VIA UNIVERSITY COLLEGE

BACHELOR OF CONSTRUCTING ARCHITECTURE

DISSERTATION

EARTHSIHP – Do they have a future in Denmark?

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TITLE PAGE

BATCoM
Bachelor of Architectural Technology and Construction Management

DISSERTATION TITLE: EARTHSHIPS – Do they have a future in Denmark?

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DATE/SIGNATURE:

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25/05/2012

VIA Student number 143956

Number of copies: 2

Number of pages: 33 @2400 charaecters per page

NOTE: This dissertation was completed as part of a Bachelor of Architectural Technology and Construction Management degree course – no responsibility is taken for any advice, instruction or conclusion given within!

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PROBLEM STATEMENT

1. What is the subject of my dissertation?

A group of 10 students from VIA University College have decided to elaborate an interdisciplinary project of building an Earthship-inspired research facility on campus.

This group is formed by Constructing Architects, Civil Engineers, Mechanical Engineers, Global Business Engineers and Marketing managers. Together we will try to design a small house that will be built with recycled materials, using unique constructing methods to create a house that will give comfort to its visitors consuming only the energy and water it can create itself.

This report investigates on the possibility of building an Earthship in Denmark taking into consideration climate and regulations.

2. Background information. Reasons for my choice.

In order to be able to design, plan and construct an Earthship it is necessary to acquire as much knowledge as possible about the systems, processes and challenges.

Being a part of this group is a great opportunity to evolve both socially and professionally.

This is a very ambitious project that covers wide areas of the whole construction process, from design to execution, leaving no stone unturned.

Working with students with different educational backgrounds helps get a new perspective and new ideas worth looking in to.

3. Problem statement.

Is it feasible to construct a zero energy house that provides its own energy in Denmark?

Can there be comfort in a house made of recycled materials with no external source of heating?

What does the Building Regulations have to say about these houses?

What is the demand for the materials used?

What makes the Earthship different from other sustainable buildings?

Does the Earthship Global Model really work globally?

4. Delimitation.

There will be no calculations done in this project. All numbers have been researched and credited to the author.

5. Source of data.

Published books and internet. As well as group ideas created for the project.

People from Earthiship Europe organization will be consulted for further information.

6. Choice of working method.

The project will be written on a question-solution basis. Different questions will appear during the phases of design and execution of the project. It will be an on-going process.

The research and elaboration of the project will be done by the Design Team but the report will be written individually.

1. BUILDING TOMORROW

What is Building Tomorrow?

How was Building Tomorrow created?

What are the objectives of Building Tomorrow?

Building Tomorrow is a non-profit organization funded by a group of nine students, in which I am included.

It is an interdisciplinary project done in VIA University College. The studies included are Civil Engineering, Constructing Architecture, Marketing and Management, Global Business Engineering (IT and Mechanical Engineering Specializations), Land Surveying, Value Chain Management, ICT Engineering.

Building Tomorrow began as an idea among a group of friends. The idea was to build an Earthship, the first in Denmark. As time went by, the group which initially started with two students expanded to 6 and finally 9 active students.

The easiest way to work together was stabilising an organization, in this case non-profit. A General Assembly took place the 12th of March in which the *Building Tomorrow* was officially constituted.

The objective of *Building tomorrow* is to design and execute the first student initiated Earthship inspired building in the world. As mentioned, the original idea was to create a "standard" Earthship model but as studied further on, some changes were mandatory.

In the design team we work in finding new solutions for better design and use of buildings.

When the design and planning phase are over and the project is handed in, the idea for the building is to be constructed on VIA university College campus in Horsens and used for research purposes.

2. EARTHSHIP BIOTECTURE. CONCEPT

What is Earthship?

When was it created?

What are the basic ideas of Earthship?

How does it work?

The easiest way to begin defining what Earthship Biotecture actually embraces is to take each word separately.

***Earthship** n. 1. Passive solar homemade of natural and recycled materials 2. Thermal mass construction for temperature stabilization. 3. Renewable energy & integrated water systems make the Earthship an off-grid home with little to no utility bills.
***Biotecture** n. 1. The profession of designing buildings and environments with consideration for their sustainability. 2. A combination of biology and architecture.[1]

The Eartship concept was created by Michael Reynolds in the early 1970s. Michael Reynolds graduated as Bachelor of Arquitecture from the University of Cincinaty in 1969.

His mission statement when founding Earthship Biotecture consists of:

- Evolving the way humans live by evolving methods of living one home at a time.
- Make small, believable steps towards slowing down and reversing the negative impact.
- To present these steps in a way that affords easy understanding and inspires people to act.
- To empower people to make positive changes in their own lives to reduce their effect on global warming.
- To build homes that are self-reliable. [2]

During the past 40 years, Michael Reynolds and Earthship Biotecture have received a large amount of awards and worldwide recognition

2.1– CONCEPT.

The Earthship concept is based on the idea of an “independent vessel”. These vessels are not connected to any source of centralized electricity, water, sewage or gas system. Earthships also claim to be independent to Food, Materials or Monetary systems.

Not only do we have to deal with the potential unreliability of the various support systems, but we have to deal with the unreliability of the system which gives us access to the support systems.[3]

These vessels must be capable of producing the necessary environment for comfort, and intend to do so at an affordable cost.

[1] http://www.architexting.com/earthships-biotecture
[2] Michael Reynolds, http://earthship.com/Learn-More/earthship-biotecture-media-resume.html
[3] Reynolds, 1990, *Earthship vol.I*

2.2– BASIC IDEAS.

The Earthship concept revolves around 6 design principles, which are explained more accurately in chapter 2.3.

1. Thermal/Solar Heating and Cooling.
   The indoor climate must be comfortable no matter the external temperature.
2. Solar and Wind Electricity.
   Earthships produce their own electricity with photovoltaic panels and wind turbines.
3. Contained Sewage Treatment.
   Sewage is contained and reused in the house, both with outdoor and indoor sewage treatments.
4. Building with Natural and Recycled Materials.
   Materials used must be local to avoid energy consumed during transport. Fabrication process, if any, should be low energy consuming and CO_2 friendly.
5. Water Harvesting.
   Rain water is collected and used up to four times throughout the house.
6. Food Production.
   Eartships are built with a greenhouse which provides the perfect environment for food growth. [4]

2.3– SYSTEMS IN AN EARTHSHIP

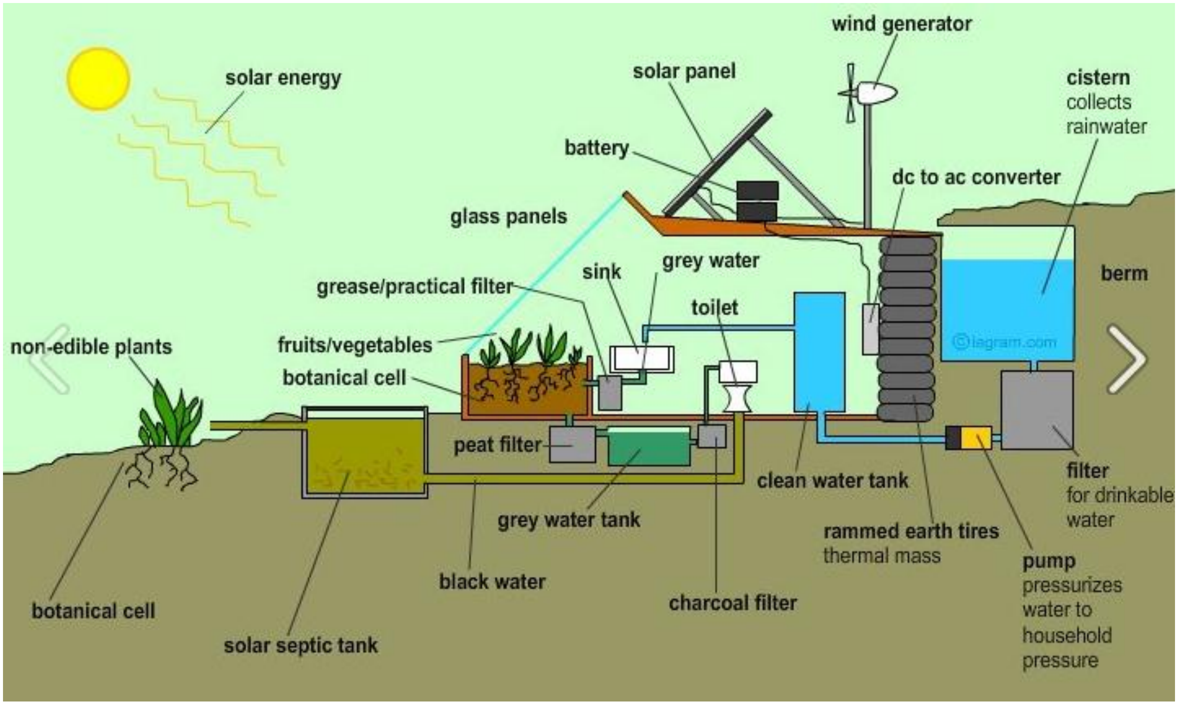

Fig. 1 - Simplication of Systems

"The aesthetics of the Earthship is a result of the systems' requirements." M. Reynolds.

[4] https://earthship.com/design-principles.html

2.3.1 – Heating and cooling:

To utilize the energy that is radiated from the sun, building's orientation, shape, insulation, thermal mass, climate and many other factors have to be considered in an early design process.

Passive solar energy generally refers to the process of capturing energy by using specific construction techniques. This requires building's components, such as windows, walls and floors, to be designed in a way that they store and distribute solar energy with no additional electrical input. In the winter time solar energy in the form of heat is distributed in the building and in the summer time the same energy enables building to be naturally ventilated.

Active solar building design differs from the passive by the fact that mechanical or electrical devices such as pumps or fans are used to distribute and move the heat and when combined with the passive design principles the system is considered to be hybrid.

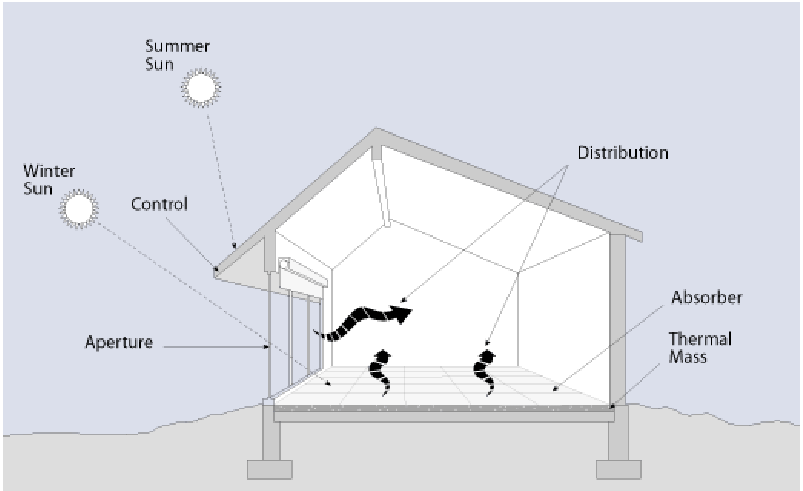

Fig. 2 - Five Elements of Passive Solar Design

Heat transfer in the construction is analysed considering the three types of heat movement – convection, conduction and radiation

Heat is stored in the form thermal mass. The first law of thermodynamics states that when free interchange of heat takes place the hotter of two bodies loses energy and the colder gains it. In passive solar design the heat absorbed and stored will constantly move to obtain equilibrium throughout the mass of the building. This is the principle in which heating and cooling in Earthships is based on.

2.3.1.1 - Thermal mass

Thermal mass is a form of passive solar heating and is introduced in the construction for energy storage and control of thermal indoor climate by moderating temperature swings throughout the year. Thermal mass is used to store and distribute the energy, both passive and active.

Solar radiation is stored by the mass and after a period of time distributed back to the room in a form of heat and radiant heat.

There are specific characteristics that the material must have to work efficiently as a thermal storage. To reduce reflectance and increase absorption of light the colour of material must be dark. The amount of heat a material can store and the rate it can be transmitted and released in the air have to be considered.

These characteristics are determined by certain properties of material:

Density – is the mass of a material in relation to its volume. More dense materials have more mass and tend to absorb and store more heat.

Thermal conductivity – indicating how rapidly and easily heat can move through a material.

Specific heat – is the amount of heat that is needed to raise the temperature of material. The more energy needed to increase the temperature, the worse it is for thermal mass.

Volumetric heat capacity – indicates the amount of heat stored in material when being raised in temperature of 1ºC.

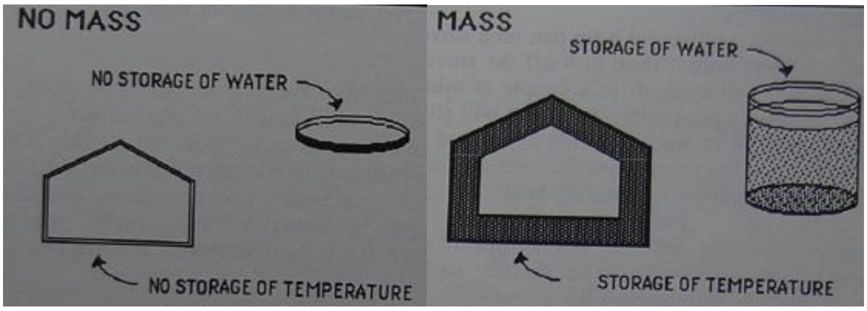

Fig. 3 - Analogy between water storage capacity of a barrel and energy storage of mass.

Insulation prevents heat losses, making the energy stored in the mass radiate towards the living space. This way, if a house is built with mass surrounding the living space and this mass is wrapped with insulation, the house will act as a battery.

Earth is not a good insulator, but a sufficient layer does prevent the penetration of cold. "*For example, in areas where the winters reach 30 degrees below zero, the ground does not freeze below 4 feet (1.22m). Therefore 4 feet of earth is enough insulation to maintain temperatures above freezing in this area*"[5]

Burying the Eartship recreates the frostline, making the great part of the walls, and of course the ground, at a frostfree depth. Doing this the external temperature most of the house is subjected to is over 0ºC.

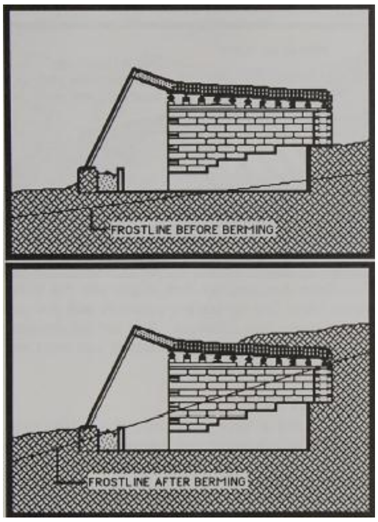

Fig. 4 - Frost line recreation

[5] Reynolds, 1991, *Earthship vol.2*

Active solar building design differs from the passive by the fact that mechanical or electrical devices such as pumps or fans are used to distribute and move the heat and when combined with the passive design principles the system is considered to be hybrid.

2.3.2 – Materials

The main properties that make a material suitable for an Earthship are:

- The materials must be found locally. *Indingenous.*
- Recycled.
- Natural.
- Low energy used during fabrication or transformation.
- Dense if being used for thermal mass.
- Durable and resilient (if built in an earthquake territory).
- Easy construction. Unskilled labour must be able to build the house. The materials must be light enough to be manipulated by man, and the construction solutions must be simple to execute.

Most common materials used are tired rammed with earth, timber logs, sandbags, can and bottles, straw…

The tires are filled with compacted soil forming the massive thermal mass wall which also is the main load bearing structure of the house.

Two of the biggests concerns when it comes to building with a new concept are Thermal performance and Fire risk.

As far as insulation goes, the R-value (lambda) of rammed earth is very low compared to other materials. Research was carried out by the Commonwealth and Scientific Research Organization found the U-value for an earth wall to be 1.97 W/m^{2}ºC for a thickness of 450.[6]

Thickness (mm)	U-value W/M(squared) (degrees)C
250	2.86
300	2.56
350	2.33
400	2.14
450	1.97

Fig. 5 - U-value of an Earth wall

Due to the high U-value, in cold climates an extra layer of soil and a thermal wrap need to be implemented. Only using rammed earth tires produces cold bridges and great heat loss. The Concept evolved and an extra layer of soil was added externally protecting the house from heat loss and creates a barrier between the house and the moist earth.

Furthermore, in order to have a decent U-value in the construction, polystyrene should be added wrapping the whole construction.

As far a fire demands go, tires filled with earth provide a good fire resistance due to their mass.

[6] CSIRO, Commonwealth and Scientific Research Organization.

Rammed or packed earth can be classified as a non-combustible material. A 300mm wall is capable of providing fire resistance for at least 90 minutes.[7]

2.3.3 – Structure:

As any other building, Earthships have two load directions, vertical and horizontal. Vertical are gravitational loads, self-weight and use load.

The roof construction is made of timber beams supported on the mass walls, depending on the span and the dimensions of the beams, they can be placed from every 60cm to every meter.

Loads from the roof are transferred to the walls which are dense compacted earth and are very resistant. Tires have a dimension of 733mm making them a very thick wall that transfers the load to a wide surface reducing the pressure. Since the pressure is low due to the thickness of the walls, the soil is capable of resisting it and therefore there is no need for a foundation.

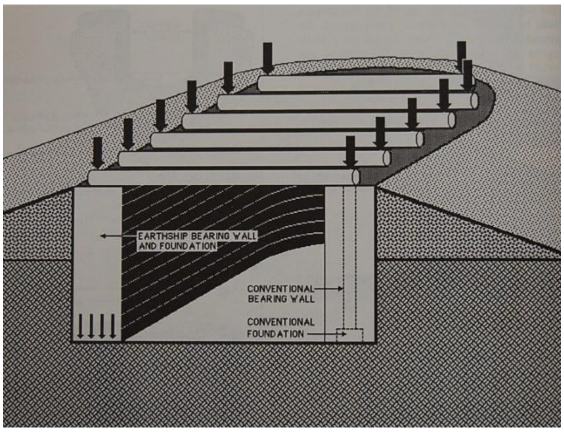

Fig. 6 - Load transmission

Horizontal loads are wind from the south façade and earth pressure from the walls buried in the ground. The walls in this case act as shear walls and retaining walls, again being as thick and dense as they are, the walls have no problem containing these actions.

Since the buried walls are below a frost free depth there is no danger of thermal movement caused by the earth.

Internal walls are not load-bearing and have no need for special foundation. Internal walls are usually 150mm and made of cans, a spread footing of 200mm wide and 200mm deep is sufficient.

2.3.4 – Water System:

Earthship houses are not connected to a centralized source of water. Rainwater and melted snow are collected and channeled through silt filters leading to a water tank.

Since the roof acts as water catchment it should be a flat roof, 1-4º and should be covered with a non-pollutant material to avoid contaminating the rain water. Metal sheets are a good example of non-contaminating roof covering.

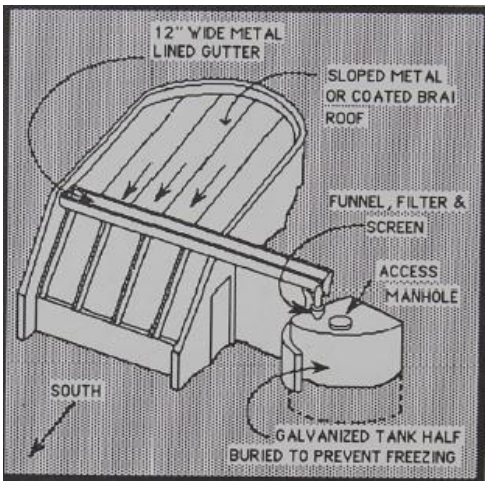

Fig. 7- Water catchment diagram

Water systems in ordinary houses depend on electricity one way or another, whether to activate pumps or valves.

Earthships can't afford to spend electricity on water pumps when things can be done naturally. Water through the building circulates by gravity. The water

[7] http://www.greenspec.co.uk/rammed-earth.php

tanks are situated at a certain height for gravity circulation to work at its best.

The building is equipped with what Micheal Reynolds calles a *Water Organizing Module,* this module consist among other things of filters to purify water and make it drinkable. All water fed to the appliances is drinkable (except toilet).

Solar power heats up the hot water in most cases. Although other types of heating may be required, such as natural gas or electric heating.

2.3.5 – Sewage System:

A differentiation must be made between the types of waste water, black water and grey water. Black water comes from toilets and needs to be treated before it can return to the earth. Grey water comes from the other appliances and is reasonably clean, if the soap used is environmentally friendly grey water can be lead back to the earth without further treatment.

Earthships propose the use of compost toilets that don't create any black water at all or septic tanks. The black water should be stored in the tanks for a long period of time to allow the solids and paper to dissolve and start the decomposition process. When the tank is full the liquid decomposed material is evacuated to the soil.

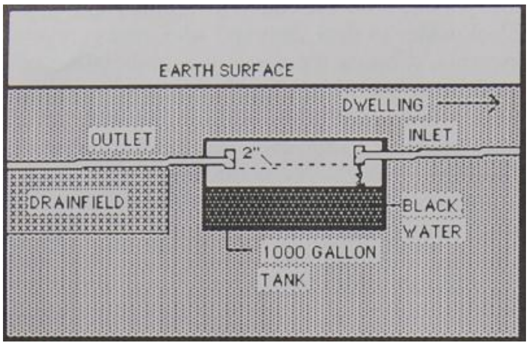

Fig. 8 - Inlet ad outlet of the Septic Tank

Grey water is in no cased mixed with the black water. Grey water from bathroom and kitchen sink is filtered through a grease and particle filter and afterwards drained to a botanical cell or planter. Water from the shower is of greater volume and can't be kept inside, a good distribution of water is important.

The water that comes from the botanical cell is collected at a *Grey Water Organizing Module* which pumps the water into the toilets

Micheal Reynolds recommends the following:

1. *Use a compost toilet.*
2. *Drain kitchen sink into an indoor planter.*
3. *Drain all bathroom sinks into the nearest planter to avoid piping.*
4. *Don't use dishwasher.*
5. *Drain tubs and showers into well distributed exterior landscape.*
6. *Drain washing machines into well distributed exterior landscape.*[8]

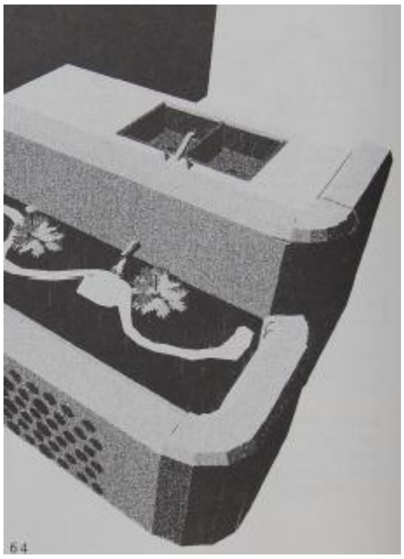
Fig. 9 - Diagram representing the grey water treatment from kitchen sink.

[8] Reynolds, 1991, *Earthship vol.2*

2.3.6 – Electrical System:

Enough electricity should be provided to light itself and run various appliances. In colder climates, energy might also be needed to start auxiliary heating methods.

Energy is captured by wind and sun, with windmills and photovoltaic panels, these must be sufficient to produce enough energy to meet the demands. The energy that is produced is then stored in batteries for later use.

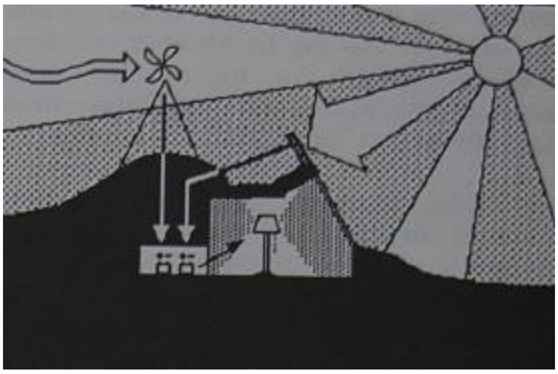

Fig. 10 - Energy production

The design and the use must be carefully analysed before the system is designed. The first step would be to consider the need for heating and cooling, cooling can be ruled out due to the Eartship design and for the same reason heating should be considered as a minimal consumption, if not negligible. Traditional water systems require electricity for pumping the water through the pipes and keeping the tank pressurized, the Eartship's approach and location of the water tanks can reduce this energy consumption as well. As for domestic hot water, solar hot water systems can produce a sufficient amount of hot water depending on the location. If it were not enough, the heating can be by either gas or electricity; Michael Reynolds recommends the use of gas over electricity as it is more efficient.

Lighting systems also have to be highly efficient. During the day time, the house is designed with windows and skylights so artificial light are rarely needed.

Electrical appliances must be kept to a minimum, the objective is to eliminate, reduce or control the amount of energy.

Photovoltaic Electrical panels convert sunlight into small charges of electricity. The electricity is stored in batteries as 12 or 24 volt Direct Current. Most of the appliances in a household work on Alternating Current, meaning that the current must go through an inverter. This process has an energy loss of approximately 10%. It is advisable that whenever possible use DC appliances.

The *Power Organizing module* converts Direct current to Alternating current. This module is a prefabricated system which includes circuit breaker and converters and is fitted into a wall in the interior.

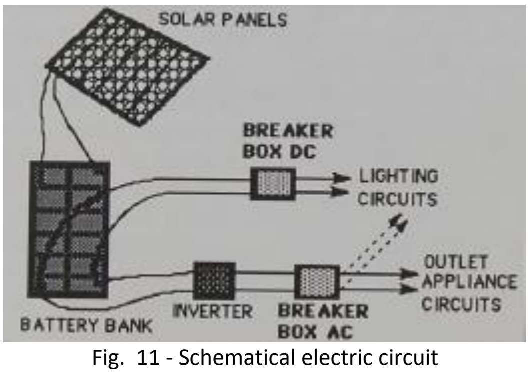

Fig. 11 - Schematical electric circuit

2.3.7 – Ventilation System:

When air gets heated up it becomes less dense and rises. An opening skylight is placed on the highest point of the building allowing the hottest air to escape. Ingress of air is done through the lowest point creating a natural current

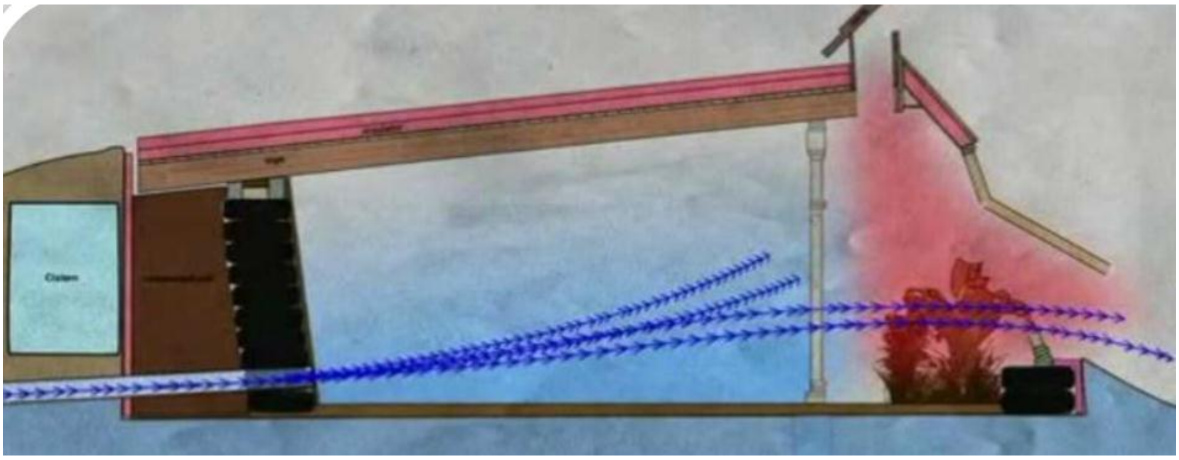

Fig. 12 - Air flow

The air inlet pipe is buried in the ground making the thermal mass heat or cool the air going through the pipe.

2.3.8 – Food System:

Eartships are designed with a Green House adjacent to the living space. This Green House is of vital importance since it controls many tasks of the systems.

The Greenhouse or *buffer zone* works as that precisely. It is an area that eases the transition between the inside and the outside. The façade with most heat loss is the South façade due to it being covered with windows almost completely. This greenhouse optimizes the use of solar energy and thermodynamics and more comfortable indoor temperature all year round is achieved.

The skylight for ventilation is also places in the greenhouse because due to its construction is it the highest point.

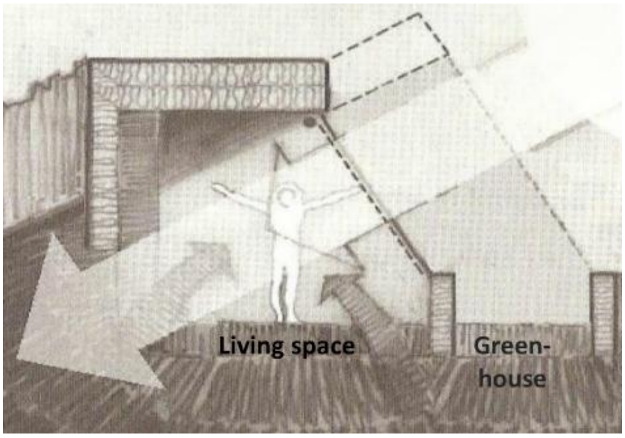

Fig. 13 - Buffer zone

Plants are protected from extreme temperatures and because of the glass façade facing South, they have sufficient Sun. Plants receive their nutrients with the waste compost and water from rainwater.

3. ZERO ENERGY HOUSES, PASSIVE HOUSES AND EARTHSHIP

Are Earthships different to zero energy and passive houses?

Is it more beneficial and how.

In the past years sustainability in construction has become a big issue as more and more forms of sustainable living are being introduced. The Earthship concept is not alone, other concepts as passive houses or zero energy houses are also becoming increasingly popular.

The Passive House standard originated in 1988 and is designed by 5 main principles; Insulation, Air Tightness, Solar Gain, Heat Exchange and Minimized Thermal Bridges.

Passive houses have the following requirements:

- The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year (4746 btu/ft² per year) in heating and 15 kWh/m² per year cooling energy OR to be designed with a peak heat load of 10W/m²
- Total primary energy (source energy for electricity and etc.) consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m² per year (3.79 × 104 btu/ft² per year)
- The building must not leak more air than 0.6 times the house volume per hour (n50 ≤ 0.6 / hour) at 50 Pa (N/m²) as tested by a blower door.
- U-values (thermal transmittance) of external walls, floor slabs and roof areas of Passive Houses range from 0.10 to 0.15 W/(m²K).[9]

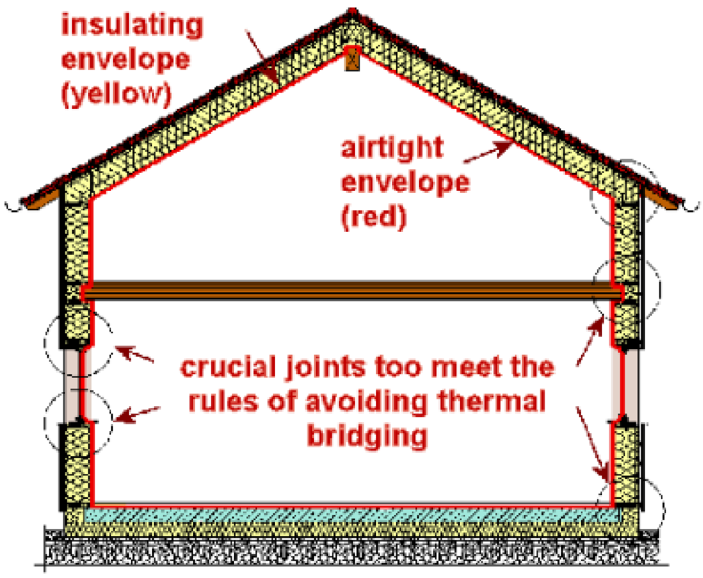

Fig. 14 - Passive house standards

[9] http://www.passivehouse.com/

Zero Energy houses have no net energy consumption and a carbon zero emission. Zero energy houses can be independent from the grid but usually they are connected to avoid the possibility of having a power shortage.

Energy is harvested on site with solar panels and wind turbines, this combined with an important reduction on the energy consumption can make the zero energy houses produce more energy than they consume, turning into Energy Plus houses.[10]

Earthships, passive houses and zero energy houses share the same basic concepts and the same goal. This goal is to build in a sustainable manner to reduce energy consumption. Passive Houses focus on the reduction of heat loss to reduce the energy consumption, Zero Energy houses are forced to reduce the energy consumption to make the demands meet the supply of on-site production.

Earthship takes these ideas to another level, setting the house to be completely off the grid and designing it such a way to reduce heat loss and obtain maximum energy gain. The way the Earthship concept was created there are no specific demands the house must meet. The construction and the elements used are very rudimentary so no U-values or energy frames are calculated, this can lead to an inefficient design or construction.

[10] http://www.nrel.gov/docs/fy06osti/39833.pdf

4. EARTHSHIP MODELS AND EXAMPLES

What are the different designs?

How do these buildings perform in reality Worldwide?

In the combination of known techniques such as thermal mass and passive houses lies the origin of the first Earthships. Techniques, systems and designs have changed vastly throughout the years, each new model improving the one before.

The first model created was the Hut-model which is essentially a tire circumference. This evolved to the base of all future models, the U-model. The hut opened up creating a straight façade where the greenhouse was added. There Huts and U's were combined to create a house as big as the client desired.

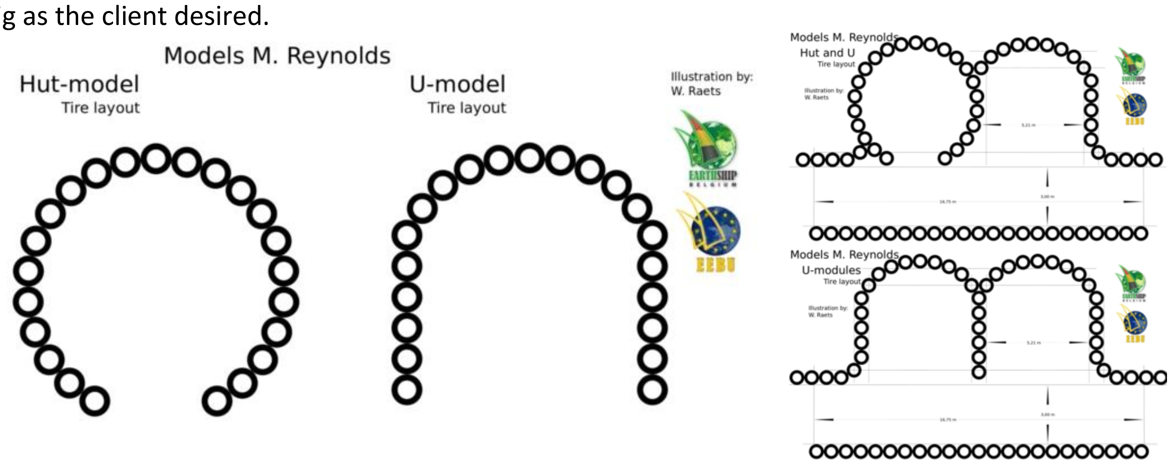

Fig. 15 - First modules

Later on in the journey, the Packaged model was introduced. Now the Earthship became rectangular with the south façade glazed and the rest buried in soil.

Finally the latest modification led to the Global model in 2007. The Global model takes the shape of the Packaged model and introduces the greenhouse from its predecessor. [11]

Apart from the aesthetic changes, building components also changed during this evolution. The ventilation system was introduced with the Global model, as well as the placement of insulation in colder climates. Construction materials were changed and optimized.

Systems were also improved, specially the water filtration.

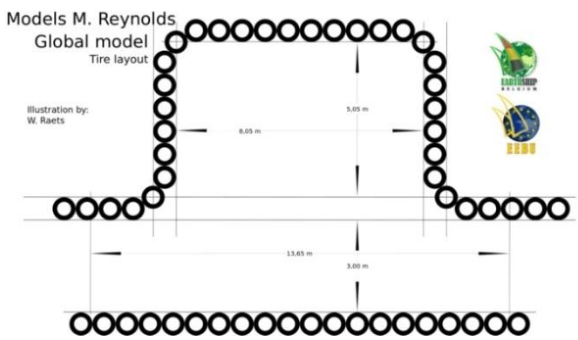

Fig. 16 - Global Model

[11] http://earthshipeurope.org/index.php/earthships/evolutions

4.1 REAL EARTHSHIPS

The most relevant are the ones built in Europe, both in terms of General construction regulations (Eurocodes) and climate (only in some cases).

The first Earthship in Europe was constructed in Belgium in 2000. It was a demonstration house without any systems built under Earthship Biotecture's control. In reality this Earthship did not have any use ad no research was done.

The second house was built in Scotland 2002. The design was a simple U-module built as a demonstration as well. In this house the following adaptations were included:

- Vertical glass on the front
- The greenhouse/buffer zone was introduced. A second layer of glass on the inside to act as a buffer, creating a double glazed corridor in front of the bulding.
- A thermal wrap insulation all around the building and a waterproof membrane.
- Traditional stone facings on the front of the building.[12]

Fig. 17 - Earthship Fife, Scotland

When constructing the tire wall, wet soil was used. This evaporated creating moisture in the roof caivity causing problem with the timber in the roof. No data of the performance of this Earthship was collected.

Next up was Spain, with an Earthship being built in the coast. The construction finished in 2008. As an opposition to the changes in Scotland, no insulation layer was placed and the second glass layer was not constructed either. The Spanish climate is much softer and doesn't need the winter precautions that Scotland might require. In fact sun blockers were introduced to keep the house cool in the summer

This Earthship had a problem with the waste water treatment. They decided to direct the water from the kitchen and washing machine to the septic tank. This avoided bad smells and made the water in the toile look cleaner. It also avoids problems with the particle filter getting clogged with grease. This change was introduced to all the Earthships built from that time.

. This Earthship worked without any further problems, except from an overheating in summer reduced with the use of sun blockers like awnings.

Fig. 18 - Awnings in Earthship Spain

[12] http://earthshipeurope.org/index.php/earthships/europe?showall=&start=2

In spring 2002 a house in the United Kingdom as built. The design combined all of Reynolds models. Due to the climate, as well as in Scotland a layer of insulation was placed. The University of Brighton placed sensors in the wall of the construction to measure its thermal performance.

After monitoring the University of Brighton concluded:

- *Initial results indicated the thermal 'battery' – the rammed earth tyre wall – was moderating the external severe temperatures but satisfactory thermal comfort conditions will require additional heating in winter and some means to relief the summer overheating*
- *The earthship is still settling to its thermal equilibrium with the surrounding and long term monitoring will be needed to establish better understanding of its behaviour.*
- *Studies are under way including computer simulations to evaluate alternative design options to improve the thermal performance*[13]

The absence of floor insulation creates a very big temperature difference. Ventilation system does not work correctly with the high humidity of England should be modified. As well the thermal mass appears not to be working as good as it should, it is probably too thick for the solar radiation received. Again in this Earthship the big problem of mould is present due to the condensation caused by cold bridges.

Fig. 19 - Earthship Brighton

The first Global Model was built in France in 2007. Another Global model was built in The Netherlands. Because of the high water level and the poor soil, big concrete foundations were needed to be able to distribute the pressure.

The model built in The Netherlands is very peculiar since it has an open North façade. It has been documented that the building is closed during winter time because of the cold. The high humidity of the country and the lack of sun were not thought of during the design phase and that resulted in a poor working Earthship. There is mould inside the building and the cement around the tires has cracked. [14]

[13] K. Ip and A. Miller, *Thermal behaviour of an earth sheltered autonomous building.*

[14] Performance information obtained during conference call with Willy Raets (Earthship Belgium) the 23/03/2012.

5. THE DANISH ENVIRONMENT. CONDITIONS AND DEMANDS

How is the Danish Environment?

What are the differences between Denmark and Taos?

As an introduction to Danish climate it can be said that Denmark has a temperate climate, it is largely conditioned by winds from the West and by the fact that all the country can be considered as coastal climate. The mean temperature in February, the coldest month, is 0° C, and in July, the warmest, 17° C. Rain falls fairly evenly throughout the year, the annual average amounting to approximately 61 cm.

Being up north as it is, the length of the day with sunlight varies greatly. From short days in winter with average six hours of sunlight, to long days in summer with more than double hours. In average per year, it has been found that Denmark has 4.38 hours of sunlight per day. [15]

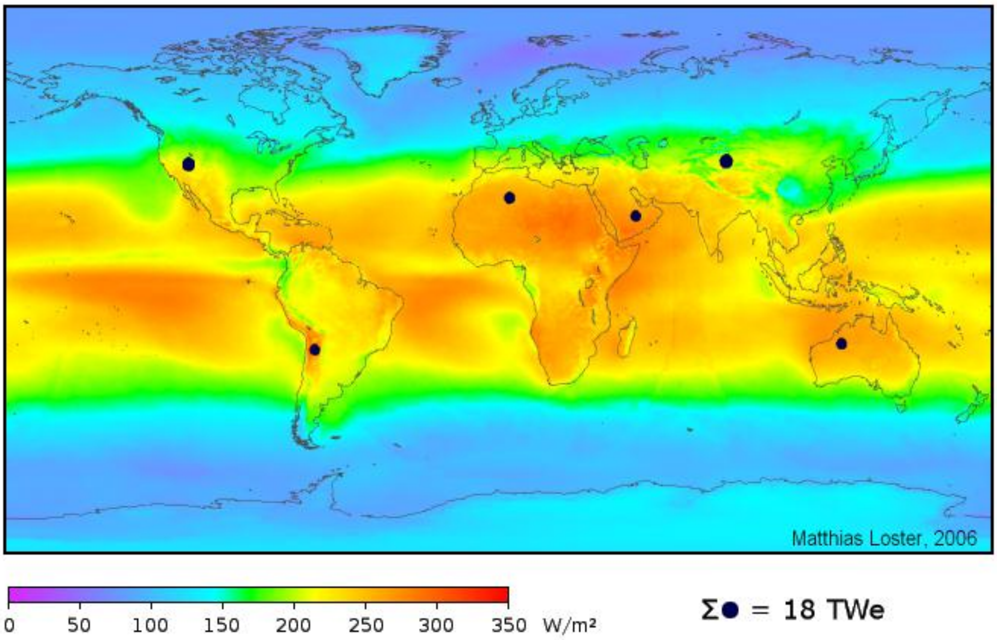

Fig. 20 - Insolation Map

The insolation map in Fig.20 shows the solar radiation in watts per square meter. Denmark ranges from 100-150 W/m^2.

More specific numbers have been taken for Copenhagen.

- Copenhagen, Denmark latitude & longitude; 55°41'N 12°32'E.
- Altitude; 9 m.
- The average temperature in Denmark is 8.6 °C.
- The range of average monthly temperatures is 18 °C.
- The warmest average max/ high temperature is 22 °C in July.
- The coolest average min/ low temperature is -3 °C in February.
- Denmark receives on average 600 mm of precipitation annually or 50 mm each month.

[15] http://goscandinavia.about.com/od/denmar1/ss/weatherdenmark.htm

- On balance there are 171 days annually on which greater than 0.1 mm of precipitation (rain, sleet, snow or hail) occurrs or 14 days on an average month.
- The month with the driest weather is March when on balance 32 mm of rain, sleet, hail or snow falls across 12 days.
- The month with the wettest weather is July when on balance 71 mm of rain, sleet, hail or snow falls across 14 days.
- Mean relative humidity for an average year is recorded as 79.0% and on a monthly basis it ranges from 68% in May & June to 88% in December.
- There is an average range of hours of sunshine in Denmark of between 0.6 hours per day in December and 8.2 hours per day in June.
- On balance there are 1603 sunshine hours annually and approximately 4.4 sunlight hours for each day.
- On balance there are 76 days annually registering frost in Denmark and in January there are on average 20 days with frost.[16]

The following graph (Fig. 21) displays the information per month

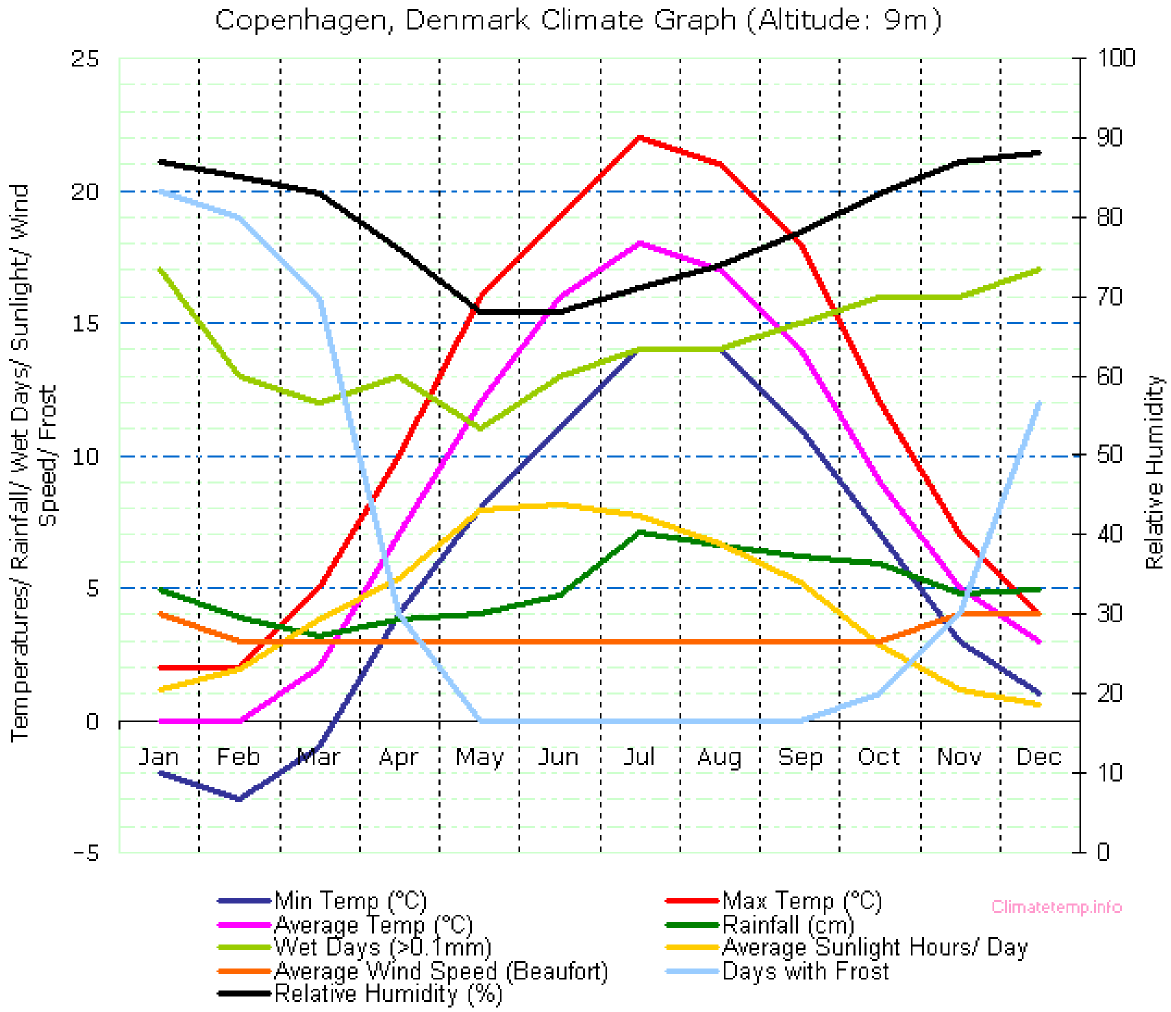

Fig. 21 - Copenhagen Climate Graph

[16] http://www.climatetemp.info/denmark/

The Earthship concept originated in New Mexico, United States, more specifically in Taos, where a whole Earthship community has been established.

The following information has been collected from Albuquerque, New Mexico.

- Albuquerque, New Mexico, Usa latitude & longitude; 35°3'N 106°37'W.
- Altitude; 1618 m.
- The average temperature in Albuquerque, New Mexico, is 13.6 °C.
- The range of average monthly temperatures is 24.5 °C.
- The warmest average max/ high temperature is 33 °C in July.
- The coolest average min/ low temperature is -5 °C in January.
- Albuquerque, New Mexico receives on average 206 mm of precipitation annually or 17 mm each month.
- On balance there are 60 days annually on which greater than 0.1 mm of precipitation (rain, sleet, snow or hail) occurs or 5.0 days on an average month.
- The month with the driest weather is January, February, November when on balance 10 mm of rainfall (precipitation) occurs.
- The month with the wettest weather is August when on balance 33 mm (1.3 in) of rain, sleet, hail or snow falls across 9 days.
- Mean relative humidity for an average year is recorded as 36.0% and on a monthly basis it ranges from 23% in June to 49% in January & December.
- There is an average range of hours of sunshine in Albuquerque, New Mexico of between 7.1 hours per day in January and 12.2 hours per day in June.
- On balance there are 3460 sunshine hours annually and approximately 9.5 sunlight hours for each day.

Having compared the two climates, it is obvious that some changes have to be done to the model for it to work in the Danish climate. The changes will be discussed in Chapter 6 and 7.

6. DANISH REGULATIONS. POSSIBBLE OR IMPOSSIBLE.

Codes and Permits?

What are the Danish Regulations?

Which Regulations can be adapted?

Which are the demands for building elements?

What has to be changed in the Earthship model?

Are the any examples in Denmark?

Building Regulations and Institutions control the type of housing that can be built. New concepts and materials have to go through rigorous tests to be sure that they meet the requirements set on the Regulations. This is a long, complicated and expensive process.

Even though the Building Regulations are common to the whole Danish territory, it is each Kommune who grants or denies the Building Permit according to their by-laws.

The most relevant Regulations to take into consideration are the Comfort and Health and Safety related.

Conditions such as accessibility, design and layout will have to be treated separately with each design, and analysed when necessary. As design is something that is not inborn in the Earthship concept it will not be discussed.

6.1 - BUILDING REGULATIONS

Chapter 4 of the Danish Building Regulations refers to Structure specifications.

4.1(1) Buildings must be constructed so as to provide satisfactory conditions in terms of function, safety, sustainability and health. Buildings must be constructed in accordance with best practice, using materials which are appropriate for the purpose.[17]

There is no clarification as of what is considered appropriate materials. The structure must be able to withstand the loads during its life span and construction process. It has been proven by experience that the wall construction is very stable and able to carry the load. The roof construction used can be considered quite traditional since it is mainly wooden structure. The logs must be dimensioned according to regulations.

4.1(3) Foundations must be taken down to frost-free depth and load-bearing ground

Most of the construction itself is excavated down to a frost-free depth.

4.1(6) Building structures and materials must not have a moisture content which is liable to increase the risk of mould growth once the building is occupied.

Soil used for filling up the tires must be as dry as possible. Furthermore a damp proof membrane should be placed I the building envelope to avoid moist entering the house.

[17] [17] Building Regulations 2010. Ch 4 – Structres. General.

Structures must be designed according to the Eurocodes and the specific Danish annexes. Important Standards and EN codes that should be consulted are:

· *DS/EN 1990 Basis of structural design, with DS/EN 1990 DK NA*

· *DS/EN 1991-1-1, Densities, selfweight, imposed loads for buildings, with DS/EN 1991-1-1 DK NA*

· *DS/EN 1991-1-2, Actions on structures exposed to fire, with DS/EN 1991-1-2 DK NA*

· *DS/EN 1991-1-3, Snow loads, with DS/EN 1991-1-3 DK NA*

· *DS/EN 1991-1-4, Wind actions, with DS/EN 1991-1-4 DK NA*

· *DS/EN 1991-1-5, Thermal actions, with DS/EN 1991-1-5 DK NA*

· *DS/EN 1991-1-6, Actions during execution, with DS/EN 1991-1-6 DK NA*

· *DS/EN 1991-1-7, Accidental actions, with DS/EN 1991-1-7 DK NA*

·*DS/EN 1995-1-1, Design of timber structures, Common rules and rules for buildings, with DS/EN 1995-1-1 DK NA*

· *DS/EN 1995-1-2, Design of timber structures, Structural fire design, with DS/EN 1995-1-2 DK NA*

4.2(6) When materials and constructions not covered by the Eurocodes listed in 4.2(1) are used, documentation must be provided demonstrating that satisfactory safety conditions are in place.

Tires are not a recognized material and it is not covered by any Eurocodes. The documentation presented could be test results of a Standarized method, documentation about the positive usage on other buildings and an acceptance safety level

Concerning Fire Safety, Building Regulation demands that buildings must withstand fire for sufficient time to evacuate all the people in it and provide rescue openings to help this evacuation.

5.1(1) Buildings must be constructed, laid out and fitted out so as to achieve satisfactory protection against fire and the spread of fire to other buildings on the same and neighbouring plots. There must be appropriate provision for rescuing people and for fighting fires.

5.2(7) The number of rescue openings in a fire-resisting unit must be appropriate for the number of people for which the room is designed. Rescue openings must be located and formed in such a way that people can make their presence known to the emergency services. They must also be formed such that people can be rescued via emergency services ladders or by themselves, unless the building is laid out as specified in 5.2(8).[18]

The design of the escape routes and rescue openings is a big problem due to the Earthship being buried in 3 or the 4 sides. The rescue openings would only be possible on the front façade.

Due to the open design of the Earthships, all the rooms have direct access to an escape route, meaning that in order to evacuate the building no matter from which room you come from, you always exit to an escape route and not through another room.

5.5.1(1) Internal surfaces must be such that they do not contribute significantly to fire or to smoke emission during the period of time needed to allow people occupying the room to reach safety.

Most of the Earthships are plastered with a traditional mud/clay/lime plaster that is fire resistant and will not combust.

As mentioned before, rammed tires wall resist for more than 90 minutes, being that sufficient time for evacuation.

[18] Building Regulations 2010. Ch 5 – Fire Resistance

The Danish Building Regulation 2010 specifies in chapter 6 the demands of the Indoor Climate

6.2(1)Buildings must be constructed such that, under their intended operational conditions and at levels appropriate for the human activities to be carried out in them, comfortable, healthy temperatures can be maintained in the rooms occupied by any number of people for an extended period.[19]

The indoor climate covers Thermal Indoor Climate, Air Quality, Acoustic climate, Light Conditions.

According to DS/EN ISO 7730:

International Standard which purpose is to present a method for predicting the general thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. To specify acceptable thermal environmental conditions for general and local thermal comfort… The standard applies to people exposed to indoor environments where the aim is to attain thermal comfort, or indoor environments where moderate deviations from comfort occur.

This is done with the computer application ECOTER based on the Fanger Method[20], which includes factors such as Transmit ion of thermal sensation; Metabolic energy produced by the body; External mechanical work: Heat loss by diffusion of water through the skin; Heat loss by evaporation of sweat; Latent heat loss by respiration; Sensible heat loss by respiration; Heat loss by radiation; Convection heat loss; Air temperature; Thermal resistance of clothes; and Air pressure.

ISO establishes that for dwellings where no work is executed, with average air pressure and velocity, the minimum comfortable temperature in winter fluctuates from 17-19ºC.[21]

Ventilation has to be sufficient to assure a healthy and comfortable indoor climate, by mechanical, natural ventilation or hybrid ventilation.

6.3.1.1(1) Buildings must be ventilated. Ventilation systems must be designed, built, operated and maintained such that they achieve no less than the intended performance while they are in use.

Taken the Earthship concept of reducing energy consumption and systems, the ventilation will be done naturally. BR'10 explains that natural ventilation functions by air being supplied via valves in external walls and removed via natural up draught through exhaust ducts from kitchens and bathrooms/WCs above the roof. [22]

6.3.2.1(1) Building materials must not emit gases, vapors, particles or ionizing radiation that can result in an unhealthy indoor climate.

It is important that the tires used are completely off gassed and will not emit anymore unhealthy gas to the room.

Pollutants accessing the building are also regulated by the BR'10, the biggest concern is the Radon pollution

6.3.3.2(1) Ingress of radon to the indoor climate must be limited by making the structure which is in contact with the subsoil airtight or by using other measures to equalize effect.

When making the floor construction in contact with the soil, the easiest way of avoiding radon pollution is making the floor air tight and provide an exhaust for the concentrated radon. A radon stabilizing layer should be used and can consist of leca nuts.

[19] Building Regulations 2010. Ch 6 – Thermal Indoor Climate

[20] http://tecno.sostenibilidad.org/index.php?option=com_content&task=view&id=424&Itemid=50

[21] http://www.ual.es/GruposInv/Prevencion/evaluacion/procedimiento/B-%20Condiciones%20f%EDsico-ambientales/4-Ambiente%20t%E9rmico.pdf

[22] Building Regulations 2010. Ch 6.3.1.2(2)

Light conditions

6.5.1 (1) Working areas, occupiable rooms, habitable rooms and shared access routes must have satisfactory lighting without causing unnecessary heat loads.

6.5.2 (1) (…) must have sufficient daylight for the rooms to be well lit. Windows must be made, located and screened such that sunlight through them does not cause overheating in the rooms.

Because of the design of the Earthship, only one side of the building is opened. It faces the South to catch as much light as possible, even in winter. This requires a fixed and thoughtful design to promote the ingress of light towards the inside of the rooms.

Overheating is not a problem, in fact the windows used have a high G-value (coefficient which measure the solar energy transmittance of glass) to absorb as much heat as possible.

Energy Consumption is of vital importance in the Earthship model. Since all energy used must be produced by the house alone, the house cannot afford to lose any heat.

7.1(1) Building must be constructed so as to avoid unnecessary energy consumption for heating, hot water, cooing, ventilation and lighting while at the same time achieving healthy conditions.

6.2 - DEMANDS FOR BUILDING ELEMENTS

Fire:

Earthships are usually family houses, the buildings are then classified as Category 4 buildings. If the building has less than 1000m^2, usually the case. The building components must be R30 if they are load bearing and EI30 is they are only separating.[23]

U-value:

The minimum insulation the Earthship can have must give a U-value of:

External walls and basement walls in contact with the soil.	0.30
Ground slabs, basement floors in contact with the soil and suspended upper floors above open air or a ventilated crawl space.	0.20
Ceiling and roof structures, including jamb walls, flat roofs and sloping walls directly adjoining the roof.	0.20
External doors, rooflights, doors and hatches to the outside or to rooms/spaces that are unheated and these as well as glass walls and windows to rooms that are heated to a temperature more than 5 K below the temperature in the room concerned.	1.80[24]

6.3 - CHANGES IN THE EARTHSHIP DUE TO REGULATIONS AND CLIMATE

Earthship Denmark is currently planning a construction in Holbaek. A interview was held with them where they explained what problems they had with the Kommune and what modifications they are going to make.

Harvesting water was not allowed. The Kommune claims that the quality may be affected by organic matter, dirt, insects or air pollution. Using improper materials can also cause pollution.

[23] SBi 216.
[24] BR 2010, Table 7.6.1

Solar radiation is what activates the thermal mass, it heats up the air and mass inside the house. With an average of 4.38 hours of sunlight per day and energy of 100-150 W/m^2 it is easy to assume that in Denmark the mass will reach a lower heat level than in Taos. Since not all of the thermal mass will be heated up it might be interesting to reduce the thickness of the mass.

The average temperature in Denmark is quite low; in order to keep the indoor temperature comfortable it is necessary to implement floor and wall insulation.

The "ideal wall" (Fig. 20) created my Michael Reynolds has this principle, it has dense mass towards the inside and insulation towards the outside.

INSULATION
Neither collects nor stores temperature. It simply blocks the passage of temperature .
Insulation has tiny air spaces that slow the movement of temperature

DENSE MASS
Absorbs and stores temperature. It has absence of air spaces that conducts the temperature allowing it to travel into the mass and be contained there.

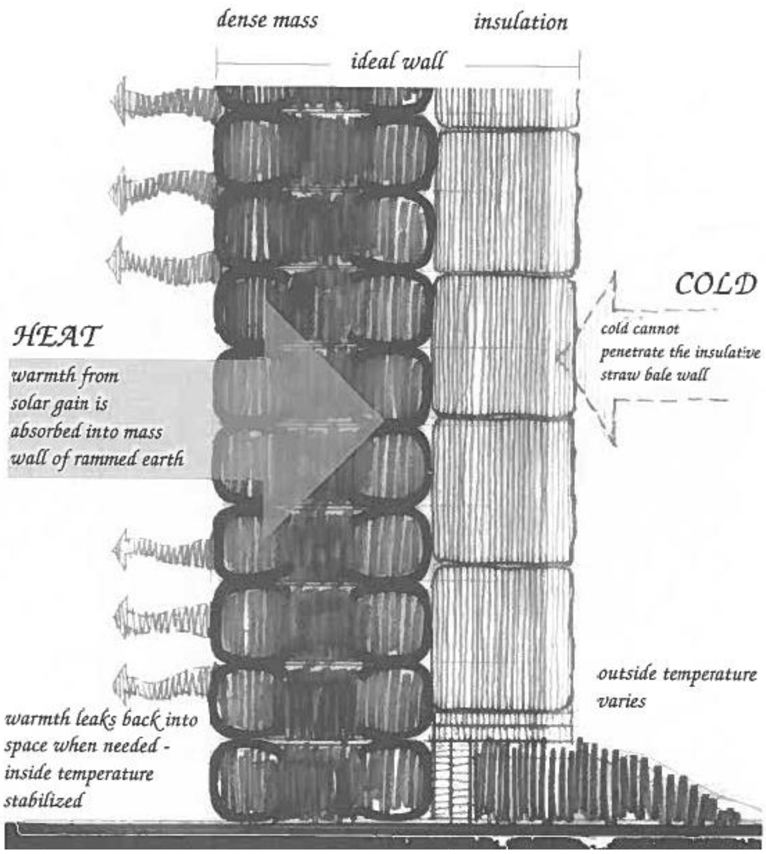

Fig. 22 - Ideal wall

Thermal mass would be on the inside to absorb the heat. Insulation would keep the heat from escaping and separate I from the exterior temperature.

7. BUILDING TOMORROW. DANISH EARTHSHIP

What are the building components?

How is the construction process?

CONSTRUCTION PRINCIPLE

Terrain deck: Mussel shells – Base course – Terrain textile with damp proof membrane – Particle board substrate with grooves for floor heating – Sound dimming mat – Wood planks

External wall: Hard insulation – Used car tires with compressed dirt – Damp proof membrane – Intelligent climate panels (Ex. SkamoPlus or LehmOrange PCM)

Roof: Green roof of sedum plants – Terrain textile – Drain system plates – Anti root membrane – Hard insulation – Damp proof membrane – OSB – Truss construction of round timber – Intelligent climate panels

South façade: Energy efficient windows with a high solar gain – Frame of round timber – Walls of clay and bottles

INTERIOR DESIGN

BT Alpha is going to have a net area of approx. 35 m^2, divided in to two rooms. The front room is called a "buffer-zone", that makes sure that the cold from the windows stays away from the main room, but that the rays from the sun is used to heat up the thermal mass in the walls. The "buffer-zone" will be the entrée of BT Alpha. You will step in to a green area where you can grow different vegetables and such. The "buffer-zone" and the main room is separated by a big window section. In the main room there will be a sink and the necessary furniture.

TERRAIN

The excavation is set out by land surveyor students from VIA UC's land surveyor education following the drawings made in cooperation with Building Tomorrows Design Team. The excavation will include BT Alphas gross area + 1 meter perimeter of working space, in 1,5 meters depth. In front of BT Alpha a "ramp" will be excavated which will later be used as the staircase for the front.

TERRAIN DECK CONSTRUCTION

The load bearing wall construction of compressed car tires is build up from the base and will also function as the frame for pouring in the mussel shells. The mussel shells are compacted as they are poured so we get a more stable floor construction. When the layer of mussel shells reaches the wanted thickness a layer of base course is poured and compacted on top of it. This layer will be the "working layer" for the construction until the house is sealed off. When the house is sealed off the DPM in the floor is connected to the DPM in the wall and the substrate floor can be laid. The floor planks can now be placed inside the house for drying out until they are to be put down. Just before the floor is put down the floor heating pipes are placed in the grooves.

EXTERNAL WALL CONSTRUCTION

As described earlier the car tires are built up from the base. Because of the big surface of the tires an actual foundation is not necessary. As the compression of the tires progresses the hard insulation is mounted on the outside of the wall and dirt is being filled up around the house partly to keep the insulation in place but also to avoid scaffolding on the outside. The tires are compressed to finished level so that the roof construction can begin. Before the substrate floor is put down the DPM is applied to the inside of the car tires. When the substrate floor is then laid the intelligent climate panels can be built up.

ROOF CONSTRUCTION

The roof is constructed of round timber, joined with old fashioned timber connections. The round timber will be visible in the final result. The round timber is mounted on top of a wall plate that has been fixed to the external wall. On top of the timber a OSB board is nailed down as a substrate for the rest of the roof construction. The DPM is fixed on top of the OSB and is joined to the DPM in the external wall. On top of the DPM the hard insulation is glued so there won't appear any cracks in the insulation layer during the rest of the construction. On the hard insulation we put an anti-root membrane so the roots from the plants on the roof won't penetrate the insulation layer and weaken the insulation ability. After this the drain system is installed for collecting the rain water with a finish of sedum plants to give a nice colourful surface. When the house has been sealed off we can mount the ceiling panels (intelligent climate panels).

SOUTH FAÇADE

The south façade mainly consists of windows as a part of the concept. First a frame of round timber is build, after that the walls of recycled bottles and a mixture of clay and other natural materials. The windows and doors are then mounted in the round timber and the house is considered "sealed".

8. CONCLUSION

Earthship has become a worldwide phenomenon. But what still is unclear is if it is a suitable concept to be used worldwide.

It is a known fact that is works as promised in Taos, where most of the Earthship Community is located. Also works fairly well in hot countries like Spain. But even in Spain these are only being constructed in the South and the coast.

The Earthships built in the rest of Europe have given a lot of problems and none of them behave as they should, according to the information researched. The thermal mass is not acting at its full potential, this is of course caused by the insufficient solar radiation. The thermal mass is too thick to get fully charged and in winter more energy is being used into heating the enormous thermal mass than supplying heat to the interior. If the layer of thermal mass was reduced this would work more efficiently. Even though the thermal mass is not giving out the heat expected it still regulates the temperature and makes the indoor climate slightly warmer in the winter.

Another big problem being faced in Earthships is the moist leading to mould inside the house. Being buried into the ground and using natural materials, the house needs to breath. On the other hand the house is being sealed by a damp proof membrane, making this impossible. Earthships are full of cold bridges that create condensation, the best way to avoid this mould appearing is to eliminate the cold bridges, place the damp proof membranes correctly and have sufficient ventilation.

With the problems that have occurred in almost all Earthships in Europe, it is impossible not to think that this is not the correct solution and the Global Model does not exist.

Europe has far better solutions for sustainable buildings at the moment, like sandbags or Straw houses. An excellent example of this is Friland, where they build with natural materials and produce some of their own electricity and manage waste.

The positive point about the Earthship concept is that it is always evolving; it is a work in process. Every problem that appears in one Earthship, is studied and corrected for the next. For the Global Model to be able to work in Europe more changes have to be made and all factors must be taken into consideration.

The Earthship concept takes sustainability to an extreme making the ideas sound like an utopia. The reality is that they are there, and in some aspects they work. I is definitely something that needs time and research in order to obtain a perfect comfortable house that fulfils all the requirements demanded for a modern house.

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11. ANNEXES

BUILDING TOMORROW DRAWINGS