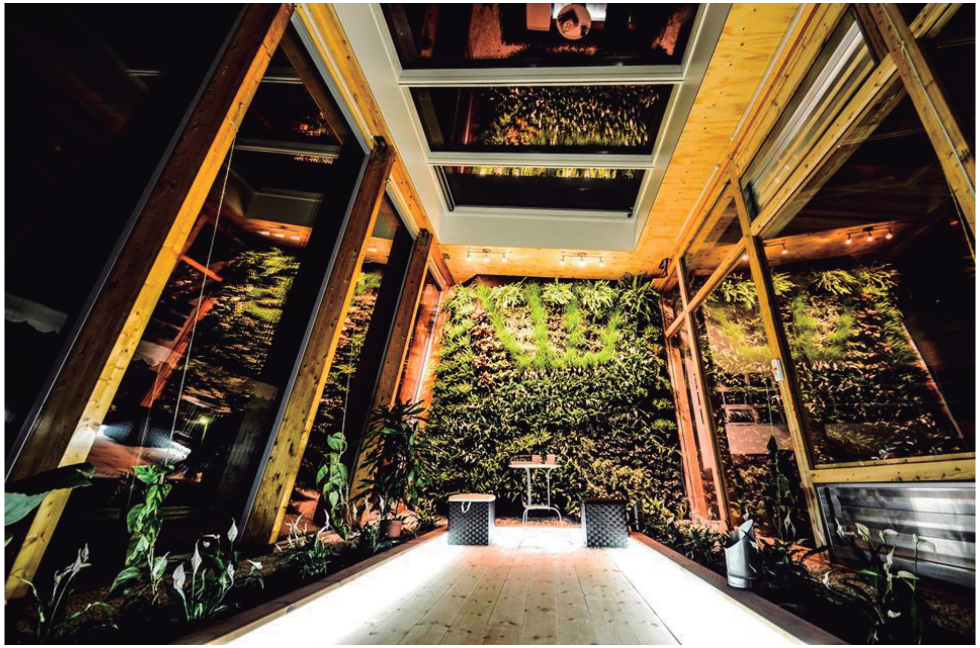
INVESTIGATION ON THE ENERGY CONSUMPTION AND THERMAL INDOOR CLIMATE CONDITIONS OF AN EARTHSHIP BUILDING



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Trabajo Fin de Máster

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Abstract

This study investigates the Indoor Environmental Quality (IEQ) and energy performance of Earthship buildings in Denmark. Earthship is a type of passive solar building, whose walls are made with used tyres and rammed earth and uses renewable sources to provide energy supply. A prototype of this kind of building has been analysed. This type of construction has already been studied through modelling and experimental data. In this investigation, the main architectural-design parameters regarding the building energy consumption and IEQ have been studied through numerical modelling. The results of this study clarify the influence of the main architectural-design parameters on the thermal behaviour and energy consumption of Earthship buildings in Denmark.

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1.INTRODUCTION

1. Introduction

1.1. Background

The study of energy consumption and Indoor Environmental Quality (IEQ) has become important in relation to building design processes. In recent years, these areas have been investigated individually. On the one hand, the operative temperature in a house should be within a comfortable range for its inhabitants. On the other hand, energy consumption should be minimized, aiming nowadays to zero-energy constructions. For this reason, the interaction between the main architectural-design parameters on both areas of study should be analysed.

Earthship buildings, a type of earth-sheltered construction, were developed in the 1970s by the architect Michael Reynolds. Currently, alternative housing construction systems are employed, aiming to reduce the excess of construction waste.

This research studies the effects of the main architectural-design parameters on the IEQ and energy consumption of Earthship buildings. Several investigations deal with this kind of construction, in which some existing Earthship buildings have been analysed through monitoring (real data) and energy/Indoor Climate modelling.

The case of study is “Building Tomorrow Earthship” (“BT Earthship” or “BT House”), located in VIA University College, Horsens (Denmark). This building has been constructed recently, and a preliminary study on it has been carried out through energy modelling, using BSim software [1]. In this investigation, the building energy consumption and IEQ will be modelled. Thus, the results of this study will provide useful information regarding the influence of the main architectural-design parameters on the thermal behaviour Earthship buildings in Denmark.

1.2. Aims and objectives

The aim of this study is to investigate the main architectural-design parameters affecting the thermal IEQ and the energy consumption of Earthship constructions in order to rank the influence of such design-parameters on the aforementioned fields and propose optimum solutions.

In the following list of objectives, the different purposes of the study are described:

a) To identify the main characteristics of the construction of existing Earthship buildings regarding IEQ and energy consumption using available research and documentation.
    1 To select the main architectural-design parameters (orientations, floor area, distribution, etc.) affecting the IEQ and energy consumption of Earthship buildings.
    2 To determine the main construction characteristics (construction solutions, materials properties, etc.) regarding Earthship buildings.

b) To define the main design-parameters and construction features of the case of study "BT Earthship".
    1 To determine the main architectural-design parameters (orientations, floor area, distribution, etc.) affecting the IEQ and energy consumption of "BT Earthship".
    2 To establish the main construction characteristics (construction solutions, materials properties, etc.) of "BT Earthship".

c) To create a numerical model capable of simulating the thermal behaviour of Earthship constructions in Denmark.
    1 To define the geometry, architectural-design parameters and loads of the model.
    2 To rank the influence of the main architectural-design parameters on the thermal indoor environmental conditions and energy consumption of the model.

1.3. Research methodology

This section describes the research methodology employed in this study. This is composed of four phases: literature review, preliminary study and energy modelling.

The different phases of this study are described below:

1 Literature review:

   a. Study the literature concerning the existing Earthship construction. To gather all the information (energy simulations and real data) deals with this kind of construction, in relation to its thermal behaviour and energy consumption using: academic books, scientific databases, technical brochures of the systems and materials, technical handbooks, standards, and contact with researchers and experts in the field.

2 Preliminary study:

   a. Study the main architectural-design parameters of Earthship building. To determine the most relevant architectural-design parameters of this kind of buildings (orientation, construction solutions, use of green house, etc.) based on the previous literature.
   b. Analysis of the case of study "BT Earthship". To associate the available information in the literature regarding the construction solutions employed in the existing Earthship buildings in order to compare it with the building object of study.

3 Numerical model:

   a. Definition of the numerical model using BSim software. To create a building energy model in order to study the thermal behaviour and energy consumption of the "BT Earthship", including its geometry and loads.

b. Comparison of the influence of the different architectural-design parameters on the IEQ and energy consumption of the “BT Earthship”.

1.4. Limitations and scope

This research is focused on the study of thermal indoor environmental quality and energy consumption in Earthship buildings. Therefore, the scope of this work is: to review all the literature concerning this matter, to identify the main architectural-design parameters, to create an energetic model of the “BT Earthship” and to rank the influence of the main architectural-design parameters.

The limitations of this study can be divided in two groups:

Specific limitations:

-The authoress of this study has been working recently as a researcher in a similar field. However, she is still not an expert on this matter.

-In this investigation an existing theory is applied. So, a new one is not developed.

-The research in this kind of construction is pretty recent. Thus, the comparison of the results from this study with previous investigations will be limited.

-This work has been done in a short period of time (from September of 2014 until July of 2015).

Conditional limitations:

-“BT Earthship” is still been built.

-Regarding “BT Earthship” construction, there was not any project or research on it so that it is difficult to know how it was built.

-BSim software has been used to analyse this kind of building, but it has never been tested.

2. LITERATURE REVIEW

2. Literature review

2.1. Earthship building: State of the art

2.1.1. History and evolution

One of the most important current problems is the climate change and its environmental consequences [2], [3]. Buildings and infrastructures use 40% of the materials extracted from our planet, and around 40% of all the human-generated waste is produced by the construction industry [4]. In Europe, energy consumption in buildings represents almost 40% of the total final energy use and these are responsible of 36% of the European Union's total carbon dioxide emissions; and 50% of the building energy consumption is employed in HVAC systems. Furthermore, current society employs around 90% of their time indoor. For this reason, energy efficiency policy has become relevant taking into account the relation between IEQ and building energy performance [5], [6], [7], [8].

The use of earth in building is one of the oldest worldwide [9]. For 5000 years now, soil as a construction material has been widely employed due to its suitable thermal and mechanical properties. Ground temperatures are more stable than external air temperatures, which are higher in summer and lower in winter. Consequently, the ground has a relevant potential as energy storage media in construction [10]. That helps to save energy in HVAC systems keeping a comfortable environment [11]. Thus, earth-sheltered construction is being investigated as an alternative to traditional construction techniques [12].

The concept of Earthship, a type of earth-sheltered construction, was developed in the 1970s by the architect Michael Reynolds in Taos, New Mexico (USA). The Earthship is a type of passive building, partially buried and built with reused car tyres and rammed earth, which uses renewable energy supplies. The goal of the Earthship concept is to build off-the-grid houses materializing the idea of "the independent vessel", with minimum material costs, using alternative housing construction systems, recycled, reclaimed and waste materials, passive solar principles and unskilled work. This type of construction is planned to be made by its residents, without much external assistance [13], [14], [15], [16].

At the beginning, the Earthship buildings were built using "U module system" The construction is formed by interconnected U-shaped modules, whose walls are curved and built with tyres and rammed-earth. These modules can be placed in relation to each other following several rules regarding their disposition and orientation. They all have to be facing the same direction without causing shadows on the glass wall of the closest U modules. Afterwards, the concept of Earthship has evolved towards "Packaged Earthship". In place of several U-shaped modules, a perimeter wall is built with tyres and rammed-earth. Can walls divide the inside space into rooms. Walls are straight instead of curved (Figure 1), [13], [15].

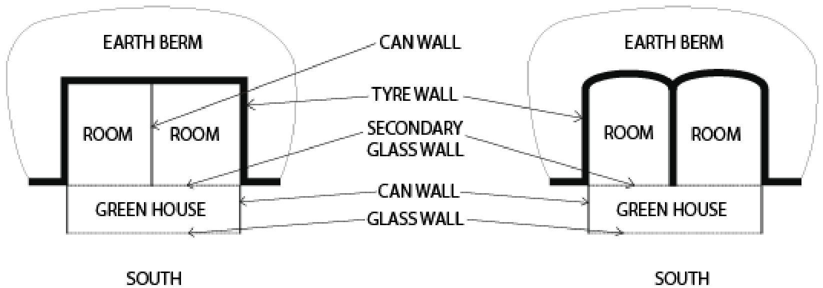


Figure 1: Schematic floor plan of “Packaged Earthship” (left) and “U module system” (right) [13]

Table 1: Specific regulations deal with earth construction in several countries [12]

Country	Regulation	Date of publication	Observations
Germany	Earth Building Code	1944	Put into practice in 1951 with DIN 18951
	DIN 18951	1951	
	Lehmbau Regeln	1998	Technical recommendations
Australia	Bulletin 5	1952	One of the first countries with specific regulations on earth construction
	Australian Earth Building Handbook	2002	
Spain	Bases for design and construction with rammed earth	1992	Rammed earth and adobe based buildings
New Mexico (USA)	New Mexico Building Code	1991	Rammed earth and adobe based buildings
New Zeland	NZS 4297:1998	1998	Engineering design and earth buildings
	NZS 4298:1998	1998	Materials and workmanship for earth buildings
	NZS 4299:1998	1998	Earth buildings not requiring specific design
Zimbabwe	SAZS 724:2001	2001	Zimbabwe Standard Code of Practice for Rammed Earth Structures

Approximately 50% of the world's inhabitants live in earth based constructions. This kind of building system predominates in developing countries. Nevertheless, earth-based residences have also been built in some European countries such as Germany, France or UK [12], [17], [18].

Furthermore, the use of earth constructions has increased considerably in US, Brazil and Australia, oriented towards sustainable construction solutions. Several national specific regulations related to earth constructions have been identified, and are summarized in Table 1. Germany was the first country where earth building regulation was developed, and Spain was the third one. These are the only two European countries that have specific regulations with regard to this type of construction [12].

In conclusion, Earthship, a type of off-the-grid passive solar building constructed with reused car tyres and rammed-earth and which uses renewable sources for energy supplies, is becoming increasingly important due to current efficient energy policy worldwide.

2.1.2. Materials and solutions

The comparison between an aboveground and an underground building has been carried out taking into account the study of Benardos (2014). An earth sheltered residence provides improved energy performance against an aboveground building. Nonetheless, economic costs of earth sheltered buildings are approximately 8% higher than aboveground ones [19].

The thermal mass of the ground helps to keep stable the indoor temperatures in earth-sheltered buildings [19], [20]. This kind of building requires a lower amount of energy for cooling and heating, because of the soil thermal capacity. Hence, the selection of a proper soil has to be considered due to its important influence on the annual energy balance of the underground buildings. However, the type of soil does not influence substantially the energy efficiency and indoor climate conditions of aboveground buildings [10].

Therefore, soil evaluation is a major requirement, soil tests and physical properties of the earth products made with the soil should be considered for earth buildings. It is important to analyse particle size distribution, the percentages of gravel, sand, silt and clay, plasticity, salt content, moisture content, compressive strength and erosion of soil products [21].

One of the most distinctive characteristics of Earthship buildings is the use of car tyres, aluminium cans and glass bottles as building materials. Despite having high embodied energy levels, these are recycled materials, highly durable and with good thermal and mechanical properties. Numerous studies about off-gassing and degradation of tyres suggest that these resist ultraviolet radiation, ozone, water and ice, and do not degrade groundwater quality. Besides, they maintain good properties to be used as building materials. The tyres are used to contain the compacted earth on the main walls. Aluminium cans and glass bottles are used as filling material for interior walls [13], [22].

As it was reported in Soebarto's Article (2009), the use of rammed earth walls would provide similar indoor temperatures, in summer, to an insulated rammed earth wall. However, in winter, using only rammed earth walls, the temperature would be 5 degrees cooler [23]. Consequently, in order to conserve energy the ideal composition of a rammed earth wall is to place earth (thermal mass) in the interior face of the wall and thermal insulation in the external face. The earth acts as a thermal storage and the insulation helps to keep the indoor temperature [24].

In conclusion, earth-sheltered buildings present a good energy performance due to the thermal properties of the earth. Earthship buildings employ reused car tyres, aluminium cans and glass bottles as building materials. Their walls act as energy storage at the same time as keep stable the inside temperatures.

2.1.3. Cases

The first Earthship residence was built in Taos, New Mexico (USA). This place has a semi-arid climate with low rainfall, sunshine during the whole year and extreme outside variations of temperature. Nowadays there are many of them built around the world, in USA, New Zealand, Spain, France, UK, the Netherlands, Czech Republic, Canada, Mexico, Africa, Guatemala and Haiti [16].

In particular, fifteen projects of Earthship buildings exist in Europe; six of them have been constructed in the last ten years. The latter ones have been outlined in Table 2 [18].

Even though there are numerous cases of Earthship buildings around the world, many of them have not been studied from a scientific point of view. In 1996 Grindley and Hutchinson investigated the thermal behaviour of an Earthship building in Taos, New Mexico (USA) through monitoring and modelling [25]. Later on, in 2007 Kruis and Heun looked into the thermal behaviour of an Earthship in New Mexico (USA) [26]. Ip and Miller (2009) tried to find out and monitored an Earthship building in Brighton (England) [14]. Howarth and Nortje (2010) built and monitored an Earthship in France [27]. Taos Global Earthship was studied by Freney, Soebarto and Williamson (2013) using monitoring and modelling throughout 2012 [28].

Earthship buildings located in Taos, New Mexico (USA) are the most deeply studied around the world regarding IEQ and energy consumption. Nevertheless, two other buildings have also been investigated and monitored in England and France.

Table 2: Description of the Earthship buildings in Europe [18]

Name	Location	Use of building	Floor area	Project cost	Construction year	Renewables used
Earthship Fife	Fife, Scotland	Visitor centre in sustainable building	31,5 m²	26.034£ materials only	2004	Micro-hydro turbine, wind turbine, PV panels
Earthship Brighton	Brighton, England	Education and community centre	123,6 m²	320.000£	2006	PV panels, wind turbine
Earthship France	Ger, Manche, Normandy, France	Residential	130 m²	188.000€	2008	PV panels, solar thermal, wind turbine
Earthship Valencia	Valencia, Spain	Residential	188 m²	63.000€	2009	PV panels
The Groundhouse	Central Brittany, France	Residential	140 m²	Unknown	2010	PV panels
Cuevos del sol	Almería, Spain	Residential	81 m² (phase 1)	17.000€ (phase 1, not include labour)	Began 2007	Wind turbine (planned)

2.1.4. Monitoring

Once built, the thermal behaviour of Earthship buildings has not been analysed in depth. Grindley and Hutchinson (1996) monitored the Taos Earthship building [25]. Ip and Miller (2009) monitored the Brighton Earthship in England [14]. Freney, Soebarto and Williamson studied the thermal performance of the Taos Earthship building throughout the year 2012 [28]. These are the only published results.

Grindley and Hutchinson monitored and studied the internal surface, air and main radiant temperature, and external air temperature of the Taos Earthship building during three days from 21st to 23rd of June 1996. The measured data during this period were the following ones: internal mean radiant and air temperatures between 24ºC and 29ºC and extreme external temperature between 4ºC and 35ºC. Hence they predicted that there would be overheating in the building during the summer [25].

Brighton Earthship (England) was monitored by Ip and Miller from winter 2004 to spring 2005, with the building unoccupied. External temperature, thermal storage capacity of walls (sensors were placed at three different heights and depths of the walls) and relative humidity, air and radiant internal temperatures were measured. In relation to the thermal storage (temperature of walls): it was observed that the higher points were at lower temperatures during the winter, the effect was inverted during the summer. It follows that wall temperatures closer to the surface are higher and change more rapidly. Indoor temperatures were stable and within a comfortable range due to the thermal inertia of the walls. Nevertheless a heating system was proposed for the building to be occupied. Even so, the thermal behaviour of this building should be analysed for a longer period of time [14].

Indoor air temperature and humidity in Taos Earthship building were measured throughout the year 2012. The house was inhabited for short periods in winter and continuously during the remainder of the year. The average interior air temperature is within an acceptable range in the main room, except in the last three months of the year. However, there is overheating and large differences between maximum and minimum air temperatures in the greenhouse [16], [28], [29].

Even though several Earthship buildings have been built all over the world, this kind of building has been designed for a specific climate. For this reason, regarding the abovementioned data, in Earthship buildings located in other climate zones, additional heating should be required. However, in general the greenhouse has a high risk of overheating in summer.

2.1.5. Modelling

Several energetic analyses of earth-sheltered buildings have been performed using DesignBuilder [28], Epa-Cad [19] and ENERWIN [23]. Detailed information regarding the discretization process and modelling assumptions taken when using Design Builder has been found. Heat transfer is assumed to be one-dimensional through different layers of materials. Therefore, the tyre walls geometry has to be discretized to a layered structure (1-D spatial discretization). The tyre geometry is modelled as two rubber layers of 10 mm thickness separated 650 mm, with compacted earth between them. Other proposed solution is to model the insulated tyre wall as a 1600mm layer of compacted earth with 1900 kg/m^3 of density and without heat transfer (adiabatic conditions) through the external surface of the wall [28].

Grindley and Hutchinson (1996) studied the thermal performance of an Earthship building in Taos through monitoring and modelling. They employed the TAS computer model, based on weather and soil temperature data from the Los Alamos Laboratory. In this study, the energetic model was used in Taos and UK. In both locations the Earthship building would overheat in summer and also would need backup heating during winter periods [25].

Kruis and Heun (2007) monitored an Earthship in New Mexico (USA) and used this data to calibrate the model. The latter one was employed to simulate several climates in USA: humid continental (Grand Rapids), continental sub-arctic (Anchorage), tropical savannah (Honolulu) and semi-arid (Albuquerque). In all of them would be reduced the cooling and heating energy requirements [26].

Taos Global Earthship has been analysed using a DesignBuilder model. The construction materials used in the model are: tyres filled with rammed earth in the exterior walls, concrete in the interior wall and floor, sand and flagstone in the greenhouse floor, and steel, polyisocyanurate foam (PIR) and softwood in the roof. The energetic and indoor environment simulation model was calibrated with the indoor air temperature data, along with ground temperature modelling equations. Statistical methods were used to calculate the Coefficient of Variance (CV) of the Root Mean Square Error (RMSE) between the simulated and measured data in order to validate the results of the simulation [30], [31], [28].

Once the Taos model was validated, this model was extrapolated to other locations in Europe: Paris, Albacete, Seville, Valladolid and London. Considering the different climate conditions, ground temperatures were estimated. These temperatures for each place were calculated using the TgroundES software [30], through the relation between interior and exterior temperatures, and greenhouse and exterior temperatures. London and Paris ground temperatures were generated using the Brighton Earthship data, because of their similar cool and cloudy conditions [14]. Spanish ones were obtained using the Taos data, due to their similarity in relation to solar radiation. Thus, in cool and cloudy climates (London and Paris) it shows that heating systems are necessary during winter. In temperate climates (Seville, Valladolid and Albacete) there are thermally comfort conditions throughout the year [28].

In the aforementioned data due to energetic models it is showed that in Earthship buildings located in cold climate zones, additional heating should be required. Furthermore, the greenhouse has a high risk of overheating in summer in all the locations studied.

3. Preliminary study

3. Preliminary study

3.1. Architectural-design parameters

From a general point of view, the authoress analyses in this chapter which are the main architectural-design parameters that influence on the energy behaviour and IEQ of a building.

The environmental factors that affect the thermal environment are: temperature (radiant, air and surface), humidity, air velocity and clothing and activity level [32].

3.1.1. External conditions

The external conditions have a great influence on the design of the building form. Building form should be taken into account and adapted to a specific climate and orientation due to its influence in the amount of construction materials and energy consumption.

A. Climate

Climatic conditions have a large influence on the building design. This study is focused on the comparison between the most representative climate zones, as stated in Köppen Classification System, which are: hot and humid, hot and arid, temperate and cold (Table 3) [33].

Table 3: Climate zones [33]

Climate zone	Climatic conditions
Hot and humid	Slight annual variations in temperature Monthly average temperatures above 18°C High solar radiation, precipitation and humidity during the whole year Climate conditions outside the comfort zone for most of the year
Hot and arid	High temperatures Great changes between daily and night time temperatures Scarce humidity and little rainfalls
Temperate	Stable temperatures and low rainfall Warm and dry summers (average temperature exceeding 10°C) Cool and wet winters (average temperature between -3°C and 18°C)
Cold	Cold winter temperatures and short summers Significant difference between winter and summer seasons Low sun radiation

B. Orientation

Building orientation is an essential parameter in the building design. Several factors of the building environment should be analysed, as well as sun path diagram and prevailing winds. In general, the north and south facades should be the longer ones (with the long axis east-west) in order to maximize the solar gains on the south face; and the best orientation in the northern hemisphere is between -30° and 30° due south [33], [34].

In hot and humid climates East-West axis is turned 5º to north of east. In hot and arid climates East-West axis is turned 25º to north of east. In temperate climates East-West axis is turned 18º to north of east. In cold climates East-West axil is facing south [33].

3.1.2. Architecture

Once the external conditions have been analysed, the next step is to study the envelope of the building and the architectural parameters. The heat gains provided by solar radiation are an important architectural factor.

The parameters regarding this kind of construction solutions have been identified and carefully studied in Chapter 2 following the principles of Earthship buildings [13], [14], [15], [16].

3.2. Case of study: Building Tomorrow Earthship

3.2.1. Construction

This building has been constructed recently (from June 2013 to September 2015) by nine Danish and international students from VIA University College, Horsens. They represent several educational programmes (civil engineering, constructing architecture, mechanical engineering, ICT engineering, marketing management, global business engineering, etc.). VIA University College and some private companies helped the students during the construction process. The construction process of the house is shown in Appendix 2.

3.2.2. Location

Horsens is a Danish city in east Jutland with a population of around 50.000 people. This city is the site of the council of Horsens Municipality (Central Jutland Region) [Figure 2].

Building Tomorrow Earthship is located in Chr M Østergaards Vej 39 close to VIA University College in Horsens (Denmark) [Figure 3].

Figure 2: Location of Horsens in Denmark

Figure 3: Location of Building Tomorrow Earthship in Horsens

3.2.3. Climate

The Danish weather is mainly determined by the proximity to the North and Baltic seas and the European continent. Thus, the weather changes depending on the dominant wind direction and the season [35].

Denmark has a relatively warm climate in relation to other geographic zones at the same latitude. This is due to the warm North Atlantic Drift originated in the tropical seas off the American east coast. The average annual temperature for the whole country is 7.7°C and 7.4°C in central Jutland [35].

The average annual precipitation in Denmark is 712 mm. Central Jutland is the rainiest region of Denmark, which exceeds 900 mm of rainfall yearly [35].

3.2.4. Orientation

The main façade of the building is the southern one because it is the window wall. This is rotated 8° to the south-east following the principles of Earthship buildings [15] [Figure 4].

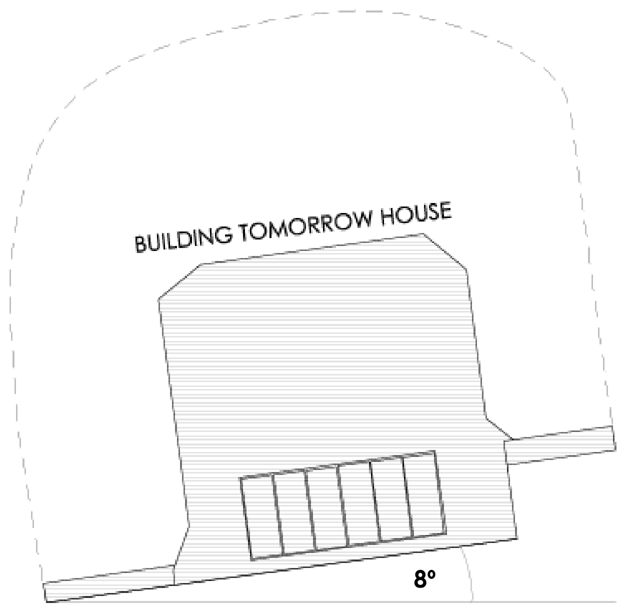


Figure 4: Orientation of Building Tomorrow Earthship

3.2.5. Construction characteristics

The construction characteristics of Building Tomorrow Earthship are deeply analysed in Appendixes 2 and 3.

The house is divided in two different spaces: the greenhouse (29,60 m²) and the main room (34,90 m²). Both are habitable spaces but only the main room is heated.

The composition of all the building elements is described in Appendix 1.

3.2.6. Systems and HVAC

As it has been mentioned before, this building has been constructed following the principles of an Earthship, an off-the-grid house.

The systems used in the house are the following ones (Appendixes 1 and 3):

- HVAC system
- Floor heating system
- Water system
- Electricity
- Sensors

4. RESULTS AND DISCUSSION

4. Results and discussion

In this section, an analysis of the results of the model using the BSim software will be carried out. Firstly, the real case has been studied. Secondly, this model has been modified taking into account the main architectural-design parameters and focusing on Earthships principles. The BSim model inputs are described in Appendix 1.

5.1. Real case

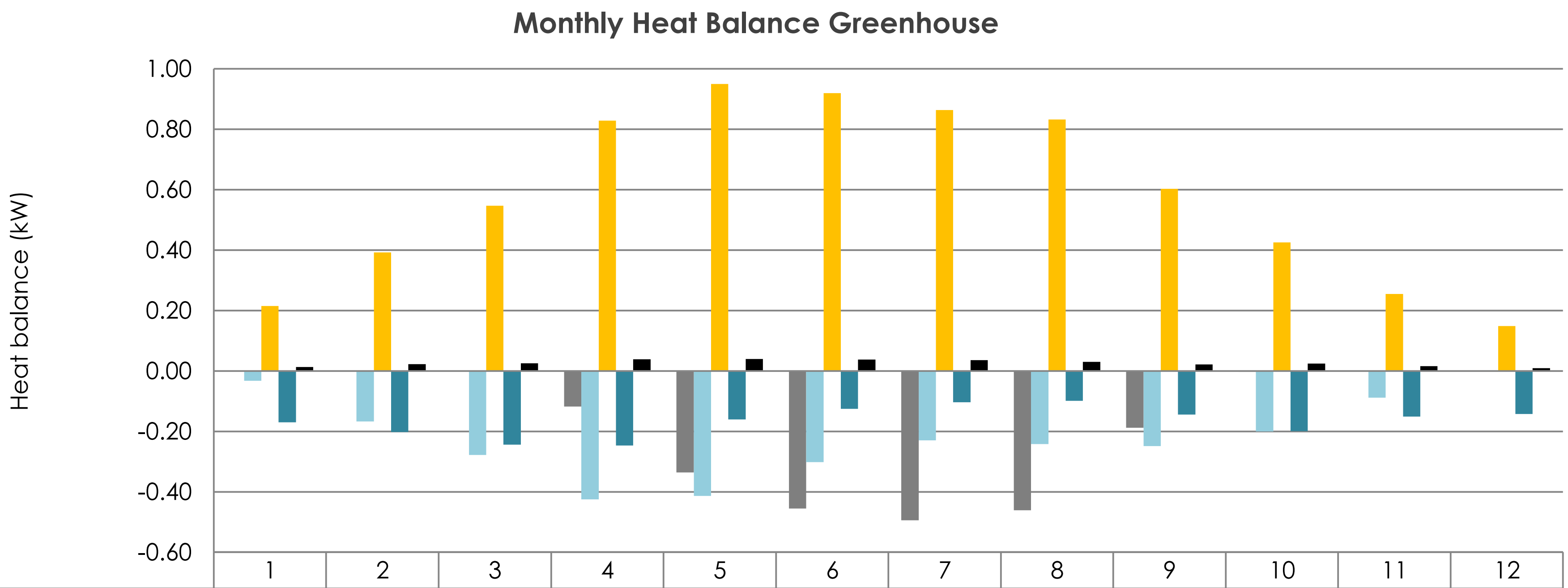
The analysis of the case of study (real case) is divided in two parts: in the first one the heat balance will be analysed and in the second one, ICQ conditions in the house will be studied.

5.1.1 Heat balance

Regarding heat balance, each space of the house has been analysed monthly and annually.

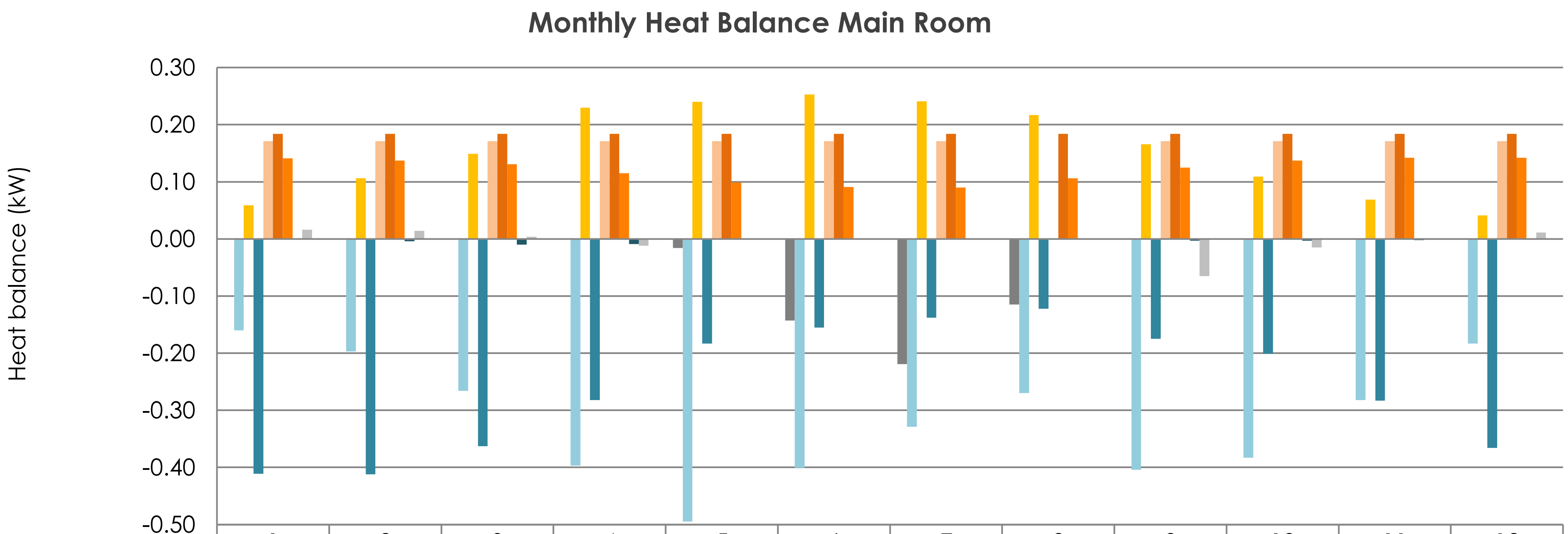
In Figure 5, it can be appreciated that the main heat gain is provided by sun radiation in the greenhouse. It is higher in summer. This contributes to a reduction of the heating needs of the house. Infiltration, transmission and venting provide the heat losses. The venting system helps to reduce the overheating in summer.

In Figure 6, it is shown that the main heat gains are provided by sun radiation, people, equipment and lighting in the main room. This contributes to a reduction of the heating needs of the house. Transmission and infiltration provide the main heat losses throughout the year. Venting also provides heat loss but only in summer, because this system is programmed to work from May to August when the interior temperature is above 24 °C in this space. On balance, there is no need for extra heating or cooling systems in this space.



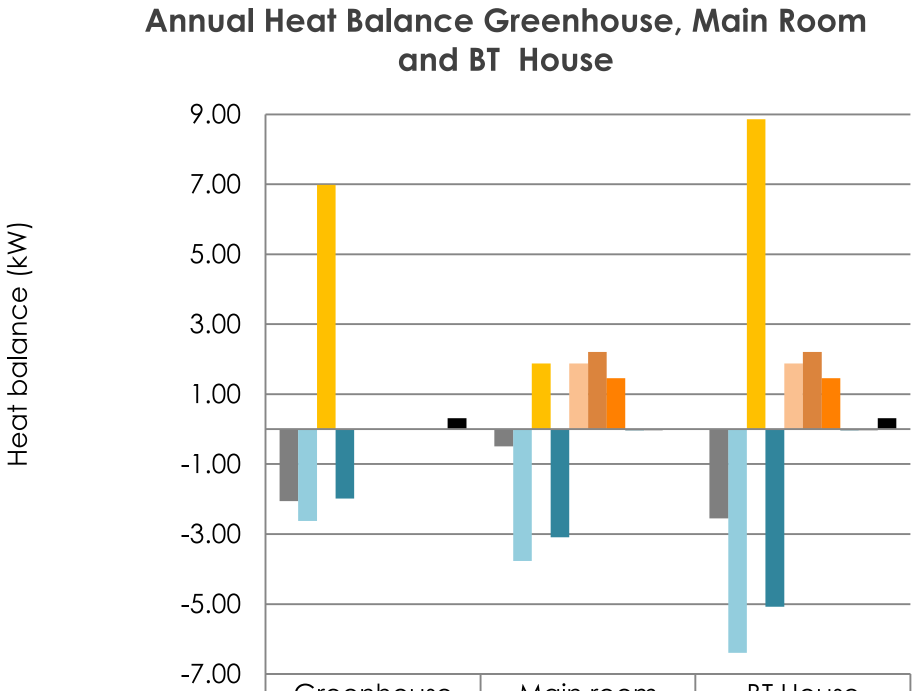
	1	2	3	4	5	6	7	8	9	10	11	12
Venting (kW)	0.00	0.00	0.00	-0.12	-0.34	-0.46	-0.49	-0.46	-0.19	0.00	0.00	0.00
Transmission (kW)	-0.03	-0.17	-0.28	-0.43	-0.41	-0.30	-0.23	-0.24	-0.25	-0.20	-0.09	0.00
Sun Radiation (kW)	0.22	0.39	0.55	0.83	0.95	0.92	0.86	0.83	0.60	0.43	0.26	0.15
Infiltration (kW)	-0.17	-0.20	-0.24	-0.25	-0.16	-0.13	-0.10	-0.10	-0.14	-0.20	-0.15	-0.14
Total (kW)	0.01	0.02	0.03	0.04	0.04	0.04	0.04	0.03	0.02	0.02	0.02	0.01

Figure 5: Monthly Heat Balance Greenhouse



	1	2	3	4	5	6	7	8	9	10	11	12
Venting (kW)	0.00	0.00	0.00	0.00	-0.02	-0.14	-0.22	-0.12	0.00	0.00	0.00	0.00
Transmission (kW)	-0.16	-0.20	-0.27	-0.40	-0.50	-0.40	-0.33	-0.27	-0.40	-0.38	-0.28	-0.18
Sun Radiation (kW)	0.06	0.11	0.15	0.23	0.24	0.25	0.24	0.22	0.17	0.11	0.07	0.04
Infiltration (kW)	-0.41	-0.41	-0.36	-0.28	-0.18	-0.16	-0.14	-0.12	-0.18	-0.20	-0.28	-0.37
People (kW)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.00	0.17	0.17	0.17	0.17
Equipment (kW)	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Lighting (kW)	0.14	0.14	0.13	0.12	0.10	0.09	0.09	0.11	0.13	0.14	0.14	0.14
Mixing (kW)	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ventilation (kW)	0.02	0.01	0.00	-0.01	0.00	0.00	0.00	0.00	-0.07	-0.02	0.00	0.01
Total (kW)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 6: Monthly Heat Balance Main Room



	Greenhouse	Main room	BT House
Venting (kW)	-2.06	-0.49	-2.55
Transmission (kW)	-2.63	-3.77	-6.39
Sun Radiation (kW)	6.98	1.88	8.86
Infiltration (kW)	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21
Lighting (kW)	0.00	1.46	1.46
Mixing (kW)	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.05	-0.05
Total (kW)	0.31	0.00	0.31

Figure 7: Annual Heat Balance Greenhouse, Main Room and BT House

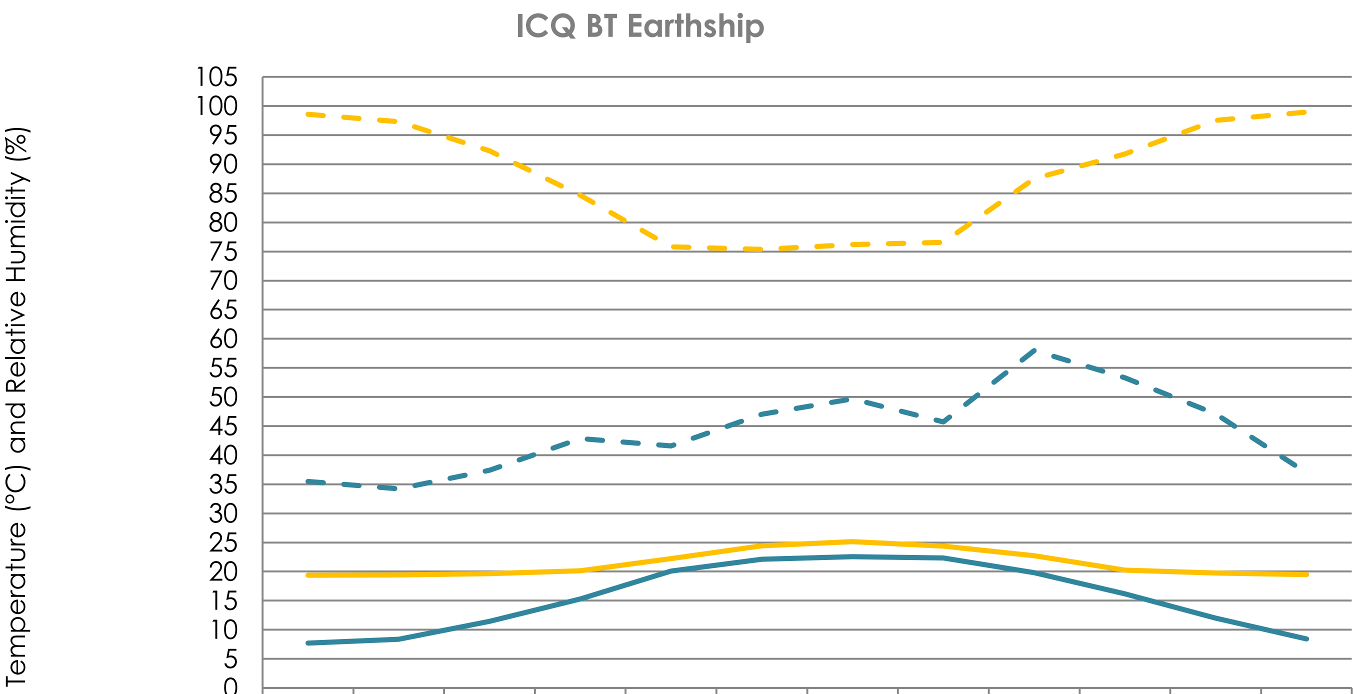
In Figure 7, it can be noticed that on balance the energy behaviour of this building is efficient due to how this has been built and how the passive systems employed in it are working.

5.1.1 ICQ

Concerning the ICQ conditions, each space of the house has been analysed monthly.

In Figure 8, it is shown that the relative humidity is above the comfort range (55-90%) [36] and the operative temperature is below this range (20-26°C) [32] in the coldest period in the greenhouse. They are within a comfort range the rest of the year.

In Figure 8, it can be seen that the relative humidity is within a comfort range (30-70%) [36] during the whole year in the main room. Regarding the operative temperature, this is just below the comfort range (20-26°C) [32] in the winter period. It is in a comfort range the rest of the year.



	1	2	3	4	5	6	7	8	9	10	11	12
Rel Humid GH (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98
Rel Humid MR (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top MR (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Top GH (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42

Figure 8: Monthly ICQ BT Earthship

5.2. Architectural-design parameters analysis

In this section a comparison between the real case and some variations in the model regarding the main architectural-design parameters are carried out. These parameters are divided in two different areas: external conditions and construction solutions.

5.2.1. External conditions

Regarding the external conditions of the building several orientations of the house and different climate zones have been studied.

- **Orientation**

As it has been mentioned before, the case of study (real case) is rotated 8° to the south-east following the principles of Earthship buildings [15]. This house has been compared with the same building in the same place with identical characteristics changing the orientation of the main façade for north, east and west.

- East (90°)

In Figure 9, it can be appreciated that the annual heat balance of both cases is pretty similar. The most significant differences between them are regarding the transmission and sun radiation.

In Figure 10, it can be noticed that the relative humidity and operative temperature in both scenarios are quite similar.

- North (180°)

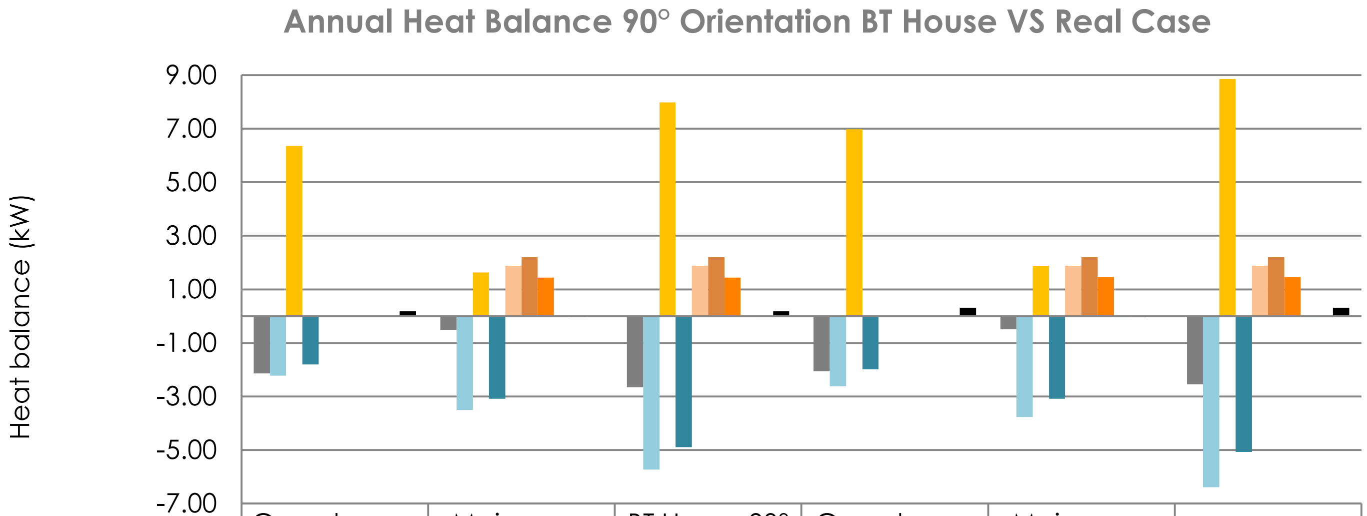
In Figure 11, it can be appreciated that the annual heat balance of both cases follows the same pattern. The most outstanding differences between them are regarding venting and sun radiation.

In Figure 12, it can be noticed that the relative humidity and operative temperatures in both scenarios are quite similar.

- West (270°)

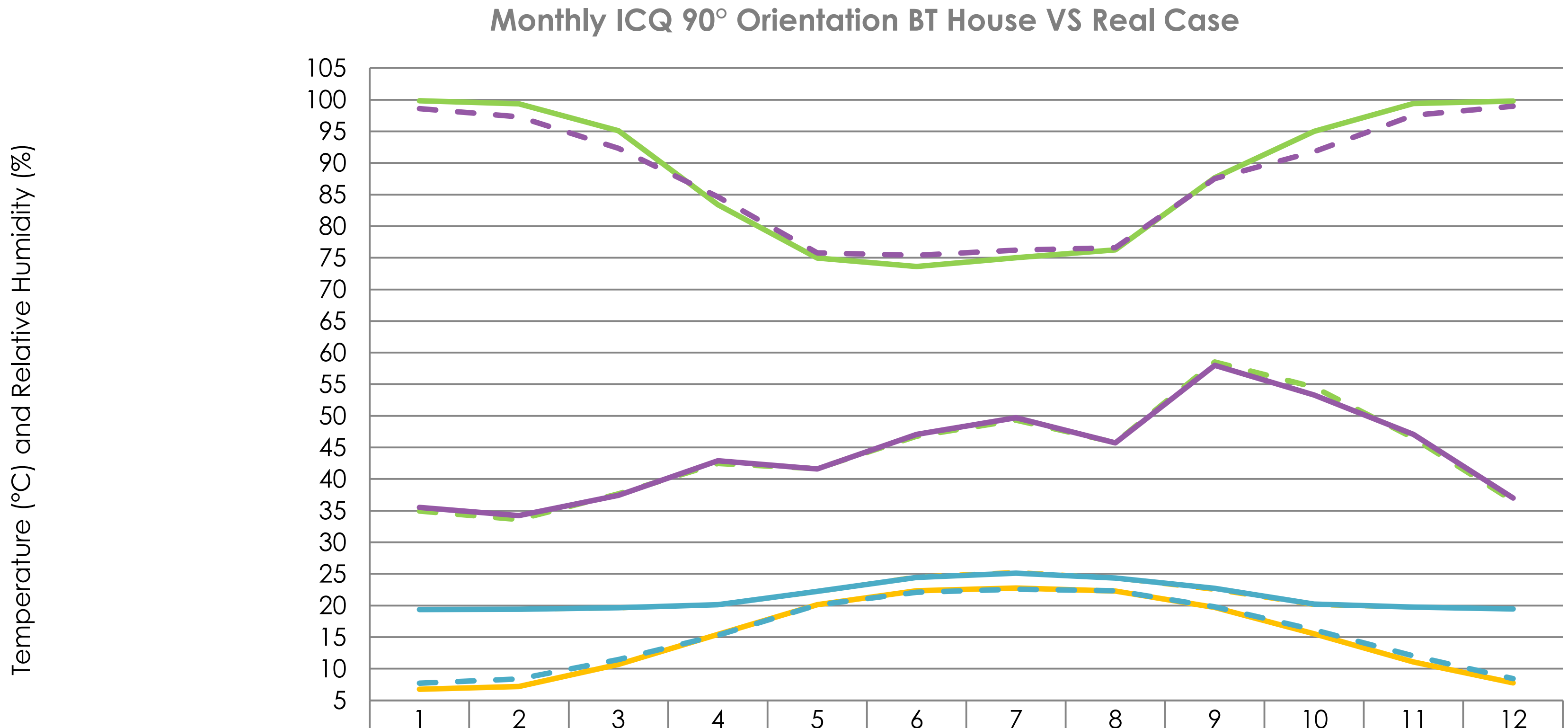
In Figure 13, it is shown that the annual heat balance of the western building is the only one that is not positive. In that case, the energy behaviour of the house is not efficient. The most significant differences between them are regarding venting and infiltration.

In Figure 14, it can be noticed that the relative humidity and operative temperatures in both scenarios are pretty similar. The most important difference between them is concerning the relative humidity in the greenhouse, which is more stable in the real case.



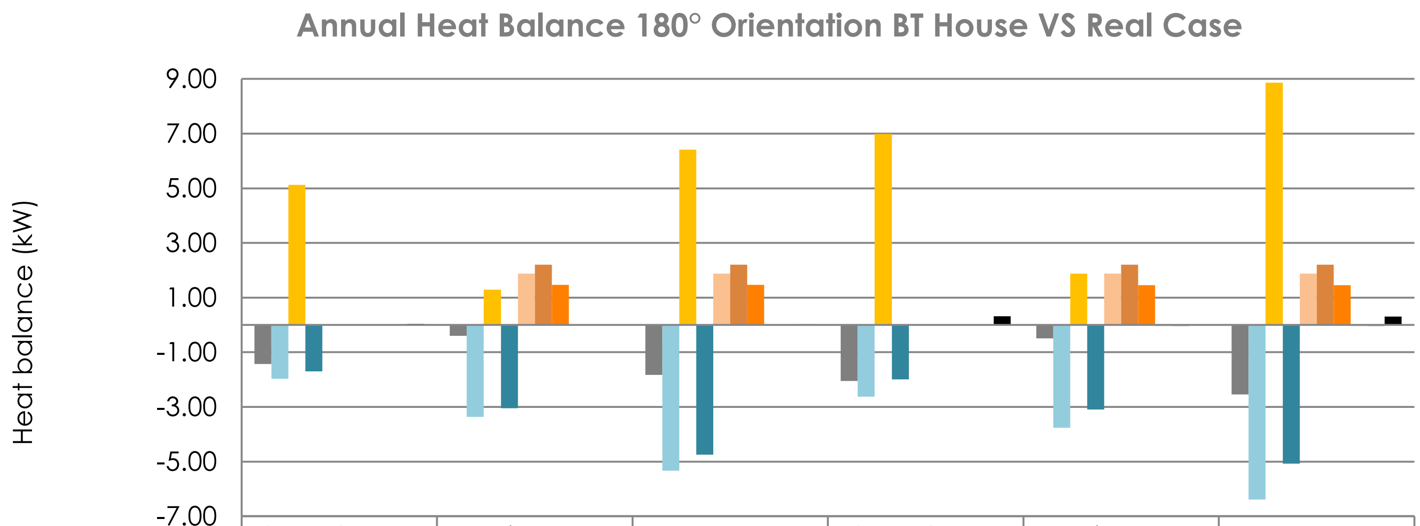
	Greenhouse 90° Orient.	Main room 90° Orient.	BT House 90° Orient.	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-2.14	-0.51	-2.65	-2.06	-0.49	-2.55
Transmission (kW)	-2.22	-3.51	-5.74	-2.63	-3.77	-6.39
Sun Radiation (kW)	6.36	1.63	7.99	6.98	1.88	8.86
Infiltration (kW)	-1.81	-3.08	-4.89	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.44	1.44	0.00	1.46	1.46
Mixing (kW)	0.00	-0.02	-0.02	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.03	-0.03	0.00	-0.05	-0.05
Total (kW)	0.19	0.00	0.19	0.31	0.00	0.31

Figure 9: Annual Heat Balance 90° Orientation BT House VS Real Case



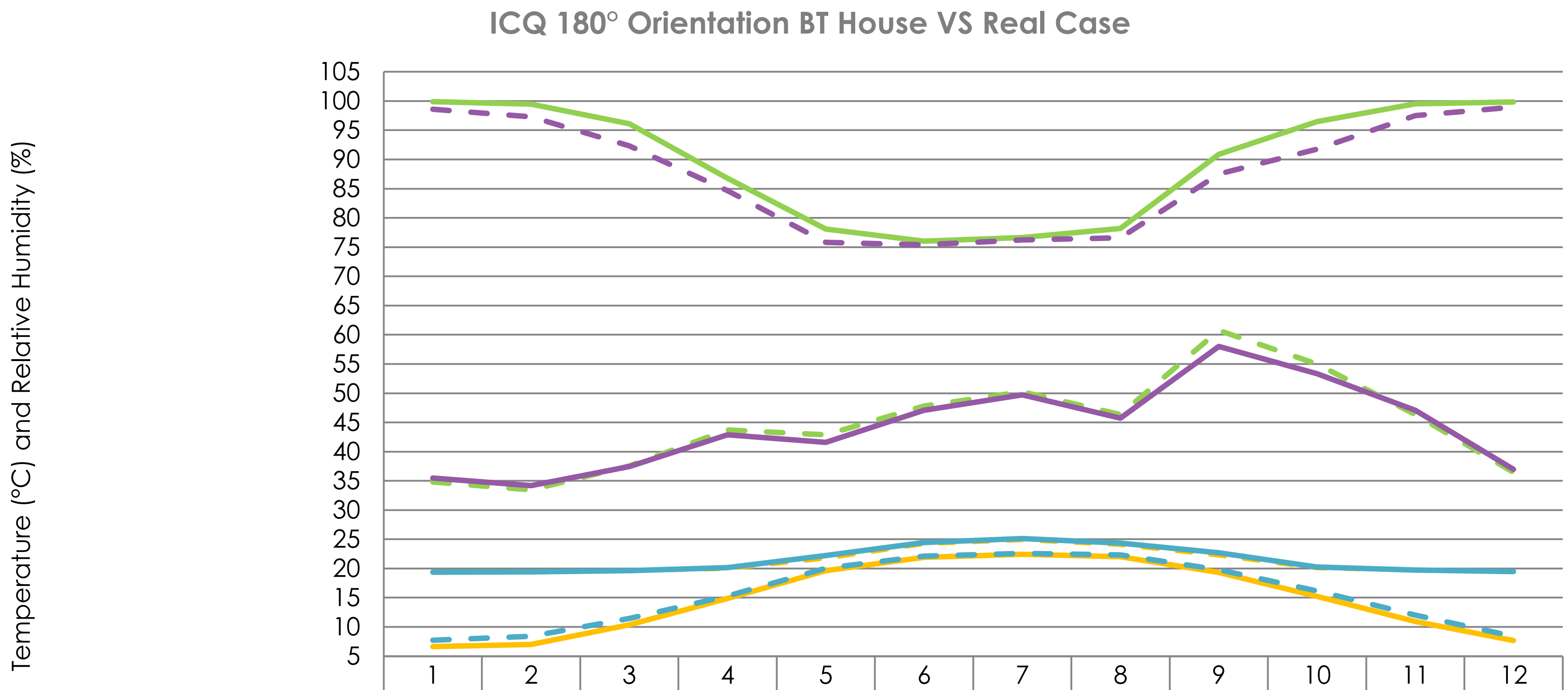
	1	2	3	4	5	6	7	8	9	10	11	12
Top MR 90° Orient. (°C)	19.34	19.39	19.62	20.11	22.19	24.53	25.25	24.34	22.54	20.11	19.75	19.47
Rel Humid MR 90° Orient. (%)	34.94	33.61	37.68	42.46	41.65	46.79	49.32	45.78	58.5	54.54	46.51	36.54
Top GH 90° Orient. (°C)	6.77	7.17	10.69	15.44	20.13	22.31	22.78	22.3	19.7	15.52	11.06	7.78
Rel Humid GH 90° Orient. (%)	99.86	99.37	95.08	83.42	74.94	73.62	75.01	76.25	87.64	95.02	99.41	99.77
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 10: Monthly ICQ 90° Orientation BT House VS Real Case



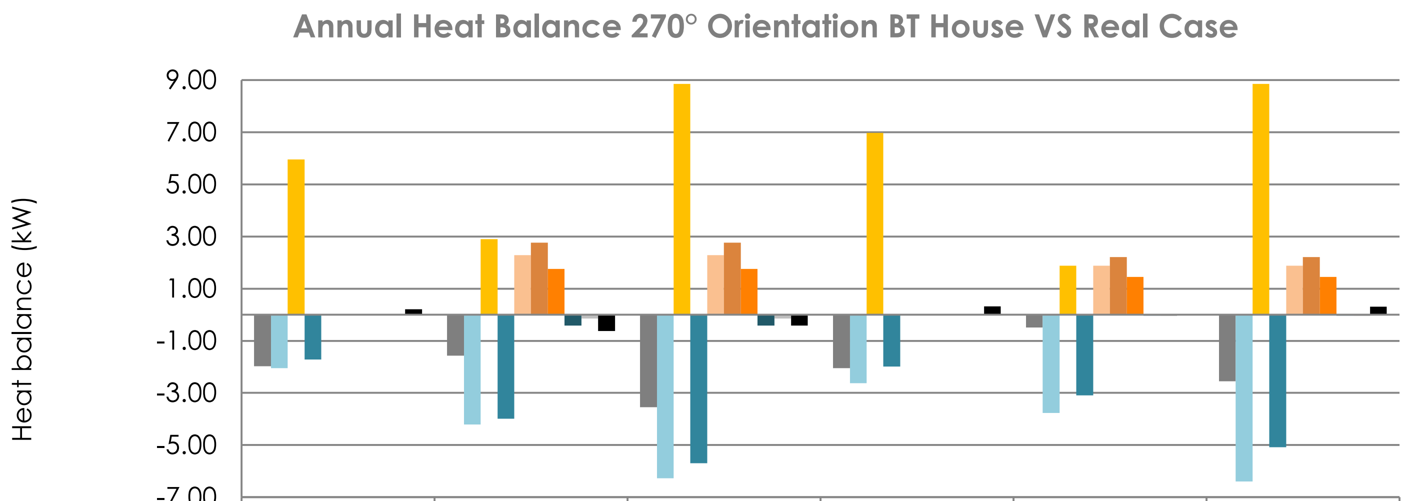
	Greenhouse 180° Orient.	Main room 180° Orient.	BT House 180° Orient.	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-1.43	-0.40	-1.83	-2.06	-0.49	-2.55
Transmission (kW)	-1.97	-3.36	-5.33	-2.63	-3.77	-6.39
Sun Radiation (kW)	5.12	1.29	6.41	6.98	1.88	8.86
Infiltration (kW)	-1.69	-3.05	-4.74	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.46	1.46	0.00	1.46	1.46
Mixing (kW)	0.00	0.00	0.00	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.03	-0.03	0.00	-0.05	-0.05
Total (kW)	0.03	0.00	0.03	0.31	0.00	0.31

Figure 11: Annual Heat Balance 180° Orientation BT House VS Real Case



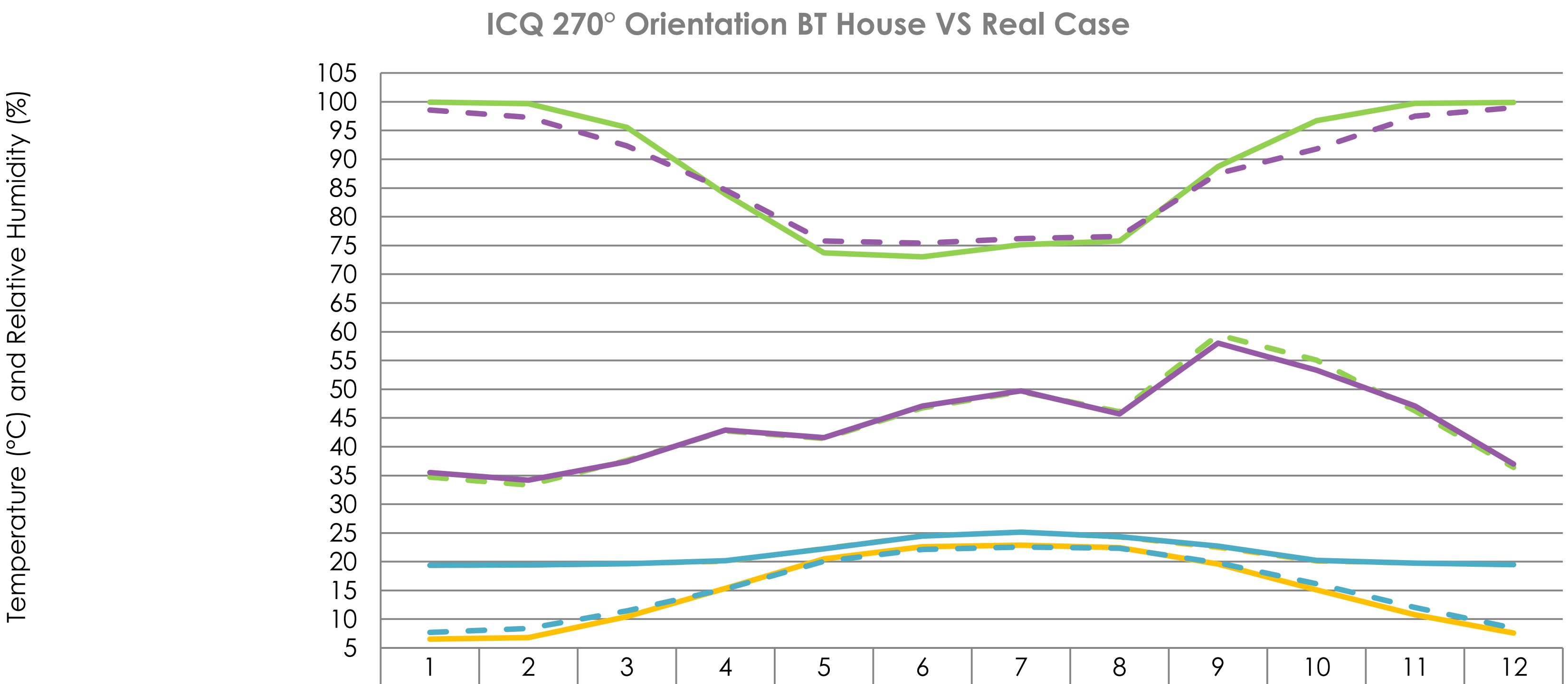
	1	2	3	4	5	6	7	8	9	10	11	12
Top MR 180° Orient. (°C)	19.33	19.39	19.62	19.99	21.75	24.22	24.93	24.1	22.29	20.08	19.74	19.46
Rel Humid MR 180° Orient. (%)	34.83	33.47	37.56	43.72	42.86	47.81	50.25	46.36	60.73	55	46.37	36.45
Top GH 180° Orient. (°C)	6.62	6.98	10.34	14.88	19.63	21.92	22.41	21.99	19.32	15.23	10.91	7.67
Rel Humid GH 180° Orient. (%)	99.91	99.5	96.11	86.77	78.09	76.02	76.62	78.22	90.87	96.46	99.53	99.84
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 12: Monthly ICQ 180° Orientation BT House VS Real Case



	Greenhouse 270° Orient.	Main room 270° Orient.	BT House 270° Orient.	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-1.98	-1.57	-3.55	-2.06	-0.49	-2.55
Transmission (kW)	-2.05	-4.22	-6.27	-2.63	-3.77	-6.39
Sun Radiation (kW)	5.95	2.90	8.85	6.98	1.88	8.86
Infiltration (kW)	-1.71	-3.99	-5.70	-1.99	-3.09	-5.08
People (kW)	0.00	2.29	2.29	0.00	1.88	1.88
Equipment (kW)	0.00	2.76	2.76	0.00	2.21	2.21
Lighting (kW)	0.00	1.76	1.76	0.00	1.46	1.46
Mixing (kW)	0.00	-0.42	-0.42	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.14	-0.14	0.00	-0.05	-0.05
Total (kW)	0.21	-0.62	-0.41	0.31	0.00	0.31

Figure 13: Annual Heat Balance 270° Orientation BT House VS Real Case



	1	2	3	4	5	6	7	8	9	10	11	12
Top MR 270° Orient. (°C)	19.33	19.39	19.62	20.03	22.32	24.53	25.16	24.24	22.44	20.07	19.74	19.46
Rel Humid MR 270° Orient. (%)	34.73	33.33	37.64	42.75	41.4	46.78	49.59	46.08	59.45	55.08	46.21	36.38
Top GH 270° Orient. (°C)	6.51	6.78	10.47	15.34	20.48	22.61	22.86	22.44	19.58	15.1	10.74	7.6
Rel Humid GH 270° Orient. (%)	99.94	99.67	95.54	83.9	73.7	73.01	75.15	75.8	88.71	96.72	99.72	99.88
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 14: Monthly ICQ 270° Orientation BT House VS Real Case

Taking into account the aforementioned results regarding the different orientations, the western orientation is the only one in which the energy behaviour of the building is less efficient than the real case. Thus, this orientation is not beneficial for the building.

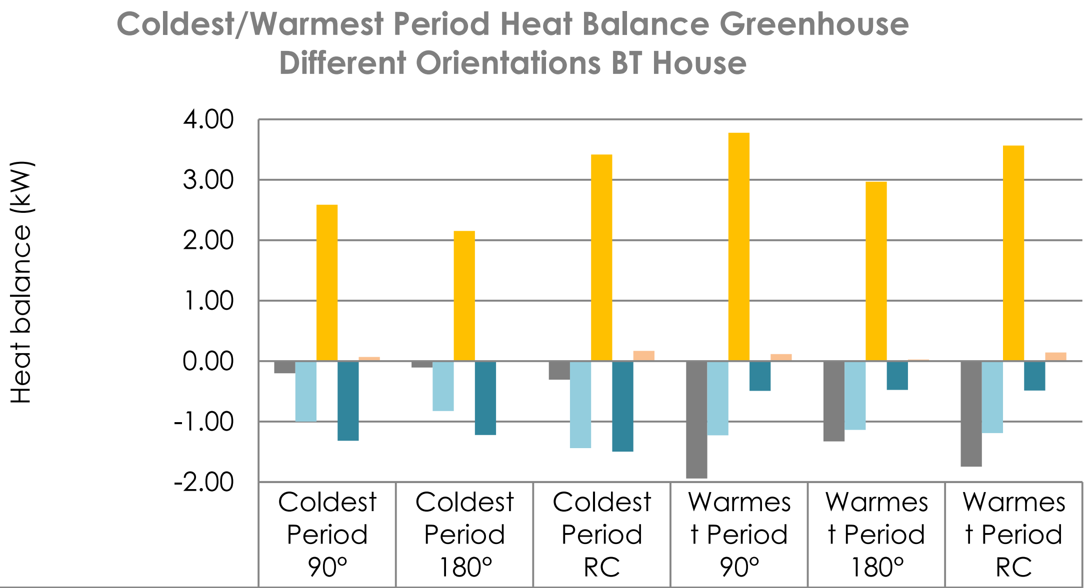
A second analysis regarding the heat balance during the coldest and warmest periods has been carried out by comparing eastern and northern orientations to the real case.

The coldest and warmest periods are according to the floor heating system schedule. The coldest period ranges from September to April and the warmest one from May to August.

In Figure 15, it is shown that the best heat balance in the greenhouse in the coldest period is found in the real case. However, the best one in the warmest period appears in the north orientation of the house.

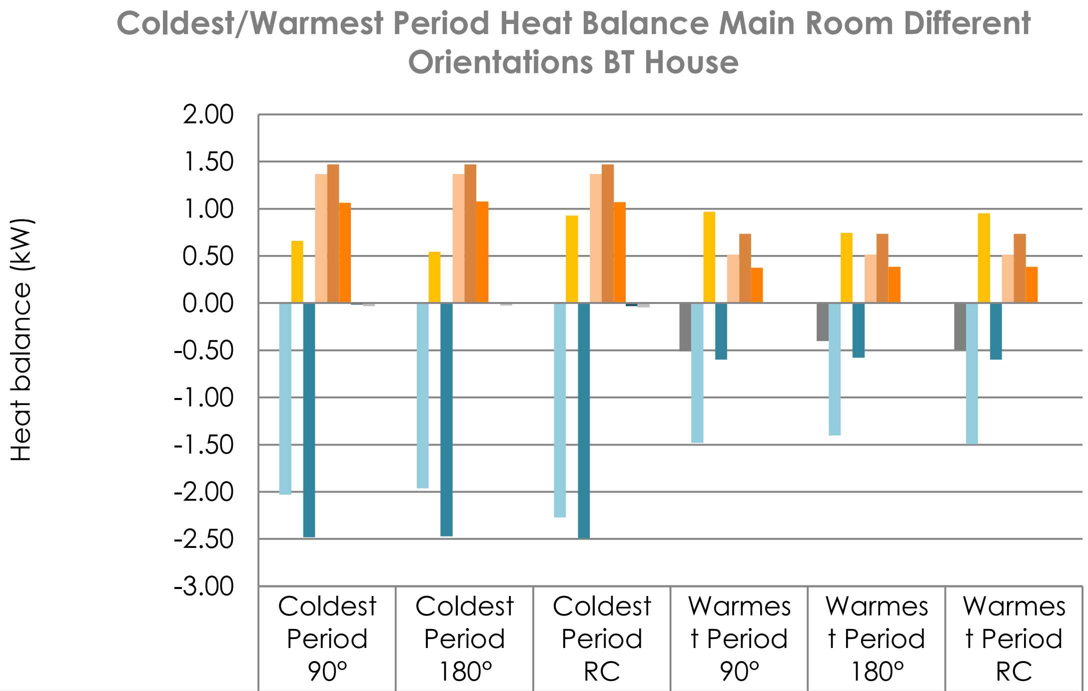
In Figure 16, it can be appreciated that the heat balance in the main room during the coldest and warmest periods is quite similar. The most outstanding differences between them are in relation to venting, transmission and sun radiation.

To sum up, the orientation of this building that has the more efficient behaviour is the south. This one has the greatest energy behaviour considering the whole year. However, if only the warmest period is taken into account the northern one provides the best heat balance. The heat gains provided by the sun radiation are the lowest ones in the warmest period in the north orientation.



	Coldest Period 90°	Coldest Period 180°	Coldest Period RC	Warmest Period 90°	Warmest Period 180°	Warmest Period RC
Venting (kW)	-0.20	-0.10	-0.31	-1.94	-1.33	-1.75
Transmission (kW)	-1.00	-0.83	-1.44	-1.23	-1.14	-1.19
Sun Radiation (kW)	2.59	2.16	3.42	3.78	2.97	3.57
Infiltration (kW)	-1.32	-1.22	-1.50	-0.49	-0.47	-0.49
Total (kW)	0.07	0.01	0.17	0.12	0.03	0.14

Figure 15: Coldest/Warmest Period Heat Balance Greenhouse Different Orientations BT House



	Coldest Period 90°	Coldest Period 180°	Coldest Period RC	Warmest Period 90°	Warmest Period 180°	Warmest Period RC
Venting (kW)	0.00	0.00	0.00	-0.51	-0.40	-0.49
Transmission (kW)	-2.03	-1.96	-2.27	-1.48	-1.40	-1.50
Sun Radiation (kW)	0.66	0.54	0.93	0.97	0.75	0.95
Infiltration (kW)	-2.48	-2.47	-2.49	-0.60	-0.58	-0.60
People (kW)	1.37	1.37	1.37	0.51	0.51	0.51
Equipment (kW)	1.47	1.47	1.47	0.74	0.74	0.74
Lighting (kW)	1.06	1.08	1.07	0.38	0.39	0.39
Mixing (kW)	-0.02	0.00	-0.03	0.00	0.00	0.00
Ventilation (kW)	-0.03	-0.03	-0.05	0.00	0.00	0.00
Total (kW)	0.00	0.00	0.00	0.00	0.00	0.00

Figure 16: Coldest/Warmest Period Heat Balance Main Room Different Orientations BT House

- **Climate**

In this section, the comparison between the real case and the house under study in different climate zones is analysed. The most representative climate zones are the following: Tenerife (Spain) hot and humid, Taos (USA) hot and arid, Madrid (Spain) temperate and real case in Horsens (Denmark) cold [33].

- <u>Madrid (Spain)</u>

In Figure 17, it can be appreciated that the main difference between both cases is that the heat gains provided by the sun radiation are higher in Madrid than in Horsens.

In Figure 18, it is shown that the operative temperature in both spaces (greenhouse and main room) is higher in Madrid than in Horsens during the whole year. Although the relative humidity is lower in the greenhouse during the whole year, it is lower in the main room during summer though higher in winter in the house located in Madrid in comparison to the one in Horsens.

- <u>Tenerife (Spain)</u>

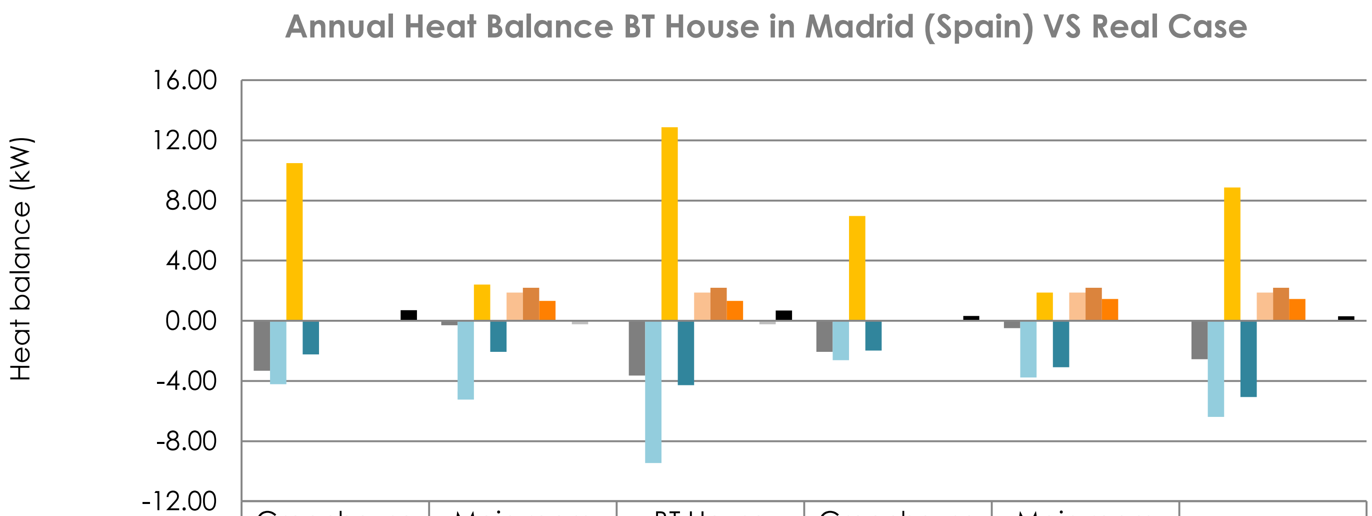
In Figure 19, it can be noticed that the sun radiation provides around the double heat gains in Tenerife than in Horsens. The transmission and infiltration loads provide higher heat losses in Tenerife than in Horsens.

In Figure 20, it can be appreciated that the operative temperature in both spaces (greenhouse and main room) is higher in Tenerife than in Horsens during the whole year. Although the relative humidity is lower in the greenhouse during the whole year, it is lower in the main room during summer though higher in winter in the house located in Tenerife in comparison to the one in Horsens.

- Taos (USA)

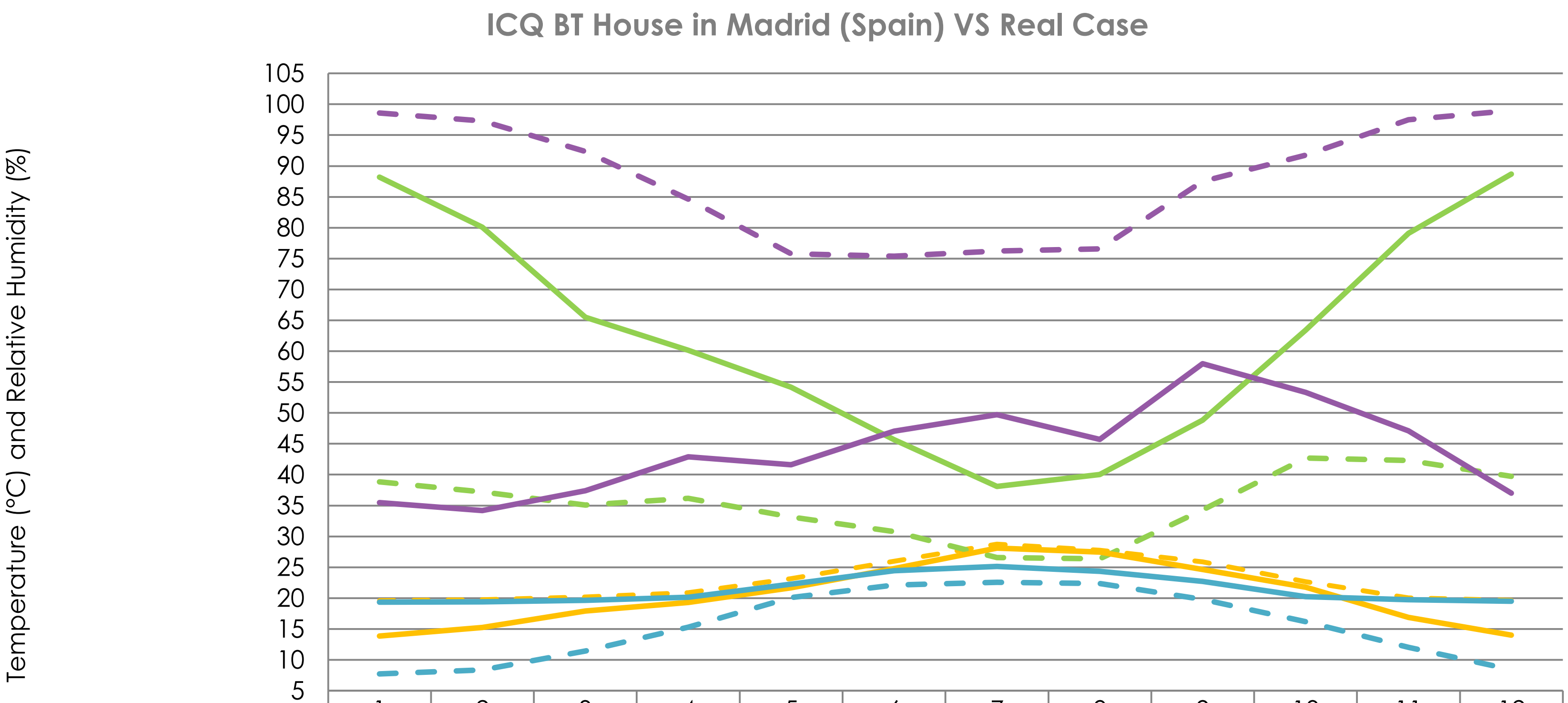
In Figure 21, it is shown that the heat gains provided by the sun radiation are substantially higher in Taos than in Horsens. The venting, transmission and infiltration loads provide higher heat losses in Taos than in Horsens.

In Figure 22, it can be seen that the operative temperature in the greenhouse is higher during the whole year in the house located in Taos than in the one in Horsens. In the main room it is higher only in summer in Taos than in Horsens. Regarding the relative humidity, it is lower in the greenhouse during the whole year but in the main room it is lower in summer but higher in winter in Taos than in Horsens.



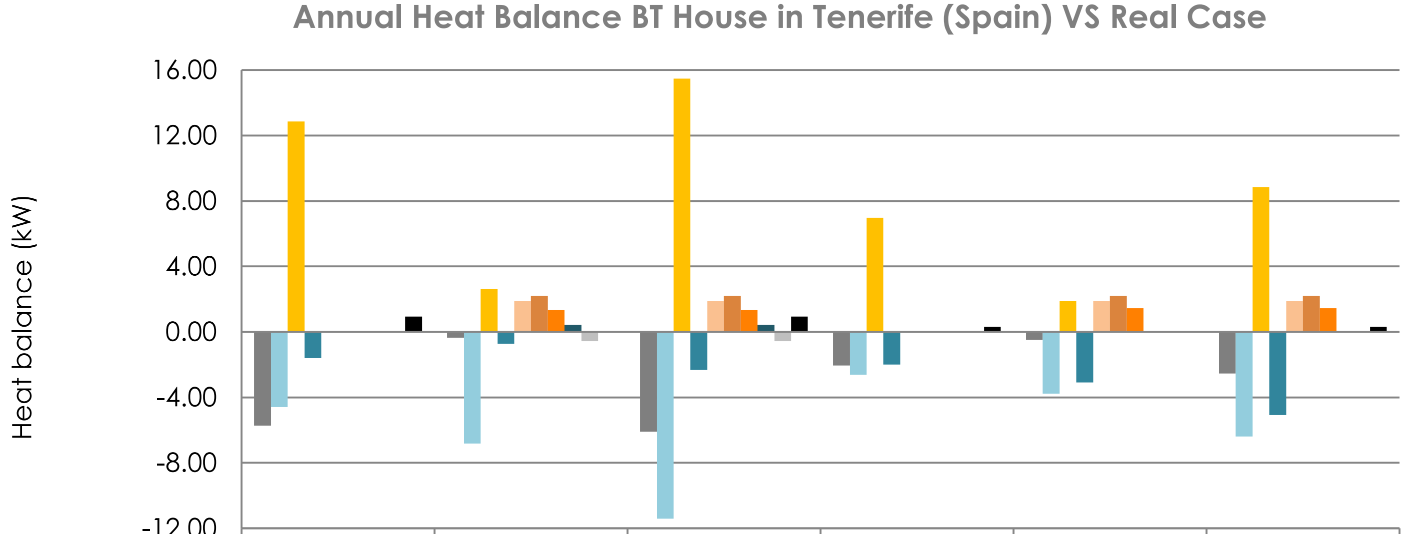
	Greenhouse Madrid	Main room Madrid	BT House Madrid	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-3.33	-0.30	-3.63	-2.06	-0.49	-2.55
Transmission (kW)	-4.22	-5.24	-9.46	-2.63	-3.77	-6.39
Sun Radiation (kW)	10.48	2.40	12.88	6.98	1.88	8.86
Infiltration (kW)	-2.23	-2.06	-4.28	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.33	1.33	0.00	1.46	1.46
Mixing (kW)	0.00	0.01	0.01	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.24	-0.24	0.00	-0.05	-0.05
Total (kW)	0.70	-0.01	0.69	0.31	0.00	0.31

Figure 17: Annual Heat Balance BT House in Madrid (Spain) VS Real Case



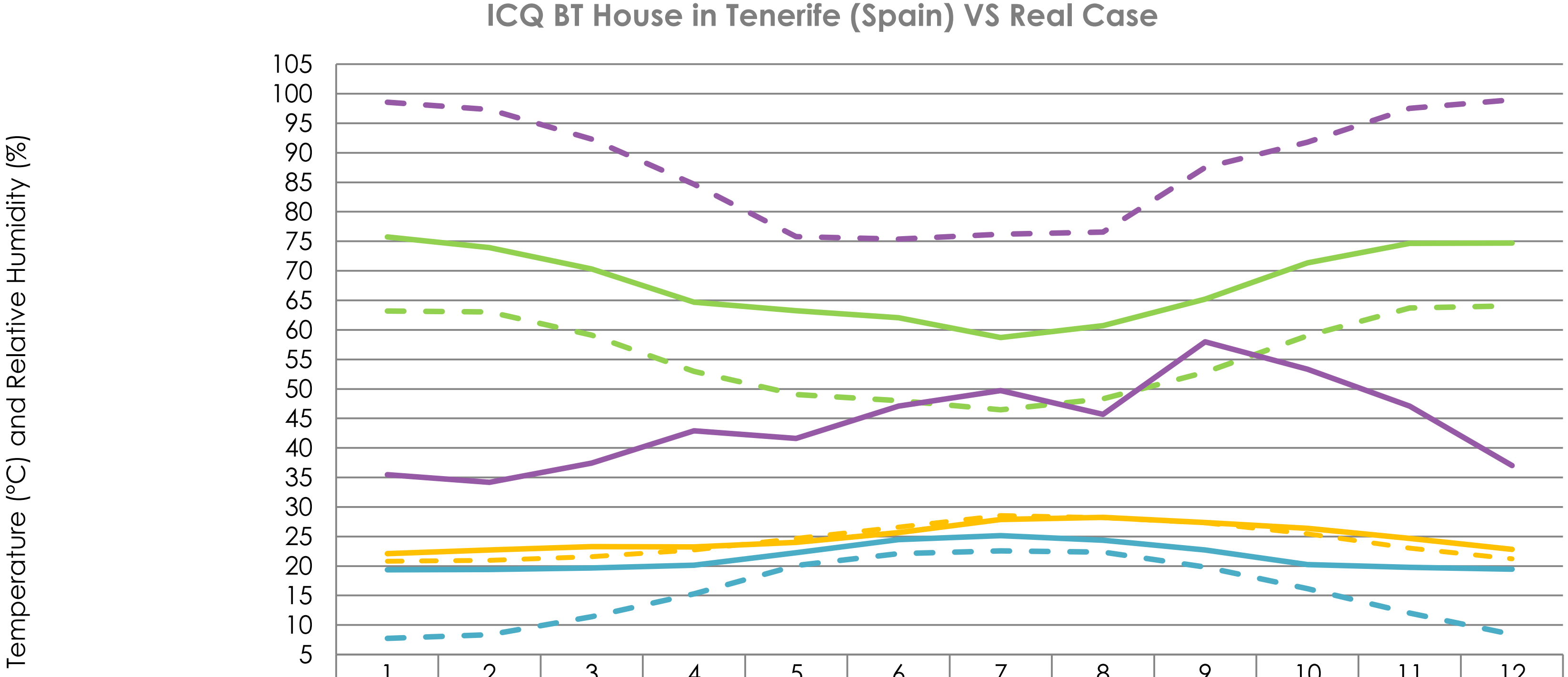
	1	2	3	4	5	6	7	8	9	10	11	12
Top MR Madrid (°C)	19.6	19.72	20.21	20.87	23.16	25.97	28.75	27.73	25.89	22.64	20.06	19.66
Rel Humid MR Madrid (%)	38.85	37.21	35.08	36.16	33.15	30.78	26.59	26.39	34.27	42.69	42.29	39.73
Top GH Madrid (°C)	13.88	15.24	17.89	19.32	21.68	24.77	28.09	27.48	24.62	21.77	16.87	14.02
Rel Humid GH Madrid (%)	88.18	80.07	65.48	60.14	54.15	45.67	38.1	40.03	48.81	63.41	79.08	88.69
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 18: Monthly ICQ BT House in Madrid (Spain) VS Real Case



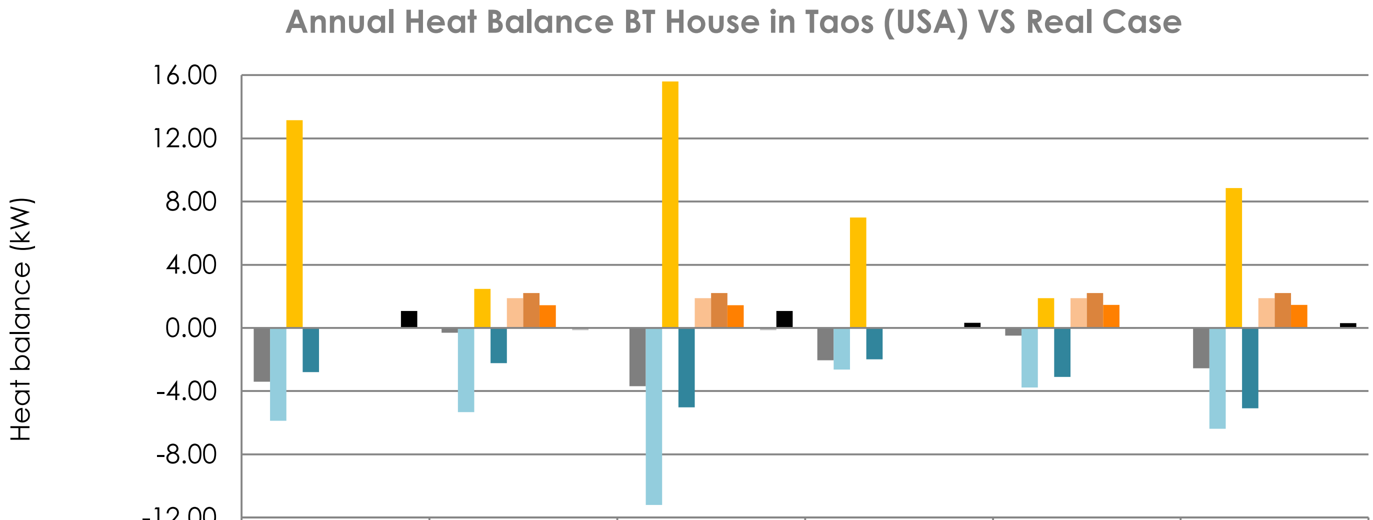
	Greenhouse Tenerife	Main room Tenerife	BT House Tenerife	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-5.73	-0.36	-6.09	-2.06	-0.49	-2.55
Transmission (kW)	-4.59	-6.83	-11.41	-2.63	-3.77	-6.39
Sun Radiation (kW)	12.86	2.63	15.48	6.98	1.88	8.86
Infiltration (kW)	-1.60	-0.72	-2.32	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.33	1.33	0.00	1.46	1.46
Mixing (kW)	0.00	0.43	0.43	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.57	-0.57	0.00	-0.05	-0.05
Total (kW)	0.94	0.00	0.93	0.31	0.00	0.31

Figure 19: Annual Heat Balance BT House in Tenerife (Spain) VS Real Case



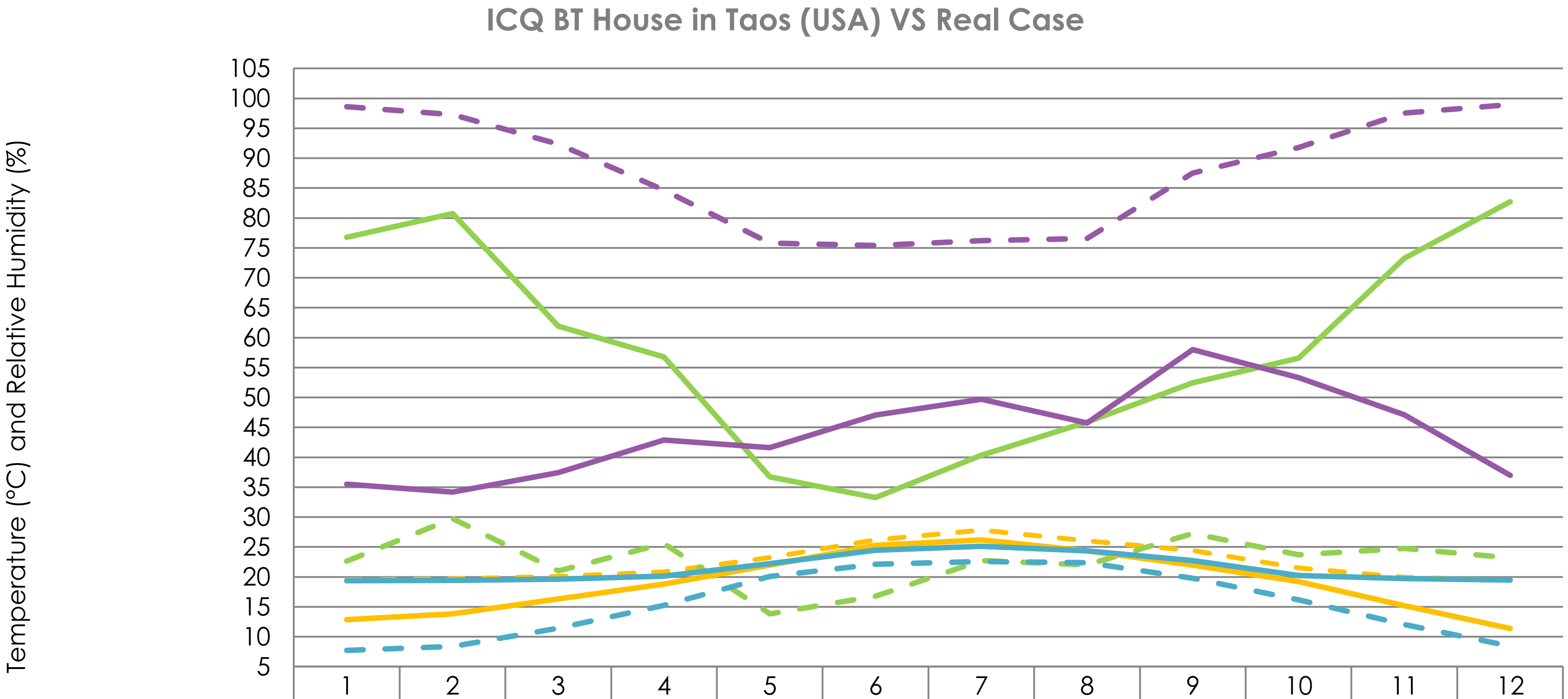
	1	2	3	4	5	6	7	8	9	10	11	12
Top MR Tenerife (°C)	20.79	20.98	21.6	22.71	24.65	26.57	28.55	28.17	27.33	25.43	23.01	21.19
Rel Humid MR Tenerife (%)	63.17	63.04	59.12	52.99	49.04	48.02	46.46	48.33	52.81	59	63.69	64.08
Top GH Tenerife (°C)	22.07	22.7	23.27	23.22	23.98	25.64	27.86	28.24	27.35	26.39	24.69	22.81
Rel Humid GH Tenerife (%)	75.76	73.95	70.34	64.69	63.24	62.05	58.72	60.73	65.21	71.33	74.67	74.72
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 20: Monthly ICQ BT House in Tenerife (Spain) VS Real Case



	Greenhouse Taos	Main room Taos	BT House Taos	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-3.40	-0.30	-3.70	-2.06	-0.49	-2.55
Transmission (kW)	-5.87	-5.33	-11.20	-2.63	-3.77	-6.39
Sun Radiation (kW)	13.14	2.46	15.61	6.98	1.88	8.86
Infiltration (kW)	-2.80	-2.23	-5.03	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.43	1.43	0.00	1.46	1.46
Mixing (kW)	0.00	0.01	0.01	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.14	-0.14	0.00	-0.05	-0.05
Total (kW)	1.07	0.00	1.07	0.31	0.00	0.31

Figure 21: Annual Heat Balance BT House in Taos (USA) VS Real Case



	1	2	3	4	5	6	7	8	9	10	11	12
Top MR Taos (°C)	19.53	19.68	20.09	20.84	23.22	26.19	27.82	26.03	24.42	21.51	19.91	19.48
Rel Humid MR Taos (%)	22.61	29.76	21	25.59	13.81	16.79	22.74	22.04	27.26	23.67	24.75	23.19
Top GH Taos (°C)	12.84	13.8	16.31	18.8	21.94	25.29	26.2	24.37	21.94	19.2	15.2	11.39
Rel Humid GH Taos (%)	76.78	80.73	61.9	56.77	36.7	33.25	40.35	45.88	52.45	56.59	73.25	82.75
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 22: Monthly ICQ BT House in Taos (USA) VS Real Case

Taking into account the above-mentioned results concerning the different climate zones, this building presents the best energy behaviour in Horsens. This is due to the functioning of the systems that has been designed for this location.

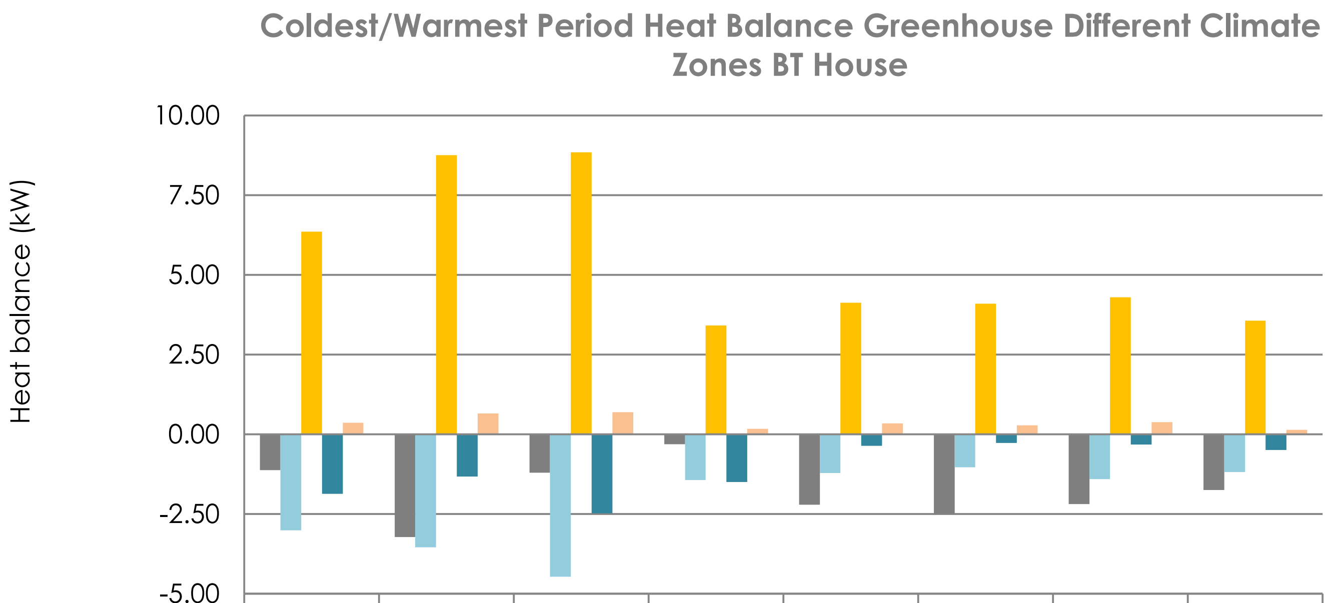
Nonetheless, a second analysis regarding the heat balance during the coldest and warmest periods has been carried out in which a comparison between Madrid, Tenerife and Taos to the real case has been made in order to show in more detail the period of the year in which the most important differences between them are found.

The coldest and warmest periods are according to the floor heating system schedule. The coldest period ranges from September to April and the warmest from May to August.

In Figure 23, it is shown that the greatest heat balance in the greenhouse during the coldest period is in the house located in Taos due to the sun radiation. However, the best one in the warmest period is in the real case.

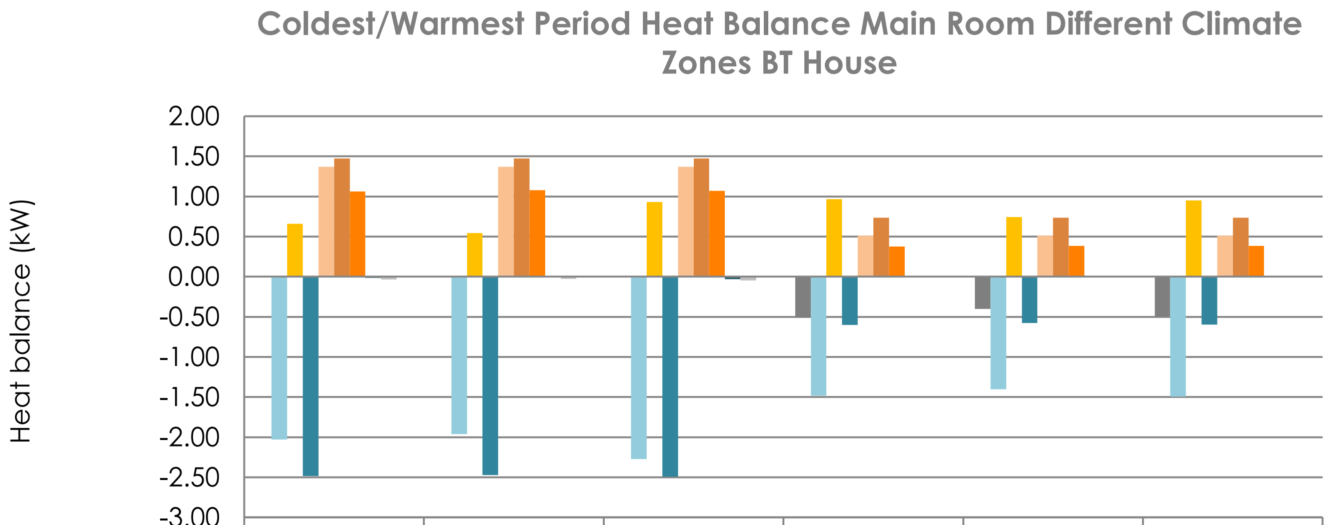
In Figure 24, it can be appreciated that the heat balance in the main room in the coldest and warmest periods is quite similar. The most important differences between them are in relation to transmission, sun radiation and infiltration in the greenhouse.

On balance, this building contains the greatest energy behaviour considering the whole year in Horsens because of the way in which it has been designed. However, the house located in Taos provides the most efficient behaviour in the coldest period.



	Coldest Period Madrid	Coldest Period Tenerife	Coldest Period Taos	Coldest Period RC	Warmest Period Madrid	Warmest Period Tenerife	Warmest Period Taos	Warmest Period RC
Venting (kW)	-1.12	-3.23	-1.21	-0.31	-2.21	-2.50	-2.19	-1.75
Transmission (kW)	-3.01	-3.55	-4.47	-1.44	-1.22	-1.04	-1.40	-1.19
Sun Radiation (kW)	6.36	8.76	8.84	3.42	4.12	4.10	4.30	3.57
Infiltration (kW)	-1.87	-1.33	-2.48	-1.50	-0.36	-0.27	-0.33	-0.49
Total (kW)	0.36	0.65	0.69	0.17	0.34	0.28	0.38	0.14

Figure 23: Coldest/Warmest Period Heat Balance Greenhouse Different Climate Zones BT House



	Coldest Period 90°	Coldest Period 180°	Coldest Period RC	Warmest Period 90°	Warmest Period 180°	Warmest Period RC
Venting (kW)	0.00	0.00	0.00	-0.51	-0.40	-0.49
Transmission (kW)	-2.03	-1.96	-2.27	-1.48	-1.40	-1.50
Sun Radiation (kW)	0.66	0.54	0.93	0.97	0.75	0.95
Infiltration (kW)	-2.48	-2.47	-2.49	-0.60	-0.58	-0.60
People (kW)	1.37	1.37	1.37	0.51	0.51	0.51
Equipment (kW)	1.47	1.47	1.47	0.74	0.74	0.74
Lighting (kW)	1.06	1.08	1.07	0.38	0.39	0.39
Mixing (kW)	-0.02	0.00	-0.03	0.00	0.00	0.00
Ventilation (kW)	-0.03	-0.03	-0.05	0.00	0.00	0.00
Total (kW)	0.00	0.00	0.00	0.00	0.00	0.00

Figure 24: Coldest/Warmest Period Heat Balance Main Room Different Climate Zones BT House

5.2.2. Construction solutions

Taking into account the wide variety of construction solutions, in this study, only two different modifications in the real tyre wall have been carried out following the principles of Earthship buildings [15]. The first one consists of changing the real tyre wall for another one with the same materials but placing an extra tyre with rammed earth (double tyre wall). The second one consists of removing the interior wood panel (without interior panel wall). In this case, the interior layer of the tyre wall is the tyre itself.

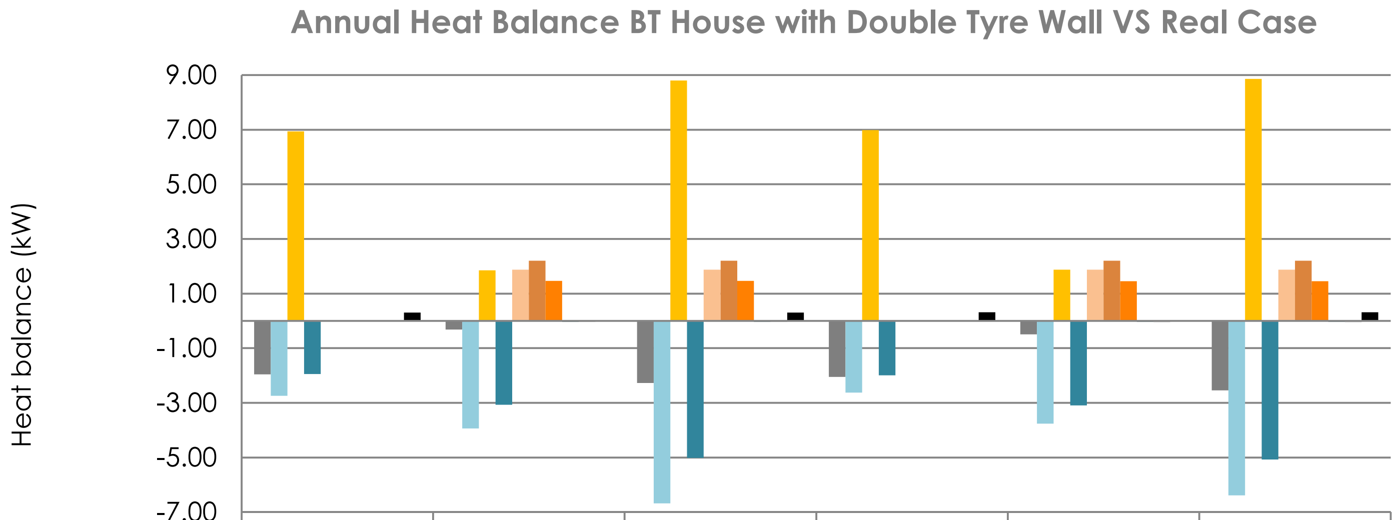
- **Double Tyre Wall**

In Figure 25, it is shown that despite of the fact that the amount of annual heat gains is the same in both cases, the most important differences between them are related to venting and transmission in the main room and in the greenhouse.

In Figure 26, it can be noticed that the relative humidity in the main room and in the greenhouse is higher during summer period in the house with double tyre wall than in the real case. The operative temperature in the main room is more stable during summer period in the house with double tyre wall. The operative temperature in the greenhouse is quite similar in both scenarios.

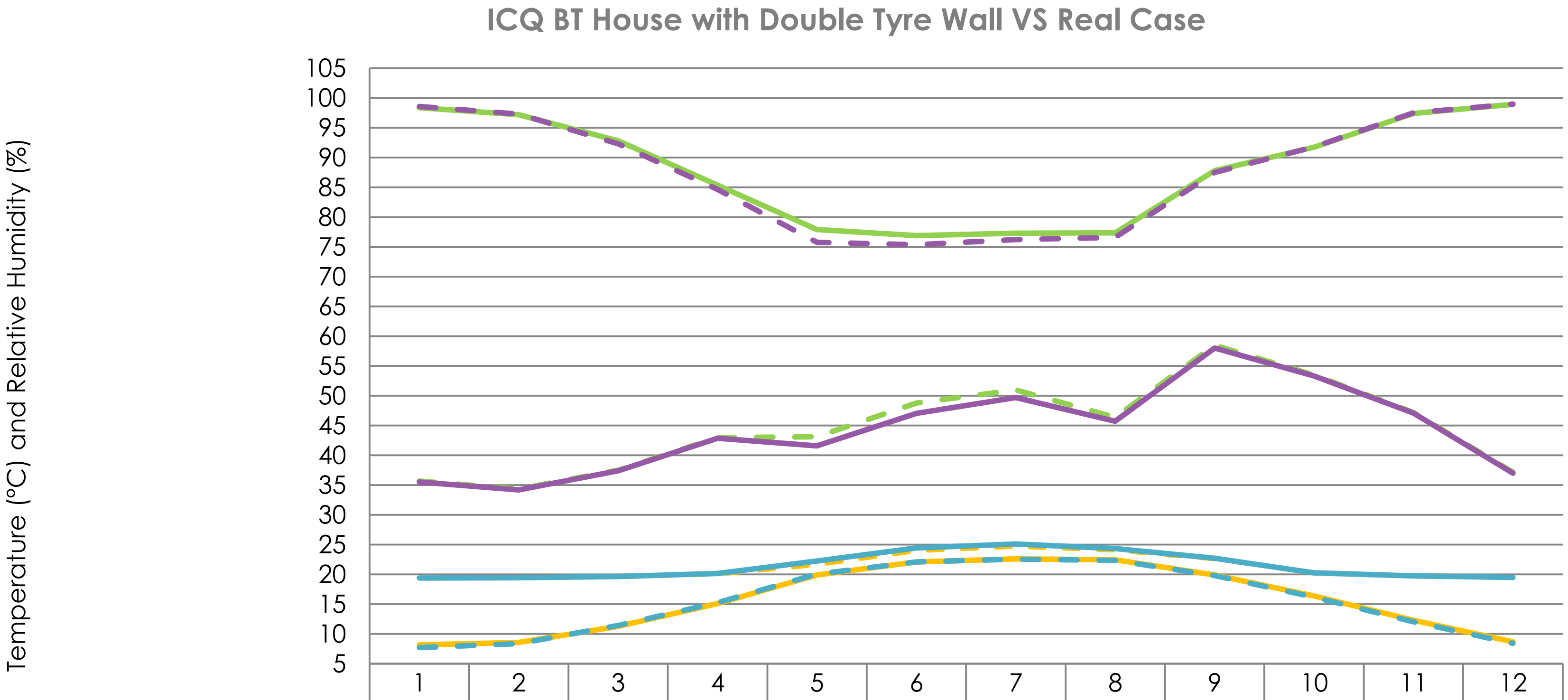
- **Without Interior Panel Wall**

In Figure 27, it can be seen that the energy behaviour is quite similar in both cases. The amount of annual heat gains is almost the same in both scenarios. In Figure 28, it is shown that the relative humidity and the operative temperature in both spaces (main room and greenhouse) follow the same pattern. In conclusion, changing these materials does not affect the energy behaviour and ICQ conditions of the house.



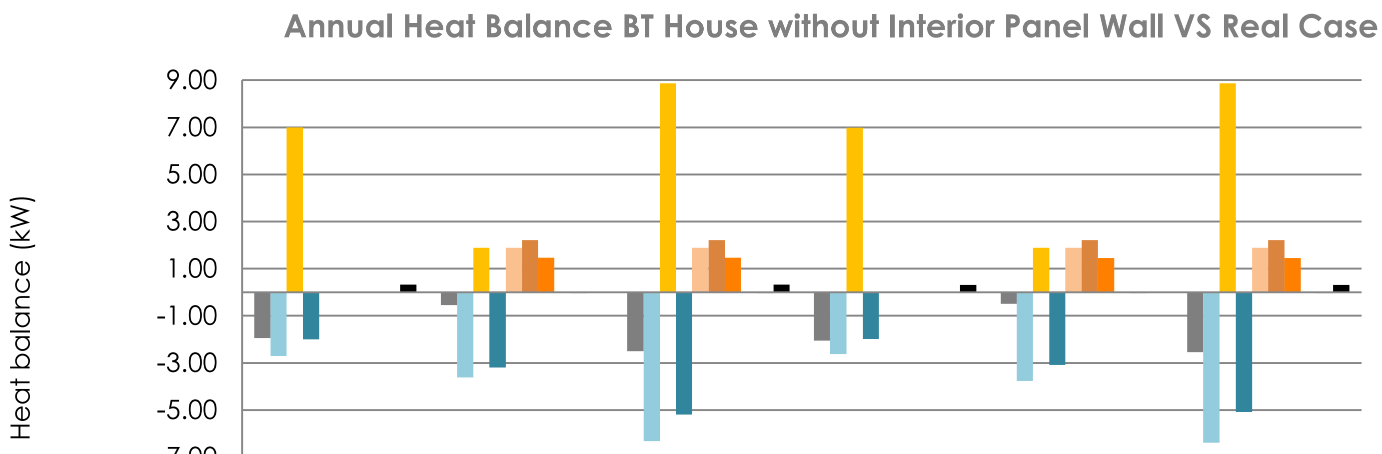
	Greenhouse Double Tyre Wall	Main room Double Tyre Wall	BT House Double Tyre Wall	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-1.96	-0.32	-2.28	-2.06	-0.49	-2.55
Transmission (kW)	-2.75	-3.94	-6.68	-2.63	-3.77	-6.39
Sun Radiation (kW)	6.95	1.86	8.80	6.98	1.88	8.86
Infiltration (kW)	-1.94	-3.07	-5.02	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.46	1.46	0.00	1.46	1.46
Mixing (kW)	0.00	-0.03	-0.03	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.04	-0.04	0.00	-0.05	-0.05
Total (kW)	0.30	0.00	0.31	0.31	0.00	0.31

Figure 25: Annual Heat Balance BT House with Double Tyre Wall VS Real Case



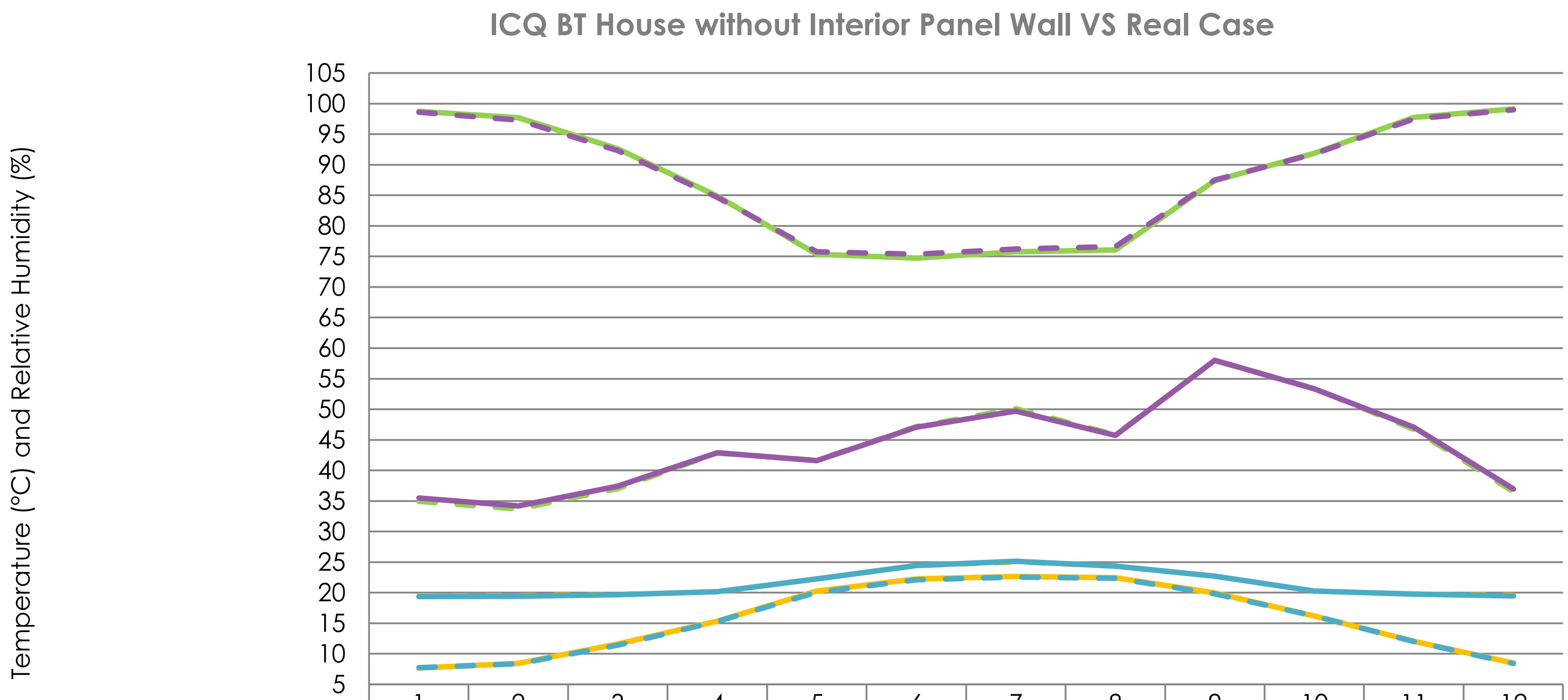
	1	2	3	4	5	6	7	8	9	10	11	12
Top MR Double TW (°C)	19.38	19.39	19.61	20.06	21.65	23.96	24.7	24.09	22.61	20.31	19.78	19.48
Rel Humid MR Double TW (%)	35.69	34.33	37.48	42.96	43.14	48.76	51	46.4	58.48	53.45	47.2	37.16
Top GH Double TW (°C)	8.17	8.55	11.27	15.08	19.88	22.07	22.61	22.43	19.9	16.4	12.32	8.67
Rel Humid Double TW (%)	98.39	97.22	92.81	85.38	77.92	76.92	77.3	77.34	87.82	91.74	97.4	98.94
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 26: Monthly ICQ BT House with Double Tyre Wall VS Real Case



	Greenhouse No Int Panel Wall	Main Room No Int Panel Wall	BT House No Int Panel Wall	Greenhouse RC	Main room RC	BT House RC
Venting (kW)	-1.95	-0.55	-2.50	-2.06	-0.49	-2.55
Transmission (kW)	-2.71	-3.61	-6.32	-2.63	-3.77	-6.39
Sun Radiation (kW)	6.99	1.88	8.87	6.98	1.88	8.86
Infiltration (kW)	-2.01	-3.19	-5.20	-1.99	-3.09	-5.08
People (kW)	0.00	1.88	1.88	0.00	1.88	1.88
Equipment (kW)	0.00	2.21	2.21	0.00	2.21	2.21
Lighting (kW)	0.00	1.46	1.46	0.00	1.46	1.46
Mixing (kW)	0.00	-0.03	-0.03	0.00	-0.03	-0.03
Ventilation (kW)	0.00	-0.05	-0.05	0.00	-0.05	-0.05
Total (kW)	0.32	0.00	0.32	0.31	0.00	0.31

Figure 27: Annual Heat Balance BT House without Interior Panel Wall VS Real Case



	1	2	3	4	5	6	7	8	9	10	11	12
Top MR No Int P W (°C)	19.51	19.58	19.74	20.1	22.18	24.38	24.97	24.34	22.73	20.2	19.8	19.61
Rel Humid MR No Int P W (%)	34.91	33.69	37.04	42.82	41.64	47.15	50.1	45.83	57.97	53.4	46.74	36.54
Top GH No Int P W (°C)	7.7	8.44	11.62	15.34	20.28	22.24	22.66	22.46	19.96	16.2	12.07	8.47
Rel Humid GH No Int P W (%)	98.76	97.69	92.62	84.89	75.37	74.71	75.75	76.09	87.41	91.87	97.73	99.16
Top MR RC (°C)	19.37	19.42	19.64	20.15	22.24	24.45	25.12	24.36	22.71	20.24	19.75	19.48
Rel Humid MR RC (%)	35.49	34.2	37.42	42.88	41.59	47.06	49.7	45.71	58	53.32	47.08	36.99
Top GH RC (°C)	7.72	8.38	11.43	15.27	20.07	22.11	22.57	22.35	19.8	16.17	12.02	8.42
Rel Humid GH RC (%)	98.58	97.3	92.33	84.65	75.79	75.39	76.21	76.59	87.5	91.78	97.52	98.98

Figure 28: Monthly ICQ BT House without Interior Panel Wall VS Real Case

5. CONCLUSIONS

5. Conclusions

In this research, the thermal and energy behaviour of the Building Tomorrow Earthship and the influence of the main architectural-design parameters on it have been analysed through modelling. Taking into account the results of those models, the conclusions of this study are described below.

Real Case:

In the greenhouse, the sun radiation provides the main heat gain, which is higher in the warmest period of the year, because the external glazings are placed in this space. Despite of the fact that there is a high risk of sun radiation in the greenhouse, the operative temperature and the relative humidity are within a comfort range in the warmest period. In the coldest one, the relative humidity is above 90% and the operative temperature is below 20ºC. So, comfort conditions are not reached in winter.

In the main room, the monthly and annual heat balances are zero, due to the fact that this space is not in direct contact with the exterior and the floor heating and ventilation systems are used in this room. Regarding the relative humidity, it is within a comfort range during the whole year. Furthermore, the operative temperature is more stable than in the greenhouse because of the use of heating and ventilation systems.

On balance, the energy behavior of this building is efficient due to how it has been built and how the passive systems employed in it work. So, this is not an off-the-grid building, it is a low energy building.

Orientation analysis:

Regarding the comparison between the northern, southern, eastern and western and the real case, the western is the only one in which the energy behaviour of the building is less efficient than the real case. Thus, this orientation is not beneficial for the building in this particular situation.

Besides, the south facing building (real case) provides the greatest energy balance throughout the year. However, if it is only taken into account the warmest period, the northern one provides the best heat balance. The heat gains provided by the sun radiation are the lowest ones in the warmest period in the north orientation.

Climate analysis:

In relation to the comparison between the house under study in different climate zones - Tenerife (Spain) hot and humid, Taos (USA) hot and arid, Madrid (Spain) temperate) and real case (Horsens (Denmark) cold -, this building has the greatest energy behaviour considering the whole year in Horsens because of the way in which it has been designed. However, the house located in Taos provides the most efficient behaviour in the coldest period.

In conclusion, this is the most influential parameter that should be considered in order to analyse the energy consumption and the ICQ conditions of a house.

Construction analysis:

Concerning the comparison between the real case, the same building with double tyre wall and the same building without interior panel wall, it could be concluded that **this → these** modifications do not affect the energy behaviour and ICQ conditions of the building.

General conclusions:

To sum up, this study is the first step that should be carried out in order to analyse the energy consumption and the ICQ conditions of a house. However, this is not enough to identify the real thermal behaviour of the house. It will be necessary to monitor the house in order to validate the results of the model.

Besides, regarding the architectural-design parameters analysis, it should be neccesary to develop a regression model (parametric analysis) in order to rank the influence of these parameters on the energy consumption and ICQ conditions of the house.

Future research lines:

Monitoring the thermal behaviour of the house should be carried out for at least one year.

Regarding the analysis of the different architectural-design parameters, there are more parameters that should be analysed: the dimension of the glazings, the implementation of solar shadings and the thickness and kind of insulation. Furthermore, taking into consideration the functioning of the systems in the different situations, a more specific study should be carried out.

The development of a regression model (parametric analysis) should be carried out, in order to rank the influence and optimize the combination of the main architectural-design parameters on the thermal indoor environmental conditions and energy consumption.

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7. APPENDIX

7. Appendix

7.1. Appendix 1: BSim Model Inputs

- **Location**

The building is located in Denmark, in the country with scattered windbreaks.

- **Ground properties**

The type of soil has been studied by VIA Energy Park staff [37]. The minimum temperature of the soil is 6°C and the maximum one is 20°C at a depth of one meter.

The temperature of the ground that surrounds the building ranges from 2°C to 24°C.

- **Orientation**

The orientation of the building is 8° (from North to West).

- **Geometry**

The geometry of the building has been simplified as it can be appreciated in Figure 29.

The building is divided in two different thermal zones (main room and greenhouse). The main room is heated and the greenhouse is unheated. However both are habitable spaces. They have different properties and systems which will be subsequently analysed.

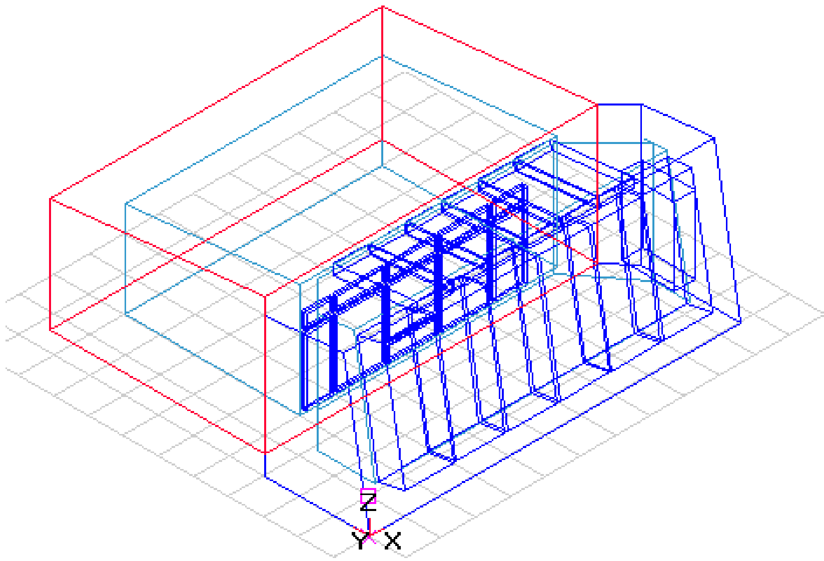


Figure 29: 3D geometry model

- **Building elements**

The external walls are: tyre wall, tyre wall (vertical garden), eastern wall and southern wall.

The internal wall is: inner wall (it divides the two thermal zones).

The different types of floors are: main room floor and greenhouse floor.

There is only one kind of roof.

The external windoors are: southern glazings, the main door and the skylights.

The internal windoors are: the interior glazings and the interior door.

The composition of all the building elements is described in Table 4, Table 5, Table 6, Table 7, Table 8, Table 9, Table 10, Table 11 and Table 12.

Table 4: Tyre wall materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal Properties	
			Cp (J/kg K)	Lambda (W/m K)
Wood panels HDF	0.0045	950	1800	0.14
Wood	0.012	600	1800	0.14
Air gap (ventilated)	0.05	500	1000	0.1
Tyre rubber	0.01	1120	750	0.25
Clay	0.713	1600	1200	1.4
Tyre rubber	0.01	1120	750	0.25
Concrete (1/2/3)	0.01	1860	800	0.95
EPS insulation	0.15	16	750	0.031
Polypropylene Waterproof membrane	0.001	1180	800	0.18
EPS insulation foam	0.1	17	750	0.042
Polypropylene Geotextile	0.001	900	1800	0.15

Table 5: Tyre wall vertical garden materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal properties	
			Cp (J/kg K)	Lambda (W/m K)
Wood	0.012	600	1800	0.14
Polyethylene Damp Proof Membrane	0.001	900	2303	0.4
Polypropylene Geotextile	0.001	900	1800	0.15
Tyre rubber	0.01	1120	750	0.25
Clay	0.713	1600	1200	1.4
Tyre rubber	0.01	1120	750	0.25
Concrete (1/2/3)	0.01	1860	800	0.95
EPS insulation	0.15	16	750	0.031
Polypropylene Waterproof membrane	0.001	1180	800	0.18
EPS insulation foam	0.1	17	750	0.042
Polypropylene Geotextile	0.001	900	1800	0.15

Table 6: Eastern wall materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal properties	
			Cp (J/kg K)	Lambda (W/m K)
Wood panels HDF	0.0045	950	1800	0.14
Wood	0.012	600	1800	0.14
Rock wool	0.2	45	840	0.035
Wood	0.012	600	1800	0.14
Wood (Facade)	0.012	600	1800	0.14

Table 7: Southern wall materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal Properties	
			Cp (J/kg K)	Lambda (W/m K)
Wood	0.075	600	1800	0.14
Glazing (see Table 12)	-	-	-	-

Table 8: Inner wall materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal Properties	
			Cp (J/kg K)	Lambda (W/m K)
Wood	0.14	600	1800	0.14
Glazing (see Table 12)	-	-	-	-

Table 9: Main room floor materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal properties	
			Cp (J/kg K)	Lambda (W/m K)
Laminated bamboo	0.012	400	1800	0.18
Polyethylene foam	0.002	70	2300	0.05
Chipboard heat panel	0.023	600	1700	0.2
Sand and clay	0.094	1200	2100	1.5
EPS insulation	0.05	17	750	0.042
Sand and clay	0.094	1200	2100	1.5
EPS insulation foam	0.1	17	750	0.042
Gravel	0.04	1600	1000	0.7

Table 10: Greenhouse floor materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal properties	
			Cp (J/kg K)	Lambda (W/m K)
Untreated spruce	0.018	470	1800	0.12
Sand and clay	0.094	1200	2100	1.5
EPS insulation	0.05	17	750	0.042
Sand and clay	0.094	1200	2100	1.5
EPS insulation foam	0.1	17	750	0.042
Gravel	0.04	1600	1000	0.7

Table 11: Roof materials properties

Layer	Thickness (m)	Density (kg/m³)	Thermal properties	
			Cp (J/kg K)	Lambda (W/m K)
Timber joists	0.012	600	1800	0.14
Oriented strand board (OSB) plates Plywood	0.004	700	1600	0.17
Polypropylene Waterproof membrane	0.001	1180	800	0.18
EPS insulation	0.15	16	750	0.031
Polypropylene Waterproof membrane	0.001	1180	800	0.18
Polypropylene Geotextile	0.001	900	1800	0.15
Polystyrene drainage plate	0.025	1050	1300	0.16
Polypropylene Geotextile	0.001	900	1800	0.15
Sedum	0.06	1200	1670	1.5

Table 12: Glazings properties

Glazing properties	Exterior glazings			Interior glazings	
	Southern glazings	Main door	Skylights	Interior glazings	Interior door
Heat transmittance (normal)	0,35	0,53	0,58	0,66	0,53
Heat transmittance (diffuse)	0,11	0,11	0	0	0,11
Light Transmittance	0,71	0,71	0,8	0,77	0,71
U value (W/m²K)	0,62	0,6	1,1	1,6	0,6
Direct solar radiation transmittance	0,34	0,43	0,34	0,76	0,43
Reflectance (side 1)	0,24	0,32	0,24	0,12	0,32
Reflectance (side 2)	0,16	0,16	0,16	0,12	0,16
Absorptance (side 1)	0,27	0,25	0,27	0,08	0,25
Absorptance (side 2)	0,01	0,01	0,01	0,11	0,01

- **Cold bridges**

The existing cold bridges have been taken into account. They are the following:

-Tyre wall/roof: 0,000623624 W/m²K

-Tyre wall/floor: 1,020429185 W/m²K

- **Systems**

Assumptions:

-The building is considered as a dwelling and category B in the simulation.

-The occupancy level is assumed to be 2 people.

-The required ventilation rate is assumed to be 21 l/s per occupant (considering category B and 40% smokers) [38].

- The permissible vertical air temperature difference between head and ankles is assumed to be <3°C [38].

- The permissible range of the floor temperature is assumed to be 19-29°C [38].

- The required ventilation rate is assumed to be 7 l/s [38].

- The operative temperature is between 23 – 26 (0,5 clo) in summer and between 20 – 24 (1 clo) in winter [32].

- The maximum mean air velocity is 0,22 m/s in summer and 0,18 m/s in winter [32].

A. Main room

- <u>People load:</u>

Occupancy is assumed to be 2 people.

64,50 m^2 (House + Greenhouse) x 0,03 people/m^2 [16] = 1,94 people

The metabolic rate is 106 W/m2 considering an adult with sedentary and domestic activities, with a skin surface area of 1,8 m2 (male) and 1,6 m^2 (female). The heat generated is 0,18 kW/person [36].

106 W/m^2 x 1,7 m^2 = 180,2 W ≈ 0,18 kW/person

The people load is assumed during the whole year except August. The day profile of this load is considered the following:

70% from 0h to 07h

10% from 08h to 16h

70% from 17h to 24h

- Equipment

The equipment heat load is 0,67 kW.

The equipment load is assumed during the whole year. The day profile of this load is considered the following:

36% from 19h to 06h

19% from 07h to 18h

- Infiltration

The basic air change is 0,02/h in the main room.

This load is assumed twenty four hours per day during the whole year.

- <u>Mixing</u>

The air flow is 0,16 m^3/s in the main room.

This load is assumed from 10h to 18h during the coldest period (from January to April and from September to December).

- <u>Ventilation</u>

The input parameters of this load are described in Figure 30.

The air is taken from the greenhouse.

This load is assumed from 08h to 20h during the coldest period (from January to April and from September to December).

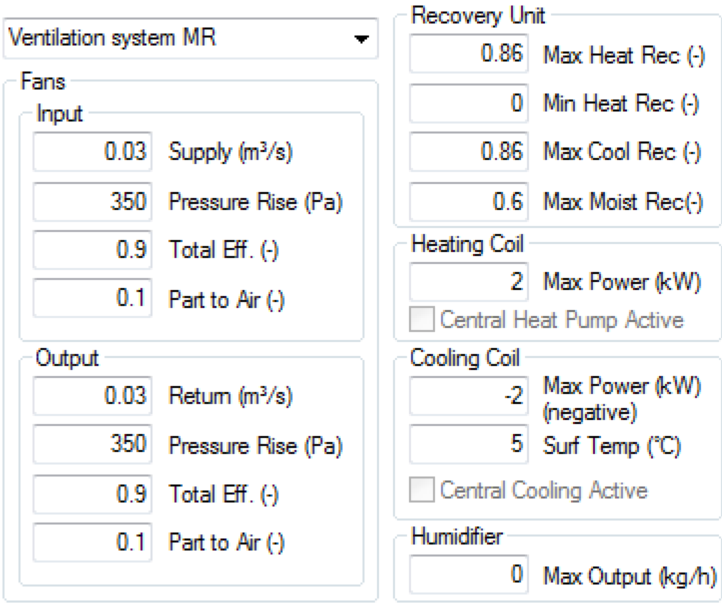


Figure 30: Input parameters of ventilation load

- Floor heating

The room set point is 20°C.

This load is assumed from 06h to 22h during the coldest period (from January to April and from September to December).

- Lighting

The lighting level is 200 lux.

This load is assumed from 16h to 08h during the whole year.

- Venting

The basic air change is 1/h in the main room.

This load is assumed from 08h to 20h during the warmest period (from May to July).

B. Greenhouse

- Venting

The basic air change is 4/h in the main room.

This load is assumed from 08h to 21h during the coldest period (from January to March and October to December) and from 08h to 21h during the warmest period (from April to September).

- Infiltration

The basic air change is 0,2/h in the main room.

This load is assumed twenty four hours per day during the whole year.

- Moisture Load

The moisture load is 0,44 kg/h in the greenhouse.

This load is assumed twenty four hours per day during the whole year.

7.2. Appendix 2: Building Tomorrow Earthship Construction Process

01_CONSTRUCTION PROCESS

01.1_EXCAVATION PHASE

01.2_TYRE WALL CONSTRUCTION

01.3_STRUCTURE

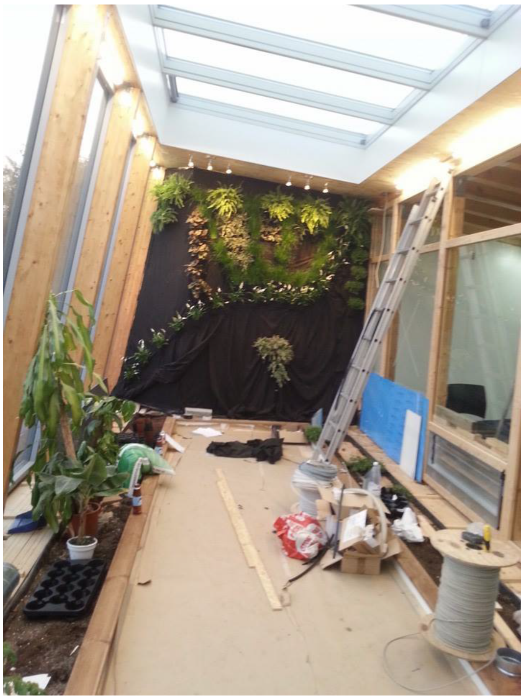
01.4_ROOF CONSTRUCTION

01.5_WATER SYSTEM

01.6_INTERIOR





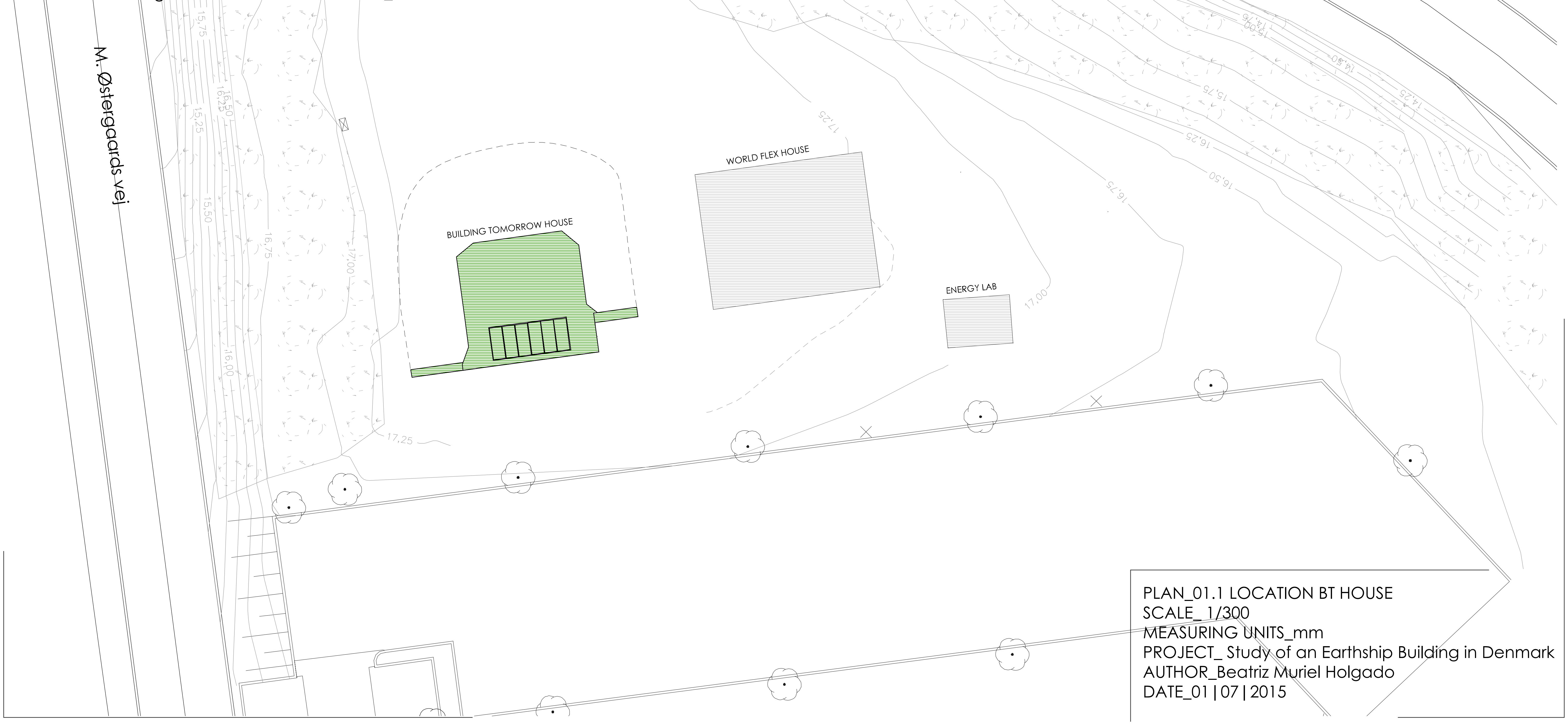


01.7_EXTERIOR

7.3. Appendix 3: Building Tomorrow Earthship Plans

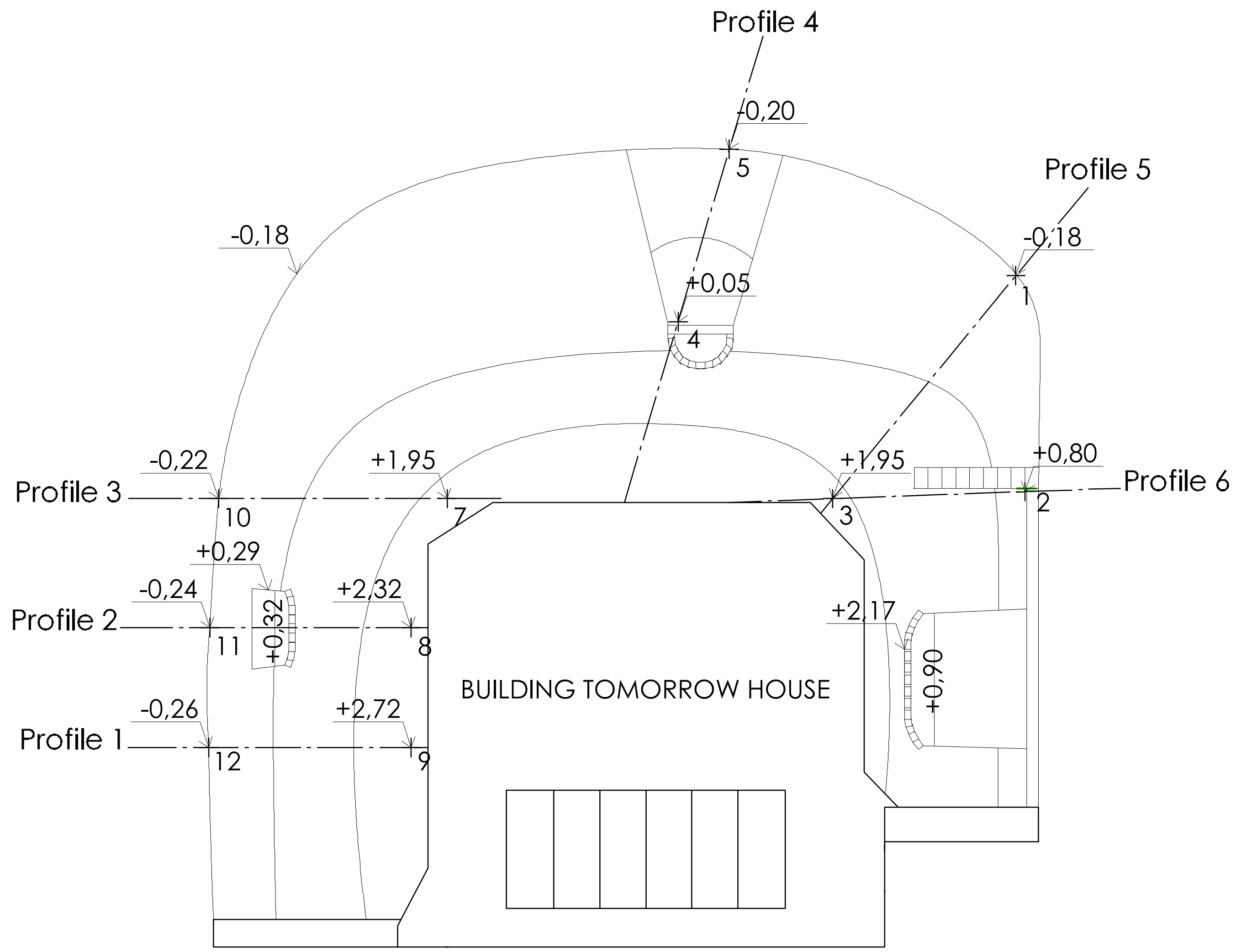
01.1_LOCATION BUILDING TOMORROW HOUSE

Location of Building Tomorrow House in Horsens_ 1/50000

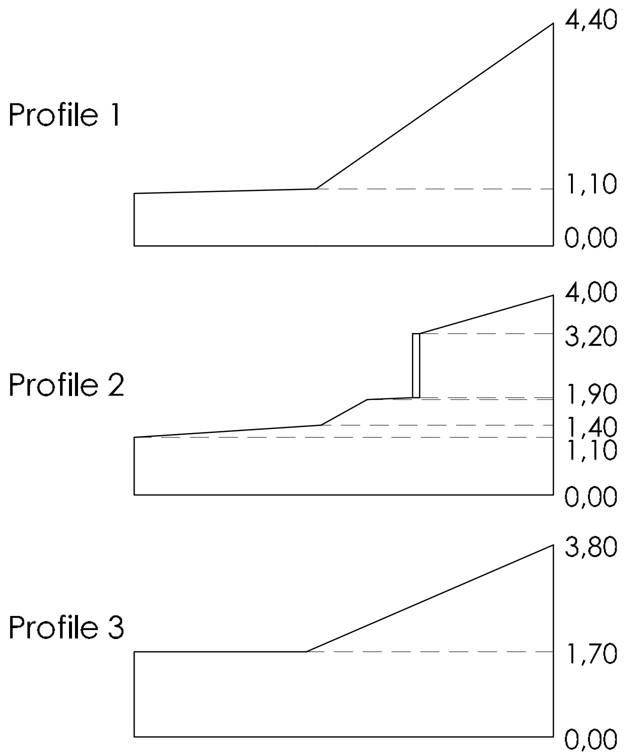


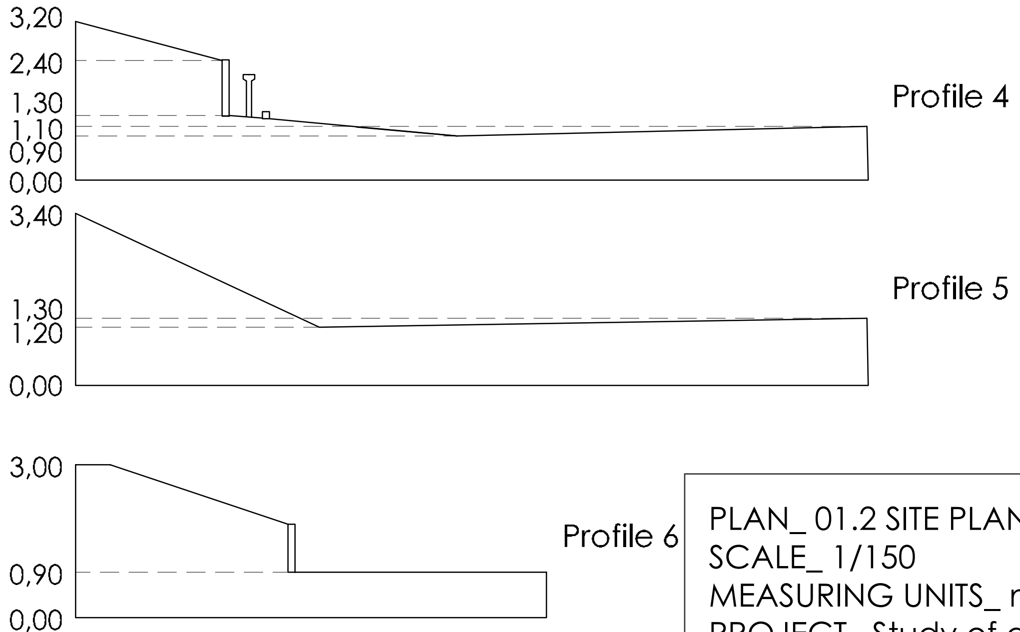
PLAN_01.1 LOCATION BT HOUSE
SCALE_ 1/300
MEASURING UNITS_mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_Beatriz Muriel Holgado
DATE_01|07|2015

01.2_SITE PLAN



Level curves and measuring points plan_ 1/150

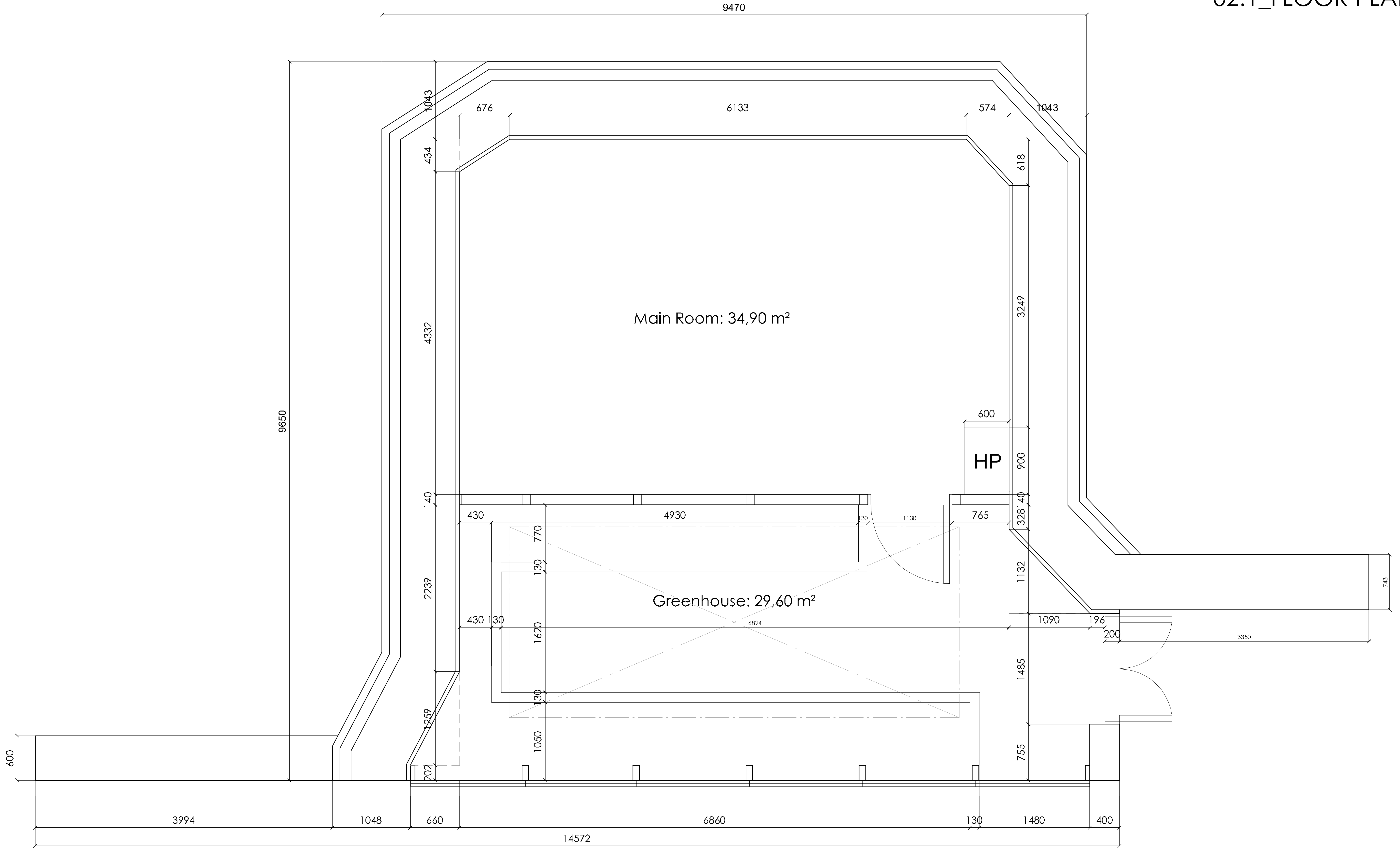




Terrain Profiles_ 1/150

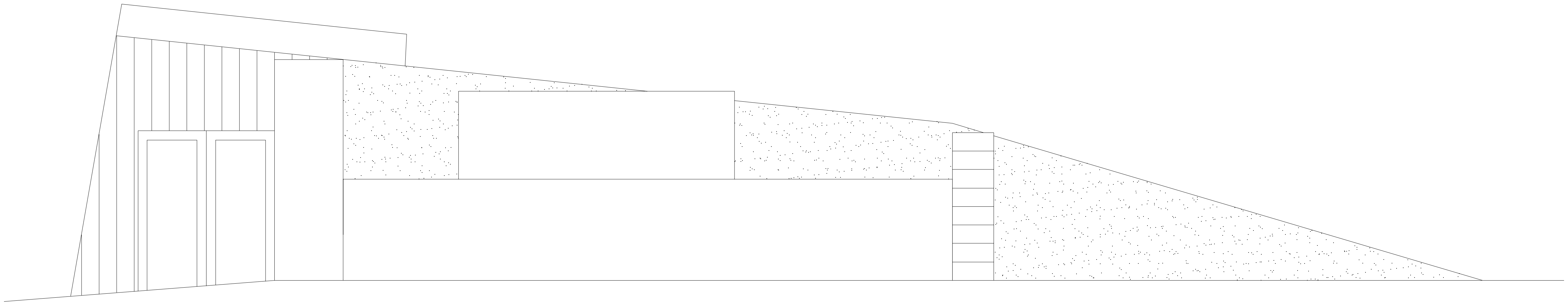
PLAN_ 01.2 SITE PLAN
SCALE_ 1/150
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

02.1_FLOOR PLAN



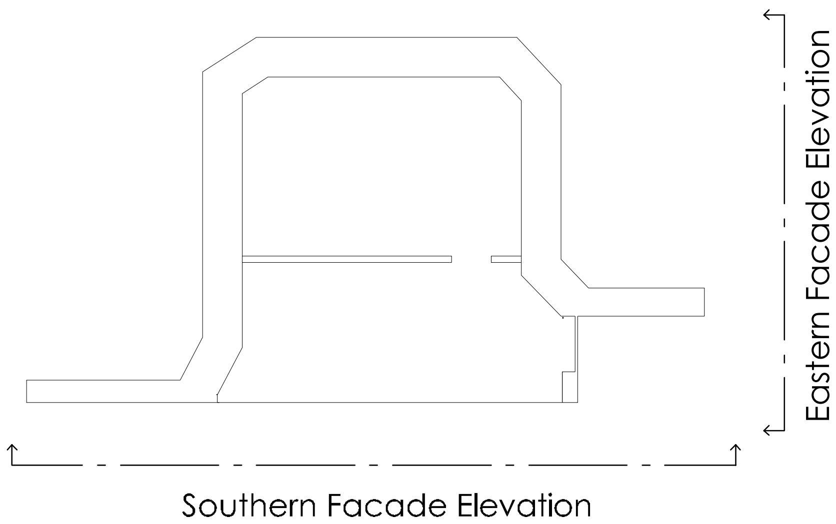
Height + 0,00 mm

PLAN_ 02.1 FLOOR PLAN
SCALE_ 1/50
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015



Eastern Facade Elevation

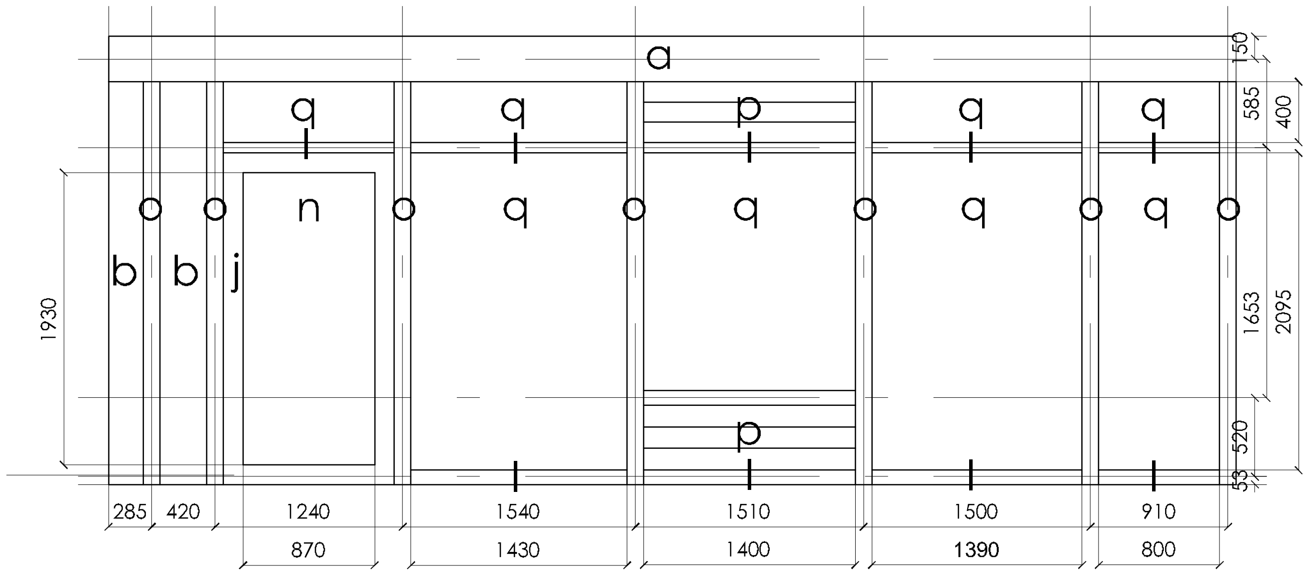
Southern Facade Elevation



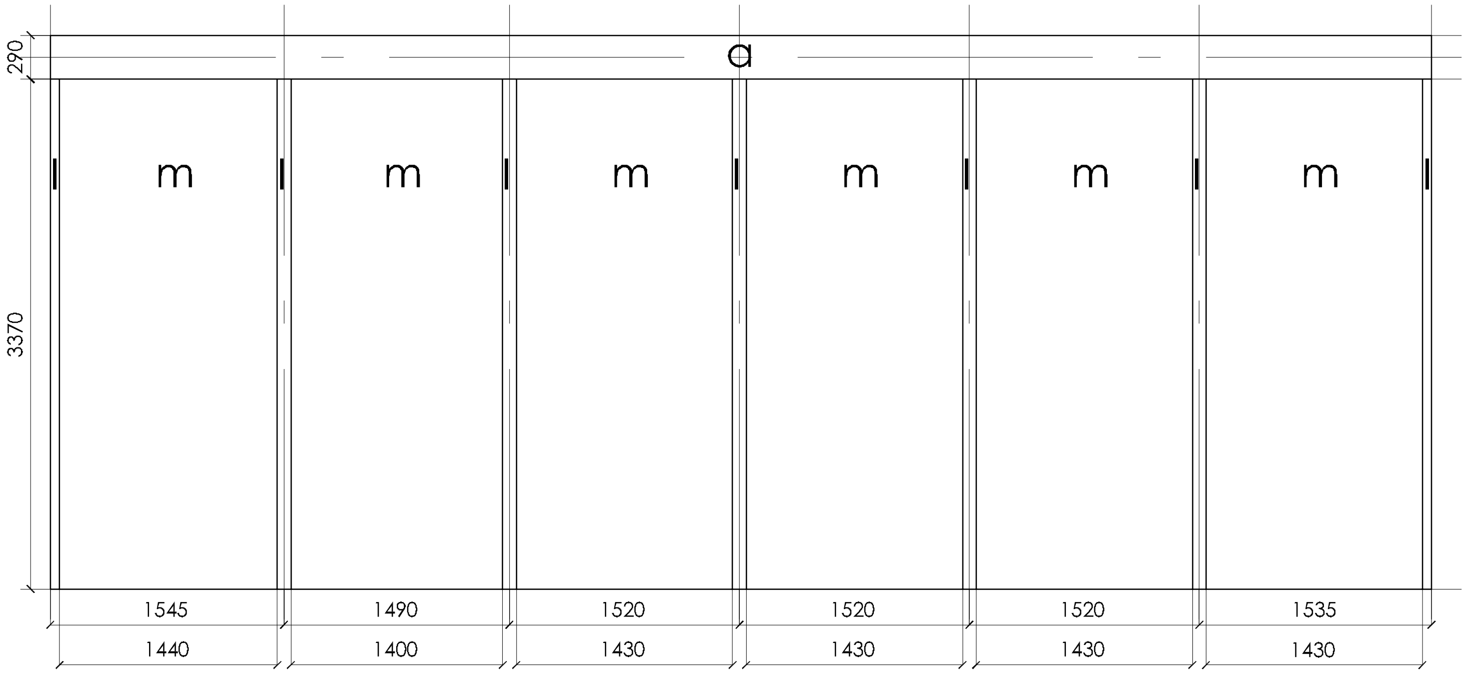
PLAN_ 02.2 ELEVATIONS
SCALE_ 1/50
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

02.3_GLAZING ELEVATIONS

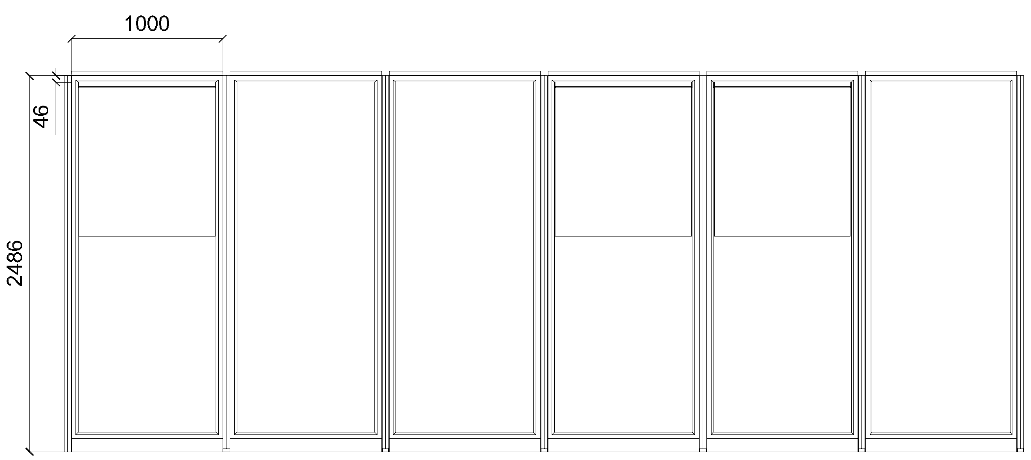
Elevation 1. Interior glazing_1/50



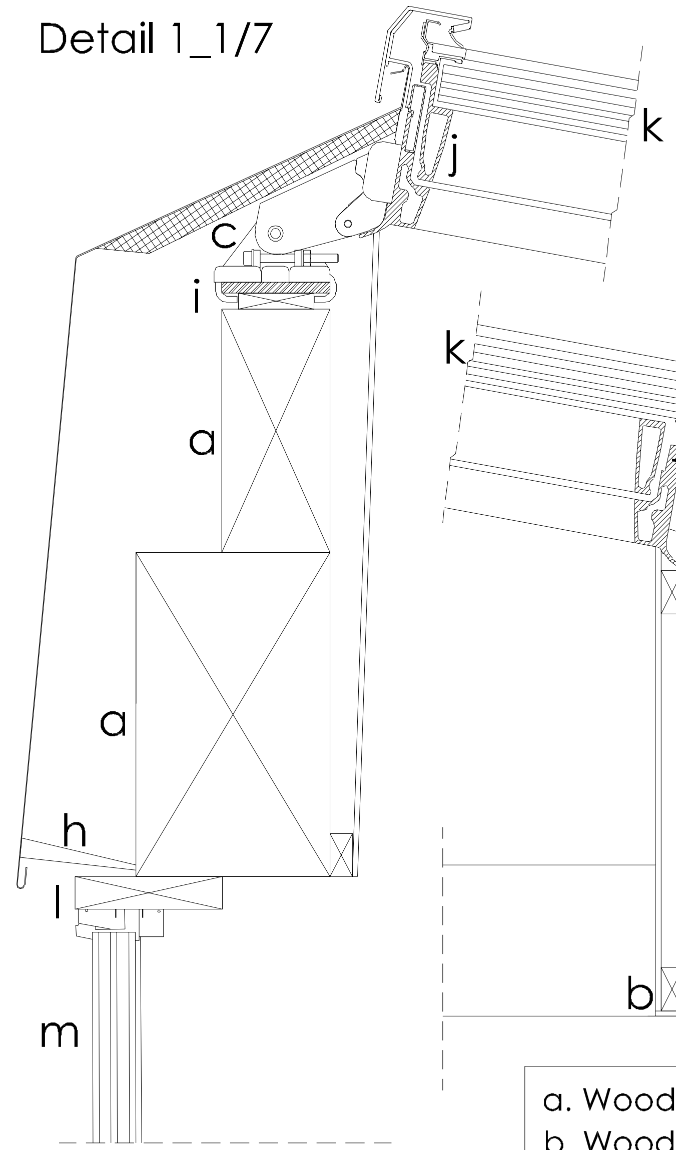
Elevation 2. Exterior glazing_ 1/50



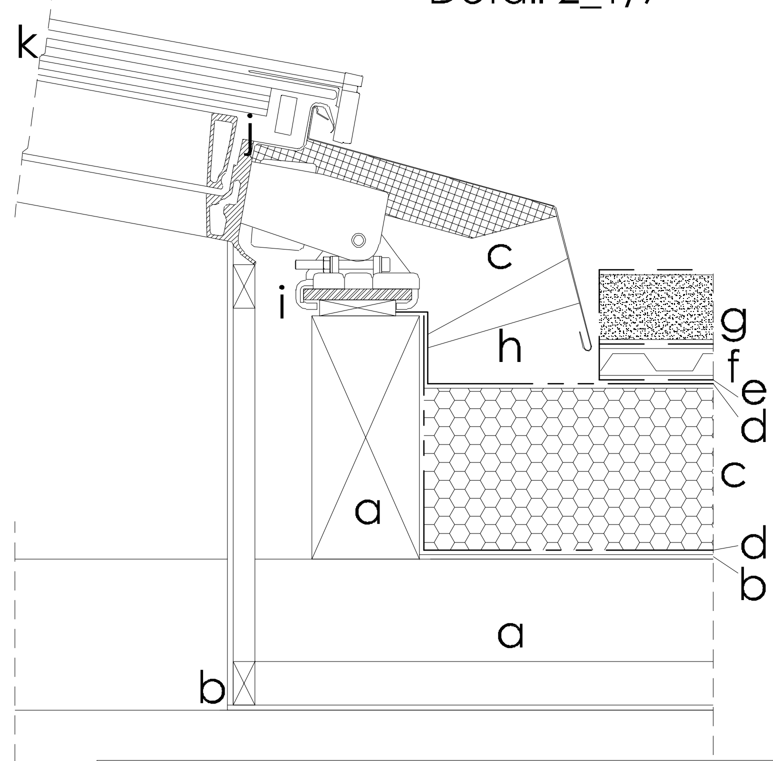
Elevation 3. Skylights_ 1/50



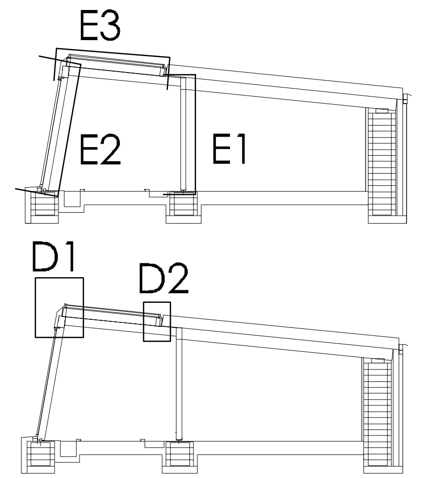
Detail 1_1/7



Detail 2_1/7



*Details 1 and 2 according to Velux

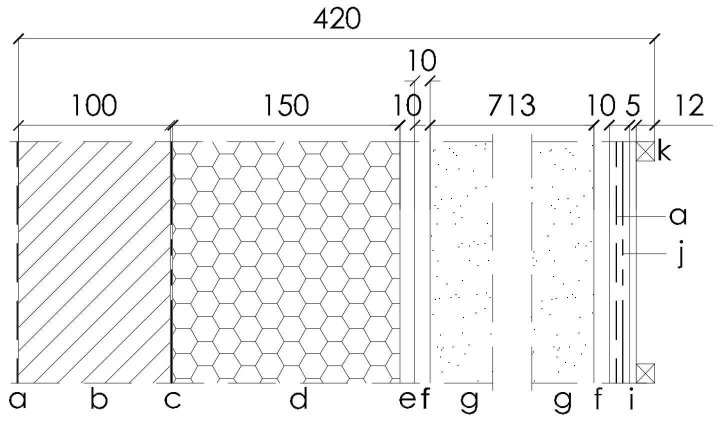


Glazing elevations scheme

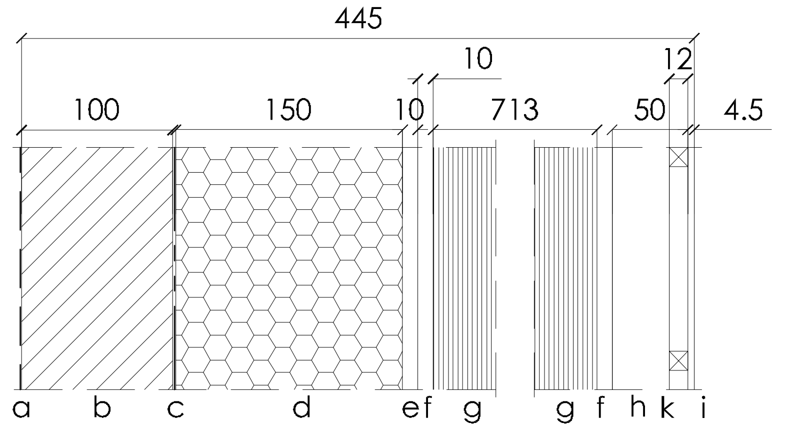
a. Wooden beam
b. Wood panels HDF
c. EPS insulation
d. Polyethylene damp proof membrane
e. Polypropylene geotextile
f. Polystyrene drainage plate
g. Sedum
h. Snow stop
i. Clamp
j. Wooden and aluminium frame
k. Triple glazing (4+6+4+6+4) Uw: 1,0 W/m²K
l. Wooden frame
m. Triple glazing (4+6+4+6+4) Uw: 0,62 W/m²K
n. Triple glazing (4+6+4+6+4) Uw: 0,52 W/m²K
o. Wooden internal glazing column
p. Ventilation grid
q. Single glazing (4) Uw: 1,6 W/m²K

PLAN_ 02.3 GLAZING ELEVATIONS
SCALE_ 1/50 1/7
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

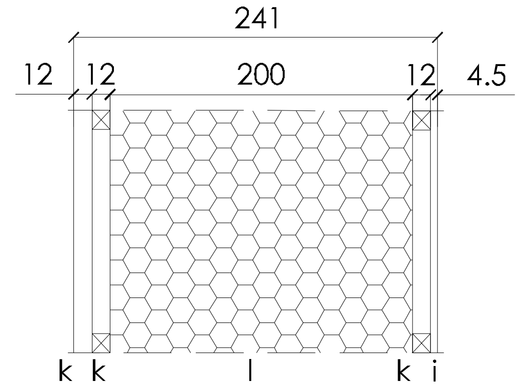
Detail 1. Tyre wall vertical graden_1/5



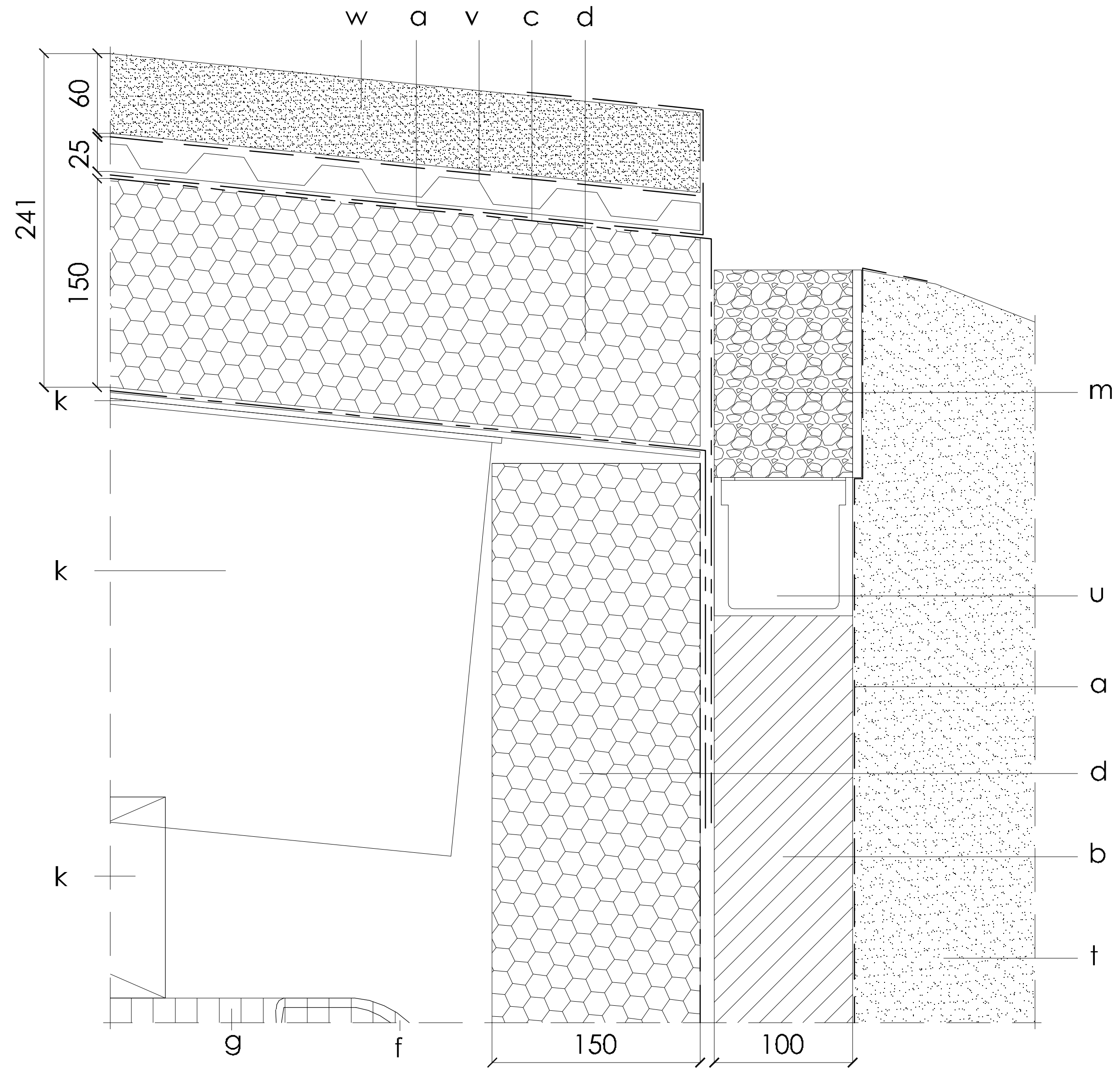
Detail 2. Tyre wall_1/5

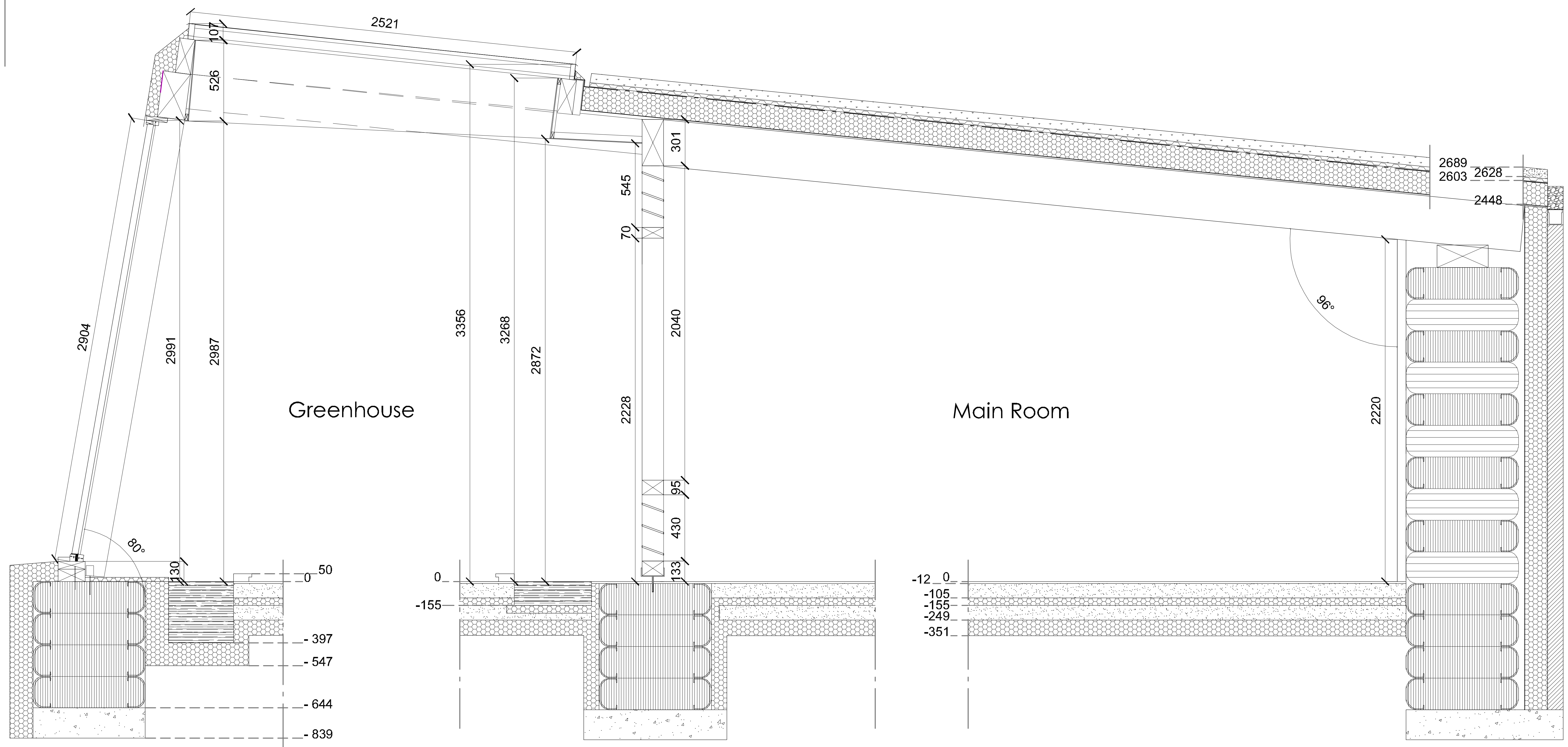


Detail 3. Eastern wall_1/5



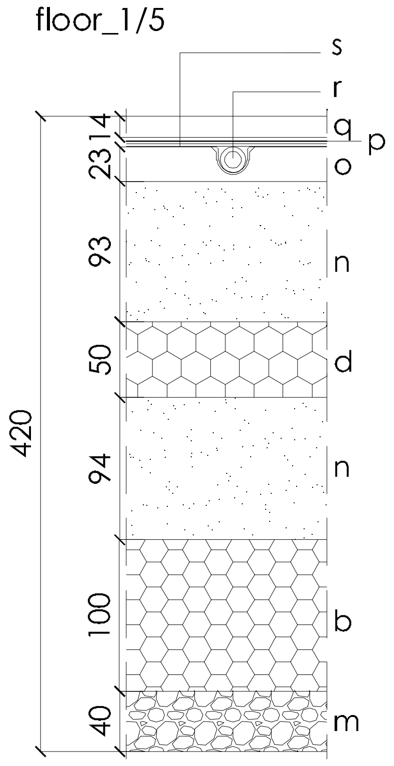
Detail 4. Roof_1/5



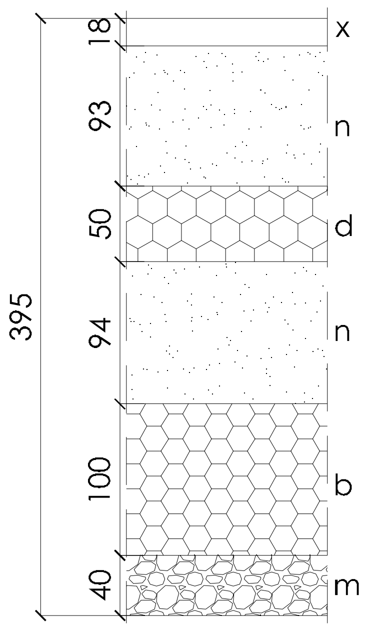


Construction Section_ 1/25

Detail 5. Main room floor_1/5

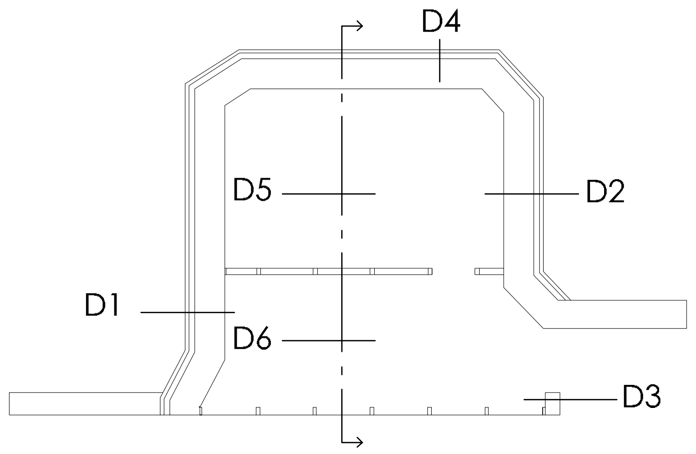


Detail 6. Greenhouse floor_1/5

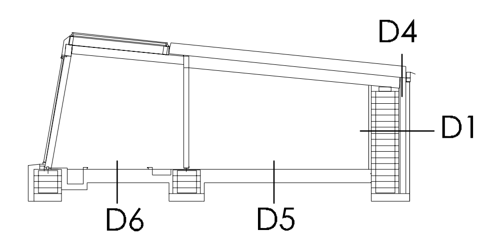


MATERIALS

- a. Polypropylene Geotextile (thickness: 1mm/density: 900 kg/m³)
- b. EPS Drainage insulation foam (density: 17 kg/m³)
- c. Polypropylene Waterproof membrane (thickness: 1mm/density: 1180 kg/m³)
- d. EPS insulation (density: 16 kg/m³)
- e. Concrete 1/2/3 (density: 1860 kg/m³)
- f. Tyre rubber (density: 1120 kg/m³)
- g. Clay (density:1600 kg/m³)
- h. Ventilated air gap (density: 500 kg/m³)
- i. Wood panels HDF (density: 950 kg/m³)
- j. Polyethylene damp proof membrane (thickness: 1mm/density: 900 kg/m³)
- k. Wood (density: 600 kg/m³)
- l. Rock wool (density: 45 kg/m³)
- m. Gravel (density: 1250 kg/m³)
- n. Sand and clay (density: 1200 kg/m³)
- o. Chipboard heat panel (density: 600 kg/m³)
- p. Polyethylene foam (density: 900 kg/m³)
- q. Laminated bamboo (density: 400 kg/m³)
- r. Polyethylene pipe (density: 900 kg/m³)
- s. Aluminium heat emmision plate (density:2700 kg/m³)
- t. Soil
- u. PVC drainage channel (density: 800 kg/m³)
- v. Polystyrene drainage plate (density: 24 kg/m³)
- w. Sedum (density: 1200 kg/m³)
- x. Untreated spruce (density: 470 kg/m³)

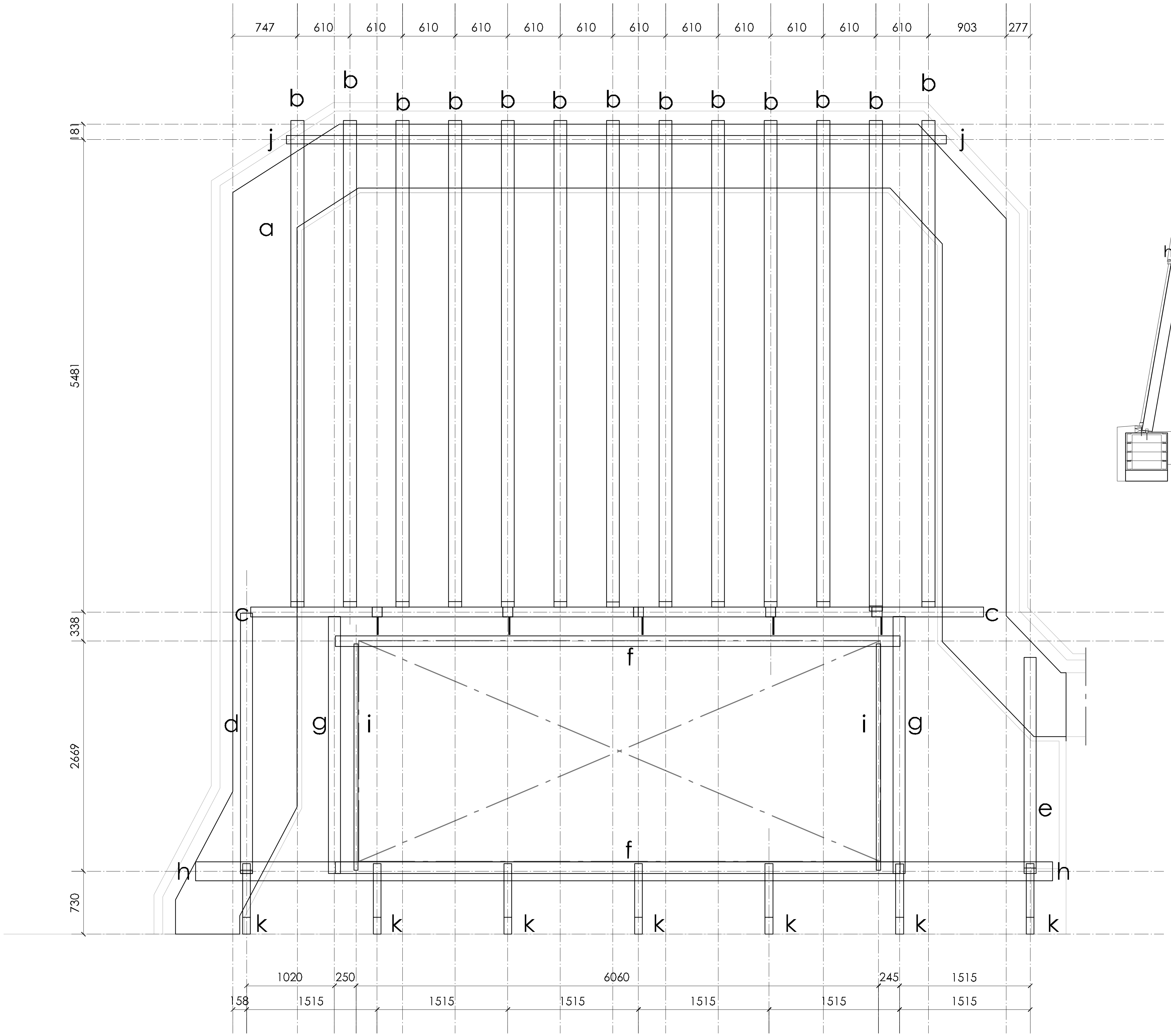


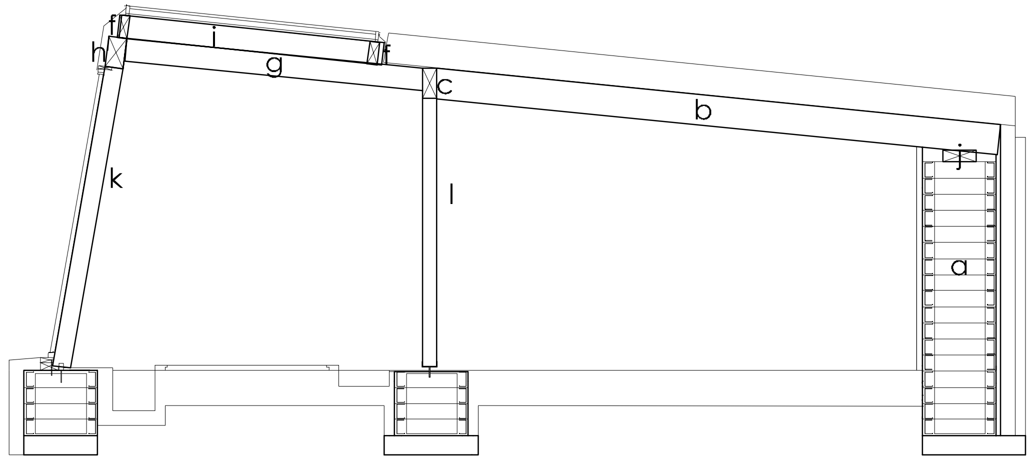
Details scheme



PLAN_ 02.4 CONSTRUCTION SECTION AND DETAILS
SCALE_ 1/25 1/5
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

03.1_STRUCTURAL FLOOR PLAN





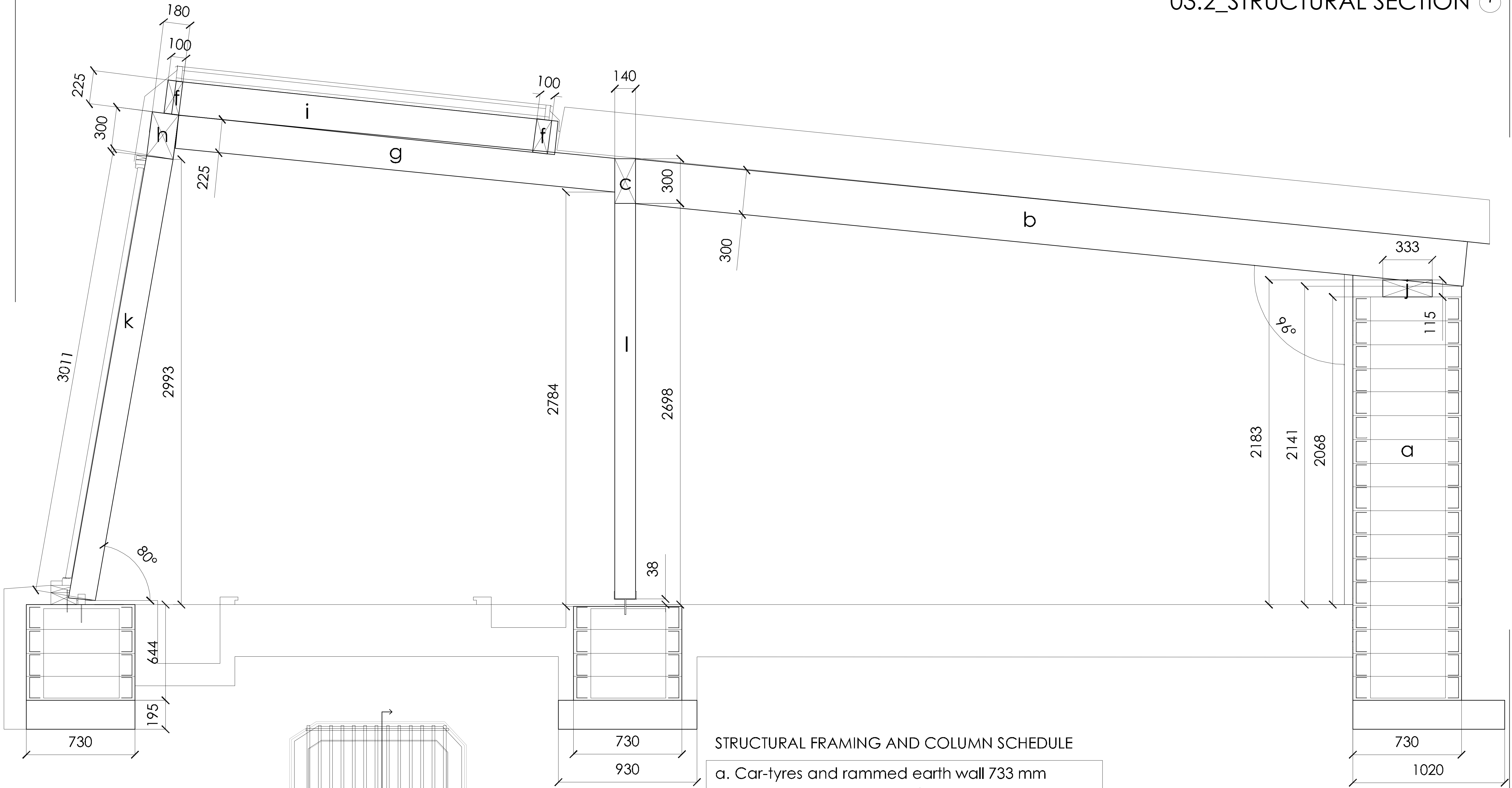
Section scheme

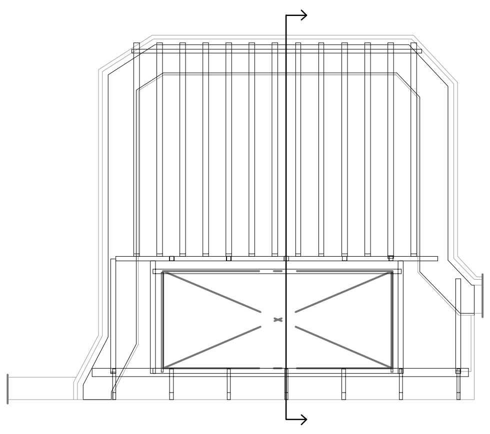
STRUCTURAL FRAMING AND COLUMN SCHEDULE

a. Car-tyres and rammed earth wall 733 mm
b. Wooden beam over main area 150x300 mm
c. Wooden beam over internal glazing 140x300 mm
d. Wooden end beam East 140x300 mm
e. Wooden end beam West 140x300 mm
f. Wooden window supporting rafter 100x225 mm
g. Wooden beam over buffer zone 100x225 mm
h. Wooden front facade beam 180x300 mm
i. Wooden window edge beam 50x225 mm
j. Wooden wall edge beam 115x333 mm
k. Wooden main facade column 140x180 mm
l. Wooden internal glazing column 140x140 mm

PLAN_ 03.1 STRUCTURAL FLOOR PLAN
SCALE_ 1/50
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

03.2_STRUCTURAL SECTION





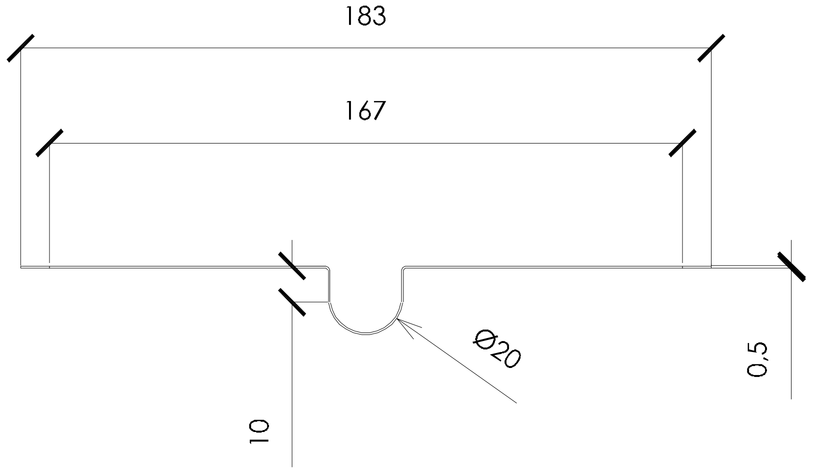
Section scheme

STRUCTURAL FRAMING AND COLUMN SCHEDULE

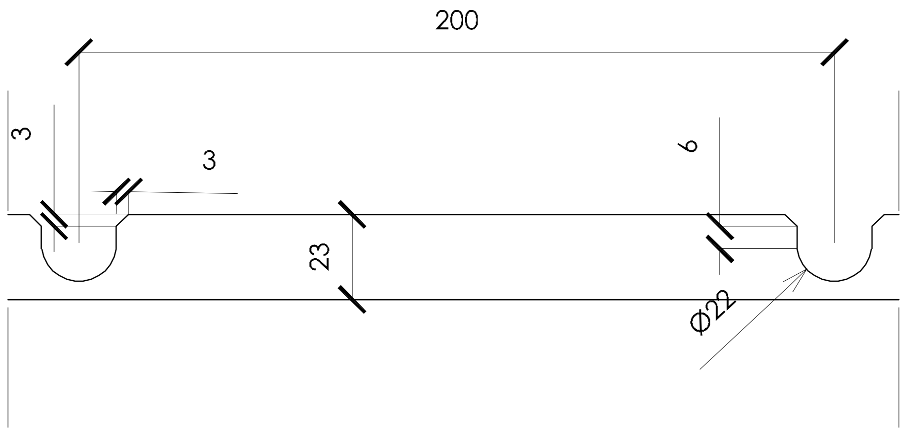
a. Car-tyres and rammed earth wall 733 mm
b. Wooden beam over main area 150x300 mm
c. Wooden beam over internal glazing 140x300 mm
d. Wooden end beam East 140x300 mm
e. Wooden end beam West 140x300 mm
f. Wooden window supporting rafter 100x225 mm
g. Wooden beam over buffer zone 100x225 mm
h. Wooden front facade beam 180x300 mm
i. Wooden window edge beam 50x225 mm
j. Wooden wall edge beam 115x333 mm
k. Wooden main facade column 140x180 mm
l. Wooden internal glazing column 140x140 mm

PLAN_ 03.2 STRUCTURAL SECTION
SCALE_ 1/25
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

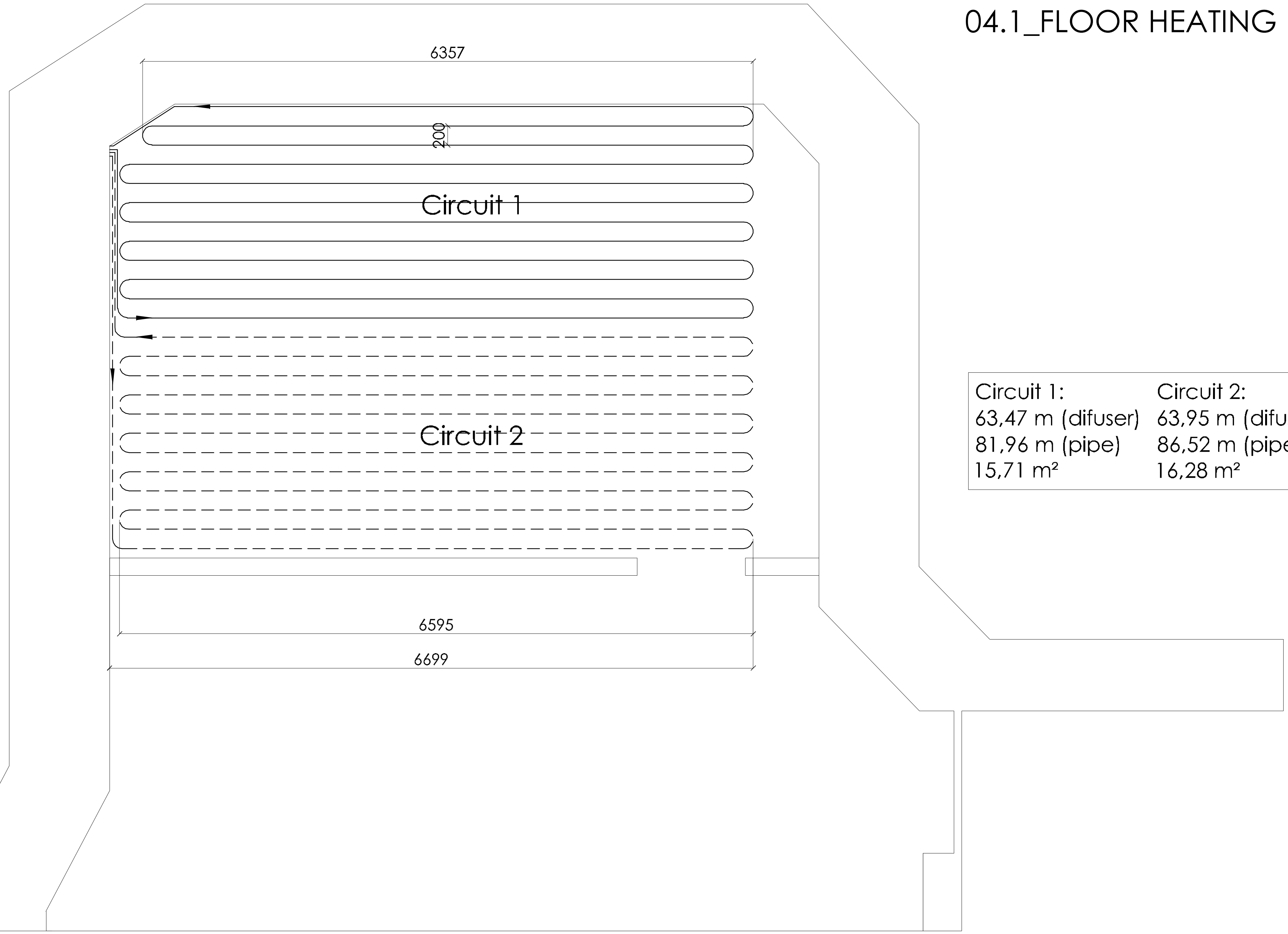
04.1_FLOOR HEATING



Heat distribution plate_ 1/2



Heat panel_ 1/2

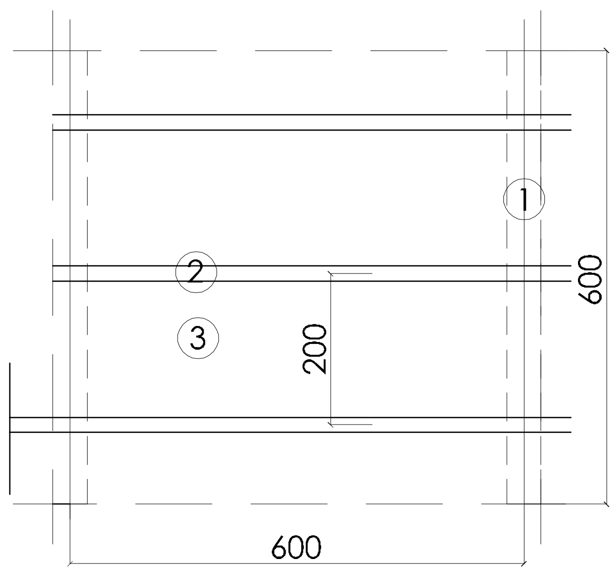


Circuit 1:	Circuit 2:
63,47 m (difuser)	63,95 m (difuser)
81,96 m (pipe)	86,52 m (pipe)
15,71 m²	16,28 m²

Floor Heating Plan_ 1/50

Summary table

Component	Dimensions	Materials	Density
Pipes	17x2 mm, 120 m	Fornettet polyethylene equipped with oxygen diffusion barrier	900 kg/m³
Heat emmision plate	1150x190x0,5mm	Aluminium	2700 kg/m³
Heat panel	17x2 mm c/c 200 mm	Chipboard	600 kg/m³

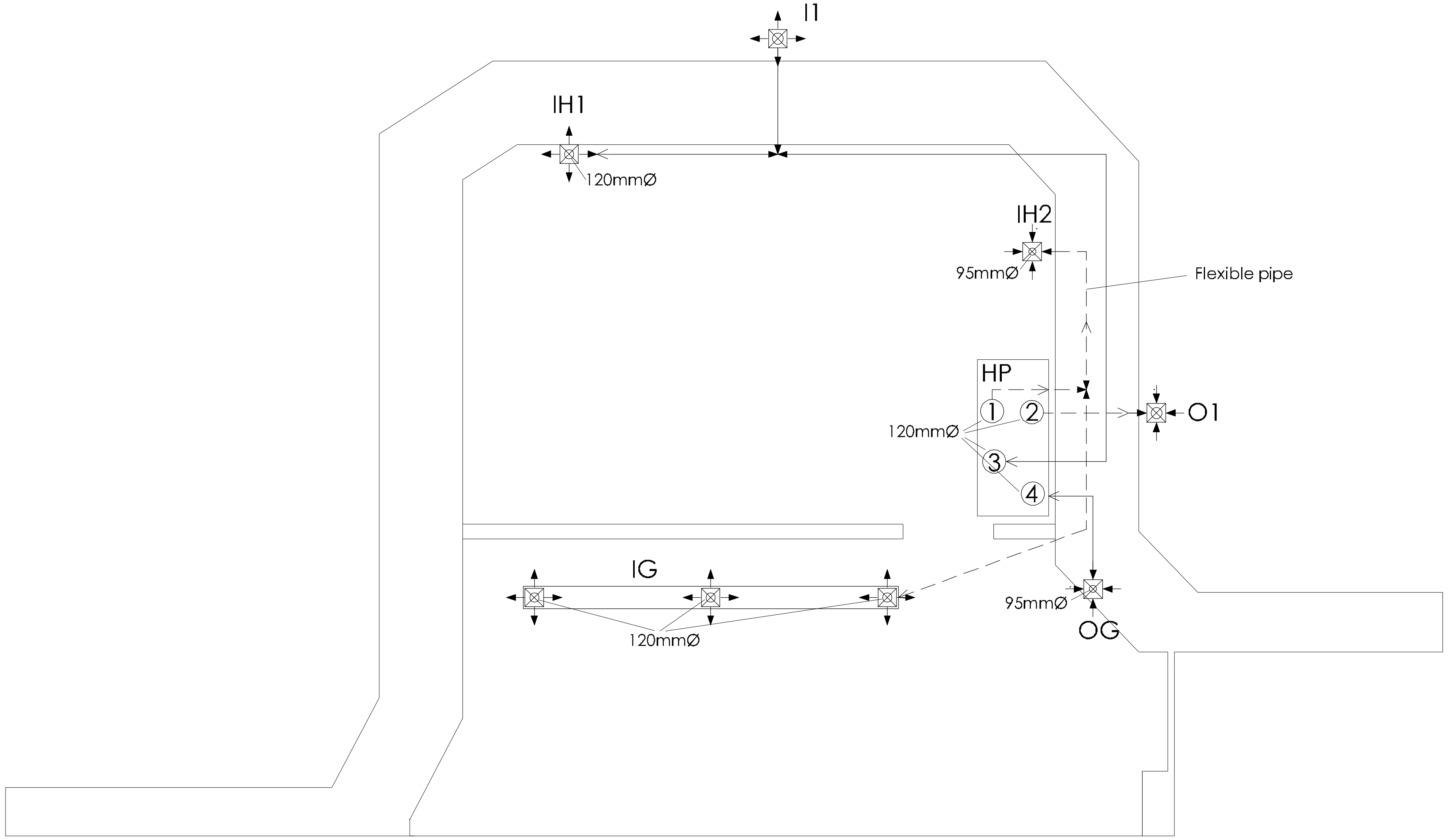


Heat panel plan_ 1/10

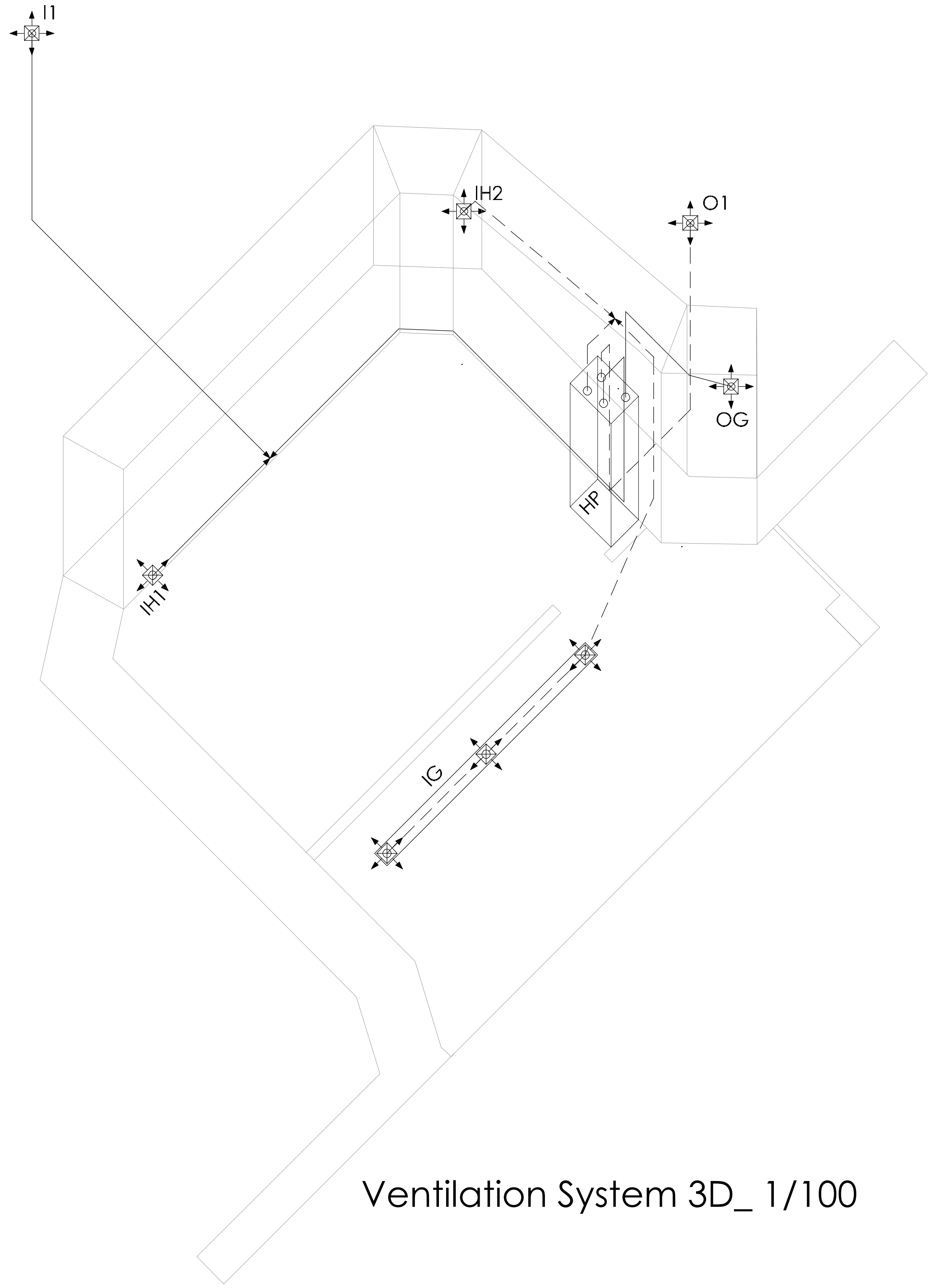
1. Wood joist
2. Pipe
3. Heat panel

PLAN_ 04.1 FLOOR HEATING
SCALE_ 1/50 1/10 1/2
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

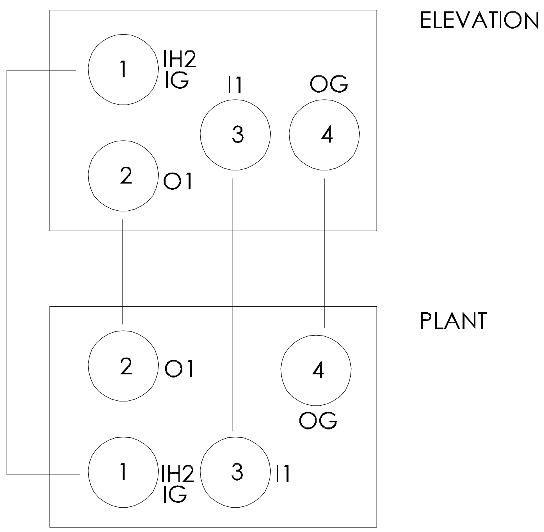
05.1_VENTILATION SYSTEM



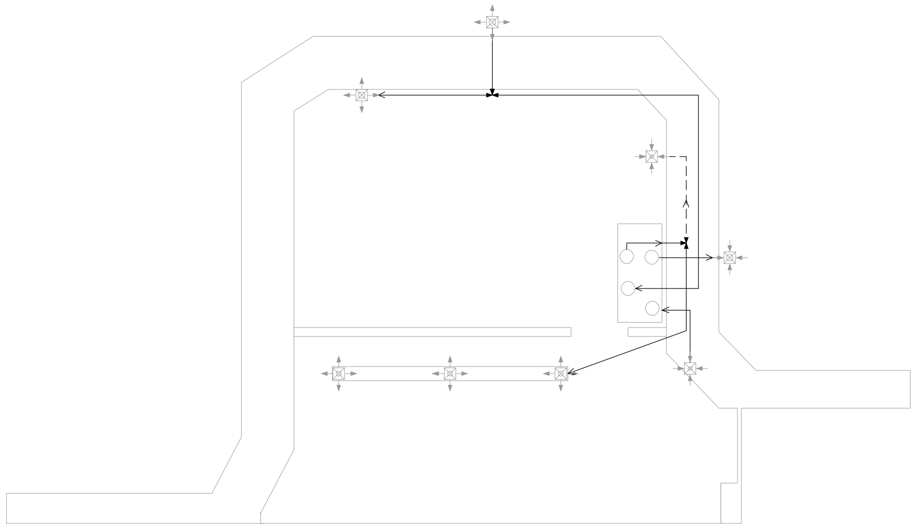
Ventilation System_ 1/75



Ventilation System 3D_ 1/100



Heat pump connections



Ventilation System materials scheme

Simbology

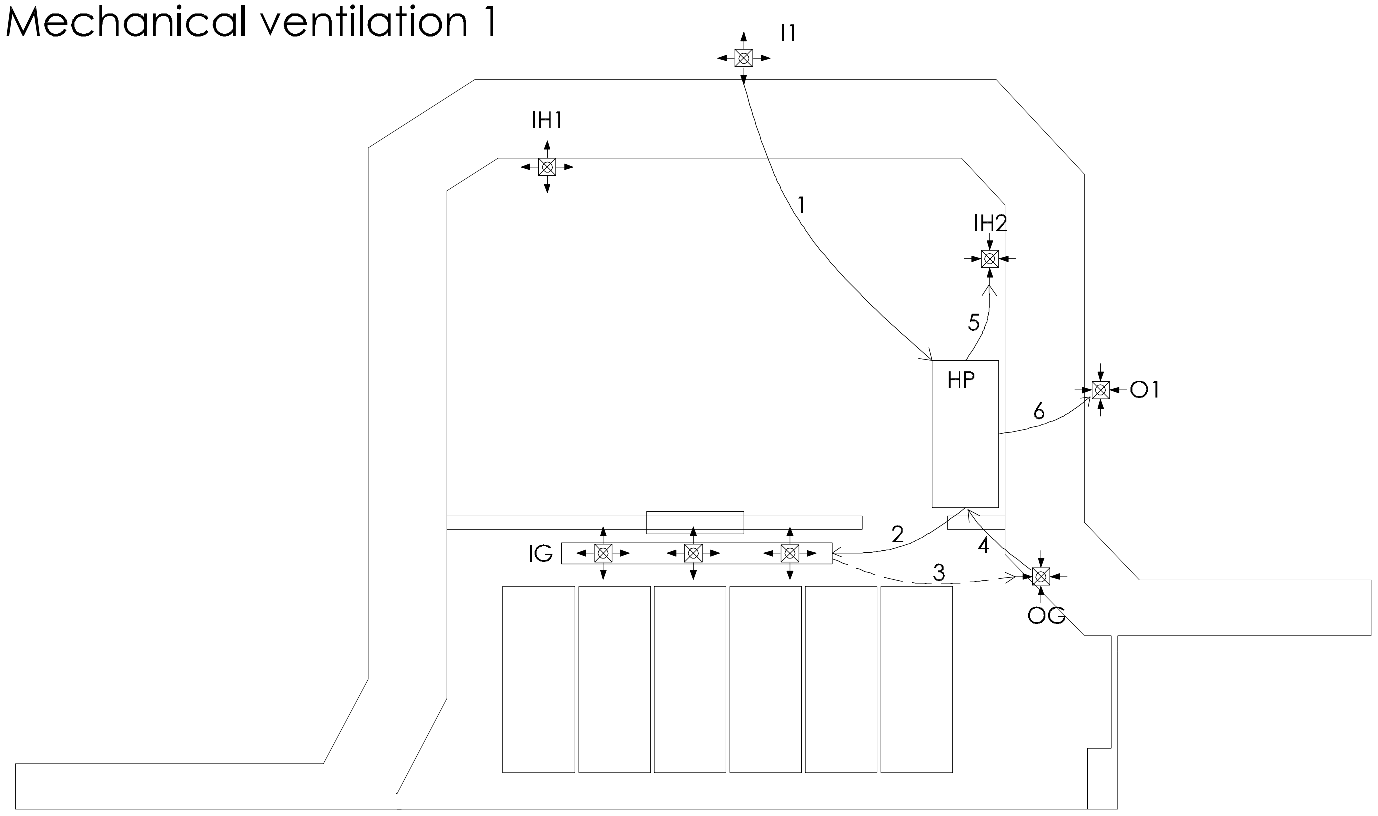
Inlet	Inlet HP
Outlet	Outlet HP

I1: Inlet tower
IH1: Inlet house (nat. vent.)
IH2: Inlet house (mech. vent.)
IG: Inlet greenhouse
O1: Outlet tower
OG: Outlet greenhouse
HP: Heat pump

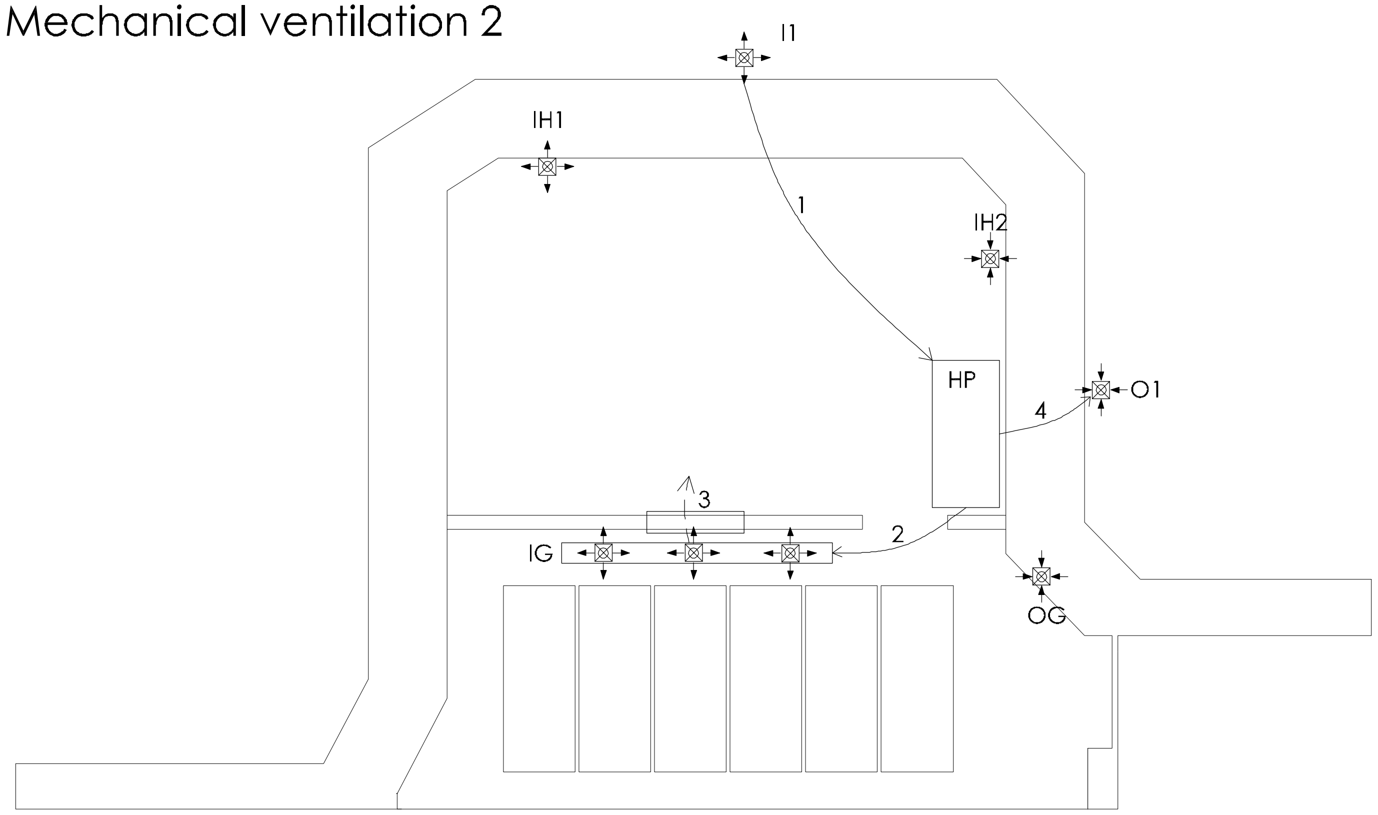
Materials:
Rigid pipes
Stainless steel
Flexible pipes
Vinyl tissue overlapped on a steel core

PLAN_ 05.1 VENTILATION SYSTEM
SCALE_ 1/75 1/100
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

Mechanical ventilation 1



Mechanical ventilation 2



Mechanical ventilation 1 description

1. I1 is used to bring fresh air into the heat pump.
2. Air moves from the heat pump through the pipes and goes to the greenhouse through IG.
3. Air circulates through the greenhouse from IG to OG.
4. Air moves from OG through the pipes and goes to the heat pump.
5. Air circulates from the heat pump through the pipes and goes to IH2.
6. Air moves from the heat pump through the pipes and goes outside the house through O1.

Mechanical ventilation 2 description

1. I1 is used to bring fresh air into the heat pump.
2. Air moves from the heat pump through the pipes and goes to the greenhouse through IG.
3. Air circulates through the greenhouse from IG to the heat pump using the grids.
4. Air moves from the heat pump through the pipes and goes outside the house through O1.

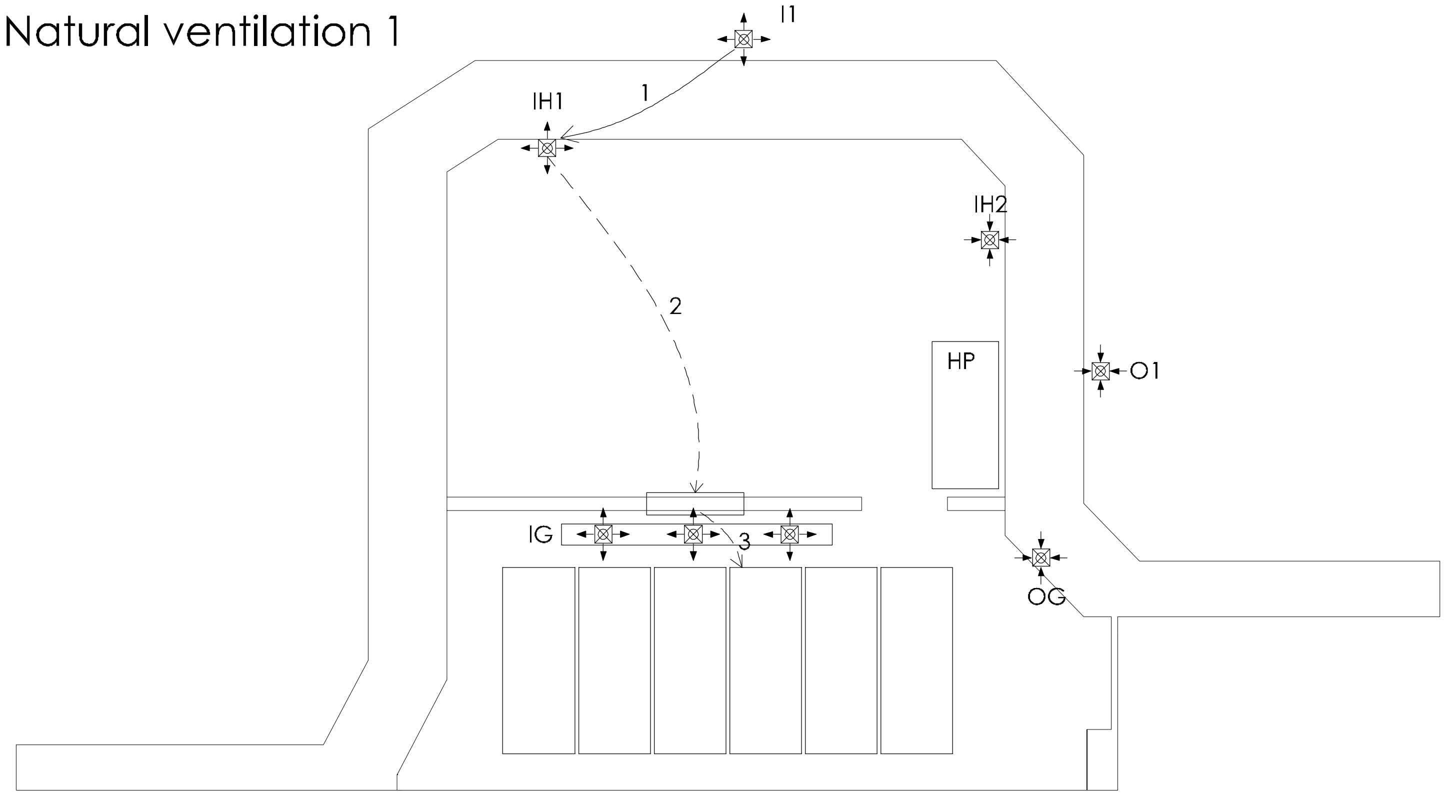
Simbology

Inlet	→ Pipe
Outlet	- → Air

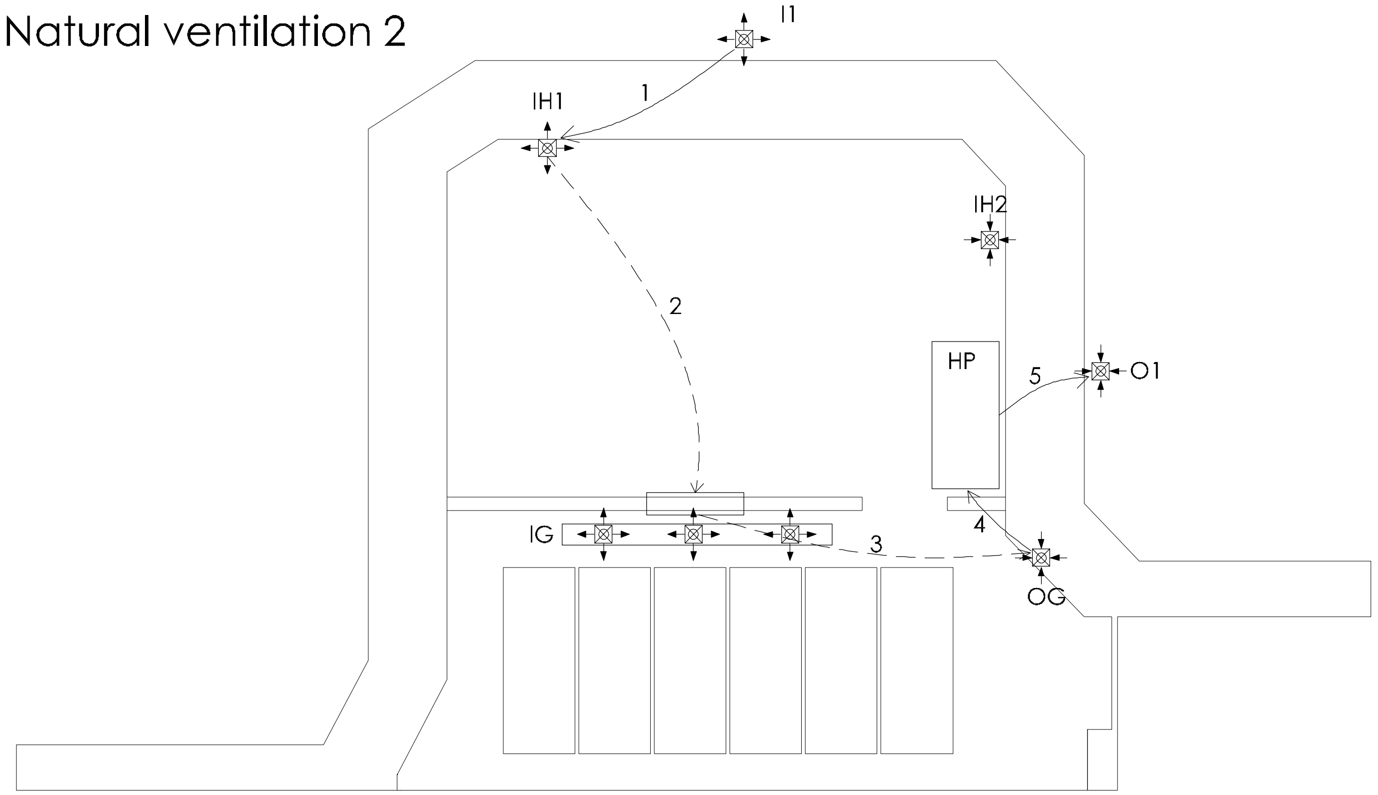
I1: Inlet tower
IH1: Inlet house (nat. vent.)
IH2: Inlet house (mech. vent.)
IG: Inlet greenhouse
O1: Outlet tower
OG: Outlet greenhouse
HP: Heat pump

PLAN_ 05.2 MECHANICAL VENTILATION
SCALE_ 1/100
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

Natural ventilation 1



Natural ventilation 2



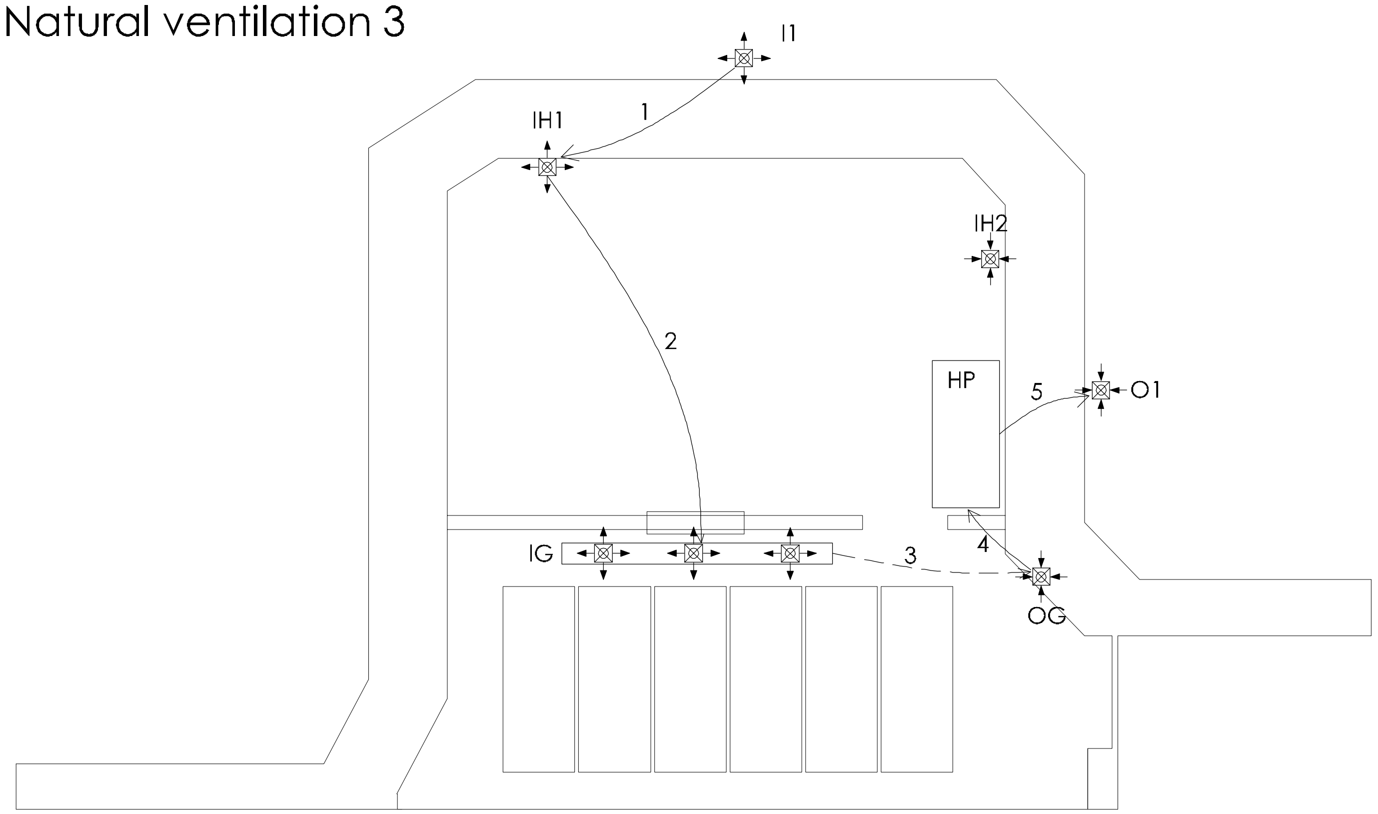
Natural ventilation 1 description

1. I1 is used to bring fresh air into the main room through IH1.
2. Air circulates through the main room from IH1 to the grids.
3. Air moves through the greenhouse from the grids to the skylights and goes outside the house.

Natural ventilation 2 description

1. I1 is used to bring fresh air into the main room through IH1.
2. Air circulates through the main room from IH1 to the grids.
3. Air moves through the greenhouse from the grids to OG.
4. Air moves from OG through the pipes and goes to the heat pump.
5. Air moves from the heat pump through the pipes and goes outside the house through O1.

Natural ventilation 3



Natural ventilation 3 description

1. I1 is used to bring fresh air into the main room through IH1.
2. Air circulates through the pipes from IH1 to IG.
3. Air moves through the greenhouse from IG to OG.
4. Air moves from OG through the pipes and goes to the heat pump.
5. Air moves from the heat pump through the pipes and goes outside the house through O1.

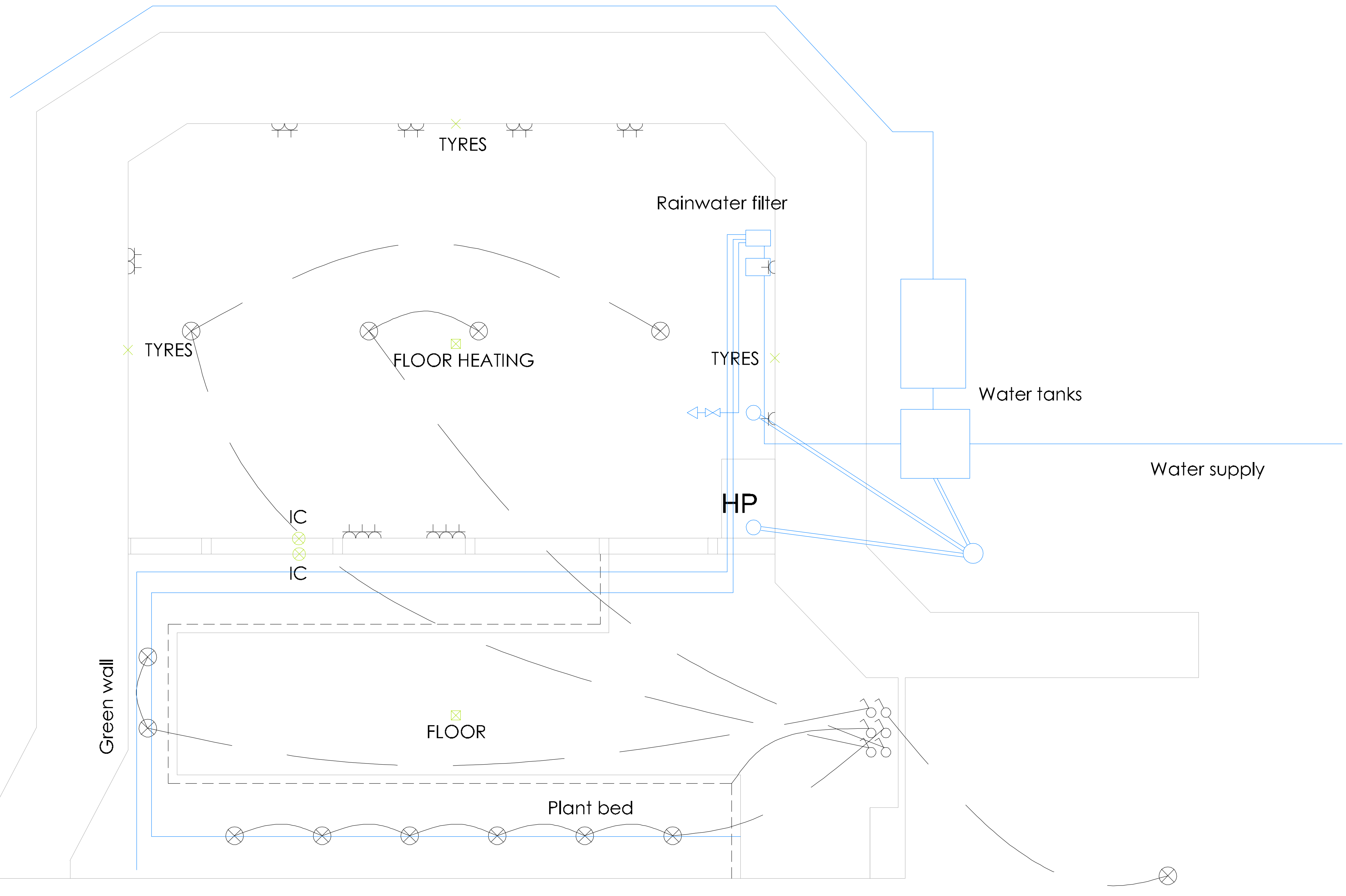
Simbology

Inlet	Pipe
Outlet	Air

I1: Inlet tower
IH1: Inlet house (nat. vent.)
IH2: Inlet house (mech. vent.)
IG: Inlet greenhouse
O1: Outlet tower
OG: Outlet greenhouse
HP: Heat pump

PLAN_ 05.3 NATURAL VENTILATION
SCALE_ 1/100
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01|07|2015

06.1_ELECTRICITY AND WATER SYSTEMS AND SENSORS



Electricity System

Switch	Socket
Light	LED light

Water System

Water Supply System
Waste System

Sensors

Temperature sensors
Temperature and humidity sensor

PLAN_ 06.1 ELECTRICITY, WATER AND SENSORS
SCALE_ 1/50
MEASURING UNITS_ mm
PROJECT_ Study of an Earthship Building in Denmark
AUTHOR_ Beatriz Muriel Holgado
DATE_ 01 | 07 | 2015