Resilient Home Add-On

Quebec, Canada

1. Presentation

Document Pages:

Initial Parameters

Existing bungalow on a predominantly wooded three-acre lot, located in Bromont, Quebec, Canada.

The owners are a middle-aged couple of active professionnals who like to garden in their spare time. They wanted to add to their existing home:

- A greenhouse to extend the growing season;
- A relaxation space that can be used throughout the year;
- Sustainability and resilience without significantly altering the existing house to minimize the construction's environmental footprint.

Project Timeline

2021: Clarification of needs and design

Nov. 2021: Permit request

Feb. 2022: Permit received

May 2022: Construction started

Nov. 2022: End of general construction

2023: Finishing stage

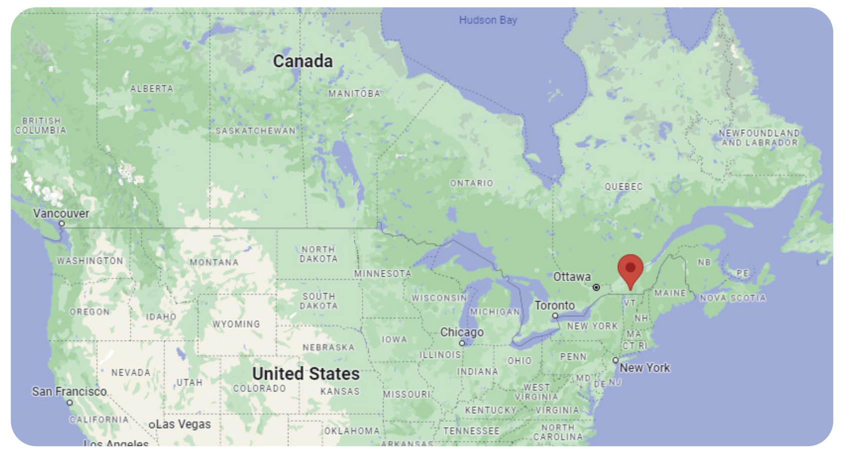
2024: Landscaping

Night View,
S-E Corner,
March 2023

Geographic Position

Bromont, Quebec, Canada

45° 19' 45" N / 72° 37' 33" W

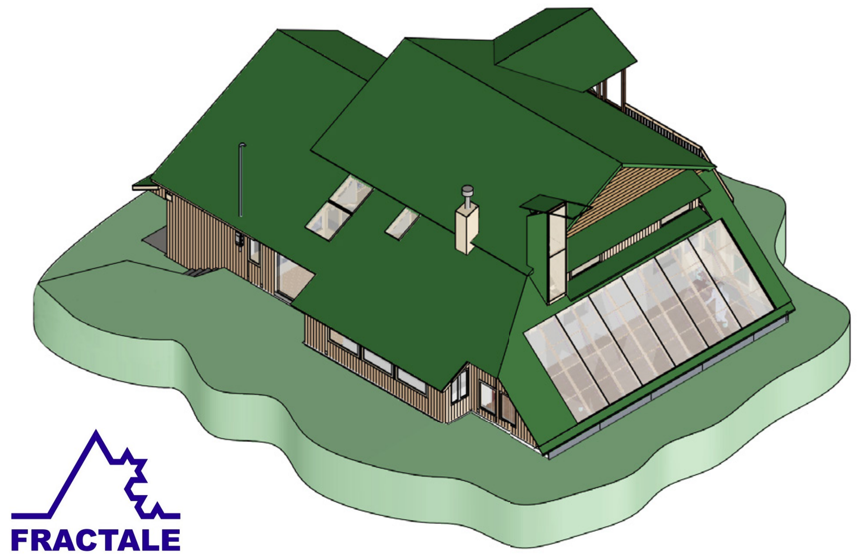


Map of North-America, Source: Google map

Satellite picture of the site, Source: Infolot

North View

Isometric S-W View



During Construction, N-W corner, May 2022

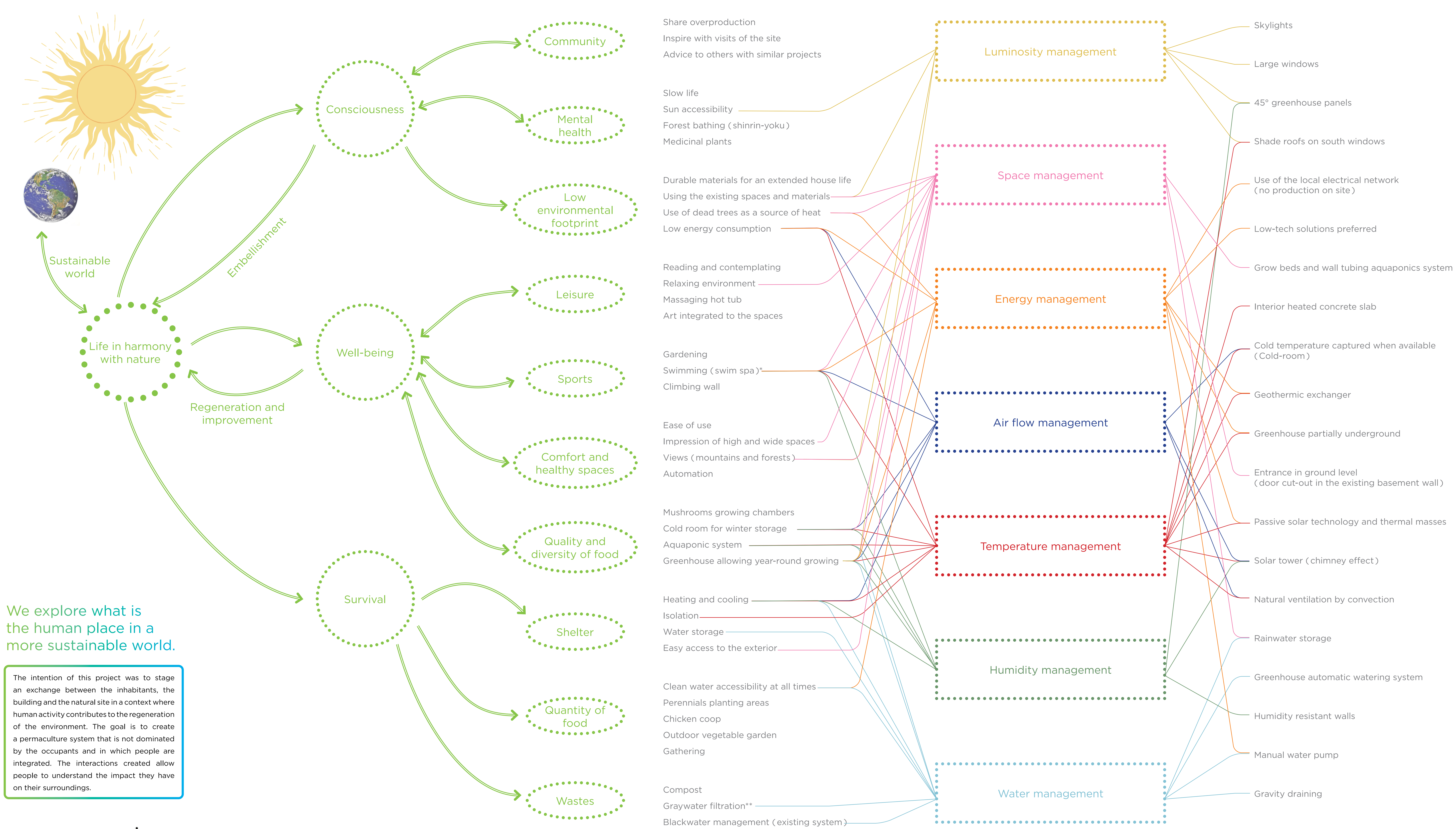
Inside the Greenhouse, Simulation, view to the S-W

S-W corner, Solar tower extracting air even during winter

FRACTALE

2. Philosophy

Mind Map of Needs and Solutions



We explore what is the human place in a more sustainable world.

The intention of this project was to stage an exchange between the inhabitants, the building and the natural site in a context where human activity contributes to the regeneration of the environment. The goal is to create a permaculture system that is not dominated by the occupants and in which people are integrated. The interactions created allow people to understand the impact they have on their surroundings.

Ego-centered Approach

Ecological Approach

Regenerative Approach

Renewable Energy Context

Quebec generates most of its electricity from 94% hydroelectric power and 5% wind power. The cost of electricity per kWh is among the lowest in the world, about 0.08 $CA /kWh (0.06 $US).

Since the house is only connected to the Quebec renewable energy grid, it would not be interesting both environmentally and budget-wise to equip the house with new solar panels or a small wind turbine with batteries, as these would leave a larger environmental footprint than connecting to an existing strong grid. The resilience of the home is reinforced either through passive systems or redundancy to minimize the impact of a temporary power outage. Example: Adding a manual water pump or heating the house with wood from the field. This choice only applies to this location, in other countries or remote locations the decision could be different.

* About swim spa

The request came from the owners, who were eager to incorporate swimming and relaxing in the water into their daily lives without overly burdening the Earth with such luxury. Our goal was to accommodate this request in a way that minimizes the footprint of this decision. See calculations on page 4, almost all of the heat loss from the swim spa is captured in the greenhouse and it becomes part of the greenhouse's climate system.

** About graywater filtration for this project

See water management on page 4

Our definitions applied to this project:

Resilience:
Limit dependence and have alternatives.

Holistic:
The design integrated into the lives of the occupants is greater than the sum of the individual systems within it.

Regeneration:
The natural process of restoring something that has been damaged.

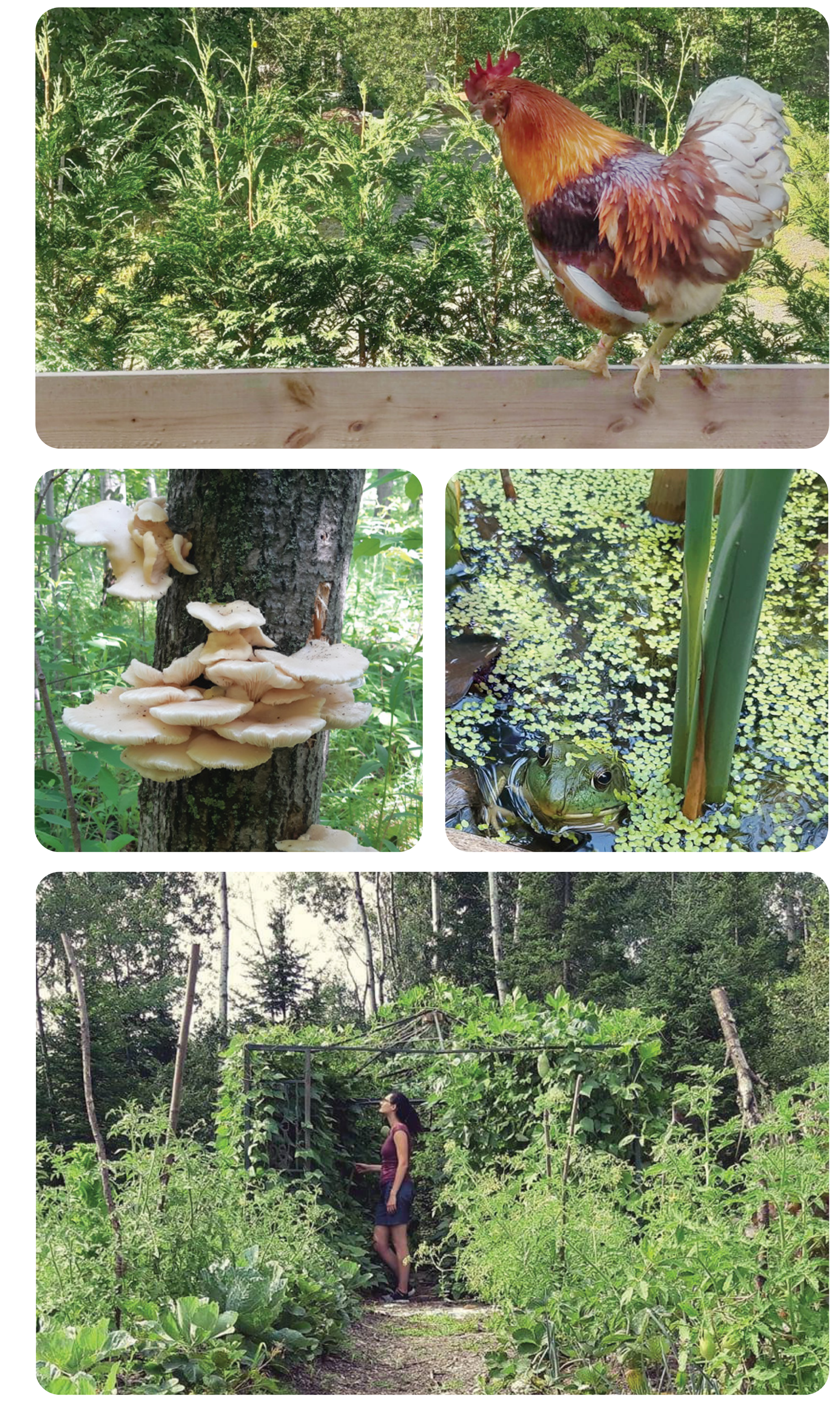
Sustainable:
Designed in a way that does little or no harm to the environment and therefore can persist for a long time.

Lifestyle

The building becomes part of a regeneration perspective. There is less need for residents to move: If the changes on the original house had not been made, the equivalent of pollution from traffic would have been greater.

The goal is to look at the big picture of our daily lives and determine which activities have a greater impact on the Earth. This thought process allows us to better understand which battles need to be prioritized to maximize the impact of the project.

The food produced in the greenhouse provides a long-term amortization of the infrastructures. Aside from interest costs, the fundamental impact is reduced pollution from automobile traffic and the elimination of packaging (which is not yet very well recycled in Canada). The house provides benefits that reduce pollution by improving the lives of the residents.



Philosophy of the Project

We believe it is more sustainable and challenging to work with existing buildings and redesign them to meet the needs of residents in an environmentally responsible manner than to build new infrastructure on undeveloped land.

Human activity is inevitable and pollutes the environment. Our goal is to reduce the impact through hyper-proximity and amenities. Needs must be truly understood and identified, consequently the use of the infrastructure and equipment chosen will be maximized during the life of the building.

Our vision is a world where people realize that living in a resilient and sustainable environment is accessible to everyone. Sustainable construction concepts can be perceived as a niche and those who already own a building often cannot imagine them being applied to their property. With this example, we hope to show how we have already customized an existing conventional home to a more resilient lifestyle in order to inspire others to apply these principles to their own projects.

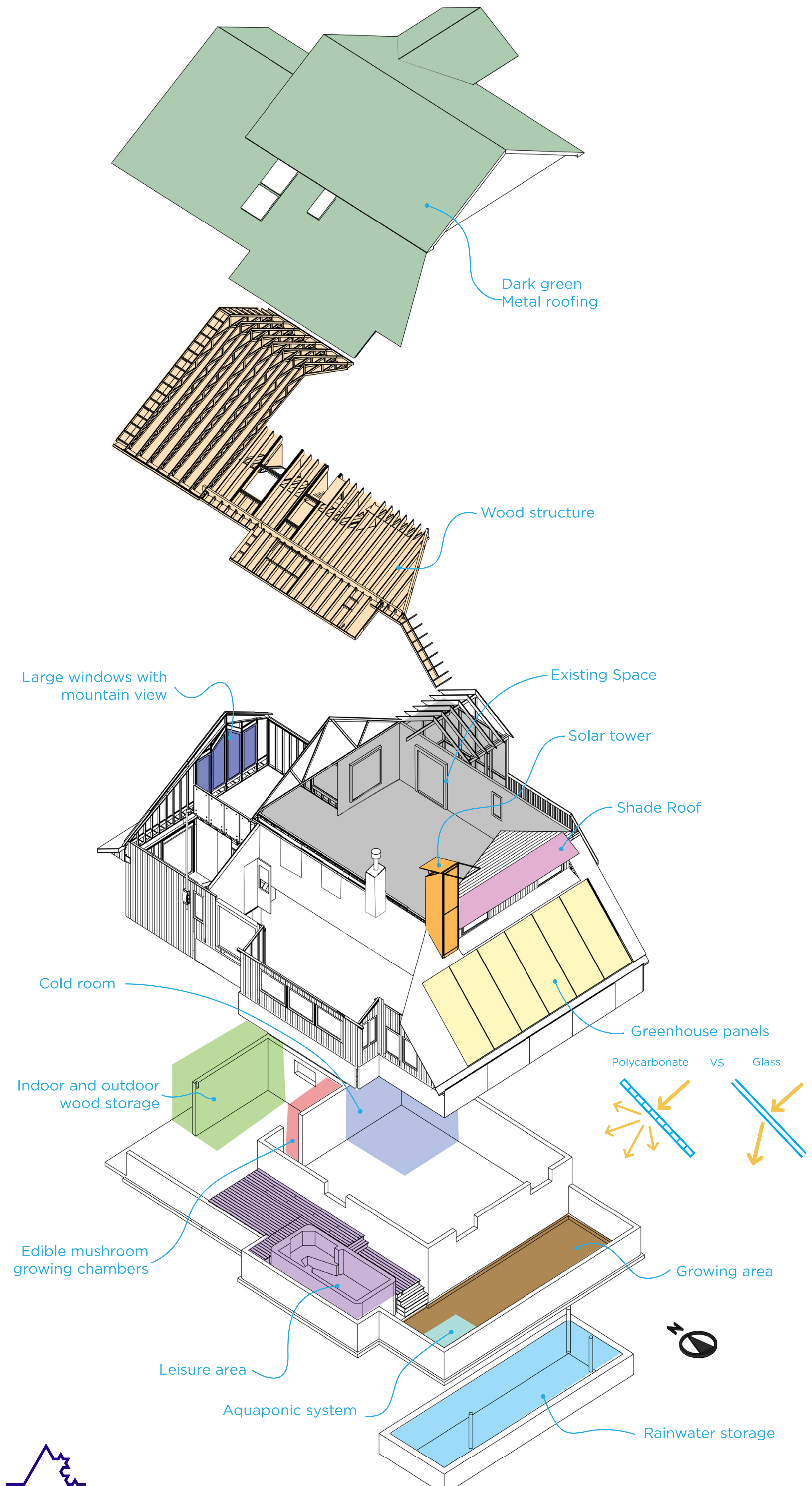
We promote a life of abundance and accomplishment in which the infrastructure serves as a tool to directly satisfy some of the basic needs of the occupants without being self-sufficient or off the grid.

Regeneration of the environment starts with awareness of the inevitable impact our own lives have on the Earth. It begins at the moment a resilient house is functional as opposed to a conventional house that, with its inhabitants, will always drain energy from the environment.

We believe that every aspect of the project should be integrated into a broader philosophy. This project is an engineering and design challenge for us. We developed the functionality until the design became simple and obvious.

"Design is not just what it looks like and feels like.
Design is how it works."
-Steve Jobs

3. Architecture



Design Choices

The leisure area is connected to the greenhouse, so the climate there is much more pleasant than outside. The layout of the hot tub and patio creates a space that promotes relaxation while providing quick access to the outdoors. The greenhouse also benefits from the heat and humidity of the hot tub.

A wall covering made from lime plaster and Marseille soap was chosen for this area as it can sustain hard humid conditions. The color blue for the interior of the leisure area was chosen to imitate a clear summer sky and psychologically bridge the short winter days. Additionally, it gives a Mediterranean style and warmth to the space. The existing roof slope was extended to create this space, so that the building faces the prevailing westerly wind.

Timber-frame construction is the most used method for residential buildings in the region. Therefore, this material is readily available and not too expensive. Its ability to store CO_2 is an additional advantage of this material. For the insulation of the buildings, 70% recycled glasswool was mainly used. Most of the windows that were removed during construction were reused in the greenhouse design to reduce waste.

Sheet metal was chosen for the roofing of the project. It has a long life expectancy. With a 40-year warranty, it lasts much longer than any other roofing material and is recyclable. In this harsh climate, the main material usually used is asphalt shingles, which need to be replaced more frequently (20 yrs) and produce a lot of waste. Sheet metal is well suited to withstand snow and ice in winter. The color dark green was chosen to make the house visually blend in with the wooded surroundings at any time of the year.

The growing area has a built-in water storage tank underneath. This strategy maximizes space and heat absorption by creating a thermal mass that also serves as a rainwater storage tank. At the same time, it serves as a source of irrigation for the plants and keeps the temperature in the greenhouse above freezing. The aquaponic system was placed in a corner of the greenhouse where there is both shade and direct light, near the circulation path for better daily monitoring.

The beams and greenhouse panels are easily removable to allow maintenance and replacement of parts. The guying maximizes light penetration by making the beams as narrow as possible, preventing unnecessary shading in the growing area. The moldings and the structural polycarbonate panels used for the translucent surface come from an industrial greenhouse system allowing to have durable panels at a reasonable cost.

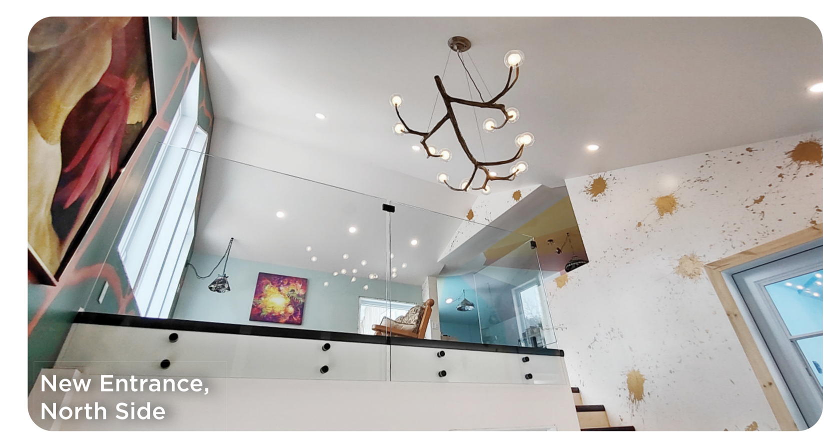
Polycarbonate has translucent properties. Light is diffused when it hits the material, providing a good distribution of light. Glass has transparent properties and clear windows are the best to see through but can burn foliage. Since we do not need to see through the greenhouse panels, plants were prioritized in the choice of material.

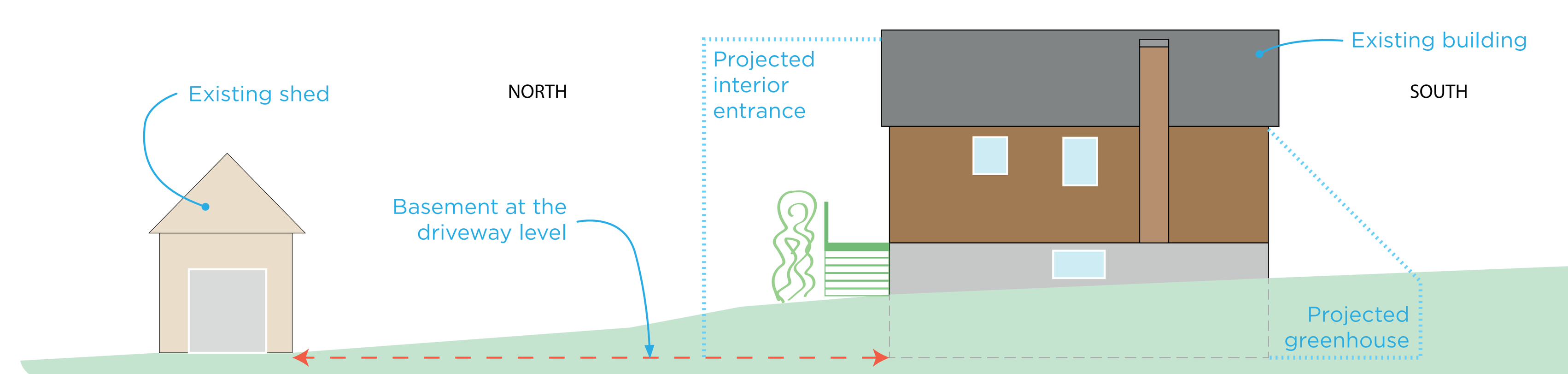
The north-facing large windows allow views of the mountains from the kitchen and of the entryway from the couch in the living room. It also gives more light to the open space. In addition, the problem of seasonal overheating of the southern rooms was solved by installing shade roofs on the windows. These let the sun into the room in winter and provide warmth, but in summer, when the sun is higher, the roof prevents the direct rays from reaching the interior.

Levels and Circulation

The topographic survey showed that the existing entryway was at the same elevation as the floor of the basement. Since the south side was backfilled at the original construction, we restored the natural topography of the site by lowering the soil level on the south side of the house and creating a mid-level space with the planting floor of the greenhouse. An interior entrance was created on this level to solve circulation problems inside the house as well as to connect the leisure and greenhouse area wrapping the original house.

A doorway was cut through the basement wall to provide circulation between the different levels and rooms (cold room, workshop, wood stove).


New Entrance,
North Side



Maximizing Natural Light

The view of the forest from the kitchen was to be preserved according to the wishes of the residents. The challenge was to ensure maximum visibility while providing natural ventilation to the kitchen without transferring moisture between the greenhouse and the interior of the house. Thus, the idea for the motorized skylight and window arrangement was born.

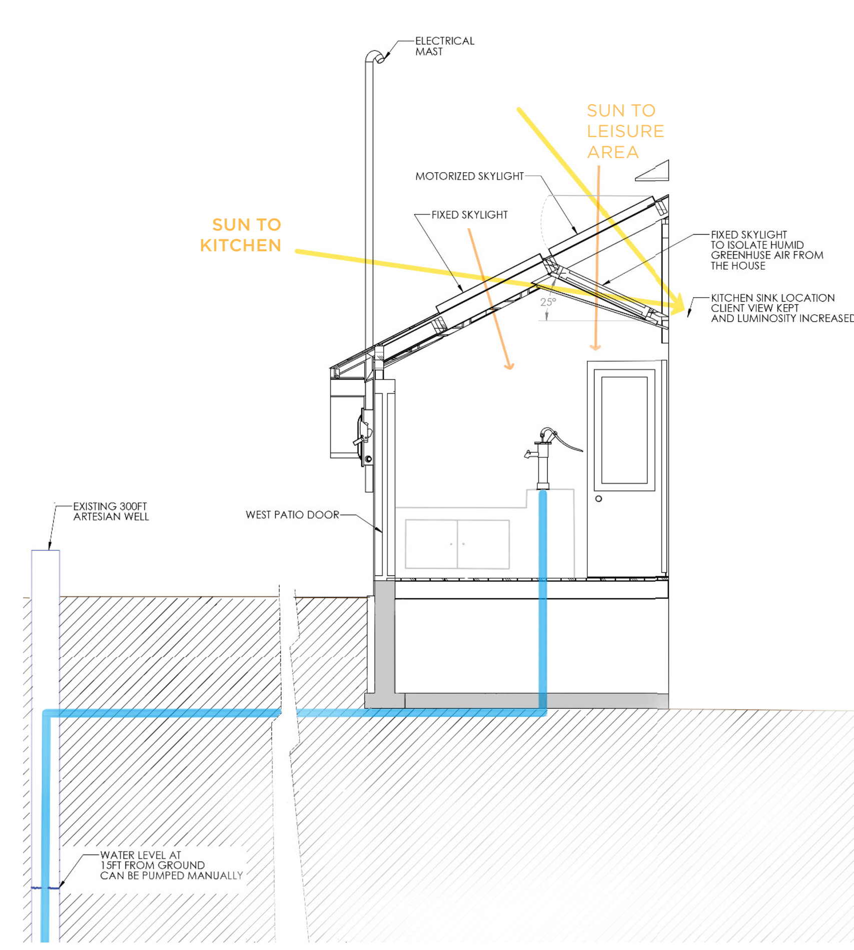
Structurally, the distance between the two windows had to be reduced to achieve a minimal visual impact. The higher skylight is placed under the eaves to allow snow to slide off the upper roof. The snow isn't stopped by an overhanging top window edge.

Manual Water Pump

In the original state of the house, the electric pump was the only water supply and in the event of a power outage, it was inoperable. The accessibility to the artesian well water was a challenge to be solved.

After checking the water quality and depth of the well, it was determined that it was possible to install a hand pump in the leisure area (water at 15 ft in the well). For this purpose, a pipe had to be laid through the ground to the well.

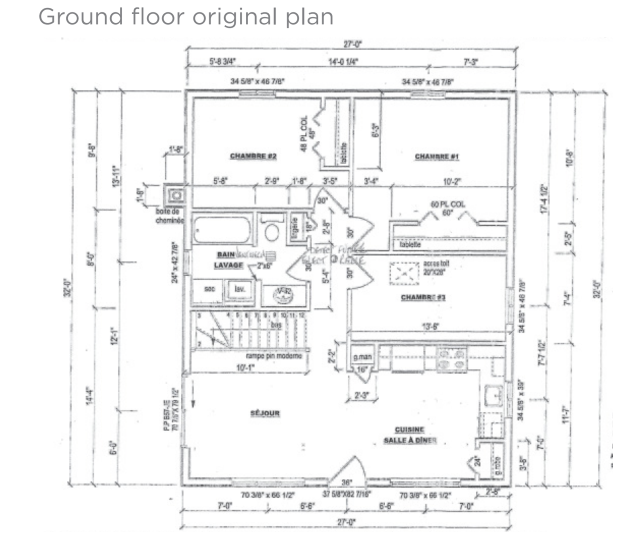
Skylight Arrangement & Manual Pump Piping



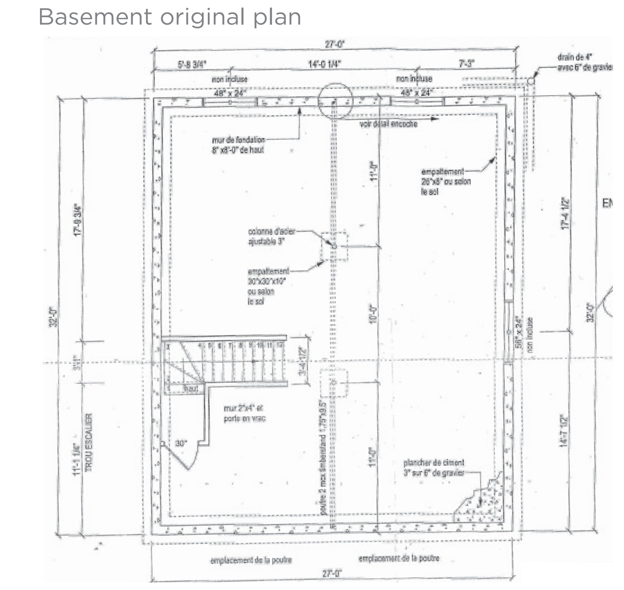
Existing House Floorplan

We decided to keep the existing functional pre-manufactured bungalow and expand it with intermediate spaces. This decision allows us to reduce construction waste and focus on the improvement of the resiliency.

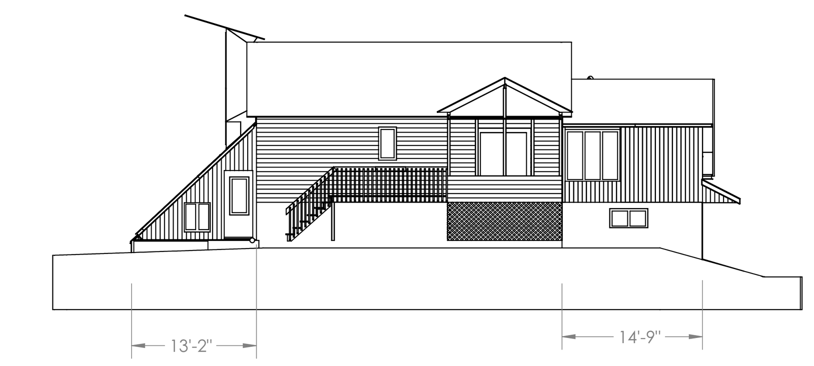
Ground floor original plan



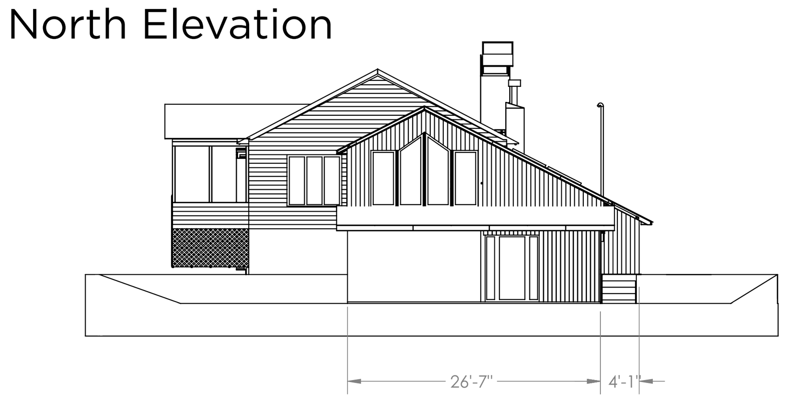
Basement original plan



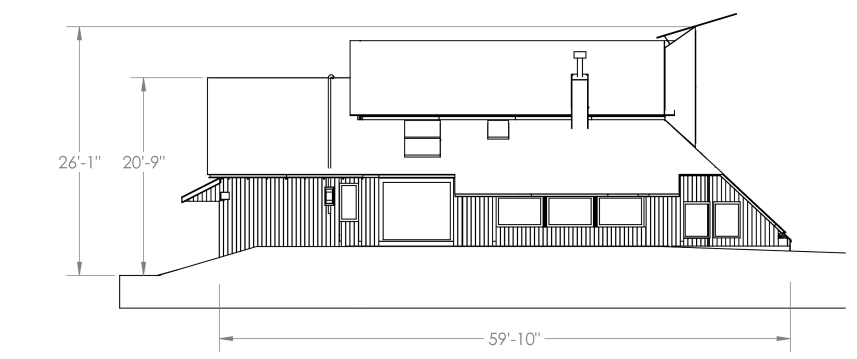
East Elevation



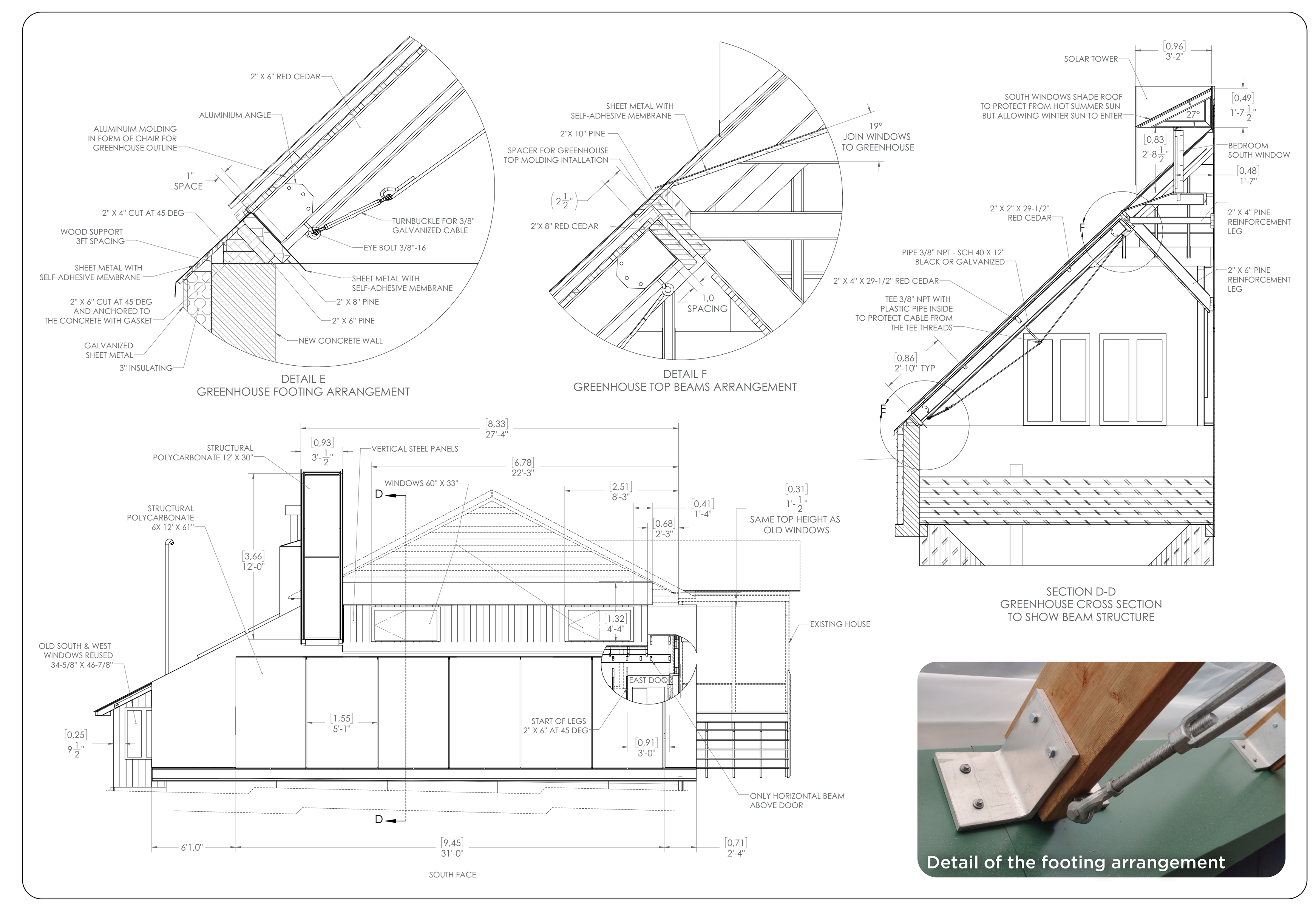
North Elevation



West Elevation

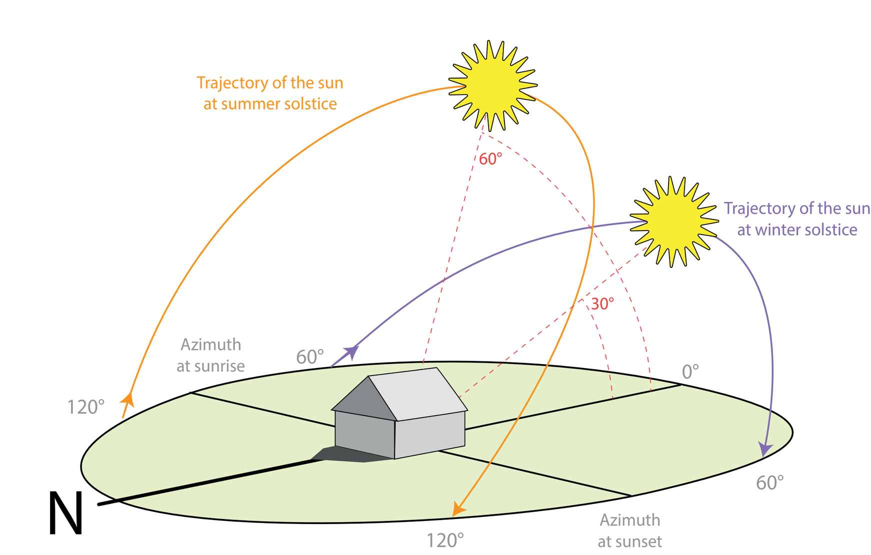


South Elevation & Greenhouse Structure Details



Sun exposure

The greenhouse was placed on the south wall to ensure maximum sun exposure. At this latitude, the sun is always on the south side of the house, which is the best orientation for spaces that are designed to heat with passive energy. This additional area also improves the insulation of the existing house.



FRACTALE

4. Air, Temperature & Humidity Control

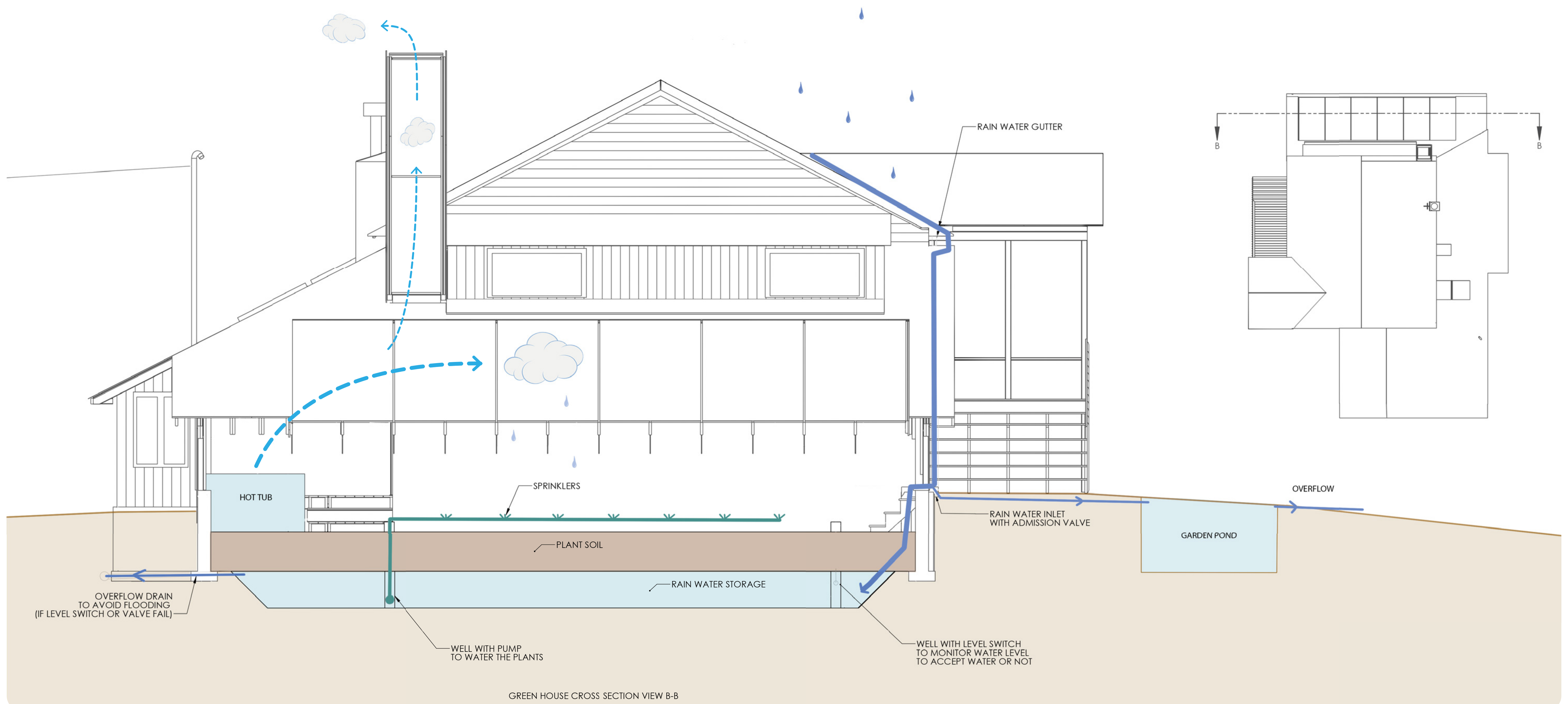
Water Management

Rainwater is collected from the roof and stored in a gravel reservoir under the greenhouse, from which water can pumped directly to irrigate the plants. There is 40% water in the spaces between the rocks (18m^3 gravel volume equal to 7m^3 of water stored). It is important to prevent the overflow of the greenhouse floor with a gravity drain to ensure the integrity of the greenhouse structure. Automatic irrigation systems are convenient, especially for people with an active life.

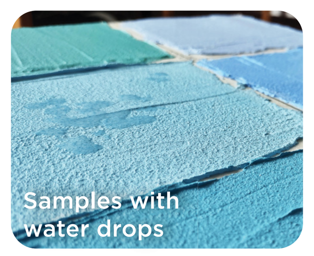
The existing equipment such as the artesian well and the peat septic field were evaluated and judged to be adapted to the needs and their use was maintained. Local regulations also required that each house have a conventional wastewater system. We decided to allow a future conversion of the greenhouse water storage into a graywater purification system with plants, to be ready when the local regulations will evolve.

An outdoor frog pond serves as a retention pond for rain overflow and a means of pest control in the garden by attracting predators.

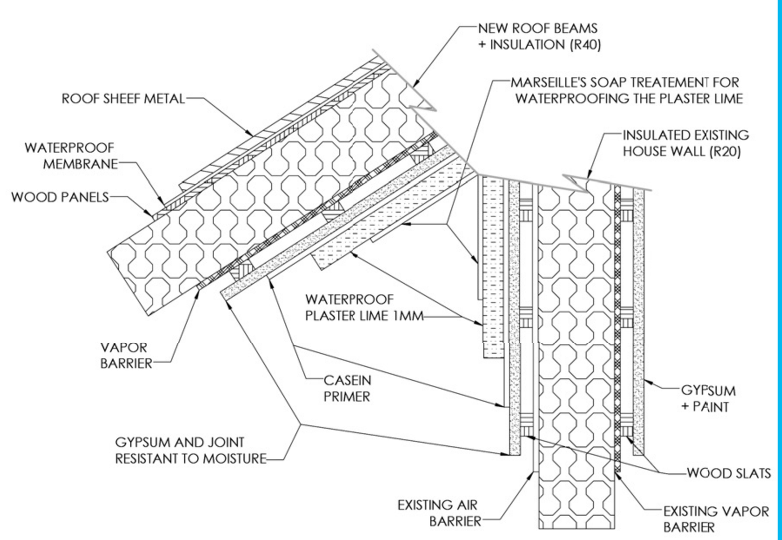
Water Management of the Greenhouse Space



Composition of the Walls Between the Existing House and the Greenhouse



Waterproof Wall Composition (Cross-Section)



Optimal Angle of the Panels and Chimney Effect

The opening of the solar tower is controlled by temperature. The mechanical gas spring cylinders start to open at 20°C (68°F) and are fully open at 30°C (86°F). A climbing wall is the access point to adjust the gas spring system, doubling its function as a recreational sport. It is a fun way to integrate functionality into the architecture.

We used geothermics to optimize the efficiency of the culture area. It is embedded in the ground, naturally capturing its heat. In addition, the panels have a precise angle according to the solar path. The sun angle is 60 degrees in summer and 30 degrees in winter, so 45 degrees is the best compromise for all seasons. Finally, the basement wall of the existing building serves as a thermal mass to regulate the temperature inside the greenhouse.

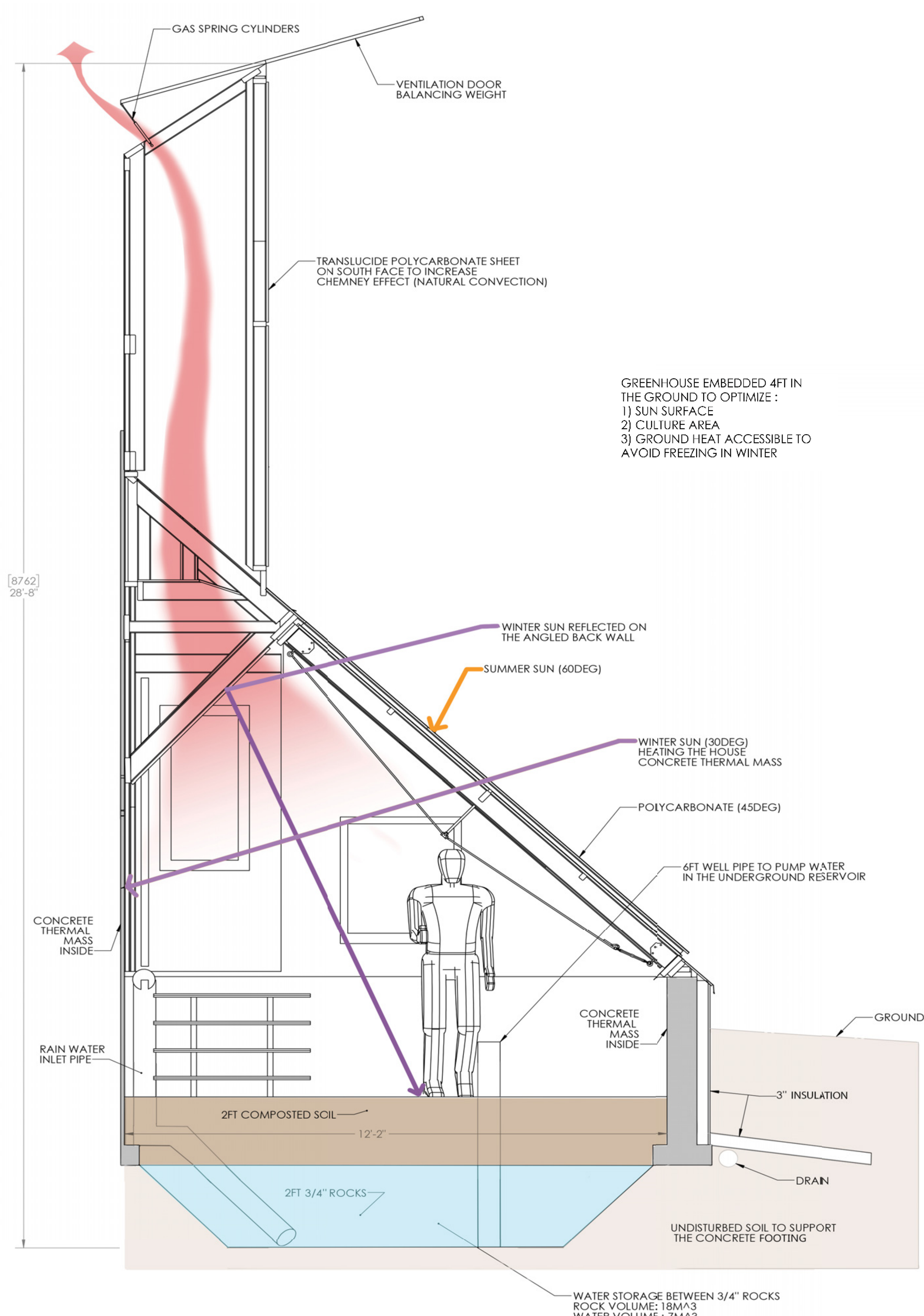
Control of the Airflow

Lack of air circulation can cause plant diseases and mold formation. To remedy this problem, the sun is used to increase natural convection by heating the dark sheet metal that covers the inside of the sun tower thought the translucent south panel.

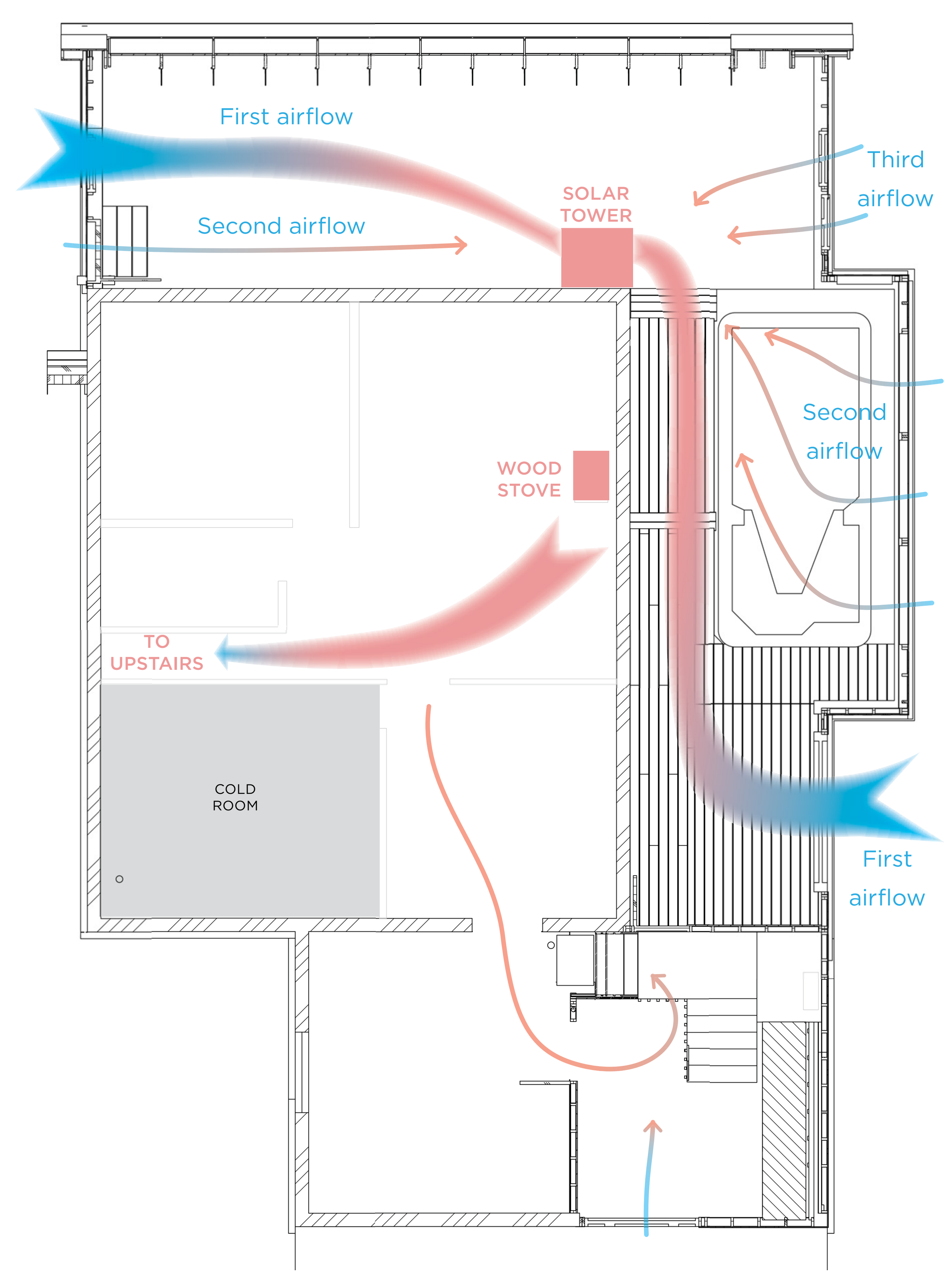
With this system we can control the airflow from the inside. Windows and doors can be opened depending on the inside and outside temperature. In addition, these openings allow pollinators to enter the greenhouse in the summer.

Inside the house, we use the existing wood stove as a heat source. It also provides redundancy in the event of a power outage, since an electric heating system is already installed. Its emplacement in the basement also provides heat on all levels through convection.

Solar Angle & Greenhouse Thermal Masses

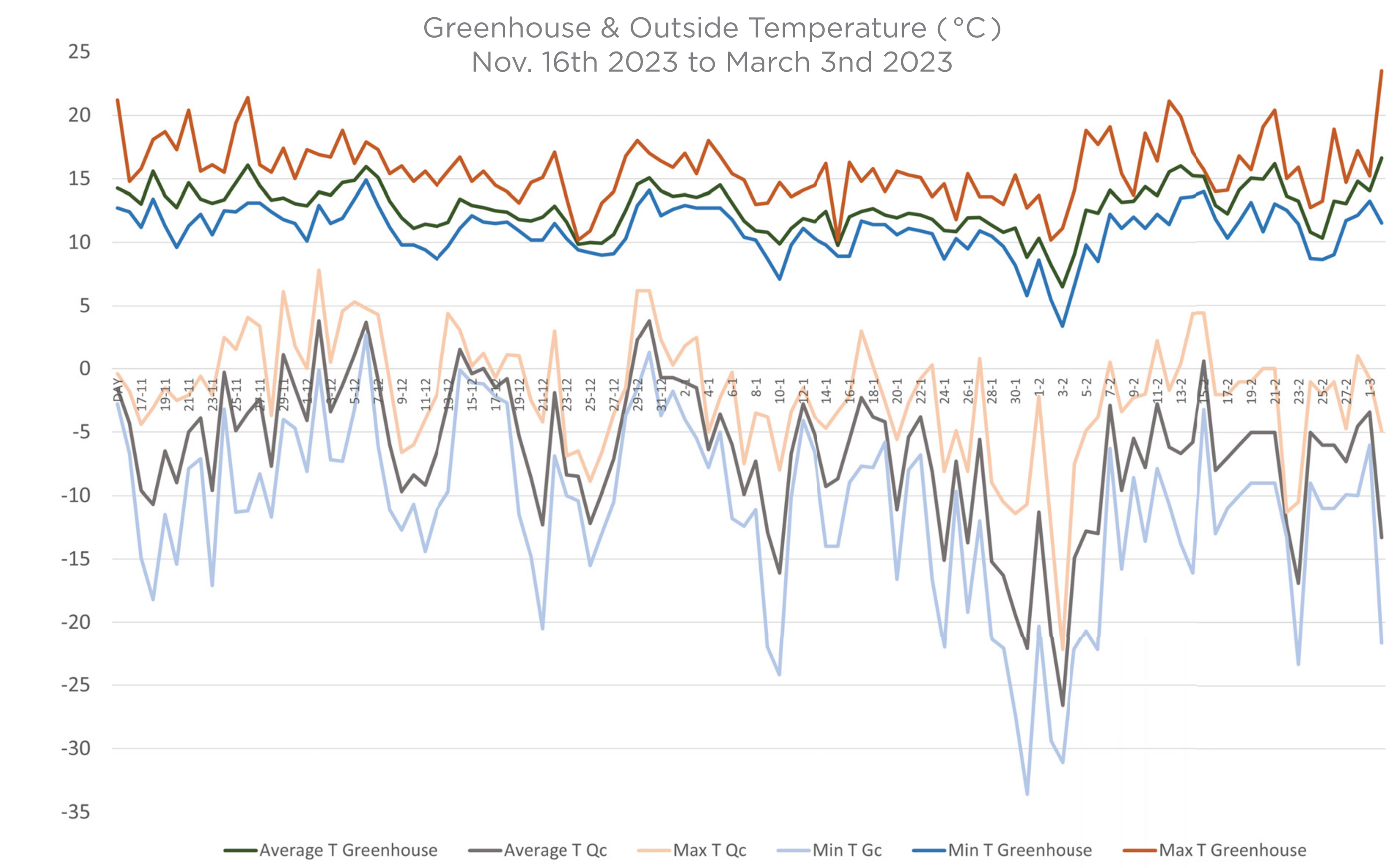


Airflow Paths Through the House



Performance of the Greenhouse Winter 2022-2023

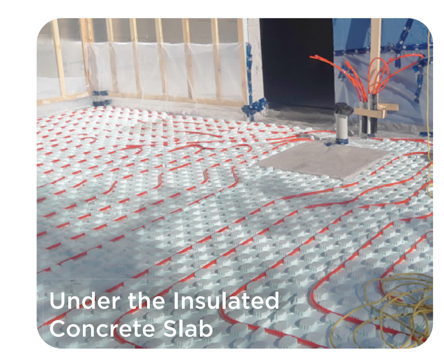
Greenhouse temperatures were recorded between November 16th 2022 and March 3rd 2023. The result: even at -30°C (-22°F), it did not freeze in the greenhouse (min. 3 °C or 37°F). This successfully confirms the efficiency of the insulation and the passive heat recuperation system.



Thermic Exchanger and Concrete Heated Slab

An insulated concrete slab with heat carrying pipes would allow for low heat consumption and comfortable warmth in the entrance during the cold months.

The ground temperature is nearly constant and can provide cooling in the summer. 300 feet of 1" diameter pipe buried at 6 feet underground would carry a fluid that absorbs the cold of the earth.



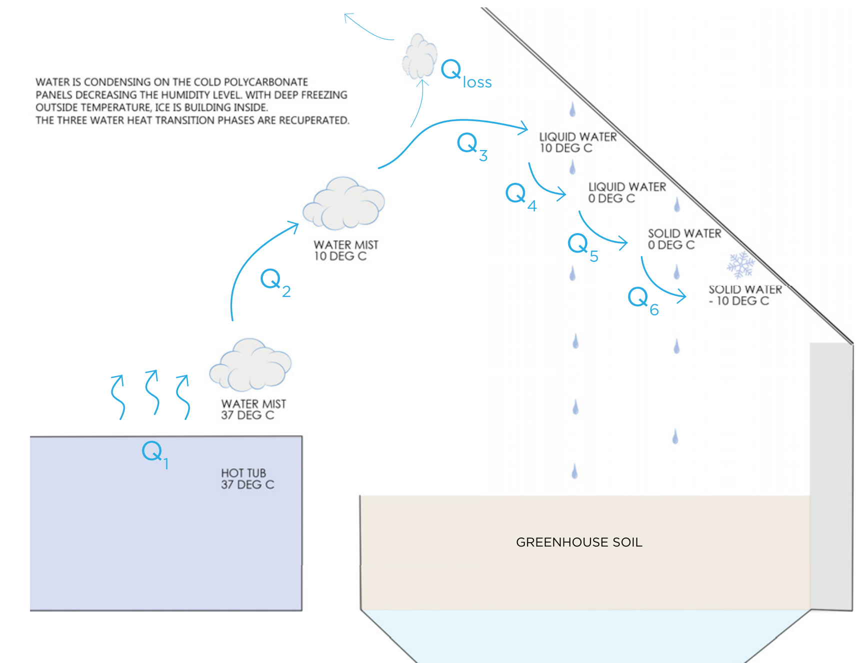
Calculation: Performance of the Passive Heat Recuperation System

Residents recorded an average hot tub consumption of about 20 kWh/day during the severe winter. In winter, almost all the water going in the air, in humidity, is condensed back on the polycarbonate panels of the greenhouse, lowering humidity and warming the greenhouse with an efficiency of 87 %.

The remaining 2.5 kWh is ventilated by the solar tower. We decided to maintain a small opening at the top to allow new air to circulate in the greenhouse for the plants to transpire. Otherwise in the cold months, the air would always be saturated in the winter and the plants could die.

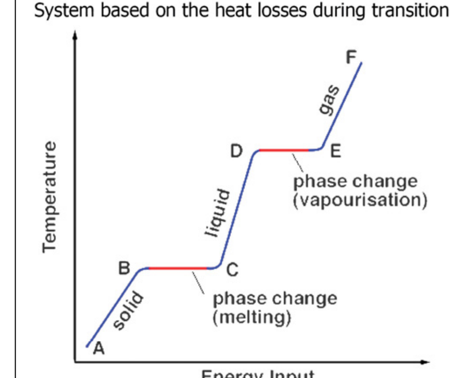
The minimal greenhouse temperature was 3 °C (37°F), the insulation can be considered sufficient and the heat recovery through the hot tub mist is a success.

Humidity Management During Winter



Passive Heat Recuperation System Calculation

System based on the heat losses during transition phases of the water



Specifique Heat capacity of water

$$C_{w\_liquid} := 4184 \frac{J}{kg \cdot K}$$

$$C_{w\_vap} := 2100 \frac{J}{kg \cdot K}$$

$$C_{w\_solid} := 2093 \frac{J}{kg \cdot K}$$

Latent Heat capacity of water

$$L_{w\_vap} := 2265000 \frac{J}{kg}$$

$$L_{w\_fusion} := 334000 \frac{J}{kg}$$

Formulas of heat calculation:

$$Q_{same\_phase} := m_{water} \cdot C_{heat} \cdot \Delta T$$

$$Q_{change\_phase} := m_{water} \cdot L_{heat}$$

ΔT Temperature differential

C_{heat} Specifique heat (see water heat table)

L_{heat} Transition phase Latent heat

m_{water} Mass of water which is changing phase or changing temperature

Q Heat in Joule (J)
1000J = 0.2778 Watt hour

Inputs parameters :

$T_{spa} := 37\ °C$ $\quad T_{wndws} := -10\ °C$

$T_{moy} := 10\ °C$ Average Temperature in the greenhouse in winter

$m_{water} := 12.6\ kg$ Residents add 100 gal(378L) per month of water in spa in winter So about 12.6L per day of water is released in the greehouse that help protect against freezing

$$Q1 := m_{water} \cdot L_{w\_vap} = 7.928\ kWh \qquad Q3 := Q1$$

$$Q2 := m_{water} \cdot C_{w\_vap} \cdot (T_{spa} - T_{moy}) = 0.198\ kWh$$

$$Q4 := m_{water} \cdot (C_{w\_liquid} \cdot (T_{moy} - 0\ °C)) = 0.146\ kWh$$

$$Q5 := m_{water} \cdot (L_{w\_fusion}) = 1.169\ kWh$$

$$Q6 := m_{water} \cdot (C_{w\_solid} \cdot (0\ °C - T_{wndws})) = 0.073\ kWh$$

$$Q_{tot} := Q1 + Q2 + Q3 + Q4 + Q5 + Q6 = 17.44\ kWh$$

$$\eta := \frac{Q_{tot}}{20\ kWh} = 0.87$$

Efficiency of the passive heat recuperation system

$$\eta := 87\%$$

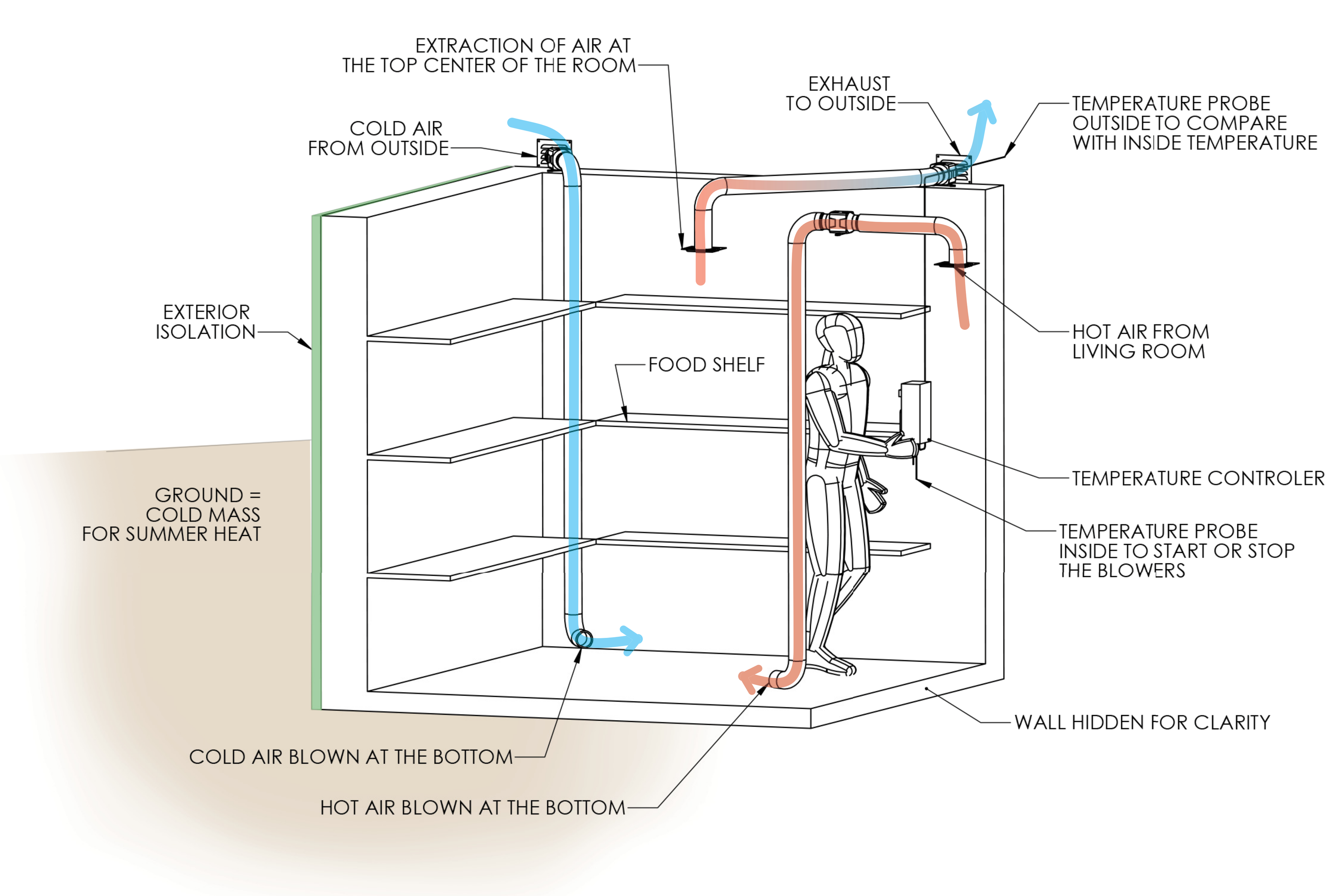
5. Food Resiliency Systems

Cold Room

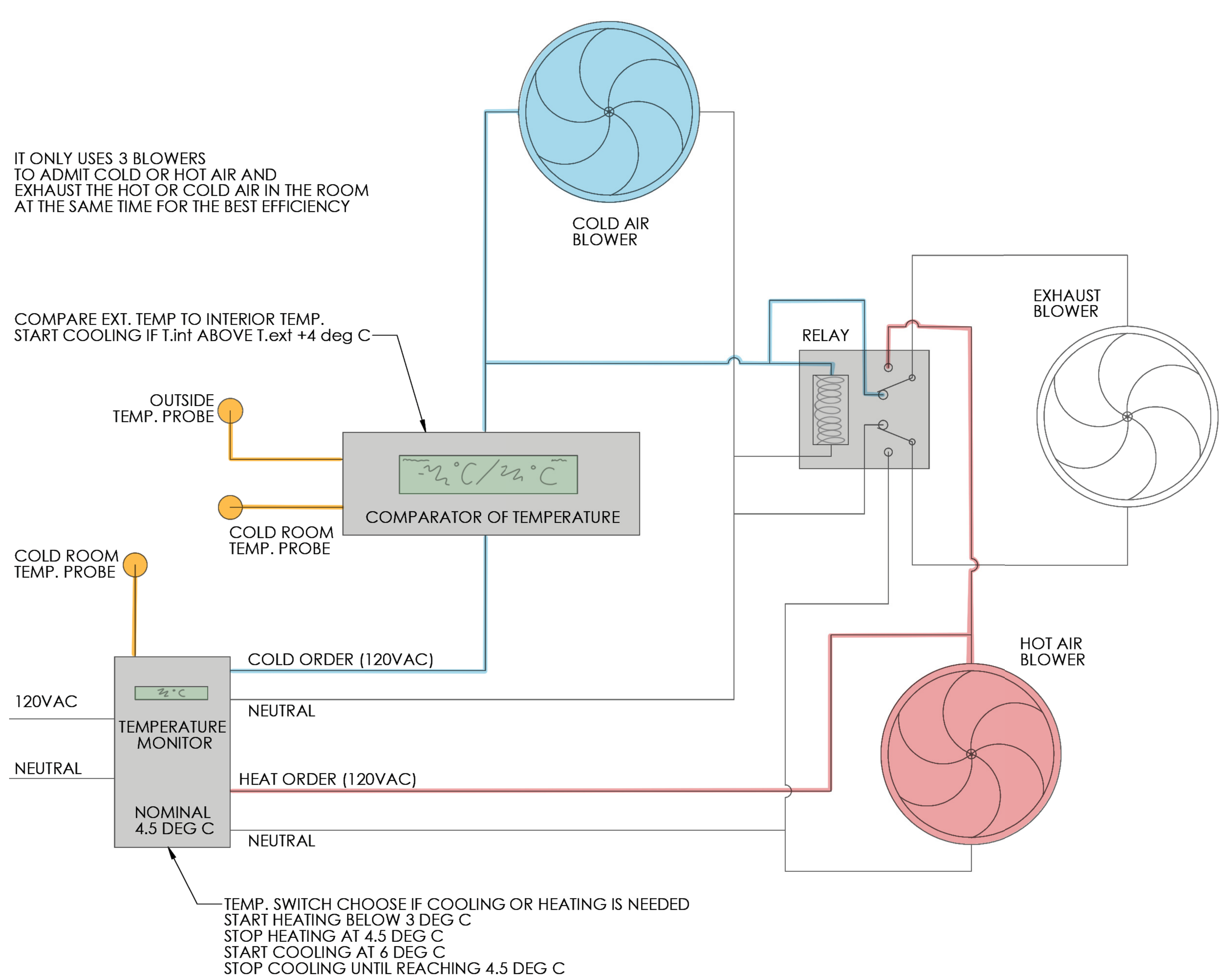
The best place for a cold room at this latitude is in the north of a building, where there is not a direct sun that can affect the temperature of the room. Good insulation is necessary, in this case the room is insulated from the outside and inside. The room also does not have a window.

The room is primarily used for storage of crops and large quantities of food. From November to March, the cold room is at refrigerator temperature (about 6°C on average, 43 °F). The room is semi-passive, there is no system that directly heats or cools, there is only exchanges with the environment through the small fans.

Cold Room Controlled Airflow Paths



Cold Room Electrical Schematics



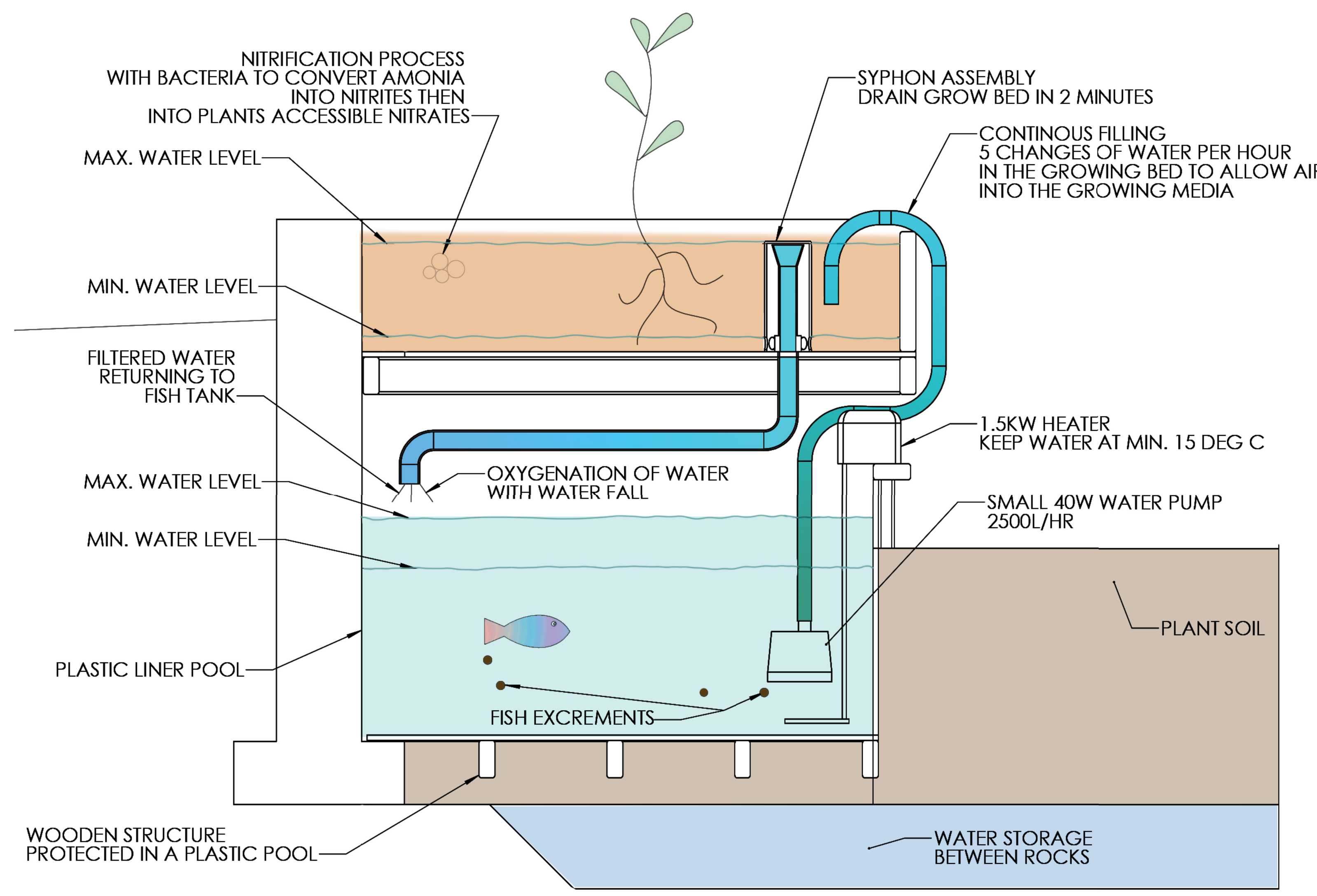
Aquaponic system

The main function of the aquaponic system is to concentrate plantations to maximize growing space. The strength of this type of system is the nitrate cycle which allows a strong production of leafy vegetables.

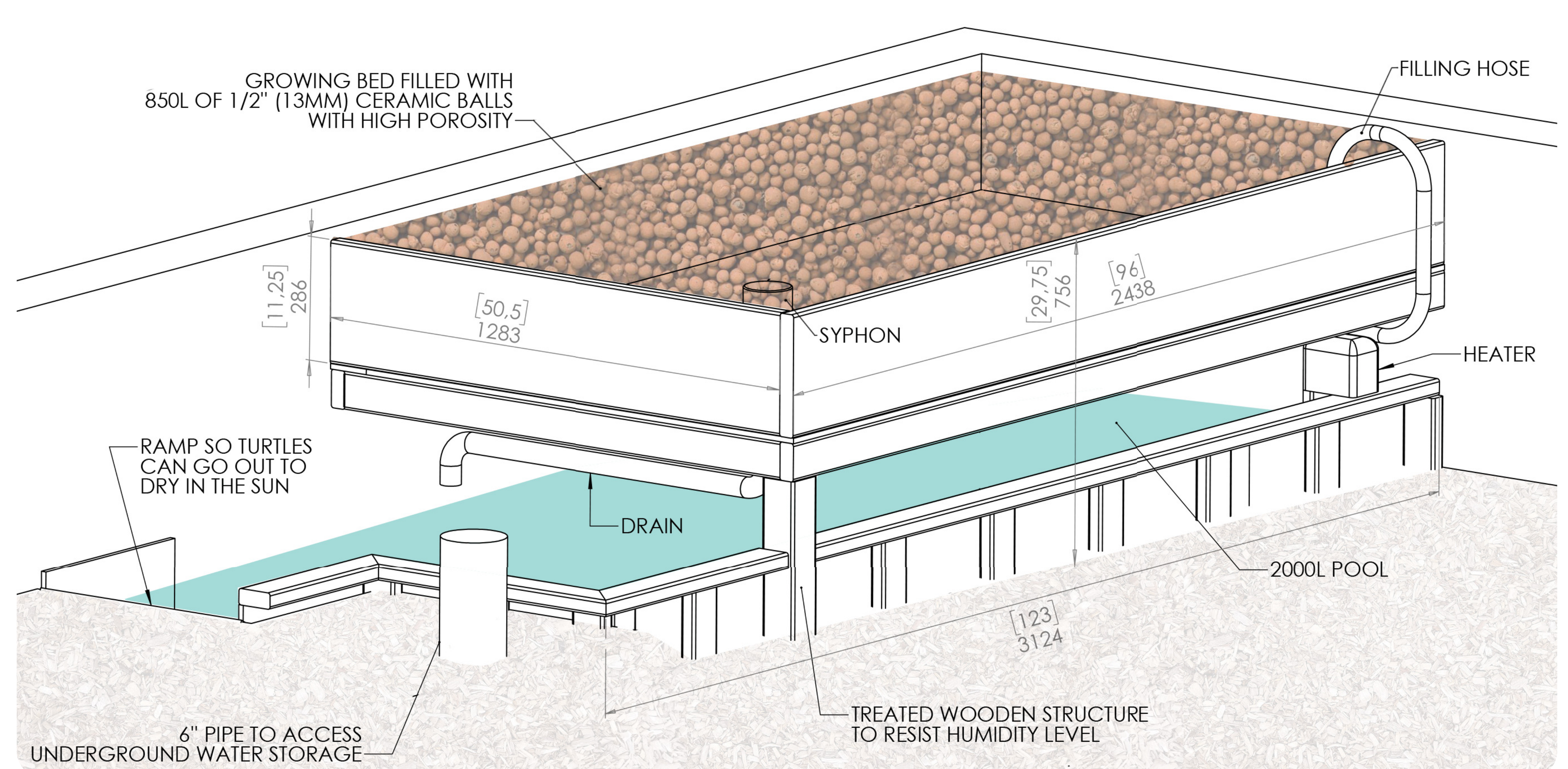
An expansion of the aquaponic system is planned and will allow plants to grow directly in flowing water pumped into pipes. Pipe sections will be used to optimize the planting area along the western windows.

Example of lettuce growing directly in a pipe system

Aquaponics Principles



Aquaponic System Arrangement

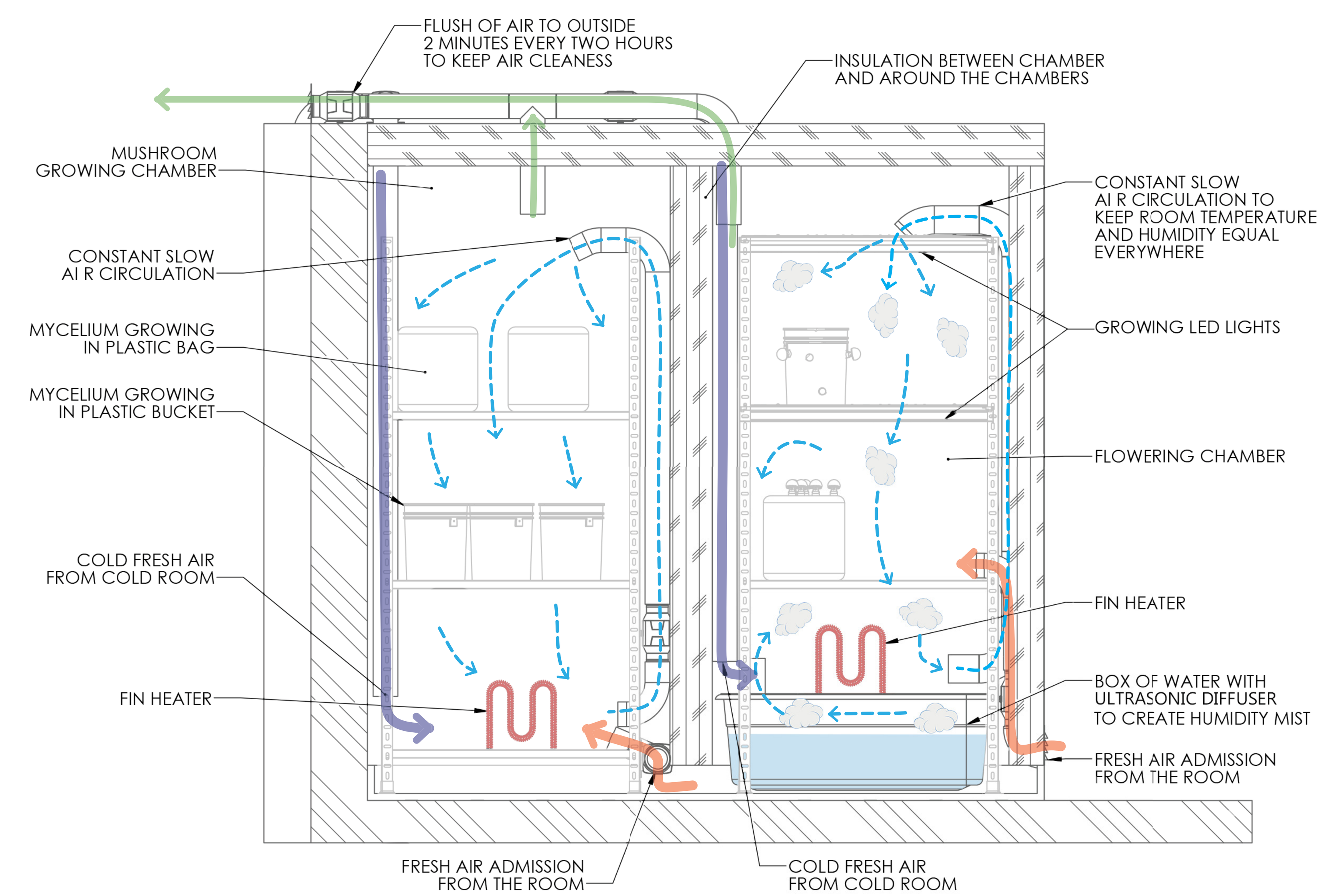


Edible Mushrooms Growing Chambers

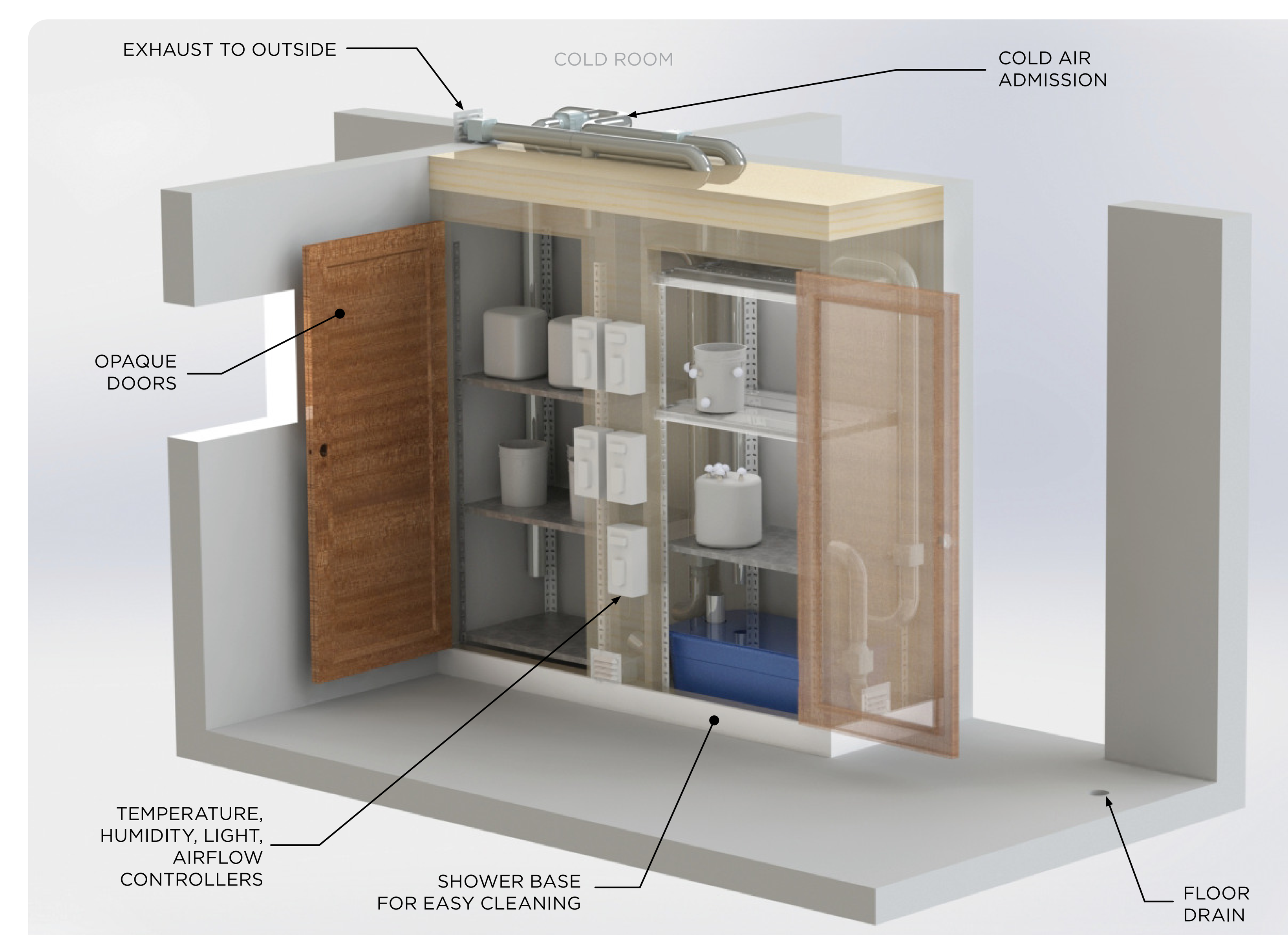
Mushrooms have numerous health benefits and are very valuable on the market, so it is worth growing them. Two strictly controlled rooms are required, both chambers need different conditions to function properly.

The growing chamber requires a dark (often heated) room for the mycelium to spread in the culture media. When the mycelium is fully grown, it needs a thermal, hydric, and physical shock in order to transition to the next stage. The fruiting chamber requires a lighted, humid, and ventilated space that is often colder than the other room.

Mushrooms Chambers, Operating Conditions



Mushrooms Chambers Parts



6. Landscaping

Landscape Design Plan

Landscaping Plant List

Latin name	Common name	Qty	Category	Native	Bearer
Actinidia kolomikta	Kiwi	2	Climbing		x
Ajuga reptans	Ajuga	20	Perennial		
Apios americana	American groundnut	2	Climbing	x	x
Aralia cordata	Golden Aralie	5	Perennial		x
Armoracia rusticana	Horseradish	17	Perennial		x
Asarum canadense	Wild Ginger	11	Perennial	x	x
Asparagus officinalis	Asparagus	30	Perennial		x
Chrysanthemum	Daisy	14	Perennial		x
Fragaria vesca	Strawberry	8	Perennial		x
Gaultheria procumbens	Wintergreen	4	Perennial		x
Hablitzia tamnoides	Caucasian Spinach	2	Climbing		x
Helianthus tuberosus	Sunchoke	23	Perennial		x
Hemerocallis	Daylilly	11	Perennial		x
Hippophae	Sea-buckthorn	3	Shrub		x
Hosta	Hosta	4	Perennial		x
Humulus Lupulus	Hops	7	Climbing		x
Juniperus sabina	Juniper Sabine	9	Conifer		x
Levisticum officinale	Lovage	13	Perennial		x
Lilium orientalis 'Stargazer'	Lilly 'Stargazer'	10	Perennial		x
Malus	Apple tree	1	Tree		x
Malus	Crabapple tree	1	Tree		x
Matteucia struthiopteris	Ostrich Fern	24	Perennial	x	x
Microbiota decussata	Siberian cypress	2	Conifer		
Nepeta	Nepeta	14	Perennial		x
Origanum vulgare	Oregano	6	Perennial		x
Paeonia japonica	Peony	10	Perennial		
Prunus Evans	Evans cherry tree	1	Tree		x
Rheum rhabarbarum	Rhubarb	21	Perennial		x
Rosa rugosa	Hardy roses	4	Shrub	x	x
Rubus idaeus	Raspberry	25	Shrub		x
Rubus occidentalis	Black raspberry	22	Shrub	x	x
Satureja	Savory	6	Perennial		x
Symphytum	Comfrey	14	Perennial		x
Thymus serpyllum	Creeping Thyme	28	Perennial		x
Vaccinium angustifolium	Bleueberry	11	Shrub	x	x
Vitis	Grape vines	38	Climbing		x
Wisteria macrostachya	Wisteria	7	Climbing		

Total Plants (Units)	430
Total Native (%)	89
Total Bearer (%)	17

Simulation of the Vegetable Garden
(South Side)

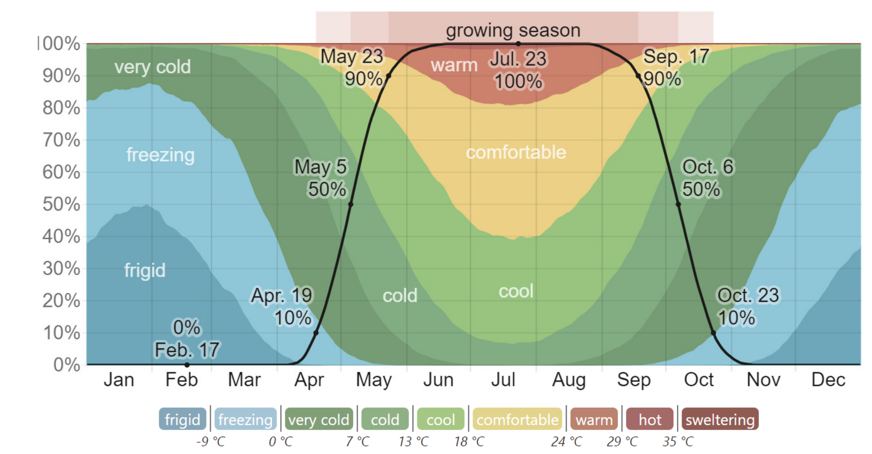
Hardiness Zone 5a, Continental Climate

In summer, the days are generally warm, humid and long. During winter, the days are short and cold, with occasional snowfalls. The wind directions are mainly southwest.

A hardiness zone is a geographic area defined by a certain minimum average annual temperature. This system was developed by the United States Department of Agriculture and range between thirteen zones.

In Zone 5, Plants can withstand temperatures no lower than -28°C (-20°F). These plants would not survive the severe winters in zone 4 or below. They can withstand zones 5 to 8, but they would probably not endure the hot, dry summers as well as insufficient dormancy time in zone 9 and higher. In this zone, the last frost usually occurs around April 15 and vegetable are usually planted around mid-May.

Illustration of the Growing Season



The Percentage of Time Spent in Various Temperature Bands and the Growing Season in Bromont.
The black line represents the percentage chance that a given day is within the growing season.
Source: WeatherSpark.com

Integration to the Landscape

The forest was preserved and most of the grassy areas were converted into planting areas in which the building is integrated. The wider space design includes a vegetable garden that allows crop rotation, as well as zones for rustic plants, perennials, fruit trees and vines.

Medicinal Rain Garden
Capturing the Water Runoff

S-W Corner, July 2022
Wood Structures
Allow Carbon Storage

Wood Storage

The area in the entryway is designated for drying and storage of the firewood. It was intentionally chosen to incorporate the woodpile esthetic typical of the Canadian region.

Simulation of the North Side

Carbon Footprint

According to *Circular Ecology*, carbon emissions from the construction of a building can be estimated at 0.5 to 1 ton of CO_2 per m². The built-up area of the project is 116 square meters, so the carbon to be offset is 58 to 116 tons to compensate for the ecological footprint.

The forested area on the property is about 2 acres. According to *8 Billion Trees*, an organization that specializes in carbon offsets, one acre of trees absorbs about 2.6 tons of CO_2 per year. This means that the trees on the property absorb about 5.2 tons of CO_2 per year and can process the carbon emitted by the construction of the building in 12 to 22 years. This is without taking into account the carbon saved by on-site activities such as food production (see lifestyle section). The lifetime of the building was an important parameter for the project and can be estimated at more than 50 years based on the choice of materials.

Plantation Strategies

The strategy for plantings in the overall project can be summarized as diversity. The building is only one part of this broader vision. Multiple growing areas with different climates allow for a variety of plants to be grown on site.

Outdoor

The outdoor area would be used to grow perennials adapted to harsh climatic conditions, as well as annuals that are needed in large quantities, such as potatoes. Edible and native plants are prioritized for the landscaping as well.

In the greenhouse

The environment created in this area is advantageous for plants that require heat and a long growing season.

In the aquaponic system

This type of growing system is more suitable for leafy vegetables and plants that have high nitrate requirements.

Plants List Example

Greenhouse		Outdoor	
In the Ground	Aquaponics	Annuals	Perennials
Cantaloup	Arugula	Basil	Asparagus
Citrus	Basil	Beans	Blueberries
Cucumber	Bok choi	Beetroot	Fiddleheads
Eggplant	Celery	Brocoli	Hemerocallis
Endive	Chives	Cabbage	Hops
Fig	Collard greens	Carrot	Horseradish
Kiwis	Galangal	Chili pepper	Nepeta
Lamb's lettuce	Ginger	Corn	Oregano
Onions	Kale	Garlic	Raspberries
Peppers	Lemongrass	Leek	Rhubarb
Radish	Lettuce	Parsnip	Savory
Shallot	Mustard greens	Peas	Schisandra
Spinach	Okra	Potatoes	Sea-buckthorn
Sweet potatoes	Strawberries	Pumpkin	Sunchoke
Tomatoes	Swiss chard	Saffron	Thymus
Turnip	Tomatoes	Snow peas	Wild ginger
Watermelon	Wasabi	Squash	Wild roses

Outdoor crop rotation

We recommend dividing the outdoor vegetable garden into four sections, rotating crops each year.

They are identified below and on the landscaping plan as G1, G2, G3 and G4.

G1:

Demanding plants not to be dug up
(Cruciferous, Liliaceae, Solanaceae, Cucurbitaceae)

G2:

Plants with low requirements
(Chenopodiaceae, Umbelliferae, Root greens, Legumes)

G3:

Demanding plants to be dug up
(potatoes, garlic)

G4:

Fallow, use chickens or fabric barrier to eliminate weeds, add compost or green manure and turn the soil.

About Us

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