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Bengt Warne's Naturhus: sustainable living in a Northern European climate

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Sommario

La prima parte della tesi introduce Bengt Warne e il suo *Naturhus* (Casa Naturale), evoluto per oltre 40 anni. Vivere nel primo *Naturhus* ha premesso a Warne di attuare la sua filosofia "Symbio Housing" (coltivare piante per depurare l'aria e ottenere cibo, utilizzare il sole per risparmire energia, riciclare acque grigie e rifiuti organici). Lo Stensund Wastewater Aquaculture di Warne ha supportato ricerche per il recupero delle acque reflue e per le Living Machines di John Todd. Il libro di Warne *På akacians villkor* convinse Charles Sacilotto e Anders Solvarm a costruire il loro *Naturhus* (il secondo è oggetto di specifico approfontimento nel capito 3).

Il *Naturhus* è una normale casa di legno, racchiusa da una serra. Nello spazio residuo si viene a creare un microclima, con spazi per attività e coltivazione. La temperatura nello spazio cuscinetto è più alta dell'esterno (4-5 °C nel *Naturhus* di Solvarm, dimostrato da Liban Usman – paragrafo 3.4). In un clima nord-europeo, questo permette nel periodo marzo-ottobre buone condizioni di crescita per fiori, frutta e verdura mediterranea, protetti dalla serra da neve, pioggia, e vento. In questo spazio è possibile produrre cibo in estate (75% di autosufficenza per frutta e verdura nel *Naturhus* di Solvarm, 30% per Sacilotto). Inoltre, i *Naturhus* di Solvarm e Sacilotto hanno un sistema di recupero delle acque reflue. Nel sistema di Sacilotto l'acqua non può essere bevuta; le acque grigie sono usate per irrigare le piante edibili e le acque nere quelle non edibili. Nel sistema di Solvarm, entrambe le acque adibite all'irrigazione, e circa 300 l sono filtrati e utilizzati ogni giorno. I risultati ottenuti nella tesi confermano che le idee di Warne degli anni '70 erano valide. Il computo metrico effettuato dimostra però che il *Naturhus* di Solvarm non è un edificio totalmente ecologico dal momento che è formato da calcestruzzo al 28%, acciaio zincato al 3%, e da un totale del 31% di blocchi Leca e mattoni.

Solvarm fa parte della società GreenHouse Living che riprende le idee di Warne e costruisce *Naturhus* sempre più efficenti.

Parole chiave: Nature House, Naturhus, Bengt Warne, Greenhouse Living, wastewater treatment.

Abstract

The first part of this thesis introduces Bengt Warne and his *Naturhus* (Nature House), evolved for over 40 years. Living in the first *Naturhus* allowed Warne to fulfil his “Symbio Housing” philosophy (growing plants to clean the air and to obtain food, using the Sun to save energy, recycling grey water and organic waste). Warne’s Wastewater Aquaculture provided research for the recovery of wastewater and for John Todd’s Living Machines. Warne’s book *På akacians villkor* convinced Charles Sacilotto and Anders Solvarm to build their own Naturhus (the second is the subject of specific study in chapter 3).

The *Naturhus* is an ordinary log house, enclosed by a greenhouse. A microclimate with spaces for activity and cultivation is created in the buffer space. The temperature in the buffer space is higher than outside (4-5 ° in Solvarm *Naturhus* demonstrated by Liban Usman – paragraph 3.4). In a Northern European climate, this allows from March to October good conditions for growing Mediterranean flowers, fruits and vegetables, protected by the greenhouse from snow, rain, and wind. Here, it is possible to produce food in summer (75% self-sufficiency for fruit and vegetables in Solvarm *Naturhus*, 30% for Sacilotto). Furthermore, Solvarm and Sacilotto *Naturhus* have a wastewater recovery system. In Sacilotto system water cannot be drunk; grey water is used to water edible plants and black water non-edible ones. In Solvarm system, 300 l of daily grey and black water are filtered and used for the watering. The results obtained in the thesis confirm that Warne's ideas of the 70s were valid. However, the bills of quantities show that Solvarm *Naturhus* is not a fully ecological building since is made of 28% concrete, 3% galvanized steel, and a total of 31% Leca block and bricks.

Solvarm is part of the GreenHouse Living company that resumes Warne’s ideas and builds more and more efficient *Naturhus*.

Keywords: Nature House, Naturhus, Bengt Warne, Greenhouse Living, wastewater treatment.

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CHAPTER 1

Introduction

This thesis analyzes Bengt Warne’s projects in Sweden. The projects are presented in chronological order to describe the evolution of the *Naturhus*, a building concept that can solve the waste of water and allow to produce one own’s food even from Mediterranean plants. To get an overview*,* Warne's mindset and ideas will be presented at the beginning. Writing this thesis was an inspiration for me, as there are no studies about the *Naturhus* in English and no in-depth information about the architect and his revolutionary ideas.

In the first paragraph the plan, the openable skylight, and the indoor gardening experiments in the Water Lily House will be examined, describing their influence on future *Naturhus*.

The first *Naturhus* will be studied in detail, through a research carried out in the archives of ARKDES Museum. The systems are ordered following the four elements of Warne's philosophy, highlighting untried ideas. The final paragraph describes current state of the first of the *Naturhus*.

Warne's Stensund Wastewater Aquaculture gave fundamental results in the recovery of wastewater for John Todd’s Living Machines and for further *Naturhus*.

Warne’s projects in Sweden and the philosophy of “Symbio Housing” expressed in his book *På akacians villkor* convinced Charles Sacilotto and Anders Solvarm to build their own *Naturhus*. This thesis describes the Sacilotto *Naturhus* in Ingarö explaining why this one is different from others. Furthermore, the way of producing fruit and vegetables and the wastewater recovery system will be discussed. The research was carried out in ARKDES Museum archives and with the collaboration of Charles Sacilotto (on field).

For Solvarm *Naturhus,* in Sikhall, the research was carried out based on direct measurements, interviews with Anders Solvarm and comparison with working project drawings.

Solvarm managed to build his house alone, and the embodied energy was calculated. The materials and their environmental impact are sometimes incongruous with Warne’s philosophy. Warne's ideas from the 1970s are verified through the Solvarm *Naturhus*; the results obtained are set out in the conclusions. For this reason, bills of quantities about materials are estimated and evaluated as well.
This thesis shows how indoor microclimate allows Mediterranean plants to survive despite the adverse conditions of Sweden. Plants and natural ventilation systems are an essential part to keep the microclimate inside the greenhouse stable. The balance of the *Naturhus* microclimate stands between the indoor amount of plants, the amount of water that plants need, the wastewater that the system can purity and use for the watering, and the amount of moisture that plants produce. This balance will be evaluated. Data from two theses, by Liban Usman and Persson and Wennerstål, compare this microclimate with outdoor, based both on direct measurements and simulations. The results obtained are set out in the conclusion. The last paragraph describes the new *Naturhus*, built by Solvarm and his company after Warne’s death.

1.1 Purpose

The purpose of this thesis is to introduce the architect Bengt Warne and his studies and projects in Sweden (related to ecology, energy saving, technology and architectural philosophy) starting in the late 1960s. The goal of this document is also to verify Warne’s idea through his last projects and promote the *Naturhus* concept that could be resumes for other European countries.

This thesis consists of two parts. The first one concerning the beginning of the *Naturhus* and its development over the years; the second one focusing on the Sikhall “Ecorelief” house.

1.2 Bengt Warne, the eco-architect

Bengt Oscar was born on January 21st 1929, in Gothenburg. He began his studies in 1949 at Katrineholms High School. He then studied aeronautical engineering and naval architecture at the Royal Institute of Technology (KTH) in Stockholm and moved to architecture between 1951 and 1956, adding mathematics in 1961.

He was editor of *Allt i Hemmet* magazine from 1959 to 1977 and was also teaching at international universities and colleges (mainly in KTH), as well as being a mentor of architectural and environmental organizations, since 1978. His career developed mainly in Sweden, but also worked on projects for Germany and India, developing architectural themes related to ecology (Warne B., *Curriculum vitae of Bengt Warne*).

Among his most important writings, deserve to be mentioned *Metodik för värdering av humanekologiskt byggande* published in 1989, *På akacians villkor* published in 1993 in collaboration with the journalist *Marianne Fredriksson* (Fredriksson M., Warne B., 1993), and *From Urban Bio-Nook to Bio-Gigapolis*, a concept developed from 1990 until his death in 2006 (http://bengtwarne.malwa.nu/).

The Water Lily House designed in 1962 (Warne B., *Curriculum vitae of Bengt Warne*) and built in 1964 (Warne B., *Report from a cultural exchange Sweden-USA,* 1982) in Uttran, South of Stockholm (Diamant R. M. E., 1965) was Warne's first super-insulated house. Warne used the elements of this home to expand them in its next nature house concepts. The house was strongly acknowledged in the Swedish and international press and Warne was invited to build Water Lily Houses in the United States (Warne B., 1982). In 1992, a smaller version of the house in wood and glass was also shown at an exhibition in Earl's Court, London (Fredriksson M., Warne B., 1993).

Between 1976 and 1981, he designed and built his first "natural house" (*Naturhus)* for himself and his family. The house was an experiment, in collaboration with the *Allt i Hemmet* magazine for their 20th anniversary in 1976 (Warne B., 1982).

It was conceived as an answer to how an ordinary family house could use natural resources, recycling them, and making the home almost self-sufficient.

"The Naturhus in Saltsjöbaden writes the most important problems and points their solutions", said Nobel laureate Konrad Lorentz at the World Congress on Alternatives and Environment in Vienna in 1979 (Fredriksson M., Warne B., 1993).
After the project in Saltsjöbaden, in 1982 several universities and industries asked Warne to create a second generation of low-cost nature houses (Warne B., 1982).
In addition, during his lectures on human ecology in India, he was also asked by the Indian Institute of Technology to design an eco-friendly city: the Olof Palme's Ecovillage in Uttar Pradesh. On behalf of Prime Minister Rajiv Gandhi, the project was conceived as a first large-scale Naturhus model, designed according his philosophy of "Symbio Housing" (see paragraph 1.6) (Fredriksson M., Warne B., 1993).
He moved to Berlin (Warne B., 1982), and he was invited to design the first Nature House on six floors for the International Architecture Exhibition (IBA) in 1984, "The Green Harrow" (so called due to the triangular shape) as shown in figure 1. Here, the principle of "Symbio Housing" was followed as well, through facilities for air treatment, biological waste management, rainwater and greywater treatment, and energy conservation.

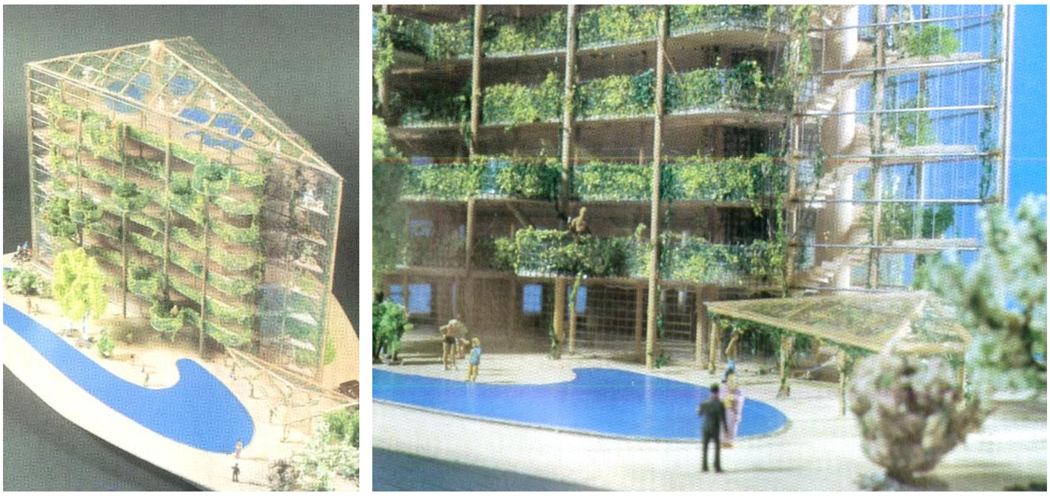


Fig. 1: The Green Harrow model

He constructed several Nature Houses in Hamburg, Germany, in partnership with architects Glässel & Thiemann.

In 1988, he designed the Stensund Wastewater Aquaculture on request of Dr. Björn Guterstam, a biologist at Stenstund Folk High School. The purpose was to research, develop and demonstrate the possibilities of recycling wastewater, working with multidisciplinary groups of researchers and students. Ended in 1989, the project provided a basis for the development of a domestic wastewater purification plant. The wastewater in subsequent Warne's projects was purified and used for water plants, providing the missing element in his total re-use concept of resources (Fredriksson M., Warne B., 1993).

Once all re-use cycles were completed, Warne worked to improve his "Symbio Housing" philosophy, designing a building with zero emissions and no environmental damage in all its construction phases, considering embodied energy, water use, and carbon dioxide emissions (Öqvist J., Warne B., 1994). In 1996, Bengt Warne and Jan Öqvist designed the Ecocyclic House (an exhibition of ecological solutions) for Skansen, a park in East Stockholm inside of the first open air museum. The project included, an ecological building that would continuously implement new ecological technologies that could be brought into ordinary buildings. Despite the commission by the Swedish Government, the project was never realized, and there was never a practical demonstration of his concept of Ecocyclic Architecture (Warne B., *The EcoCyclic House at Skansen*, 1996).

Warne's latest projects date back to 2004 and make up last generation of *Naturhus* before his death (http://bengtwarne.malwa.nu/).

In Ingarö, Warne contributed with Charles Sacilotto (Correspondence with Charles Sacilotto, 5th May 2017) to the implementation of a pre-existing wooden house. The refurbishment of the building followed its above-mentioned philosophy, included the plants and incorporating the wooden house into a greenhouse (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Bengt Warne's last *Naturhus* was built with Anders Solvarm, in Sikhall, Brålanda (Solvarm A., Interview. 3rd June 2017).

The Water Lily House, the Swedish *Naturhus,* and many others are examples of his vision of an ecological way of living.

1.3 The mindset of Bengt Warne

From the postwar period until the 1970s Europe experienced a boom in the economy, a technological development and a rise in living conditions. The necessity of a rapid solution to the urbanization and demographic growth led to the massive construction of new buildings in the cities. Growth combined with building speculation and the consumption of our planet's resources became in the 1970s an issue for urban planners and architects (Secchi B., 2005).

In Bengt Warne's vision, the modern city is a system that uses food, energy, and resources to satisfy its needs, exporting polluted air, water and waste. According to Warne, the resource-generating processes of nature can't handle this in the long run. If cities do not radically change into ecological systems that use selectively their natural resources the result can be an excessive reduction of nature (Öqvist J., Warne B., 1994).

In his book *På akacians villkor,* Warne writes about the endless problems of overpopulation in such poisoned cities. He also defines that a viable solution could be obtained through a general principle, the *Hälften till naturen* (half to nature). This is the concept of a human-ecological architecture that comprises every scale, from rooms to the global scale. This model was conceived to face a near future of overpopulation, allowing man to live in contact with nature. At the basis lies respect for all living beings, giving to nature its space at each scale.

For instance, if a person needed 10 sqm of space for a single room, they will have plants and flowers and will sleep on a bed made of only natural materials such as linen, cotton, jute, and wood. In a neighborhood with a built area of 10.000 sqm, some space will be devoted to ponds, trees, meadows, gardens and wastewater treatment installations. The *Hälften till naturen* principle takes also into account the construction materials in each scale, up to an ideal goal of 50 per cent (Fredriksson M., Warne B., 1993).

Fig. 2: The *Hälften till naturen* concept

To build sustainable buildings and cities, all actors must co-operate and become actively involved, including national governments, trade and industry entities, entrepreneurs and citizens (Fredriksson M., Warne B., 1993).

At every scale, the principle of co-operation is essential to live in harmony, not only between man and nature but also among groups of people working together in shared social facilities and living in social housing (Warne B., *Symbio Housing Symposiums*, 1982).

In the book *På akacians villkor*, four rules to live a good life in contact with nature were stated:

1, take care of the actual needs. Technology shall be subordinated to the biology bases. In lifestyle and construction, men must "learn from nature";

2, let our homes co-operate with nature, paying attention to all living organisms that live thanks to the Sun, wind, rain, soil, and plants. Houses must work according to the same principles;

3, provide the inhabitants with the possibility to control flows and cycles;

4, use sophisticated but environmentally friendly technology when nature is not enough (Fredriksson M., Warne B., 1993).

"We can build houses that work according to large natural flows, which allow the wind, the sun, the rain and the plants to respond to the energy required and that do not plunder, poison and destroy." "Today we have all the technical possibilities for this" Warne said, describing how these natural flows can be used in the house (Fredriksson M., Warne B., *På akacians villkor*, page 10, 1993).

1.4 The four elements

To understand the processes of nature and be able to control them in the architectural project, Warne subdivided them according to the four elements and studied the cycle of each. These components are:
Air: everything in gas form.
Earth: everything solid.
Water: every liquid that flows.
Fire: includes all energy such as heat, power, and light.
According to Warne, the control of these cycles solves basic problems of man: air control allows to breathe, earth control allows the growth of plants that in turn give food, water control allows to drink, and fire control allows to control heat exchanges. Control also means that if people reached a level of thermal comfort, they can transfer the excess heat to other cycles and enrich them.
The same thing applies to level of carbon dioxide, organic waste, and urine in the cycles of air, earth, and water (Warne B., Warne K., 1980).

1.5 Ecocyclic Building: Human integration with nature

Architecture is an integral part of Warne's ecological systems.
When he speaks of eco-buildings, he does not only mean buildings constructed with natural and healthy materials. He also means that the buildings should be in relation to the landscape and its potential. Architecture have an ecological interaction with the local landscape, a relationship of giving and having with man and nature (for example, new earth can be created from organic waste).

In Warne's theory, all houses should, in general, contain a recycling lifestyle. Ecocyclic Architecture should meet four requirements:

1, their construction materials are natural substances easily available;

2, they do not use synthetic and damaging substances;

3, they do not occupy any ground without maintaining its biological capacity, preserving ecosystems, organisms, and biological functions;

4, they use resource-sparing solutions for society's fundamental needs, without impoverishing nature's resources for future generations (Öqvist J., Warne B., 1994).

In accordance with the four statements, an Ecocyclic Building is a sustainable house that follows rigid recovery projects of natural resources, in which structures and lifestyles are compatible with the ecological cycle principles. In these eco-lifestyles, all housekeeping aspects are integrated into nature's recycling system, thinking in a long-term perspective and showing concern for future generations.

The Ecocyclic House for Skansen was the first example for Ecocyclic architecture: a fully ecological building that would continuously implement new ecological technologies that could be brought into common buildings.

Fig. 3: The Ecocyclic House for Skansen

The Ecocyclic Architecture concept was designed in the mid 90's as an evolution of his previous "Symbio Housing" main concept (Warne B., 1996).

1.6 The “Symbio Housing” concept

The concept of “Symbio Housing” was created by Warne as a result of his experience over the years. The difference with the above-mentioned Ecocyclic concept lies in a lesser restriction on building materials and energy efficiency through eco-sustainable resources, and in a practical realization of a low-cost building. In fact, it admits exceptions (not environmentally friendly).

Symbio Housing is a way to live in symbiosis with nature and in harmony with future generations. It also means to combine the highest environmental care, energy saving, comfort, and security, using local and accessible resources (David E. Robson, 1982).

In Symbio Housing, there are passive systems driven by sun, wind, rain, and soil that reduce service costs for energy, water, sewage, and garbage by as much as 70 per cent in comparison with an ordinary house of the 70s (more detail about the economic effects by using Symbio housing techniques are provided in section 2.4.5). Systems include superinsulation, forced and natural ventilation, sun-collecting, garbage and toilet composting, greywater filtering, Combitherm stove heating, heat-exchanging, and food production according to the principle of permaculture. The building is also a storage for heat in winter and cold in summer, using greenhouse effect, ground temperature, and ventilation strategies. Active nature-friendly systems support the passive systems. To command these systems there are manual and automatic collaborating systems (Link R., 1984).

Warne’s *Naturhus*, or Nature House, is the practical application of Symbio Housing principles (David E. Robson, 1982).

“Living in a greenhouse gives architecture a fourth dimension, where time is represented by movements of naturally recycled endless flows of growth, sun, rain, wind and soil in plants, energy, air, water and earth. I call this NATUREHOUSING." (http://bengtwarne.malwa.nu/).

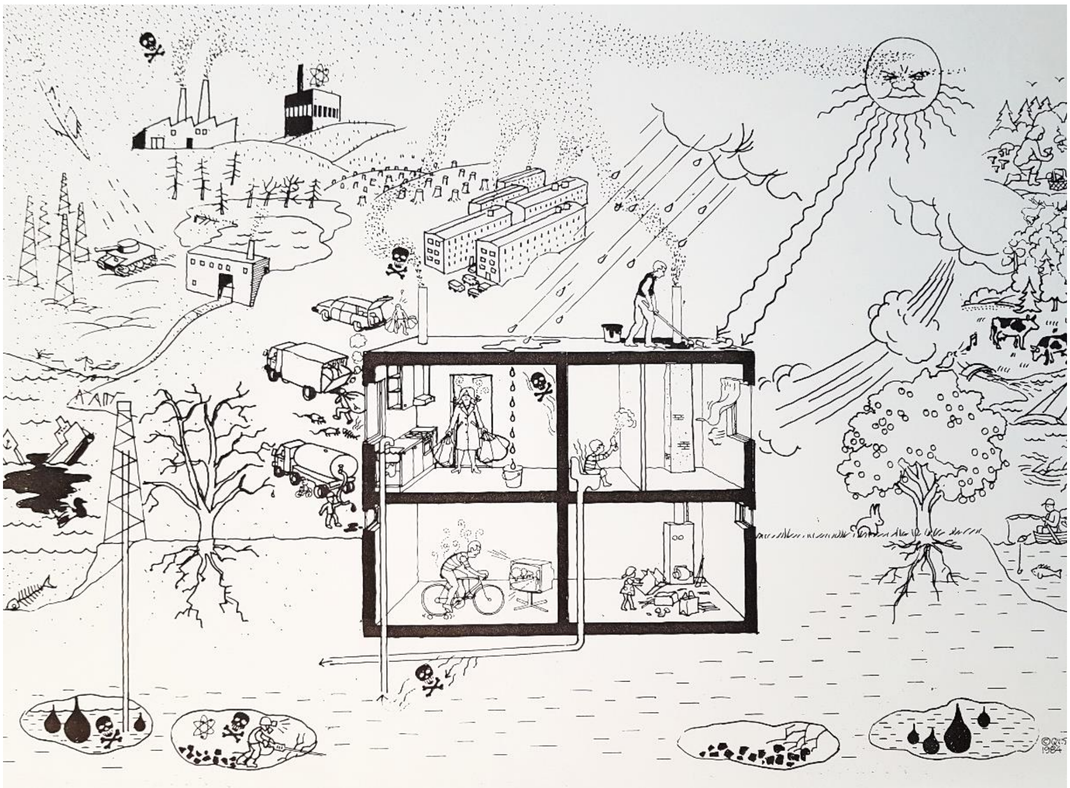


Fig. 4: Bengt Warne’s representation of the modern architecture house

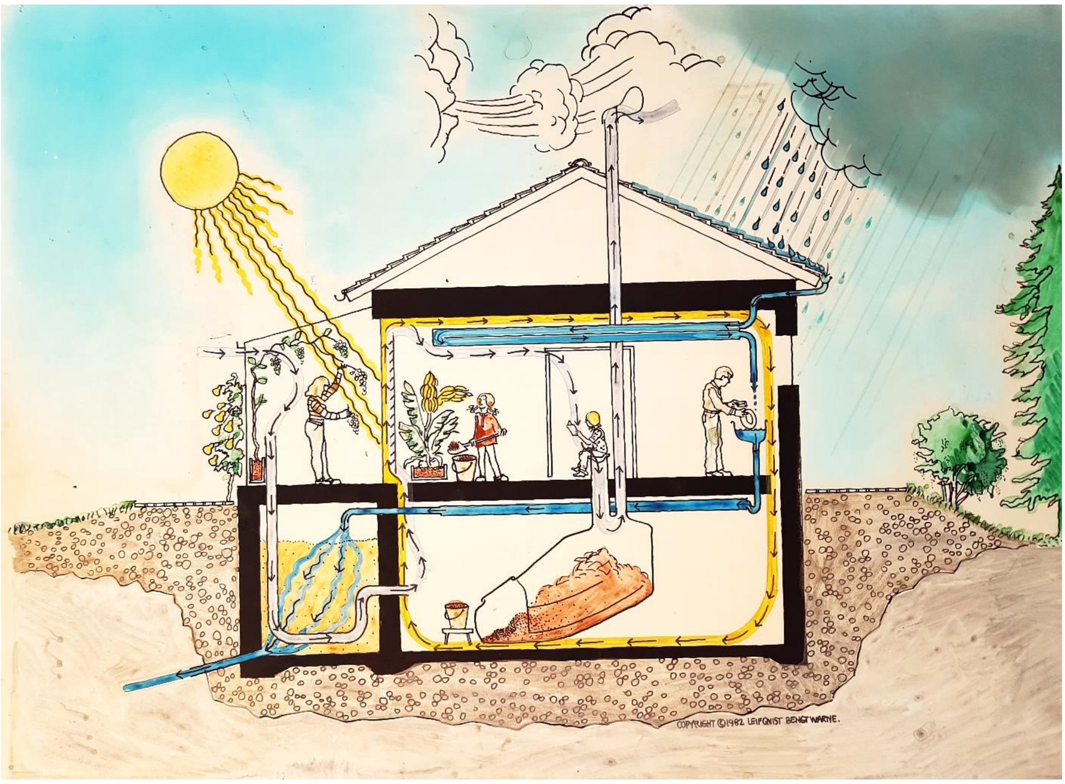


Fig. 5: Theoretical representation of “Symbio Housing”

CHAPTER 2

Definition and evolution of *Naturhus*

With the term *Naturhus,* Warne meant any building that uses natural resources to meet man's needs and then returns them, without destroying, plundering or poisoning nature.
The goal of this concept is to redefine the relationship between men and nature: an ordinary house keeps the outside out, the Natural House keeps the outside in (David E. Robson, 1982).

Naturhus is an ordinary log house, called core house, enclosed by a large greenhouse. A microclimate with space for activity and cultivation is created between the greenhouse and the core house. This space protected by snow, rain, and wind is a huge buffer space around the core house. Here the temperature is higher than outside the greenhouse. The higher temperature causes good conditions for growing flowers, fruits and vegetables in plant beds. It is therefore possible to produce one's own food.

Live in a *Naturhus* is like living inside a botanical garden constructed with several modern technologies. According to Warne's vision, the relationship between nature and machine is not opposite, cooperation is necessary for a sustainable way of living (David E. Robson, 1982).
Dualism is at the base of Warne's concept. A *Naturhus* must combine the best of urban and rural living and it should give a choice of togetherness and solitude, identity and anonymity, freedom and order, intensity and calmness, softness and hardness, shadow and sunshine, etc. According to Warne, an urban *Naturhus* shall be constructed both for separation and cooperation with other units. People shall be able to insulate themselves whenever they want. However, people shall be able to open their home to other individuals or groups.

Lastly, an urban *Naturhus* must give its inhabitants comfort in normal situations along with good protection in critical ones. This means that passive, manual, and automatic systems shall be able to work independently from each other as well as they shall be able to cooperate, in accordance with Symbio Housing philosophy (Warne B., *Report from a cultural exchange Sweden-USA*, 1982).

2.1 Air: nature and odors

People and plants are companions who need each other. When people breathe, they exhale carbon dioxide which the plants need, and they in turn give oxygen that people need (Warne B., Warne K., 1980). But plants do more than that: they regulate humidity. Several scientific studies show that adequate IAQ (indoor air quality) and plants affect well-being and mood.

In *På akacians villkor*, Warne writes that human life conditions are the same as those of Acacia plant. They need the same temperatures between 18 and 27 degrees, oxygenated air, water, 45-70 per cent humidity and half a day of sunshine rhythm. Not all plants can survive in the climate of Stockholm with a July average temperature of 16.5 °C and a January average temperature of −4.3 °C (Swedish Meteorological Institute, 1961–1990). In order to grow all kind of plants and flowers, it is necessary to protect them from the adverse climate and ensure a glazed covering that allows sunlight in. In Warne's projects there are blossoming gardens, protected by glazed roofs and walls, composed by local and tropical plants.

According to Warne “Air shouldn’t be disinfected and sterile. We can be cheered as well as depressed by the smells around us. Air means more to us than we are normally aware.” (Warne B., Warne K., 1980) On the contrary, polluted air emitted by industries and cars has negative effects on human health, and it should filtered by windows or purified through plants inside the house.

As technology advanced, the air in later Warne’s projects was also heated and reused. Living in contact with nature means respecting the smell of flowers, moisture, and the presence of bacteria that contribute to the natural ecosystem.

Bengt Warne's famous Water Lily House mimics a flower: the glass roof opens out like petals in warm weather to let the Sun shine directly into its garden and swimming pool (Link R., 1984).

Fig. 6: Front of the Water Lily House

2.2 Water Lily House

Designed as a luxury house in 1962 (Sullivan O., 1964) the concept was a combination of a pyramid glass cover for snow and an atrium house for rooms arrangement. Inspired by Mediterranean countries, the enclosed courtyard served the various spaces around it. This type of house was used also in colder climates, although it could not avoid the disadvantages related to rain, snow, freezing weather and the low height of the winter Sun (Warne B., 1969).
The original Water Lily house was designed for the Kallin family, with a living space of 256 sqm in between forest and the beach (Fredriksson M., Warne B., 1993) of

Uttran, Stockholm (Diamant R. M. E., 1965). The home was commissioned in four prefabricated units to be placed around the atrium; no-load-bearing interior walls gave the family maximum flexibility in the layout of the spaces (Fredriksson M., Warne B., 1993).

This concept was entrusted to the Oskarshamn shipyard (Diamant R. M. E., 1965), offering the lowest price on the market as well as engineering experience in steel and wood. The swimming pool and plants exposed the house to changes in temperature and humidity, and shipyard was the ideal candidate to solve these problems commonly met in ships (Sullivan O., 1964)

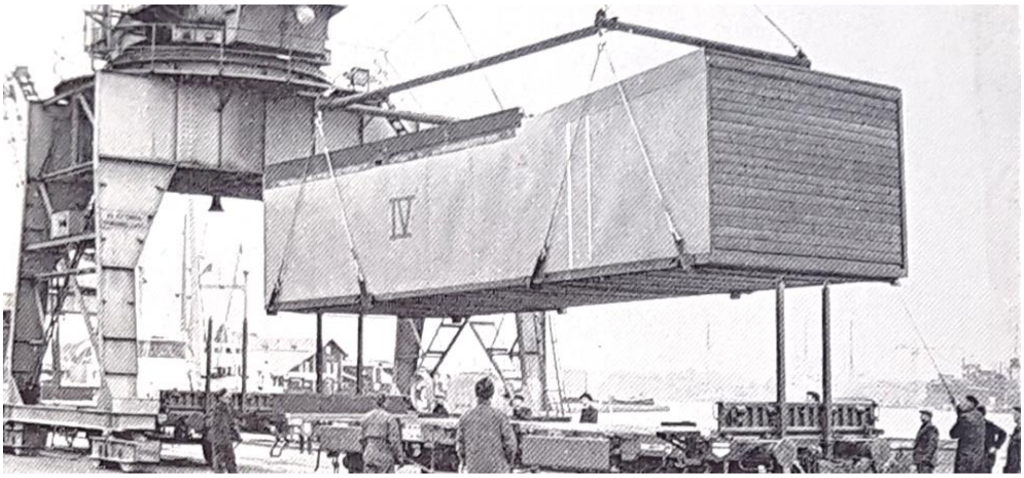


Fig. 7: The Water Lily House box unit in Oskarsham shipyard

Warne guaranteed a durability of 10 years for the systems of the house and 20 years for the hydraulic system, but the high maintenance costs and the obsolescence of the building elements have led in recent years to the original Water Lily house demolition (Warne T., Interview. 6th May 2017).

It consists of a square plan with a 16-metres side, in which the living areas surround a central square patio with indoor swimming pool and garden, as shown in figure 8. The central court with its garden, pool, solarium, and living and dining areas are the focus of the house. A small removable wood bridge connects the center of the atrium to the entrance.

The four prefabricated units make up the rest of the house. They are about 12 metres long and 4 metres wide and high (Sullivan O., 1964). Three sides are almost identical, while the fourth is more complex, containing all the plumbing for kitchen, bathroom, toilet, shower room, and boiler room, to facilitate the assembly at the site and manufacture on the shipyard (Fredriksson M., Warne B., 1993).

The fir-wood partitions can be adapted to obtain different areas such as a study in the dining room.

On the east side of the house, the children bedrooms are connected next to their hobby room and parent bedroom, dressing-room, and bathroom.

The kitchen, in the corner of the living area, was small, compact, and flexible as well thanks to the sliding panels that provide additional space (Sullivan O., 1964).

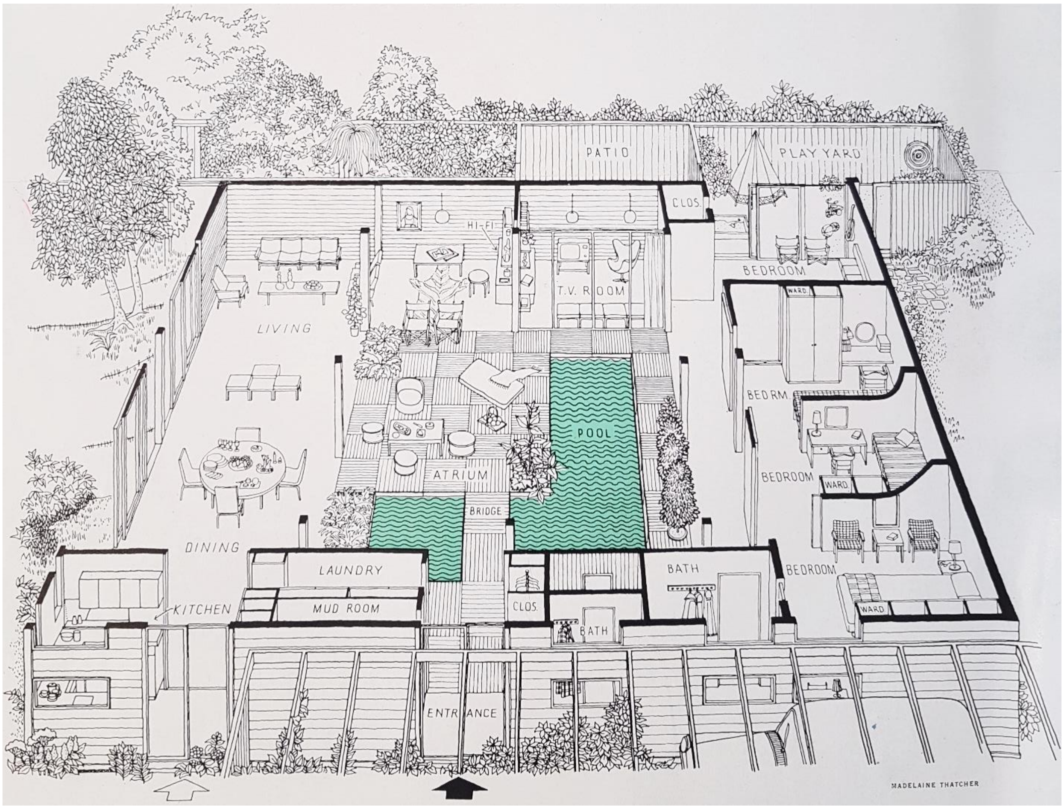


Fig. 8: Axonometric section of the first *Näckroshuset* (Water Lily house)

The walls superinsulation and the triple-glass in the Water Lily House shortened the heating season, bringing spring earlier and delayed the coming of autumn.

The pool had a temperature of 18 °C in winter and 27 °C in summer, and it was heated only by the building (Warne B., *Symbio Housing Symposiums*, 1982). The room air was kept a few degrees warmer than the water in the pool to avoid steam in the house (Fredriksson M., Warne B., 1993).

In winter, the enclosed atrium was heated by oil-fired central heating, while in summer, on sunny but cold days, extra heating was provided by infrared electric heaters, set around the atrium roof, which kept the shaded living-areas warm while the roof was open (Sullivan O., 1964).

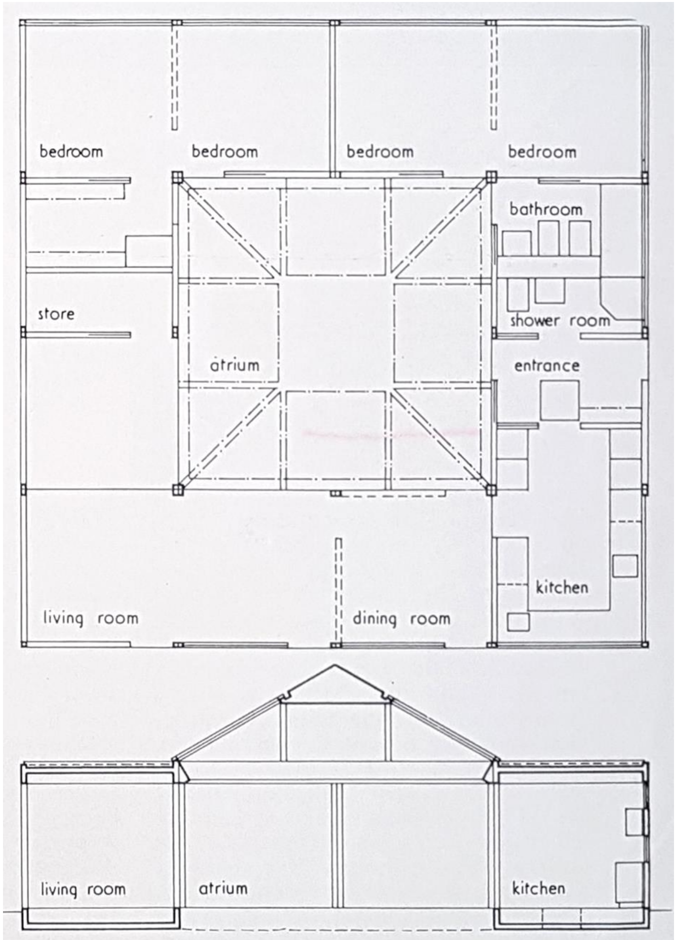


Fig. 9: Plan and section of the original Water Lily House; scale 1:200

In the atrium a substantial number of surfaces were glazed. *Thermoglass*, a triple hermetically sealed glass, was used both for the fixed and openable lights, with a total thickness of 2,50 cm. Such glass had a U-value of 0,30 The hermetically sealed triple glass was used for both the folding roof above the atrium and the entire wall next to the dining room (Link R., 1984), as shown in figure 10, and allowed the maximum solar radiation available on the market at that time.

Fig. 10: The folding roof and the glazed facade of the house

Foundations consisted of concrete walls some 90-cm deep underneath the living quarters. The crawlspaces were 90 cm deep as well, and they were lined with polyethylene foil throughout, to prevent moisture from travelling upwards from underground. The swimming pool was excavated in the ground and lined with plastics.

Solid walls of the box units have steel frames and infill panels consisting of twin layers of tongued and grooved boarding, each 1 to 2,50 cm of thickness, with a 12-cm gap in between, as shown in figure 11, with a total thickness of about 18 cm. This gap is filled with mineral wool, to give a U-value for the walls in the range of 0,04 to 0,06 (Diamant R. M. E., *The Atrium house*, 1965).

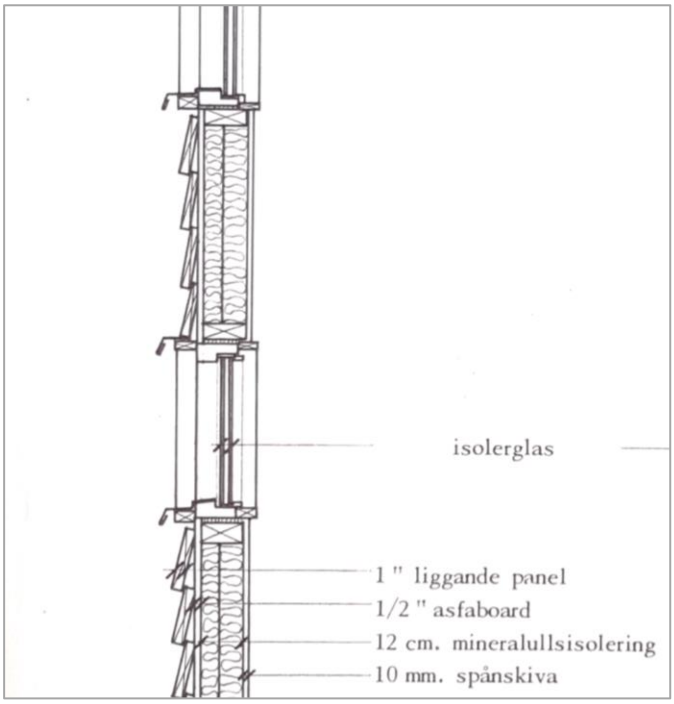


Fig. 11: Section of walls in Water Lily Houses; scale 1:20

The loadbearing elements, vertical and horizontal steel beams of T-section and U-section were used, with a maximum module of 4,00 m and a minimum of 1,00 m. Steel structures and infill panels were bolted together and consolidated by turning over sheet metal, to withstand weather.

Fig. 12: Nord-West view of Water Lily House

The floor was supported by U-section steel beams. Starting from the bottom, near the crawlspace there was a 2-cm tongued and grooved boarding, followed by a layer of insulation material. Then came a gap of about 10 cm, serving as a warm air reservoir for heating the building. Warm air from such intermediate space entered and crossed the house along a continuous crack at skirting level. Another 2,50-cm tongued and grooved boarding, covered with linoleum or parquet, completed the floor surface.

Fig. 13: Atrium floor view

A mechanical ventilation system extracted air from kitchen, bathroom, toilet, and laundry, so that these rooms were always at a lower pressure than the rest of the house. This means that air heated by the central heating plant flowed into these rooms from other rooms, via the above-mentioned continuous cracks at the skirting board level. However, warm air didn't just cross the ground floor, it also crossed the inside of the roof. Here, warm air was ducted to vents at the bottom of the openable roof to avoid vapor condensation from the swimming pool, even when low winter temperatures outside the house were experienced (Diamant R. M. E., 1965).

The roof had a total thickness of about 22 cm. Starting from the inside, it consisted of a layer of jute cloth, which is glued onto a 9-mm gypsum board. Then comes a tongued and grooved boarding 2,50 cm thick, a 15-cm gap for mineral wool and wires. After that, an air gap of about 4 cm followed the board, with another 5 cm of mineral wool insulation. Lastly, a layer of galvanized steel sheeting.

The roof fell about 10 per cent towards the atrium, and no overhang was present. In fact, rainwater was carried around the openable roof base through the gutters connected to the frame structure, avoiding thermal bridges, as shown in figure 14. The purpose of this form of roof was to allow snow to slide to the base of the pyramid roof towards the gutter, without darkening skylight. Since the roof supported a considerable amount of snow in winter, Bengt Warne used it to provide additional thermal insulation to the house. In addition, a circular drainage surrounded the atrium roof, with a downpipe within the house that collected kitchen and bathroom wastewater (Diamant R. M. E., 1965).

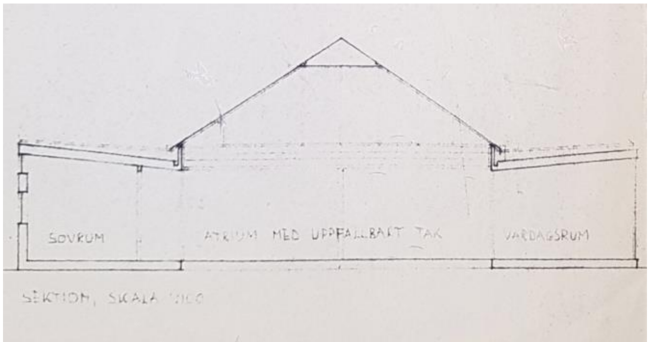


Fig. 14: The roof shape of the original Water Lily House; scale 1:200

2.2.1 Folding Roof

An openable roof consisting of 64 square metres of triple-glass panes covered the atrium.

The steel structure assembly was prefabricated at the shipyard and lifted into position after the four boxes. The four triangular glass structures were moved by four hydraulic pumps that open them in a minute at the push of a button. To open the panels fully, the large joints that link them were rotated by 150°, as shown in figure 15. In fact, during winter, the four slopes were hermetically sealed, providing additional insulation with the contribution of the snow (Link R., 1984).

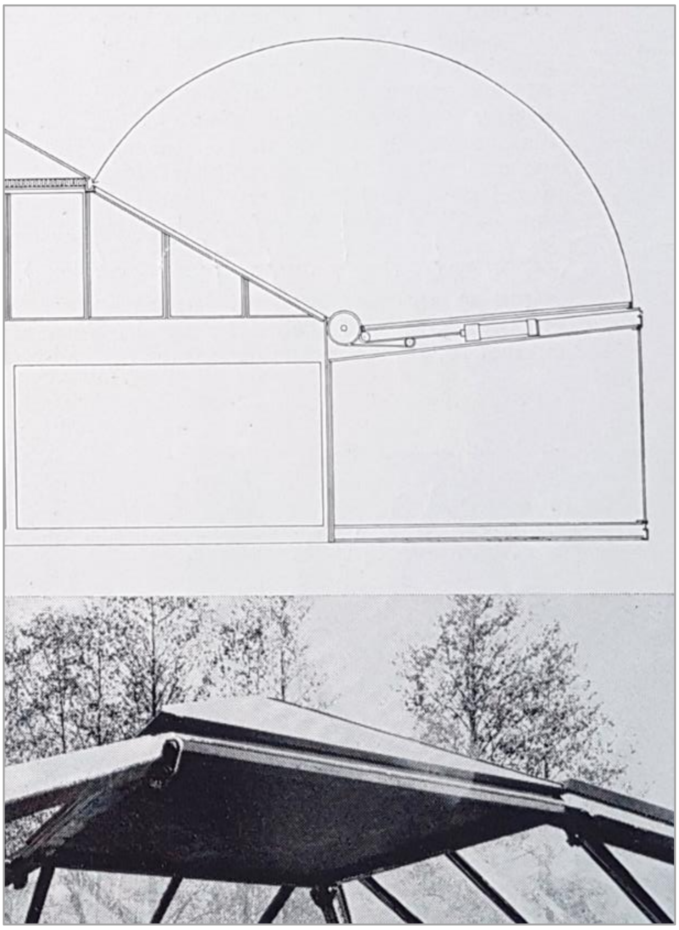


Fig. 15: The openable roof mechanism; scale 1:100

The top of the skylight was about 2 metres wide at the base, and had a slope of 30 degrees. Such top pyramid was covered with galvanized steel sheets attached to a 2-cm tick tongued and grooved boarding, insulated with mineral wool.

This central square section is surrounded by a square drainage channel that connects, through the four supporting beams, to the main drainage of the house.

The four supporting beams consisted of 6 x 12 cm steel channel sections, carrying galvanized steel water conduits attached to a 2,50 cm thick wooden board.

Fig. 16: The Water Lily House open skylight

As far as the openable sections are concerned, they are made of glass and a composite steel frame, using 4 x 8 cm steel beams in X-shape. The sections were then connected to a U section steel rail, to avoid thermal bridging. Triple glazed panes with a total thickness of 2,5 cm infilled the steel frameworks. The panes have a maximum width of 1,00 m so that each side of the openable skylight consist of not less than eight panes of different shapes, triangular, trapezoidal and rectangular. The largest of these glass units is 1,00 x 3,30 m and the smallest are 1,00 x 1,00 m. The four skylight sections were of trapezoidal shape, with a length of 8 m and a height of 3,60 m. Each pane was pivoted along its base using a total of four mechanisms attached to an 8-cm hollow pivot axle. At the center of these four axles, the gears with cogwheels, shown in figure 16, were connected by chains to other cogwheels positioned inside the roof space to move the glazed structures. When the roof panels were opened by pressing a single switch, they laid flat on the roof as a water lily (Diamant R. M. E., 1965).

Fig. 17: View of the openable skylight

In the following versions of the Water Lily House, when the skylight was closed, it was also possible to hang textiles for protection against sunlight (Botta M., *La Casa Ninfea*).

2.2.2 Affordable solutions

The interest generated by the project together with press and television convinced Warne and the Kallin family to start a company to mass-produce the Water Lily House in smaller and more affordable versions (Ridolfi F., *La casa sulla piscina*, 1966).

Some changes were needed to reduce the price to reasonable levels (Diamant R. M. E., 1965). The first substantial change concerned size: from the 256 sqm of the Water Lily House to intermediate versions (Junior type) of 144 sqm 12 m side to 100 sqm (10 m side, Compact type) where the pool is moved to a side and the atrium

used as a living room (Botta M., *La Casa Ninfea*), as shown in figure 18.
Warne's aim was also to have a light structure, and wood had long been considered, but the high cost of the treatments and the low resistance to weather did not guarantee proper functioning during years. He also wanted a considerable standardization in internal wall design, especially from the point of view of electrical outlets, which were placed only into the columns.
The small dimensions of the atrium led to a cheap skylight opening system, also providing savings in power and maintenance of the mechanical systems. In addition, smaller projects could take place in less-disadvantaged areas such as the shipyard, greatly reducing the cost of construction and transportation (Diamant R. M. E., *The Atrium house*, 1965).
Five versions of the house were built in total (Link R., 1984**)**, but in the original Water Lily House Warne had not yet implemented all of the eco-sustainable solutions he had in mind at that time (Warne B., *Symbio Housing Symposiums*, 1982). He also increased the energy efficiency starting from insulation, reaching a U-value for the wall of 0,27 and 0,24 for the roof (Archive of ARKDES Museum ARKM).

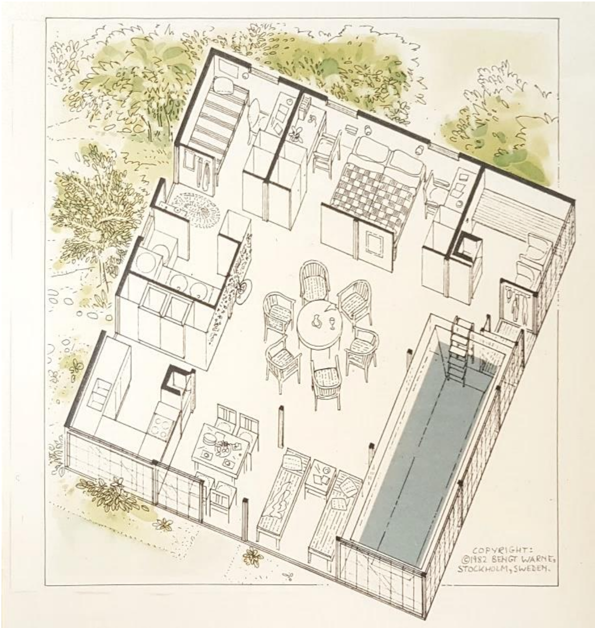


Fig. 18: The Compact-type Water Lily House; scale 1:200

After his practical experiments in following buildings, he became ecologically aware and realized projects implementing more efficient technologies to exploit natural resources (Warne B., 1982). Such technologies include solar radiation or using new types of glass, heat pumps, and products available over the years (Link R., 1984).

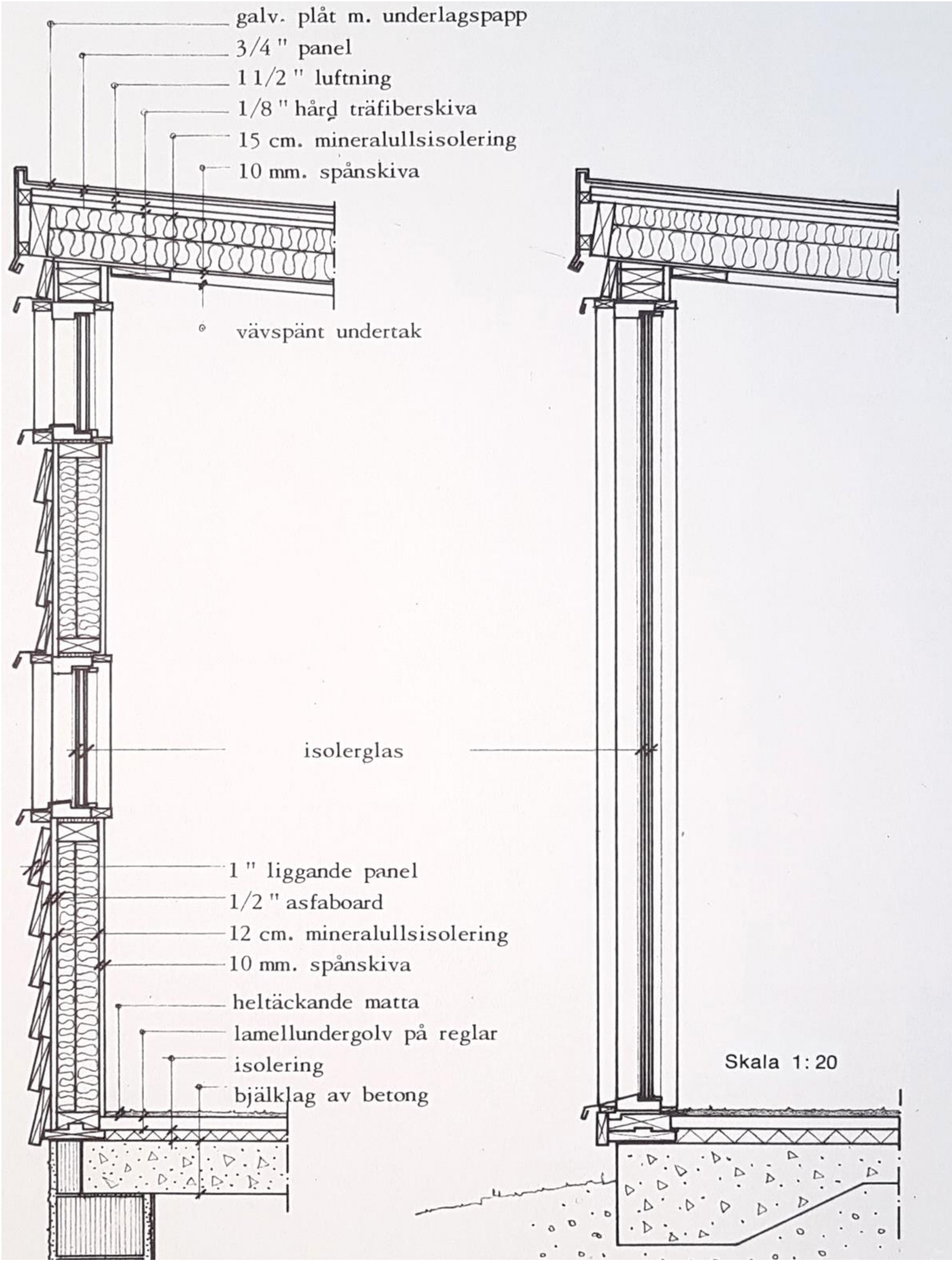


Fig. 19: Section for Water Lily House versions; scale 1:20

2.2.3 Plant experiments

Warne's idea was to use plants to purify the indoor air, while protecting them from the cold Swedish climate.

The focus of the project was the central atrium under the openable pyramid skylight, as it provided great amounts of light and air (when open). In addition, he recalled the importance of plants for “a break”, for instance for a more direct contact with the sun, outdoor air, rain, and insects. In Warne’s mind, opening a door or even a wall was not enough, plants needed the climate come directly into the house from above (Link R., 1984).

He also to limit the use of chemicals to clean the pool, but at that time he had not yet envisaged how to keep it clean in an eco-sustainable way.

Fig. 20: The atrium swimming pool

The first experiments began assuming that one square metre of grass could be enough to produce oxygen consumed by one person. For Warne, a medium sized tree could provide this as well, but potted plants, despite their contribution to air cleaning, were not effective enough (Fredriksson M., Warne B., 1993).

The architect started his experiments with small plants such as ferns, flowers, and even orange and banana trees, as shown in figure 20.

Tropical plants could grow with ease, despite the Swedish winter climate and indoor heating systems, so the experiment could be considered successful (Sullivan O., 1964).

The glass roof and later the greenhouse are not seen as separated from the outside. In fact, they must be let opened sometimes to let in insects and birds (Link R., 1984). This idea evolved, and permaculture became the basis of his further projects (paragraph 2.4).

Some of the features developed in the Water Lily House (like the plan design and the openable skylight) were useful for Warne when he started working on Nature House concepts. The atrium core was a test on air cycles of oxygen and carbon dioxide replaced by plants. Furthermore, the Water Lily House was the perfect opportunity to experiment for the first time all the cycles conceived in Warne's philosophy.

In his first *Naturhus* (paragraph 2.5) air and earth were brought to their full development, and water have not been completely developed for the limits of '80s technology and budget problems (Fredriksson M., Warne B., 1993).

2.3 Earth: Clivus Multrum and permaculture

Soil and water allow plants to live, but these two elements are not enough. Plant soil needs to be fertilized through organic waste and bacterial decomposition products. Why not use waste produced at home instead of throwing into the sewers and polluting seas and rivers?

In Warne's projects, sewer connection and garbage disposal have been replaced by Clivus Multrum. Invented by Rikard Lindström in 1939 in Sweden (http://www.clivusmultrum.eu/index.php), the Clivus Multrum is an evolution of the common composting toilet, a no-flush toilet system that uses an aerobic process to treat human wastes through composting or managed aerobic decomposition (Lüthi, C. and all, *Compendium des systèmes et technologies d'assainissement*, 2008). This system receives not only solid waste from the toilet, but also uses both liquid and solid waste from kitchen and greenhouse to transform them after a three-year bacterial decomposition process in fertilizer and irrigation water.

Humus removed from the composting container is used to enrich the soil with a nutrient concentration as high as commercial fertilizer. Humus is completely free from diseases thanks to bacterial agents. Obviously, in addition to the financial savings, this system prevents damage to the environment (Warne B., *Report from a cultural exchange Sweden-USA*, 1982). With Clivus Multrum it is possible to obtain 10-15 liters of soil per person per year (for bath, kitchen, and garden waste) (Fredriksson M., Warne B., 1993).

Gardening activities in a *Naturhus* become connected with the Clivus Multrum system and allows the growth of plants without any chemical fertilizer (Link R., 1984). Following the architect's philosophy, this type of approach must go hand in hand with that of permaculture (Warne B., *Report from a cultural exchange Sweden-USA*, 1982).

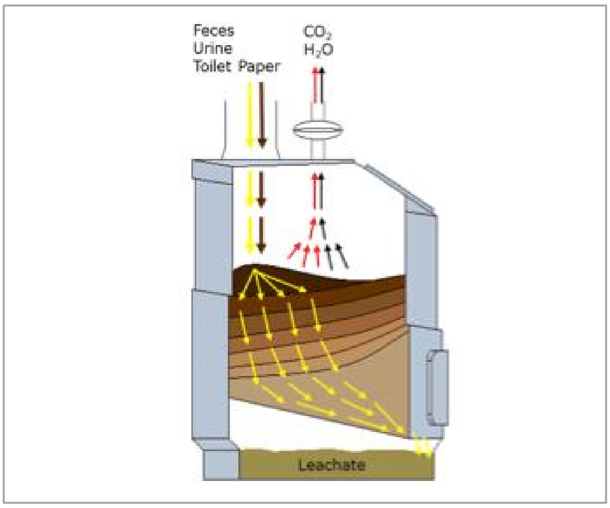


Fig. 21: The Clivus Multrum system

Permaculture allows individuals to produce own's food, fiber, and energy, and at the same time secure the stability of natural ecosystems.

David Holmgren summarizes twelve rules at the base of permaculture, eight of which are certainly recognizable in a Nature House:

1. Observe and interact with nature (in a *Naturhus*, nature is part of everyday life and must be observed and protected, as does Anders Solvarm – paragraph 3.7),
2. Collect and store the energy of nature: wood, organic waste, fruits, and seeds. (Everything in a *Naturhus* must be used and recycled),
3. Obtain a yield (grow plants to obtain food),
4. Apply and design self-regulation methods (to prevent natural balance trough uncontrolled growth of species as ants and snails that damage plants or diseases by bacteria), recognizing and accepting the feedback provided by the community and nature (to every human action there is a reaction from nature – paragraph 3.7),
5. Use renewable resources as natural materials, air, earth, water, and sun,
6. Make sure that the systems present in the project do not produce unnecessary waste - everything must be recycled,
7. Design from patterns to details,
8. Integrate each design element into the system so that they support each other (Clivus Multrum, etc.),
9. Use small solutions: systems should be designed to perform functions at the smallest scale (in a *Naturhus* the smaller scale, that of bacteria is considered),
10. Valorize both animal and plant diversity (Holmgren D., 2013) (Warne recalls the importance of biodiversity, reducing disease risk for species of plants (Warne B., 1982)).
11. Uses original solutions: the most obvious and used solutions are not always the most suitable (development of new systems - Chapter 3),

12. Adapt to large-scale system change which is beyond our control or influence the sentence: “Vision is not seeing things as they are but as they will be” emphasizes that understanding change is much more than the projection of statistical trend lines (Holmgren D., 2013).

Warne writes: “The first rule for an ecological greenhouse is to mix plants, to have a polyculture instead of a monoculture. The less kinds of plants, the more risks to get an explosion of pests, snails, insects..., many plants mean many species living on plants but it also means many species living on other species. Everybody eats everybody in a chain – that is life in any ecological system. So there will be a balance and there will always be enough for us human beings if we just help Nature continuously by watching that delicate balance in our greenhouses.” (Warne B., 1982).

Gardening through permacultural processes allows to create an ecosystem in a *Naturhus* with a diversity of insects, plants, animals, and particularly bacteria and microorganisms. Warne also recalls the importance of not disinfecting soil, water, air, and any part of the house (Link R., 1984): “The second rule is to never disinfect anything. Living in a Nature House itself means to avoid disinfection of air, water and soil. Disinfection means killing, not only our enemies in our surroundings but also the enemies of our enemies. Then the environment is open for sudden attacks of pests, armies of bugs and larvae…” (Warne B., 1982).

Permacultural balance was experimented by Warne in his first ecologically aware project in Saltjöbaden. Bill Mollison himself stayed in the *Naturhus* when he visited Stockholm to receive the Alternative Nobel Prize “The right Livelihood Award” in 1981 (http://www.ecorelief.se/).

An example of the cycles of the four elements in a Naturhus is showed in figure 22.

Everything shown in the drawing was in the Naturhus in Saltjöbaden, except the ecological pool, which the budget and knowledge did not allow to build. It was later tested by Warne in the Stensund Wastewater Aquaculture project.

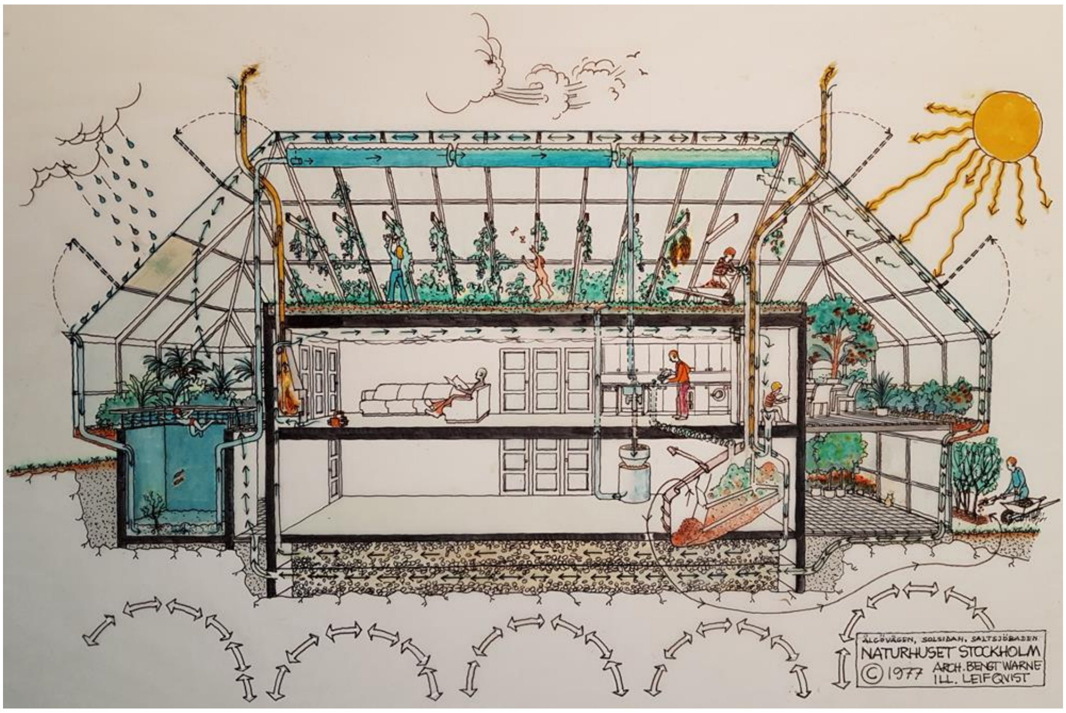


Fig. 22: The cycles of the four elements in a *Naturhus*.

2.4The First *Naturhus*

In 1974 the Swedish magazine *Allt i Hemmet* asked Bengt Warne to design a home of the future that was friendly to nature (Fredriksson M., Warne B., 1993).
He worked one year on the “Symbio Housing” concept, another year on the design and five years of experiments on the building (Warne B., 1982). Hundreds of people were involved in the project. The main consultant for energy and air treatment issues was the general director, Dr. Hugo Larsson. For the water / drain, as well as soil / waste issues, Rikard Lindströrm with his children Torbjörn and Carl were employed (Fredriksson M., Warne B., 1993).
The goal was financial savings in electricity, oil, water, sewage and garbage (Warne B., 1982).

The project was the perfect opportunity to experiment Warne’s concepts. Air and earth cycles were brought to full development, while water cycle had not yet been completely developed.

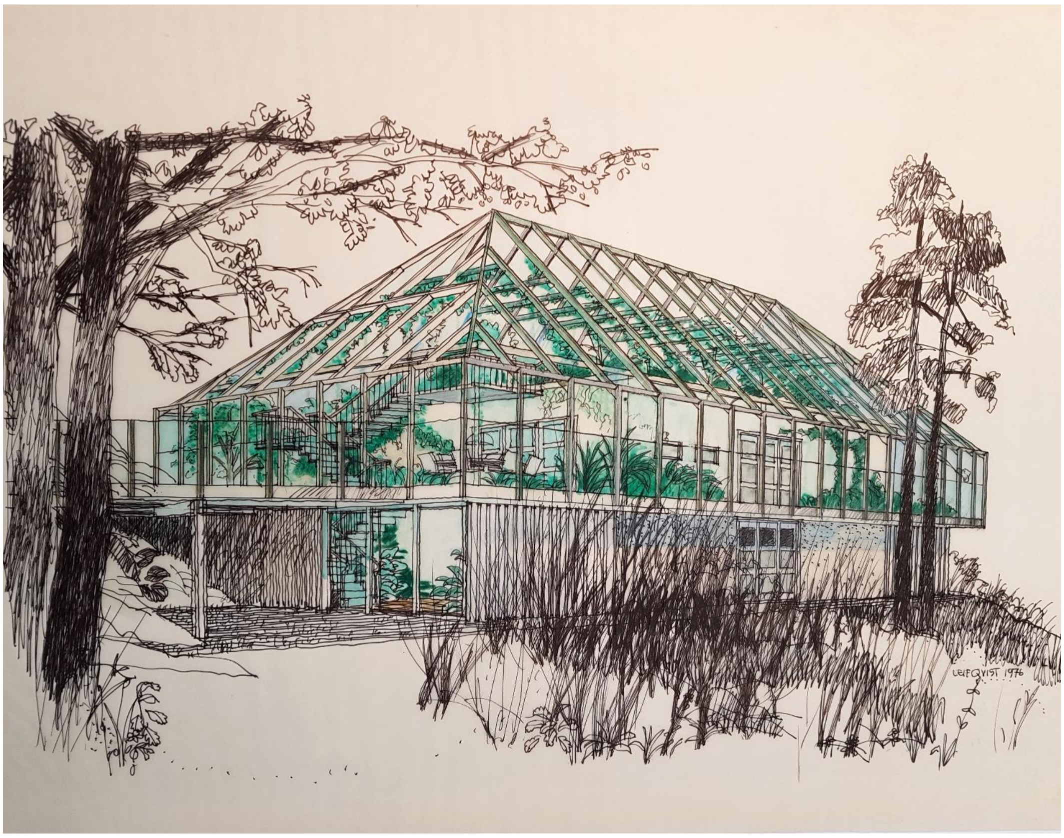


Fig. 23: Sketch of the Saltsjöbaden Nature House

The *Naturhus* is composed of a 93-sqm core house, enclosed by a 220 sqm greenhouse connected to balconies.

The living area, in the middle of the house, is an ordinary wood house. In the ground floor, the entry is in the South-East part, leading to the kitchen-dining room and living room combined in an open space of 46 sqm. Three bedrooms, the cloak room and the bathroom complete the living quarters. Around the ground floor there is a balcony that is one metre wide in both of North-East and South-West sides, four metres wide in the other two.

The house was decorated by Ulf Beckman with environmentally friendly materials like cotton, linen, wool, jute, bamboo, pine, and rice paper (Fredriksson M., 1993).

Fig. 24: Ground floor of the *Naturhus* in Saltsjöbaden, scale 1:200

On the upstairs roof of the core house there is a garden enclosed by a greenhouse. A soil layer allows plants to grow. The basement is underground for more than one side since the house is built on a slope. It is partly furnished as an appliance room, while the rest has been used mainly as a store room.

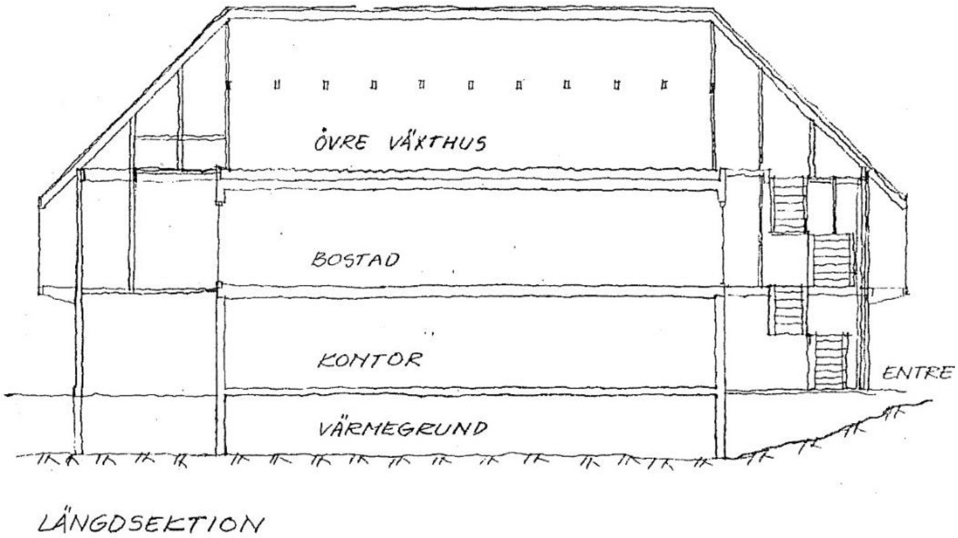


Fig. 25: Longitudinal section, scale 1:200

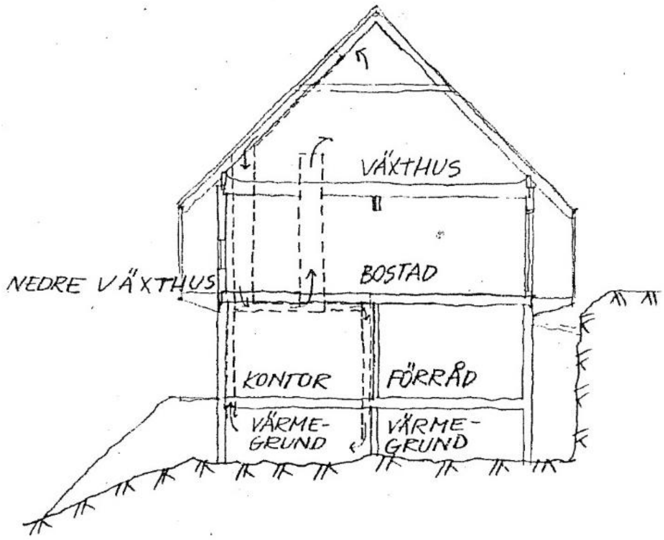


Fig. 26: Transversal section, scale 1:200

This part was thought of as a residence, or to be used as a room for other activities, for example as a *kontor* (office in Swedish).

The three floor levels are connected by South-East stairs in the entrance. In fact, no internal staircase exists; it was always necessary to use the stairs located in the buffer zone (inside the greenhouse) (Archive of ARKDES Museum ARKM).

Fig. 27: East view of the first *Naturhus*

Fig. 28: View of the living room

Building materials were carefully selected considering the amount of energy needed to produce, transport and assemble them at the building site. The materials are not harmful to the environment like wood for the structure, pebbles, glass panes, and clay for tiles. The only exceptions were concrete foundations and aluminum frames for the greenhouse and the windows.

Because of Warne's concerns that plastic creates high concentrations of positive ions in the air that have negative effects on human health, plastic was avoided. The choice of aluminum was due to practical reasons: it does not rust, it can always be recycled, it replaces many other more harmful materials and despite being very strong it makes the construction lighter.

The house is super-insulated. The perimeter walls consist of one-centimetre gypsum, a thin plastic foil, a layer of average 18 centimetres of mineral wool, one centimetre of aeration gap, and one centimetre of wood paneling.

Fig. 29: The perimeter walls enclosed in the greenhouse

Insulation was also placed around the edges of the greenhouse (see figure 41 in chapter 4.4.1), while it was not used at the basement level in order to take advantage of ground heat (Warne B., Warne K., 1980).

The ground had pebbles 50-70 millimetres in diameter, used to store heat or cold for long periods of time. The pebbles react to temperature changes quickly, while the rocks react slowly, thus serving as a buffer. To make the ground, a suitable area was excavated and filled with rocks and pebbles; then a concrete slab was built upon it (Link R., 1984).

Placing the house on the ground means having advantages such as avoiding cold floors, limiting frost damage to foundations, limiting cracks and no freezing of sewer. On the warm earth, there is a foundation of 50 cm thick concrete slabs with oil-impregnated beams of laminated wood, forming the lower story (David E. Robson, *The Lamp of Memory*, 1982). Warm air was extracted by fans and immitted into the air cycle (described in paragraph 4.4.1).

The greenhouse roof, starting from beneath, was made of chipboard, one millimetre of watertight EPDM rubber mat, and three millimetres of oil-tempered board (Link R., 1984). This is a fiberboard that has been coated with linseed oil and then cooked. The procedure gives to the fiberboard more water resistance (Akers L. E., 1966) to resist the layers of the garden soil above, made of two centimetres of gravel with sand and ten centimetres of soil (Link R., 1984).

Above the roof, there were also plant beds, initially planned as 7 cm then reaching 20 cm, as an addition to the 12 cm for flowers and small plants (Archive of ARKDES Museum ARKM).

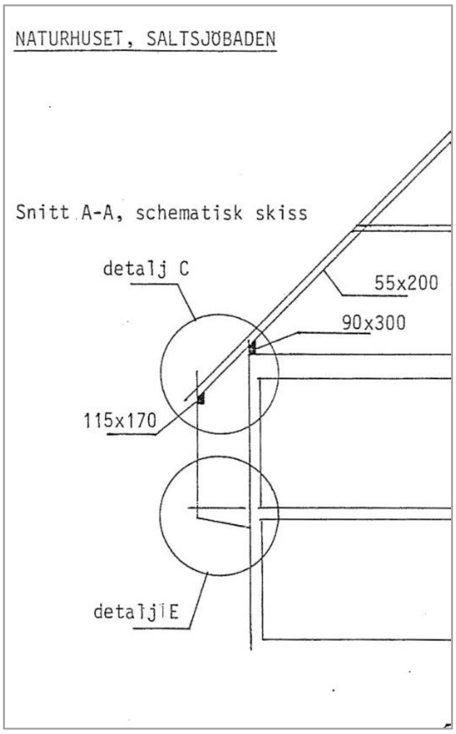
Fig. 30: The garden on the *Naturhus* roof

The *Naturhus* walls are built of wood, with interior insulation of rock wool and plasterboard. Wood is applied to beams on the roof and around the house, which were in laminated wood, as shown in figure 31 (Warne B., Warne K., 1980).

Fig. 31: View (South-East) from the *Naturhus* roof terrace

The roof glulam rafters (1, ref. figure 32 page 52) had a slope oriented at 45 °, were of 5,50 cm by 20 cm, and were placed at 1,23 m.

Centers there were 8 refers on the short side of (9,89 m) and 18 the long side (22,16 m). Under each rafter there was a square wooden pillar (5, ref. figure 32 page 52) of 55 x 55 mm (Archive of ARKDES Museum ARKM).



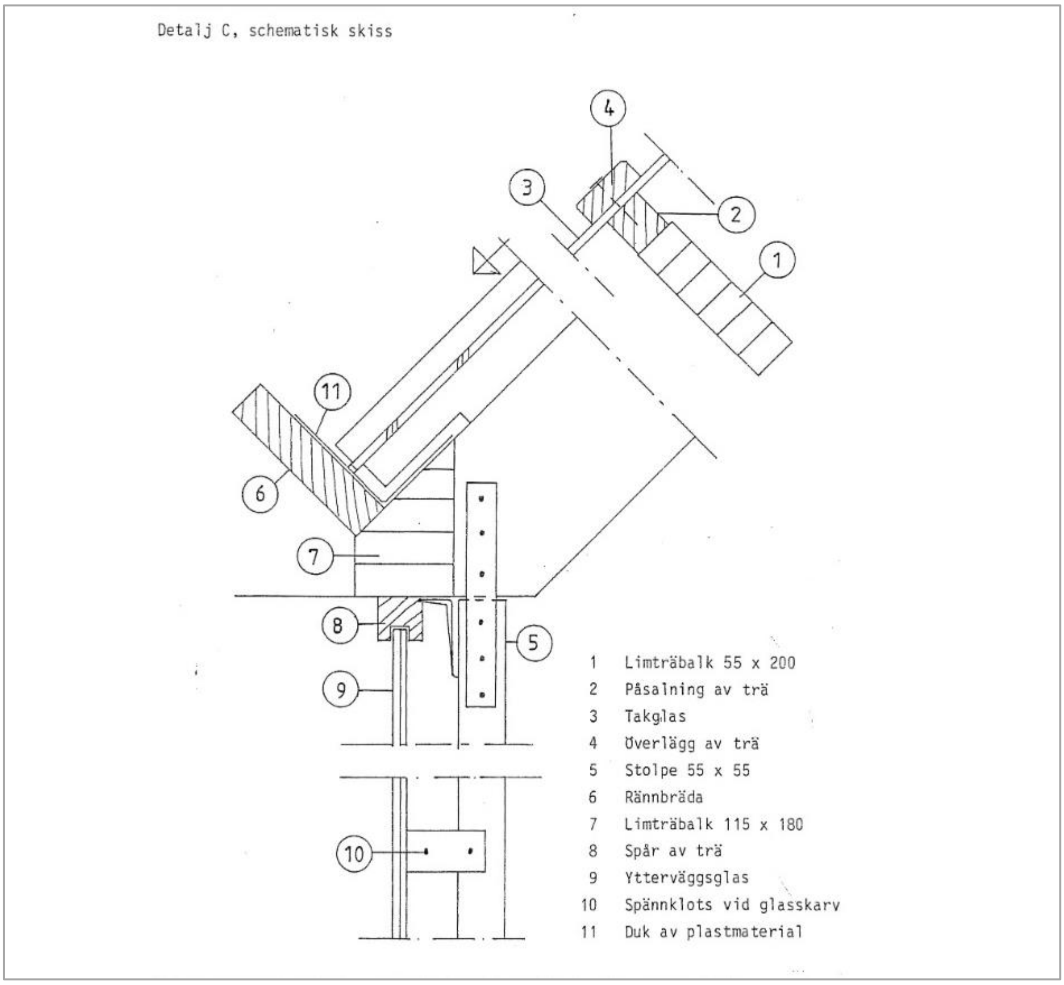


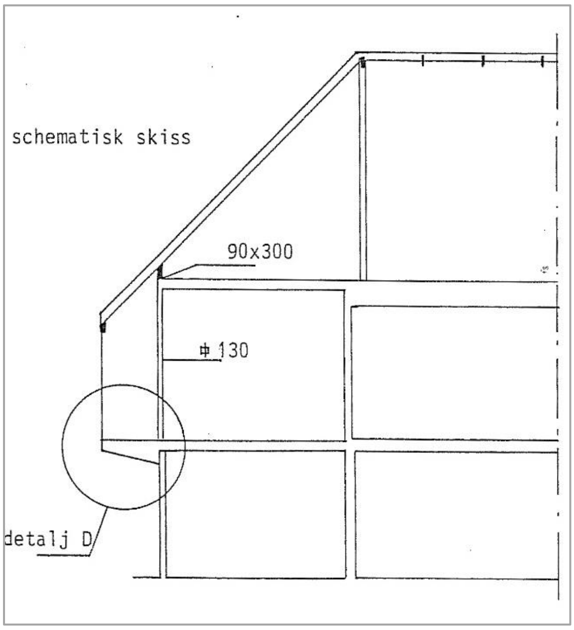
Fig. 32: Detail C , scale 1:10

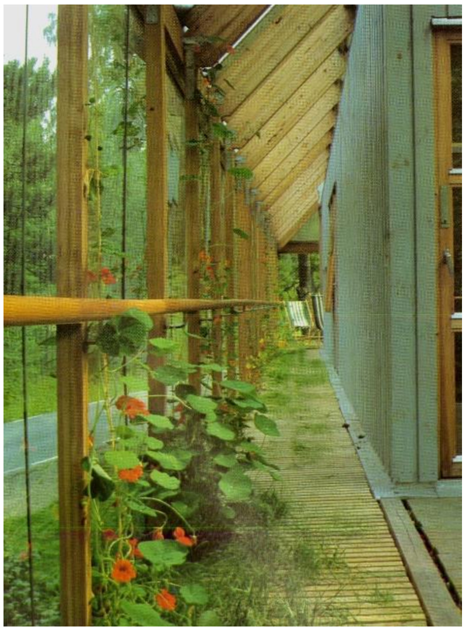
The structure was contained by a glulam ring beam (7, ref. figure 32 page 52), cut to create a trapezoidal section, with a base of 11,50 cm and height of 18 cm. Another wood profile (8, ref. figure 32 page 52) is connected to the glulam ring beam (7, ref. figure 32 page 52) to support the greenhouse glazing.

Fig. 33: The *Naturhus* greenhouse under construction (without ring beams and pillars) in 1978

The balcony runs around the house and is supported by another 55 x 250 mm glulam beam (1, ref. figure 34 page 54) and the house beam (10, ref. figure 34 page 54) 90 x 250 mm.

A layer of *lättklinkerkulor* (expanded clay spheres) (8, ref. figure 34 page 54) fills the space and is enclosed by *brädfodring* (wainscoting). Such layer is used to grow grass and flowers on the balcony, as shown in the figure, and is covered with wood boards (5, ref. figure 34 page 54) close to each other to form a walkable surface (Archive of ARKDES Museum ARKM).





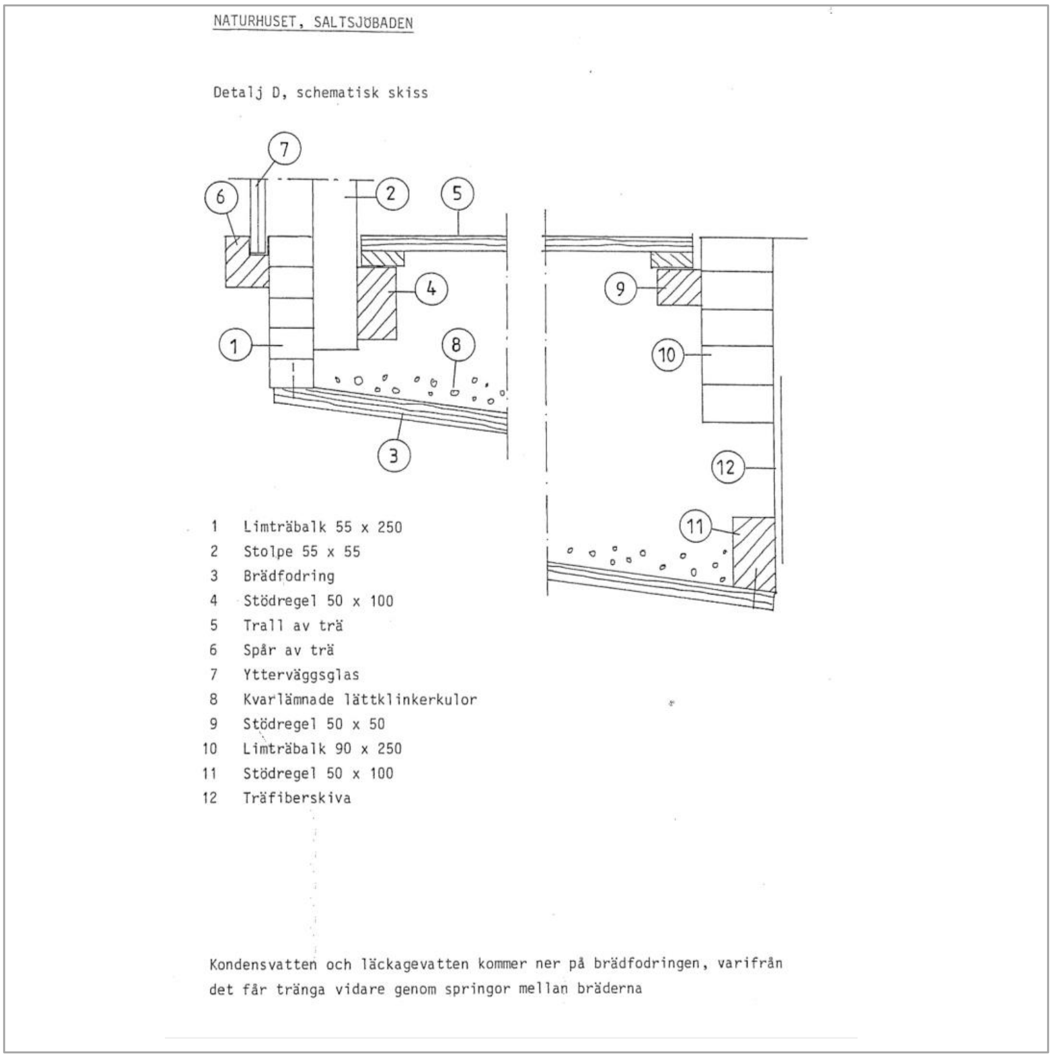


Fig. 34: Wood structure of balconies around the *Naturhus,* scale 1:10

Warne claimed that the 5 millimetres thick glass wall helped to insulate the core house from traffic noise (Fredriksson M., Warne B., 1993); it was made of single-coated tempered glass. The North-East side wall is closed for this reason (see figure 38), and vehicle noises are largely kept at bay (when both windows are closed). However, sound could penetrate through the openings above the doors (as shown in figure 48 in paragraph 4.4.4. Combitherm stove), as there were only gratings (Warne B., *Symbio Housing Symposiums*, 1982).

The greenhouse roof had a 6 millimetres thick coated tempered glass, to withstand snow and falling branches (Link R., 1984).

Some parts of the roof were opaque, to provide protection from sunlight (Archive of ARKDES Museum ARKM).

The core house windows were triple-glazed, the best that could be found at that time (Link R., 1984).

Fig. 35: The triple-glass windows inside the single-glass greenhouse

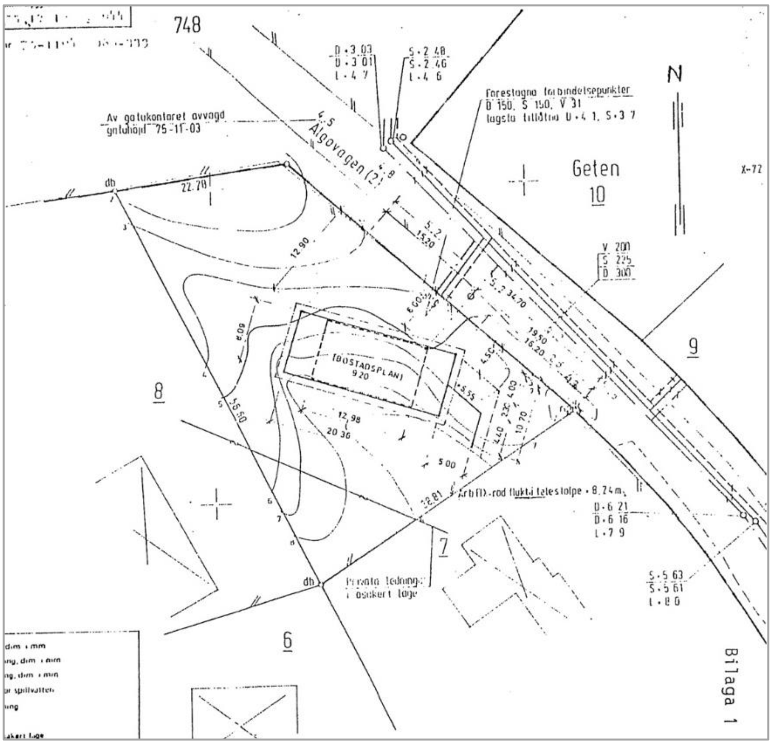


Fig. 36: Site plan, scale 1:1000

The core house is about 10 metres away from the road (figure 34) (Archive of ARKDES Museum ARKM). The trees screened the South-East (figure 37) and North-West sides (figure 31), while along the street there were no trees. The house is far from the city and in an area with low traffic (Fredriksson M., Warne B., 1993).

Fig. 37: Trees around the *Naturhus,* South-East side

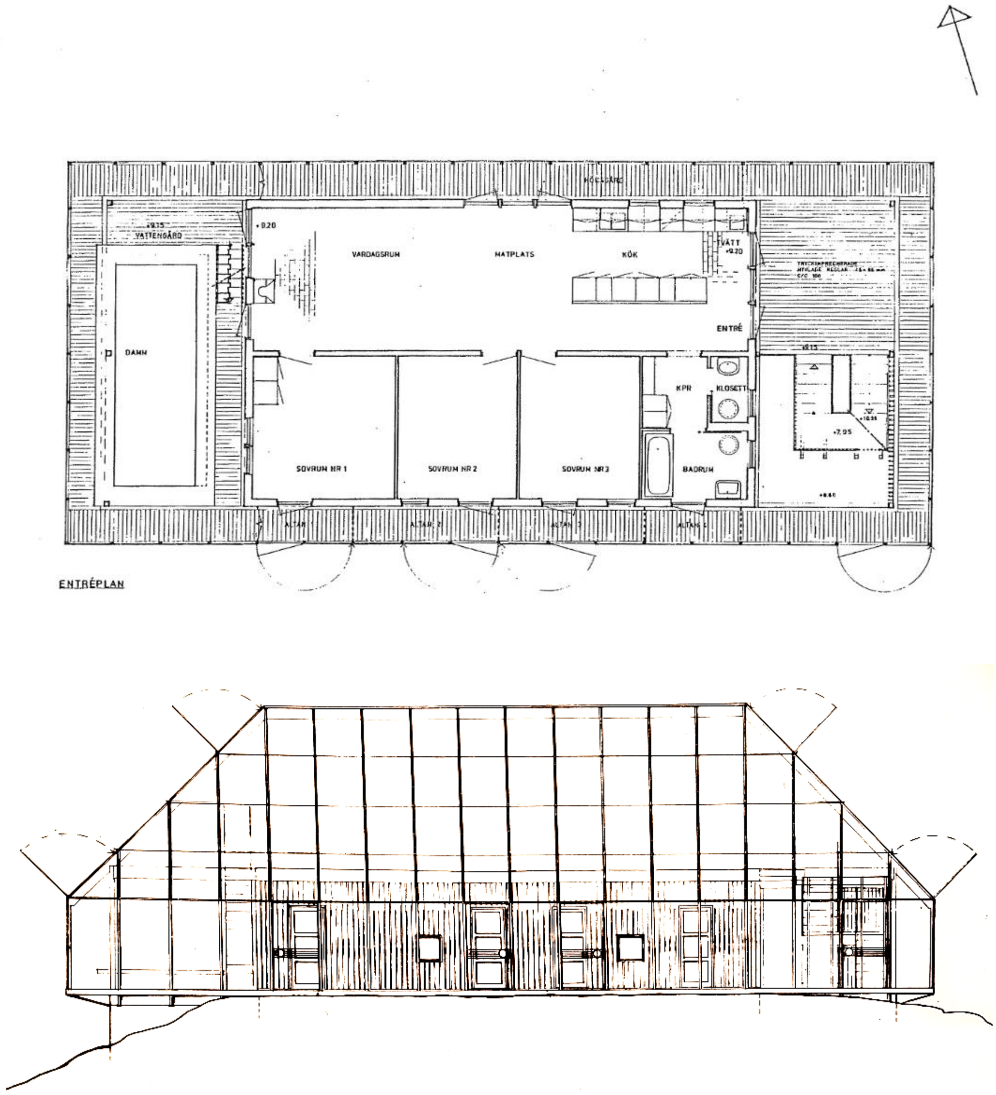


Fig. 38: Ground floor and North-East elevation, scale 1:200

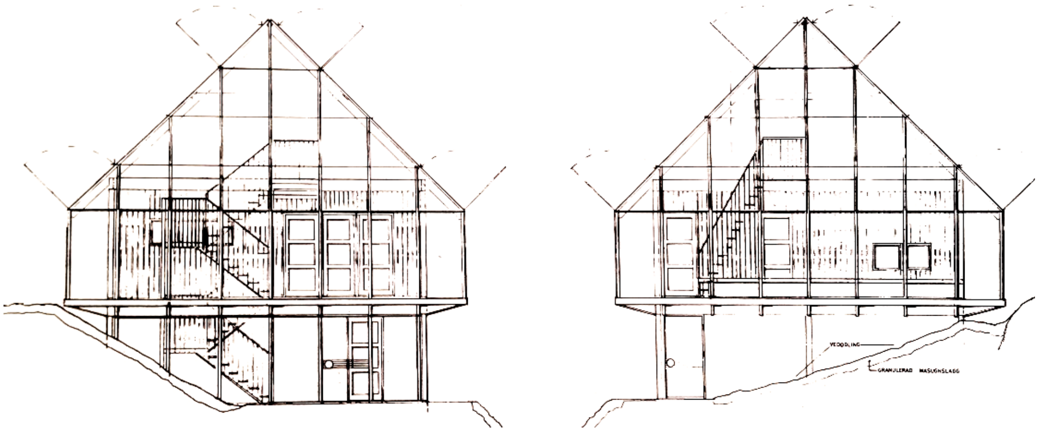


Fig. 39: South-East and North-West elevations, scale 1:200

2.4.1 Ventilation system

The better the air tightness, the greater is the ventilation required.

In summer, this is not a problem, because the windows of the greenhouse can be opened. But it was wasteful to let out the heat when it could be stored at night, in colder days or weeks. Since in the philosophy of Symbio Housing everything is recycled (be it air, soil, water, or heat), Warne decided to use fans to send overheated air under the roof of the greenhouse in a loop (as shown in figure 41), and then heated by the ground. The tube used for the ventilation is 15 metres long, 15 cm in diameter and it lay two-metres underground, below the living quarters. Rocks and pebbles stored heat, transferred and allow air to come back, refreshing the space enclosed by the greenhouse (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

Fig. 40: South-East view of the *Naturhus.* Fans at the top take air from the buffer space.

Heat stored in the ground can be used when needed, taken up by fans. “In all Symbio Housing, the ground is the regulator and the sky the producer of heat in day-light.” (Warne B., *Symbio Housing Symposiums*, 1982).

In winter time, fresh air (A, reference figure 41 page 60) is extracted from fans into the core house through a heat exchanger (B). A central fan includes a heat exchange working when needed for the kitchen, too (C). In the composting room in the basement (D), the heat for the heat exchange unit and warms the incoming air. When the fans are stopped due to a blackout, the ventilation works by convection, providing less performance and savings, (Warne B., Warne K., 1980). The heat exchanger also has a filter for the air coming from the composting chamber as a health precaution. Since air is always being drawn through the toilet stool (E), the toilet room is kept free of bad smells. According to Warne, “the bathroom is completely odor-free. Ventilation increases automatically when someone sits on the stool. The bottom opens when weight is placed on the seat and closes when the weight is removed” (David E. Robson, 1982).

The intense but not unpleasant smell coming from the composting chamber (Warne B., Warne K., 1980) is necessary for “Symbio Housing” concept. “It is a composting process, not a rottening process with methane gas and other bad smells. It smells like in the autumn when the leaves have fallen to the ground and get composted into new earth” said Warne (Warne B., *Symbio Housing Symposiums*, 1982).

The air coming from the composting process gains heat and provides additional carbon dioxide and moisture that plants need (Link R., 1984). Warne decided, as an experiment, to use air in the space between the core house and the greenhouse, despite the intense smell. “I do not let the exhausts from the ventilation pass in the living areas. As an experiment, I let them into the greenhouse, which smelled acceptable” said Warne, but after the experiment in the *Naturhus,* he changed his mind: “now I prefer to take the energy and humidity out of the used air through a heat-pump and let all the smell out through a ventilation chimney”. This can be observed in figure 41.

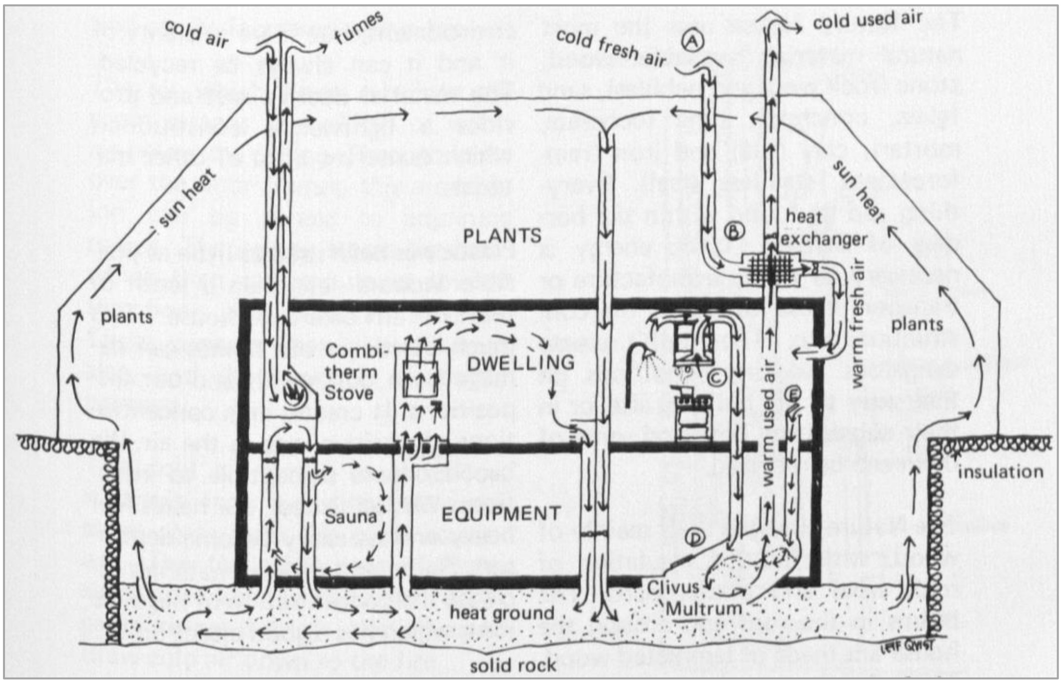


Fig. 41: Air motions design in the first *Naturhus*

Fig. 42: View of the first *Naturhus.*

As such systems recycle all the air except in the toilets, the problem with these air systems concerns smoke. The only part of the house where it is possible to smoke cigarettes is the bathroom (with ventilators that aspired unpleasant smells), near the stove or close to the kitchen ventilator. Plants and soil can absorb of some of the smoke, but for the architect it would be better to avoid it at all: “All smokers have to realize that they are an environmental problem, their pollution of air is incomparably worse than any other pollution of air, industries and cars included. If they don’t care about their own health they should care about others’ health.” (Warne B., *Symbio Housing Symposiums*, 1982).

2.4.2 Composting chamber

In the basement of the Nature House, the room with a Clivus Multrum receiving toilet, kitchen and greenhouse wastes is placed. All wastes that can’t decompose, such as glass, plastic, etc. are sorted, to be later recycled in containers. On the other hand, all organic waste slides automatically on the bottom of the Clivus Multrum container, where there is a door through which it is possible to remove the humus produced; see figure 44. The compost must be diluted with soil (Warne B., Warne K., 1980), and can be used after a process that can reach up to 5 years. This system guarantees treatment of sewage on site, no sewage transports and no water consumption, with a minimal maintenance (http://www.clivusmultrum.eu/).

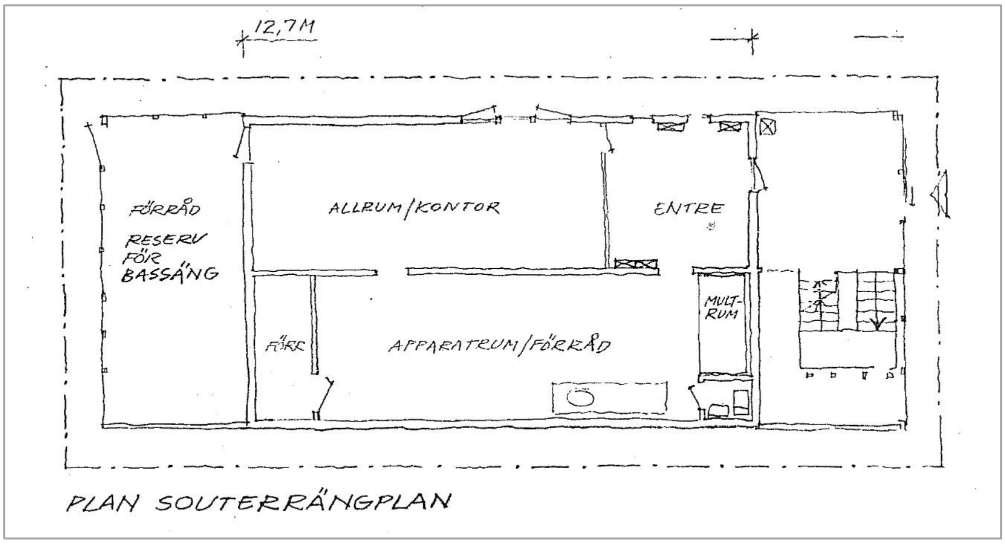


Fig. 43: Basement of the *Naturhus*, scale 1:200

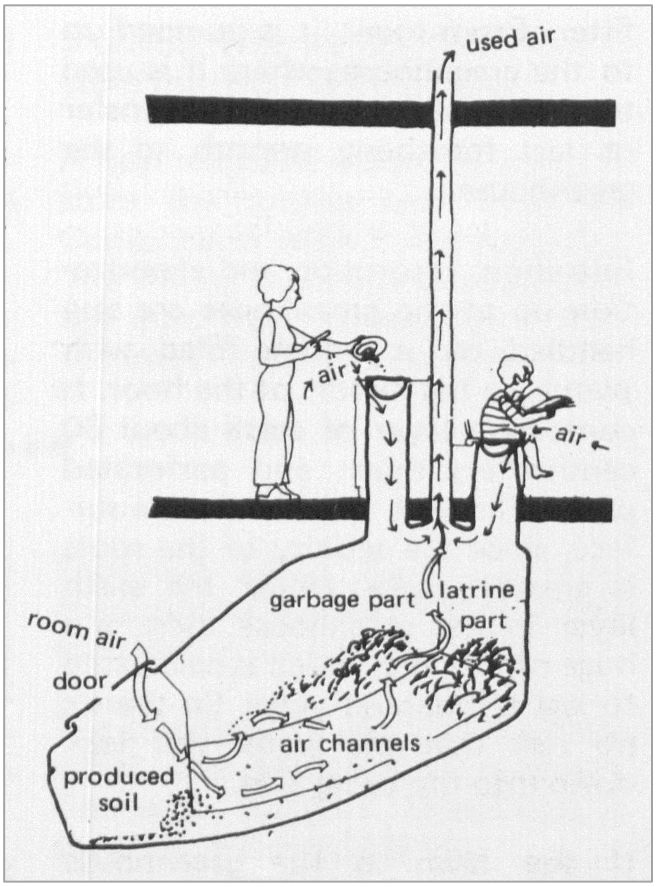


Fig. 44: The Clivus Multrum

In this first experiment Warne used a compost container about 1 metre wide, 3 metres long and 7 metres high. Chemical analysis of compost produced by the Clivus Multrum, was made by dr. Margaret Fogel and the University of Wisconsin, showed that this soil was better than the average garden compost available at that time (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

The system encountered a problem at first: Nobody had informed the architect that he would have encountered a problem with flies before arriving at the biological balance after a few years. Flies are attracted by light and fly out of the composting chamber through the openings. Warne asking the help of biologists who told him to add mites. In fact, mites kill fly larvae before they are born from eggs (Warne B., *Symbio Housing Symposiums*, 1982). Another solution was ultraviolet lamps placed above the composting chamber to attract flies and kill them (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

2.4.3 Greywater recovery system

Water (Warne) used and rain are another resource recycled in a *Naturhus*. Rainwater is collected from the roof and channeled into a sand filter (A, reference figure 45 page 64). The minerals give the water taste, microorganisms and small animals take care of purification. As in the composting room, the biological activity is high (Warne B., Warne K., 1980).

A pool to collect the water from the roof was in store, but the project never materialized because of budget problems (Fredriksson M., Warne B., 1993).

The rainwater pool (B), to be used for swimming, was the only part of Warne's plan not employed in the first Nature House. He imagined the pool to be biologically cleaned by algae, worms, insects, crustaceans, fish, microorganisms and then to be cleaned through a second sand filter at the bottom of the basin (C).

By imitating nature and letting water circulate, aerate and be biologically cleaned, Warne would have prevented stagnation and putrefaction. He also would have prevented natural imbalances by checking the balance growth of the different categories. For example, if algae grow too abundantly, the water turns green and slimy or if there are too many insects which eat algae, algae disappear.

It is important to recall that, from Bengt Warne's point of view, nothing needs to be disinfected in a Nature House because it would mean killing the required bacteria to maintain natural equilibrium (Link R., 1984).

Purified (rain) water from the pool is used in the house for bath, laundry, or washing dish. After usage such water is filtered, recycled and purified in a Clivus Trickle filtration system (D) (David E. Robson, *The Lamp of Memory*, 1982) developed and constructed on site by Rikard Lindström and his sons, Torbjörn and Carl (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

Water contains plant nutrients like phosphates, but also oils and some solid particles. The Clivus Trickle filtration system purpose is to filter particles like seeds and granules blocking the pipes. It also consists of a large funnel-shaped container filled with rocks, pebbles and sand graded in size.

The filter in the basement also works as a heat exchanger so as not to shock the plants through hot or cold water. At the end of this cycle, the greenhouse plants receive the filtered water by means of pumps (E).

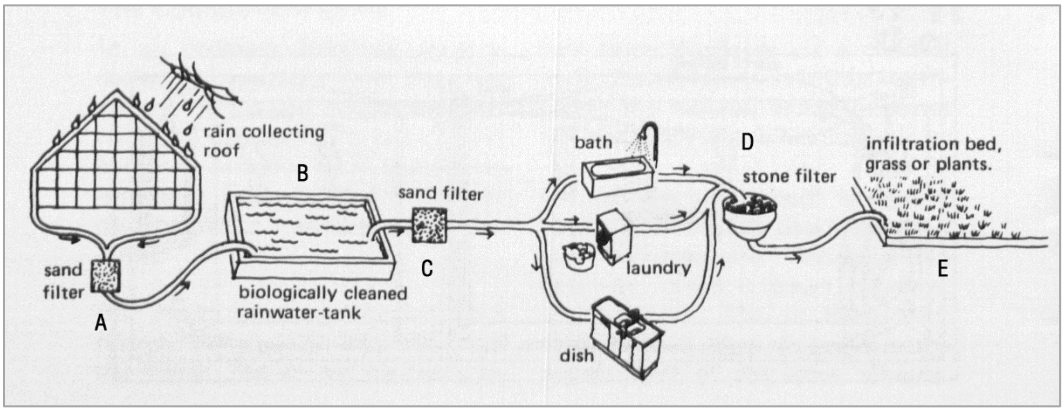


Fig. 45: The rainwater and greywater-reuse in the *Naturhus*

Almost all the water of the plants evaporates from the leaves and from the soil. Moisture can sometimes condense on the coldest greenhouse surfaces, and thus recycled. This water, as pure as distilled water, is passed through a third sand filter to mineralize and make it drinkable (Link R., 1984).

Filtration and vaporization in the greenhouse are also handled through a layer of 60 cm of earth filled with plants. To prevent the risk of water leaking down, a huge rubber mat between the soil and the living area below is placed (Warne B., Warne K., 1980).

2.4.4 Combitherm stove

For the owners, the architect wanted an open fireplace in the living room to be enjoyed alone or with friends. Warne asked for the help of an experienced engineer, Hugo Larsson, who elaborated the Nature House heating system with functionality and affordability. Designed according to the model of Northern European tile stove (*Kakelugn,* or *Kachelofen* in German), Hugo Larsson's Combitherm stove burnt firewood and paper. The result was a steel type that it has 80 per cent more efficiency than the previous *Kachelofen* model (Link R., 1984) and also contains an electric heater that can be used as a power source at night, hence the name Combitherm (David E. Robson, *The Lamp of Memory*, 1982).

It was tested by the Swedish government and after the experiment in Saltsjöbaden, it became an enormous success all over the world (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

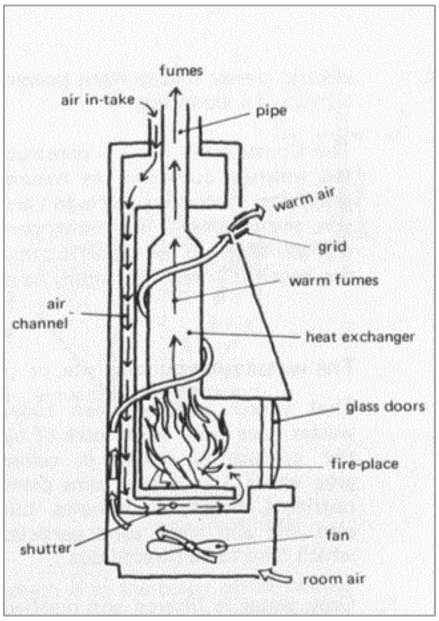


Fig. 46: Combitherm stove section; Fig. 47: Combitherm stove in the *Naturhus*

In an ordinary fireplace, warm air of the room is sucked up and out through the chimney. Warm air that comes out, draws cold air from outside and fuel is then needed to heat up again. As opposed to a fireplace, Hugo Larsson's stove is separated from the house. The air for the fireplace is taken from the outdoors via a pipe built in the chimney as shown in figure 46. The chimney serves as a heat exchanger that warms the incoming air, increasing heating efficiency (Link R., 1984).

The air heats up through the heat exchanger, heating the cold room air at floor level assisted by a fan (Warne B., Warne K., 1980).

Starting from the upper front of the stove, the warm air flows out into the room, through a grid over the door and across the next room, returning cold to the stove, then it is heated again in a loop (figure 48). The ceiling stores the heat which radiates down (Link R., 1984). The three bedrooms are heated air the slots above and below doors, and the internal temperature cannot be controlled.

The ashes of the stove are collected downstairs and used as a fertilizer (*Recycling In The Home: How Simple Division of the Waste Stream Transforms Household Wastes for Valuable Re-Use*).

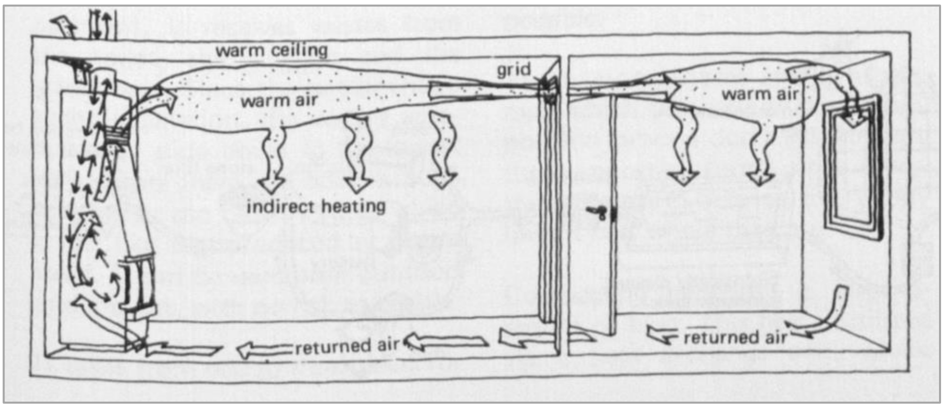


Fig. 48: The cycle of heating air flow

The *Naturhus* included chimney for natural ventilation. The chimney was a few metres higher than the ridge to increase airflow. A powered fan was placed at the top to help to the nature-driven aspiration.

At the time, Warne did not think about automatic sprinklers, operating in the event of a fire and that could also provide water on plants when needed. "Sprinklers are a bit expensive but not if they can be given extra functions in staircases with plants, e.g.", Warne said (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

2.4.5 Energy and economic efficiency

Bengt Warne's ventilation, composting, water and heating systems allowed the bills to be cut down by about 70 per cent compared to an ordinary house in the 70s.

In 1978, per capita income in Sweden was about $ 9,300 (David E. Robson, *The Lamp of Memory*, 1982). In 1982, Warne's data showed that an ordinary Swedish house for four consumed $ 2,150 worth of energy per year, as shown in figure 49. If the total income is $ 9,300, almost 25 per cent goes to pay house energy bills.

After the *Naturhus* experiments, Warne reported that his Symbio techniques cut the energy bill to $ 500, which means to return $ 138 per month to the family budget.

Figures reported by Warne show that for assumptions an ordinary 125-sqm house the average heat consumption in 1970 was 32.000 kWh/y. Thermal dispersions through heat transmission were 20.000 kWh/y of which 6.000 kWh/y were wasted through walls, 3.500 kWh/y through windows, 5.500 kWh/y through the roof, 5.000 kWh/y through the basement. Thermal dispersions through ventilation were 7.000 kWh/y and 5.000 kWh/y were spent for hot water.

Furthermore, the ordinary household consumed about 5.000 kWh/y of electricity and produced 8 m^3 waste, together with 200 m^3 wastewater every year (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

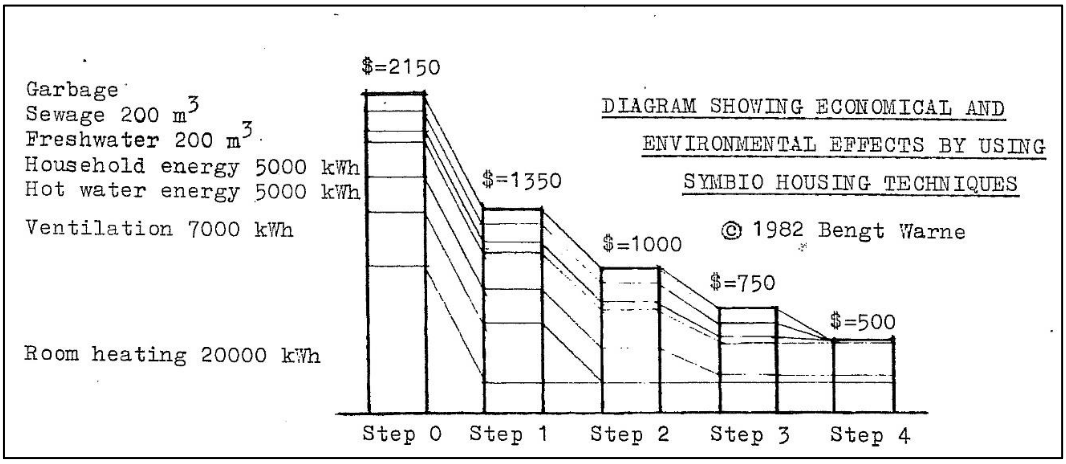


Fig. 49: Economical effects by using Symbio housing techniques

During the period 20th February 1978 to 3rd May 1981, Bengt Warne had a diary about the *Naturhus* in Saltjöbaden (Archive of ARKDES Museum ARKM).

Based on that, the architect divided the strategies experienced in the *Naturhus* in various steps.

Step 1 and step 2 show the effect of sun-driven and wind-driven systems, using super-insulation.

In comparison with an ordinary house of 125 sqm, a *Naturhus* with a 100-sqm core house enclosed by a 200-sqm greenhouse. The heat losses would be reduced (as the greenhouse would act as buffer, decreasing the temperature difference) by 10.000 kWh/y. An additional 12.000 kWh/y would be won by the greenhouse serving as a solar collector for the core house (Fredriksson M., Warne B., *På akacians villkor*, 1993). Since there is a good ventilation system in the greenhouse, the heating requirements would be reduced by further 5.000 kWh/y.

Despite the electricity-powered pumps for room ventilation, annual electricity consumption would be about 5.000 kWh/y in both cases (Fredriksson M., Warne B., *På akacians villkor*, 1993).

Step 3 and step 4 include the effect of collecting rainwater, re-using greywater and save fertilizer by a composting chamber.

According to Warne, the Clivus Multrum in Saltjöbaden generated about 1.000 kWh of heat energy per year (Warne B., Warne K., 1980), saved about $ 100 in garbage disposal charges per year, powered the heat exchanger integral to the ventilation system and erased the costs of fertilizer, without overflowing or freezing risks (David E. Robson, *The Lamp of Memory*, 1982).

In a *Naturhus* everything is recycled, and the costs of waste disposal, water supply, and wastewater management are almost erased (Fredriksson M., Warne B., 1993). "The Nature House has no flush toilets, so its annual water consumption is about 100 cubic yards (m^3) lower than an ordinary house" Warne says confirming also that it supplies drinking water by collecting rain, mineralizing it through Clivus Trickle filtration system (figure 59) (David E. Robson, *The Lamp of Memory*, 1982).

Only for non-organic materials such as metal, glass, and plastic were collected as in an ordinary house (Warne B., Warne K., 1980). Thanks to these strategies, the average heat consumption dropped to 10.000 kWh/y in a *Naturhus* from 32.000 kWh/y of the "ordinary house". Hugo Larsson's Combitherm stove met the heat demand through high efficiency.

It is reported that five kg of firewood could keep a 140-sqm Nature House warm for 12 hours with an outdoor temperature of -10 °C (Link R., 1984). Dr. Mats Wolgast at Uppsala University demonstrated that 500 kilograms of firewood per year can be heat an ordinary insulated house in Scandinavia (Warne B., *Report from a cultural exchange Sweden-USA,* 1982). "The only investments that do not pay today are solar cells and solar batteries, they will be cheap enough in the next decade for the production of the 5.000 kWh/y needed for lights, fans, pumps and transportation screws for the household of modern comfort.", Warne said, confirming that photovoltaic panels and solar collectors were not affordable at the time (Warne B., *Symbio Housing Symposiums*, 1982).

Lastly, fruit, vegetables, and spices harvested in the greenhouse provided additional savings. Further details will be given in the following paragraph.

2.4.6 Ecological experiments

The insulation made necessary to regulate indoor air humidity, which could otherwise damage both plants and building, and made possible to heat the greenhouse without anything more than the heat from lighting plus the solar heat stored in the ground (Warne B., Warne K., 1980). Since heat, humidity, and lighting could be controlled. Between 1976 and 1981 the Nature House became the central point of development and demonstration of ecological technology.

Although the most extreme temperatures recorded outdoors during the research period were -29 °C and +34 °C, the greenhouse never became cooler than 0 °C or warmer than +27 °C due to the heat storage effect of ground and the ventilation system (Fredriksson M., Warne B., 1993).

Natural lightning has many positive aspects in Sweden, but it also has many other disadvantages. Summer days are 13 hours long in the South and 24 hours long in the North in June-July and obviously the opposite in winter. People and tropical plants can't stand these conditions because there are roughly 8 hours of comfortable daylight (in fact, plants need conditions similar to humans to grow) Strong artificial lighting should be installed to keep gardens growing, but this would add substantially to the cost of fruit and vegetable. Warne remarked that, before starting gardening in a *Naturhus* in a Northern Europe, one should first study plants and their growth conditions (Warne B., *Symbio Housing Symposiums*, 1982) (hence the name of book *På akacians villkor*: "The conditions of Acacia").

In the *Naturhus* in Saltjöbaden, there were five different temperature at various levels in summer:

- at ground level, it was 20 °C, the ideal temperature for lettuce and root vegetables;
- about one metre above ground, it was 25 °C, the ideal temperature for activities;
- at about 2 metres, it was 30 °C, the ideal temperature for roof gardening of cucumber, tomatoes, grape vines, paprika, and fig trees;
- at 3 metres of height, it was 35 °C;
- at the 6-metres intake level of air, right under the roof, it was 40 °C.

Warne preferred to refer to these temperature layers with names of Mediterranean zones like Northern Italian climate, such as Venice, for the living quarters and Southern Italian or Greek climate on the roof garden (Link R., 1984).

Warne tried to mix the temperature layers e.g. with powerful fans, but it was impossible (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

The protection of the greenhouse combined with these different levels allowed for the growth of plants from temperate climates, such as potatoes, simultaneously with plants from tropical climates, such as bananas.

During the five-year research period, Warne lived in the house and made various experiments to directly check the results of his project (Link R., 1984).

On the ground floor there was a small meadow with cornflowers, peas, daisies, nasturtiums, and forget-me-nots. At the same level, there were bamboos and two fig trees, one in the greenhouse and the other in an indoor room. The one in the greenhouse grew up to 3 feet high and it yield fruits after the second year, the other died after 3 years.

In the roof level, he planted grapevine climbing up the wood structure as shown in figure 50, but it did not yield grapes until the third year (Warne B., Warne K., 1980).

Near the grapevine, there were small peach, orange, tangerine and lemon trees that also gave fruits through the years (Fredriksson M., Warne B., 1993).

In addition, there were boxes containing common Swedish vegetables such as carrots, beets, onions, radishes, lettuces, fennel, tomatoes, pumpkins, cucumbers, and peppers, as well as exotic plants (Warne B., Warne K., 1980). In the core house, it was possible to grow tropical and exotic plants including banana, mango, pineapple, and papaya. Some of them needed extra light in winter.

Fig. 50: Gardening activities on the *Naturhus* roof

The experience through the five-year research period allowed Warne to write rules for gardening in a *Naturhus* (influenced by Bill Mollison (http://www.ecorelief.se/) e David Holmgren concepts (Warne B., 1982) in the 80s (Holmgren D., 2013)):

1) mixing plants by ensuring biodiversity to prevent pests, snails, and insect;
2) ensure the proper balance avoiding uncontrolled growth of species increasing other species;
3) developing and watching ecosystem balance continuously;
4) do not disinfect anything to avoid killing species that ensure correct balance, avoiding excessive presence of ants, bugs, and larvae;
5) try any seed or plant since it is impossible to know in advance if they will live or not;
6) buy small trees and climbing plants because they rarely suffered from lack of water;

7) provide fish, small animals, and birds that can balance the ecosystem by eating insects and snails (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

In Saltjöbaden, Warne could not fully experience the water cycle by reusing rainwater. In the second generation of *Naturhus*, not only he added rainwater recovery, but it improved with a system that also uses wastewater recovery used for watering the plants.

For a better comprehension of the *Naturhus*, pictures view is reported in fig. 51.

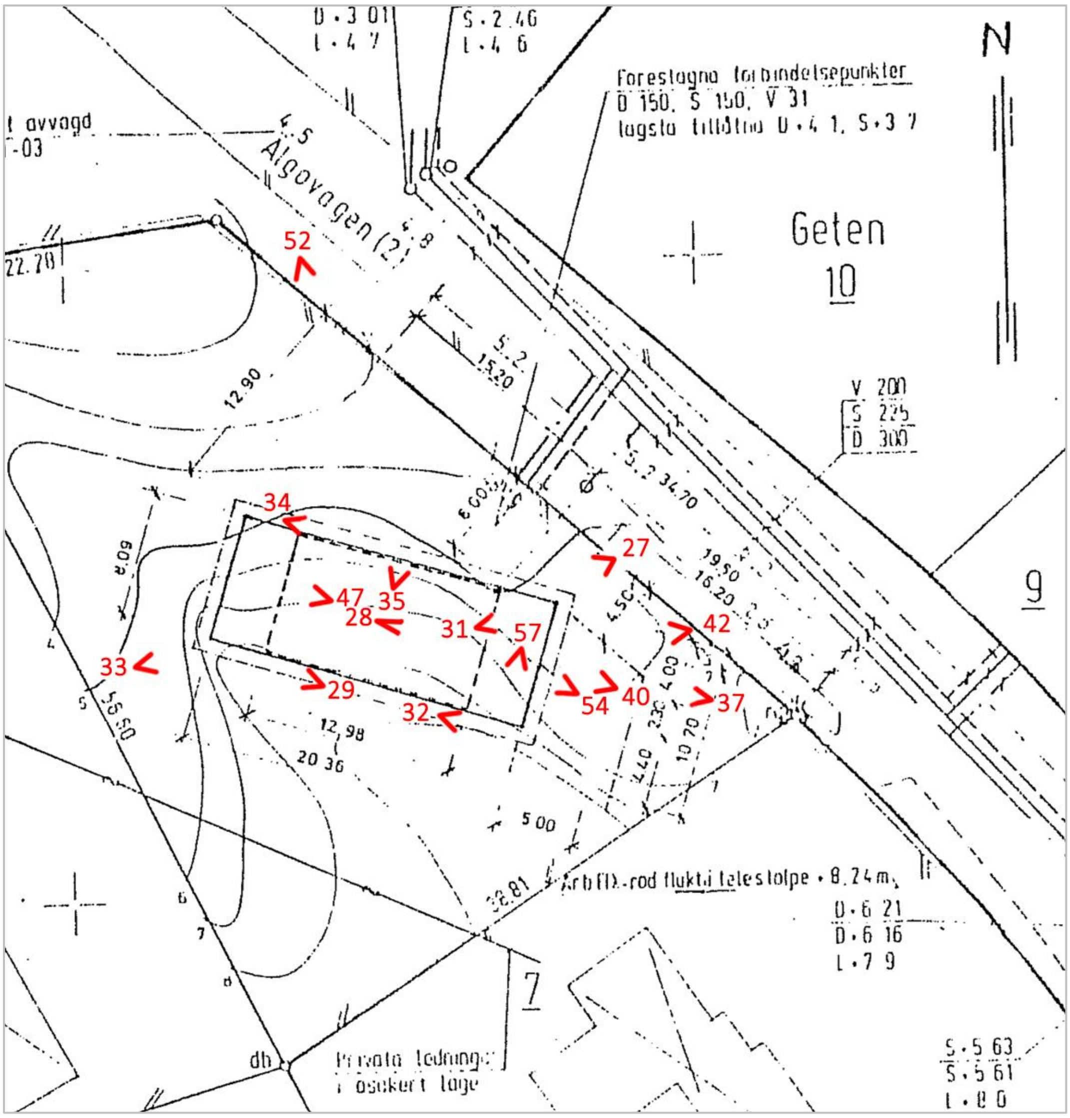


Fig. 51: Picture view, 1:500, Andrea Antolloni

2.4.7 The *Narturhus* today

In 1982, the house was bought by a family, who wanted to disengage themselves from Warne's experiments and be left alone (Fredriksson M., Warne B., 1993). The family was composed by Boel Lamrén and her husband and children, who have been in living there since 1983.

The house is used as a summer residence, while the basement as a storage. Compared to previous photos (see figures 27, 31, 32, 34, 35, 38), nowadays has spontaneous vegetation has grown on the road side and protects the house from vehicle emissions and glances, as shown in figure 52.

Fig. 52: Plant screen on the road side, Andrea Antolloni

Borel Lamrén has reported that the area has undergone changes in the urbanization (Lamrén B., Interview. 21st May 2017).

Traffic emissions are still not a problem, since the *Naturhus* is far from the city and is located in a residential road without traffic congestion, as shown in the neighborhood map (figure 53).

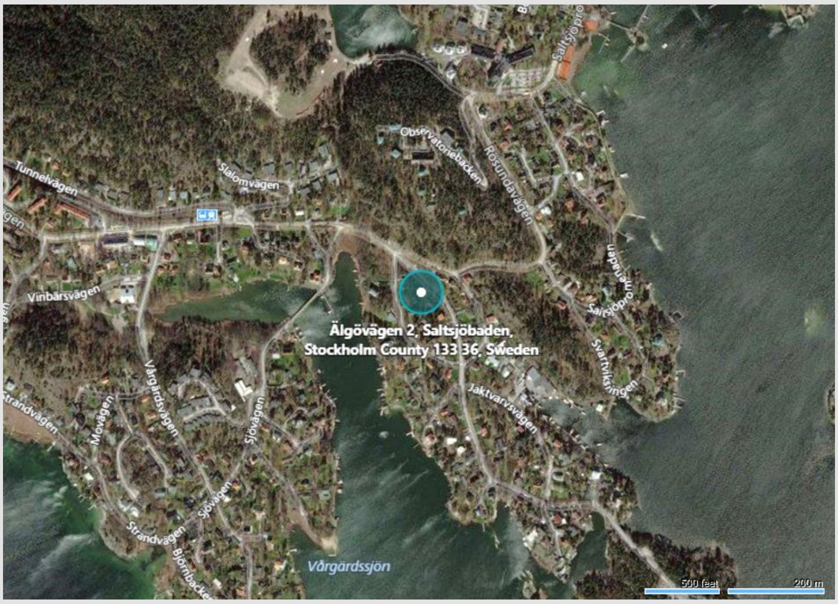


Fig. 53: Neighborhood map (2017) (Google Maps)

The house has undergone several changes over the years. The main one was in 1996 when a floor above the roof terrace was built, as shown in figure 54. The original roof garden (see figures 30, 50), was too hot in summer and the Lamrén family could not grow plants. The high temperature involved a great need of water and attention from the owners, who were no longer able to sustain. Furthermore, they could not control the amount of insects that periodically damaged the plants. The floor was built with wood.


Fig. 54: South-East view of the *Naturhus* (2017), Andrea Antolloni

The grass around the balcony (see figure 31, 32, 33, 34, 35) and the expanded clay have been removed due to unpleasant smells (molds). The owners also preferred to reduce the areas dedicated to cultivation, leaving the passage free.

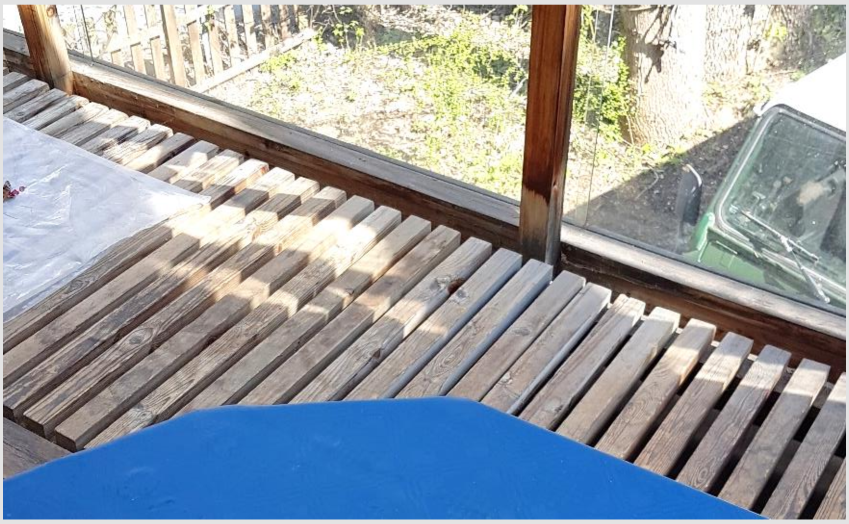


Fig. 55: The balcony that runs around the house (2017), Andrea Antolloni

Plants and flowers (spices and geraniums) grow in pots. A grapevine climbs up the stairs and the wood structure, as shown in figure 56.

Fig. 56: Grapevines in the ground floor (2017), Andrea Antolloni

Over the years, the glulam ring beams were fixed with nails, due to swelling, and became darker, acquiring a reddish color (figure 58). No other structural problem has been reported.

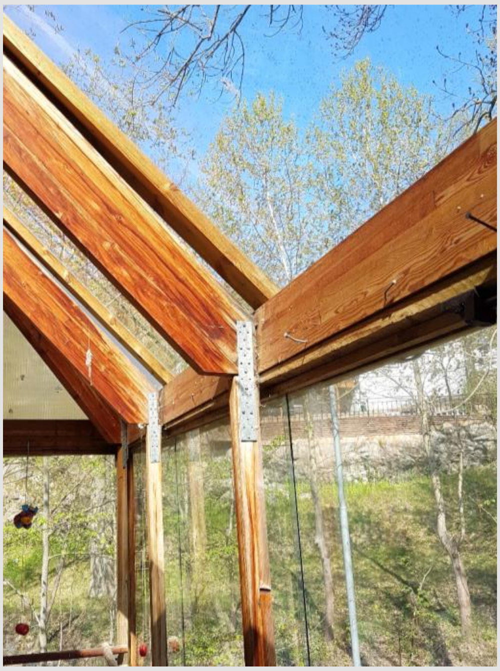



Fig. 57: Glulam ring beam (1980); fig. 58: Glulam ring beam (2017), Andrea Antolloni

The Clivus Multrum system still works, and the family empties it every two years. A small part of the compost obtained is used for plants inside the *Naturhus*, while the rest is discarded or sold to farmers.

Borel Lamrén has confirmed that the buffer space has the same average temperatures reported by Warne in the '80s. However, the addition of a floor involved changes to the project, limiting the amount of heat gained.

Due to the additional floor, the amount of heat gained is reduced in summer as well. In May, Borel Lamrén recorded inside the greenhouse a temperature higher 10 than outside, verified by thermometers placed inside and outside the house (Lamrén B., Interview. 21st May 2017). Windows are still opened manually, as in the past. No broken glass has been reported.

The Combitherm stove works and is used regularly by the family. Firewood is still taken from nearby forests.

2.5 Water: learning from nature

The third cycle in Warne's classification concerns water, a precious element that allows the life for all living beings. In houses and all hydraulic systems, ending in stagnant environments, chlorine is added to disinfect and defeat bacterial diseases (Link R., 1984). Without chlorine, stagnant water can get infected and smell within one or two hours. However, this never happens in nature, for example when water is filtered into the soil. The microorganisms in the soil never let anything rot because they make good use of water in their life cycle. In nature, water flows purely and is made drinkable by air, light, circulation and living organisms (Warne B., *Report from a cultural exchange Sweden-USA,* 1982).

To keep water alive, Warne mimics the cycles of nature without disinfecting anything, except through microorganisms, plants, and animals (as shown in paragraph 4.4.3); the greywater is filtered through rocks and minerals to give water a taste as it happens in mountain streams (Link R., 1984) see figure 59.

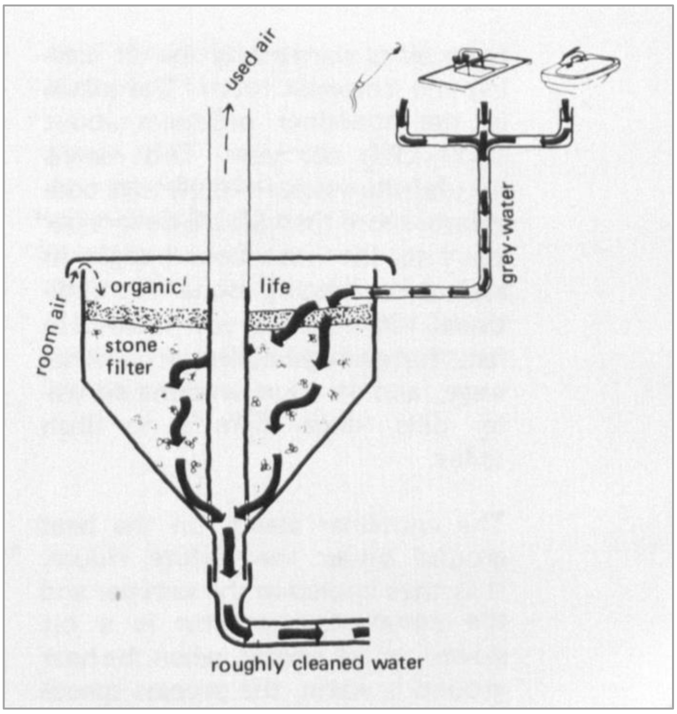


Fig. 59: Clivus Trickle filtration system for greywater

In the “Symbio Housing” approach (paragraph 1.6) everything in the house must be recycled.

The Clivus Trickle filtration system allowed the re-employment of greywater and rainwater, but the system did not re-employ wastewater since in the Saltjöbaden *Naturhus* there were no-flush toilets. The subsequent Eco-cycle system, replacing Clivus Multrum systems by making them simpler, and allowing people to use normal flush toilets (providing improvements in terms of cleaning and maintenance).

At the Stensund Wastewater Aquaculture a large-scale experiment was made for this system. It treated household wastewater using principles of ecological engineering (Björn Guterstam, 1995).

Fig. 60: The Stensund Wastewater Aquaculture; South view

This project provided the missing link in the *Naturhus* concept and the beginning of further experiments in domestic-scale wastewater recycling (Fredriksson M., Warne B., 1993).

2.6 Stensund Wastewater Aquaculture

In the early 1980, NASA and Princeton University asked Warne to collaborate in long-term programs to save endangered species from extinction. One of the projects was a gigantic ring-shaped satellite for 10.000 people, in an environment that imitated Earth. In this satellite, there were separate biotypes like a jungle, savannah, lake, swamp, etc., where the planet's species would have been saved from an ecological disaster. Warne refused the collaboration because he wanted to build projects that live in the real and natural environment, without replicate anything artificially into space. Problems can’t be solved by exporting them, because they will cause further problems.

In Bengt Warne’s view, the same thing applies to wastewater. When it is transported and released into rivers and seas, it causes more problems instead of solving them. The Stensund Wastewater Aquaculture project was a way to transform wastewater and greywater problems into resources.

The project began in 1980, asked by dr. Björn Guterstam, a biologist at Stenstund Folk High School, in Trosa, Sweden. He asked Warne to design a building for a new biological process called aquaculture (Fredriksson M., Warne B., 1993), with the aim to research, develop and demonstrate the possibilities of recycling wastewater, with multidisciplinary groups of researchers and students (Stensund Folk College, Stensund Ecological Centre SEC). Aquaculture is the farming of fish, crustaceans, aquatic plants, algae, and other aquatic organisms, (in water) under controlled conditions. It is a cultivation method that goes back to the traditional Chinese farm, where it was employed as a natural household wastewater treatment. This research was one of the first wastewater projects in Europe to identify the roots of a large-scale environmental deployment and, from there, starting processes of environmental restoration.

Since the Stensund concept, tested on a small scale in 1987, obtained encouraging results, the Swedish government provided financial support to construct it in full scale. Ended in 1989 (Björn Guterstam, 1995), the project captured worldwide attention after the international conference on Ecological Engineering for Wastewater Treatment held at Stensund Folk College in 1991 (Pat R., *Growing Hope in Sweden*).

The Stensund Wastewater Aquaculture is a research building and a water park open all year round to visitors, with a small café (figure 61).

Fig. 61: Stensund Wastewater Aquaculture café

The South-East greenhouse design allows the aquaculture to withstand the extreme temperature and light regimes in winter. In fact, the shape of the greenhouse captures the sun, providing extra heat gain.

A problem in winter was the moisture of heated water in contact with cold room air. The solution designed by Warne was that fresh air is taken through channels underneath the floor as shown in figure 63. The air entering, for example, at 10 ° C and 100% humidity is heated by the ground and flows into the building at 18 ° C with half the RH (Fredriksson M., Warne B., 1993).

In the North-West part there was the laboratory, consisting of a *kontrollum* (control room), *archiv* (archive), *pentry* (storeroom), and bathrooms. In the centre, there were the main systems for wastewater treatment with aquaculture tanks, while upstairs there was an open space for equipment and stock (Archive of ARKDES Museum ARKM).

On the sides, there were *Virbula,* or *virbela* (flowform); water games with a series of waterfalls (Fredriksson M., Warne B., 1993).

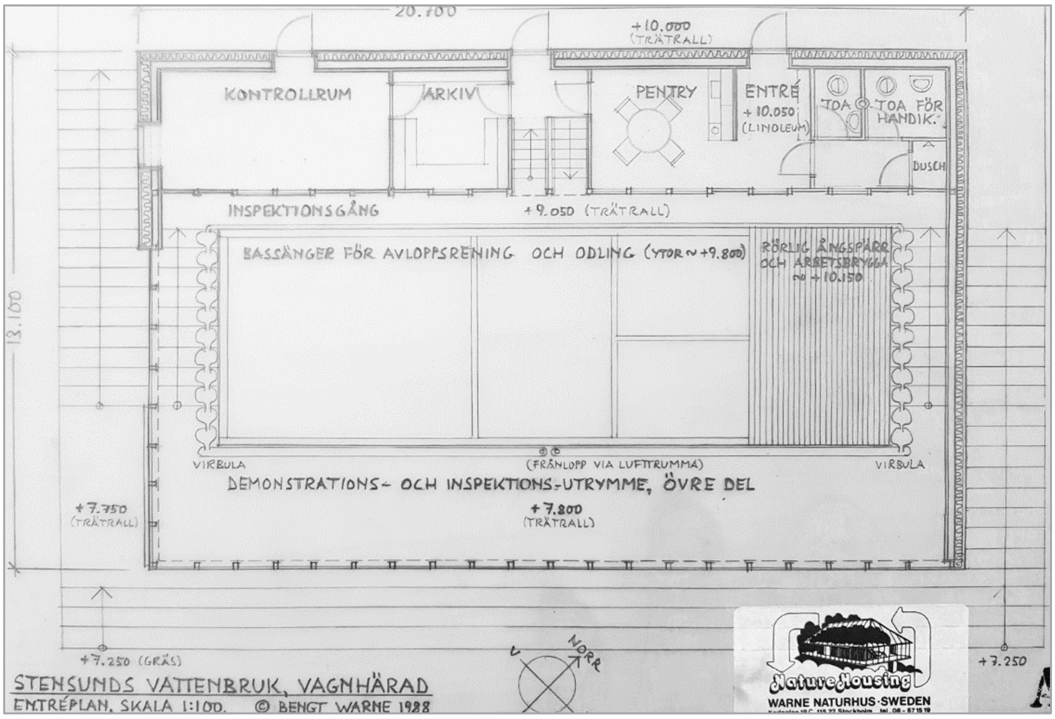


Fig. 62: Ground floor; scale 1:200

Two heat pumps, with a heat power of 9,5 kW each, help the natural ventilation by reclaiming heat from the sewage and from the excess heat in the greenhouse in spring, summer, and autumn. The sophisticated ventilation system combined with an indoor air temperature higher than the water in the tanks helps to avoid condensation problems. To compensate the little sunlight during winter, 35 lamps consume a total of 11,5 kWh per day (for 15h) were provided. The greenhouse was also with shades of aluminum foil for summer use. In addition, greenhouse windows can be opened at the top of the roof.

Thanks to these features, the good insulation, and the triple glazing, the average temperature is about 20 °C for both air and water, all year around (Björn Guterstam, 1995).

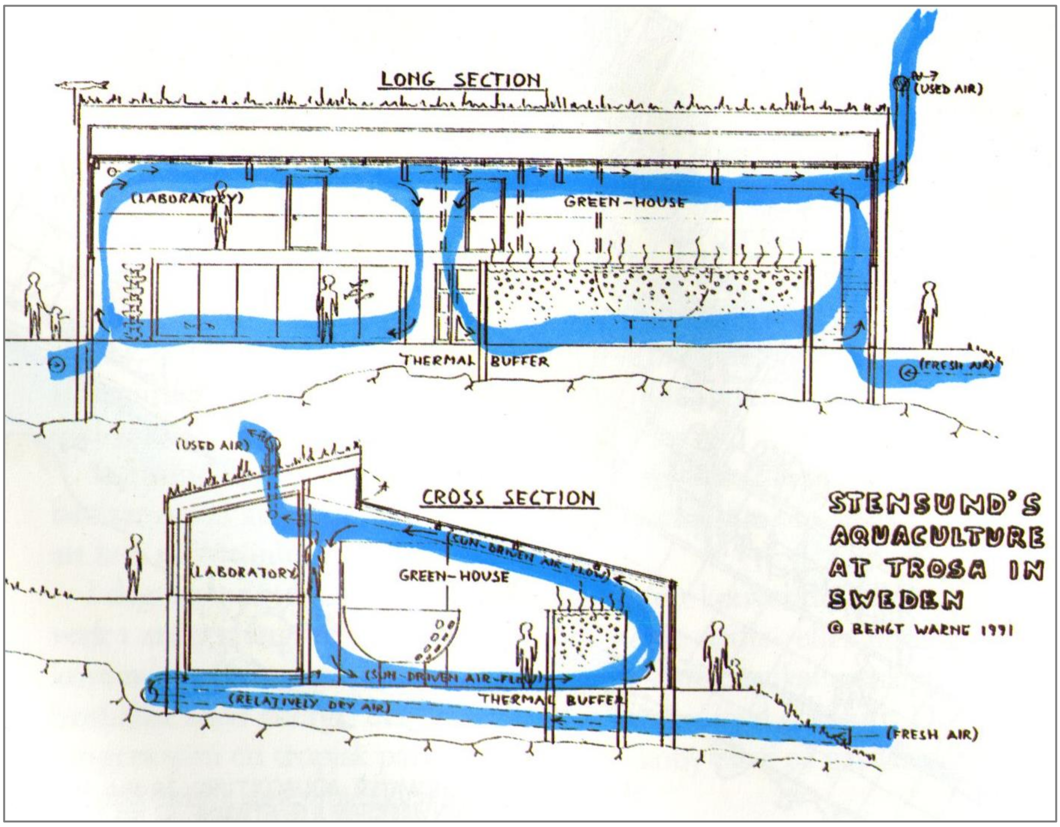


Fig. 63: Ventilation system for Stensund Wastewater Aquaculture, scale 1:200

2.6.1 Wastewater experiments

The aim of the Stensund project was to demonstrate a functioning wastewater aquaculture based on three concepts: Wastewater detoxification, plant nutrient recycling (mostly phosphorus and nitrogen) and heat reuse from wastewater process and greenhouse (Björn Guterstam, 1995).

The project started in 1989 by taking the Stensund Folk College as a model society (representing trends and relationships in the larger society). Energy and material flows were studied in terms of costs and social effects thanks to the collaboration of the college, providing water supplies and sewage system.

The results of the 4-year experiments (1990 to 1993) are available in the Swedish-language report *Stensund Vattenbruk: Ekologisk teknik för avloppsvatten*, also available.

Fig. 64: Vegetables and potted plants growing in Stensund greenhouse

Experiments were conducted in water tanks and under controlled conditions in order to study and manipulate environmental factors. During such processes, plant micronutrients and nutrients like phosphorus, nitrogen, and potassium were obtained from wastewater (Stensund Folk College, *Stensund Ecological Centre SEC*). The average daily amount of wastewater used in the school was 18 m^3 (1990 to 1993), of which 6 m^3 per day were treated in the aquaculture plants, while the remaining were treated in conventional manners. Considering that Stensund college has 100 people living there, the wastewater aquaculture showed a sewage treatment capacity of about 35 people (Björn Guterstam, 1995).

2.6.2 Water detoxification

The wastewater from Stensund is typical household wastewater from the kitchen, laundry, showers, and toilets. After three years of analysis, it turned out that outflow aquaculture water almost meets bathing water standards (in 1992 the limit per 100 ml was 1.000 coliform bacteria and 100 E-coli) as shown in figure 65. Furthermore, organic pollutants had been reduced by more than 95 per cent.

As metals can't be dissolved, they are separated from the wastewater. Results showed that metal precipitation stage, in the anaerobic tank (Paragraph 2.6.2), reduced the overall metal content by an average 40%.

In the first year, copper, the most common metal in household wastewater due to the water pipes, was reduced by 46% in anaerobic tank and by 97% through aquaculture. Much of this copper was found in aquatic plants and an insignificant amount in fishes that used them as feed, while there was a little in tomatoes. Measurements after four years showed improved results in the anaerobic tank, reaching 80% removal of copper and avoiding additional accumulation in fish.

As for the other metals, most were at recommended or insignificant levels.

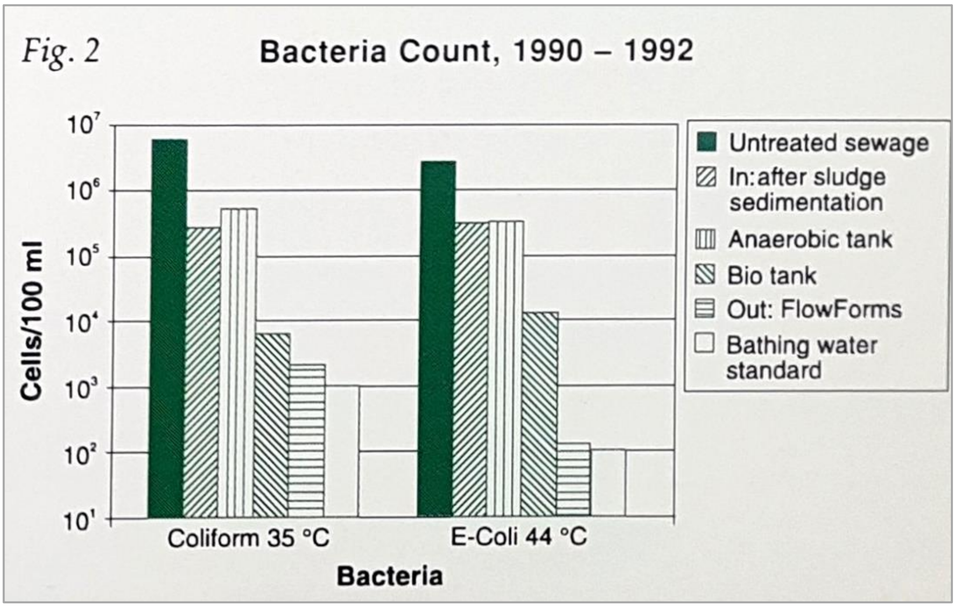


Fig. 65: Pathogenic bacteria and their decrease in Aquaculture processes

2.6.3 Plant nutrient recycling

Through plant cultivation, many kilograms of nutrients (used as fertilizer) can be recovered from the sewage each year. The nutrients are significant resources in a farm; they are mostly composed of nitrogen and phosphorus. During the 4-year period, the average nutrient reduction (inflow-outflow) was 60% for nitrogen and 72% for phosphorus, as shown in figure 66, and about 10% each were taken up by aquaculture as fertilizer (Stensund Folk College, *Stensund Ecological Centre SEC*).

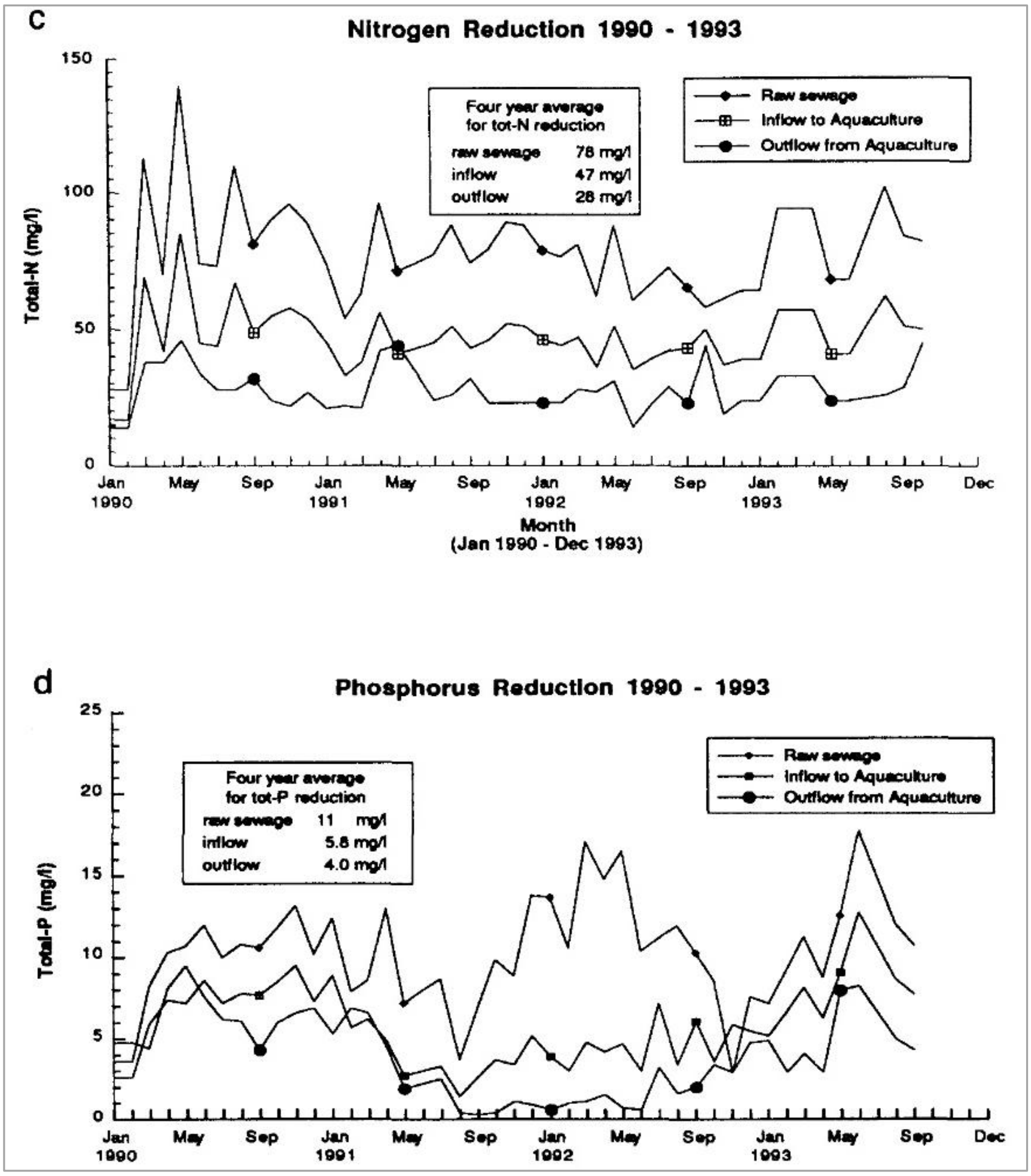


Fig. 66: The average nutrient reduction at Stensund Wastewater Aquaculture

Tomato fruits exhibited no detectable level of metal (table 1). Wastewater was tested for the plant fertilizer value (metals as micronutrients) by scanning the total nutrient content (table 2). Only Na and Cl had higher levels than recommended, due to a newly installed ion-exchanger. Most metals were at recommended or at negligible levels. The high PH-levels (7.5) in the aquaculture reduced the nutrient uptake by plants.

Metal contents in plants grown in the aquaculture (sampled 13 Nov. 1990 and measured in mg/kg dry weight, Hallin et al., 1990)

Element	*Eichhornia*	*Pistia*	*Lemna*	*Lycopersicon* (tomato)
% dry weight	4.8	5.0	1.7	6.8
Pb	< 0.6	< 0.8	9.10	< 0.4
Cd	< 0.06	0.2	< 0.2	< 0.04
Co	< 0.6	1.5	1.8	< 0.3
Cu	27	33	266	1.8
Cr	< 0.4	0.5	3.7	< 0.3
Hg	0.05	0.07	0.13	< 0.006
Ni	0.7	0.5	1.8	< 0.3
Zn	67	63	162	7.2

Tab. 1: Metal contents in plants

Micronutrients recommended for tomatoes and the measured values in the hydroponic channels (14 April 1993)

Aquaculture	Units	Hydroponics	Recommended for tomatoes
pH		7.50	5.5–6.0
Conductivity	mS/cm	2.25	2.50
Nitrate (NO_3-N)	mg/l	16	147
Ammonia (NH_4-N)	mg/l	17	7
P	mg/l	7	40
K	mg/l	30	250
Mg	mg/l	43	45
S	mg/l	18	35
Ca	mg/l	139	140
Na	mg/l	260	30–50
Cl	mg/l	> 300	30–50
Mn	mg/l	0.01	0.80
B	mg/l	0.37	0.30
Cu	mg/l	0.02	0.13
Fe	mg/l	0.04	0.20
Zn	mg/l	0.02	0.20
Mo	mg/l	0.003	0.04
Al	mg/l	0.02	< 2
Ni	mg/l	0.009	–

Tab. 2: Micronutrients recommended for tomatoes

2.6.4 Heat recycling

Theoretical energy flows showed that 19% of the aquaculture (72.000 kWh/y, ref. figure 67) was recovered for heating and hot water demands, while the excess heat was exported to an adjacent building. On an annual basis, the heat reclaimed from the greenhouse and the sewage stream amounted to 252.000 kWh. This corresponded to 25% of the school annual heat demand (heating and hot water). The heat reuse was a considerable effort; i.e. 120.000 kWh/y heat was pumped from the two heat pumps installed in the aquaculture (Björn Guterstam, 1995).
During the first three winters, the aquaculture's heat needs were largely met by sewage water heat, artificial lamps waste heat and solar gain (Stensund Folk College, *Stensund Ecological Centre SEC*).

The Stensund Aquaculture heat resource and its use

Energy source	kWh/yr
Solar radiation in southern Sweden, shining on 180 m^2	180000
Wastewater, 6000 m^3, 20°C and 10°C temperature reduction (sewage from 100 pe)	72000
Total heat resource	252000
Utilized heat resource	48000

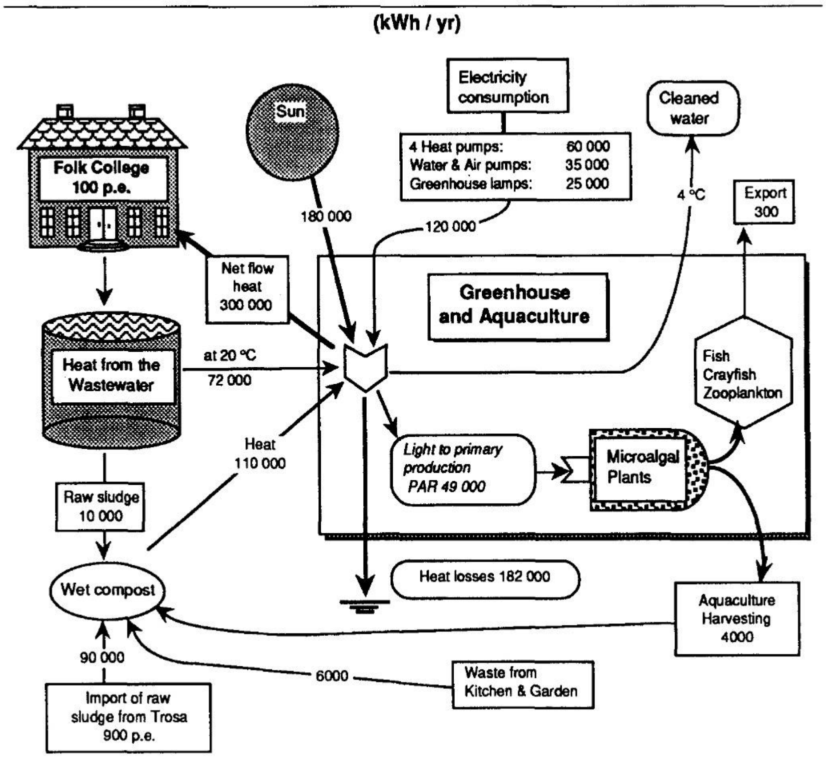


Fig. 67: Theoretical Energy Flows of Stensund Wastewater Aquaculture (1990-1993)

2.6.5 Wastewater Aquaculture System

Before entering the aquaculture, wastewater from the school was pre-treated in a series of tanks. This process, called primary settling, separated the floating fats and feces by a mechanical treatment.

After primary settling, the wastewater stream flowed through nine treatment tanks as shown in figure 68, having a total volume of 195 m^3.

The first two wastewater pumps brought the wastewater to a 28 m^3 storage tank (0). From this tank, the water was pumped further into the aquaculture to adjust the flow of the daily rhythm of aquaculture organisms.

An anaerobic tank of 20 m^3 (1) took care of degradation of organic compounds and precipitation of metal, avoiding bioaccumulation of metals and persistent chemical substances. The precipitated metals were collected from the bottom of the tank.

To complete the microbiological detoxification (and mineralization, paragraph 2.5), the wastewater stream passed into a biofilter of rocks and pebbles (2) in a vertical flow. In this aerobic tank, the water volume was 9 m^3 with a depth from 2 to 3 metres.

Another 18 m^3 of wastewater was treated in a glazed tank containing the first biota (3) (Björn Guterstam, 1995). The biota is a mixture of organisms, ranging from temperate to tropical climates, taken from aquatic environments rich in nutrients (Stensund Folk College, *Stensund Ecological Centre SEC*). In this case, there were Phytoplankton, together with eutrophic green algae (genera *Ankistrodesmus*, *Scenedesmus,* and *Chlorella*), that allowed the first step for primary production in the aquaculture food chain (3). Both artificial light (nine 400 W lamps on a 9 m^2 surface area) and sunlight was exposed to water.

The second biota pool (4) contained zooplankton *Daphnia*, *Ceriodaphnia*, *Copepoda*, *Rotifera*, *Ostracoda,* and *Protozoa*. In this 40 m^3 tank, the zooplankton consumed organic material from the preceding steps.

In a 27 m^3 pool there was a fish polyculture (5A), inspired by Chinese aquaculture principles, containing different temperate and tropical fishes like *tilapia, paco, algae grazer* and various species of carp.

Two channels (5B) and the “Fish Globe” tank of 9 m^3 (5C) with tilapia and goldfish preceded the Hydroponic of vegetables and other plants (6) like tomatoes and willow, in a 7 m^2 of total surface (as shown in figure 68). A water staircase flow-form (7) was designed to aerate the water as it left the greenhouse to reach the outdoor crayfish pond (8). In this last phase, outflow (9) to the noble crayfish with willow trees finalized water purification before entering the Baltic Sea.

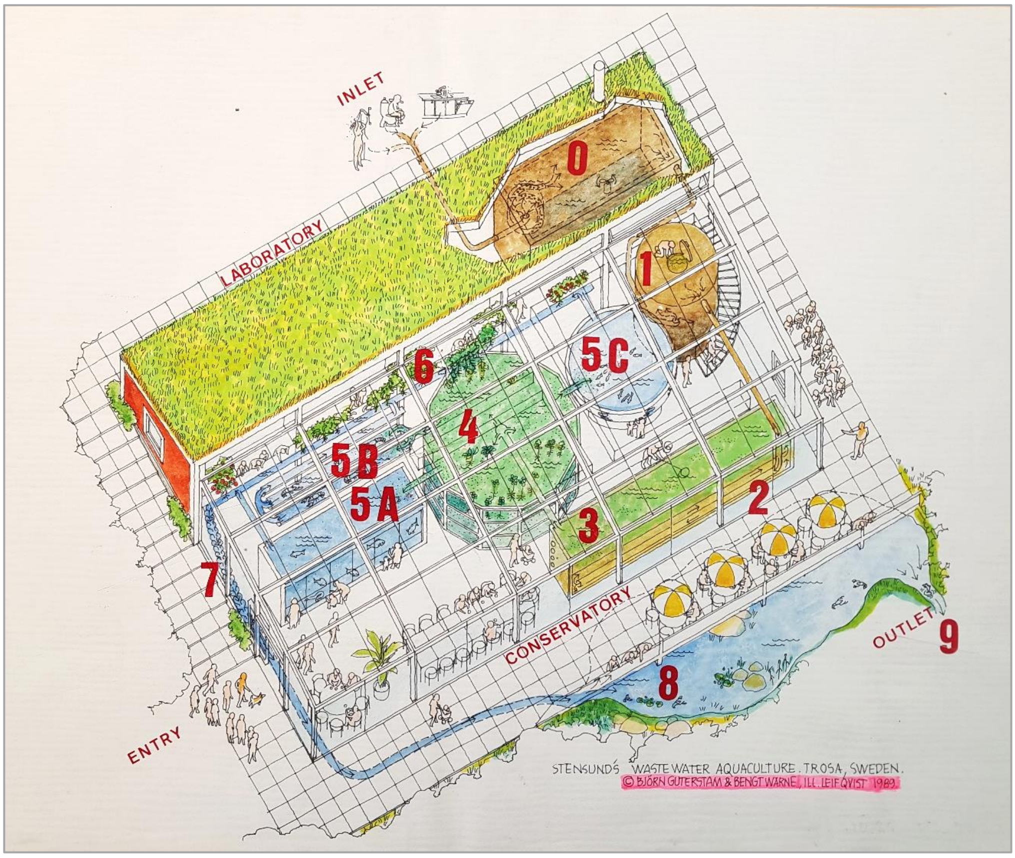


Fig. 68: Tanks and flows in Stensund Aquaculture

Due to the costs of redesigning the greenhouse (2002), it has been decided to stop the operation and the project was officially closed in 2003 (Bohemen H. V., 2005). After the results obtained by the Wastewater Aquaculture system, the first in Europe at that time, Warne started to develop an aquaculture in a smaller scale, including household scale. The aim was to allow all sewage and waste to be disposed of in the home, providing in return heat, biogas, electricity, fresh air, and food (Fredriksson M., Warne B., 1993).

This experiment marked the beginning of the development of two house-scale systems: the black and grey wastewater recovery system (Sacilotto house in Ingarö), and the Eco-cycle system (Solvarm house in Sikhall).

2.6.6 John Todd's Living Machine

The Stensund Wastewater Aquaculture was the first of its kind in Europe (Björn Guterstam, 1995), evolved from the Solar Aquatics greenhouse concept developed in the USA (also called Living Machine concept) by John Todd (Todd J., 1988).

The development started at the New Alchemy Institute, in the early 1970s. The institute's goal was developing and demonstrating environmental technologies involving energy systems, aquaculture, and sustainable architecture. John Todd tried many configurations of tanks, starting with a single cylindrical tank (3.760 l capacity) made of translucent material (see figure 69).

After fifteen years of tank combinations, The Living Machine evolved to a series (Kangas P. C., 2004). In 1988, Todd founded John Todd Ecological Design (JTED) to market his projects and vision (http://www.toddecological.com/).

The Living Machine system was built for single commercial buildings, with a few people involved. The Stensund Wastewater Aquaculture was the further step, created a larger scale ecosystem and treated a larger volume of sewage than Living Machine (figure 70). John Todd combined his knowledge with Guterstam in wastewater research, participating in the experiments.

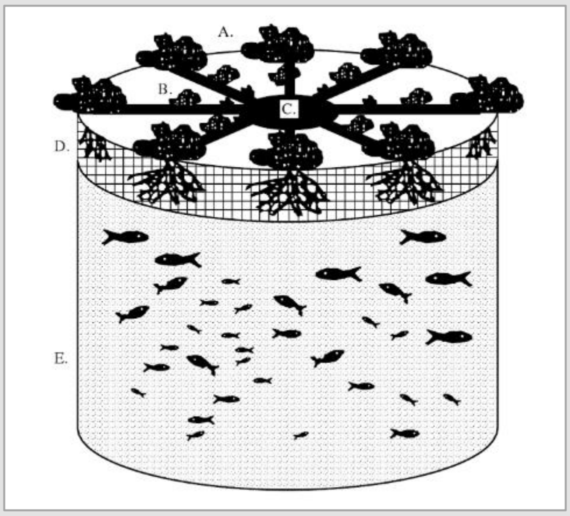


Fig. 69: Tank used in the early work of John Todd. (A) Hydroponic vegetables. (B) Styrofoam filtration for plants. (C) Core opening for fish feeding. (D) Mesh cage to prevent fish from eating plants roots. (E) Fish.

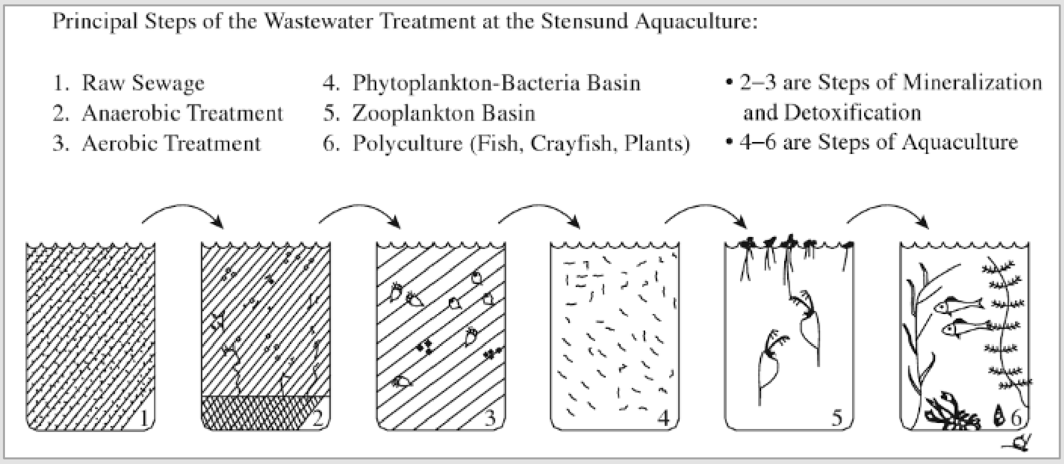


Fig. 70: Tanks configuration at the Stensund WastewaterAquaculture, by Guterstam B., Todd J. and B. (1990)

The Stensund Wastewater Aquaculture provided useful data for Todd's Living Machine (Kangas P. C., 2004). In 1993, Todd obtained the US patent “Ecological fluidized bed method for the treatment of polluted water” (Todd J., 1993) and several projects were built around the world, such as the South Burlington Eco-Machine (Kangas P. C., 2004) (figure 71) in Vermont (1995), the National Audubon Society’s Corkscrew Swamp Eco-Machine (1994) in Florida, and the Tyson Industrial Waste Lagoon Upgrade (2001) in Maryland. JTED is still active today, with projects of wastewater treatment built all over the world (http://www.toddecological.com/).

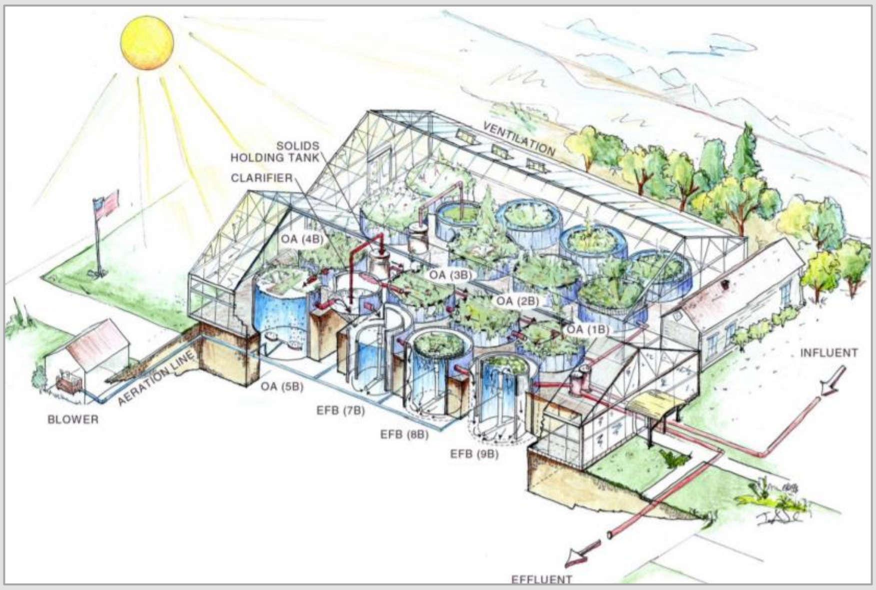


Fig. 71: The South Burlington Eco-Machine

2.7 Energy: from bonfires to the Sun

The fourth element examined in Warne's philosophy was fire, physically represented through the Combitherm stove (paragraph 2.4.4). Fire element, in Warne's view, is not only represented by the stove since it includes all energy such as heat, power, and light (paragraph 1.5) (Warne B., Warne K., 1980).

In prehistoric times, men gathered around bonfires. Bengt Warne wanted an open fireplace in the living room to experience the same feelings as ancient men (Link R., 1984), even knowing that a wood burning stove was not an ecological choice. In fact, the Combitherm stove produced carbon dioxide and powders, damaging both human health and the environment.

This bring to light one of the greatest contradictions in Symbio Housing concept. In 1982, the most economical way to heat water and buildings was the combustion of wood and gas. After the first generation of *Naturhus*, Warne began thinking about ways to make his ecological buildings, from "almost", to totally self-sufficient, avoiding damage to the natural environment. (Warne B., *Symbio Housing Symposiums*, 1982).

Warne's aim was to use solar energy as a source of heat and electricity. He did several experiments such as the Nature House in six stories, built with Jo Glässel, in Stuttgart, Germany, 1992. Here, Warne provided apartments with Clivus Multrum and reserved spaces for solar cells that can make the project self-sufficient on electricity. Despite the various experiments, these never happened due to the efficiency limits and costs of technology that did not allow access to a cost-effective use of solar energy, as it was a non-efficient technology (Fredriksson M., Warne B., 1993).

"It is bad that the solar cells and batteries are so expensive, but when they will be cheap enough they will have to produce so little energy for a household using Symbio technology that the installation will be simple and very little sunshine needed" Warne claimed at the Symbio Housing symposium in Stockholm (Warne B., *Symbio Housing Symposiums*, 1982). For these reasons, in the *Naturhus* built by

Warne during his life, solar energy was used in other ways.

In his book *På akacians villkor*, Warne recalls the problems of Swedish sun, because it radiates light for less than 8 hours in winter. In fact, in January there is an average of four daylight hours in Skåne (Southern Sweden), while none in the Arctic Circle (damaging tropical and Mediterranean plants).

According to Warne, dealing with solar energy is as important as you go up North. The rarer sunlight becomes, the more important is to take care of house heating.

Warne's approach to sunlight problems (in Sweden) was inspired by the past. He imitated the traditional South-facing position in the Greek island of Thera. Here, people dug caves, ensuring South-facing openings and using the stone mass to balance and store heat. He also remarked the importance of shades, especially in Sweden. In fact, if they are not well designed, they could contribute to cool the house, because they are three (or more as you go up North) times longer than house height itself at spring and autumn equinoxes.

According to Warne, the house of the future will be guided by these strategies and totally powered by the Sun, collecting radiation by greenhouse, and using the ground as heat storage (see paragraph 2.4) (Fredriksson M., Warne B., 1993).

In recent years, it has been confirmed that Warne's thoughts for a low-energy building can be materialized at affordable prices, also thanks to the high efficiency of solar panels. Both the owners of the *Naturhus* in Ingarö and in Sikhall wish to develop this concept and to add solar panels. However, only solar collectors for water heating has been implemented by Anders Solvarm for the time being. The use of photovoltaic panels could contribute to plant growth in winter (Solvarm A., Interview. 3rd June 2017).

The Ingarö *Naturhus* will be described in the following paragraph.

2.8 Ingarö *Naturhus*

The Sacilotto family moved to Stockholm in 2003, but the idea of living in a Nature House was born before. Charles Sacilotto read an article in *Dagens Nyheter*, a local newspaper, about a giant glass house in Dalsland designed by architect Bengt Warne. Inspired by the idea of living in harmony with nature, he also read the book *På akacians villkor* and he got in contact with Bengt Warne (Koch E., 2007), who came regularly and helped him guiding the whole project (Correspondence with Charles Sacilotto, 5th May 2017).

At first the Sacilottos looked for an empty lot to build their new *Naturhus,* but it was hard to find a plot for the house at a cheap price around Stockholm neighborhoods (https://www.youtube.com/watch?v=30ghnDOFbNQ). At that time, they thought that there were many benefits to starting from a finished home. For example, they could settle in and save costs during the construction period (Lefvert A., 2007). In 2004, Charles and Birgitta Sacilotto bought an old vacation home, a log house, in Ingarö, about 27 kilometres west of Stockholm (Google Maps). The greenhouse was built in three weeks while the family lived there (Spetz L., 2007), with a total investment of 80.000 euros (https://www.youtube.com/watch?v=30ghnDOFbNQ). The greenhouse was built by a company specializing in the construction of greenhouses, *UBA Glas & Fasad* (Correspondence with Charles Sacilotto, 8th November 2017).

After that, the family house became the third *Naturhus* in Sweden following Bengt Warne’s principle that everything must be recycled. Such project was the only starting from an existing house, which it had to be rebuilt and renovated as well. Most of the restoration work was made by Charles himself, moving walls and building about 20 square metres (Koch E., *Ett jordnära hem*, 2007).

The building work continued after Warne's death, realizing extensions on the first floor, eliminating the roof and replacing it with a terrace (Correspondence with Charles Sacilotto, 5th May 2017). The space obtained from roof removal is used for sunbathing, reading and playing (with children).

In 2007, the refurbishment was complete except finishes, such as painting some walls, wallpaper, and laying floors. (Koch E., *Ett jordnära hem*, 2007).

It is interesting to know that Charles Sacilotto has a passion for engineering and he developed himself water and wastewater recycling systems (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Fig. 72: Ingarö *Naturhus*, Andrea Antolloni

Warne's role involved designing the greenhouse, refurbishment of the existing building parts, plan upgrading, and sharing his concept of Symbio Housing (Correspondence with Charles Sacilotto, 5th May 2017).

Ingarö *Naturhus* is located on a sloping plot, on the edge of a villa area. Tall trees protect it from glances (Koch E., Ett jordnära hem, 2007).

The dimensions of this *Naturhus* are very similar to those in the first *Naturhus*. The 120-sqm wooden house is enclosed by a prefabricated 200-sqm greenhouse (http://www.naturhusingaro.se/). Such measurements are relevant because they fall short the *Hälften till naturen* concept by Warne, in which nature has to get half the space, probably for budget reasons.

Unlike the *Naturhus* in Saltjöbaden, the greenhouse and wooden house are considered as two distinct elements that don't touch each other. In this 80-sqm space, flowers, vegetables, and climbing plants are grown (https://www.youtube.com/watch?v=30ghnDOFbNQ) from April to October (Correspondence with Charles Sacilotto, 18th October 2017).

A spiral metal staircase leads up to the roof of the house (Koch E., Ett jordnära hem, 2007); temperature rises depending as you walk up (demonstration in the paragraph X) (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Fig. 73: Ingarö *Naturhus,* Andrea Antolloni

There is no definitive plan of the house. The project underwent various changes on the original design. It is important to recall that it was pre-existent, and bound to a previous arrangement (Correspondence with Charles Sacilotto, 5th May 2017). Most of living areas faces South, despite the *kôk* (kitchen) faces North (see figure

74). The West floor floor is more than 2 metre higher than the East one. They are connected by a ramp with a 22% slope (Archive of ARKDES Museum ARKM).

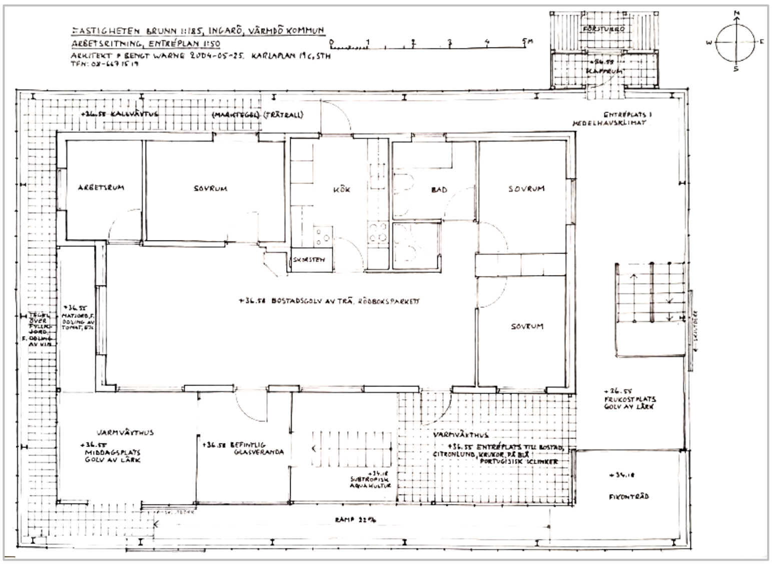


Fig. 74: Ground floor; scale 1:200

2.8.1 Microclimate

The greenhouse increases indoor temperature and shelters the house from rain, snow, and wind.

During summer, the house accumulates heat. Excess heat is expelled through windows at the top of the greenhouse roof. It is important to recall that, in the first *Naturhus,* technology didn't allow to have automatic openings controlled by weather stations yet; here there are automatic windows at the top of the greenhouse that open and close according to temperature and weather, as shown in figure 75.

Inside the house, warm air rises and there are various temperature layers depending on the level. Since the roof of the existing house has been removed, the new terrace space is warmer than the ground level of the core house (see paragraph 3.4) (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Fig. 75: Automatic windows above the greenhouse roof, Andrea Antolloni

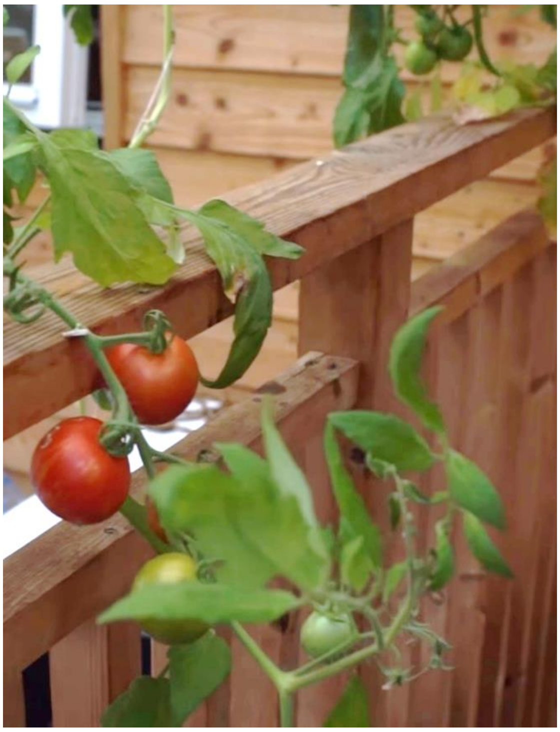
The roof terrace is used especially in spring and autumn, while in summer it is more uncomfortable due to the high temperatures it can reach. In the roof, on evolution of the previous *Naturhus*, there are sliding solar screens made of textiles that cling to the greenhouse structure, as shown in figure 76.

In winter, the average temperature difference between indoor and outdoor space is more difficult to undergo changes because there are few hours of light, less than 8 hours of daylight (Correspondence with Charles Sacilotto, 31st May 2017).

The microclimate in the greenhouse depends heavily on Sun and cloud coverage: if there is no Sun, the internal temperature does not differ much from the outside of the greenhouse. However, the house warms up very quickly as the Sun rises and even an hour of light makes a lot of difference for energy consumption.

The greenhouse allows to shorten the winter season (in terms of heat gained), and extend the summer one, from the end of March to the middle of October, and it allows plants to grow. Inside the greenhouse, plants can survive from middle March to end October (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Fig. 76: Sun protections in the greenhouse



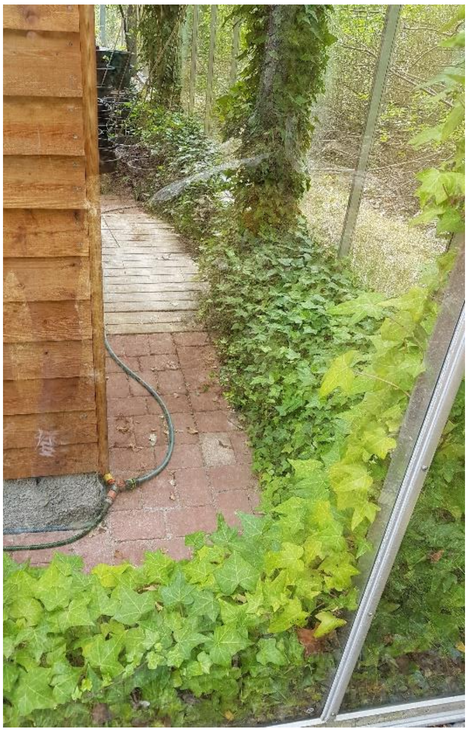


Fig. 77: Tomato and ivy (fig. 78) inside the greenhouse, Andrea Antolloni

In the *Naturhus* are cultivated several types of plants such as tomatoes, cucumbers, broccoli, melons, potatoes, grapevines, etc. (http://www.naturhusingaro.se/).

On the roof terrace are grown in pots several plants, including aromatic spices and flowers. To survive the winter weather, plants need the protection of the greenhouse and artificial light when natural light hours are less than 8 (https://www.youtube.com/watch?v=30ghnDOFbNQ).

In the partially buried basement, there is a six-cubic metres plant bed that not only gives the family fresh vegetables and spices, but also cleans the household wastewater (see paragraph 2.8.2) (Spetz L., *Boende i växthus*, 2007).

The small size of the buffer space, about one metre wide on 3 sides and about 3 by 6 metres in a corner, doesn't allow to grow a large amount of plants. Charles Sacilotto explained that they haven't any extensive production, most of the fruit and vegetables are consumed by the family.

In a year, the family can grow (with a very variable yield over the years) 10 kg cucumber, 5 kg tomatoes, 5 kg carrots, 5 kg potatoes, and 20 kg grapes. Moreover, aromatic plants produce spices, which are used daily in the family kitchen. Organic waste is collected in a container and reused as fertilizer (Correspondence with Charles Sacilotto, 31st May 2017). In summer, they obtain 30% self-sufficiency in terms of fruit and vegetables (Correspondence with Charles Sacilotto, 23rd January 2017).

Fig. 79: The grapevines in the buffer space

The greenhouse wasn't the only innovative feature of the Sacilotto house. It was also completely independent from city aqueduct and sewer since the family has their own well and a wastewater recovery system developed by Charles Sacilotto (Correspondence with Charles Sacilotto, 27th October 2017). There were a urine-separating toilet and a system composed by centrifuges, tanks, plant beds, and garden ponds to filter the water. In such system, energy from the waste is reclaimed, and nutrition is returned to nature (for plants outside and inside the greenhouse). However, the *Naturhus* has been connected to the municipal aqueduct and sewer in September 2015 (http://www.naturhusingaro.se/).

The connections were very expensive and cost about 300,000 SEK at that time (30.500,00 €, 2015) because of the hilly area, and they wanted to avoid these costs with their system. However, Charles Sacilotto was forced to comply, because it was the initial condition in the permission to build.

In recent years, Charles Sacilotto confirmed that the costs have risen compared to the previous system, which now costs at least 3,000 SEK per year (305.00€, 2017) (Correspondence with Charles Sacilotto, 8th November 2017).

2.8.2 Black and grey wastewater recovery system

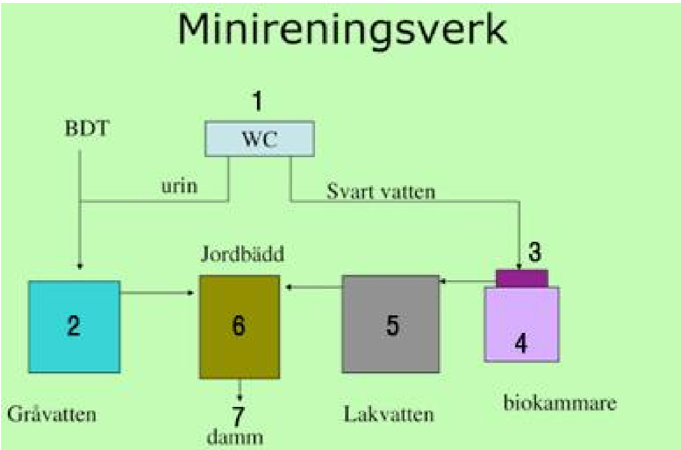


Fig. 80: The black and grey wastewater recovery system of Ingarö *Naturhus*

Unlike the first *Naturhus*, the Clivus Multrum system was replaced by a new installation developed by Charles Sacilotto (Correspondence with Charles Sacilotto, 27th October 2017). The system was placed in the basement and collected greywater and wastewater from toilets (1) in the upper floors. The *Naturhus* had a separation-type toilet, as shown in figure 81. Here, the urine compartment worked with a small hole that acted as a filter and allowed only the passage of liquids. The toilet also had a water saving system, which allows to separate the water flow for urine or feces duct (https://www.youtube.com/watch?v=30ghnDOFbNQ).

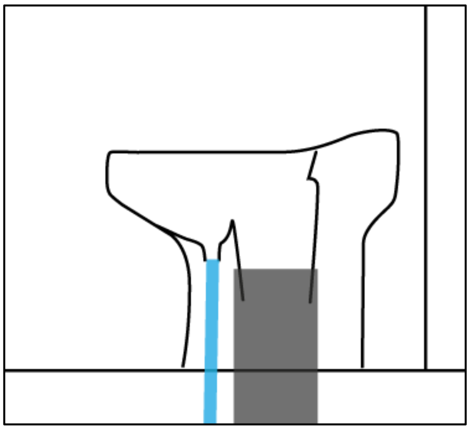


Fig. 81: Separation-type toilet

Black water and urine follow two different cycles. Two tanks, one cubic metre each (2) (Correspondence with Charles Sacilotto, 21st October 2017), are connected together and stored urine (from the toilet) and greywater from shower, dishwasher, etc., for subsequent treatments.

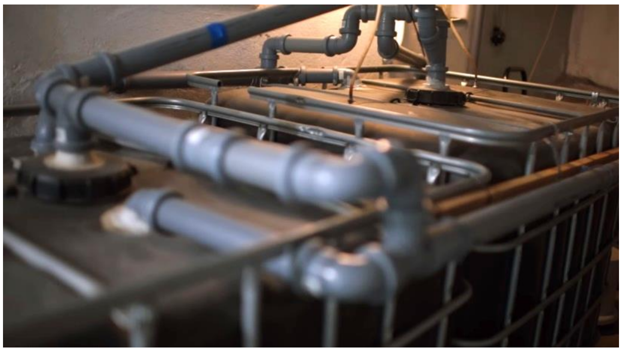


Fig. 82: Tanks for storing greywater (*Gråvatten*) and urine

Black water descended into a separator (3) that used centrifugal force to separate the toilet discharge water from solid substances. The high-speed rotation separated the liquid to the exterior, while the solids fell in a collector tank at the bottom (4) (https://www.youtube.com/watch?v=30ghnDOFbNQ).

Fig. 83: Separator (*Biokammare*) of the black water

The solids could to be used in the ground, extracted from the composting chamber every 6 months. This compost was used as fertilizer to grow non-edible plants.
The organic waste from the kitchen and plants was used to fertilize edible plants inside the greenhouse (https://www.youtube.com/watch?v=30ghnDOFbNQ).
The liquid collected from (3) was stored in a further 1 cubic metre's tank (5), as shown in figure 84 (Correspondence with Charles Sacilotto, 21st October 2017).

Fig. 84: Tank for storing blackwater (*Lakvatten*)

In both tanks, greywater (2) and blackwater (3), the use of any chemical agent was fully avoided (https://www.youtube.com/watch?v=30ghnDOFbNQ). In fact, an anaerobic purification process (Spetz L., 2007) take place so that harmful bacteria would die after a few days (https://www.youtube.com/watch?v=30ghnDOFbNQ).
Then, from the gray water and urine tanks (2), and from the black water tanks (5), the liquids flew into a natural purification system based on soil, rocks, and plants: a *jordbädd* (plant bed) (6).

Fig. 85: *Jordbädd* in the basement of the house*;* external view, Andrea Antolloni

The system was very simple: every time water came to the above-mentioned tanks; the same quantity of water flew in the plant bed in the basement by gravity (https://www.youtube.com/watch?v=30ghnDOFbNQ). Water used for services was around 60 square metres in summer 2017, while rainwater measurements have never been performed (Correspondence with Charles Sacilotto, 23rd January 2017). All the drainage tubes were 30 centimetres in diameter to ensure that the water was slowly purified in plant bed soil. The plant bed (figure 86) was about 6 cubic metres in volume (Correspondence with Charles Sacilotto, 21st October 2017) and about one metre deep. Here, are cultivated plants and vegetables such as cucumbers, ivy, mint, basil, parsley, strawberries, squashes, tomatoes, and broccoli. Charles Sacilotto reported that there weren't bad smells inside the room.

Fig. 86: The *Naturhus Jordbädd,* Andrea Antolloni

Excess compost that was not used as plant fertilizer was ejected into a small pond (7), figure 88. Such pond, located about 15 metres away from the house, was checked by Eurofins about once a year, analyzing the bacterial level of the water (figure 87). There was significant level of bacteria, especially Coliform bacteria, but always lower than the law and with no danger for humans (https://www.youtube.com/watch?v=30ghnDOFbNQ). In 2011, E-coli was < 1 CFU per 100 ml (9 per 100 ml for drinking quality) and Coliform bacteria was > 2.400 CFU per 100 ml. According to the Swedish standards in the household the limit is <500 for drinking, <1.000 for swimming, and <5.000 for fishing (EN ISO 6222, 1999) (Correspondence with Charles Sacilotto, 23rd January 2017) (see also paragraph 2.6.2 page 80).

Analysrapport

eurofins

AquaGruppen
Box 45
281 21 Hässleholm

Rapport utfärdad av
ackrediterat laboratorium

Report issued by
Accredited Laboratory

Journalnr	VDJ004854-11		Sida 1 (1)
Kundnr	8473326-1825649		
Provtyp	Brunnsvatten		
Ankomsttemperatur	6,7 °C	Provtagningsdatum	2011-04-15
		Provet ankom	2011-04-15
		Analyserna påbörjades	2011-04-15
		Analysrapport klar	2011-04-27
Provets märkning	Sacilotto		

Analysnamn	Resultat	Enhet	Mäto.	Metod/ref	Ort
Odlingsbara mikroorg. 22°C, 3 dygn	>5000	cfu/ml		SS- EN ISO 6222:1999	J
Antal koliforma bakterier 35°C	>2400	/100ml		Colilert	J
Antal E.coli	<1	/100ml		Colilert	J

Mikrobiologisk bedömning:
Otjänligt
pga att antalet koliforma bakterier är mycket högt (hälsomässig anmärkning).
Koliforma bakterier finns i tarmkanalen hos djur och människor men även som omgivningsbakterie i jord och förorenat vatten.
Dessutom tjänligt med anmärkning:
pga att odlingsbara mikroorganismer (3 dygn, 22°C inkubering) är högt (hälsomässig anmärkning).
De höga bakterietalen kan bero på dålig omsättning, nyanläggning, ytvattenläckage eller nyligen utförda arbeten.
Bedömning enl SOSFS 2003:17

Fig. 87: Water analysis, performed by Eurofins in 2011

Fig. 88: The place where the pond was until 2015, Andrea Antolloni

CHAPTER 3

Case study: Sikhall *Naturhus*

In 1996 Anders Solvarm decided to build his own house. He had always been interested in houses and old construction technology, as well as deeply keen on nature and lifestyle issues (Hemnet-redaktionen, 2014). His program was to build a low budget house, following the Swedish tradition.

He started the basement of what was to be a simple log house in 1998, but he stopped building for almost 2 years to take care of his children. After that, construction slowed down.

In 2001, Solvarm started thinking about building a shelter above the house to make it easier to complete the project. In fact, he realized that he would have lost too much time with bad weather conditions such as rain or snow. He also thought of having a huge tent to protect the log house, so the idea of using a shelter began to grow slowly. At the same time, Solvarm read the book *På akacians villkor* (as Bengt Warne and Marianne Fredriksson), and he changed his mind, thinking that a greenhouse could be a better solution for his project. Afterwards, he met Bengt Warne, who became his mentor and model. The aim of Solvarm was to make Warne's concepts simpler and more affordable for a normal family.

The construction of the greenhouse and Warne's concepts brought to light issues. Solvarm began investigating building engineering at universities and companies, but he was struck by how little knowledge was available about *Naturhus*. He hesitated during the construction and he began to doubt even what experts said.

As simple as it may have been from an architectural point of view, the idea of the greenhouse was particularly complex in the realization phase; the Solvarms (Anders and Rosemary) resorted to calling a company specializing in the construction of greenhouses, *UBA Glas & Fasad,* the same company that erected the greenhouse in Ingarö *Naturhus*.

In late 2001, the company built an ordinary 315-sqm greenhouse with a steel prefabricated structure and a gable roof, with a total cost of 600,000 SEK (63.000,00 €, 2001).

At this point, protected by weather, Solvarm built the wooden house on the foundations built earlier, while his family settled in a house close to the site.

He built the wood house following the tradition of Swedish *stockstuga,* a type of log cabin constructed using the blockbau system.

The house was built starting by the consultation of some books and thanks to the advice from artisans by Solvarm and his father. At that time, he did not pay attention to details. Since the Solvarms were having children and they needed it early, he built the house very quickly.

Fig. 89: Bengt Warne at Anders Solvarm's construction site

The construction of the house ended in 2004 (A. Solvarm Interview. 3rd June 2017). Stairs, roof railings, maintenance footbridges, and shades were built after 2011 (Popescu A., 2011).

Solvarm has never stopped adapting his project, which it is still subject to modifications (A. Solvarm Interview. 3rd June 2017).

3.1 Concept

The aim of the project was to live in a sustainable way with nature through Warne's solutions, make them affordable to a normal family and minimize global non-renewable energy consumption. By rethinking the ordinary house, this project minimizes emissions and energy waste, while maintaining a good standard of living for the owners.

Solvarm's *Naturhus* covers three aspects: material, energy and eco-cycle of water and nutrients (GreenHouse Living, 2014) according to Warne's four rules (as seen in paragraph 1.4), the cycles of the four elements (paragraph 1.5), and some parts of Symbio Housing philosophy (paragraph 1.7).

Fig. 90: Front view of Sikhall *Naturhus,* Andrea Antolloni

Sikhall *Naturhus* is made of two parts: a core house, and a buffer space around the core house (enclosed by the greenhouse).

Contrary to what happens in Saltjöbaden *Naturhus* (as shown in paragraph 2), the core house and the greenhouse never touch each other. They are two distinct elements, with a greenhouse that has been used as a shelter during the construction of the house. The greenhouse serves as a protection against weather, but it offers also noise and UV radiation protection. In addition, it is used as a solar collector, creating a Mediterranean-like microclimate in the buffer space.

The glass shell responds to the weather by automatic windows controlled by weather station sensors, placed at the top of the roof. The roof sensors open the glass panes when temperature rises over 25 degrees, and they were closed during rain or other severe weather conditions. The windows can be opened and closed manually, to obtain a suitable temperature. Such technology is very common in normal Swedish greenhouses, i.e. it is used in farms.

Fig. 91: Simplified 3D model of Sikhall *Naturhus*

As in the first *Naturhus*, here the air is input through a passive ventilation system. The system consists of two 20-metres pipes that use geothermal energy to heat the air and transfer it into the greenhouse, as shown in figure 96. Air is taken from outside through a well-shaped air hole (figure 92). The fresh outdoor air flows through the pipes and gets preheated (by the ground), heating the buffer space. In summer, warm air comes in and gets cooled down by the ground.

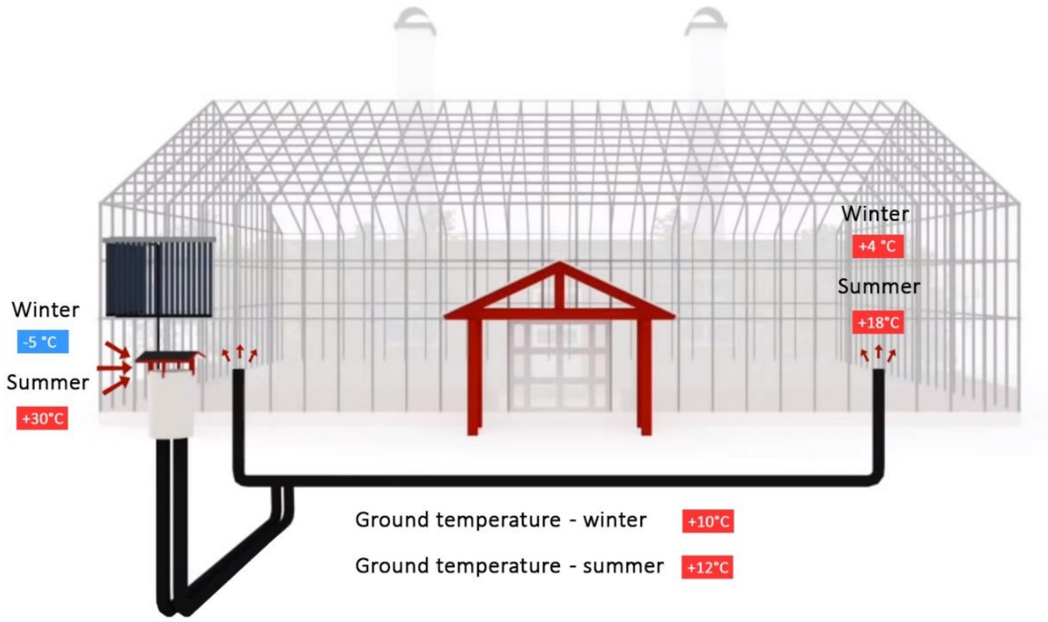


Figure 92: Simplified ventilation system; showing air/ground heat exchange (Liban Usman, 2016)

Inside this climate-shell, the plants grow and contribute to the improvement of the IAQ, regulating air humidity and providing shade, fruit, and vegetables (more detail in paragraph 3.7). In this space, black and grey wastewater and kitchen waste are treated (A. Solvarm Interview. 3rd June 2017). This system is a development at a residential scale of the Stensund Wastewater Aquaculture model.

When the water is treated by the system, the nutritious liquid solution is used to water all the plants in the buffer space (GreenHouse Living, 2014). Once a year, solid waste has to be removed. The solids can be used as fertilizer for the soil. Furthermore, the system has the potential to integrate a biogas recovery system (more details are in paragraph 3.6) (A. Solvarm Interview. 3rd June 2017).

The house is equipped with two solar collectors. The solar collectors supply hot water for shower and washing, as shown in figure 93. Two fireplaces, one used as a stove and one as an oven, are used for heating water when solar collectors are not enough. Solvarm cuts the firewood himself, consuming from 40 to 60 kg per day (Correspondence with Anders Solvarm, 13th February 2018).

In 2007, two high efficiency vacuum solar collectors were installed in the South corner of the greenhouse, looking respectively South-East and South-West. Each solar collector contains 30 vertical tubes. These collectors were not self-built by

Solvarm: they come from China and were bought from a Swedish company called Sfinx solar. The efficiency of the system is not comparable to that of recent solar collectors. In winter, they require a lot of maintenance to avoid freezing (A. Solvarm Interview. 3rd June 2017).

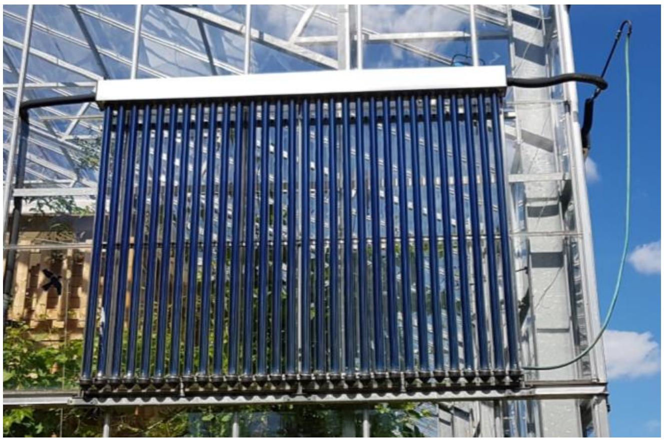


Fig. 93: Solar vacuum collector, Andrea Antolloni

The project is constantly evolving. In the future, the house could also include wind turbines, photovoltaic panels and other forms of energy production from renewable sources, to reach 100% self-sufficiency (GreenHouse Living, 2014). For the time being, only photovoltaic panels are installed; this is scheduled for 2019 (figure 94). Such semi-transparent panels will be installed on the roof of the greenhouse, replacing the glass panes (Solvarm A., Interview. 3rd June 2017).

Fig. 94: Semi-transparent photovoltaic panels, planned for 2019, Andrea Antolloni

The Sikhall *Naturhus* consists of a 145-sqm single-level log house, enclosed by a 315-sqm greenhouse (ref. figure 95 page 115). Since the flat roof of the log house is covered by the greenhouse, it serves as a terrace - a multifunctional area that can be used both in summer and winter. An external stair connects the terrace with the ground floor.

The core house has a rectangular plan and it is placed asymmetrically inside the greenhouse which is also rectangular. To the South, the distance between the long side of the greenhouse and the core house is about 4 metres. To the West, the distance between the short side of the greenhouse and core house is about 3 metres. To the North and East, the distance is about 1,5 metres. This buffer space is used for gardening. Since it is also a transit area, plants are placed at the edges (paragraph 3.7 figure 143).

The plan, as in the Water Lily House, is simple, and regular. A large enclosed central space splits the house in two, with the facilities at the sides. The central space is a multifunctional area; in winter half of this space is used for indoor cultivation. Here, a glazed roof (25 sqm) allows plants to receive sunlight.
The house is designed for 5 people, with 3 single bedrooms and a master bedroom; two bathrooms are placed in between. The studio is in the South corner of the house.

A wooden path on a 60% slope (as shown in figure 96) leads to the basement, partially buried. The basement follows the arrangement of the ground floor; a central multifunctional area, and technical and store rooms at the sides. The Eco-cycle system (to the West) is connected to the hydraulic fittings in the adjacent room. Under the two fireplaces, there are rooms used to collect ashes.

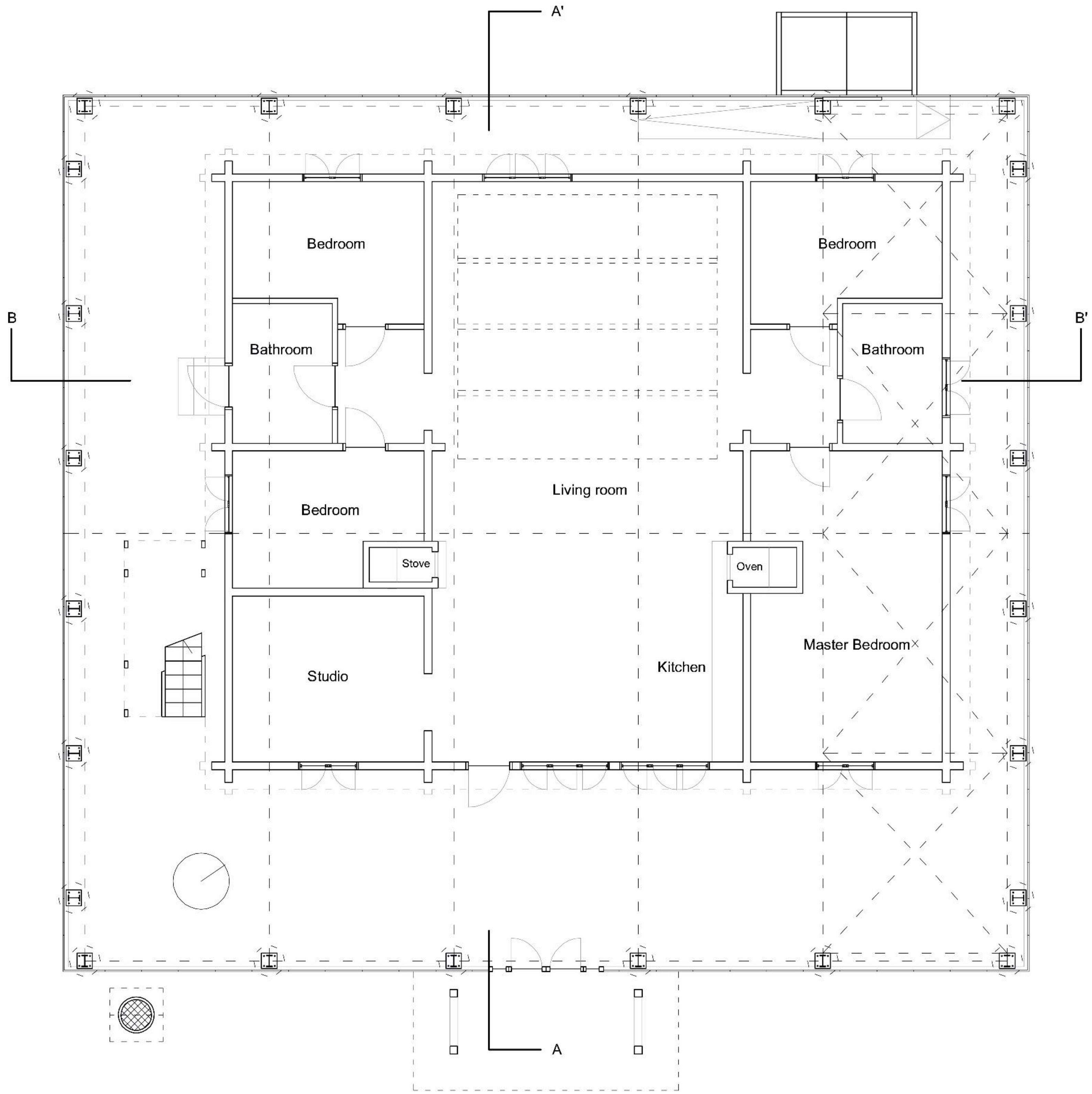


Fig. 95: Ground floor; scale 1:100, Andrea Antolloni

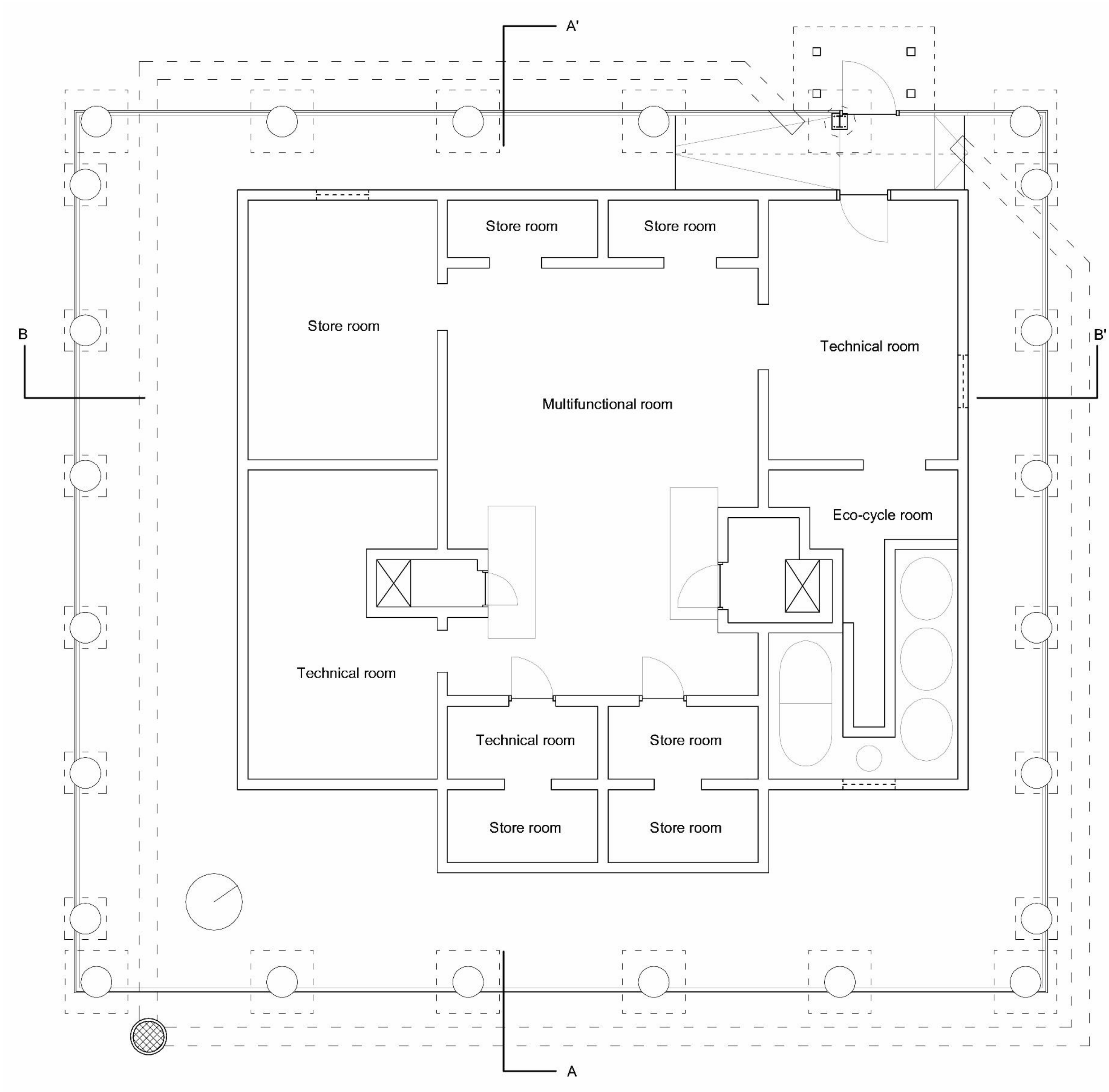
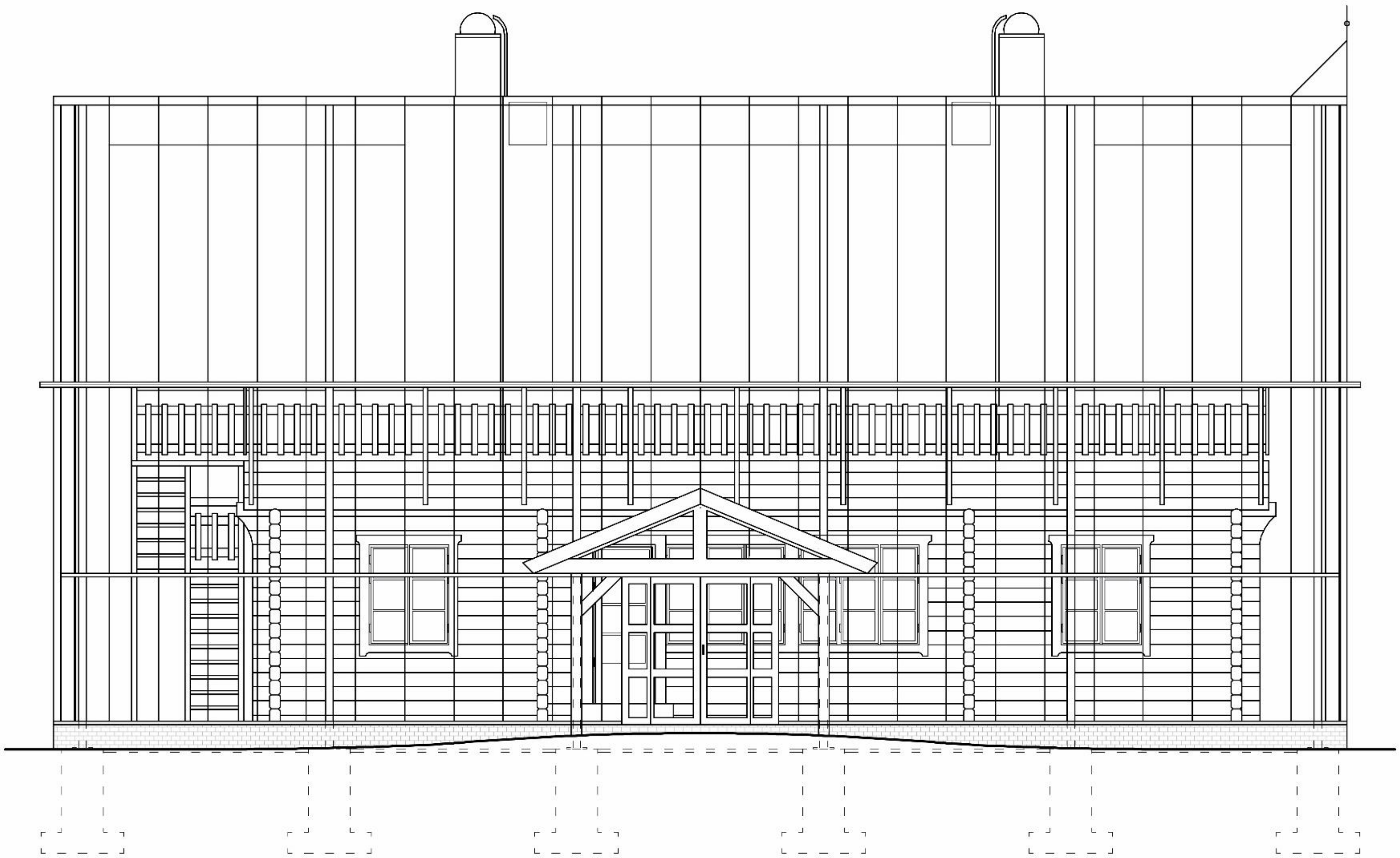
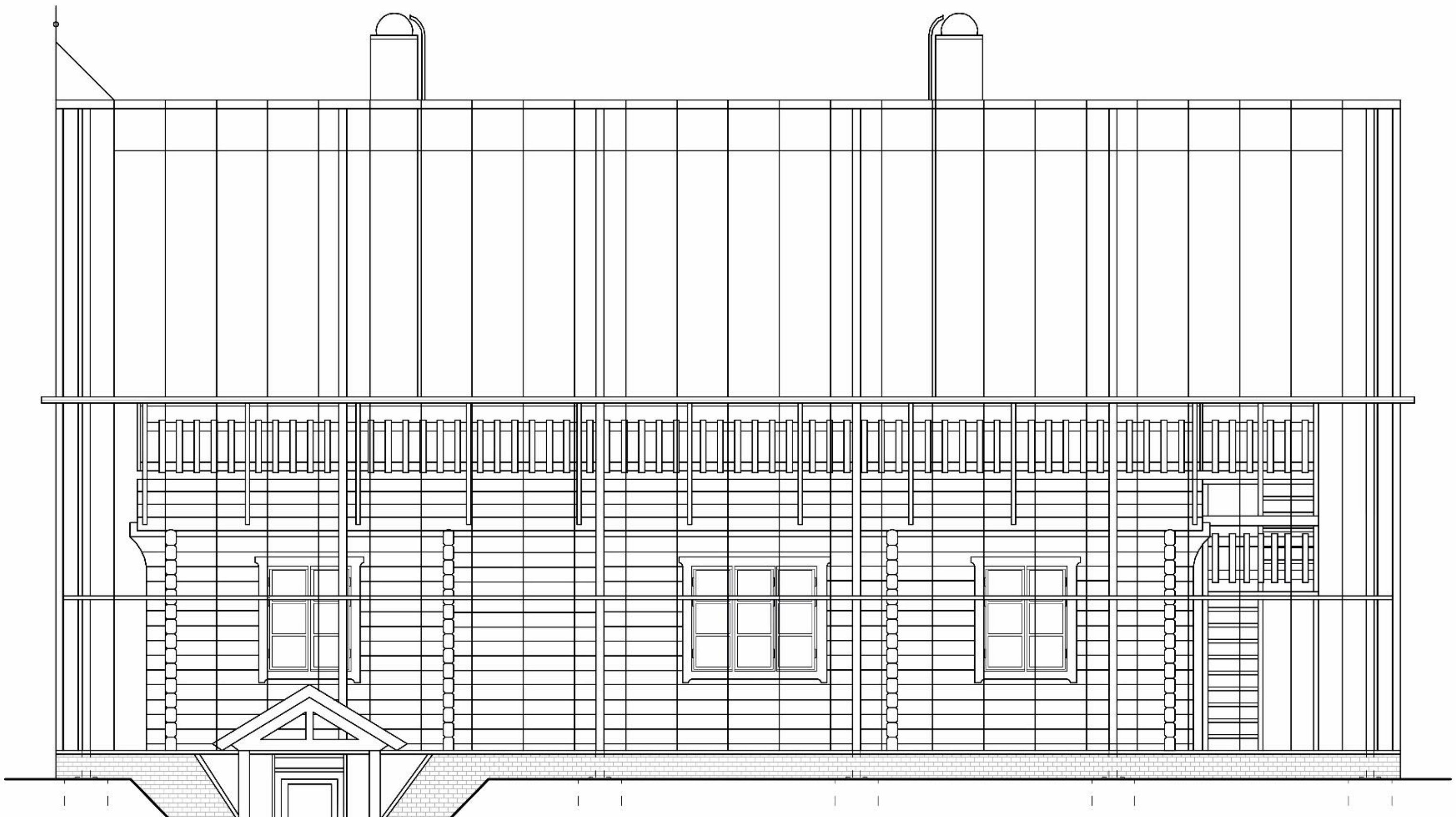


Fig. 96: Basement; scale 1:100, Andrea Antolloni





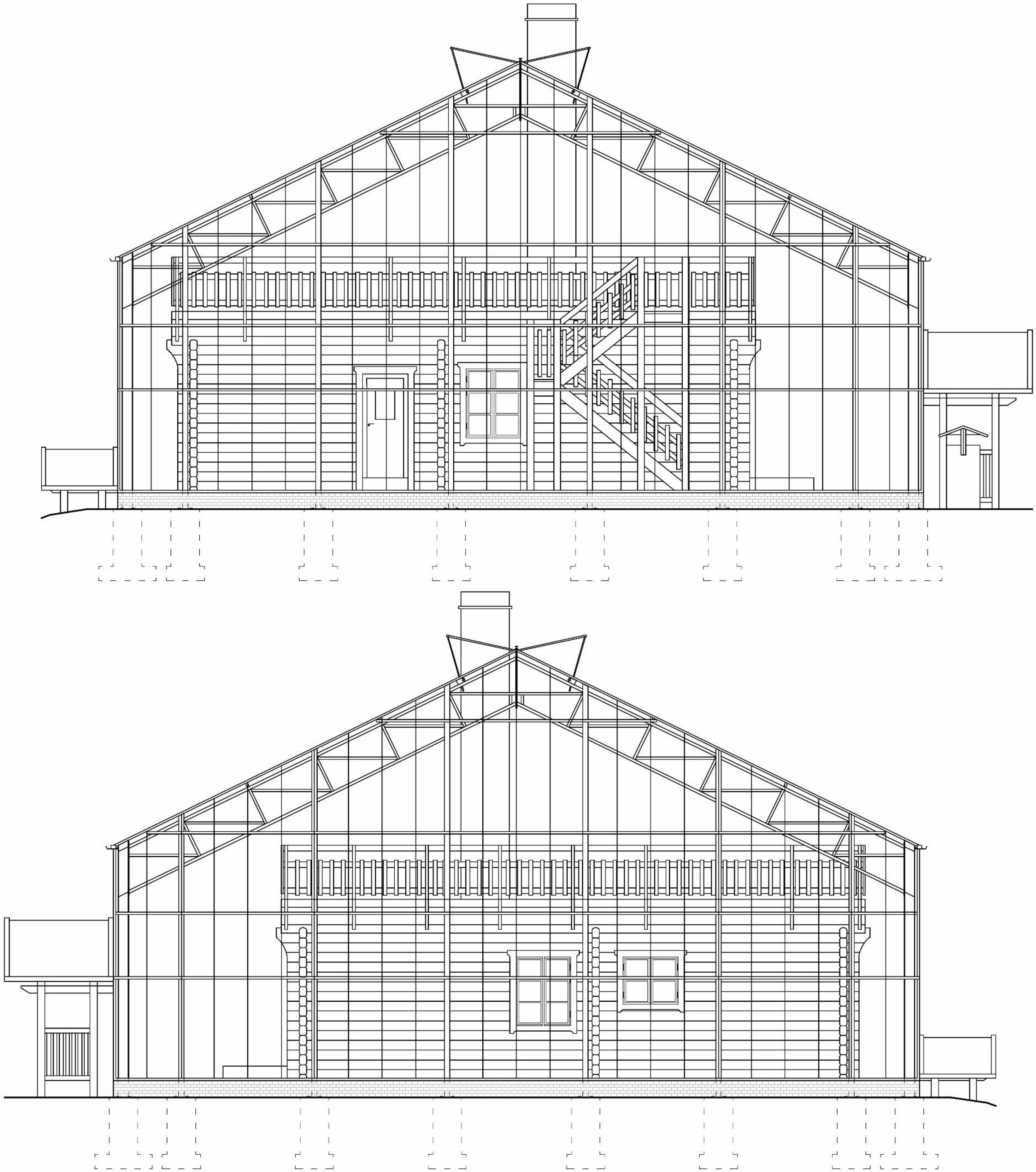


Fig. 97: In order: South-East, Nord-West, South-West, Nord-east elevation; scale 1:100, Andrea Antolloni

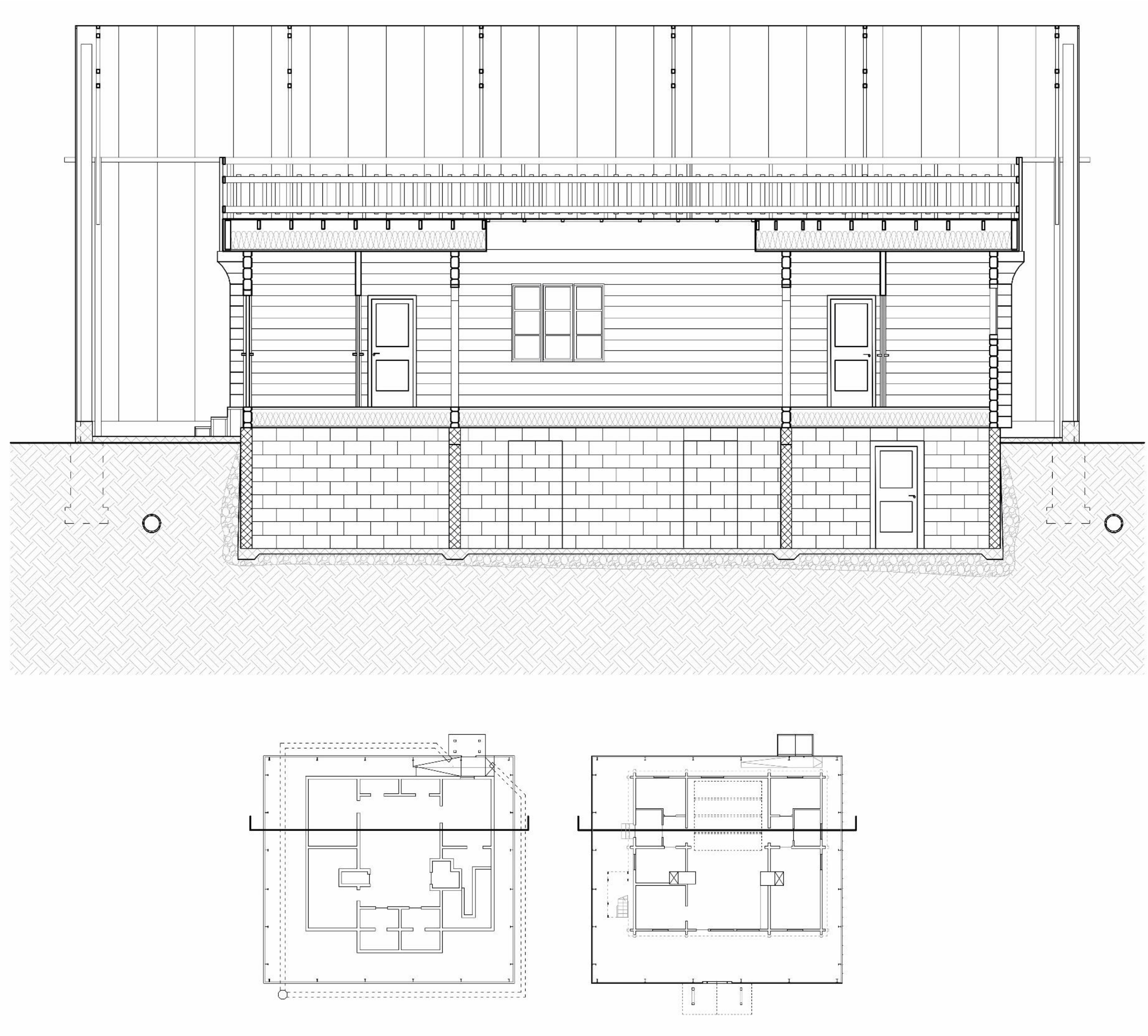


Fig. 98: Section A-A', Andrea Antolloni

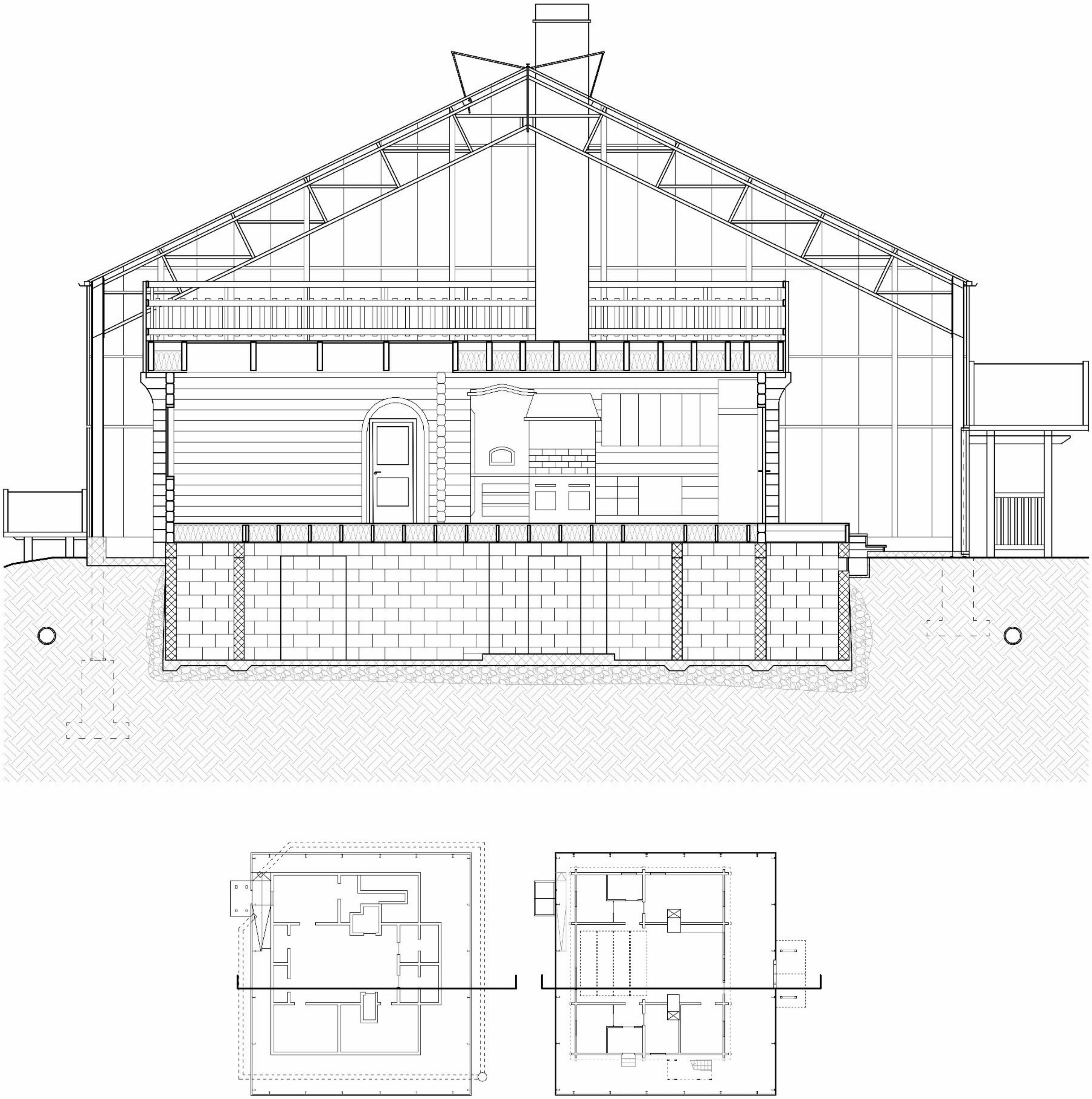


Fig. 99: Section B-B', Andrea Antolloni

3.2 Environment and climate

The *Naturhus* is located near Sikhall, Brålanda, a locality situated in Vänersborg municipality (Google Maps). The town of Vänersborg is 20 km away from Sikhall via highway and it is the closest town for services such as supermarkets, hospitals and schools (Solvarm A., Interview. 3rd June 2017). Vänersborg is located on the Southern shores of lake Vänern, about 45 km away from Uddevalla (Google Maps).

Fig. 100: Location of Sikhall

Based on Köppen climate classification, this part of Sweden has an oceanic climate (Cfb). Since the nearby town of Uddevalla is touched by the North Sea, it is also heavily influenced by a warm summer humid continental climate (Dfb) (Köppen climate classification). In addition, there is a further element to be included in the climatic equation: lake Vänern; which plays an inertial thermal mass role, moderating atmospheric temperature (Popescu A., 2011).

An oceanic climate generally features fresh summers and fresh but not cold winters. It has a monthly mean temperature below 22 °C in the warmest month, and above 0 °C in the coldest month.

There is usually no dry season here, as precipitation is distributed throughout the year (Köppen climate classification).

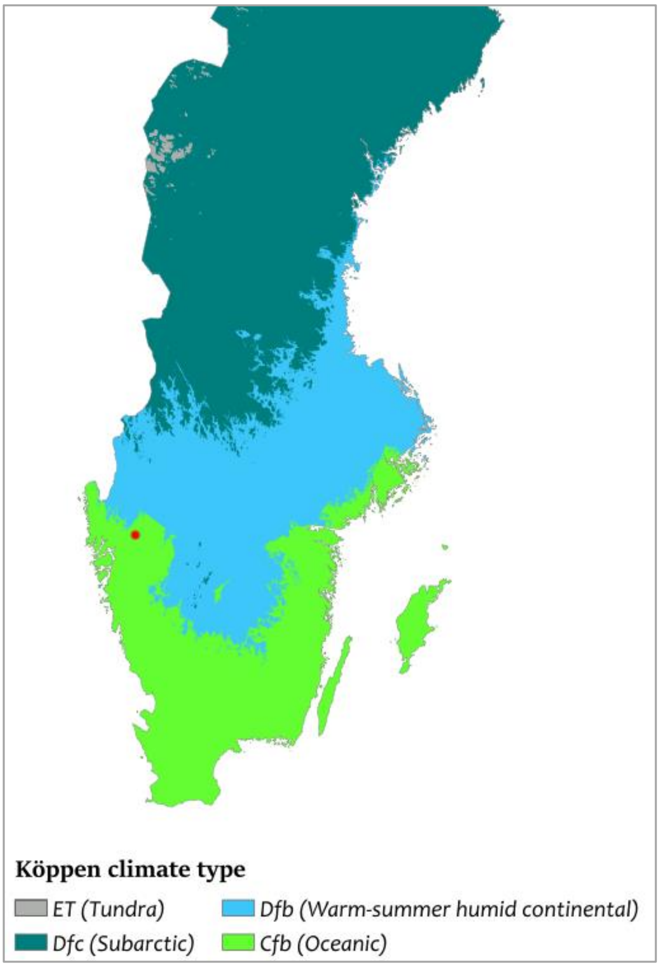


Fig. 101: Köppen climate type of Sweden

As far as vegetation is concerned, Sikhall is in a transition zone between the deciduous forest zone, dominated by trees such as birches, and the coniferous forest zone, where evergreen conifers predominate (*Bonniers Lexikon*, 1990).

Near the Vänern lake, there are birches and other deciduous trees, while in the areas adjacent to the *Naturhus* there are pine, spruce, and fir woods. Since that, the timber used for building the *Naturhus* came from forests of pine and fir (A. Solvarm Interview. 3rd June 2017), felled by five farmers.

Fir wood was chosen because it is the most common wood in the area and is easy to cut. Most of the logs used were collected in forests located average at 3-4 kilometres from *Naturhus*. However, the largest logs were felled from forests up to 20 km away. This fact contributed to keeping grey energy low (Correspondence with Anders Solvarm, 5th November 2017).

3.3 Material analysis

The main material for the core house is wood, mostly fir and some pine, in line with the Swedish *stockstuga*, a traditional wood construction built according to the blockbau system. The interior lining of the house is entirely made of fir, spruce, and pine boards; high-quality pine was used for door and window frames.

Solvarm is not an expert, however the core house was self-built by Solvarm and his father after reading a few construction books and thanks to the help of local joiners. He also reports that the construction of the log house took about 3 years and he was alone. Construction work was shared with Anders's job, from early morning to evening, while the night was dedicated to his children. Being a non-professional, it took him a full day to cut a single log: half a day was spent in the forest felling and transporting the log to the sawmill, the other half sawing and solving the connection problems among joints (A. Solvarm Interview. 3rd June 2017).

For the log transportation, a tractor (50 kW) with a wagon was used, covering a total distance of 15 km with an average speed of 30 km/h. So, Solvarm spent 25 kWh for each log. The log was saw in the sawmill by axe, saw (4 kW) and chainsaw (3 kW). The saw cut is done in 15 minutes, spending 1 kWh. Solvarm used the chainsaw for half an hour, spending 1.5 kWh (Correspondence with Anders Solvarm, 21st January 2018).

Inner and perimeter walls sum to 90 m in length, 288 logs were used spending 7,920 kWh; adding 186 logs for beams and floors a total of 13.035 kWh (46.926 MJ) was spent (see table 3 and 4).

	n° (-)	L (m)	s (m)	h (m)	Volume (m^3)	Weight (kg/m^3)	Weight tot (kg)
Bearing Walls	16,00	90,00	0,15	0,20	43,20	550	23.760
	n° (-)	Area (m2)					
Floors	4,00	150,00		0,03	18,00	550	9.900
	n° (-)		b (m)	h (m)	Volume (m^3)		
Roof girders	26,00		0,10	0,54	16,15	550	8.880
Roof joists	20,00		0,05	0,16	2,24	550	1.232
Ground floor beams	20,00		0,05	0,30	4,20	550	2.310
				Tot	83,79	550	46.082

Tab. 3: Wood data, Andrea Antolloni (Bjørn Berge, 2009)

		EE for one log						
	Logs	Saw (kWh)	Chainsaw (kWh)	Tractor (kWh)	Tot (kWh)	EE (kWh)	Diesel (g/kWh)	Diesel (kg)
Walls	288	1,00	1,50	25,00	27,50	7.920	220	1.742
Floors	120	1,00	1,50	25,00	27,50	3.300	220	726
Beams	66	1,00	1,50	25,00	27,50	1.815	220	399
Tot	474	1,00	1,50	25,00	27,50	13.035	220	2.868

Tab. 4: Number of logs and embodied energy, Andrea Antolloni

Fig. 102: Details of the core house blockbau, Andrea Antolloni

Solvarm stacked logs and cut them to be connected. The joints in the logs were carved manually by saw blade or ax, following the Swedish tradition (A. Solvarm Interview. 3rd June 2017). Linen, a material obtained from textile waste, was used is in the space between the logs, to provide insulation (Correspondence with Anders Solvarm, 21st November 2017). The linen was an evolution, since in the past musk was used (Popescu A., 2011). The connections take place 25 cm before the two ends of the logs stacked orthogonal to each other, and this means that logs extend beyond the corner intersection (to guarantee stability). In fact, this stability can be obtained in logs protrude more than 10 cm beyond the corner (Falletti F., 2013). The logs were shaped to a hexagonal section, starting from a cut in sawmill, and removing the four corners (Solvarm A., Interview. 3rd June 2017). The cutting of the connections was carried out in a central position. The connection was made more complex, following a method between tradition (fig 103) and modernity (fig 104).

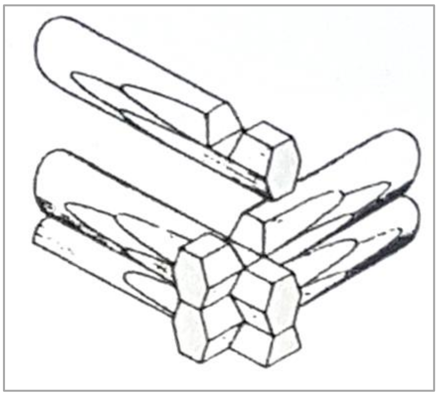



Fig. 103: Swedish traditional lock notching; fig. 104: Lock notching used by Solvarm

The cuts used to interrupt the wood section were made in a pattern of the wall and wood nails, represented in dotted lines, were used to secure further stability between the layers, as shown in figure 105.

The maximum length of a log is 6,90 m, but actually in a few cases they exceed 6 m (Correspondence with Anders Solvarm, 21st November 2017).

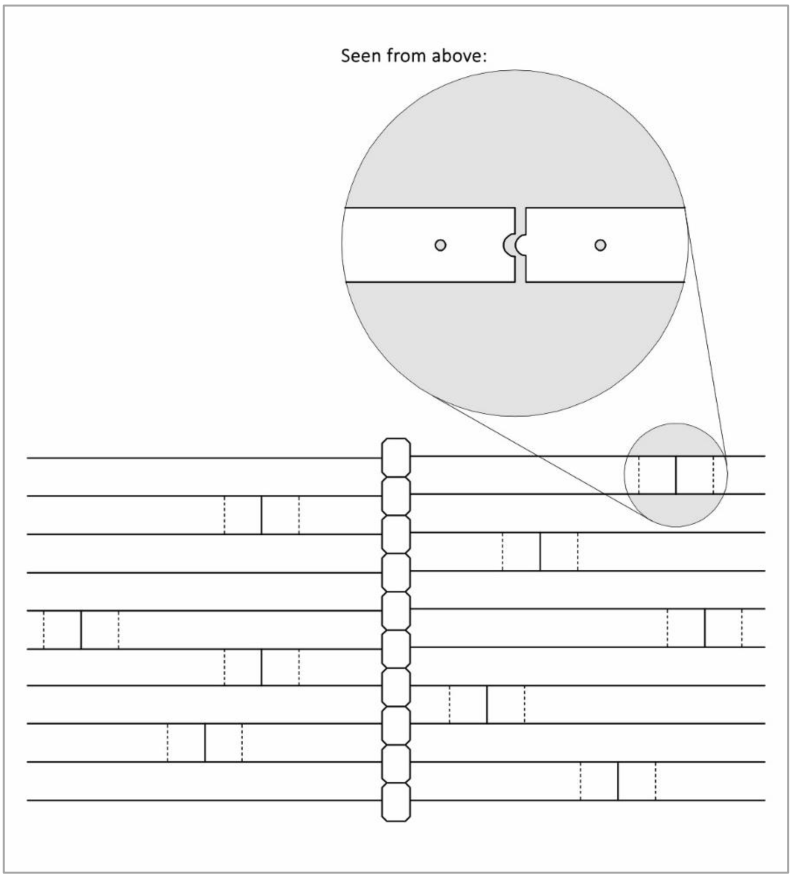


Fig. 105: Pattern of log house walls, and connection detail, Andrea Antolloni

The ground floor consists of 78 beams, 5 x 30 cm (in green, figure 106) that lie on the basement walls (see figure 99). The roof consists of 54 girders 10 x 55 cm and 46 joists 5 x 15 cm (in green, figure 107) (see figure 98) less than 6 m long.

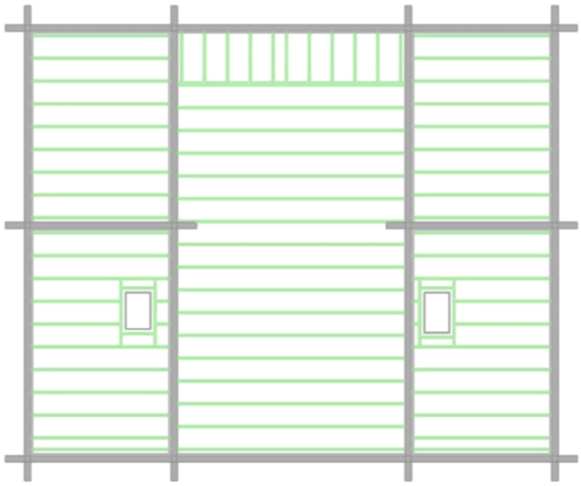


Fig. 106: Ground floor structure, scale 1:200, Andrea Antolloni

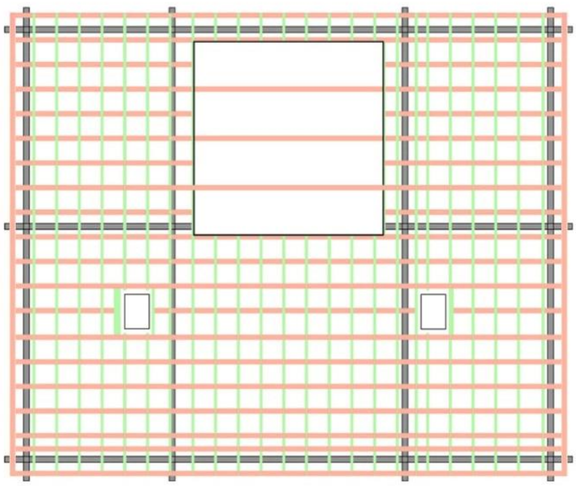


Fig. 107: Roof structure, scale 1:200, Andrea Antolloni

Timber was also used for the 1,10-metres high railings and the stairs. In this case, the timber was sawn into planks and nailed together.
The doors and windows were made by Solvarm's father. He has roughly estimated

about 5 days of about 8 hours of sawing for each window. It can be considered that 10 windows took about 400 hours of work (A. Solvarm Interview. 3rd June 2017). The virtual savings from the free work made by his father was about 40 euros per hour; a total of 20.000 euros counting Swedish taxes.

There are 10 windows, with a size ranging from 1,75 x 1,60 m (figure 108) to 1,15 x 1,00 m, with the exception, in the basement, of a small window of 1,05 x 0,35 m (Correspondence with Anders Solvarm, 23rd October 2017).

The windows are stuck into the wall, and at the sides are placed against vertical casements (A. Solvarm Interview. 3rd June 2017).

Fig. 108: The double windows in the living room

Thermal insulation is placed between the basement and the ground floor, and in the roof. The insulation is *Termoträ*, a renewable and biodegradable spruce and pine cellulose, with a coefficient of transmittance from 0,035 to 0,043 W/m˚C. The insulating layer in the roof is 0,35 metres in height, while it is an average of 0,25 m between the basement and the ground floor (http://www.termotra.se/).

	A (m^2)	h (m)	Volume (m^3)	Weight (kg/m^3)	Weight (kg)
Roof Termoträ	100,00	0,35	35,00	28	980
Ground floor Termoträ	135,00	0,25	33,75	28	945
Tot			**68,75**		**1.925**

Tab. 5: *Termoträ* (net volume), Andrea Antolloni (Bjørn Berge, 2009)

Fig. 109: *Termoträ* insulation in Sikhall *Naturhus*

A rubber mat is placed on the roof to provide additional protection against water, as shown in figure 110. Although the core house is protected by the greenhouse, water could damage it anyway because plants on the roof are watered, and windows and skylights are pressure-washed. Glass cleaning operations are performed once a year, and Solvarm reports that the whole terrace becomes wet. Furthermore, the waterproofing membrane offers extra protection in case a glass of the greenhouse breaks because of hail.

Another thing not to underestimate is condensation: moist air condensates on the warm side of the glass panes, especially in winter, and droplets fall on the terrace. Water can also mix with the dirt accumulated over the months, creating mud. Without rubber mat, water could fall into roof cracks, damaging the wood (A. Solvarm Interview. 3rd June 2017). The solution was designed by Warne, after his experience with the first *Naturhus* (Correspondence with Anders Solvarm, 20th January 2018). Much of the condensation is however collected into steel sections and channeled outside.

Fig. 110: The rubber mat placed on the log house roof, Andrea Antolloni

	h (m)	A (m^2)	Volume (m^3)	Specific Weight	Weight (kg)
Rubber mat	0,002	150,00	0,30	1.100	330

Tab. 6: Rubber mat data, Andrea Antolloni (www.oppo.it)

The greenhouse has a prefabricated steel loadbearing structure, galvanized steel frames and tempered float glass. Greenhouses create a protective environment for plants, and the sunrays heat up the building (due to the greenhouse effect) (A. Solvarm Interview. 3rd June 2017). Steel and glass were provided and assembled by a professional company specialized in greenhouses, UBA Glas & Fasade (http://www.uba.se/).

Aluminum frames were used in the Saltjöbaden *Naturhus* however, galvanized steel frames were employed to set the glass panes. This material is the only exception to Warne's philosophy, since its embodied energy is high. In future *Naturhus*, it might be replaced by timber to withstand the Swedish climate (additional information is provided in paragraph 3.4) (A. Solvarm Interview. 3rd June 2017).

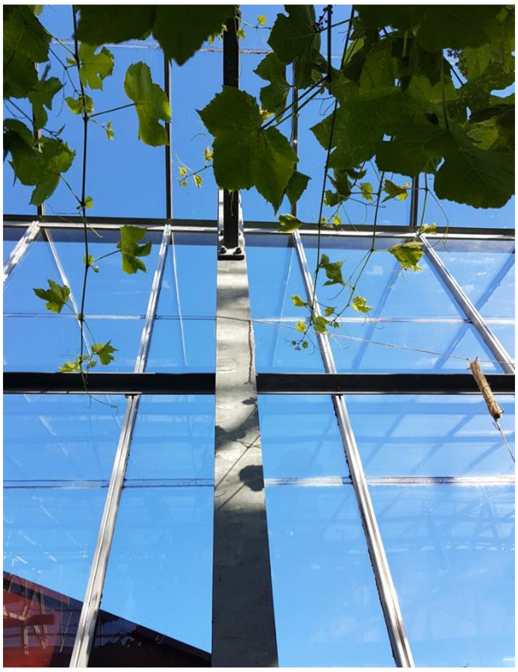



Fig. 111: Glazing frames and glass; fig. 112: Vertical galvanized steel column, Andrea Antolloni

Warne's preliminary designs specified columns from 140 to 200 IPE (Archive of ARKDES Museum ARKM), but during construction they were increased to 220 by the company, to increase structural security (as shown in figure 95) (A. Solvarm Interview. 3rd June 2017).

Each column is connected to a concrete pier foundation by a welded steel plate and four 17 mm bolts (figure 113). For 24 columns 960 bolts were used (tab 8).

Six column pairs carry trusses that support the greenhouse roof. The trusses are connected to the columns by plates and bolts. Each truss is realized by welding two 60 x 60 mm chords with 50 x 50 mm webs. Beams and plates support the steel frame that carries the glass panes (Correspondence with Anders Solvarm, 23rd October 2017).

Steel profile	n° (-)	Section area (m^2)	L (m)	Volume (m^3)	Specific weight (kg/m)	Weight (kg)
IPE 220 column	24	0,003337	5,20	0,42	26,20	3.270
IPE 140 roof	1	0,001643	18,60	0,03	12,90	240
IPE 140 roof	2	0,001643	19,10	0,06	12,90	493
Tot				0,51		4.002

Trusses	n° (-)	s (m)	L (m)	Area (m^2)	Volume (m^3)	Specific Weight (kg/m)	Weight (kg)
60x60	24	0,03	9,00	0,00068	0,15	5,37	1.160
50x50	72	0,03	1,60	0,00056	0,06	4,43	510
50x50	60	0,03	0,80	0,00056	0,03	4,43	213
Tot				0,00181	0,24		1.883

					Volume (m^3)		Weight (kg)
Tot trusses + IPE					0,75		5.885

Tab 7: IPE and trusses data, Andrea Antolloni (www.oppo.it)

		For each column		For each bolt		
	columns	Joints to foundation	Joints to elements	L (cm)	Weight (g)	Weight tot (kg)
Bolts M10 (galvanized steel)	24	4	10	5,00	52,42	50,32

Tab. 8: Bolts data, Andrea Antolloni (www.oppo.it)

Fig. 113: Column-pier foundation connection; fig. 114: Column-truss connection, Andrea Antolloni

The braces are welded with the IPE and are about 1 cm in diameter. They are in the North-East part and help to withstand horizontal forces (figure 115).

Fig. 115: Greenhouse bracings, Andrea Antolloni

The glass used for the greenhouse is a 4-mm tempered float glass. Despite the reduced thickness, after sixteen years only four panes have broken: the first in 2001, when one of the children threw a stone. Another one in the first floor, when Solvarm was cleaning with the high-pressure washer and a stone struck the glass panel at high speed. Two of them in the roof, possibly because of a large temperature difference between inside and outside the greenhouse (in fact, in winter it may be less than 15 °C at night and during the day, when the temperature reaches about 20 °C, the steel frame is subject to thermal deformation forces.

Glass	Area (m^2)	s (m)	Volume (m^3)	Specific weight (kg/m^3)	Weight (kg)
Perimeter walls	370	0,004	1,48	2.400	3.552
Greenhouse roof	320	0,004	1,28	2.400	3.072
Tot	690	0,004	**2,76**	2.400	**6.624**

Tab. 9: Glass panes data, Andrea Antolloni (Bjørn Berge, 2009)

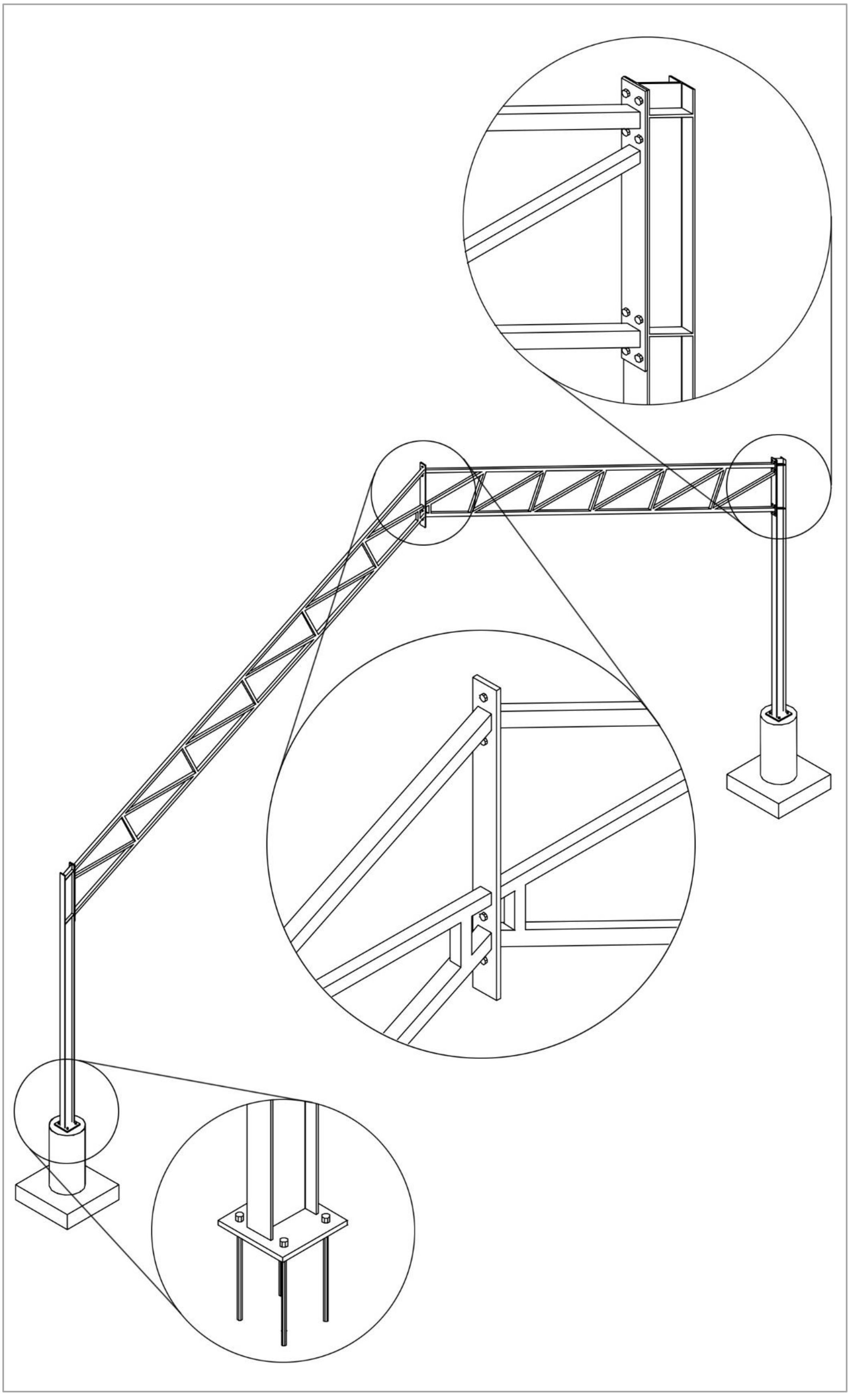


Fig. 116: Steel joints (scale 1:100) and connection details (scale 1:20), Andrea Antolloni

The greenhouse has been slightly modified after completion to facilitate maintenance work. Below the trusses, as shown in figure 117, at the sides and near the chimneys, wooden walkways are hung to facilitate glass cleaning and replacement work.

The figure 117 also shows the two engines that operate the opening systems, controlled by two weather stations inside and outside the greenhouse.

The openable windows are 1.5 m wide and are placed near the edge of the greenhouse roof, with a side covering almost 17 metres and the other about 15 metres (Archive of ARKDES Museum ARKM). A series of motors, held in place by steel bars of circular hollow section, opens the windows by slides steel rods.

Fig. 117: Maintenance footbridge, opening mechanisms and weather station, Andrea Antolloni

In figure 118, several elements that were added to the standard greenhouse are shown, such as the chimneys/greenhouse connections, and the inspection hatches for the chimneys near the openable windows. In addition, the greenhouse trusses are used to support auxiliary elements, like timber walkways to access the inspection hatches of the chimneys. These walkways were designed by Warne (Archive of ARKDES Museum ARKM) and built by Solvarm using wooden boards laid on the greenhouse trusses.

Plants like the grapevines in the buffer space, are supported by cables tied to the greenhouse beams and trusses, along with textile curtains and shades (A. Solvarm Interview. 3rd June 2017).

Fig. 118: Secondary structures that stick to the trusses, Andrea Antolloni

Green roofs are a traditional feature of Swedish wooden constructions. Layers of earth and grass are a protective and insulating solution. In most cases, the soil layer placed on a bed of tree bark is contained by wooden joists arranged horizontally at the edges of the roof and anchored by pegs (Falletti F., 2013).
We find small green roofs upon the entrances of Anders Solvarm's *Naturhus*. They do not have a thermal function as in the past, rather aesthetic and functional in snowy periods.

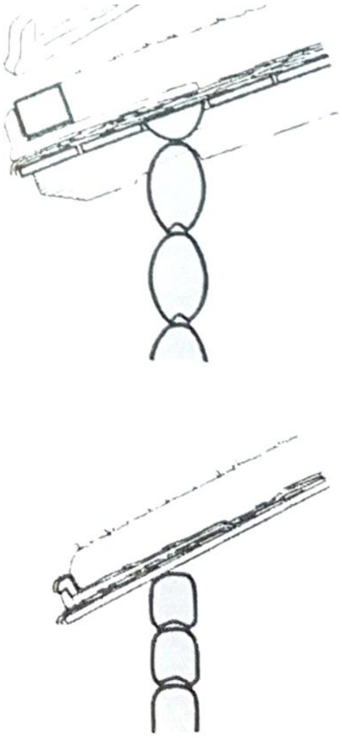


Fig. 119: Traditional solutions for green roof (Falletti F.); Fig. 120: *Naturhus* North-West entrance

Solid and hollow bricks, about 25x12x6 cm, were used for the two chimneys (figure 121), below grade perimeter walls, plinth wall, and the buffer space floor. The buffer space floor is made of hollow bricks, to facilitate the exchange of heat (ground/air). The boxes of the plant beds are in solid bricks in order to retain water. Bricks are not a very common building material in Sweden, and in fact they were manufactured in Denmark. They were bought from neighboring farms (Correspondence with Anders Solvarm, 6th November 2017).

Solvarm wanted to use old handmade bricks, but a Finnish specialist advised him to buy them to obtain bricks of the same size, in order to make the building process easier and save time.

Fig. 121: The fireplace used as an oven

Traditional bricks were used for other small parts of the house, as for walls in the buffer space 40 cm deep; they were hand-made by Solvarm himself using the clay from the site mixed with straw and cow dung (A. Solvarm Interview. 3rd June 2017). To bond the bricks, in most of the cases a mix of sand and clay was used; clay was extracted from the pond next to the house, following the tradition. In other places, like in the brick wall of the North-West slope, standard Portland cement and sand were used.

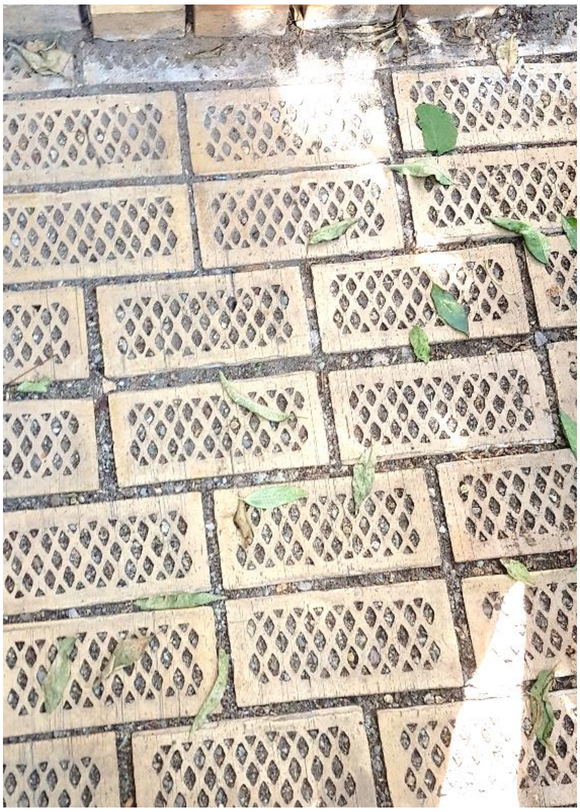


Fig. 122: The exterior floor in the buffer space inside the greenhouse, Andrea Antolloni

Bricks	h (m)	A (m^2)	Volume (m^3)	Specific weight	Weight (kg)
Solid bricks greenhouse	0,40	7,07	2,83	1.900	5.373
Solid bricks garden	0,20	7,93	1,59	1.500	2.379
Solid bricks chimney	10,00	1,90	19,00	1.900	36.100
Hollow bricks floor	0,06	84,00	5,04	600	3.024
Tot			**28,45**		**46.876**

Tab. 10: Solid and hollow bricks data (Bjørn Berge, 2009)

Concrete is also used for the foundations of the greenhouse and the log house (Correspondence with Anders Solvarm, 6th November 2017). The greenhouse ones are pier foundations, 30 cm thick ranging from 800x800 to 1.200x1.200 cm in plan, placed 1,5 m below grade (Archive of ARKDES Museum ARKM) (see figure 98, 99). The log house one has a slab-on-grade foundation, made by a single layer of concrete, 10 cm thick. In addition, a foundation 20 cm thicker was used to support the load of the two chimneys and the loadbearing walls of the basement.

Foundation	n° (-)	a (m)	b (m)	h (m)	Volume (m^3)	Specific wei	Weight (Kg)
Pier 800x800	12,00	0,80	0,80	0,03	0,23	2.400	553
Pier 1200x1200	12,00	1,20	1,20	0,03	0,52	2.400	1.244
		pi (-)	A (m2)				
Pier Ø600	24,00	3,14	0,09	1,20	8,14	2.400	19.533
Slab (core house)			190,00	0,10	19,00	2.400	45.600
Tot					**27,89**		**66.930**

Tab. 11: Pier and flat foundation data (Bjørn Berge, 2009)

The basement walls are made of Leca blocks (figure 123) (A. Solvarm Interview. 3rd June 2017) 20x50x25 cm (Correspondence with Anders Solvarm, 23rd October 2017). Solvarm chose this material because it offers excellent protection against moisture and frost; and is particularly suitable for the Swedish climate (Correspondence with Anders Solvarm, 21st January 2018). The inner face of Leca block walls in the basement has painted in white by Solvarm himself (A. Solvarm Interview. 3rd June 2017).

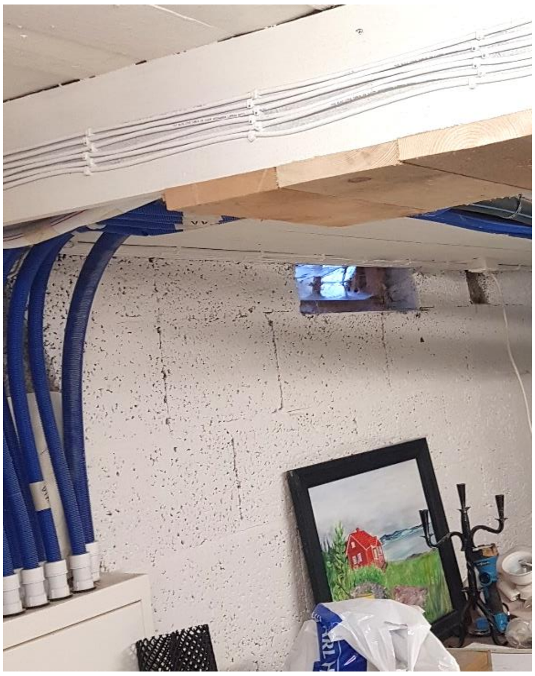


Fig. 123: Basement wall made by Leca blocks, Andrea Antolloni

	s (m)	Perimetral walls (m)	h (m)	Volume (m^3)	Specific weight (kg/m^3)	Weight (kg)
Leca block	0,20	135,00	2,25	**60,75**	450	**27.338**

Tab. 12: Leca block data (Bjørn Berge, 2009)

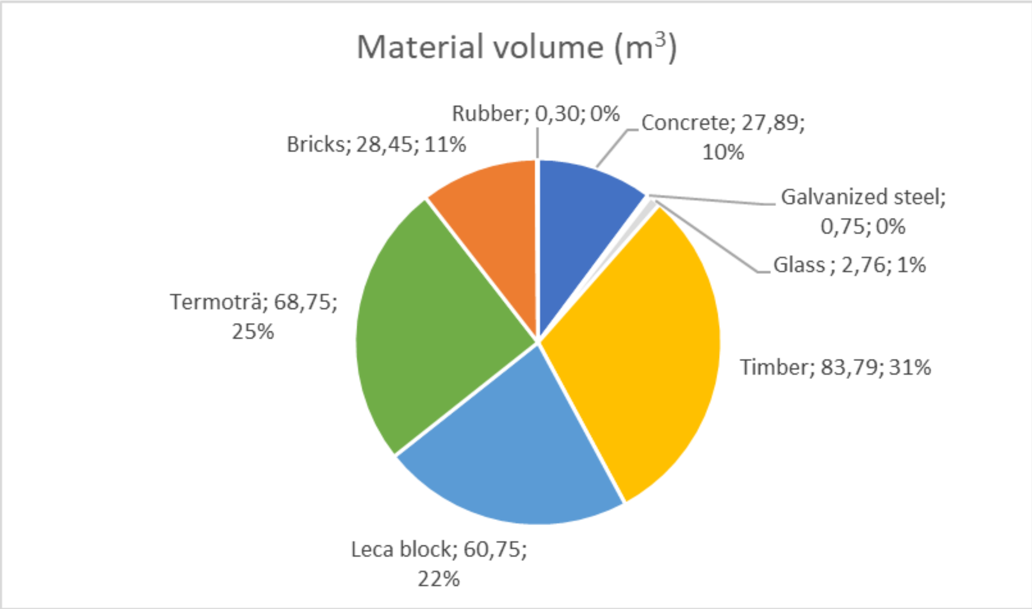


Fig. 124: Materials volume that make up Solvarm *Naturhus,* Andrea Antolloni

In the Solvarm *Naturhus* weight calculation, the plant bed on the roof was added as contributes to the total weight. As predicted, the core house, foundations and basement are the heaviest parts of the house (by material and building parts).

	A (m^2)	h (m)	Volume (m3)	Specific weight (kg/m^3)	Weight (kg)
Soil (Plant bed roof)	18,50	1,10	20,35	1.800,00	**36.630**

Tab. 10: Plant bed data

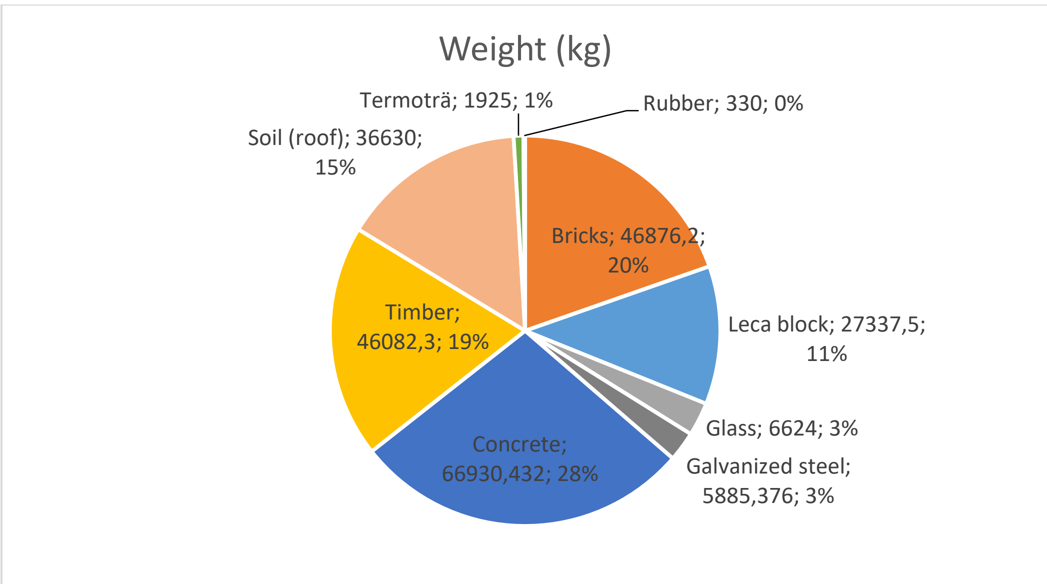
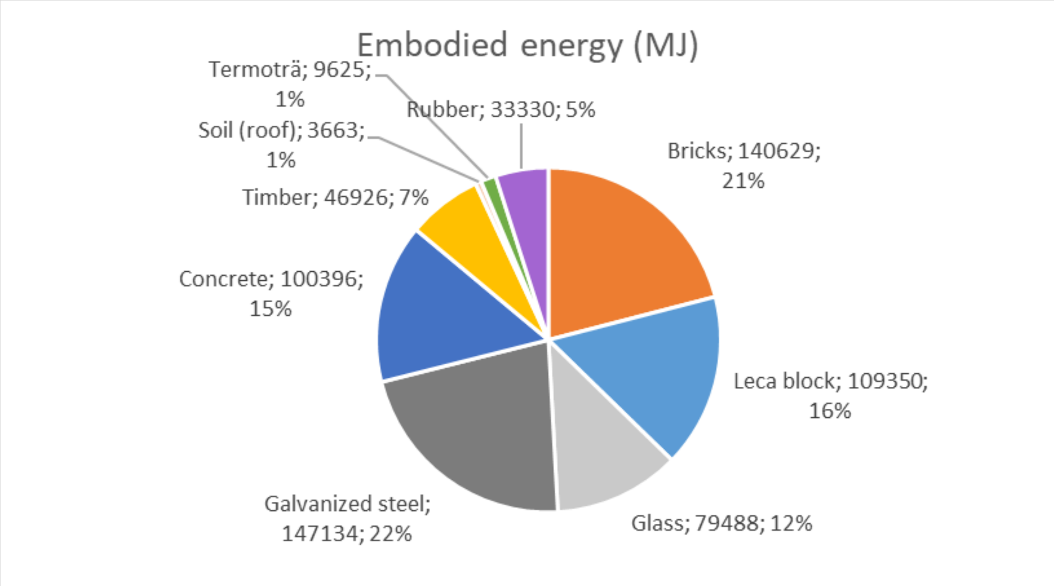


Fig. 125: Material weight, Andrea Antolloni

The analysis showed that steel has the largest energy consumption, followed by Leca block and bricks (for an average of 46.926 MJ timber embodied energy).

Material	Weight (kg)	EE (MJ/kg)	EC (kgCO2/kg)	EE tot (MJ)	EC (kgCO2)
Bricks	46.876	3,00	0,19	140.629	8.906
Leca block	27.338	4,00	0,35	109.350	9.568
Glass	6.624	12,00	0,70	79.488	4.637
Galvanized steel	5.885	25,00	2,20	147.134	12.948
Concrete	66.930	1,50	0,18	100.396	12.047
Timber	46.082		0,30	46.926	13.825
Soil (roof)	36.630	0,10	0,02	3.663	842
Termoträ	1.925	5,00	0,23	9.625	443
Rubber	330	101,00	3,18	33.330	1.049
Tot				**670.541**	**64.266**



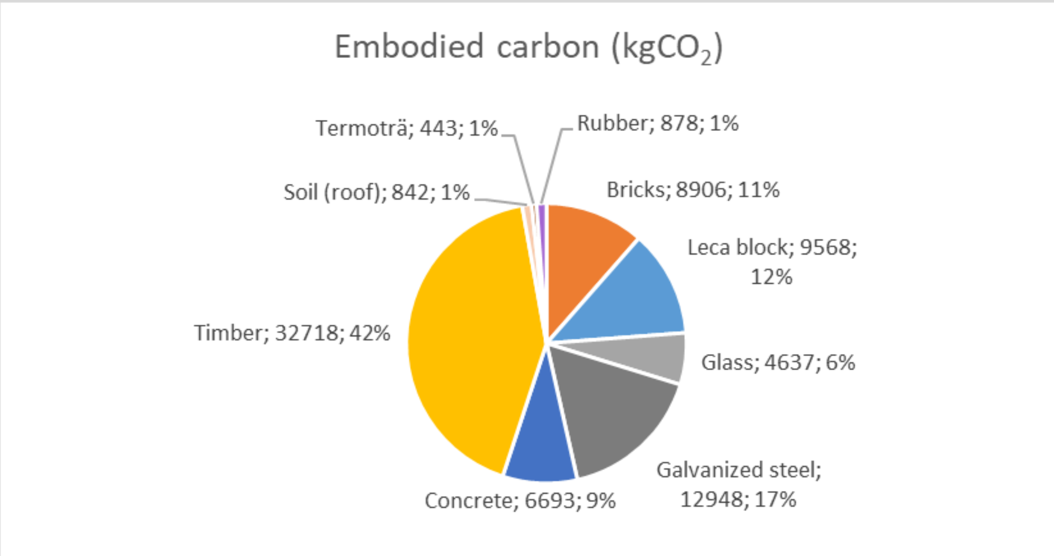


Fig. 126: Embodied energy and embodied carbon (Bjørn Berge, 2009), Andrea Antolloni

3.4Microclimate

Like in the first *Naturhus*, in Sikhall *Naturhus* air temperature and humidity level are different than outside. This is due to the greenhouse effect, the heat storage capacity of the ground and the timber core house walls, hit daily by solar radiation. The greenhouse allows the ability to cultivate fruits and vegetables, reducing heat losses (A. Solvarm Interview. 3rd June 2017).

The factors that influence thermal balance are: heat conduction and convection through the greenhouse shell, radiation entering the system, walls and roof condensation, heat dissipation through ventilation systems, infiltration and exfiltration through openings, heat gains and losses through the ground, and firewood stoves inside the core house.

The factors that influence humidity balance are: solar radiation, ventilation systems, infiltration and exfiltration through openings, and transpiration from plant leaves (more information is provided in paragraph 3.8). The amount of solar radiation depends on several factors such as glass properties (transmittance and absorption of the glass), the angle of Sun rays against the greenhouse surfaces, the orientation of greenhouse surfaces, and the cloud coverage (Usman L., 2016).

It is evident that Sikhall *Naturhus* is closely related to the amount of light it receives. Sunlight allows a very rapid heating of the house, but heat loss is equally rapid in the absence of light.

A cloud coverage chart of the nearest city, Gothenburg, is provided below.

	Jan	Febr	Mars	April	Maj	Juni	Juli	Aug	Sept	Okt	Nov	Dec
Kiruna	14,1	12,5	12,7	12,9	14,1	15,3	14,5	15,2	16,1	15,3	16,7	15,9
	4,5	3,5	5,6	5,3	3,9	3,3	3,3	2,9	2,4	3,9	3,4	3,4
Umeå	15,5	12,5	11,9	11	8,1	9,4	8,8	10,1	11,5	13,7	17,3	17
	6,1	5,4	7,2	6,2	7,4	5,8	6,1	6,2	4,6	5,4	4,1	4,9
Östersund	14,5	12,6	12,4	11,3	10,4	11,6	11,3	11,5	13,6	15	18	15,9
	4,5	4	6	4,8	6,3	3,5	4,7	4,6	3,3	3,1	1,6	3,3
Västerås	18,5	15	12,2	10,5	8,7	7,8	8,3	9,9	9,9	14,7	19,7	19,9
	3,8	4	7,3	5,8	7,8	5,7	6	5,6	5,5	4,6	2,7	2,9
Göteborg	18,1	14,7	13,7	12,5	10,2	11	11,2	12,1	13	16,3	20,1	20,5
	4,1	4,1	7,1	6,2	7,6	5,5	5	4,8	4,6	3,8	1,8	2,4
Kalmar	19,3	16,8	14,4	11,5	9,7	8,3	8,5	9,6	10,3	15	18,8	21,2
	3,1	3	6	5	7,6	6,3	6,1	5,3	4,8	3,8	2,2	2,5
Malmö	19,2	16,4	13,4	11,6	8,1	8,4	8,8	9,6	9,1	14,4	18,8	21,1
	3,1	3	6,2	5,5	7,6	6,5	5,2	5,2	5,6	3,8	1,8	2

Tab. 13: Number of clear and cloudy days on average per month

Since warm air rises in the greenhouse according to stack effect, there are different temperatures depending on the level. A Northern Italian climate is experienced on the ground floor, ranging between 25 and 30 degrees in summer days. On the roof terrace there is a temperature similar to the one in Southern Greece, reaching 45 degrees. In the basement a Swedish climate is preserved due to the ground influence.

In 2016, measurements were made by Liban Usman, a Karlstads University student, in a thesis aimed to scientifically demonstrate the efficacy of Solvarm's Naturhus (A. Solvarm Interview. 3rd June 2017). The purpose of his study was to detect the daily mean temperatures and humidity and compare results with daily average temperatures and RH outdoors. Data were collected during April and were verified through two methods: VIP-Energy of Sikhall *Naturhus* and IDA-ICE of a similar *Naturhus* from data collected by Persson and Wennerstål (Usman L., 2016) (Persson O., Wennerstål P., 2015).

To perform the measurements of the greenhouse temperature and RH, four Datalogger Mitec Satellite T and two Datalogger Mitec Satellite TH were used. The first sensors measure only temperature while the second are designed to measure both temperature and RH.

The six devices were placed at various locations, taking into account locations where the temperature undergoes significant differences.

Three Satellite T and a Satellite TH were employed on the roof terrace 3.4 metres above the ground level. On the North side, on the South side, and on the west side. The Satellite TH was placed in the eastern part of the roof terrace, pointing to the entrance door. Each Satellite on the roof have.

The other Satellite T was placed in the entrance hall of the core house, while the other Satellite TH was used as an outdoor temperature reference and placed outdoors, sheltered.

Figure 127 shows the daily average temperature in the greenhouse and outdoors during the month of April. The red line corresponds to the air temperatures in the greenhouse while the blue of the outside ones. The y-axis indicates the temperatures, while the x-axis the days.

The average temperature of the greenhouse is always higher than the outdoor average temperature. For April, it is scientifically confirmed that solar radiation and greenhouse effect increase the daily average temperature of the greenhouse of Sikhall *Naturhus*.

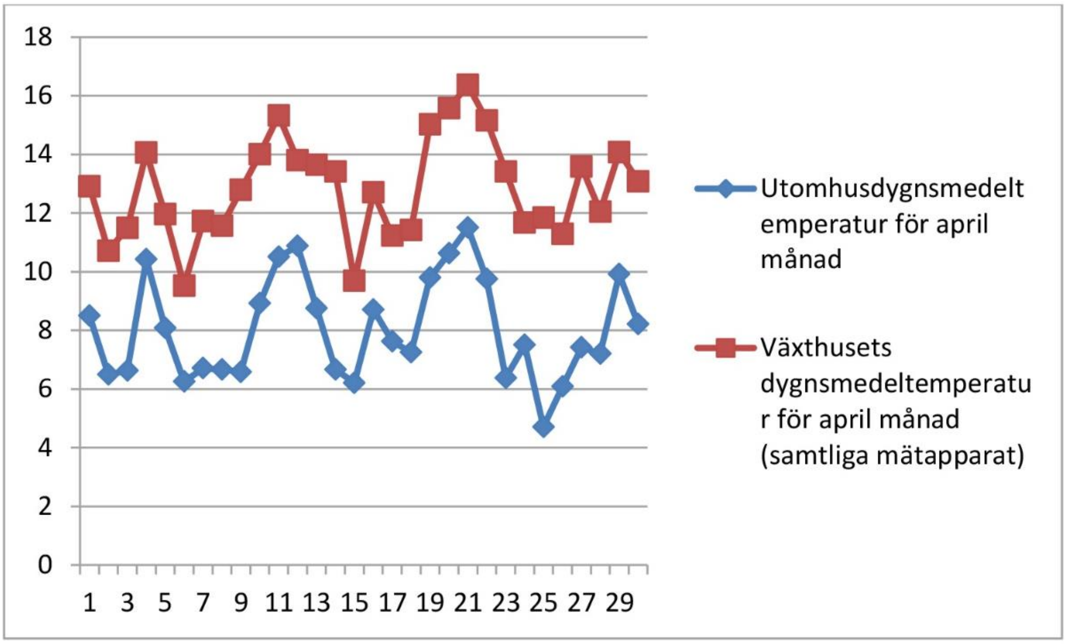


Fig. 127: Comparison between greenhouse (red) and outdoor (blue) daily average temperatures for April 2016

Measurement device	Monthly average temperature
Satellite T, South-East side, ground level	12.6 °C
Satellite TH, South-East side, 3.4 metres	14.5 °C
Satellite T, North-East side, 3.4 metres	12.3 °C
Satellite T, North-West side, 3.4 metres	11.95 °C
Satellite T, South-West side, 3.4 metres	12.7 °C
Average for all Satellites	12.8 °C
Satellite TH, placed outdoors	8 °C

Tab. 14: Average monthly temperature for each sensor for April 2016

Figure 128 shows a comparison of daily average temperatures in the greenhouse and outdoor (in orange).

The satellite in the North-East side was marked in blue, while South-West, North-West, South-East, are respectively red, green, and violet.

The last Satellite T in the entrance hall of the core house at ground level was marked in light-blue.

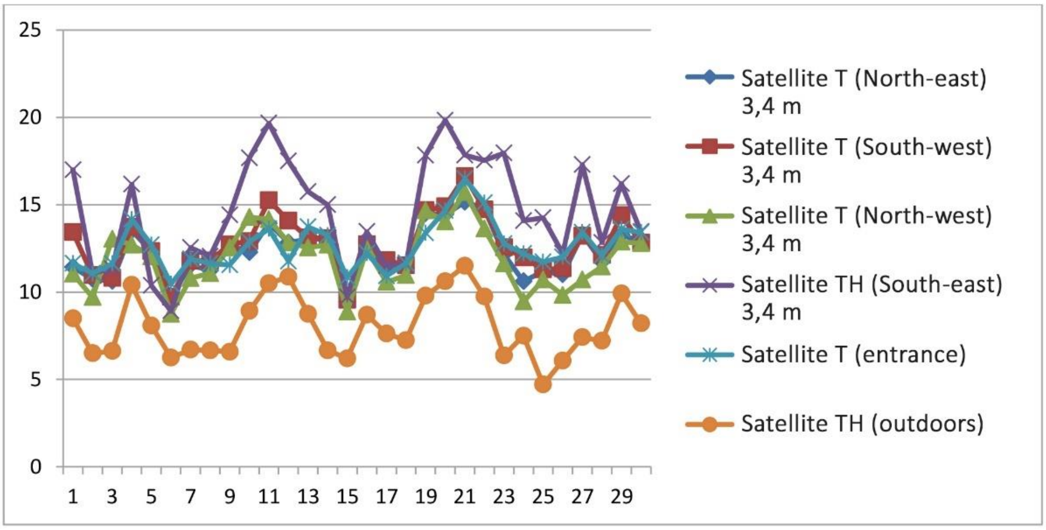


Fig. 128: Comparison between each Satellite and outdoor daily average temperatures

The North-West side, represented in green colour, had the lowest daily average temperature in April. In his bachelor thesis, Liban Usman explains that the North-West side was often shaded and darker than the others (due to the shading of the trees). However, because even such lowest average temperature (11.95 °C) was higher than the outside.

The greenhouse South-East side showed the highest daily average temperature due to solar radiation that reached directly this part of the house in the afternoon.

As previously written, the height also plays a significant role. The South-East side sensor at ground level recorded lower temperatures compared to that located at 3.4 metres in the same side (12.6 °C against 14.5 °C).

The greenhouse temperature depends on outdoors temperature. If the outdoor temperature is high, the greenhouse temperature is also high and vice versa.

After direct measurements in April, values were simulated for all the year by VIP-energy, using a schematic Revit model of the house. The temperature of the greenhouse in blue colour, the temperature outside in red, and the difference between the two in green, as in figure 129.

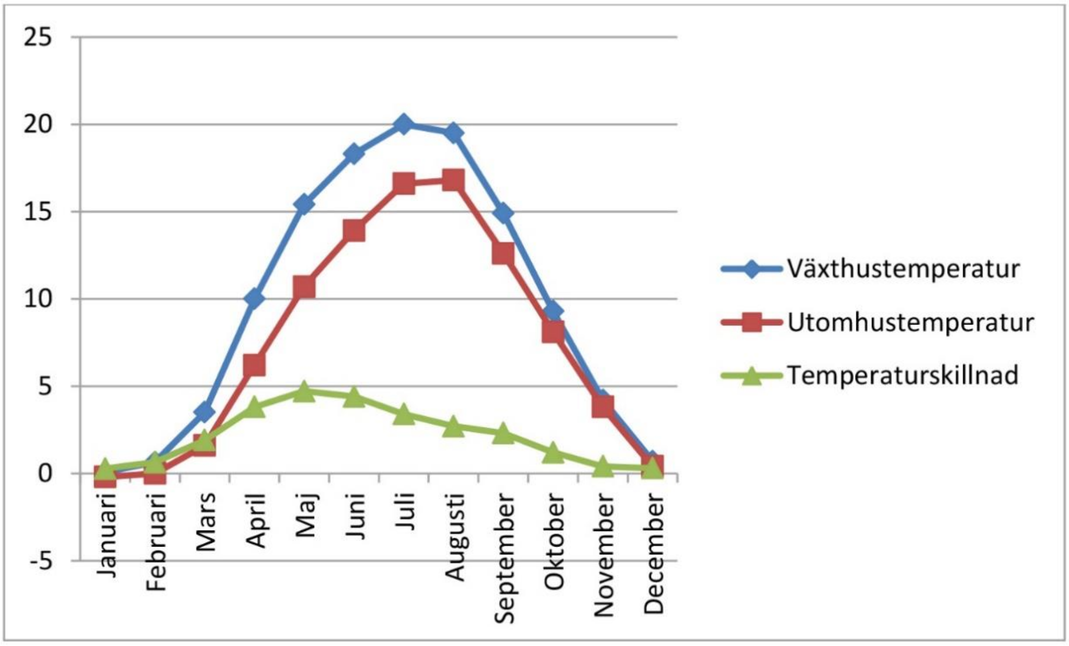


Fig. 129: Estimated monthly average temperatures in the greenhouse and outdoor

In winter months solar radiation is low, which means that the greenhouse does not contribute much to create a warmer environment. As soon as the Sun shines for more than eight hours (in March), the temperature difference increases (Usman L., 2016).

VIP-energy confirmed Solvarm's statement: the higher temperature differences occur during the month of May (A. Solvarm Interview. 3rd June 2017). The results were compared with IDA-ICE, a simulated method considering a similar *Naturhus,* called Sundby *Naturhus*, built by Solvarm and his company GreenHouse Living, in 2014 (see paragraph 3.9)

These methods confirmed that the greenhouse provided a higher average temperature than the outdoors, as shown in table 15.

	Greenhouse T.	Outdoors T.	T. difference
VIP-Energy (Sikhall *Naturhus*), in April (simulated)	10 °C	6.0 °C	4.0 °C
Satellite T data (Sikhall *Naturhus*) yearly (direct measurement)	12.8 °C	8.0 °C	4.8 °C
IDA-ICE (Sundby *Naturhus*), yearly (simulated)	8.9 °C	4.4 °C	4.5 °C

Tab. 15: Average temperatures according to VIP-Energy, Satellite T and IDA-ICE method.

Since it was not possible to simulate the greenhouse temperature in Sikhall, the Sikhall *Naturhus* simulation used Gothenburg temperature. It is evident that outdoor temperature used in the VIP-Energy simulation were not the same as the temperature in Sikhall. In addition, Gothenburg temperatures were not the actual temperatures in 2016, but they were average values derived from the comparison of several years (Usman L., 2016). Sundby is located between Stockholm and Norrtälje (http://www.sundbynaturhus.se/) and certain features of the *Naturhus* built there differ from Sikhall *Naturhus,* including design, material, etc.

Months	Sikhall Naturhus T.	Sundby Naturhus T.	T. difference
January	0.07 °C	-2.5 °C	2.57 °C
February	0.64 °C	0.7 °C	- 0.06 °C
March	3.5 °C	2.9 °C	0.6 °C
April	10 °C	8.9 °C	1.1 °C
May	15.4 °C	16.2 °C	- 0.8 °C
June	18.3 °C	18.1 °C	0.2 °C
July	20 °C	20.1 °C	- 0.1 °C
August	19.5 °C	18.9 C	0.6 °C
September	14.9 °C	14.1 °C	0.8 °C
October	9.3 °C	8.6 °C	0.7 °C
November	4.2 °C	2.9 °C	1.3 °C
December	0.7 °C	-1.0 °C	1.7 °C

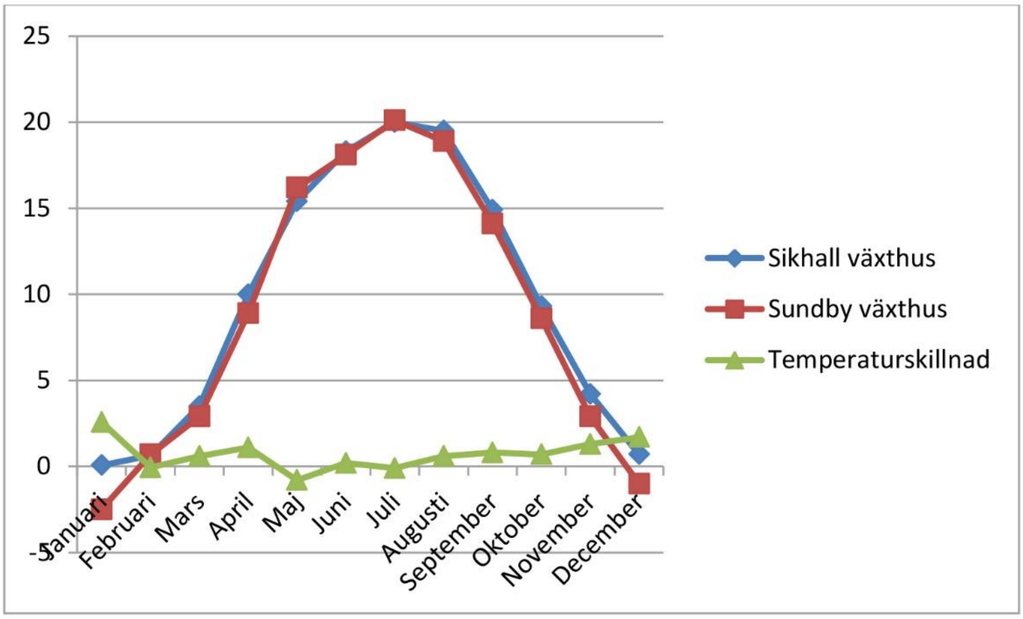


Fig. 130: VIP-Energy method in Sikhall and IDA-ICE method in Sundby (inside the greenhouse)

The temperature in the two *Naturhus* followed the same pattern throughout the year. Outdoor temperature data were compared as well, as shown in table 13 (figure 131)

Months	Sikhall outdoor T.	Sundby outdoor T.	T. difference
January	0.07 °C	-2.5 °C	2.57 °C
February	0.64 °C	0.7 °C	- 0.06 °C
March	3.5 °C	2.9 °C	0.6 °C
April	10 °C	8.9 °C	1.1 °C
May	15.4 °C	16.2 °C	- 0.8 °C
June	18.3 °C	18.1 °C	0.2 °C
July	20 °C	20.1 °C	- 0.1 °C
August	19.5 °C	18.9 C	0.6 °C
September	14.9 °C	14.1 °C	0.8 °C
October	9.3 °C	8.6 °C	0.7 °C
November	4.2 °C	2.9 °C	1.3 °C
December	0.7 °C	-1.0 °C	1.7 °C

Tab. 16: Monthly outdoor average temperature in Sikhall and Sundby

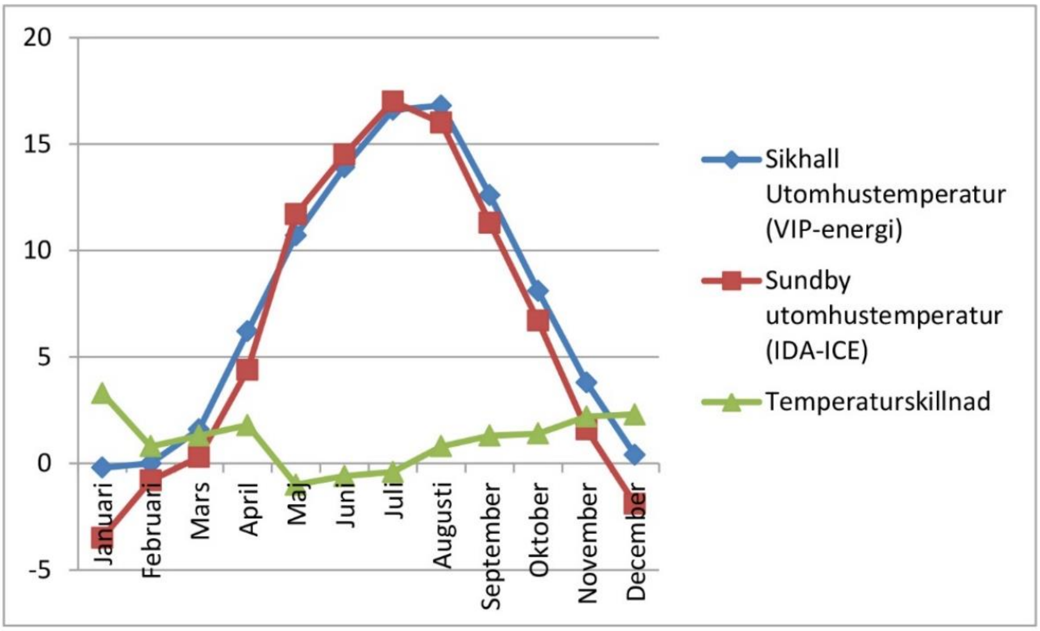


Fig. 131: Monthly outdoor average temperature in Sikhall and Sundby

Finally, Liban Usman compared daily average greenhouse and outdoors RH for Sikhall *Naturhus* during the month of April 2016, as shown in figure 132. The measurements show that the relative humidity within the greenhouse, in blue colour, was lower than that measured outdoors, in red.

When the damp air in the greenhouse is vented away from windows at the ridge, it is replaced by drier air at lower temperature and vapor content, which is heated by the greenhouse. This causes the relative humidity to decrease.

When relative humidity decreases, plants grow in the buffer space to maintain their balance as a reaction. This biological phenomenon would cause the air inside the greenhouse to become moister than outdoors. However, it was found that the greenhouse air was drier than outdoors because the heated air in the buffer space increases saturation, and therefore decreased RH.

Plants become essential for RH regulation because they can increase value. A low humidity level could break the ecosystem of the *Naturhus*, as well as a high value (paragraph 3.8).

In 2015, Solvarm reported that the greenhouse allowed to lower consumption, with a reduction of 30% compared to an ordinary house (Usman L., 2016).

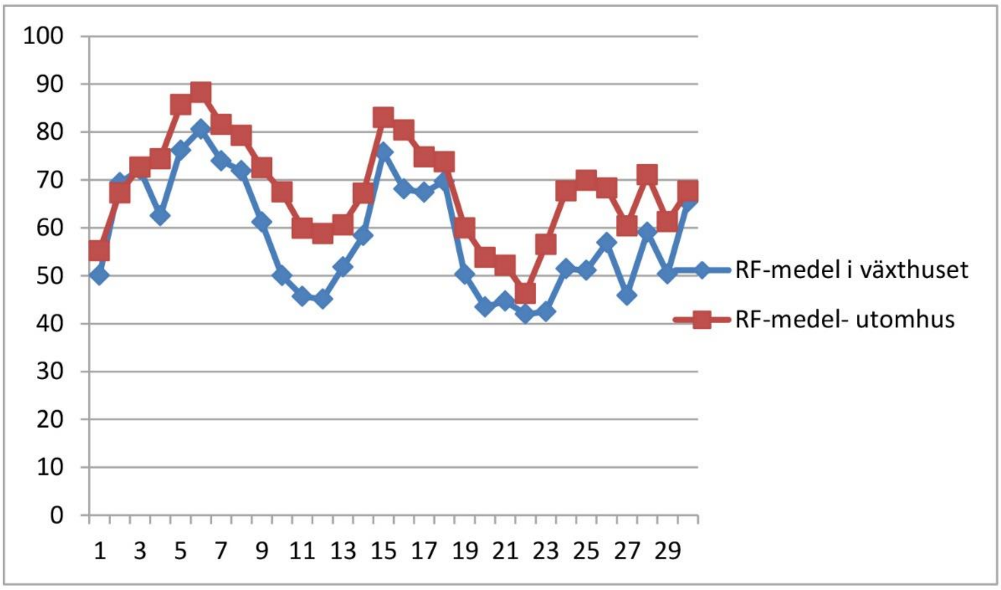


Fig. 132: Daily greenhouse and outdoors RH in Sikhall *Naturhus* for April 2016

The average greenhouse RH was 58% against outdoors RH of 68%.

In April, plants haven't yet reached their maximum blowing and growth, and the RH gained from plants transpiration is lower than in summer. However, temperature is too higher in summer, and the leaves of the plants cannot produce enough moisture. Air could be too dry and hot, but there are different solutions to solve such problem: automatic ventilation systems can replace a large amount of air in a few minutes, underground ventilation pipes can contribute to maintain the temperature balance, and plants in their maximum vitality can shade the house and maintain RH balance thanks to their leaves. In addition, entrance doors can be left open, contributing to natural ventilation (A. Solvarm Interview. 3rd June 2017). More details about natural, automatic, and manual ventilation system are provided in the next paragraph.

In conclusion, the values calculated by Liban Usman were fairly accurate since Satellite T data, VIP-Energy and IDA-ICE method provided similar values for both greenhouse and outdoor temperature. The fact that the greenhouse has a higher temperature than outdoors reduces the need for space heating when the Sun shines. This reduces energy consumption especially in March, April, May, September, and October (Usman L., 2016).

3.5 Air ventilation systems

The air cycle of Sikhall *Naturhus* is simpler than the one designed for the first *Naturhus.* In Sikhall, heat recovery from fans at the top of the greenhouse and from Clivus Multrum were eliminated. Warne's idea was simplified to make it easier to build for a non-professional, and to reduce costs.

The system consists of two pipes that run below grade and use geothermal energy to heat the air and transfer it into the greenhouse. Outdoor air enters thanks to a well-shaped cavity outside the greenhouse, as shown figure 133 on the left. The air runs around the core house in two pipes that are 35 centimetres in diameter and 20 metres long (as shown in figure 96), facilitated by a 2-metres difference in level (stack effect). This system allows a continuous operation, naturally and without energy spent. Air is finally released in the buffer space.

Fig. 133: The natural ventilation system (inlet and outlet), Andrea Antolloni

In the first *Naturhus*, windows were opened manually. In Sikhall the greenhouse openings are operated automatically by two weather stations, positioned inside the greenhouse and on its roof (as shown in figures 117, 134). Here, there are 42 openable glass modules covering a horizontal projection of 45 square metres, about one-eight of the floor area. The roof motors open them automatically when the greenhouse temperature exceeds 25 degrees, but they shut down automatically when it rains and in case of storm. A control station in the ground floor allows to operate them manually.

When the windows are open, the stack effect draws warm air from below out and calls cooler air from the underground pipes (and infiltrations in the greenhouse shell), with a higher flow rate at lower levels.

In addition to these passive ventilation systems, the two doors can be left open and used to provide ventilation as well, although less efficiently (A. Solvarm Interview. 3rd June 2017).

Fig. 134: Openable glass panels on the top of the greenhouse, Andrea Antolloni

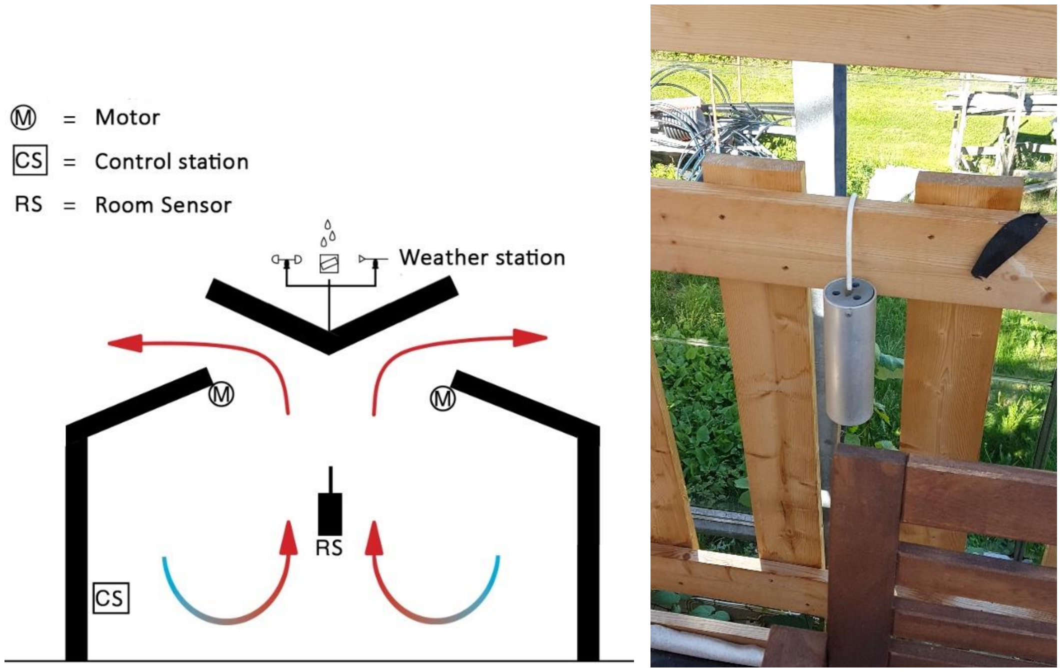


Fig. 135: Weather control devices (Drivadan, Andrea Antolloni)

3.6 Ecological solutions: "The Eco-cycle system"

Black and grey-wastewater and kitchen waste are treated (in the Eco-cycle System) to become a liquid fertilizer and a solid fertilizer collected once a year. Such system was imagined by Warne and designed by Solvarm. Subsequently, it was upgraded and improved by Solvarm and consultants to be free of excessive prices, maintenance, and security issues. After devising this project (and adapting it to his *Naturhus*), Solvarm began to install it in other homes in Sweden, with his company, the GreenHouse Living.

The system is located in the basement and it is composed of 5 tanks, as shown in figure 136. Anders Solvarm has his own well and therefore does not pay water bills, just electricity operating the various pumps of the system. Wastewater and solid waste flow into the first 3 tanks (1,2,3 figure 136), each larger more than one cubic metre. Here the solution is divided in floating and sinky substances. This takes place without filters, passing naturally through mid-height connections from one tank to the other. A siphon (A) conveys liquid in the fourth tank (4) clean water anaerobically. Water is purified in a phytodepuration process on the roof and is collected in the fifth tank (5). Finally, water is used in a second phytodepuration in the buffer space.

The only maintenance required by this system, save in exceptional cases, involves the removal of solid substances from the containers, this is performed once a year and takes about two hours.

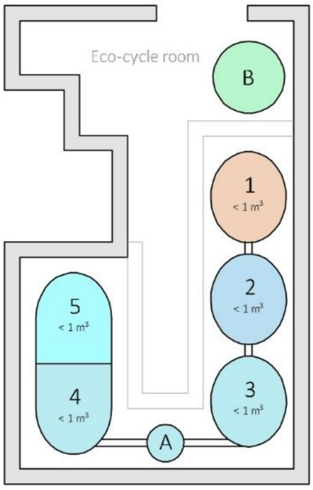


Fig. 136: The Eco-cycle system room, scale 1:100, Andrea Antolloni

An experimental integration to the Eco-cycle system was developed with Chalmers University of Göteborg. This project included a biogas recovery system (B) from the anaerobic tank, but it has not been possible to tested it due to the safety measures of Swedish laws. In fact, in order to comply with the norms, it would be necessary to include security features, for example steel safety doors and plastic covers, which would increase costs, grey energy, and environmental damage (A. Solvarm Interview. 3rd June 2017). With this biogas recovery system, the Eco-cycle system would be allowed to extract heat and natural gas (CH_4) and produce electricity. CNG could be obtained by methane (http://www.ch4biogas.com/technology/). In theory, it could also serve to fuel Solvarm's methane car. It is important to recall that Vänersborg is 20 km away from Sikhall and is the closest town for primary services such as supermarkets, hospitals, and schools (paragraph 3.2). As a consequence, it forces the family to move continuously, limiting the benefits that the *Naturhus* brings to the environment. A pump transports the water from the last tank of this system in two different cycles, that have been developed in the last five years.

Fig. 137: The Eco-cycle system, Andrea Antolloni

Contrary to the *Naturhus* in Saltsjöbaden, the Eco-cycle system overcomes the division between the Clivus Multrum (earth cycle) and the Clivus Trickle filtration system (water cycle) and produces a single liquid fertilizer solution. Once it exits this system, the solution is used to irrigate a plant bed on the roof of the core house, as shown in figure 138 (A. Solvarm Interview. 3rd June 2017). Eight pipes 50 mm in diameter have drilled holes and use underground pressure pumps to water such soil (Correspondence with Anders Solvarm, 2nd February 2018). The plant bed extends about 20 sqm and is 1,10 metres deep starting from the top of the roof.
Self-built by Solvarm after Warne's death, the fertilizer solution was filtered in a *jordbädd* (plant bed) with paprika and pumpkin plants, along with the substrate composed by a mix of expanded clay, peat, pumice and charcoal 0 to 18 mm in diameter. Charcoal is an essential element in *Naturhus* microbiology. It provides much space for microorganisms in its irregular and porous volume, unlike in rocks or pebbles where bacteria can only live on the surface. Reducing density by increasing the space for bacterial growth increases the filtration and water purification capacity. Water collected from this natural filtration system is periodically checked by experts, reaching a purity level ten times higher that of the water supplied by the municipality (A. Solvarm Interview. 3rd June 2017).

Fig. 138: The plant bed on the roof of the core house, Andrea Antolloni

From here, the water is pumped to water the plants in the buffer space. The plant bed running around the buffer space is larger than 18 sqm (figure 138) and runs around the house with a depth between 0,4 and 0,7 m; the substrate mix here is gravel, sand, expanded clay, and charcoal. (Correspondence with Anders Solvarm, 23rd October 2017). 300 l (60 l/person) of water is sent to the plant beds every day; the plants only need to be wet once a day to fresh their leaves (Correspondence with Anders Solvarm, 2nd February 2018). The water was tested to swim in, but not to drink due to high risk for bacteria.

Doctors check the quality of water in chemical laboratories and Solvarm, pushed by his ecological spirit, tastes it together with his cats. A report of May 2017 based on a one-year measurement, claims that this system is more than 10 times better at purifying water then the municipal system (Correspondence with Anders Solvarm, 23rd October 2017). The analysis was performed by Dr. Hamse Kjerstadius of the Emulsionen company, in comparison with Holmängen's ARV (the municipality system). The total emissions of nitrogen and phosphorus were lower for the *Naturhus* (a factor of 10 for phosphorus and 100 for nitrogen). Some amounts of these nutrients were recycled into plant beds. No nutrients were recycled from Holmängen's ARV, as all its sludge was sent to landfill (Kjerstadius H., 2017).

Fig. 139: The water stream in the entrance, Andrea Antolloni

For aesthetic reasons, the water flows down to the ground floor forming small streams at the entrance, as shown in figure 139. Small waterfalls at the entrance of the house were also planned to cool it during the summer (Correspondence with Anders Solvarm, 23rd October 2017). The excess water that is not used for irrigation is collected in a tank outside the house and used, for example, to take a shower or wash hands. As this tank has a limited capacity, Solvarm is forced to expel excess water out of the system. Such water is released into a small artificial pond near the house, containing red carps, as shown in figure 140. The pond is charged in winter, while virtually no water is released in summer.

Solvarm told me that he had observed that some of his plants suffered from heat and needed more water, so he told his children to wash their hands more often. It is interesting to know that in other parts of the world water use is seen from an economic point of view, to spare water and use it only when it needs it. In Solvarm's *Naturhus* system, water is collected and reused, so it is not wasted in sewers, rather is used by plants and organisms.

The development of the Eco-cycle system took place through continuous improvements to find the correct balance, for example between the size of the tanks and the amount of sanitary water needed by the family. Other factors included the amount of plants, the climatic conditions and the rainfall, and many others. The "try and learn" method is at the basis of the *Naturhus* concept (A. Solvarm Interview. 3rd June 2017). Such method goes hand in hand with permaculture and other experiments in *Naturhus* built by Warne, as discussed in the previous paragraphs.

Fig. 140: The pond near the Sikhall *Naturhus,* Andrea Antolloni

The collection of rainwater in the house is planned for the coming years, as well as a swimming pool for children on the roof: similarly to what was planned by Warne in the first *Naturhus*, Solvarm designed the roof terrace for a future swimming pool whose water is purified by plant beds. The water of such swimming pool will be reused for non-drinking services such as toilets, washing machines, etc.

As previously said, solid fertilizer is obtained from the Eco-cycle system by emptying the tanks once a year. The solid substances should be stored for at least 6 months or heated over 70 degrees to kill the pathogens before spreading it in the environment. Anders Solvarm and the GreenHouse Living are working on a new system that does not need any further treatment.

For a better understanding of the Eco-cycle system and its cycles, a diagram is provided below (figures 141, 142).

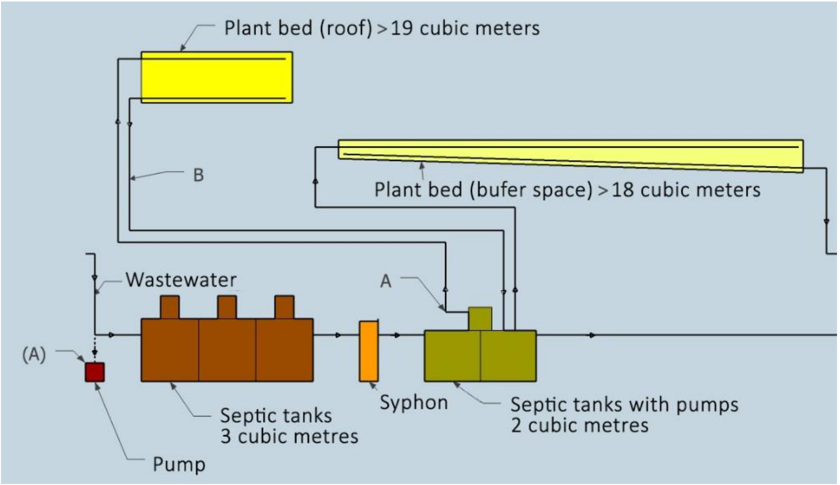


Fig. 141: The Eco-cycle system (within greenhouse)

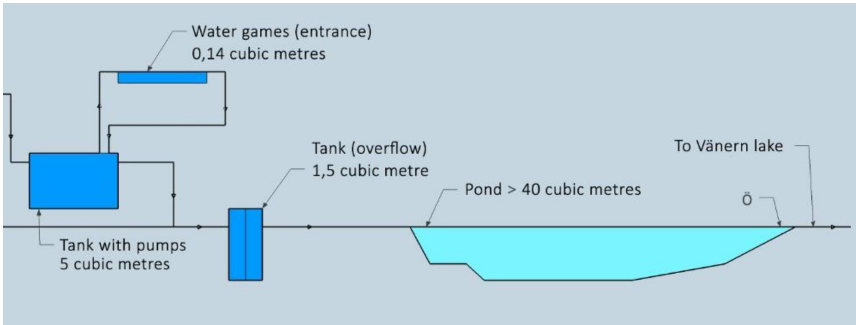


Fig. 142: The Eco-cycle system (outside greenhouse)

Pumps (A) introduce grey and black water into the tanks (in brown), where an anaerobic process is performed. A siphon (in orange) conveys liquid from the 3 tanks to further two tanks (in green). From here, the water is brought by pumps to the first plant bed above the core house roof (in yellow) and then it is returned to the second tank and is brought to plant beds in the buffer space. The two plant bad facilities are inside the greenhouse (figure 139). In front of the entrance, a water collection tank (in blue) takes care of the reuse of water, small streams and water games. Excess water is collected into a second tank (Å) outside the house and the overflows into a pond with fish (in light blue). Lastly, the water is drained to the Vänern lake (Correspondence with Anders Solvarm, 23rd October 2017).

3.7 Gardening

The total gross area available for plant growth is equal to the surface of the 315-sqm greenhouse, since it is possible to grow plants both in the buffer space around the 145-sqm core house and on top of it. The surface around the log house is about the same as the log house itself, following Warne's concept "*Hälften till nature*" discussed in paragraph 1.2.

Cultivation takes place in three zones: in the buffer space, inside the core house, and outdoor.

On the flat roof, pots and plant beds have been installed. The temperature is considerably higher there than at ground level and this allows to grow plants that endure Mediterranean temperatures such as lemon, paprika (figure 136), chili pepper, squash, and figs. (A. Solvarm Interview. 3rd June 2017). The cultivated plants change; tomatoes, pumpkins, aubergines and courgettes have been introduced at some stage (Correspondence with Anders Solvarm, 4th February 2018). There are also flowers such as geraniums and cyclamens, attracting butterflies and small insects. Even small birds can enter the greenhouse. In the first years birds happened to slam against the glasses, but inexplicably this ceased in recent years, without painting them (A. Solvarm Interview. 3rd June 2017).

Near the chimney and the plant bed (figure 143) there is a small wooden greenhouse covered by an opaque thermal cover. It is used as a nursery small plants in spring and as a winter storage for citrus (it is kept above 0 degrees with a small electric heater) (Correspondence with Anders Solvarm, 4th February 2018).

At the ground level strawberries, kiwis, lettuce, tomatoes, and cucumbers are planted along with apricots, lemon, and fig trees. In addition, many herbs are grown, such as mint, sage, laurel, parsley, rosemary, and basil. In Solvarm's *Naturhus* there are also grapevines which constitute the largest amount of vegetation (figure 141). They grow from the the buffer space and cling to the core house, forming a covering that protects it from the sun.

Fig. 143: The grapevines in the buffer space, Andrea Antolloni

Fig. 144: Lemon trees, geraniums, and herbs on the roof of the log house, Andrea Antolloni

Figure 145 and table 17 show the gardened plants; however, it is important to recall that the amount and type of plants change every year.

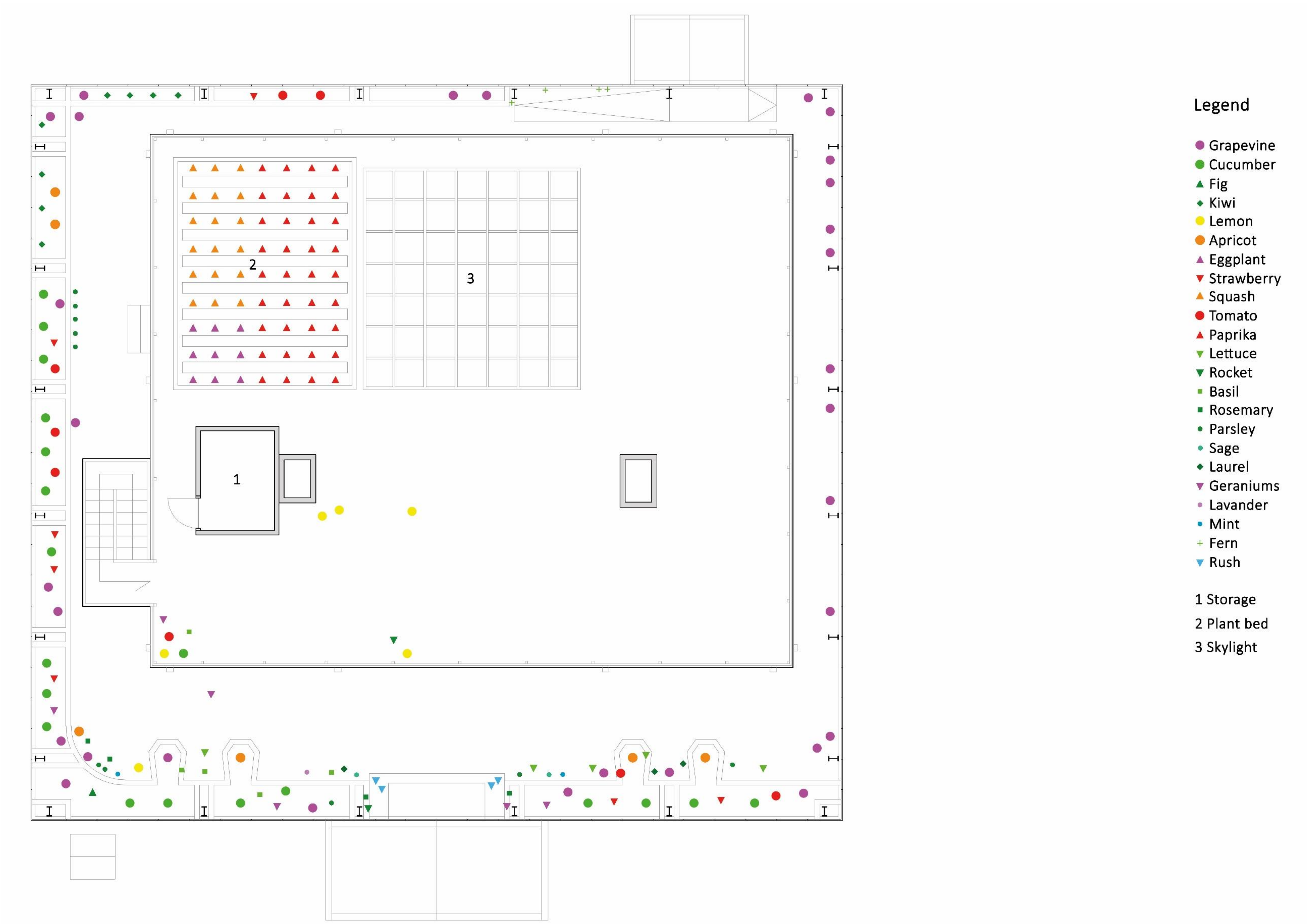


Fig. 145: Map of plant cultivation, Andrea Antolloni

Plant type	n° (-)	Dimension	h (m)	r (m)
Grapevine	31	Large	4,0	1,50
Apricots	6	Medium	1,5	0,75
Fig	1	Medium	1,5	0,75
Lemon	6	Small	1,5	0,75
Cucumber	19	Small	1,5	0,75
Squash	27	XSmall	0,5	0,25
Paprika	36	XSmall	0,5	0,25
Lettuce	5	XSmall	0,5	0,25
Rocket	2	XSmall	0,5	0,25
Tomato	2	XSmall	0,5	0,25
Rosemary	4	XSmall	0,5	0,25
Geraniums	6	XSmall	0,3	0,20
Sage	3	XXSmall	0,3	0,20
Mint	1	XXSmall	0,3	0,20
Parsley	10	XXSmall	0,3	0,20
Lavander	1	XXSmall	0,3	0,20
Ferns	3	XXSmall	0,3	0,20
Rush	4	XXSmall	0,3	0,20
Tot	**167**			

: Plants data (buffer space), 3rd June 2017

Planting a tree means a restriction of space which could be used differently, and this can lead problems (Correspondence with Anders Solvarm, 23rd October 2017). In accordance with Warne’s philosophy, study, design, and practical experiments are the keys to maintaining all kinds of balance. For example, in the past years Solvarm planted an American pumpkin. However, this plant grew out of control, suffocating other plants and becoming a problem for both the ecosystem and circulation. This also happened with a Chinese lettuce which overgrew, suffocating the surrounding plants.

When problems of overgrowth occur, it is essential cutting the plants and extirpating their bulbs (A. Solvarm Interview. 3rd June 2017).

In autumn, the leaves of most plants fall. As a result, moisture can drop much low and plants may not survive (Usman L., 2016). Therefore, Solvarm has thought of employing evergreen plants, but the solution has not yet been implemented (A. Solvarm Interview. 3rd June 2017).

In winter, the cultivation of Mediterranean plants is difficult since there are less than 8 hours of sunlight per day. The greenhouse temperature keeps plants for the next year, while cultivation is limited to lettuce, rocket, and grapevines (in pot) that grows indoor, with extra LED-light. The glass roof in the back half of the living room provides natural light for winter gardening; this skylight can be shaded with opaque sheets supported by wooden frames. In the future, semi-transparent PV panels designed by Solvarm may help save the costs of indoor lighting, increasing the amount of plants grown inside (Correspondence with Anders Solvarm, 23rd October 2017).

Finally, outdoor root vegetables are grown. These plants can withstand the local climate throughout the year. Solvarm grows potato, carrot, beetroot, parsnip, and some herbs in 16 plant beds 50 cm deep and of about 2 sqm. This helps to increase the percentage of self-sufficiency in vegetables, saving space in the buffer space (figure 145) and indoor (figure 146, 148).

In the future, Solvarm wants to increase outdoor cultivation; his goal is to double the plant beds (Correspondence with Anders Solvarm, 21st January 2018).

Fig. 146: Indoor gardening; fig. 147: Outdoor gardening, Andrea Antolloni

Figure 148: The Solvarms and their living room (2017)

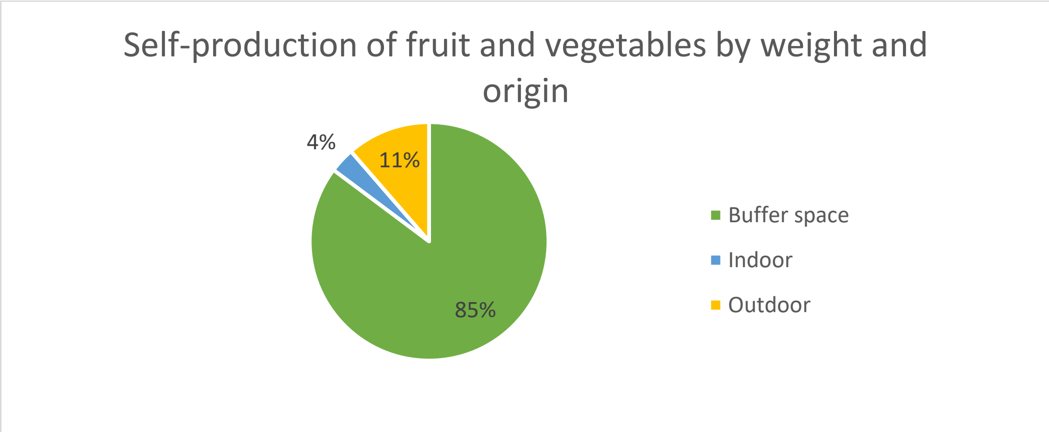
As previously stated, plants are essential to maintain the moisture balance in the *Naturhus*. They are also an integral part of the house in economic terms, producing fruit and vegetables for the family of 5 people.

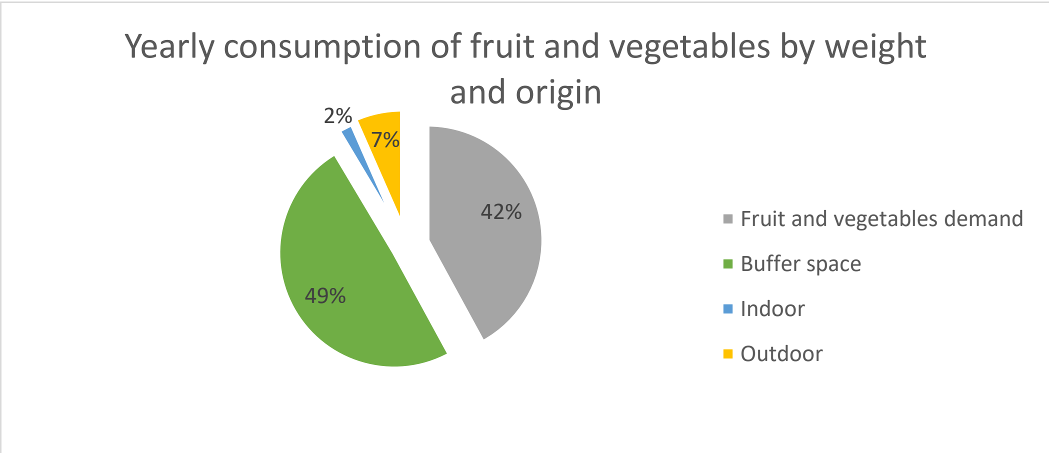
A total amount of fruits, vegetables, and spices, from 500 to 1.000 kg per year is produced. The grapevines alone produce from 200 to 400 kg of grapes per year and this contributes to saving (Correspondence with Anders Solvarm, 23rd October 2017).

The Solvarms consume an average amount of fruit and vegetables of 350 g per person per day and reached a 50% self-sufficiency in the three summer months. They consume 1,6 kg of food per person per day. To summarize the information, a table of the average consumption and production of food is provided, considering a waste of 20%.

					Production (kg)		
Fruit and vegetables	Day n° (-)	Person	Daily consumption (kg/p)	Fruit and vegetables demand (kg)	Buffer space	Indoor	Outdoor
April-September	182	5	0,35	318,50	750	10	50
October-March	183	5	0,35	320,25	0	20	50
All year	365	5	0,35	**638,75**	750	30	100

Food	Day n° (-)	Person n° (-)	Daily consumption (kg/p)	Food waste (-)	Food demand (kg)	Tot production (kg)
All year	365	5	1,6	20%	3504	880





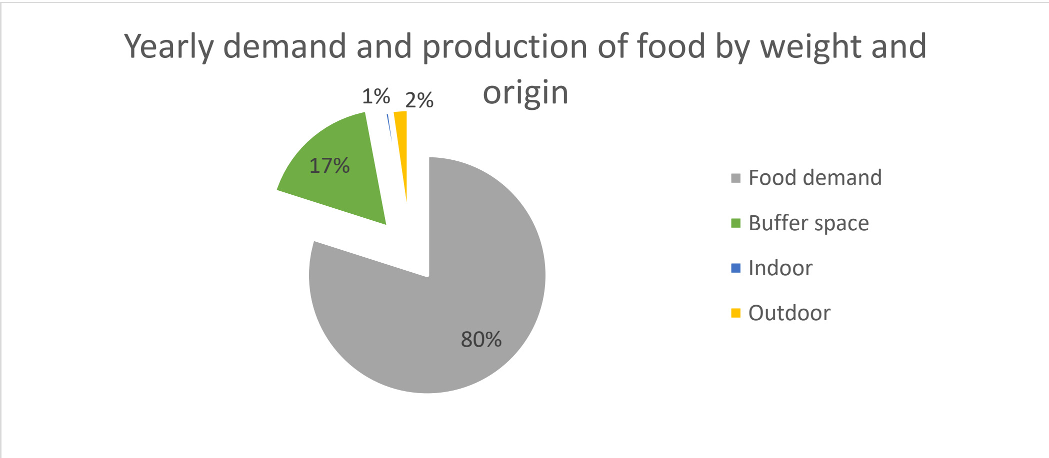


Fig. 149: Production and consumption data, Andrea Antolloni

Solvarm reported that they reach yearly a 20% self-sufficiency in terms of food. Since the *Naturhus* has reached the maximum exploitable space for indoor cultivation, Solvarm wants to increase gardening outdoor, to reach 25% of food production. Furthermore, he plans to obtain food from animal husbandry in 2018 (Correspondence with Anders Solvarm, 21st January 2018).

3.8 The Ecosystem of the *Naturhus*

As previously described, a small ecosystem with its own microclimate is created inside the greenhouse.

In agreement with Warne's philosophy, plants grow here without chemical pesticides and surface disinfection. In fact, *Naturhus* ecosystem has its own settings, designed and regulated by Solvarm and his GreenHouse Living team. The Eco-cycle system helps to maintain this balance by providing water to grow plants without human intervention.

The greenhouse effect allows the growth of Mediterranean plants (figure 150), which outside would not survive in the Swedish climate (table 18). The increase of indoor temperature from 10 ° C to 15 ° C compared to the outside leads in mostly of cases to a decrease in humidity levels (Solvarm A., Interview. 3rd June 2017).

Plants contribute to raise the humidity of the air inside the greenhouse, maintaining it at 40% to 70%. The amount of plants is a determining factor: if the amount of moisture produced were less than that evaporated in the greenhouse, the air would be too dry, not allowing the correct growth of all plants in the *Naturhus*. Even bacteria may suffer from this lower level in humidity, as well as insects, small animals, and even humans.

Once the temperature for plants growth has been reached, the moisture content must also be taken into account. The greenhouse humidity depends on the balance between the amount of incoming and outcoming air. A considerable increase in humidity is possible through the transpiration of plants and the evaporation of water (and a small increase through human generated moisture), but only if the windows are closed. On the other hand, the moisture content can be reduced by condensation and ventilation of indoor air (paragraph 3.5).

During summer the hot air inside the greenhouse can lead to moisture condensation, but it doesn't cause any other problem, because the windows at the top of the greenhouse can always be opened to let new air in (Usman L., 2016).

Fig. 150: Plants in the buffer space, West view

One of the main matter of the *Naturhus* is to know the amount of water that has to be applied into the soil; too much water means a waste of water. Too little water causes the plants to wilt.

As only temperature data is available (paragraph 3.4), a theoretical method (the Blaney-Criddle method) to calculate the reference crop evapotranspiration (ETo in mm/day^{-1}) has to be used. It should be noted that this method is not very accurate; it provides a rough estimate (www.fao.org).

Only the grapevines will be considered in the calculation as they are greater in quantity, occupying about 50 m^2 (Solvarm A., Interview. 3rd June 2017).

Fig. 151: Description of the ETo estimation, FAO

The reference crop evapotranspiration (ETo) is the amount of water needed to meet the water loss through evapotranspiration (1), in this case 4.4 mm/day^{-1} (for 58° 29' N Sikhall latitude [tab. 18] and 12.8 °C T mean in April 2016 - paragraph 3.4).

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$$ETo = p\ (0.46\ T\ mean + 8) \qquad (1)$$

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60°		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16

Tab. 18: Mean daily percentage (*p*) of annual daytime hours

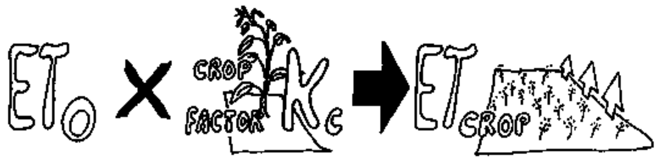


Fig. 152: Description of the ET crop estimation, FAO

The crop water need (ET crop) is calculated monthly, using the formula (2); in this case 3.96 mm/day^{-1} for grapevine (0.90 Kc – tab 19).

$$ET\ crop = ETo \times Kc \qquad (2)$$

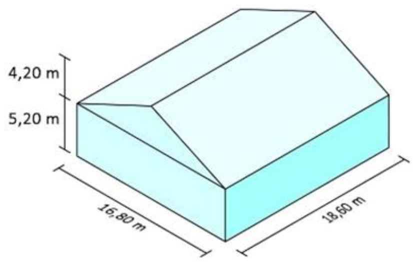
Crop	$K_{c\,ini}$	$K_{c\,mid}$	$K_{c\,end}$	Maximum Crop Height (h) (m)
m. Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes				
- Table or Raisin	0.30	0.85	0.45	2
- Wine	0.30	0.70	0.45	1.5-2
Hops	0.3	1.05	0.85	5

Tab. 19: Crop factor (Kc) for grapevine

The evapotranspiration rate is normally expressed in millimetres (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. As one hectare has a surface of 10.000 m^2 and 1 mm is equal to 0,001 m, a loss of 1 mm of water corresponds to a loss of 10 m^3 of water per hectare. In other words, 1 mm day^{-1} is equivalent to 10 m^3 ha^{-1} day^{-1} (table 20).

	depth	volume per unit area		energy per unit area *
	mm day^{-1}	m^3 ha^{-1} day^{-1}	l s^{-1} ha^{-1}	MJ m^{-2} day^{-1}
1 mm day^{-1}	1	10	0.116	2.45
1 m^3 ha^{-1} day^{-1}	0.1	1	0.012	0.245
1 l s^{-1} ha^{-1}	8.640	86.40	1	21.17
1 MJ m^{-2} day^{-1}	0.408	4.082	0.047	1

Tab. 20 Conversion factor for evapotranspiration (www.fao.org)



	a (m)	b (m)	Area (m^2)	h (m)	Volume (m^3)
Core House	11,50	14,00	161,00	5,20	837,20
Greenhouse walls	16,80	18,60	312,48	5,20	1.624,90
Greenhouse roof					625,00
Buried Basement					13,00
Tot buffer space			**151,48**		**2.262,90**

Tab. 21: *Naturhus* data, Andrea Antolloni

The grapevines have a daily evapotranspiration of 0,198 m^3 (198 liters) of water (6 liters for each plant).

The data are interesting since there is no direct rain inside the *Naturhus*. With a daily consumption of 300 l, the Eco-cycle system (paragraph 3.6) allows water to be reused and saved. The values can be considered acceptable since Anders Solvarm reported that in summer (plants at their maximum growth) almost no water is released from the Eco-cycle system to the pond (paragraph 3.6).

3.9 The GreenHouse Living company

Anders Solvarm has made a job of his experience in the *Naturhus*. In fact, he builds *Naturhus* with his company, GreenHouse Living. This company partners with Darking (engineering), Ecorelief (the Solvarms), Emulsionen (energy and environmental technology), and Tailor Made Architects (A. Solvarm Interview. 3rd June 2017). Solvarm is the chairman of the Naturhusförening, an association that promotes the spreading of the *Naturhus* (http://www.greenhouseliving.se/); Charles Sacilotto is active in the Naturhusförening as vice chairman.

Ecorelief has also been involved in the design and construction of Sundby *Naturhus*, in Vallentuna, giving comments and suggestions. Here, they also constructed the Eco-cycle system.

The project was modelled on Solvarm house in Sikhall, but in a smaller scale. An energy simulation made by Persson and Wennerstål showed that the heat demand in a year for Sundby *Naturhus* would have been decreased by 32,9 % if the core house was enclosed by a greenhouse. The energy demand is 35,8 kWh/sqm per year, measured after construction (Persson O., Wennerstål P., 2015).

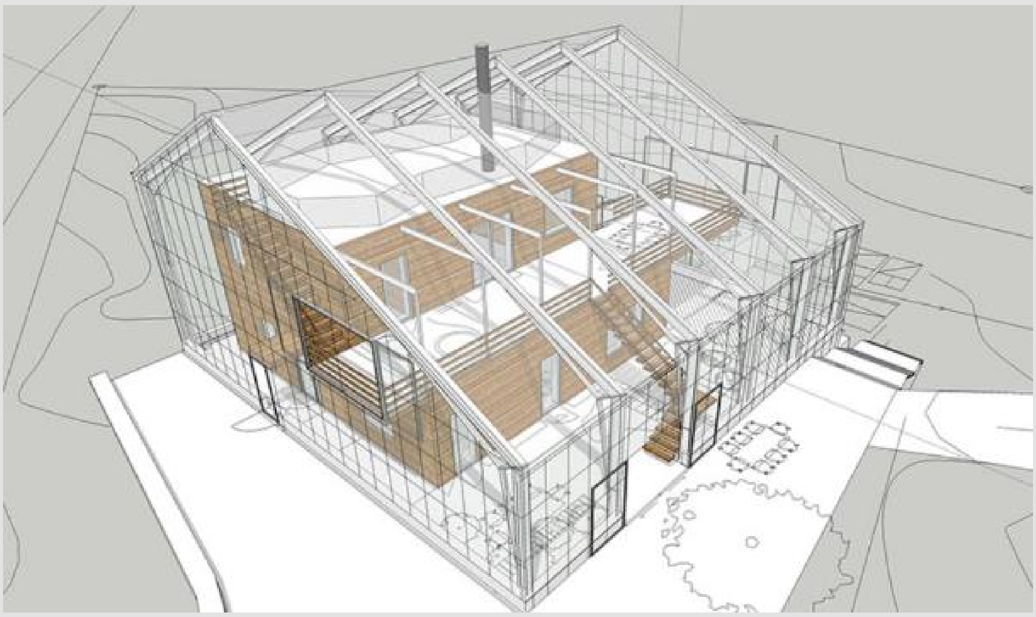


Fig. 153: Sundby *Naturhus,* 2014

In 2015, GreenHouse Living built Uppgrenna *Naturhus*, in Gränna. An existing barn was partially demolished and replaced by a modern building with a flat floor and surrounded by a greenhouse (figure 154) (A. Solvarm Interview. 3rd June 2017).

This project is the first commercial *Naturhus* that experiments with the possibility of selling what is produced indoor (and also outdoor). The building consists of a 520-sqm spa, with a small café and a conference area. As in Solvarm *Naturhus,* the roof and the buffer space have plant beds, and there is no connection to municipal sewer (http://tailor-made.se/).

A 35-sqm conservatory of citrus trees is involved in the Eco-cycle system to clean wastewater from kitchen and bathrooms. Grapevine, apricot, melon, fig, tomato, and peach are also growing, producing fruit and vegetables from March to October (http://uppgrennanaturhus.se/).

Fig. 154: Uppgrenna *Naturhus,* 2015

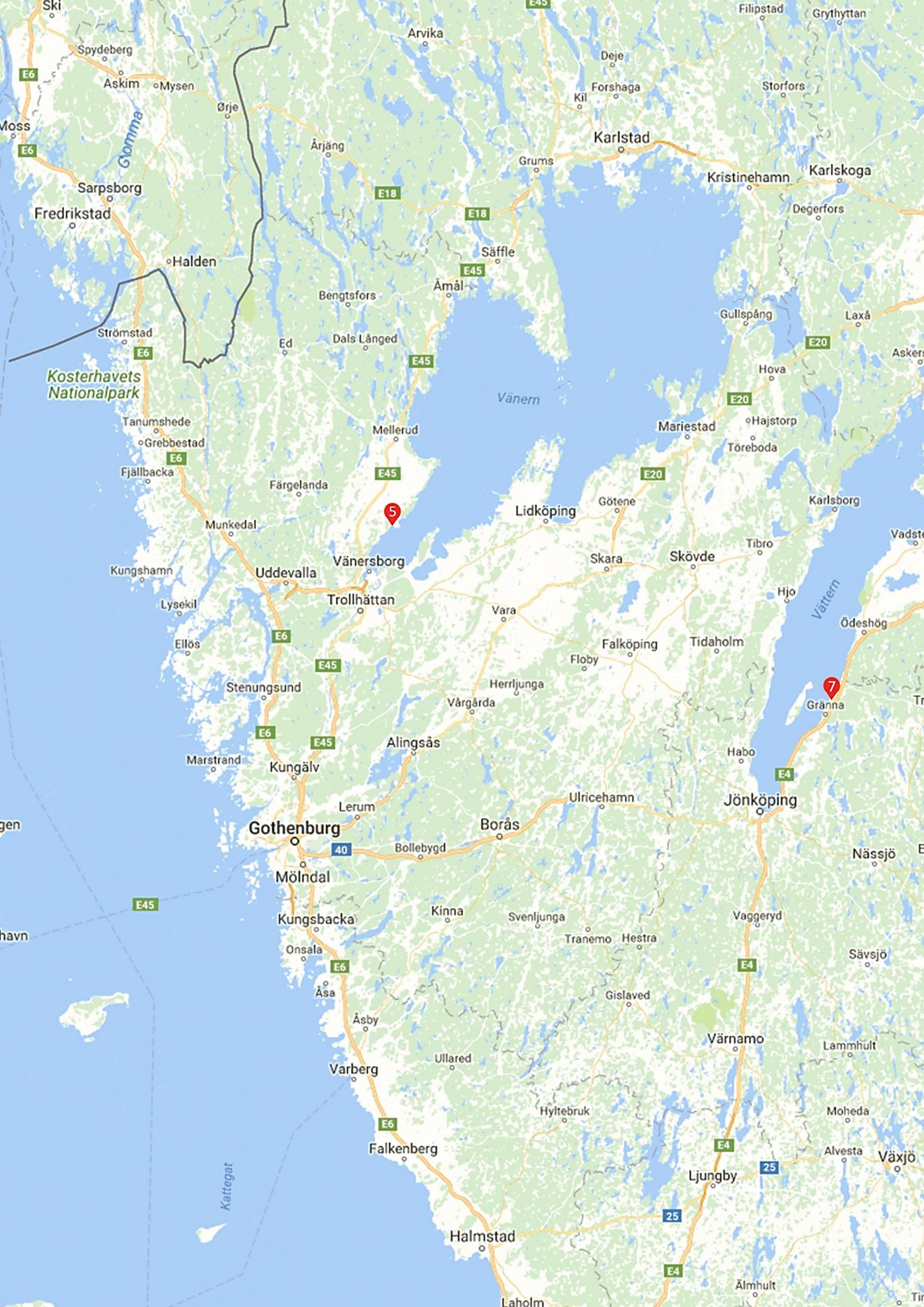
More Greenhouse Living *Naturhus* are under development, as the Felleshus (in an urban environment in Linköping) or the Lindbaken Nature House (a residence in Uppsala) (http://www.greenhouseliving.se/).

CHAPTER 4
Conclusions

This thesis shows the *Naturhus* evolution. Warne fulfilled his ideas and the "Symbio Housing" concept he developed in the 70s persuaded Charles Sacilotto and Anders Solvarm to build their own *Naturhus*. Solvarm and Sacilotto houses and their wastewater recovery systems were examined. In Sacilotto's system output water cannot be drunk but can be used for watering non-edible plants. In Solvarm's Eco-cycle system the purified water is tested to swim in and is used to water edible plants. The Eco-cycle system purifies 300 l of wastewater per day, balancing the watering cost for plants. Mediterranean plants can survive in the buffer space from March to October. In summer, the Sacilottos are 30% self-sufficient in terms of fruit and vegetables; the Solvarms reach 75%. Future in-depth analysis could provide the correct balance between the plants quantity, wastewater reuse for the watering, and food production.

For the log house of Solvarm *Naturhus* the embodied energy is 46.926 MJ. By weight, Solvarm *Naturhus* is made of about 28% concrete, 3% galvanized steel, 19% timber, 11% Leca block and 20% bricks; the plant bed on the roof increases the weight by 15%. Rubber on the roof, although with relatively low weight, has a high embodied energy and embodied carbon. Liban Usman measured a difference of 4 °C between indoor and outdoor (April 2016) and of 4.8 °C from annual simulation. Despite the presence of plants, the average buffer space RH was 58% against 68% outdoors (April 2016). A possible development for this thesis concerns the eco-cycle system, which could be studied and combined with plants evapotranspiration and air moisture content analysis. Persson and Wennerstål showed that the yearly heat demand for Sundby *Naturhus* decreased by 32,9 % thanks to the greenhouse (2015). This is also confirmed by Usman simulations for Solvarm *Naturhus*. The results scientifically demonstrate that Warne's ideas in the 70s were valid.

In recent years, the GreenHouse Living is developing *Naturhus* in Sweden. It could be interesting to investigate if these *Naturhus* can be adapted to other European countries.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Kristinehamn
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Sarpsborg
Fredrikstad
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Halden
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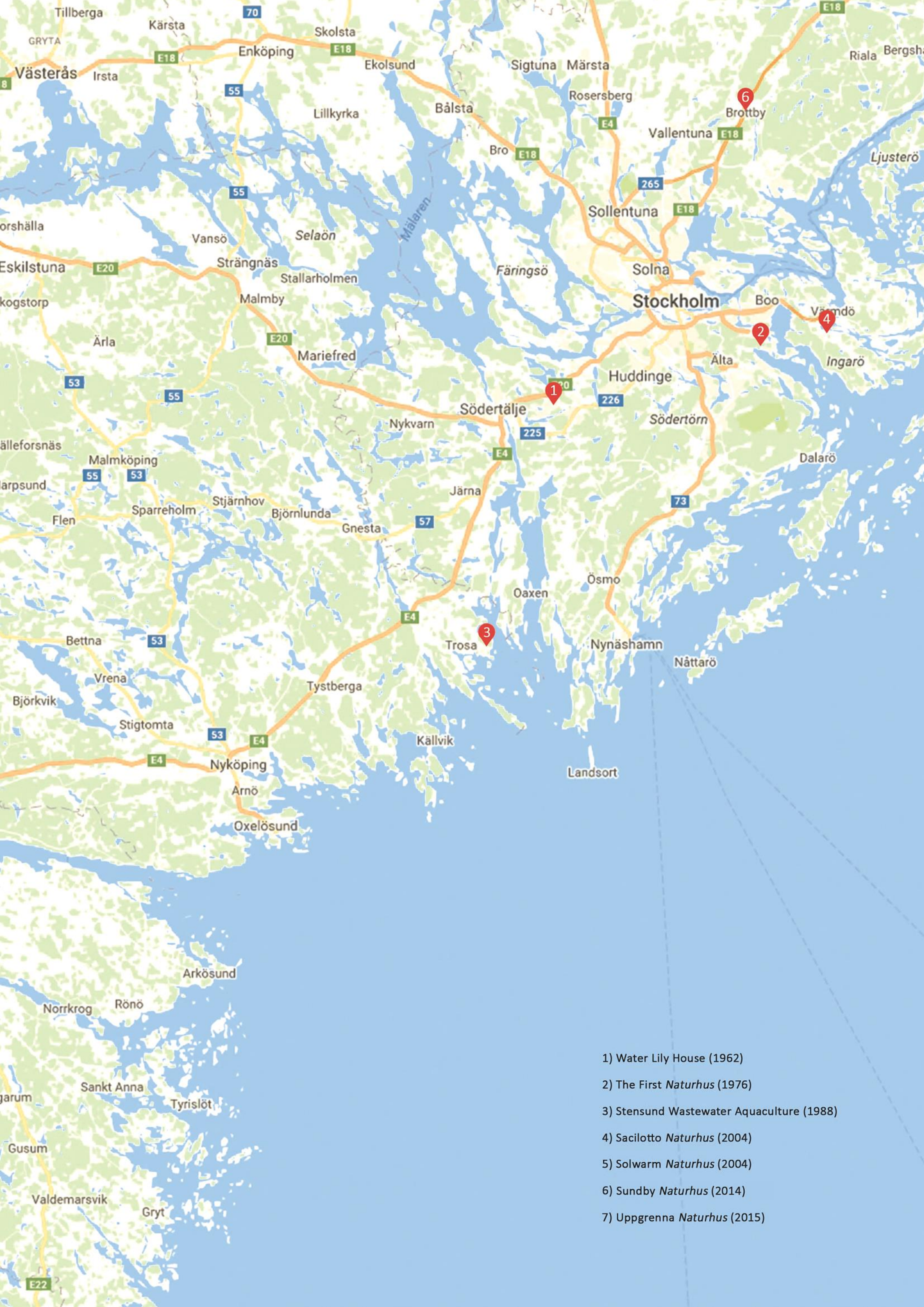
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1) Water Lily House (1962)
2) The First Naturhus (1976)
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