and in particular to the humidity of certain areas of the cellar, avoiding potential microbial development, which could be detrimental to the quality of the wines.

Figure 12. Main ecological insulation materials, www.eco-logis.com.

+ Plant structures

The use of plants in architecture is not new. The "Hanging Gardens of Babylon" and, closer to home, the traditional houses of Scandinavia, as well as ancestral buildings in Turkey and Mongolia, or those built by certain Amerindian peoples, use plants on their roofs, in particular to limit the temperature difference between summer and winter. Moreover, Virginia creeper and other climbing plants often colonise the walls of our homes (Photo 6). The use of vegetation in urban architectural projects meets several expectations: the need for proximity to living elements, a precious source of oxygen and freshness, a bioclimatic strategy allowing the retention, filtration and reuse of rainwater, as well as the storage and sequestration of carbon, while at the same time integrating the building into the landscape more harmoniously. The use of this vegetation is also interesting for the cellars, in order to limit the energy needs of air conditioning, to develop a space in the wine tourism area, supporting biodiversity, with an ecological dimension.

Photo 6. Natural vegetation wall in the Miguel Torrès winery in Curico, Chile, photo by J. Rochard.

- Green wall

There are several techniques for creating a green wall. The most common is to build a vertical steel structure parallel to the building facade to support it (Fig. 13). The space between the wall and the structure allows air to pass through and keeps the wall away from the wet area. PVC modules are attached to the structure to hold polyamide felt supports on which the plants grow. A sprinkler system at the top of the structure provides a gravity feed of water and nutrients along the wall. Water not used by the plants is collected at the foot of the wall and in the upper irrigation system along with the nutrients.

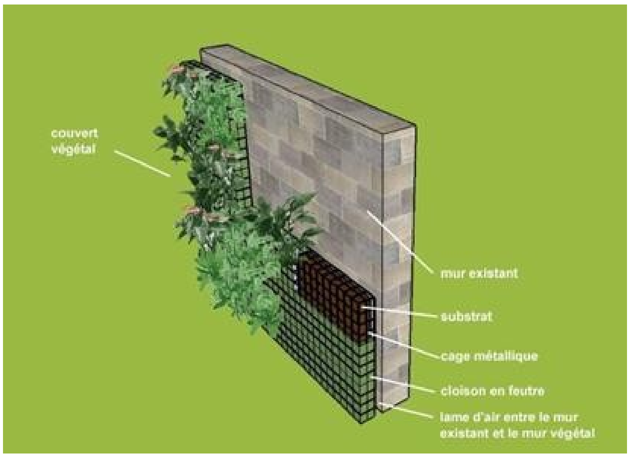

Figure 13. Cross-section of a green wall, www.murmurev egetal.com.

- Green roof

The green roof (Fig. 14) is placed on a horizontal structure (concrete, steel or wood) which has to support the weight of the installation (including the humidification of the substrate and possibly snow). In addition to its insulating and thermal inertia properties, the green roof acts as a buffer against water run-off during periods of heavy rainfall (Fig. 15). It is also a support for biodiversity, which can be enhanced with a variety of local grape varieties or plants in the wine tour.

Figure 14. Structure of a green roof, www.liaisonveg etale.com.

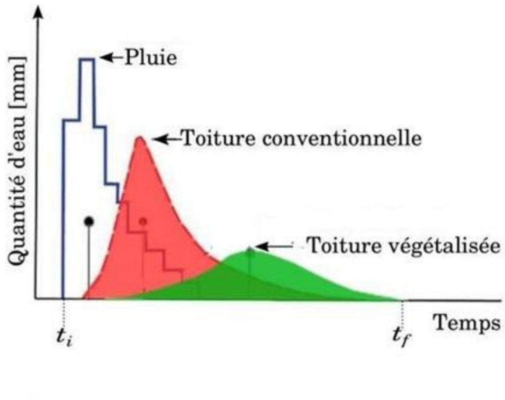

Figure 15. Buffer effect on rainfall runoff of a green roof compared to a conventional roof, according to R. Bouzouidja.

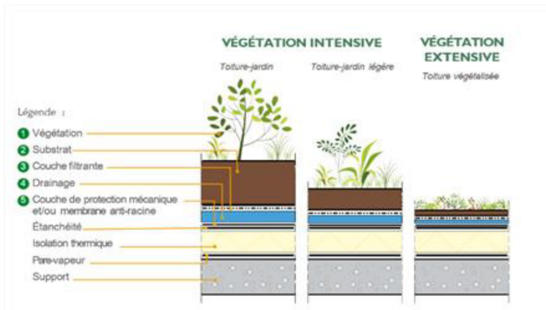

Figure 16. Different types of green roofs, www.matgeco.be.

Three techniques for greening roofs can be considered (Fig. 16).

+ Intensive vegetation with a thickness of soil generally between 30 and 90 centimetres. The water reserve increases the weight of the whole and requires a reinforced building structure. This system is truly a hanging garden that adapts to many plant species, including shrubs. The installation of a reconstituted soil on the roof, often integrated into the wine tourism circuit, makes it possible to enhance local biodiversity, with the possibility of planting local varieties and flora (Fig. 17).

+ Semi-intensive greening. While remaining moderate in weight, they make it possible to decorate a roof terrace with ornamental perennials, grass or small bushes.

+ Extensive vegetation, which is less effective in terms of insulation, is easier to implement because the plants use very little soil (6 to 20 centimetres thick of a specific substrate). The vegetation system constitutes a plant carpet of sedum (succulent perennial plant) which gradually adapts to its environment and functions almost autonomously. However, watering during hot periods and fertiliser application during the year are compulsory. It is possible to use them conventionally for roof slopes up to 20% and with special devices for higher slopes.

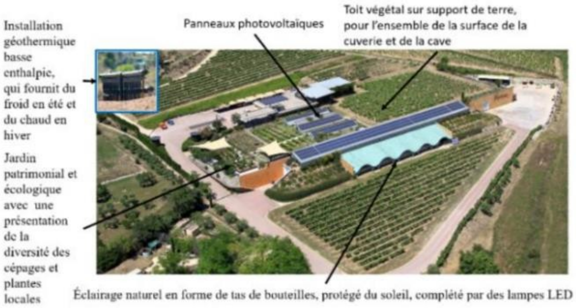

Figure 17. Description of the Gramona ecological cellar in the Catalan region of Penedès in Spain Catalonia, photo www.gramona.com.

+ Ventilation control

The air in the cellar must be renewed in order to limit the level of humidity and to clean up the internal "atmosphere" (odour, micro-organisms). Mechanical ventilation is often considered for large wineries. By controlling the operation of the ventilation with a clock, it is possible to favour ventilation during the night in summer (lower temperature) and during the day in winter (higher temperature), in order to reduce the energy requirements for air conditioning.

Buildings with a high height can have a phenomenon of hot air accumulation under the roof (Fig. 18), which can also result in a variation of the temperature in the tanks (warmer zone in the upper part, with a risk of acetic pitting). To avoid this phenomenon and at the same time limit the energy requirements for air conditioning, it is possible to consider extracting the hot air under the roof with a dynamic extractor. This can be combined with a solar panel power supply.

Figure 18. Temperature variations with height in a building, Scheme J. Rochard.

Photo 7. Example of under-roof warm air extraction in the McLaren Vale region of Australia, photo J. Rochard.

Ventilation must also take into account the optimum humidity level (Photo 8). Low humidity in the cellar promotes wine loss through evaporation (consume). High temperatures, associated with low relative humidity, increase the "consume" as well as the transfer of oxygen, which is financially penalizing (loss of wine), with also a risk of development of acetic bacteria, if the filling of the barrels (topping up), is not ensured regularly. When the humidity rate is excessive, risks of runoff inside the cellar, prejudicial to the quality, are to be feared The optimum humidity level is generally around 70-85%.

Photo 8. Natural humidity control in the cellar by maintaining the link with the subsoil in the barrel storage area. Photos J. Rochard.

+ Definition

Figure 19. The different renewable energies www.energie-eolienne.over-blog.

3 Renewable energy

Renewable energy is a source of energy that renews itself quickly enough to be considered inexhaustible on a human time scale (Fig. 19). Renewable energy comes from regular or constant natural phenomena caused by the stars, mainly the sun (radiation, evaporation cycle, photosynthesis, biofuels, etc.). The renewable character of an energy depends on the speed at which the source regenerates, but also on the speed at which it is consumed. Thus, for example, wood is considered to be a renewable energy with a balance between growth and cutting, and provided that the forest maintains its ecological functions.

+ Low-energy geothermal energy

Geothermal energy, from the Greek geo (earth) and thermos (heat), refers both to the science of studying the internal thermal phenomena of the earth and to the technology that aims to exploit it. The earth's geothermal flux is generally much too low to be used directly with a "high temperature" process, except in areas with hot springs or superficial magma chambers. However, below 4.50 to 10 m, the ground temperature is constant throughout the year. It is close to the annual surface average (11 to 16 °C in European wine regions). Like an underground cellar, the thermal inertia of the subsoil is used by means of boreholes into which tubes are inserted, in which glycolated water circulates, which supplies a heat pump (Fig. 20). Thus, in winter, the system provides a natural source of heat and, conversely, in summer, a source of coolness. The depth of the borehole is generally between 80 and 120 m for brine probes.

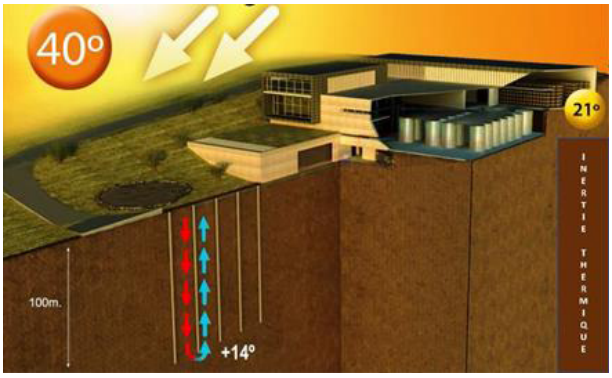

Figure 20. Application of geothermal energy in the cellars to take advantage of the thermal inertia of the subsoil (coolness in summer and warmth in winter), Bodegas Regalia de Ollauri in La Rioja, Spain, www.marquesdeteran.com.

The advantages of this system (small surface area and constant temperature at a depth of 100 or 150 metres) mean that it can be installed in most sectors, although there is an economic constraint linked to drilling. One of the complementary approaches, developed in particular in Alsace, consists of storing the excess heat in the subsoil during the summer period, linked in particular to the fermentation of the musts, and reusing it in winter.

+ Canadian wells

The term "Canadian well" was first used in 1977 by the architect Claude Micmacher. It seems that the Romans were already using sophisticated pipe systems to heat themselves with the air circulating underground. The Canadian well, or puits provençal, with an underground ventilation system uses geothermal energy in a passive way (Fig. 21). In

In winter, it transfers fresh air into the building and in summer it transfers fresh air, thus saving on air conditioning. Horizontal ducts are installed at a depth of about 1-2 metres to pre-treat the ventilation air in the buildings. From a practical point of view, the ground temperature at shallow depths in wine-growing areas is about 15 °C in summer and 5 °C in winter. This system must be equipped with a drain trap for condensation water inside the pipes. From the air treatment room, the air is distributed with ventilation inside the building via a pipe network (Fig. 22).

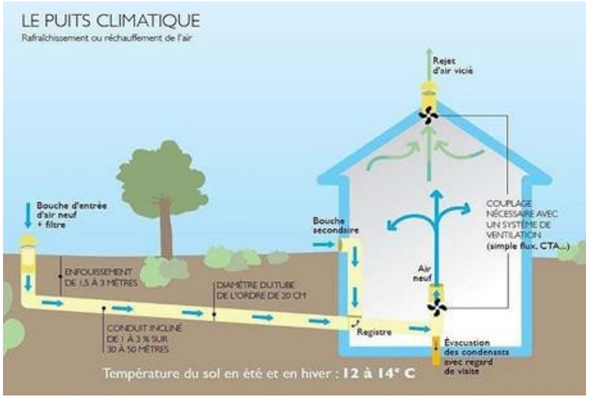

Figure 21. Principle of a Canadian well, www.ademe.fr.

+Solar energy

Solar energy provides temperature conditions for life and drives the water, wind and carbon cycles in the biosphere. But it can also be used directly to produce heat at different temperature levels for a variety of purposes: space heating and cooling, hot water and steam production, and electricity generation through panels with solar collectors.

The potential for solar energy production varies according to the average local insolation (Fig. 24),

External air inlet

Dehumidification and air distribution

Indoor air diffuser

Figure 22. Example of a Canadian well at Château de Malleret in the Médoc, photos J. Rochard.

the exposure and inclination of the collectors (Fig. 25). In the northern hemisphere, the optimum is 35 degrees from the horizontal, with a southern orientation.

In the initial phase of development, solar was often developed for resale to the local supplier. Currently, due to the evolution of subsidies, the electricity produced is mainly used for the winery's internal needs (Photo 9). Beyond the economic aspect, the internal production of energy limits the risk of energy disruption, which already concerns certain regions of the world and which could increase with climate change and international tensions.

PRINCIPLE OF THE PHOTOVOLTAIC EFFECT

The photovoltaic effect was discovered by Alexandre Edmond Becquerel in 1839. It is obtained by absorbing photons in a semi-conductive material that generates an electrical voltage. Sunlight consists of photons containing energy corresponding to the different wavelengths of the solar spectrum. When a photon passes through the photovoltaic cell, it creates a hole in the top layer, which is negatively charged (Fig. 23). This then generates an electrical voltage with the lower layer, which is positive. The photons are then collected by electrical contacts on the surface. Electricity is thus produced in the form of direct current.

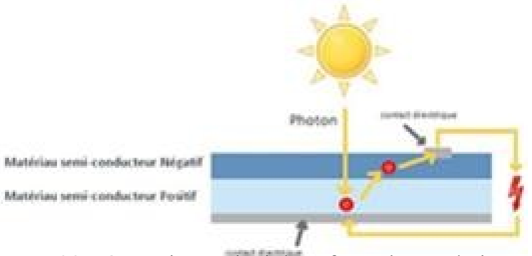

Figure 23. Operating principle of a photovoltaic cell. www.mypower.engie.fr.

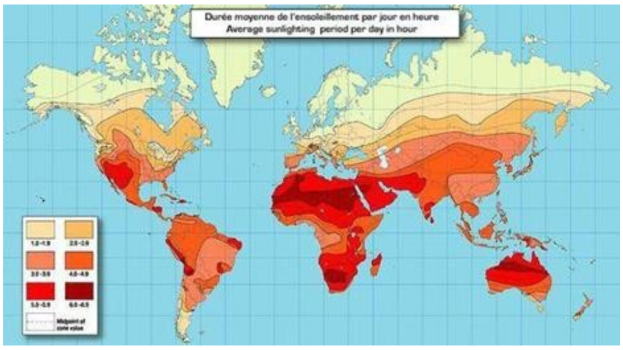

Figure 24. Map of average sunshine duration around the world, www.cleantechnica.com.

orientation	Inclinaison par rapport à l'horizontale (°) 0	15	25	35	50	70	90
est	88 %	87 %	85 %	83 %	77 %	65 %	50 %
sud-est	88 %	93 %	95 %	95 %	92 %	81 %	64 %
sud	88 %	96 %	99 %	max 100 %	98 %	87 %	68 %
sud-ouest	88 %	93 %	95 %	95 %	92 %	81 %	64 %
ouest	88 %	87 %	85 %	82 %	46 %	65 %	50 %

Figure 25. Energy production potential in percent by tilt and orientation of solar collectors, www.ef4.be.

Photo 9. Solar panels installed in the Miguel Torres winery in Curico, Chile, photo J. Rochard.

+ Biomass

Biomass is composed of all living organisms on the continents and in the oceans, whether they are micro-organisms, plants or animals. Through photosynthesis, involving chlorophyll molecules, plants use the sun's energy to break down the water (HO) they contain in their cells and the carbon dioxide (CO2) from the atmosphere to transform them into plant material, mainly carbohydrates (sugars) and cellulose.

Composting is, to some extent, an energy recovery process. Indeed, compost limits the energy impact of fertilisers, which require a lot of energy to produce. The most common use of biomass for energy purposes is either directly in the form of "biofuels" such as wood, vine shoots, pomace, or after transforming it into
"The CO2 emitted during combustion or oxidation is fixed by the plants as they grow, which, unlike fossil fuels, does not affect the CO2 concentration in the atmosphere. The CO2 emitted during combustion or oxidation is re-fixed by the plants as they grow, which, unlike fossil fuels, does not impact the CO2 concentration in the atmosphere.

The vineyard biomass results from the renewal of plots and grubbing-up without replanting: vine shoots, the framework, the stocks and the stumps, which represents approximately between 1.2 and 2.5 tonnes of dry matter per hectare per year. The vineyard biomass results from the renewal of plots and grubbing-up without replanting: vine shoots, framework, stocks and stumps, which represents approximately between 1.2 and 2.5 tonnes of dry matter per hectare per year.

Most of the pruning wood is left on the ground, allowing for the addition of organic matter to the plot. Some of the pruning and grubbing wood can be used as a renewable energy source and used for combustion (heating of the winery's operating buildings and possibly the dwelling house and wine tourism structures). Vine shoots are harvested in bulk or in bundles and eventually transformed into wood pellets to fuel biomass boilers (Photo 10).

Constraints include the need to ensure drying for at least one year, the presence of impurities and a high ash content as well as the possible risk of transferring pesticides to the atmosphere during combustion. From a practical point of view, the continuous boiler feed system must take into account the risk of vaulting due to the fibrous nature of the vine shoots. Of course, this recovery must take into account the need to conserve sufficient organic matter in the vineyard, which usually means that wood is not harvested systematically every year in the same plot.

Photo 10. Vine shoot recovery unit for hot water production and distillery supply implemented in the Plantaze winery in Montenegro, photo J. Rochard.

4 Water management

+ Quantity of water used in the cellar

The amount of water used in cleaning operations varies significantly from one winery to another. The type of winemaking, cleaning technologies and staff awareness are all determining factors in water consumption. The most commonly used values range from 3 to 30 litres per litre of wine produced (Fig. 27). Harvesting and vinification, which, depending on the region, take place over a period of 2 to 6 weeks, account for a large proportion of annual water consumption (40 to 60%). In an LCA approach, beyond the consumption within the winery, the overall "water footprint" must also include the water needed for inputs as well as for waste and by-product management, and of course, which can represent a very large quantity in some regions, the irrigation of the vineyard.

Knowledge of water consumption is an essential prerequisite for making water savings and for sizing and optimising the effluent treatment system. This approach must be carried out with rigour. Obtaining usable results is based on separate metering of borehole water and concession water. These meter readings make it possible to correlate water consumption with the activity of the establishment and to detect the periods or activities for which water savings should be made. From experience, for wineries that have an economical, or even free, water supply (borehole for example), the volumes used annually are often significant, but as soon as a project to treat individual or collective effluents is envisaged, saving measures become a priority requirement.

SINNER'S CIRCLE

In 1959 in Germany, a Henkel employee by the name of Herbert Sinner developed a theory of cleanliness based on four interrelated factors. Known as Sinner's Circle, or TACT (Temperature / Mechanical Action / Chemistry / Time of Action), this system states that a decrease in one or more of these factors must be compensated by an increase in the others (Fig. 26). Thus, depending on the type of cleaning to be carried out, it is possible to obtain an equivalent, and sometimes even superior, result while using less water, by optimising the various cleaning factors:

+ **Chemical action**: application of detergents and other cleaning products.
+ **Mechanical action**: manual action (sponge, broom) or use of cleaning machines (high pressure cleaner, scrubber, hoover, etc.).
+ **Temperature:** the higher the water temperature, the better the results.
+ **Action time**: the longer the application time, the more effective the product's action.

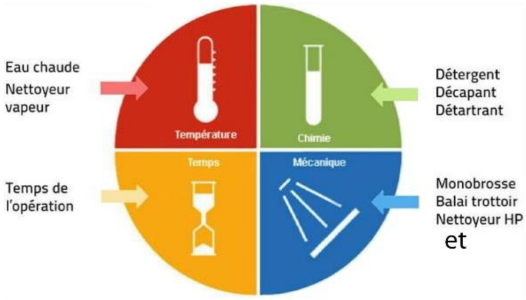

Figure 26. Main factors for cleaning a surface (SINNER circle) www.science-environnement.com.

Dry pre-cleaning, using brushes, squeegees or brooms, removes residues and solid debris that can lead to clogged pipes. This pre-cleaning reduces the pollution load, while considerably reducing the volume of water used. The use of a squeegee for cleaning floors, especially near the pressing or devatting area, considerably reduces water consumption compared to direct jet cleaning.

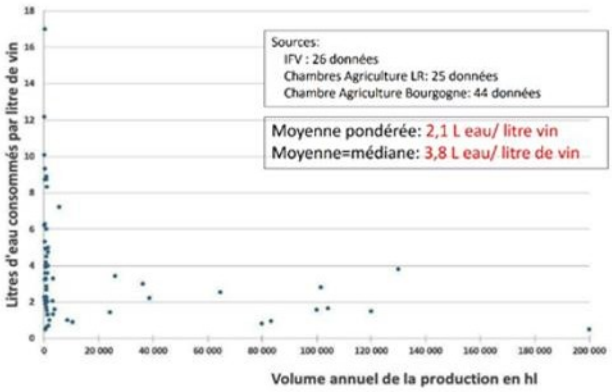

Figure 27. Average water consumption in the cellars established by J. M. Desseigne, based on data from the IFV, the Chambers of Agriculture of Burgundy and Languedoc-Roussillon.

+ Consumption reduction strategies

Reducing water consumption should not compromise the quality of cleaning and general hygiene in the winery. It is important to implement training and awareness-raising for staff, particularly during harvest periods, when the operational workforce is often made up of temporary, poorly qualified employees. Not leaving a tap running initially, carrying out dry pre-cleaning (squeegee, broom), are all basic gestures that limit the use of water. The result is above all linked to the permanent concern of the management staff to limit waste.

From a practical point of view, the main aspects to be taken into account are the following:

- Cleanability of substrates

The smoother the surface, the easier it is to clean. The coating of cement surfaces with epoxy resins and the type of stainless steel finish affect all tank cleaning operations.

- Blowers

High-pressure washing (110 to 200 bars), thanks to its powerful mechanical effect, facilitates the removal of dirt from the floor and equipment while consuming a small amount of water. Nevertheless, this technique has some disadvantages: dispersion of dirt, risk of damaging the surface of electrical hydraulic circuits. An alternative technique is to install a medium pressure network (generally 15 to 20 bars) in the cellar.

- Foam gun

The foam gun is a device that generates "foam" from the cleaning product through the action of gas injection. This foam, due to its condition, will cling to the surface to be cleaned and thus increase the contact time and the efficiency of the cleaning, especially in the case of vertical parts.

- Use of hot water

The widespread use of hot water circuits is a step towards optimising cleaning by using less water and often less cleaning products. The use of hot water must be reasoned out, taking into account not only water savings but also energy consumption and user safety. Of course, the installation of a solar water heater or the use of a bio-sourced fuel to feed the boiler (wood or vine shoots).

+ Water-saving cellar designs

It is important to integrate the constraints related to cleaning operations into the design of a cellar, by choosing facilities that facilitate the work of the operators. The proximity, ease of opening and closing taps and the use of hose reels and automatic shut-off systems (Photo 11), combined with staff awareness and training, often make it possible to significantly reduce water consumption without compromising hygiene. As far as the structure is concerned, the optimal choice of floor covering, slope and collection system for washing water also contributes to a water-saving strategy. With regard to the cooling of the tanks, which is generally essential for white wine production, the use of waste water run-off is a very water-consuming item, which most often justifies the installation of exchangers linked by a refrigerant to a cooling unit.

Photo 11. Reel system with a stop device automatic, Photo J. Rochard.

+ Floor drains

Floor cleaning accounts for a significant proportion of overall water consumption, so it is important to optimise the design of the gutters and to choose the most suitable surface (Fig. 28). With regard to the floor covering, in addition to the ease of cleaning, the risk of slipping must be taken into consideration. In many cases, a compromise has to be found depending on the slope, the frequency of cleaning and the number of passages.

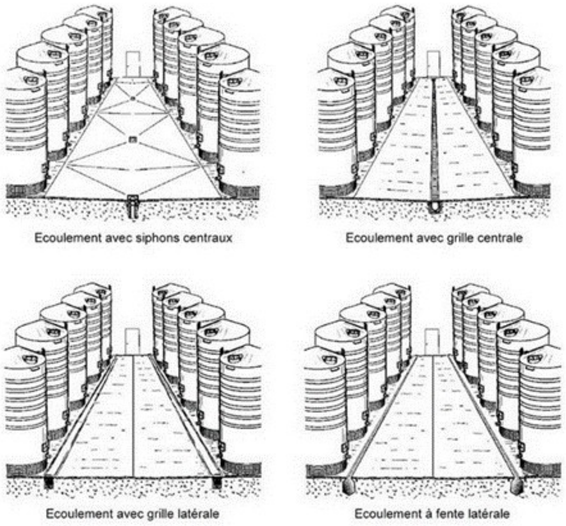

Figure 28. Different types of flow in a winery according to J. Rochard.

+ Cooling of fermenting musts

Temperature control during the alcoholic fermentation of white wines is still sometimes achieved by simply running water. The cooling potential of water is important when it volatilises (about 600 cal/g), but from a practical point of view, given the poor ventilation of the interior vats, the ambient hygrometry generally exceeds 95% and in these conditions, evaporation takes place very little. Thus, cooling occurs solely by heat transfer, which leads to high water consumption (500 to 1000 litres per hectolitre of wine). The installation of internal (flags) or external (belts) heat exchangers solves this problem of rejection while increasing the efficiency of temperature control.

5 Cellar effluent treatment

+ Impacts

The pollution contained in cellar effluents comes either from the components of the grapes, must or wine (skins, stalks, soil, sugar, acids, lees, alcohol, polyphenols, yeasts, bacteria), or from descaling and cleaning products, or from products used in the vinification process (filtering media, glue, for example). For all these effluents, organic matter is the main source of pollution.

Similarly, cases of pollution linked to toxic effluents may be encountered from time to time (cleaning and descaling products). Discharges from wine presses and cellars are likely to disturb the biological balance of rivers, particularly during the harvest period. The fight against pollution in the wine industry is based on two complementary approaches. Upstream, an adaptation of the production process must be implemented to reduce the pollution load and ensure optimal water management. Downstream, the treatment of cellar effluents, carried out individually or collectively, can be envisaged with several techniques: evaporation, spreading, biological devices.

Organic matter from wastewater, when discharged in large quantities into a river, pond or lake, causes micro-organisms to multiply and degrade it. The micro-organisms take up the oxygen dissolved in the water, to the detriment of the fauna and flora of the natural environment. In addition, the suspended matter in the discharges limits the passage of sunlight, which is essential for photosynthesis, the source of oxygenation of the environment (Fig. 29). These environmental impacts can lead to the local mobilisation of fishermen's or nature protection associations as well as local authorities, in particular when the discharges can destabilise the operation of domestic wastewater treatment plants during the grape harvest and wine-making period. Indeed, most often, wine-growing effluents are discharged into a treatment plant that has not been designed to handle the additional pollution caused by the grape harvest (increase in the population of the villages, effluents from the grape harvesters).

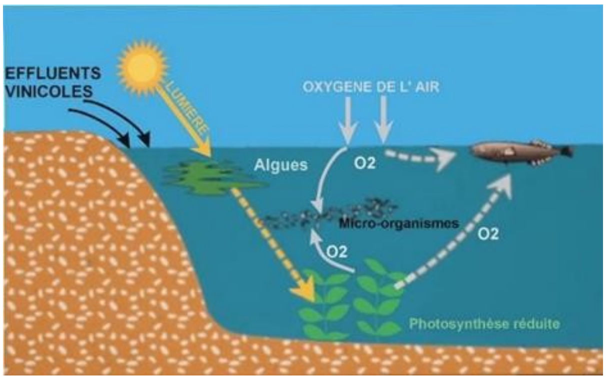

Figure 29: Impact of cellar effluent on an aquatic environment according to J. Rochard.

+ Conventional treatments

The fight against pollution in the wine industry is based on two complementary approaches. Upstream, an adaptation of the production process must be implemented to reduce the pollution load and ensure optimal water management. Downstream, the treatment of cellar effluents, carried out individually or collectively, can be envisaged with several techniques: evaporation, spreading, biological devices (Fig. 30). In the case of classic biological treatments, the transformation of organic matter is based on the development of micro-organisms. The mechanisms take place with the addition of oxygen (aerobic system) or in an anaerobic environment (methanisation) [7].

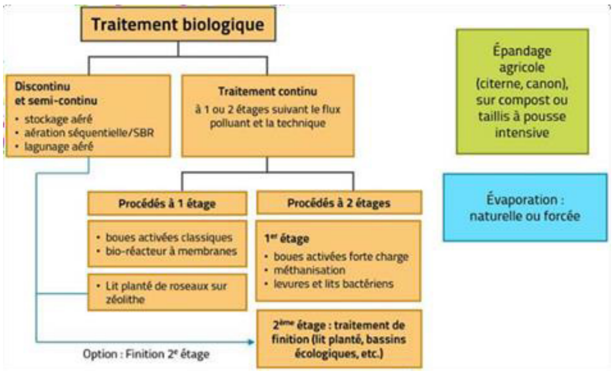

Figure 30. Main treatment methods for cellar effluents according to J. Rochard, diagram www.groupe-esa.com.

+ New ecological approaches to treatment

- *Context*

Until now, the most used treatment processes, beyond land application and evaporation, were based on technological developments of aerobic and to a lesser extent anaerobic processes. Current research aims to integrate sustainable development guidelines into the operation of the treatment system. Thus, the treatment of effluents must integrate different orientations: low energy consumption and limitation of waste (sludge), which is increasingly difficult to manage by agronomic means. In addition, in connection with the concept of ecotourism, a harmonious integration of the system can be envisaged, which combines both a limitation of odour and noise pollution, and an enhancement of the landscape and possibly of biodiversity in the winery's environment [8].

Ecological systems, which are inspired by wetland ecosystems, can be integrated into the diversity of winery effluent treatment systems. Their rustic design, simplicity of management, low energy consumption and landscape enhancement are all arguments that interest professionals wishing to develop sustainable approaches to cellar effluents. Beyond the aesthetic dimension, it is possible to recreate artificial wetlands that enhance local biodiversity [9]. Furthermore, the prospect of water resource scarcity seems to be emerging in many regions, in connection with climate change. This constraint could lead in the future to a strengthening of regulations concerning the reuse of water from treatment, particularly for cooling or irrigation purposes.

Finishing treatment with sand reed beds is now being developed for most new installations. More innovative developments using direct treatment on zeolite, which considerably limits the volume of the upstream basin, offer interesting prospects for the future, in particular with the probable reinforcement of the conditions of discharge to the natural environment and in the perspective of a development of water recycling.

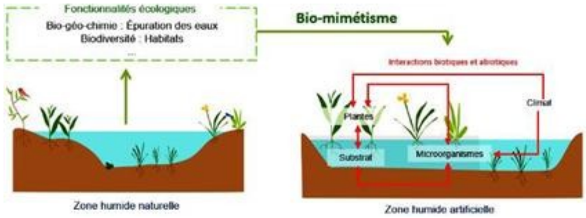

Figure 31. Comparison of a natural wetland with a man-made feature. Source www.blue-set.com.

- Principle of phytoremediation

Soil purification is a mechanism that has been used for a long time, especially in the technique of spreading effluents. Another approach is to use the natural purification principle of wetlands linked to plants with a high root potential and adapted to alternating dry and wet conditions (Fig. 31). Some of these plants, in particular reeds (*Phragmita Australis*), also transfer oxygen to the soil via the stem. The treatment system mimics the natural water purification process in marshes, where wastewater is naturally pre-filtered and stripped of solid particles, and then undergoes natural physical, chemical and especially biological mechanisms. The overall process degrades organic matter, transfers metal compounds to the leaves, filters and significantly reduces pathogens in the wastewater (Fig. 32).

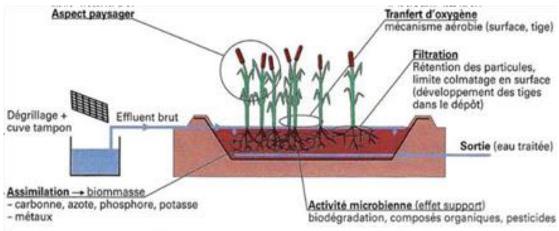

Figure 32. Operating principle of an ecological effluent treatment system using a reed bed, after J. Rochard.

In addition to its purification function, the installation of an ecological system can be integrated into a landscape and biodiversity approach in the winery's environment and serve as a support for an eco-œnotourism approach (Fig. 33).

Figure 33. An example of ecological (biodiversity, landscape) enhancement of cellar effluent treatment by reed beds (Blueset system being installed at the Buzet cooperative in south-west France).

The classic approach of treatment by a sandy planted bed as a finish presupposes the retention of an aeration tank upstream, with a fairly large storage and treatment volume, which consumes energy and is the source of potential olfactory and visual nuisances. This constraint has led to research into "direct treatment" of effluents, without or with a small buffer storage, which obviously requires rigour in the cellar to limit volumes, loads and pollutant concentration.

One way of optimising the process is to use zeolite, a highly adsorbent material, compared to the sand or gravel of traditional filters. About a hundred Zeofito® devices, developed by www.amethyst.it (Photo 12), have now been installed, mainly in Italy, for various purposes: complete treatment of cellar effluents, possibly combined with urban effluents from the wine-growing area, before discharge into the natural environment, or partial treatment at a domestic wastewater treatment plant, or finishing treatment for existing plants that are not operating optimally, or that are moving towards reuse of the water, in particular for ornamental ponds, cooling devices or irrigation.)

ZEOLITE USED BY THE MAYA TO PURIFY WATER

Zeolite has long been recognised as a mineral with excellent adsorption properties. About 2700 years ago, Greek and Roman engineers used zeolites as pozzolans in cement in the construction of large-scale hydraulic structures, such as aqueducts, bridges, dams and harbours. Recent research has pointed out that the material was also used by the ancient Mayan civilisation in Guatemala, probably 1000 BC, to purify water stored in tanks. This material is used as a substrate for reed beds, with the possibility of direct treatment of cellar effluent (Zeofito® process) [10] (Fig. 34 and Photo 12).

Photo 12. A zeolite is a rock formed from a microporous aluminosilicate skeleton, the voids of which optimise the adsorption and biodegradation processes of the reed root system. Source www.amethyst.it.

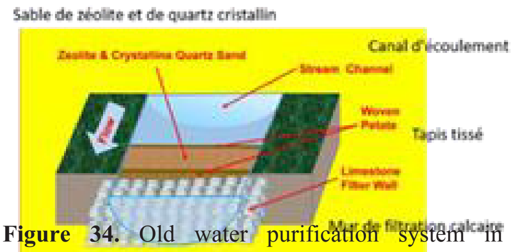

Figure 34. Old water purification system in Tikal, Guatemala. The filtration system, using quartz crystal sand and zeolite, is positioned just upstream or in the entrance to the reservoir. K. Barnett Tankersley et al.

Photo 13. Effluent treatment using a reed bed on a zeolite support with the Zeofito ® device (Baroli winery in the Italian Piedmont). The treatment system, which does not cause any nuisance, is installed directly in the visitor circuit, near the winery.

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- Keys to successful ecological treatment

An ecological treatment system for cellar effluents must be associated with a rigorous environmental approach upstream (Fig. 34). For example, the discharge of filtration soil can lead to malfunctions in any effluent treatment system, but even more so for ecological systems due to the accumulation of non-biodegradable silica over time. Particular attention must be paid to the optimal management of water and by-products (sludge, lees, scaling solution, filtration earth, etc.). At the same time, if the operation of these systems is simple and rustic, the realization must be entrusted to specialists, with if possible a good experience of the wine sector, to optimize the design and dimensioning (integrating in particular the peak of activity during the periods of grape harvest and wine making).

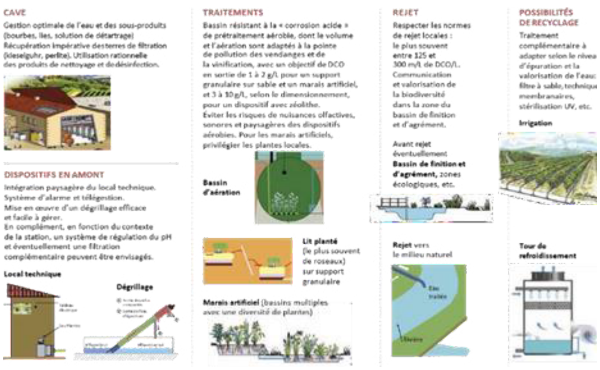

Figure 35. Key elements for the success of an ecological cellar effluent treatment project (after J. Rochard). Diagram Revue des œnologues N° 181 special November, in context 2021.

- + Reuse of water after treatment

Of the 165 billion m³ of wastewater collected and treated per year worldwide, only 2% is currently reused. The reuse of treated wastewater (ReUse) is a rapidly expanding technique, mainly associated with agricultural recovery. It consists of recovering wastewater after several treatments designed to eliminate suspended solids, dissolved pollution, pathogenic germs and micro-pollutants, while avoiding an increase in soil salinity. The major advantage of reuse is that it provides an alternative resource that makes it possible to limit water deficits, better preserve natural resources and alleviate water shortages (Fig. 36).

In countries where current freshwater supplies are limited, and where this is likely to increase due to both climate change and population growth, it is likely that reuse will develop, and perhaps even be a regulatory requirement in the most sensitive areas.

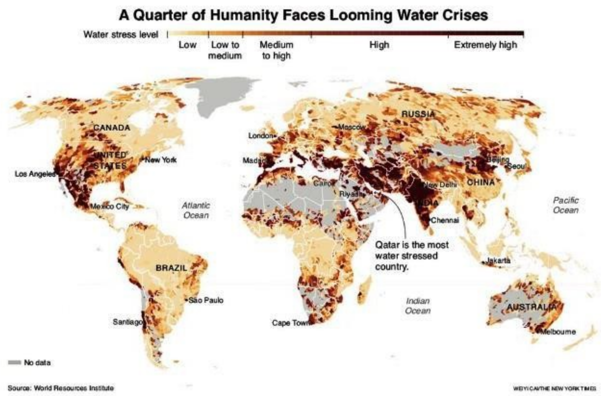

Figure 36. Map of areas most affected by water shortages in the coming decades. Source www.wri.org, published by www.courrierinternational.com.

The effluent, after a first level of treatment, usually with an aerobic biological plant, undergoes different purification processes, which vary according to local standards and the purpose of the recycling. The most common separation devices are micro and ultrafiltration and reverse osmosis. In addition, chlorine, ultraviolet and ozone treatments can also be considered. It is important to take into account the initial level of pathogens and micropollutants, which is usually higher after a simple biological process and much lower after ecological finishing devices, especially when the aggregate is fine and adsorbent, thus facilitating the recycling strategy (Fig. 37).

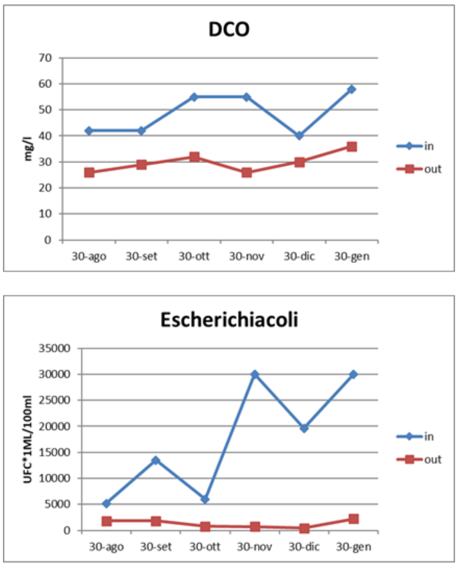

Figure 37. Comparison of COD (top) and Escherichia coli pathogens (bottom) downstream of the Italian municipal wastewater treatment plant of Cossato in Piedmont) with activated sludge (blue) and after additional treatment with a planted bed on a zeolite support (red).

In addition to the technical aspects, it is also important to take into account the potential reluctance of certain professionals and consumers to reuse wastewater for agricultural and wine production. Thus, phytoremediation systems, which are an advantageous complement to conventional treatment systems, can confirm the objective and subjective reliability of the techniques implemented.

5 Cellar environment

Beyond the building itself, it is important to integrate the environment of the winery into the ecological approach, both with regard to the neighbourhood and to wine tourists. Landscapes, biodiversity, accessibility for people with reduced mobility, activities and areas for children and various aspects related to sustainable development must be integrated into the project.

+ Parking

A vegetated parking area, combined with systems that ensure good bearing capacity (gratings, paving stones, etc.), allows water to infiltrate and then be filtered and purified naturally by the soil. These systems have several advantages:

- During **heavy rainfall**, rainwater infiltrates into the ground and does not overload the rainwater system, which limits the risk of flooding, amplified by the increase in waterproofed surfaces.
- Vegetated parking lots counteract **the lowering of the** local **water** table by absorbing water.
- Precipitation does not run off **"dirty" impermeable** soils**,** which are **loaded with polluting particles** (hydrocarbons, solvents, motor oils, fuels, etc.) before arriving in collection systems or waterways.
- Permeable surfaces **are more humid** and contribute to the evapotranspiration of the soil, **reducing the heat increase** (heat island effect) and thus providing greater comfort for staff and visitors.
- Grassed car parks contribute to the quality of outdoor spaces by increasing the presence of vegetation in the built environment; they therefore have an **aesthetic and biodiversity role.**

Parking a car in very hot conditions contributes to a greenhouse effect inside the vehicle, which is unpleasant for the occupants and increases the need for air conditioning. It is possible to implement a shading system, notably with a pergola (Photo 13) or shelters that can eventually be covered with solar panels.

Photo 14. Shading of a car park with a vineyard pergola (Bodega Casa Madero in Mexico). Photos J. Rochard.

+ Amenity pool

Formerly found mainly in the parks of castles, these pools are increasingly integrated into an ecological and contemplative vision of architecture. With the gentle splashing of a water jet, a fountain, a waterfall or basins, and the surrounding freshness, the pond is a particularly popular place for adults and children alike. Of course, this pool should be fed, if possible, by rainwater recovery or the reuse of cellar effluents, in particular with the use of an ecological treatment system (Photo 14). In addition, it is possible to integrate an artificial wetland, supporting an ecosystem, with a very rich flora and fauna. Of course, the constraints (risk of drowning, especially for children, presence of mosquitoes, risk of bad odours if the water is not sufficiently purified) must be integrated into the design as well as the operation.

6 Conclusion

The construction of a winery and the choice of equipment associated with the design of the structure require careful consideration of economic, functional, quality and user safety aspects. In addition, the landscape and biodiversity aspects enhance the environmental image of the winery and the wines [9].

Photo 15. Amenity pond and wetland created in connection with the treatment of cellar effluent at Château Smith Haut Lafitte in Bordeaux, photo J. Rochard.

Furthermore, regulations and standards are changing rapidly, which justifies anticipating sustainability requirements in order to avoid costly retrofitting in the coming years. Until now, energy aspects have not been a major concern for the wine industry. It is clear that we are now entering a period of conflict with the depletion of fossil fuels, while at the same time there is increasing pressure to reduce the greenhouse effect. For all wineries, it is first necessary to quantitatively identify consumption by type of activity and to estimate the overall needs of the sector (direct and indirect) and if possible to determine the environmental impact of this thermal management. The optimal design of buildings, with good insulation, possibly supplemented by ecological devices (green roofs or walls, etc.) and alternative energies (solar, geothermal, Canadian wells, biomass, etc.) is part of this dynamic of ecological design of wineries. At the same time, the wine industry is a major source of by-products and organic waste. Optimised recovery from an energy perspective can be envisaged.

Water management must also be associated with an ecological design of the winery. The old adage, *"You have to use a lot of water to make good wine",* reflects the importance of water for all cellar hygiene operations. However, in many regions, water availability is tending to decrease and this phenomenon could become more pronounced with climate change and the increase in global demand (domestic, agricultural and industrial), which justifies the development of a strategy to reduce consumption, also motivated by easier implementation of the effluent treatment system. The design of the floors, the performance of the cleaning and cooling systems, as well as the training and awareness-raising of the personnel, are all aspects to be integrated into the management of the wineries, with an environmental management process based on a search for continuous improvement. Concerning cellar effluents, phytoremediation techniques are progressively developing, and in particular reed beds on a sand support, in addition to classic treatments, or on zeolite, with for this last technique, the possibility of avoiding upstream aerated basins. The rustic design, the simplicity of management, the low energy consumption, the enhancement of the landscape and the local biodiversity, are all arguments that interest professionals wishing to develop sustainable approaches to cellar effluents. Moreover, the use of these ecological systems, with a high potential for eliminating micropollutants and pathogens, will gradually make it possible to consider the reuse of effluents, after treatment, notably for irrigation. Nevertheless, like any ecological system, the vision must be global. Thus, the choice of this type of treatment imposes upstream optimal management of water and by-products (sludge, lees, descaling solution, filtration earth, etc.).

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