Sustainability in Construction

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ABSTRACT

The purpose of the thesis was to explore sustainability in construction. ”BS Project” is an architectural company that is working on a project of a multistory house, located in Sofia, Bulgaria. The investor wants the future building to be sustainable and to be certified as a passive house by PHI (Passive House Institute), Germany.

The aim was to explore the sustainable solutions that can be applied in a house in order to become an eco-efficient, passive house. The research provides information about climate and environmental conditions in the specific town and area. Based on the requirements for a passive house, the goal of the study was to reduce the energy consumption to minimum by using mainly natural resources.

Different methods used in green building are researched. Systems and methods for a wall structure decreasing the U-value of the wall component are also described. Using the systems and methods will make the building eco-efficient.

According to the results of this study it can be concluded that by applying all of the methods and systems and using the proper materials in the wall structure, the new multi-story building can reduce the energy consumption and meet the requirements of the passive house certificate.

Keywords sustainability, passive house, eco-efficiency, green building, greenhouse.

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1 INTRODUCTION

The climate change, air pollution and reduction of the quantity of Earth`s natural resources are one of the biggest worldwide problems nowadays. Every year scientists are working on projects for decreasing the carbon dioxide emissions. The sphere of building constructions is one of the main problems of controlling carbon dioxide emissions. Worldwide buildings, in developed countries, are consuming over half of the produced energy and the same are producing over half of climate-change gases. According to “United Kingdom Green building council” statistic -energy from fossil fuels, consumed in the construction and operation of buildings accounts for approximately half of the UK’s emissions of carbon dioxide. (Williamson, Radford & Bennetts .2003,10-14)

Respectively sustainable architecture is a movement which is concentrated on making eco-efficient and human well-being buildings. Different methods can be applied for making the building eco-friendly, passive house. The choice of building materials, and transport, could play a main role in reducing the bad side effect on the nature. Passive houses are a good alternative against the huge use of gas, petrol, electricity and materials that cause production of emissions.

BS Project is an architectural company focused on the sustainability. During the last couple of years they have made buildings which are certificated as passive houses. Green buildings are rare in Bulgaria, because of many reasons and traditions in construction. BS project is trying to popularise sustainable architecture and add a new method that could be applied to local building constructions.

The newest house project will the biggest build-up area as passive house till now, as a non-residence building, made by BS Project. According to climate and area specifications methods and materials will be chosen, that will provide a good foundation for the future eco-house. A conceptual architecture design was made, of a multi-storey house. The research is concentrated on choosing the best option of consistence of the wall structure. Materials and methods criteria will be connected to the requirements for an eco-efficient passive house “Passive house institute”, Germany.

1. SUSTAINABLE ARCHITECTURE

The modern type of building is literally destroying the planet. The population of the planet is rapidly increasing which requires more residential buildings. Buildings are the single most demanding polluters on the planet, consuming over half of the all energy used in developed countries and producing over half of all climate change gases.
The idea of the green buildings began in the 1970s and was a practical response to the high prices of oil. That made people start thinking about the oil resources and made claims about how much oil and gas was left. There were very critical assumptions that in the next 30 years the planet will be out of oil and gasses. Even though most of those assumptions did not become true, there are many of them that still have not be proved wrong.
Sustainable architecture is simply assumed by ethical, cultural and conceptual issues. This kind of architectural thinking is based on the connection between the building and the surrounding environment, not only in the way of cultural and style design but making a union with the nature. The building is not looking only from the prism of “the building is a machine for living”-proposed by the French Architect Le Corbusier, but a system of different components that have to be in unison with the habitants and the environment surrounded. The building is not just a fixed construction, furniture, HVAC systems and daylight. There are more things like natural ventilation, cooling ecological use of light and water resource that turn a building into home. (Williamson, Radford and Bennetts .2003,33-44) The green house is made over three main principles of design:

-Design for the climate
-Design for the environment
-Design for design for time, be it day or night, a season or the lifetime of a building and design a building that will adapt over time.

Passive house buildings require good research about the conditions, which the eco-house will be exposed to in future. According to sustainable design it is important that the outside environment can be used to produce benefits and positive internal environment. The internal environment has considerations as: thermal environment, noise, sound, light and energy resources.
One of the main factors is the climate in the particular location. Weather conditions play the main role in choosing materials and design of the whole system of the eco-efficient green building. Materials that are used in buildings cause effects on the environment. All the building materials are proceeding in some way, before they can be incorporate into a building. When building a simple construction e.g. a wooden cottage the materials could be found locally. This minimize the impact

caused by transportation and fabrication. This processing material inevitably requires the use of energy and results in waste generation.

It is estimated that in Bulgaria, almost one-fourth of the CO^2 emissions and energy consumption are because of the producing and transportation building materials. Can be calculated the total environmental impact if it is considered to observe the whole process from choosing materials through transportation, building, and use of energy day-by-day, during the exploitations of the building in a long term period. The way of thinking when building a sustainable house is about the future consequences. In a long term period of time, how this building affect the environment, how eco-efficient will be and how long the life of building will be. It has been measured that the tendency in building normal houses is that as older they get as more supplies they use.

Nowadays there are organizations supporting green buildings and promote the way of “green” architectural thinking.(Roaf, Fuentes, Thomas 2001,13-50)

2.1 LEED

LEED organization is a worldwide rating system for eco-efficient buildings. (Shown in Figure 1 below.)

Figure 1.LEED organization.

LEED or (Leadership in Energy & Environmental Design) has been developed by ”The United States Building Council in 1994year.LEED is a rating system for design, process of building, operation, construction, maintenance of green buildings and neighborhoods. The goal of the rating system is to decrease the environmental impact caused by buildings and provide to habitants eco-friendly, healthy place of working or living. The system has been improved in 2009. The LEED 2009 performance credit system aims to allocate points "based on the potential environmental impacts and human benefits of each credit." These are weighed using the environmental impact categories of the United States Environmental Protection Agency`s Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts.

LEED certification is based on the following criteria:

-Sustainable sites
-Water Efficiency
-Energy and Atmosphere
-Materials and Resources
-Indoor Environmental Quality
-Innovation and Design

LEED certification is granted by the Green Building Certified Institute (GBCI), which handles the third-party verification of a project's compliance with the LEED requirements.

The certification process for design teams is made up of two consecutive applications: one including design credits, and one including construction credits. All of the LEED credits in each rating system are assigned to either the design application or the construction application. The design credits include those that are the purview of the architect and the engineer, and are documented in the official construction drawings. The construction credits include those that are predominantly under the purview of the contractor, and are documented during the construction and commissioning of the building. LEED certificate has different systems. Each rating system groups requirements that address the unique needs of building and project types on their path towards LEED certification. Once a project team chooses a rating system, they'll use the appropriate credits to guide design and operational decisions.There are five rating systems that address multiple project types:

- Building Design and Constructions
- Interior Design and Construction
- Building Operations and Maintenance
- Neighborhood Development
- Homes

The Building are rated and certified by the scale:

- Certified 40-49 points
- Silver 50-59 points
- Gold 60-79 points
- Platinum 80 points and above

Taipei101 is the name of skyscraper situated in Taipei city, Taiwan, officially Republic of China. It is known as World Financial Center. It is the third tallest building in Asia and the tallest and largest green building of LEED Platinum certification in the world since 2011. (Figure 2).

Figure 2.Taipei, China Greg - Original photograph, 2007.

With a LEED certified building, the investor and customers are saving money, conserving energy, reducing water consumption, improving in-door air quality, making better building material choices, and driving innovation. In lifetime the investments is refunding, the operation of the building cost less. The energy and water bills will be reduced by 40%.

2.2 BREEAM

BREEAM is world`s leading assessment method for sustainable buildings. (Figure 3).

Figure 3.

BREEAM or (Building Research Establishment Environmental Assessment Methodology) has been established in 1990.It is the leading worldwide organization for environmental assessment method and rating system. More than a million buildings are registered for assessment and one-fourth million are certified and take part in BREEAM green architecture. The organization makes standards for the best sustainable building design, construction and operation. The goal for BEEAM is to comprehend all spheres of the building. The organization is concentrated on the choice of materials, transport, and construction, comfort of the interior design, eco-friendly architectural design, long term eco-efficiency and low cost consumption of the building in future. Using independent, licensed assessors, BREEAM assesses scientifically-based criteria covering a range of issues in categories that evaluate energy and water use, health and wellbeing, pollution, transport, materials, waste, ecology and management processes. Buildings are rated and certified on a scale of:

- Pass
- Good

- Very Good
- Excellent and Outstanding

By setting sustainability benchmarks and targets that continue to stay ahead of regulatory requirements and by encouraging the use of innovative means of achieving these targets, BREEAM drives greater sustainability and innovation in the built environment.

2.3 PHI

Passive house institute is the German rating system for sustainable buildings. Figure 4.

Figure 4.

An example of house certified by PHI. Figure 5

Figure 5.Frankfurt. Passive house

Passive houses are buildings in which the high level of comfort is reached with the minimum energy expenditure. There are two main lines that one passive house project is focused on i.e. first the effect of the building on environment and second the effect and comfort on human being and habitants. The Passive House Institute was established in 1990 with the pilot project of “Kranichstein Passive house” Darmstadt, Germany. That is the world`s first house with the concept of a passive. It is multi-story house with energy consumption below 12 kW.(Figure 6).

Figure 6. Kranichstein Passive House, Darmstadt, Germany

PHI is working on residential and non-residential buildings. They have built e.g. factories, schools, flats and trade centers. Passive House Institute has assumed a leading position with regard to research on and development of construction concepts, building components, planning tools and quality assurance for especially energy efficient buildings. The design and construction must follow stringent requirements in order to be estimated as a passive house.
The German Certification of passive houses is used in many countries in Europe. Green houses in Bulgaria are also certified by the German "Passive House Institute". There are criteria for residential and non-residential buildings.
"BS Project" conceptual building is a residential house. The certification criteria, described in "Passive House Institute "official requirements are:

Heating:

Specific space heating demand 15 kWh/ (m2a)
or alternatively:
heating load $\leq$ 10 W/m²

Cooling:

Total cooling demand $\leq$ 15 kWh/(m²a) + 0.3 W/(m²aK) .DDH
or alternatively:
cooling load $\leq$ 10 W/m²
And cooling demand $\leq$ 4 kWh/(m²aK)

Primary energy:

Specific primary energy demand for heating, cooling,hot, auxiliary, electricity , domestic and common area electricity

$\leq$ 120 kWh/(m²a)

This kind of certification is measuring the already made projects. It is not following all the methods that are applied, but the result and effect.

In order to begin a project for a passive house it is mandatory to make researches about climate and conditions.

In this particular project, the building that will be observed is located in Bulgaria, Sofia.

2. CLIMATE AND ENVIRONMENTAL CONDITIONS

Bulgaria is situated in the south-east part of Europe, in the Balkan Peninsula. There are two contrast climate zones in this territory-Continental and Mediterranean climate zone. The mountainous is making a barrier between the air masses. The Mediterranean climate produce hot and dry weather in the second half of the summer, the continental climate influence is in winter, producing abundant snowfalls and cold winds. The average year temperature for Bulgaria is 10, 5°; during the winter it is 0° degrees Celsius. The summers are hot and dry, the average temperature is 23°C and it can reach 35/40°C. Sofia is located in the foot of western part of the country and in the foot of mountain Vitosha. Sofia has the same climate as the rest of Bulgaria with humid continental climate and small influence of the Mediterranean climate. Summers are long, warm and sunny. In summer storms e.g. thunderstorms may also occur. The average temperature is 21°C,however during the hottest days in July and August can reach 35°C.Winter has cold nights with average temperatures of -6°/-8°C and during the days -2°/0°.the coldest days notable are in January, when they drop to -20°C.The total snowfall is nearly 90cm for 60 days in snow cover. Spring and autumn are short with dynamic, variable weather, as shown in Figure 7.

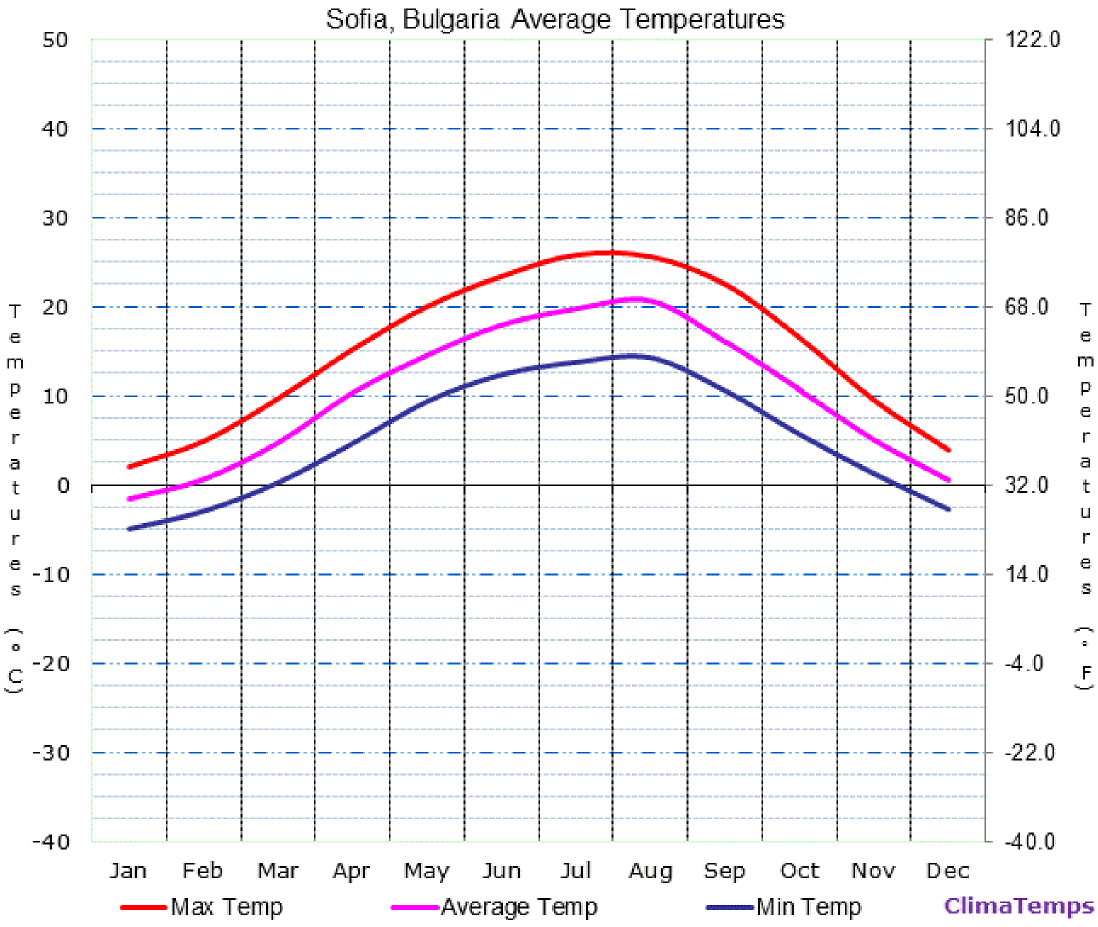


Figure 7, Sofia average temperatures
(http://www.sofia.climatemps.com/)

The relative humidity in Sofia typically ranges from 35 %(assumed as comfortable) to 97 %(very humid).Rarely dropping to 20% and reaching 100%.The air is driest in the middle of summer-July three days out of four; the most humid days are at the beginning of January when it risen to 100% humidity as shown in Figure 8.

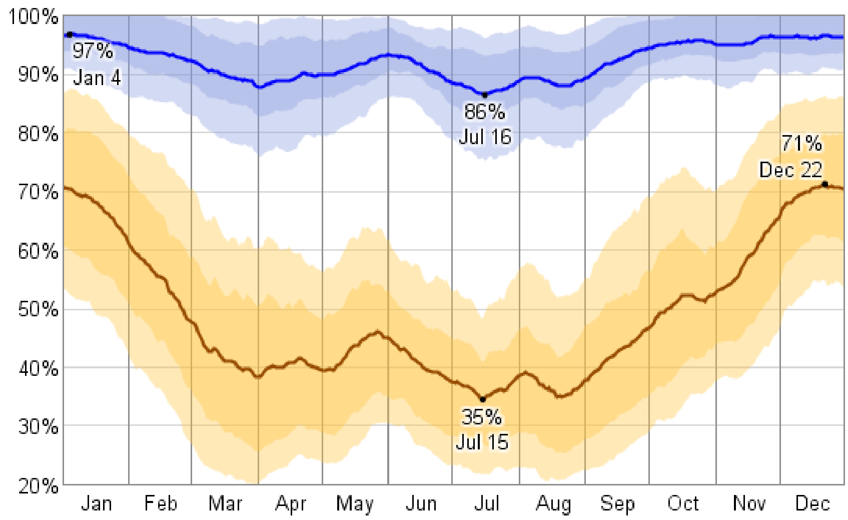


Figure 8.Relative humidity in Sofia

([http://www.sofia.climatemps.com/)](http://www.sofia.climatemps.com/)

Precipitations are more likely around middle of May, occurring in 60% of days and beginning of September occurring in 37% of days. In the region of Sofia-city there is moderate rain, thunderstorms, light rain and moderate snow. The average rainfall per year is approximately 600mm. and they increased to 1000mm. on the slope of the mountain Vitosha. Because of the continental climate, winter is drier than summer and it has rainfall nearly 120mm and for the higher parts of Vitosha- 200mm.(Figure 9 and 10).

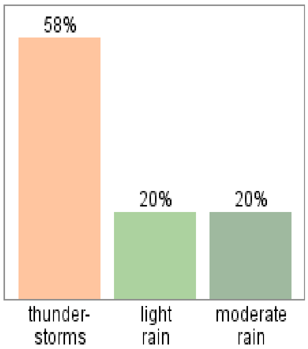


Figure 9 Warm season precipitation

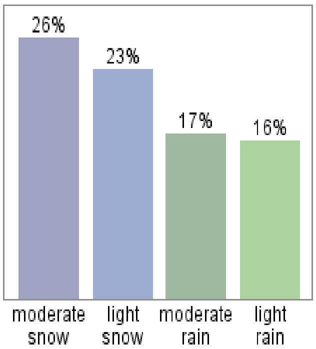


Figure 10 Cold season precipitation

Typical formation of Sofia and the area surrounding is the discontinuous snow cover in winter .The average snow cover is about 60 days. This period usually starts at the end of November and it lasts till the middle of March. The average thickness of the snow cover is about 20cm in late January and at the beginning of February. In some years it reaches 50-60cm.The building will be situated in the food of Vitosha, there, depending on altitude and exposure of the slopes, the number of days with snow cover is approximately 200, mainly from December to

March. When the average thickness there is 150-180cm and some years 250-300cm.

The characteristic value for snow load according to “National annex for EN 1991-1-3” is:

S_k= 1, 28 kN/m^2 for Sofia city and area. Snow depth shown in Figure 11.

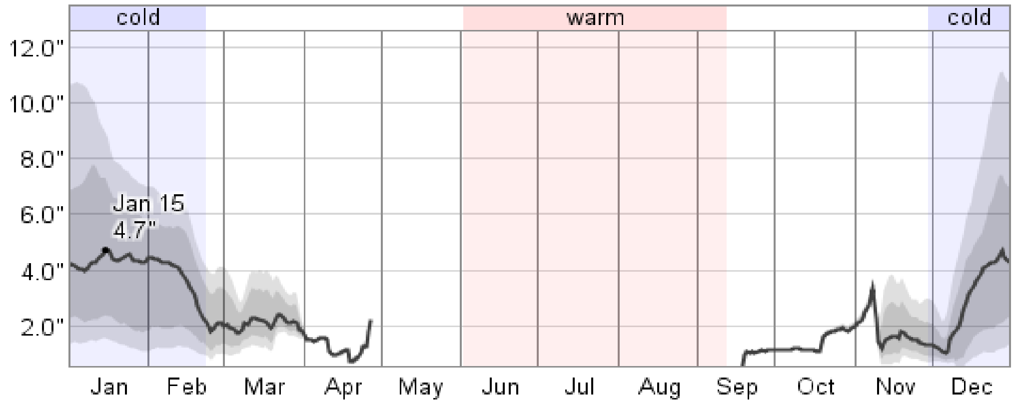


Figure 11.The median depth of snow with percentile bands.
(http://www.sofia.climatemps.com/)

The average wind speed during the year is from 0 km/h to 20 km/h. The highest wind speed is nearly 20km/h which usually appears on middle of April. The lowest average is nearly 7 km/h, at the end of October.
According to National annex for EN-1991-1-3, the wind load coefficient for Sofia and surrounding area is:

$V_{b,0}$=26, 1 m/s

The base load is:

$Q_{b,0}$=0, 43 kN/m^2

Another factor that is very important when considering the methods and material of designing passive houses is the sunshine during every single season. The duration of the sunshine in Sofia is about 2020 hours per year. The actual duration of sunshine depends on cloud cover and kettle topography. It is the lowest in December-about 50 hours and highest in July and August when the sunshine is more than 300 hours. Because of the cloud cover and the intensive air pollution over the city, a trend can be seen to reduce the duration of sunshine, which is expressed in the summer season. In the region of Vitosha Mountain, the duration is decreased to about 1860 hours per year on average due to higher clouds in the mountain.

The assessment of radiation balance for the territory of Bulgaria shows that for the summer period (31.03-31.10) the optimal angle of slope of host surface is about 30^0 and the solar radiation on $1m^2$ is between 900 kWh/m and 1200 kWh/m. About winter season (31.10-31.03) the optimal angle of slope of the host surface is about 55^0 and the solar radiation is between 300 and 390 per $1m^2$.The annual solar energy at an angle of slope 30^0 is from 1200 kWh/m to 1500 kWh/m. Daily sunrise and sunsets are shown in Figure 12.

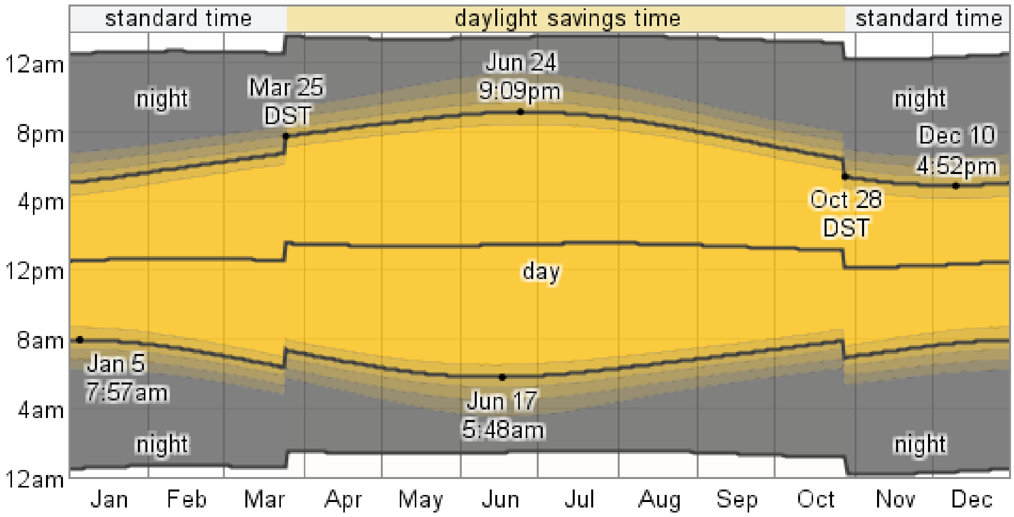


Figure 12.Sunrise and sunsets in Sofia.

Sofia has 24 administration areas. The land that will be used for your future building is located in the “Vitosha” region. Every region has different specifications about climate, underground water etc., because of the diversified relief. The mountain Vitosha is in the south part of Sofia. It makes the natural end of the town. The height is 2 990m and plays a role of barrier to the south warm masses. Figure 13 shows a satellite view of Sofia and the particular land where the construction will be.

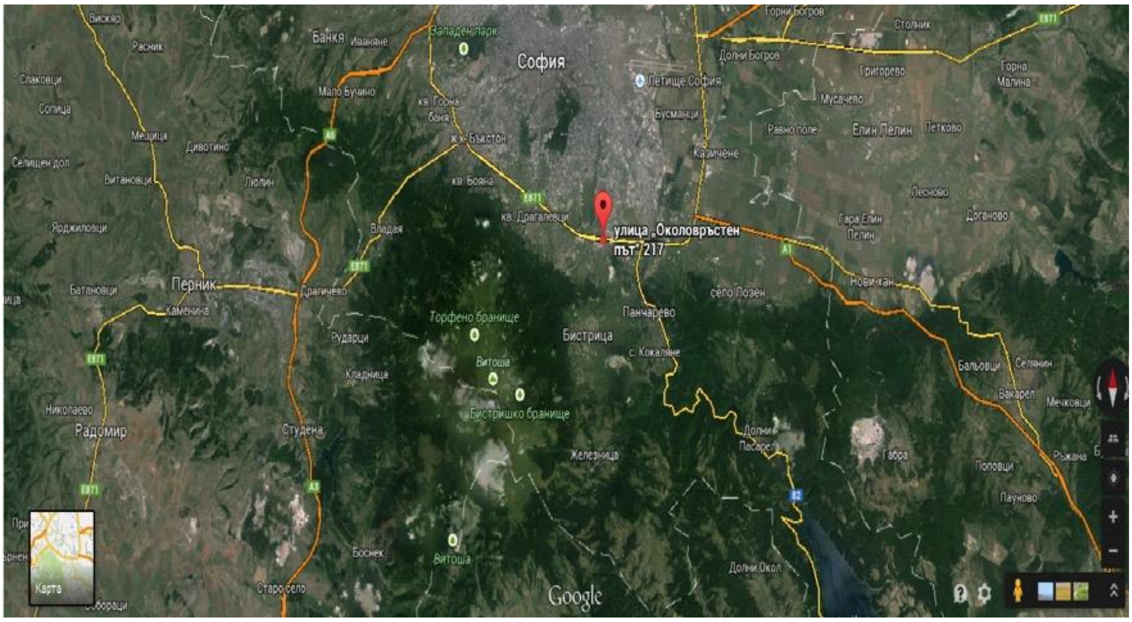


Figure 13.Sofia satellite view. Red point is the land location.

The average annual temperature in the area is $7/8^0$.January is the coldest period and the warmest is July. The number of foggy days per year is 30/35.The winter rainfall is 150-160 mm and in the highest parts -180.

The climate characteristics are the same as those of the other area; an exception makes the water melting during spring. From highest parts to the foot every year in spring time the melting snow is going downhill. According to The National Report of geology, under the influence of a variety of natural factures in the plain and hilly mountainous part of Sofia valley has formed 13 soil types. The field is mainly with cinnamon forest soils formed by different soil materials, such as sandstone, andesine, limestone, etc... Under the exclusive influence of deciduous vegetation. These soils are distributed to 700-800m.

The territory of Bulgaria is endangered by a big seismic activity. The country is divided to three seismic zones. The valley of Sofia is part of one of them; called “Srednogorie”. The maximum expected magnitude (M) earthquake in Sofia area is 7.0 on the Richter scale.

Because of the risky earthquake zone, the constructions in Bulgaria are usually monolith. Buildings are high, multistory houses, flats and public buildings. The main structure is reinforced, as a place to build formwork, columns, plates and others. The outer and inner walls are made usually with bricks. Framework systems are often to build the backbone, the walls are made separately in independent process. Reinforced concrete structure in a combination with masonry is becoming heavy, that is why a solid foundation is needed for the building.

Advantages of monolithic construction:

- Solid construction with high fire resistant
- Preferred in high buildings and a large area
- Average sound insulation

- Low maintenance

Disadvantages of monolithic construction:
- Wet processes
- Longer period of construction
- Foundations and high volume excavation
- Inability to reorganize and subsequent changes in the design

(Erdey, 2007,23-25)

There are strict requirements in the “Law on Spatial Planning”. In the ordinance of earthquake is said that:

Determination of seismic forces

Art. 10 (1) the construction of buildings and facilities must be calculated and the effect of seismic forces. In their calculation made with planar (two-dimensional - 2D) or spatial (three-dimensional -3D) dynamic models are used. Using evaluation methods by response spectra seismic forces applied at the points of those concentrated masses accepted as equivalent static loads within the accepted trends.
(1a). Seismic impact depends mainly on the strength (magnitude M) and depth (h) of the earthquake, and distance from the epicenter to the appraised structure. Parameters characterizing the seismic effects are intensity (measured on a scale of Bulgaria Sponheuer-Medvedev-Karnik-MSK), maximum and / or spectral acceleration, and velocity and displacement dr. The calculation of seismic impact is characterized by efficiency and a power factor of seism city and spectrum of computing response.
(2) Seismic effect is represented in an idealized spatial estimation model, which consists of three mutually orthogonal components of acceleration of the substrate. The first two are horizontal, and the third is vertical. Each component is defined as the acceleration as a function over time and are evenly distributed the basis for calculating construction. The three components of the accelerations are represented by computing response spectra, respectively.
(3) The calculation geometry of the structure is introduced in the global coordinate system in which the axes are orthogonal. X and Y axes lie in a horizontal plane, and the Z axis is vertical and coincides with the local axis 3 of the vertical component of the seismic action. The angle formed in the horizontal plane at the base structure between the axes X and 1 (Y and 2) has an angle of seismic influence.
(4) Irregular in plan and elevation construction is used spatial model of the seismic impact of three components and spatial computing model for their construction. The model must take into account the effects of torsion forces movements of the structure.
(5) Regular in plan, and irregular in plan, but regular height buildings, it can be assumed that the seismic effects are applied separately in the longitudinal and transverse axes. When this structure is modeled with

two independent computing models for each direction, the effects of torsion are reported under Article 25.

(6) Vertical seismic effects into account in the calculation of:

1. Horizontal and inclined cantilever structures;
2. Very high structure of bridges;
3. Frames, arches, trusses, floor or roof structures of buildings and structures with a hole of 20 m and more;
4. Reverse construction and slip, and in the presence of seismic isolation in their foundations;
5. Brick and stone structures.
6. Constructions containing any of the following structural elements: concrete flat slabs (with or without capitals), floor structure, concrete elements, balconies, bay windows, columns and planted areas with significant concentrated masses.

Art. 11 (1) Seismic forces belong to specific loads. Combinations of loads, including seismic forces relate to emergency routines. The ratio of combined efforts of seismic impacts is taken 1.0. Efforts of the other load factor combination are determined in accordance with Ordinance № 3 of 2004 on the basics of designing the structure of buildings and the impacts on them.

In Figure 14 is shown a building after an earthquake in Sofia in 1917 was VII-VIII on the Medvedev–Sponheuer–Karnik scale and 7.2 on the scale of Richter.

(Law on Spatial Planning, Ordinance № 2 of 2007 for the design of buildings and structures in seismic areas (SG. 68 of 2007)

Figure14.Consequences from the earthquake.

ARCHITECTURAL PROJECT AND DRAWINGS

The “BS project” future building is a multistory house. It is intended to be used by three families. The building has with four floors. Each family is on a separate floor, except the third floor where the apartments have a penthouse and it is connected with the upper top floor by inner stairs. The architecture is extravagant, with oval shapes and green terraces on each floor. From the top side view it looks like “Clover”. The cornice level is 15 meters. The height of a living floor is usually 3 meters tall. There are three swimming pools on the top level of the building.The roof is flat and landscaped.

3D Architectural project is shown in Figure 15.

3D Architectural project shown on Figure 15.

The whole build up area will be 5000 m^2. One “Leaf” is 386.9m^2.The three leaves are separated apartments for one family. The “Leaves” are connected with room which is common one. Where will be situated the elevator for upper floors and inside stairs. It is planned to be natural lighted, because of the glass roof, in the form of a pyramid. With a lot of the greenery on each terrace and facade, it is provided a natural insulation for wind, snow and moisture going through the wall structure during the risk seasons. Also during the summer, when the sun is very hot, the climbing plant-vines are making natural shading of the apartments. The eco-friendly appearance provides the comfort and merging with the nature. The floor plan of the first floor is wide, with a big living room and four bedrooms in each apartment. The big rooms provide the natural ventilation during the hot summer time. Because of the building shape, sun can be used as a natural lighting in every room of the apartment. The windows which are mostly “French windows” (from the floor to the ceiling) can distribute light for nearly 12hours during summer and 8 hours during the winter. The first floor plan is shown in Figure 16.

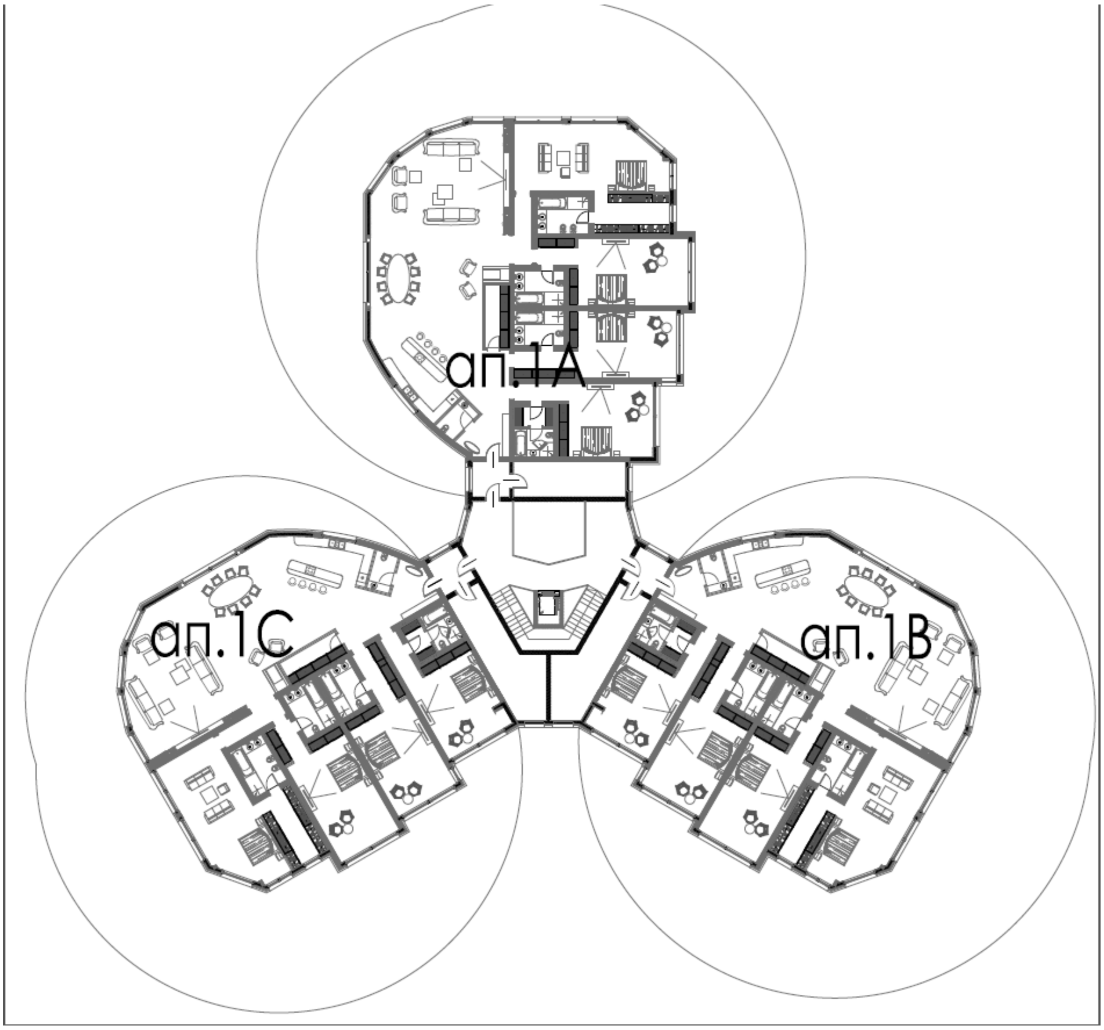


Figure 16.First floor plan.

The construction of the walls and columns will be to be earthquake resistant. According to the conceptual architecture plan, there will be shear walls and load-bearing columns. The load bearing resistance and other forces will not be observed and calculated in this technical research. They will be part of the technical architecture and engineering project which will be realized in future. One “leaf” detail plan is shown in Figure 17.

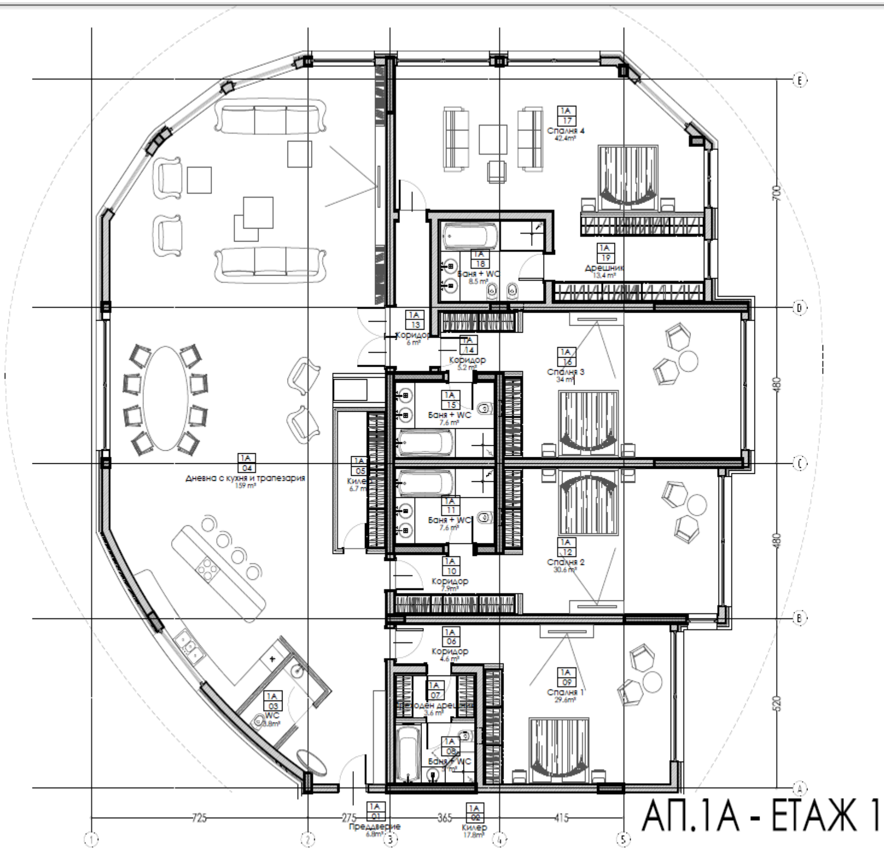


Figure 17.Detail plan of one “leaf” of the first floor.

5. METHODS AND SYSTEMS USED IN PASSIVE HOUSES

On the basis of the own and national researches different designs, practical methods and materials for optimizing the use of energy and take advantage of natural resources can be applied. One of the basic things used to build an eco-efficient and green building are the solar panels. The sun light is a natural resource of energy that could be transferred to another time of energy which will be used in our establishment. There are two opportunities that could be used.

5.1 Solar Panels

Solar panels are devices that convert light into electricity. They are referred to as "solar panels" because the majority of the time, as a powerful source of light is the sun. Some scientists call them photovoltaic, which means "light electricity." In Figure 18 solar photovoltaic panels on the roof on a building are shown.

Figure 18.Photovoltaic panels.

Solar panel is a collection of solar cells. Many small solar cells spreading over a large area can work together to provide enough power. The more light that falls on the cell, the more electricity is produced. It was conducted about the most suitable and effective solar panels on the Bulgarian market. One of the best offers based on quality, price and cheap transport were panels with: 3W, 5W, 10W, 20W, 40W, 100W, 130W, 175W, 260W .The shape and the place they could be attached to be a matter of architectural design. Usually they are on the top of the roof in order to collect the most sunlight and heat.
One of the best offers in the market is a photovoltaic panels which are 2500W, which is 2, 5 kWh/per day. These are shown in Figure 19.

Figure 19.Photovoltaic panels 2 500W.

So per 30 days the energy that could be produced is:
30 x 2.5=75 kWh/per month

According to EVN Bulgaria research the average energy consumption per family per one month, living in Sofia is = 229kWh/month
If we install the panels they will reduce the energy consumption to 157kWh/month

The cost of one pack of the panels is 2395.11 euros. In a period of 10 years the panels will produce:

$$10_{years} \times 12_{moths} \times 75\ kWh = 9\ 000 kWh$$

The average consumption of a family house will be:

$$10_{years} \times 12_{moths} \times 229\ kWh = 27\ 480\ kWh$$

If the solar panels are bought it is calculated that they could return the investment in a period 10 years. The average price that Bulgarian people buy electrical energy is nearly:
0.8 € per kWh therefore,

27 480kWh x 0.8=21 984 €/per 10years

In case of buying the panels:
For 10 years will be produced 9 000kWh, which costs:

9 000kWh x 0.8=7 200 €

So we have a benefit of 7 200€-2395.11€=4 804, 89 €

Therefore the investment is good for the eco-efficiency of the future green building and it will also pay back the investment approximately 5 years. One more advantage is that the photovoltaic panels have a guarantee of 10 years.

5.2 Water heating system

Another alternative for heating is using the underground water. In the region of Sofia there is a lot of underground water. Furthermore a lot of rain water and water from melting ice is falling through the slope of the mountain Vitosha. In 2012 was built a public building in the neighboring plot for “IKEA” Inc. During the surveying, engineers have found the presence of underground water at a depth of 56 meters.

Water drilling could be made, which will give hot water during the winter. The water source heat pumps work most efficiently compared with land and air. The temperature of the surface soil layer at a depth of 2m is relatively constant year-round. Usually the wells are at a depth which provides a drilling water a constant temperature irrespective of the outside temperature. This enables the pump to operate without fluctuations in the power and the conversion factor. Also, it can be connected to the floor heating system made by pipes which will warm up in winter and can also cool down during summer months. Water floor heating system is shown in Figure 20.

Figure 20.Water floor heating system

Collectors for the rain water can be made. They can be used for gardening by using sprinklers. This will reduce the consumption of drinking water and also the bills for it.

5.3 RECUPERATOR

One of the most important methods for making the passive house envelope is the Recuperator system. The Recuperator is a heat exchanger which performs the regeneration of heat or cold air in the ventilations system. Though it can significantly reduce the cost of electricity, the investment price is easily returned because of the reduced use of energy cost and harmless environmental impact. This ventilation system provides the residents clean and healthy environment by the air came from outside through cleaning filters. It also sucks out the dirty air, smells and dust in the air. The ventilation that recuperator makes in a building is shown in Figure 21.

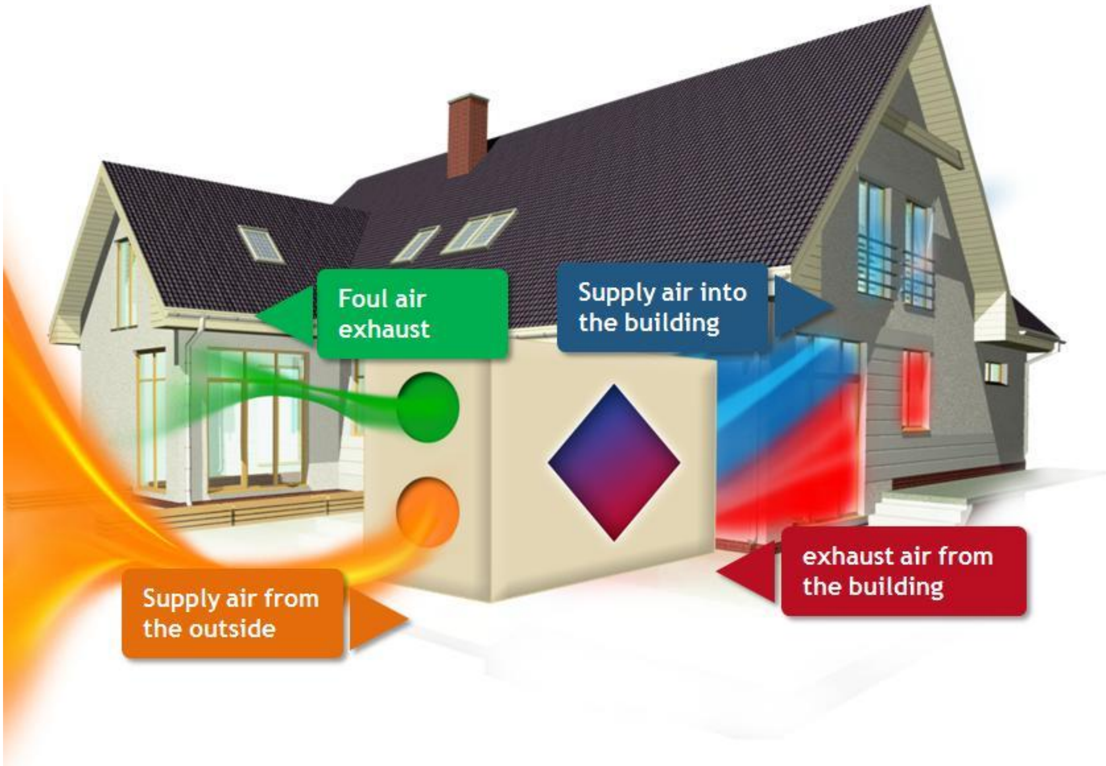


Figure 21.Recuperator system

There are two of types of Recuperator: air-to-air (plastic) or air-to-water (rotary).Recuperator air to water shown in Figure 22.

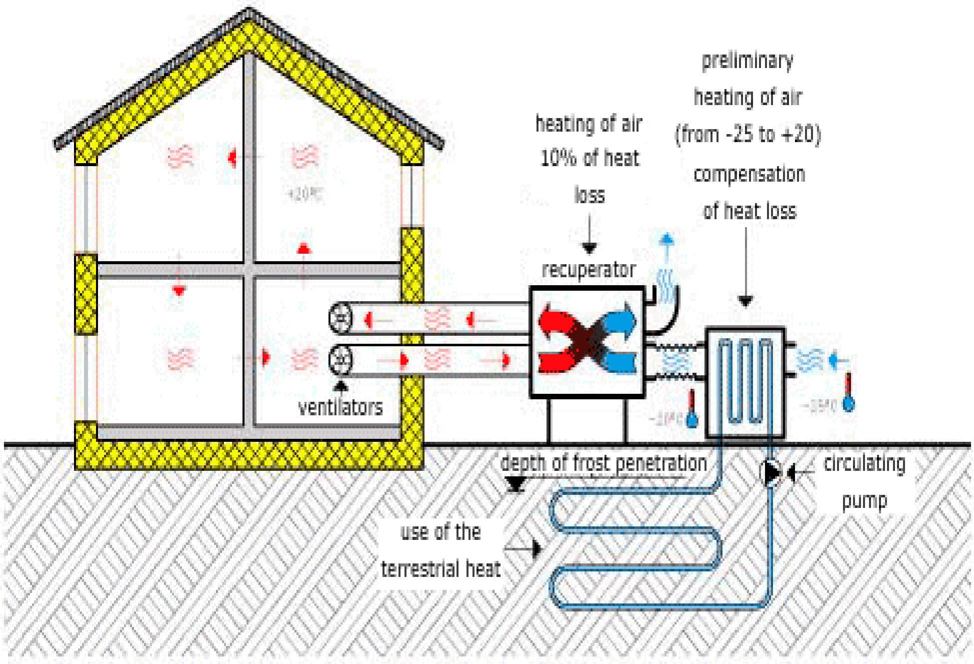


Figure 22.Recuperator

That kind of recuperator air-to-water works with water. There is a circulating water pipe, which is mostly underground. That heats the water inside the pipe with the constant temperature of the underground. When the system sucks air from outside, the circulating water already has constant temperature and heats up the air coming from outside to inside the building. Then the air meets the recuperator where it goes through filters and heats up more. The fresh and clean air is going into the building. At the same time a ventilator sucks the exhaust air from the rooms of the house. It again goes through filters and recuperator, where the warm, dirty air from inside also provides heat to warm the other air from outside. The air from inside is led out from to the pipe to the outside air.

In the recuperator air-water –air is an intermediate coolant that circulates through the pump between their two water stations. The efficiency is between 40% and 50%. The advantages of this type over the other are the greater spacing between blades, which makes it easier for cleaning up. The main advantage is that it does not need the two air flows to be brought to one and the same place, but they could be separated from each other. How the system works is shown in Figure 23.

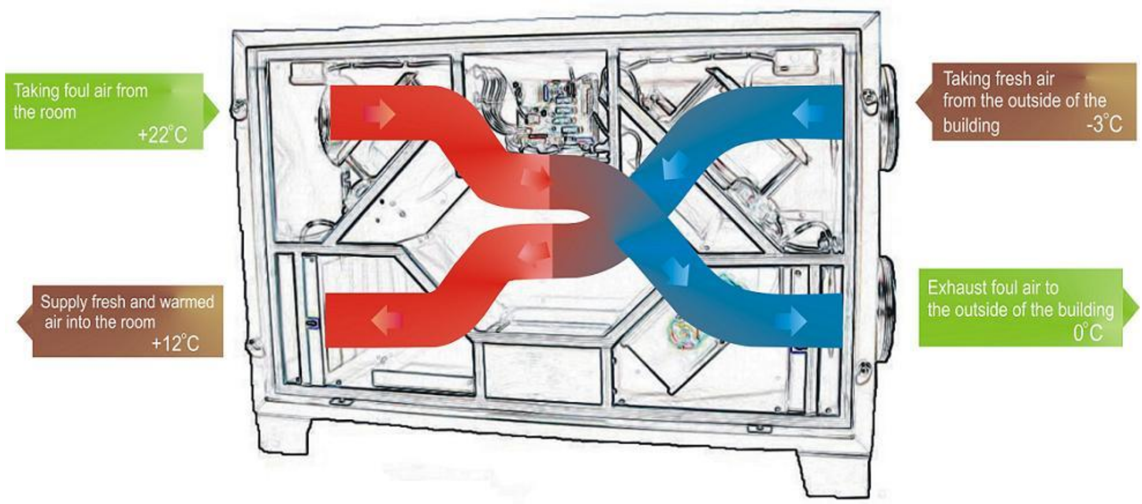


Figure 23.How the system works.

Rotary heat exchangers are air-to-air. That recuperator is made primarily of aluminium. The heat exchanger is rotated by specially designed low-revolution engines. Spinning a low speed one part is heated or cooled part passes into the portion of the cross section through which the outdoor air receives heat. Because of the low speed of a high effective heat transfer between the two streams is implemented. The effectiveness of this type of recuperator is between 70 % and 80 %.
This recuperator system could be applied in our case too. The multi-storey houses have three “Leafs” where there could be installed three separated recuperator systems.

6. WALL STRUCTURE DESIGN

The wall is the border between inside environment and the outside weather conditions. The wall is an extensive part of one construction and it is very important what it consists of. The thickness and material play a main role in the energy which will be used for heating and cooling down in different seasons. It is significant when designing a passive house or house which is eco-efficient.
There are structures where the loads are taken care of the external walls. In this case of BS project, the multi-storey house, there will be columns that will be integrated into the internal and external walls. Also, there will be part of the wall which is made from reinforced concrete .This study concentrates on what the wall should consist of in order to provide a good thermal transmittance and low energy consumption for heating and cooling. Those factors are measured with formulas

for U-value, moisture proofing and, heat protection. Also causing a heat loss should be predicted.

U-value is an overall heat transfer co-efficient. It is measuring the heat loss of different parts of the building. The calculations are usually made for the wall, roof and floor heat loss. As much as the U-value number is low as better insulation is installed. When the co-efficient is calculated a heat loss can be predicted and the energy consumption can be reduced for the inner side of the construction. The heat transfer depends on the materials that are used in the building components. Every single material has a different resistance. For each material the resistance is calculated with the following formula:

$$R=k/d$$

Where “d” is the thickness and “k” is the conductivity of the building material.
R_{si} and R_{se} are the fixed resistance values for the internal surface and external surfaces.
In our case R_{si} and R_{se} are equal to 0.13 and 0.17.
Then the Formula for U-value is:

$$U=1/\ (Rsi\ +R_{se}+R1+R2+R3\ldots.)$$

Where R1 is the resistance of the first layer of material, R2 is resistance of the second layer etc.

Moisture proofing or “Dew point” calculation is also required because the material used could not be effective enough to prevent condensation in different periods of time and the change of temperature in different seasons. The dew point is the temperature at which water vapor just starts to condense out of air that is cooling.

Heat protection also depends on the thinness and the thermal resistance of the materials used in the building component. It is important to predict thermal bridges and heat loss.

A thermal bridge is a cold bridge which usually occurs when insulated part is connected with an uninsulated one. It also occurs if there is penetration on the insulated layer, in the corners of the room, and under the windows. Thermal bridges can cause increasing values of heat losses, decreasing surface temperatures and a high level of humidity in some parts of materials. Thermal bridges are shown in Figure 24.

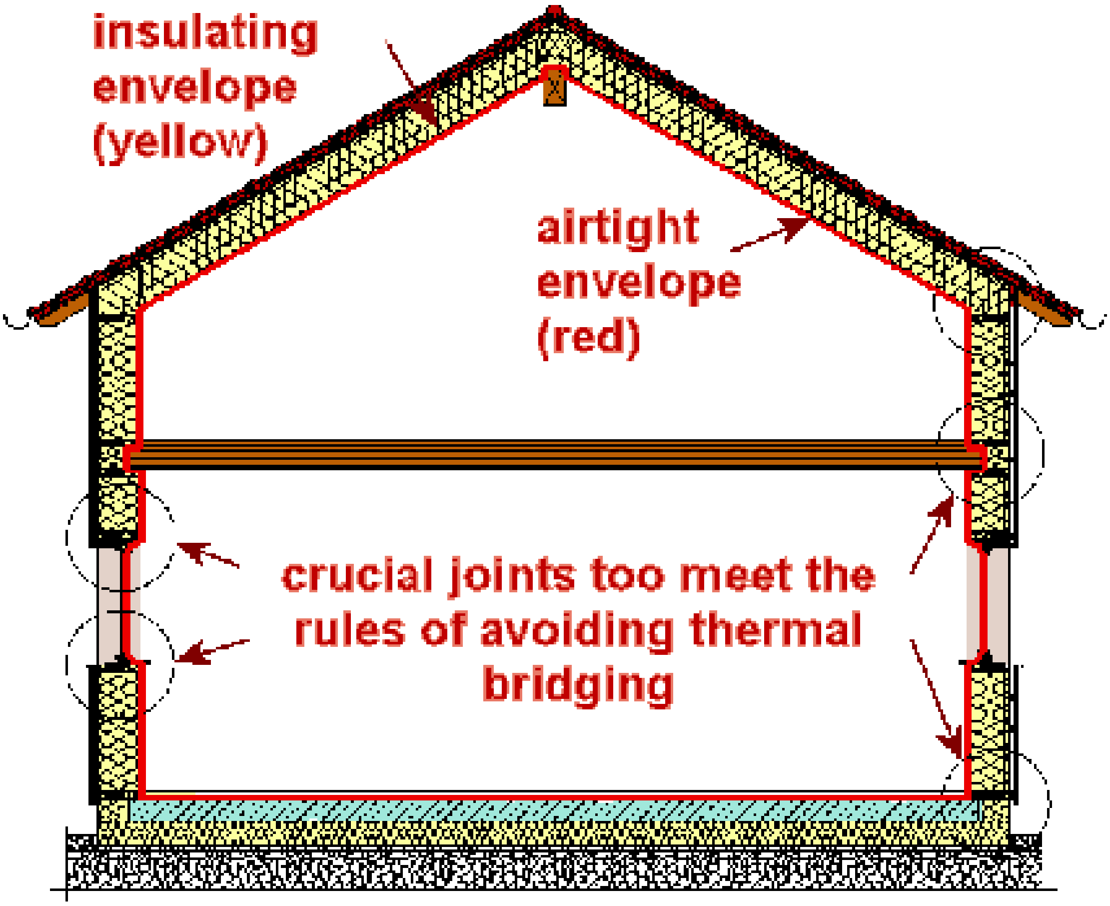


Figure 24, Thermal bridges, PHI drawing

The wall structure design in our future passive house should meet the listed requirements.

The requirement of PHI (passive house institute) states that the U-value of the wall component should be:

U_{value}=0.01 or less.

The architects from BS Project Company have made a concept detail drawing of the wall, connected to the floor and balcony. This is shown in Figure 25.

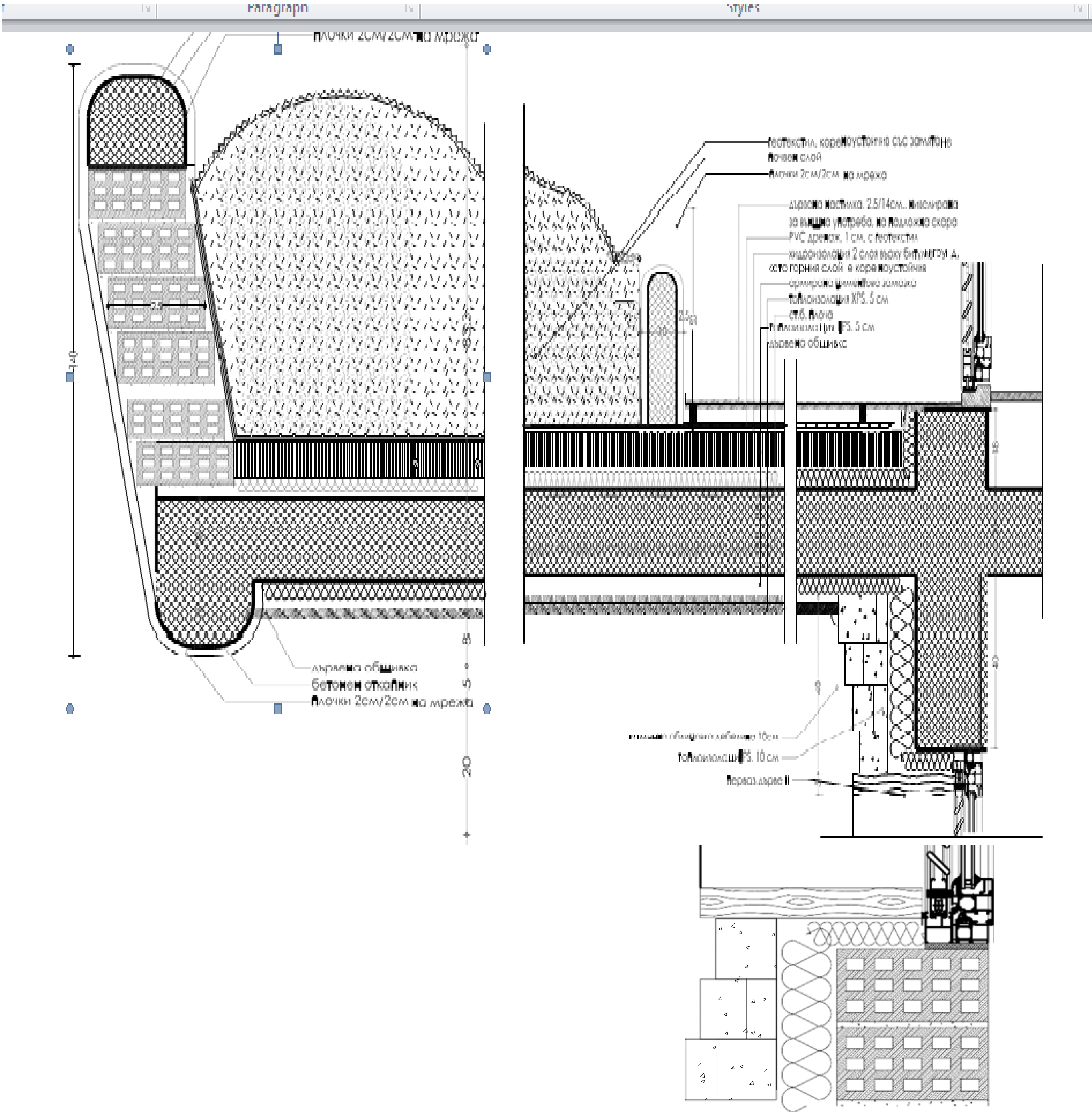


Figure 25 .Concept drawing.

In this thesis two tests are conducted about what the wall should consist of. The research concentrates on the material, the thickness of it and the price that each wall will cost to the investor. The calculations are made with a U-value calculator where are also shown the moisture proofing and heat protection.

There are five different possibilities that are observed made on the basis of the requirements for the eco-efficiency of the passive house.

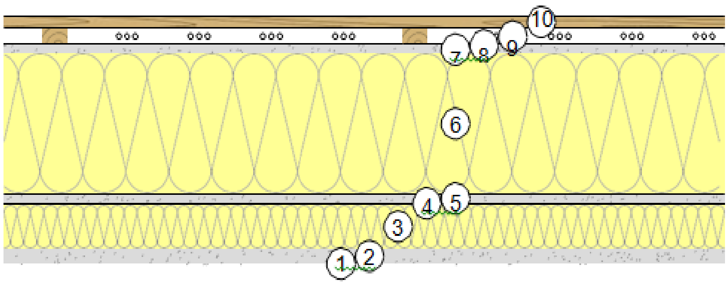
First wall structure is chosen to be:

Exterior wall, U=0,094 W/m²K

Exterior wall, U=0,094 W/m²K
erstellt am 5.9.2014

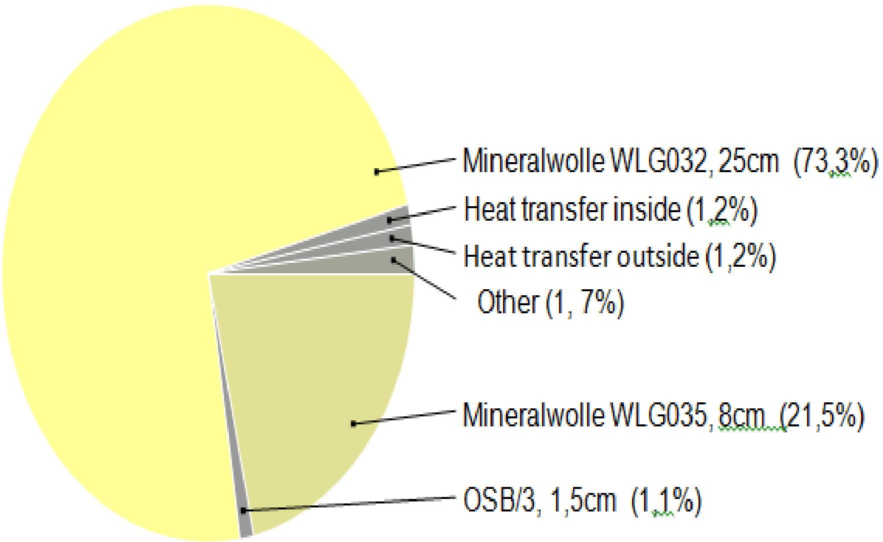
U = 0,094 W/m²K (Wärmedämmung)	Kein Tauwasser (Moisture proofing)	TA-Dämpfung: 49.0 (Heat protection)
0 ... 0.5 EnEV Bestand*: U<0,24 W/m²K	0 Condensate (kg) 1 No condensate	Temperature amplitude attenuation: 49.0 Phase shift: 11.7h

Cross-section of the component



1. Kalkgipsputz (2 mm)
2. Plasterboard (25 mm)
3. Mineralwolle WLG035 (80 mm)
4. Knauf Insulation EtaPlus (2 mm)
5. OSB/3 (15 mm)
6. Mineralwolle WLG032 (250 mm)
7. Fermacell Gipsfaser-Platte 12,5mm (12,5 mm)
8. Klimasan-S (2 mm)
9. Air (30 mm)
10. Façade (21 mm)

Contribution of different layers to the overall insulation

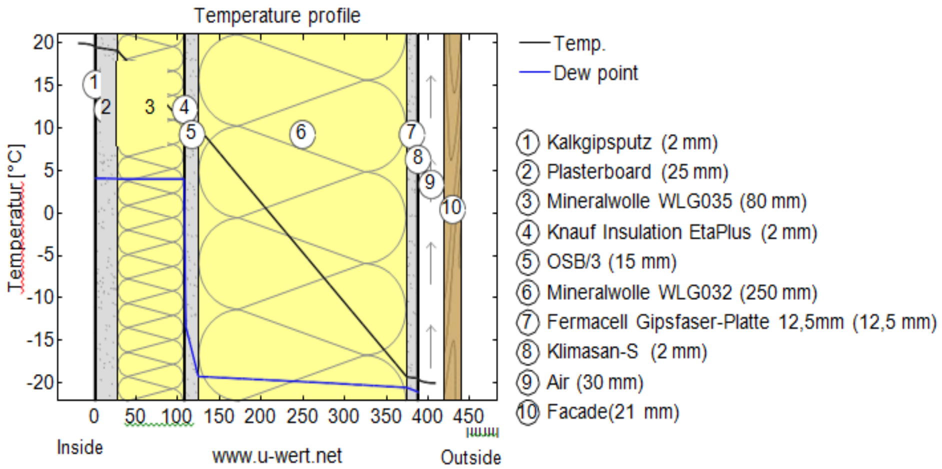


Room air:	20°C / 35%	Condensate:	0,000 kg/m²	Heat capacity:	61 kJ/m²K
Outside air:	-20°C / 90%	Time to dry:	0 Tage	Heat transfer inside:	37 kJ/m²K
Surface temp.:	19,5 °C	sd-value:	26,9 m	Weight:	61 kg/m²
Thickness:	44,0 cm				

Exterior wall, U=0,094 W/m²K

Exterior wall, U=0,094 W/m²K
erstellt am 5.9.2014

Temperature history / Condensation zone



Course of temperature and dew point within the component. The dew point indicates the temperature condenses to water vapor and condensation occurs would. As long as the temperature of the component at all points above the dew point, there is no condensation. If touch the two curves falls at the contact points of condensation.

Different layers of the wall are shown in the table 1 below.

Table 1

Layers (from inside to outside)

The following table contains the most important data of all layers of the design:

#		Material	λ [W/mK]	R [m²K/W]	Temperature [°C] min	max	Weight [kg/m²]	Condensate [Gew%]
		Thermal contact resistance		0,130	19,5	20,0		
1	0,2 cm	Kalkgipsputz	0,700	0,003	19,5	19,5	2,8	0,0
2	2,5 cm	Plasterboard	0,250	0,100	19,1	19,5	17,0	0,0
3	8 cm	Mineralwolle WLG035	0,035	2,286	10,5	19,1	1,6	0,0
4	0,2 cm	Knauf Insulation EtaPlus	0,170	0,012	10,5	10,5	0,8	0,0
5	1,5 cm	OSB/3	0,130	0,115	10,1	10,5	9,3	0,0
6	25 cm	Mineralwolle WLG032	0,032	7,812	-19,3	10,1	5,0	0,0
7	1,25 cm	Fermacell Gipsfaser-Platte 12,5mm	0,320	0,039	-19,4	-19,3	14,4	0,0
8	0,2 cm	Klimasan-S	0,077	0,026	-19,5	-19,4	0,7	0,0
		Thermal contact resistance		0,130	-20,0	-19,5		
9	3 cm	Air (ventilated layer)			-20,0	-20,0	0,0	
10	2,1 cm	Facade			-20,0	-20,0	9,4	
	43,95 cm	Whole component		10,650			61,0	

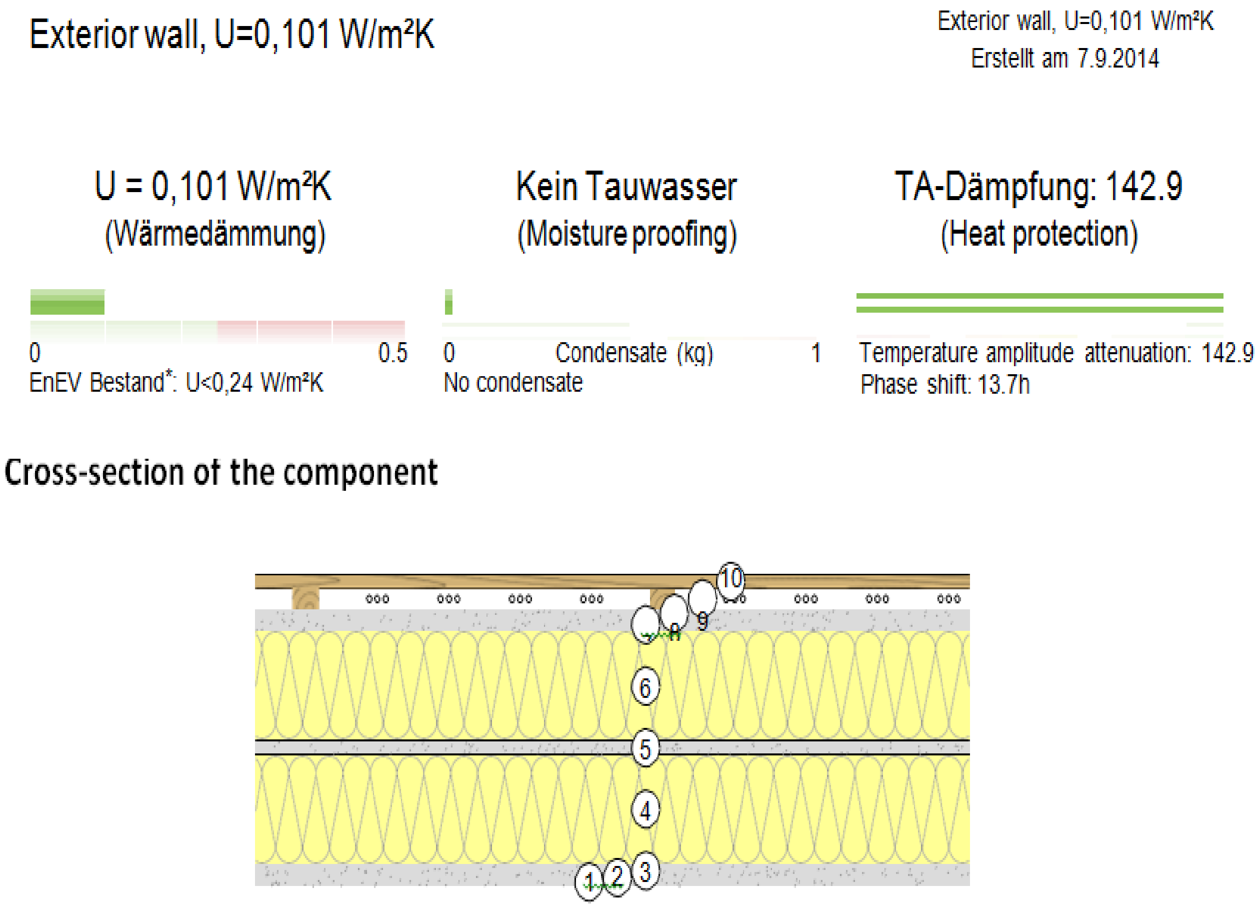
How much the wall costs is calculated 1m.x 1m. Is shown in Table 2:

Table 2

Material	**Price /m² in euros**:
Plasterboard	1,89
Mineral wool WLG 032	2,47
Knauf Insulation Eta plus	3,72
OSB/3	6,22
Mineral wool WLG 032	2,47
Gipsfaser-platte	4,02
	Total: 20,79

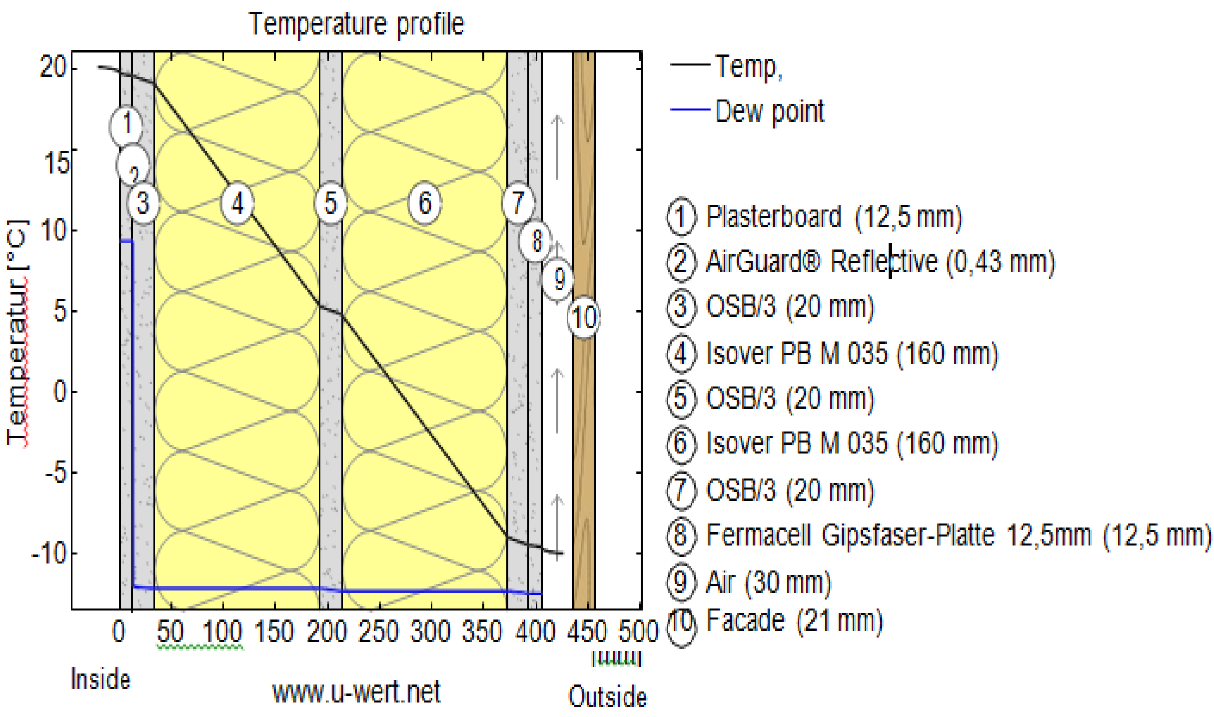
Summary:
We reach the level for eco-efficiency with a U-value=0,094, the thickness of all components is 43, 95 cm. The price for 1m^2 is 20, 79 euros.

The second wall:



1. Plasterboard (12,5 mm)
2. AirGuard® Reflective (0,43 mm)
3. OSB/3 (20 mm)
4. Isover PB M 035 (160 mm)
5. OSB/3 (20 mm)
6. Isover PB M 035 (160 mm)
7. OSB/3 (20 mm)
8. Fermacell Gipsfaser-Platte 12,5mm (12,5 mm)
9. Air (30 mm)
10. Facade (21 mm)

Temperature history / Condensation zone



Course of temperature and dew point within the component. The dew point indicates the temperature, condenses to water vapor and condensation would occur. As long as the temperature of the component at all points above the dew point, there is no condensation. If touching the two curves, drops at the contact points of condensation.

Different layers of the wall are shown in the table 3 below.

Table 3.

Layers (from inside to outside)

The following table contains the most important data of all layers of the design:

#		Material	λ [W/mK]	R [m²K/W]	Temperature [°C] Min	max	Weight [kg/m²]	Condensate [Gew%]
		Thermal contact resistance		0,130	19,6	20,0		
1	1,25 cm	Plasterboard	0,250	0,050	19,5	19,6	8,5	0,0
2	0,043 cm	AirGuard® Reflective	0,500	0,001	19,5	19,5	0,4	0,0
3	2 cm	OSB/3	0,130	0,154	19,0	19,5	12,4	0,0
4	16 cm	Isover PB M 035	0,035	4,571	5,2	19,0	3,2	0,0
5	2 cm	OSB/3	0,130	0,154	4,8	5,2	12,4	0,0
6	16 cm	Isover PB M 035	0,035	4,571	-9,0	4,8	3,2	0,0
7	2 cm	OSB/3	0,130	0,154	-9,5	-9,0	12,4	0,0
8	1,25 cm	Fermacell Gipsfaser-Platte 12,5mm	0,320	0,039	-9,6	-9,5	14,4	0,0
		Thermal contact resistance		0,130	-10,0	-9,6		
9	3 cm	Air (ventilated layer)			-10,0	-10,0	0,0	
10	2,1 cm	Facade			-10,0	-10,0	9,4	
	45,643 cm	Whole component		9,950			76,4	

How much the wall costs calculated 1m.x 1m.,

Table 4

Material	**Price per m^2 in euros**
Plasterboard	1.89
Air Guard Reflective	4.62
OSB/3	6.22
Isover PB M 035	22.54
OSB/3	6.22
Isover PB M 035	22.54
OSB/3	6.22
Fermacell Gipsfaser Platte	4.02
	Total :74.27 euros

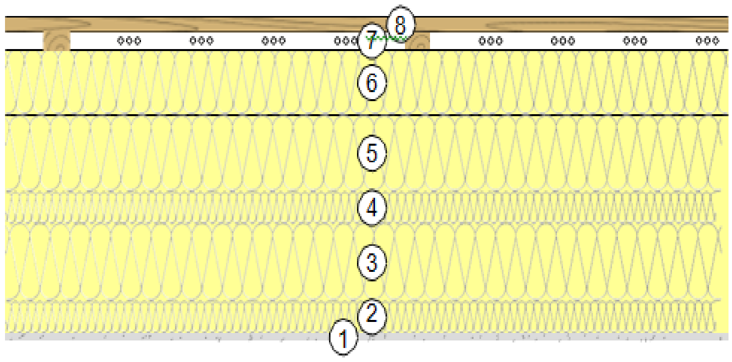
The third wall, the last wall contains two bricks of poroton:

Exterior wall, U=0,099 W/m²K

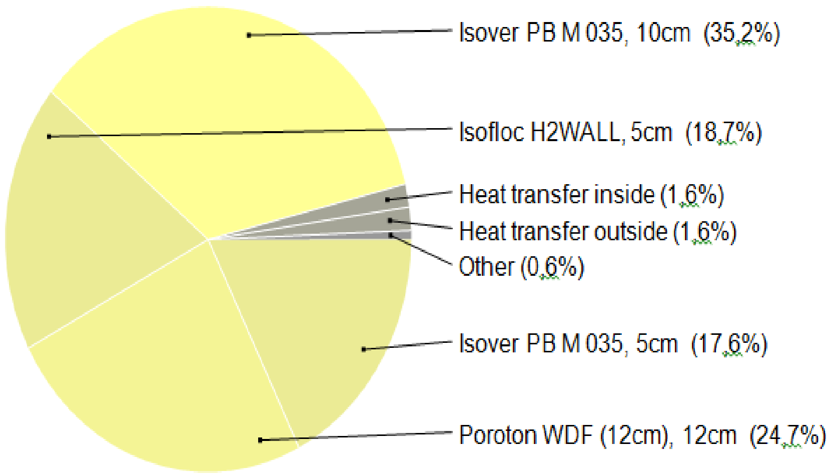
Exterior wall, U=0,099 W/m²K
Erstellt am 7.9.2014

U = 0,099 W/m²K (Wärmedämmung)	Kein Tauwasser (Moisture proofing)	TA-Dämpfung: 312.5 (Heat protection)
0 ... 0.5 EnEV Bestand*: U<0,24 W/m²K	0 ... Condensate (kg) ... 1 No condensate	Temperature amplitude attenuation: 312.5 Phase shift: 24.0h

Cross-section of the component



1. Plasterboard (12,5 mm)
2. Isover PB M 035 (50 mm)
3. Poroton WDF (120 mm)
4. isofloc H2WALL (50 mm)
5. Poroton WDF (120 mm)
6. Isover PB M 035 (100 mm)
7. Air (30 mm)
8. Facade (21 mm)

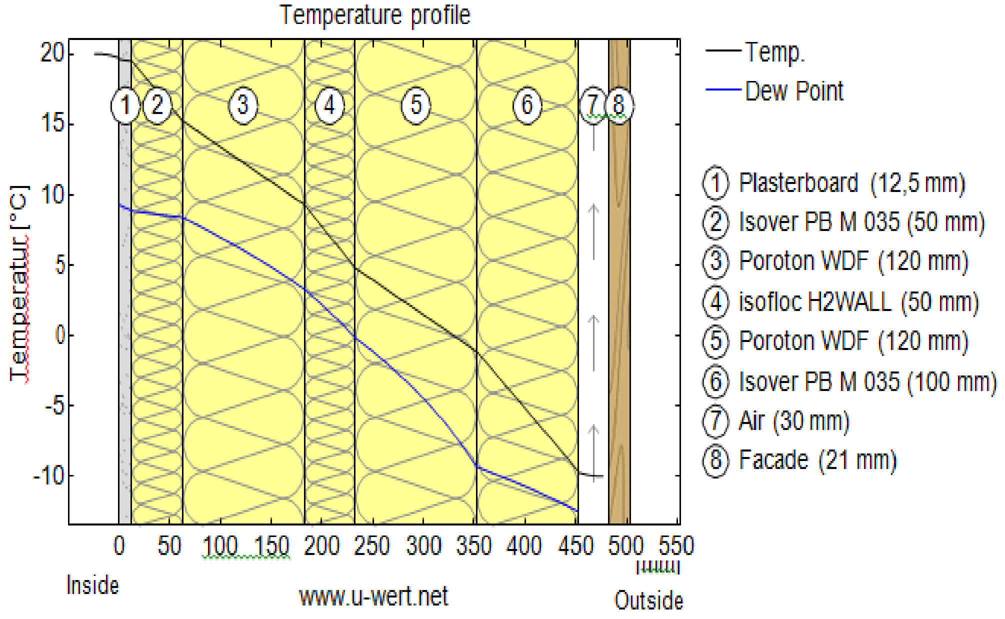


Room air:	20°C / 50%	Condensate:	0,000 kg/m²	Heat capacity:	109 kJ/m²K
Outside air:	-10°C / 80%	Time to dry:	0 Tage	Heat capacity inside:	66 kJ/m²K
Surface temp..:	19,6 °C	sd-value:	1,4 m	Weight:	117 kg/m²
Thickness:	50,4 cm				

Exterior wall, U=0,099 W/m²K

Exterior wall, U=0,099 W/m²K
erstellt am 7.9.2014

temperature profile / condensation zone



Course of temperature and dew point within the component. The dew point indicates the temperature, condenses to water vapor and condensation would occur. As long as the temperature of the component at all points above the dew point, there is no condensation. If touching the two curves, drops at the contact points of condensation.

Different layers of the wall are shown in the table 5 below.

Table 5.

Layers (from inside to outside)

The following table contains the most important data of all layers of the design:

#		Material	λ [W/mK]	R [m²K/W]	Temperature [°C] min	max	Weight [kg/m²]	Condensate [Gew%]
		Thermal contact resistance		0,130	19,6	20,0		
1	1,25 cm	Plasterboard	0,250	0,050	19,5	19,6	8,5	0,0
2	5 cm	Isover PB M 035	0,035	1,429	15,2	19,5	1,0	0,0
3	12 cm	Poroton WDF (12cm)	0,060	2,000	9,3	15,2	48,0	0,0
4	5 cm	isofloc H2WALL	0,033	1,515	4,8	9,3	0,8	0,0
5	12 cm	Poroton WDF (12cm)	0,060	2,000	-1,1	4,8	48,0	0,0
6	10 cm	Isover PB M 035	0,035	2,857	-9,6	-1,1	2,0	0,0
		Thermal contact resistance		0,130	-10,0	-9,6		
7	3 cm	Air (ventilated layer)			-10,0	-10,0	0,0	
8	2,1 cm	Facade			-10,0	-10,0	9,4	
	50,35 cm	Whole component		10,111			117,8	

How much the wall costs calculated 1m.x 1m.,:

Table 6.

Material	**Price in euros per m^2**
Plasterboard	1.89
Isover PB M 035	22.54
Poroton WDF	34.00
Isofloc H2WALL	12.33
Poroton WDF	34.00
Isover PB M 035	22.54
	Total: 126,76

6.4 Comparison of the wall

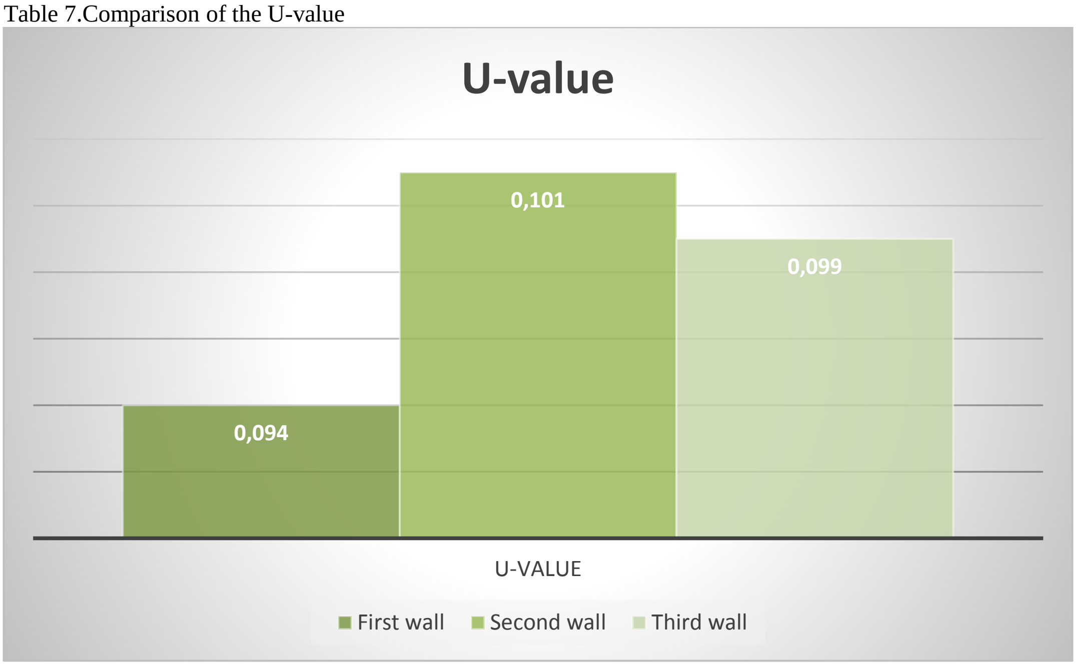
The three walls will be compared based on the results of the study conducted. The criteria will be:

1. U-value
2. Thickness of the wall
3. Cost per m^2

All of the three walls are made to reach the lowest U-value possible with certain materials. The necessary value required by PHI (Passive House Institute) for a wall structure in U-value equals 0.10 W/m^{2}K.All three walls are reach the eco-efficiency value for passive one. The difference is neglegtive. The thickness of the wall is also very important because as much as the wall is insulated as thicker it gets and that is a problem that could appear while making a concept structure of a passive house wall. The thickness should we kept in normal sizes as the regular non-greenhouse have.
When the required eco-efficient value is reached there appears the question of the cost. The costs should also be reduced to the most possible minimum.

Comparison of the U-value of walls is shown in Table 7.

Table 7.Comparison of the U-value



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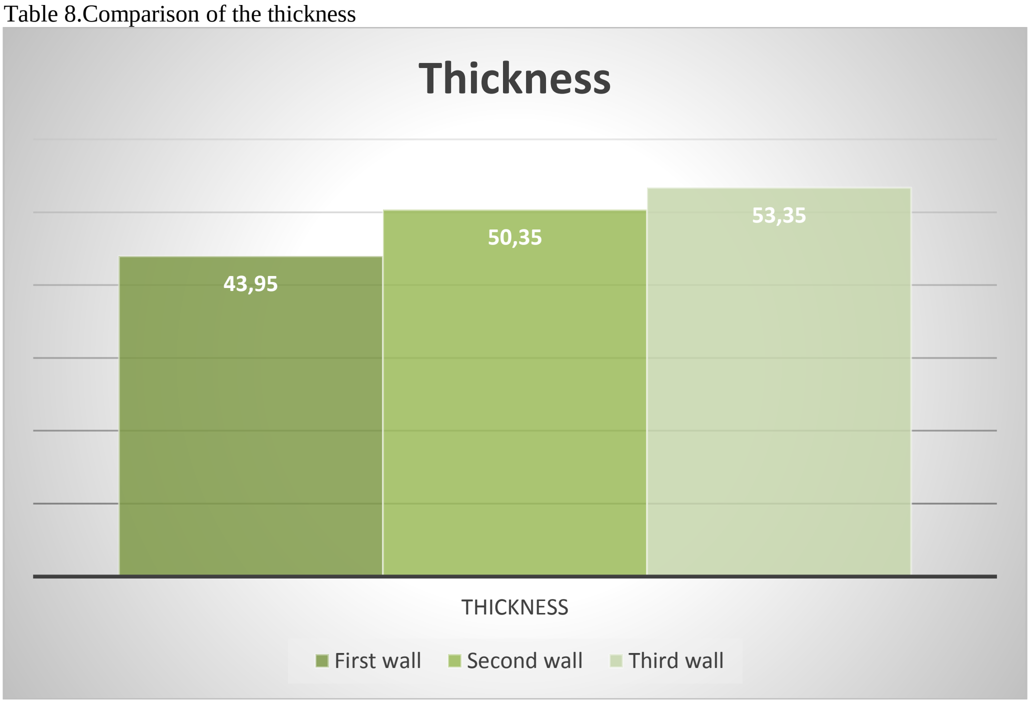
The table shows that the first wall structure has the lowest U-value.

Comparing the thickness of the wall is shown in Table 8.

Table 8.Comparison of the thickness



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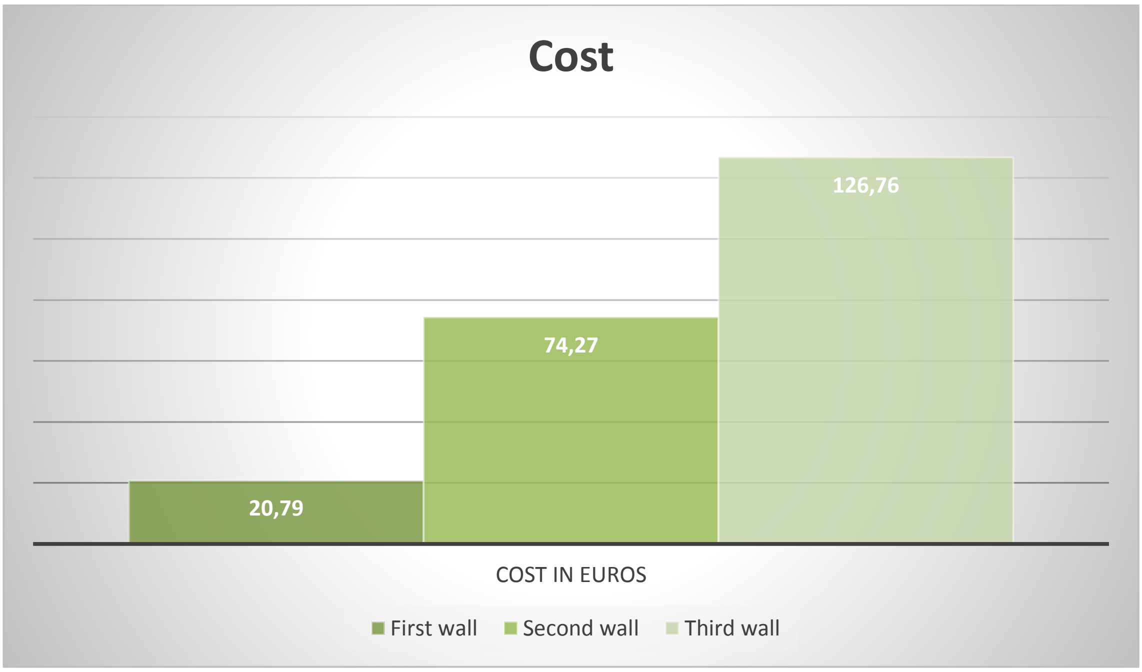
Comparing the price per m^2 is shown in Table 9.

Table 9.Cost in euros/m^2.



Based on the results of the comparisons it can be concluded that the "First wall" is the most suitable for this case and meets the requirements of Passive house institute and the wish of the investor. It has the lowest U-value, smallest thickness and lowest materials price.

CONCLUSION

Passive house building design very much depends on the climate, environmental conditions and architectural design of the future construction. The climate in Bulgaria and the conditions in the particular area are suitable enough for the different methods and systems applied in green houses. The photovoltaics, water heating system, recuperator and the materials used for walls and the whole building, can reduce the energy consumption and be efficient in a long period of time. That makes the investment profitable in the future. BS project`s multi-story house has an architectural design which is in unison with the surrounding environment and provides the opportunity for using green energy and natural resources. Based on the research it could be concluded that BS project`s multi-storey building can reach a PHI certificate when applying all the methods listed in this research and provide a healthy indoor air for the house residents and be an environmentally friendly passive house.

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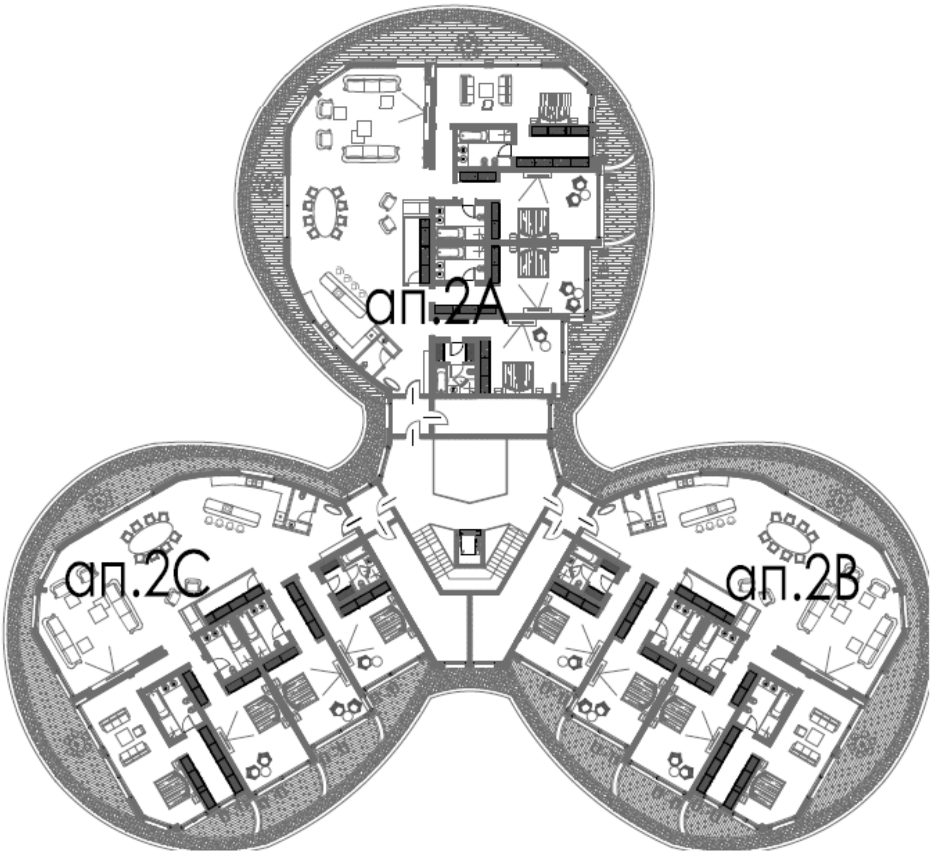
Appendix 1

BS Project`s architectural 3D concept drawing of the building: side view

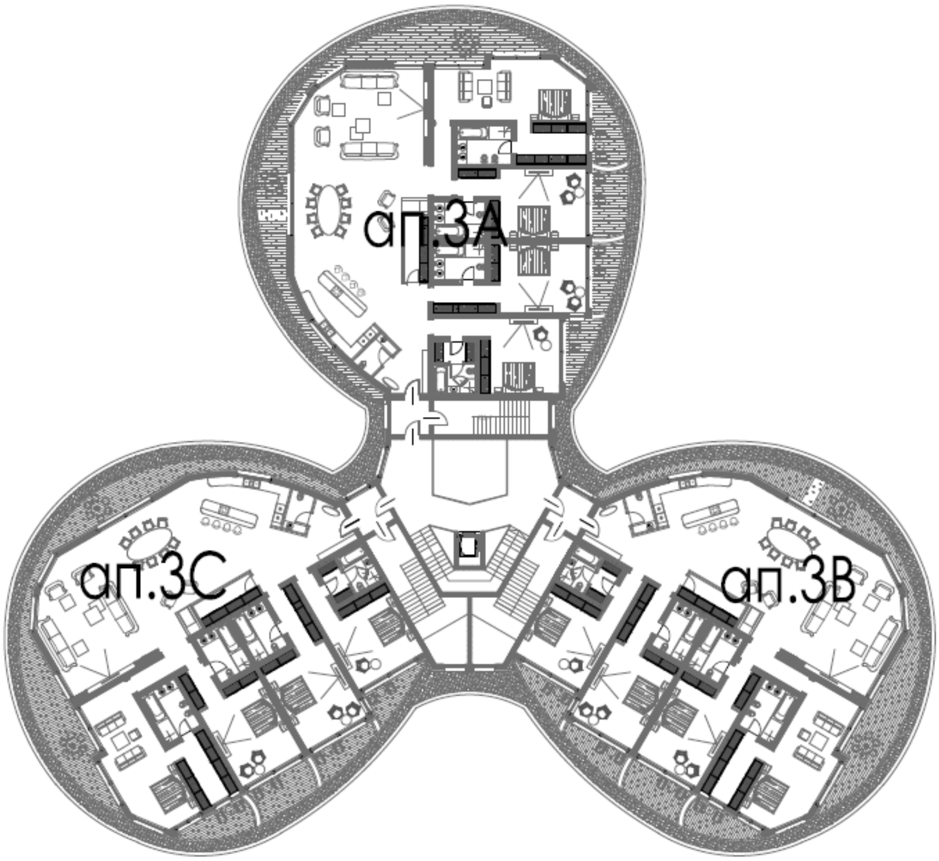
Appendix 2

Architectural drawing of the second floor of the building.



Appendix 3

Architectural drawing of the third floor of the building.



Appendix 4

Architectural drawing of the fourth floor of the building.