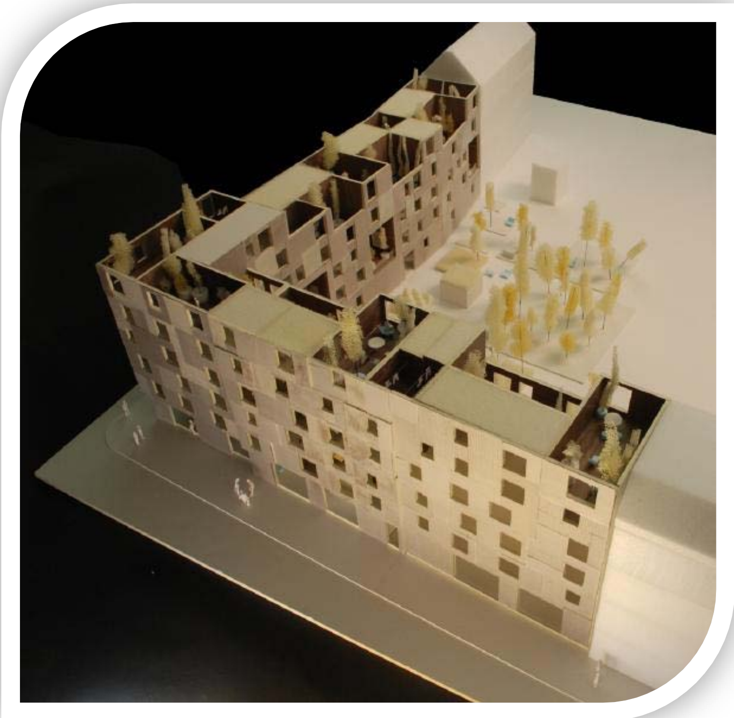
Copenhagen University College of Engineering

Ingeniørhøjskolen i København

European Project Semester

Spring 2010

A low energy house



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Presented by:

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Roman Ledoux
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Abstract

As international students taking part in the European Project Semester – EPS, we were asked to participate in a project called *A Low Energy House*, in collaboration with a Danish consulting engineering company, Cenergia.
The motivation to develop this project has been the present concern of climate change, and depletion of fossil energy resources available. Among some other solutions, a good way to face this problem is to approach the house consumption more efficiently.

The main aim of the project is to design the installations for a real block apartment, which will be soon built in the Copenhagen area, to certify it as a Class 1 building, meaning that its annual energy consumption must be less than 35’4 kWh/m^2.

To reach our goal we worked on two differentiated parts: passive solutions and active solutions. The first one involves insulation, ventilation, glazing and day lighting. While the second one deal with heating systems, solar systems, electric lighting and home automation.

After implementing all our solutions in the building, and try to change the occupants’ behaviour through guidelines, we can say we reach a global consumption of 33’5kWh/m^2/year for the whole building.

Preface

1. Acknowledgements

We would like to acknowledge Erik Stange, Urbano Domingez, Jørgen Hansen, and Ole Balslev for having supported us throughout our project.

2. Presentation of our supervisors

i. Erik Strange

Erik Strange is an associate professor of Civil Engineering at Copenhagen University college of Engineering (Ingeniørhøjskolen i København).

ii. Urbano Dominguez

Urbano Dominguez is a professor of Mechanical Engineering at Universidad de Valladolid, in Spain.

3. Presentation of the team members

i. Jan Ewald

Jan Ewald is a student at The University of Applied Sciences Kiel in Germany. He is studying the bachelor degree course Mechanical Engineering. During the 6^{th} semester of his degree, he is doing the final project at the Copenhagen University College of Engineering under the programme European Project Semester. Soon after his exchange semester he will be graduated in Germany. After that he will study the Master of Mechanical Engineering.

Concerning the project he deals with electricity technologies, wind technologies, active solar technologies, and a co generator system in order to integrate these technologies in the low energy house construction. Further he occupies with the problems of the present environmental situation.

ii. Marjolaine Bosch

Marjolaine Bosch comes from France. She is a student at the Institute of Technology in Saint Etienne, which is part of the University of Jean Monnet. She is graduated of a degree in Physical Measurements, and she specializes in acoustics and mechanical vibrations. She is currently studying a University Diploma of International Technological Education, consisting in two semesters abroad. That is why she is studying at Copenhagen University College of Engineering. Last semester, she was studying Mechanical Engineering.

Concerning the project, she is able to deal with the thermal part and the fluid part of the project. She can also do a bit of electricity, even if it is not her speciality

iii. Meritxell Padreny

Meritxell Padreny comes from Spain. She is a student at the Escola Politècnica Superior d'Enginyeria in Vilanova i la Geltrú – EPSEVG, which is part of the Universitat Politècnica de Catalunya – UPC. She is studying a Bachelor of Engineering in Telecommunications, specialized in Electronic Systems. She is on the last year of her degree and she is doing her final project at the Copenhagen University College of Engineering. After her stay in Denmark she will be graduated.

Regarding the project, she is most able to deal with the electric and electronic parts of it, such as choosing the right household devices or the lighting design, and automate them to decrease the house consumption. She will also support on the rest of parts as far as possible.

iv. Roman Ledoux

Roman Ledoux comes from France. He is a student at L'Ecole Centrale de Nantes, which is a highly selective French School of Engineering conferring a diploma equivalent to a Master's Degree. He is in his fourth year and will be graduated next year after another of specialization. The school is specialized in hydrodynamics and energetic.

Concerning the project, he learnt the ecological and economic problems the world currently has to deal with, worked with building consumption calculation tools from the ADEME (French Environment and Energy Management Agency), and he is competent in energetic, hydrodynamics, java and C programming, and electronics.

4. Comments

5. Signatures

Marjolaine Bosch	Jan Ewald
Roman Ledoux	Meritxell Padreny

Table of contents

Introduction

1. European Project Semester

The *European Project Semester* is a one-semester course, designed to train third-year engineering students to work in international teams. It is characteristic for being a multidisciplinary and multicultural programme, with English as working language.

The EPS consists in four weeks of short, intensive and project-supportive courses, such as Cross Cultural Communication, International Marketing, EU Law, etc. and a project itself. In an EPS, an international group of students works on a real-life project that has been proposed by a company.

This year, 48 international students grouped in 12 different teams, are working on real projects for different Danish companies.

2. The project

Our project is called *A Low Energy House*. It has been developed because of the present concern of climate change and depletion of fossil energy resources available. Analyzing the different causes of this problem we can note that, an interesting way to rethink the use of energy resources is to approach the housing consumption more efficiently, as well as using clean energy to supply heat and power demands. That is what Cenergia does.

Our group, whose members are presented at the beginning of this report, collaborates with the company Cenergia. It is a Danish consulting engineering firm, described as a company working for sustainability in buildings, through participation in national and international cooperation projects, demonstrating new knowledge of energy savings, and utilization of renewable energy in building projects (e.g. in urban ecological projects). They also develop sustainable technologies further and put these into practice, develop calculation tools for application by design and total economic optimization of housing projects, provide and communicate new knowledge of sustainable building. Their activities span initiation, planning and evaluation of demonstration projects, contribution to process, and product development via energy planning and project management of international cooperation projects within these fields.

Their latest project is now also our project. The construction of this Low Energy House is the result of a competition organized by the Copenhagen city council, which encouraged architects and consulting companies to present their projects with the objective to fill an empty land in the Copenhagen area, being respectful with the environment.

Therefore, the main aim of the project is to design the installations of the block apartment, to certify it as a Class 1 building, which means that its annual energy consumption must be less than 35,4 kWh/m^2.

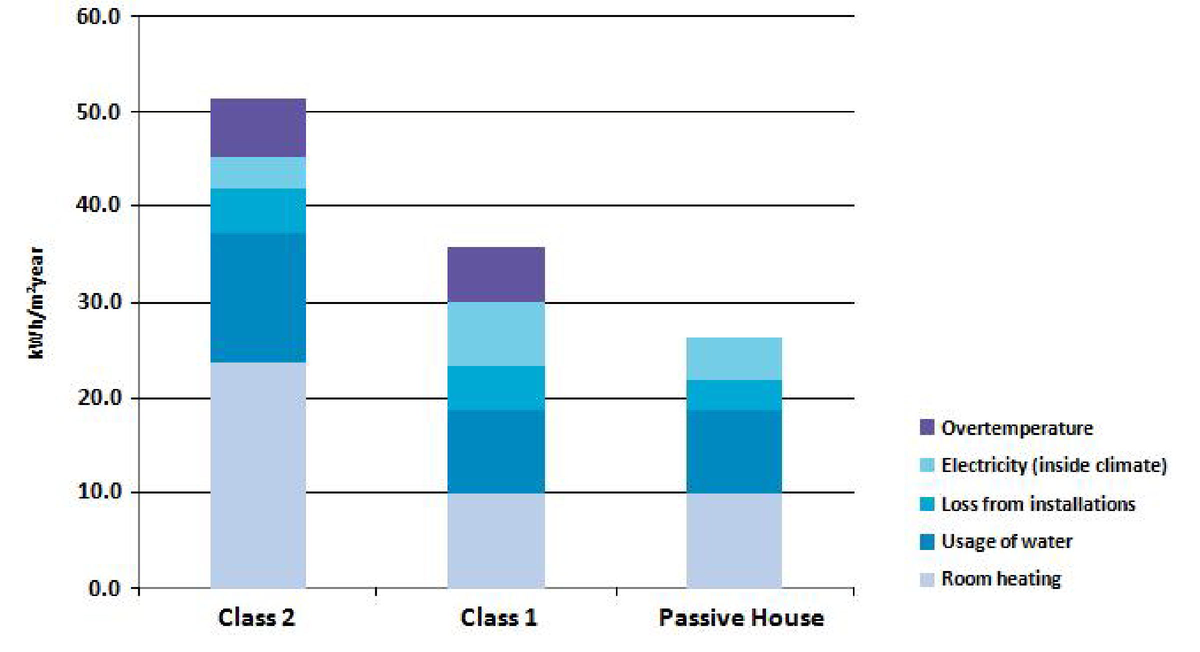


Figure 1: Energy needed for Class 2, Class 1 and Passive House distributed in different sources

We realised that nobody in our group had much experience with Low Energy Houses; therefore, as a starting point we decided to visit the ecological village of Hjortshøj, next to Aarhus, in order to get to know better the concept, and come up with some ideas.

In this report you will find researched information about renewable energies and innovative solutions for our building, in order to reach low energy consumption.

Part 1: Previous training

1. Visiting an ecological village near Aarhus

The Co-operative Community of Hjortshøj (AIH), near Aarhus, has over 200 adults and children who have chosen to live in environmentally friendly houses. Hjortshøj is an emerging location for testing, knowledge and teaching of ecology and sustainable development, including construction, power generation, social development, culture, consumption, food, waste and wastewater management, business, economics and agriculture. Their goal is solidarity among fellow human beings, and responsibility in the handling of natural resources.

They evolve in dynamic interaction with the surrounding community, including active dissemination and exchange of experiences. Once a year, they have a vision meeting where they try to look into the future. Vision meetings provide time and space to exchange new ideas and look at the daily life in a larger perspective: this gives a boost to all of us. During a vision meeting there are often concrete new ideas, which can help to continue the ongoing development in the community.

Initiatives in AIH reducing CO_2 emissions include:

Approximately half of the houses have one or more walls made of the moraine clay on their site. If you compare with traditional bricks made of clay, they save 99% of the energy normally used. When the houses eventually will have to be demolished, the earth walls will still be part of the local soil – no construction waste from these walls.

The houses are largely insulated with “paper wool”, which is granulated recycled paper. Energy used for this type of insulation is much lower than the energy used for the traditional melting of glass and minerals. The houses are also very well insulated (including some that are 15 years old), which reduces heat consumption and hence CO_2 emissions.

All heating of homes and water is done either by burning wood chips or through solar heating. Wood chips are burned in their own central wood chip stove, which is coupled to a Stirling engine, which optimizes efficiency by also producing electricity.

The first boiler was a granules boiler (180kW). By opening the door, we can find the granules tank.

	
Figure 2: Granules boiler (180kW)	Figure 3: Granules tank

Later on, they installed a central wood chip stove (160kW). You can see it following, together with the wood chip tank. Each week, a truck comes and delivers wood chips. In winter, $100m^2$ are delivered per week.

	
Figure 4: Central wood chip stove (160kW)	Figure 5: Wood chips

On the other side, a Stirling engine has been built so that electricity can be produced. We can see it on the left picture below. On the right picture we can see the wiring diagram of Stirling engine. The wood chips are burnt and the heat produced is used from the Stirling engine.

Figure 6: Stirling engine

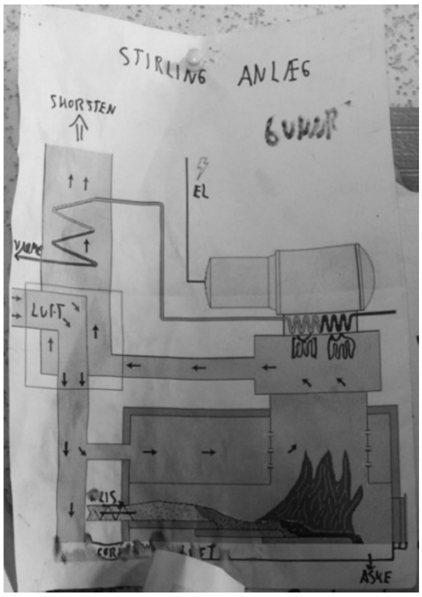


Figure 7: Wiring diagram of Stirling engine

Besides the efficient water heating system, solar heating, is used on houses roof. From May to October, only solar systems are used to heat the water up.

Figure 8: Solar panels in a roof

Figure 9: Detail of the solar panels

Each house belongs to a group, which has around 30 inhabitants. Each group is responsible for a common house. They are used to have common meals twice a week. Furthermore, it is possible for them to organize parties or events in this common area.

As we can see on the next pictures, the kitchens are very well-equipped. Besides, each common house has also a washing machine room, where the water used comes from the rain.

Figure 10: Full-equipped kitchen in one of the common houses

Figure 11: Washing machines common room

We can quote other actions which are done in Hjortshøj:

- They have 1.5 hectares of vegetables and fruits. From here, approximately 100 persons have totally fresh, sun-ripened organic food without energy consumption for packaging and transportation. In their organic agriculture program, they also produce fertilizer, animal feed, meat and eggs for their own consumption. The proportion of each person's consumption covered by locally produced commodities is voluntary and quite variable.

- Biodynamic cultivation has clearly improved the structure of the soil, now containing a large carbon reservoir. The degree of tillage is very low, whereby both the release of CO_2 and the much stronger greenhouse gas, nitrous oxide, is reduced significantly.

- Approximately, one third of the agricultural land is used for multi-year willows, fruit trees and pastures, all of which build soil carbon.

- A portion of the effluent from AIH is used as fertilizer for willow trees, thus binding CO_2 by solar means saving energy an eliminating the emission of nitrous oxide from basins as in conventional treatment.

- They sort their waste out into many categories, so a significant part is reused. It is very satisfying. Once systematized, it is no burden.

- They have 2 jointly-owned cars in Hjortshøj. For some of them, it means they do not need any car; for the others it consists in a chance to do not have to buy it. 2. In both cases, it becomes clearer what the costs are. This promotes the use of bicycles and public transportation.

After visiting the site, we visited a passive house.

The first impression we had when we entered the house was that the rooms seem smaller as the building. This is due to the width of the walls (the insulation is 50 or 60 cm wide). We can see on the picture next page that it is a key point that architects have to take into account.

Figure 12: Living room of the passive house

Figure 13: Heat exchanger inside the house

Every two hours, warm water is transported from a tank into the passive houses. When the weather is sunny, energy from the sun is used in order to heat the water located in the tank.

Then, a heat exchanger is used for heating up the water needed by the occupiers, using the heat contained in the water of the tank.

Once a good insulation is installed, people could die within 2 hours by lack of new oxygen. That's why an efficient ventilation system has to be used. The principle is simple:

- The air has to be extracted from the kitchen and the bathroom.
- This air goes through a heat exchanger.
- Thanks to this exchanger, heat is given to new air coming from the outside.
- This heated new air is distributed in the living room and in the bedrooms.

On the next left picture below, you can see an air vent located in the living room. The ventilation is also used as vacuum-cleaner. You just have to plug a pipe into the socket as you can see on the right picture below, in order to clean the ground.

Figure 14: Air vent in the ceiling of the living room

Figure 15: Plug for vacuum-cleaner

Part 2: Building's environment

1. Location of the building

As you can see in figure 16, the low energy house in question it is supposed to be placed close to the city centre of Copenhagen. The building will be located next to the crossroad between Holmbladsgade and Geislersgade. Figure 17, shows the situation. An old building was placed before, but it had to yield for the new low energy house. After the breakaway a new budding building area is developed, as you can see in figure 18. Figure 19 shows the simplified the new planned building - A low energy house as a block of flats.

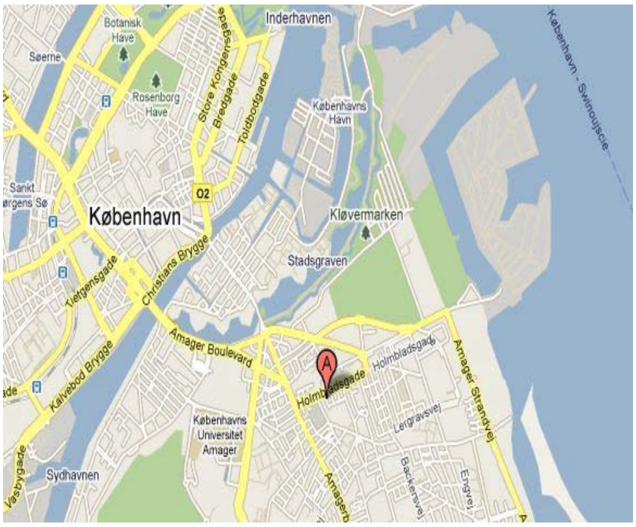


Figure 17: Map

Figure 16: Old situation

Figure 18: New situation

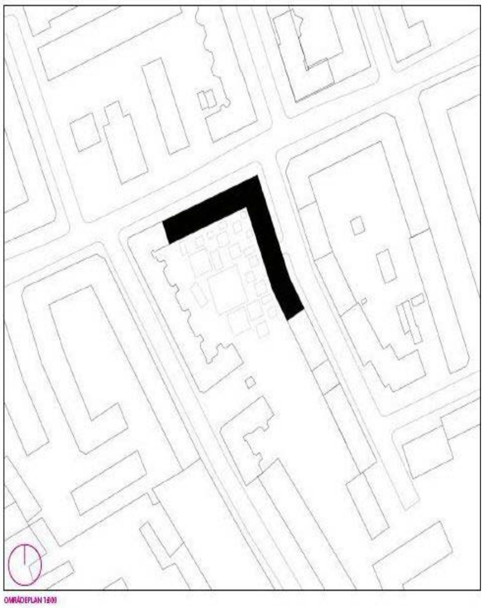


Figure 19: Planned building

2. Estimations in our building

This chapter helps to understand Cinergia's drawings and gives a possible average number of occupants. The following provides an overview of possible estimated energy consumption in our building. We have to take into consideration that the coming calculations are based on average numbers and exact statements were exceedingly difficult to find. Nevertheless it gives a dimension of how much energy is used in our block of flats.

i. Number of occupants

The number of occupants is significant for different data and the base for all calculations. For example the water consumption depends on the number of occupants living in the building. The more people are accommodated, the more water is needed. Depending on the number of occupants, a building has different electricity consumption, as well. Therefore, the number of occupants is also important for laying-up a solar thermal or solar photovoltaic system. Because of that, the group tries to find an average number of occupants in our building.

All data about the building are researched by Ole Balslev's drawings from the company Cenergia.

The block is a five-story building with a basement. The Basement is either used as garage or storage rooms. It can be reached by steps, an elevator and a lift for cars. Unfortunately the basement has been neglected because of missing data.

The ground floor consists in six different shops, which have not been selected yet. This makes the estimation difficult, as different kinds of shops have different water and electricity consumption. Furthermore, working out numbers of employees and guests for each shop proved to be very hard to tell, because these numbers are depending on business volumes and hours, popularity, location and many more. They are specific for each shop, whether it is a restaurant or baker. Therefore consider the ground floor as neutral.

For the first floor to the fifth floor, we analyzed Ole Balslev's drawings in order to know how much bedrooms could be available for each flat. Depending on the possible number of bedrooms and living space we made a statement about the number of occupants. The fifth floor has no entries for flats, but it exists for common rooms and for flat A4, flat B4, flat C3 and flat C4.

Ground floor										
Name	**Shop (S)**	**Intern Floors**	**Kitchen**	**Toilets**	**Living room**	**Other rooms**	**Balcony**	**Common room**	**Net Surface [m²]**	**Average number of employees and guests**
A	S	1	1	2	X	2	X	1	116	variable
B	S	1	1	2	X	2	X	1	116	variable
C	S	1	1	2	X	2	X	1	112,5	variable
D	S	1	1	2	X	2	X	1	91,4	variable
E	S	1	1	2	X	2	X	1	43,2	variable
F	S	1	1	2	X	3	X	1	97,1	variable

First floor										
Name	**Flat (F)**	**Intern Floors**	**Kitchen**	**Bathroom**	**Living room**	**Other rooms**	**Balcony**	**Common room**	**Net Surface [m²]**	**Average number of occupants**
A	F	1	1	1	1	3	1	1	116,5	3-4
B	F	1	1	1	1	3	1	1	116,5	3-4
C	F	1	1	1	1	3	1	1	121,6	3-4
D	F	1	1	1	1	3	1	1	94,3	3-4
E	F	1	1	1	1	2	1	1	88,7	2-3
F	F	1	1	1	1	2	1	1	96,6	2-3

Second floor										
Name	**Flat (F)**	**Intern Floors**	**Kitchen**	**Bathroom**	**Living room**	**Other rooms**	**Balcony**	**Common room**	**Net Surface [m²]**	**Average number of occupants**
A	F	1	1	1	1	2	1	1	95,4	2-3
B	F	1	1	1	1	2	1	1	95,4	2-3
C	F	3	1	1	1	4	1	1	164,4	3-5
D	F	2	1	1	1	4	1	1	121,7	3-5
E	F	2	1	1	1	2	1	1	89	2-3
F	F	2	1	1	1	2	1	1	98,6	2-3

Third floor										
Name	**Flat (F) or Shop (S)**	**Intern Floors**	**Kitchen**	**Bathroom**	**Living room**	**Other rooms**	**Balcony**	**Common room**	**Net Surface [m²]**	**Average number of occupants**
A	F	2	1	1	1	3	1	1	116,5	3-4
B	F	2	1	1	1	3	1	1	116,5	3-4
C	F	3	1	1	1	4	1	1	141,1	3-5
D	F	2	1	1	1	3	1	1	120,8	3-4
E	F	2	1	1	1	2	1	1	112,9	2-3
F	F	2	1	1	1	2	1	1	120,6	2-3

Fourth floor										
Name	**Flat (F) or Shop (S)**	**Intern Floors**	**Kitchen**	**Bathroom**	**Living room**	**Other rooms**	**Balcony**	**Common room**	**Net Surface [m²]**	**Average number of occupants**
A	F	2	1	1	1	3	1	1	139,3	3-4
B	F	2	1	1	1	4	1	1	139,6	3-5
C	F	2	1	1	1	2	1	1	111,9	2-3

Figure 20: Number of occupants

- Average number of occupants for the first floor is between 16 people and 22 persons.
- Average number of occupants for the second floor is between 14 people and 22 persons.
- Average number of occupants for the third floor is between 16 people and 23 persons.
- Average number of occupants for the fourth floor is between 8 people and 12 persons.

Assuming that no singles live in our block of flats, the average overall result for the numbers of occupants in this building is between 54 people and 79 people. This average number does not include the ground floor and the basement.

ii. Fuel oil consumption

Denmark's prices for fuel oil, like prices for electricity, gas or water, are one of the highest prices in Europe.

[1] As you can see during this report, we decided to use district heating for our building because this included a lot of advantages in comparison to all the other heating systems for

our block of flats. For example, prices of district heating are cheaper than other systems and they have low carbon dioxide emissions.[2] Furthermore the prices of district heating have been stable for the last eight years, in comparison to oil and gas prices which are increasing more and more. Denmark's district heating system is well structured, and therefore, district heating is very commercial. Around 60% of the Danish population use district heating. In comparison to Europe's other countries, it is a very high number. Depending on the use of district heating, the building consumes no fuel oil, and therefore, we have no fuel oil consumption or fuel oil costs.

iii. Gas consumption

Using district heating, we have no gas consumption for heating. Nonetheless every kitchen of our building is provided with a gas connection. The decision lies with the occupants which kind of cooker they want to use. There are standard electric cookers, gas cookers or induction cookers. According to the target of this project, we propose to use induction cookers because gas cookers or standard electric cookers are less efficient, and therefore, less environmentally friendly than induction cookers.[3] For boiling one and a half liter water, gas cookers or standard electric cookers consume more energy than induction cookers. But on the other hand, gas cookers are more economical than induction cookers or standard electric cookers because prices of gas are nearly three times less than prices for electricity. It means that for boiling one and a half liter water by gas is cheaper than boiling one and a half liter by electricity. Therefore, gas consumption is based on the choice of occupants and finally unpredictable. However gas consumption will not be very high because we do not use gas for heating.

iv. Water consumption

Denmark is one of the pioneers within sustainability activities. Last available numbers of 2008 says that a Danish person needs only 130 liters fresh water per capita each day. In comparison to other countries in Europe, this is a fairly small amount. For example:[4]

Private	Water consumption in liters per capita and per day
Norway	260
France	156
England	149
Spain	145
Denmark	130
Germany	127
Hungary	107

Figure 21: Water consumption in Europe

The total water consumption of Denmark is almost 1 billion cubic meters per year, which comes entirely from groundwater. About one third is consumed by households, one third by agriculture and market gardens, and one third by industry and institutions. The water consumption for representative households is divided as follows:

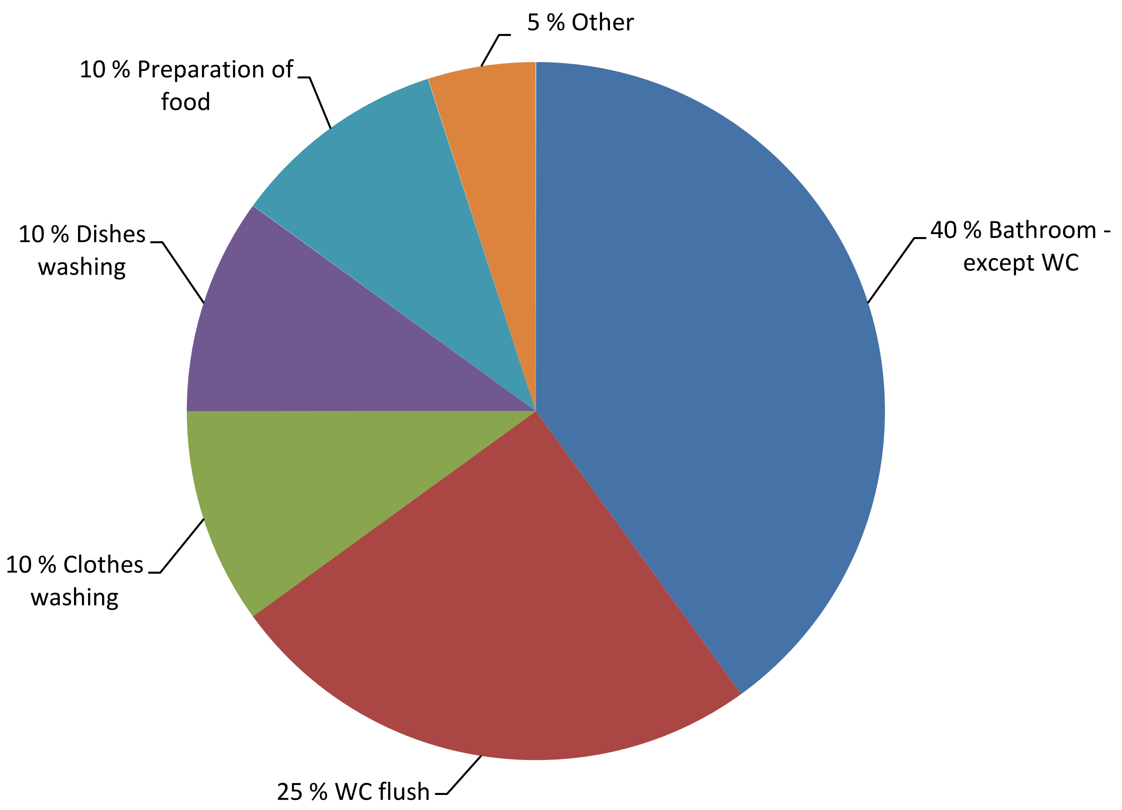


Figure 22: Water consumptions for representative households

Average water consumption for different households depends on the numbers of occupant in each flat or building. Tables of a German website indicate the consumption of different households in Germany. The difference for water consumption in average per capital and per day between Germany and Denmark is only 3 liters. Because of that and the fact that Germany and Denmark are very similar, we use these data for following calculations. We take also into account that this data are only average data, and consumption is individually reflected for each household. But in general, we expect that each flat will be under the economical average consumption because we have advantages in comparison to normal households. That means we supply guidelines for low water consumption, which propose to use new water saving systems for toilette flushes, showers and water taps. Furthermore the guidelines teach the occupants how to save water in all areas, in order to live with low energy consumption and low water consumption. The following table illustrates the relationship between occupants and water consumption.[5]

Persons	Water consumption	Assessment
1	≤ 80	economical
	> 80 ≤ 120	moderate
	> 120	excessive
2	≤ 160	economical
	> 160 ≤ 240	moderate
	> 240	excessive
3	≤ 240	economical
	> 240 ≤ 360	moderate
	> 360	excessive
4	≤ 320	economical
	> 320 ≤ 480	moderate
	> 480	excessive
5	≤ 400	economical
	> 400 ≤ 600	moderate
	> 600	excessive

Figure 23: Water consumption in liters and per day for different numbers of persons in a flat.

In order to find the water consumption for the building we made assumptions. The ground floor is still neglected. From the first floor to the fifth floor, the water consumption in average is calculated by the maximal number of occupants and economical water consumption for each flat.

Ground floor					First floor				
Name	**Shop (S)**	**Net Surface [m²]**	**Supposed number of employees and guests**	**economical water consumption [l]**	**Name**	**Flat (F)**	**Net Surface [m²]**	**Supposed number of occupants**	**economical water consumption [l]**
A0	S	116	variable	variable	**A1**	F	116,5	4	≤ 320
B0	S	116	variable	variable	**B1**	F	116,5	4	≤ 320
C0	S	112,5	variable	variable	**C1**	F	121,6	4	≤ 320
D0	S	91,4	variable	variable	**D1**	F	94,3	4	≤ 320
E0	S	43,2	variable	variable	**E1**	F	88,7	3	≤ 240
F0	S	97,1	variable	variable	**F1**	F	96,6	3	≤ 240
Result			variable		**Result**			≤ 1760	

Second floor					Third floor				
Name	**Flat (F)**	**Net Surface [m²]**	**Supposed number of occupants**	**economical water consumption [l]**	**Name**	**Flat (F)**	**Net Surface [m²]**	**Supposed number of occupants**	**economical water consumption [l]**
A2	F	95,4	3	≤ 240	**A3**	F	116,5	4	≤ 320
B2	F	95,4	3	≤ 240	**B3**	F	116,5	4	≤ 320
C2	F	164,4	5	≤ 400	**C3**	F	121,6	5	≤ 400
D2	F	121,7	5	≤ 400	**D3**	F	94,3	4	≤ 320
E2	F	89	3	≤ 240	**E3**	F	88,7	3	≤ 240
F2	F	98,6	3	≤ 240	**F3**	F	96,6	3	≤ 240
Result			≤ 1760		**Result**			≤ 1840	
Fourth floor					**Overall result:**				
A4	F	139,3	4	≤ 320					
B4	F	139,6	5	≤ 400	**≈ 7120 liter per day**				
C4	F	111,9	3	≤ 240					
Result			≤ 1760						

Figure 24: Water consumption for our building

The Danish water supply is highly decentralized and nearly all Danish drinking water comes from groundwater. Danish legislation requires full cost recovery for both water supply and sanitation (break-even principle). Therefore the water prices vary a lot from one supplier to another. Apart from the connection fee and water bill, a green tax is charged on water consumption. The consumer normally receives an overall bill for drinking water, wastewater, green taxes and VAT amount. The water and wastewater price paid by the consumer is split into 22 percent for water supply, 45 percent for wastewater and 33 percent taxes. In 2008, the average price for water and wastewater including VAT amount and green taxes was DKK 40.00 per cubic meter – one of the highest tariffs in the EU.[6]

With the aid of these data, the approximate annual average water costs, only for the flats with occupants, is calculated exemplary:

$$365\ days * 9{,}02m^3 * \frac{DKK\ 40.00}{m^3}$$

$$\frac{\boldsymbol{DKK\ 131700}}{\boldsymbol{year}}$$

v. Electricity consumption

In 2009 in Denmark, depending on suppliers of electricity, one kilowatt-hour of electricity with included taxes and duties costs in average DKK 2.01 for private households.[7] Therefore Denmark is the European's country with the highest electricity prices. In comparison to Denmark the price for electricity is only DKK 0.99 in France. France does not use the same technologies as Denmark. The most amounts of electricity in France are produced by nuclear power plants, which are not used by Denmark. It is therefore obvious that prices for electricity production in Denmark are higher than in France. As we can see in Denmark`s energy statistics for the year 2008, the country uses approximately 45% kooks, 15% natural gas, 15% wind energy, 15% other renewable energy sources and 7% oil to produce electricity.[8] The electricity consumption for typical households is divided as follows:

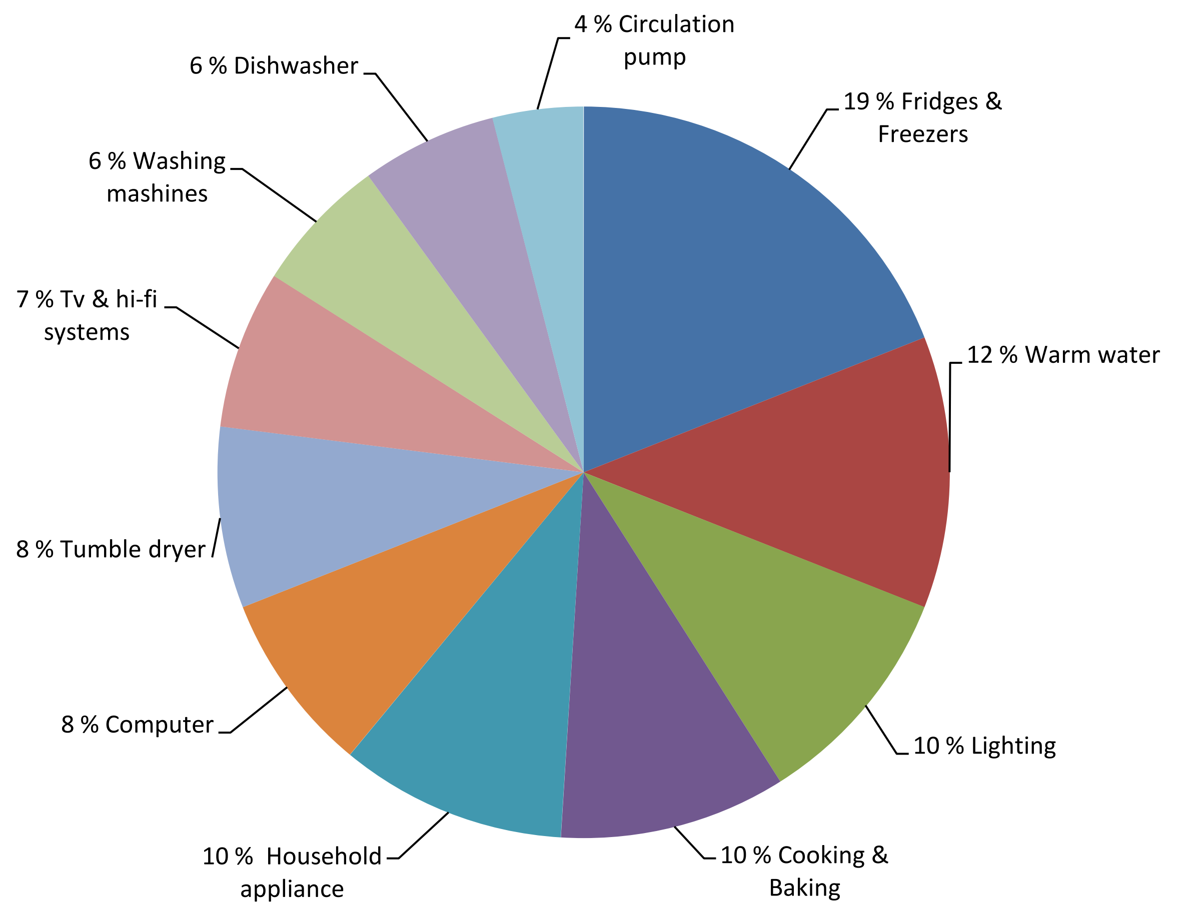


Figure 25: Electricity for representative households

According to different internet pages with different results for electricity consumption in averages, the following table illustrates the relationship between occupants and electricity consumption. [9]

Persons	Electricity consumption	Assessment
1	≤ 1550	economical
	> 1550 ≤ 1850	moderate
	> 1850	excessive
2	≤ 2000	economical
	> 2000 ≤ 2300	moderate
	> 2300	excessive
3	≤ 2550	economical
	> 2550 ≤ 2850	moderate
	> 2850	excessive
4	≤ 3300	economical
	> 3300 ≤ 3600	moderate
	> 3600	excessive
5	≤ 4100	economical
	> 4100 ≤ 4300	moderate
	> 4300	excessive

Figure 26: Electricity consumption in kilo watt hours and per year for different numbers in a flat.

This table shows only assessments values, which are adequate enough for our overview and to calculate electricity consumption in average for our block of flats.[10] In practice this data have a large scatter but we made it fit to our building. The data in the table do not include water heating because we decided to use a combination of district heating and solar collectors for domestic water. We proposed to use electric cookers as well, which is why data is included in the table. Common electricity consumption, for example for staircases, common rooms with included washing machines and freezers, basements, operation and controlling systems of the heating system, central ventilation and other systems such as door opening systems and so on, will be installed to decreases the overall energy consumption for each flat in our building. These boundary conditions are considered, too. Furthermore, according to our low energy house construction, we only want to employ Grade A equipment for common rooms and we prepare guidelines, which include how to save electricity. Because of that, we expect that occupants will also employ Grade A equipment and we will achieve a low electricity consumption.

In order to measure the electricity consumption from the first floor to the fifth floor, the average is calculated by the maximal number of occupants and economical electricity consumption for each flat. The ground floor is still neglected.

Ground floor					First floor				
Name	**Flat (F) or Shop (S)**	**Net Surface [m²]**	**Supposed number of occupants, guest or employees**	**economical electricity consumptions [kWh]**	**Name**	**Flat (F)**	**Net Surface [m²]**	**Supposed number of occupants**	**economical electricity consumptions [kWh]**
A0	S	116	variable	variable	**A1**	F	116,5	4	≤ 3300
B0	S	116	variable	variable	**B1**	F	116,5	4	≤ 3300
C0	S	112,5	variable	variable	**C1**	F	121,6	4	≤ 3300
D0	S	91,4	variable	variable	**D1**	F	94,3	4	≤ 3300
E0	S	43,2	variable	variable	**E1**	F	88,7	3	≤ 2550
F0	S	97,1	variable	variable	**F1**	F	96,6	3	≤ 2550
Result			variable		**Result**			≤ 18200	
Second floor					Third floor				
A2	F	95,4	3	≤ 2550	**A3**	F	116,5	4	≤ 3300
B2	F	95,4	3	≤ 2550	**B3**	F	116,5	4	≤ 3300
C2	F	164,4	5	≤ 3900	**C3**	F	141,1	5	≤ 4100
D2	F	121,7	5	≤ 4100	**D3**	F	120,8	4	≤ 3300
E2	F	89	3	≤ 2550	**E3**	F	112,9	3	≤ 2550
F2	F	98,6	3	≤ 2550	**F3**	F	120,6	3	≤ 2550
Result			≤ 18200		**Result**			≤ 19100	
Fourth floor					**Overall result:**				
A4	F	139,3	4		**≈ 65450 kilowatt-hours per year**				
B4	F	139,6	5	≤ 4100					
C4	F	111,9	3	≤ 2550					
Result			≤ 9950						

Figure 27: Electricity consumption for our building

With the help of these data, the approximate annual average electricity cost, only for the flats with occupants, is calculated exemplary:

$$65450\ kWh * \frac{DKK\ 2.01}{kWh}$$

$$\frac{\boldsymbol{DKK\ 131554}}{\boldsymbol{year}}$$

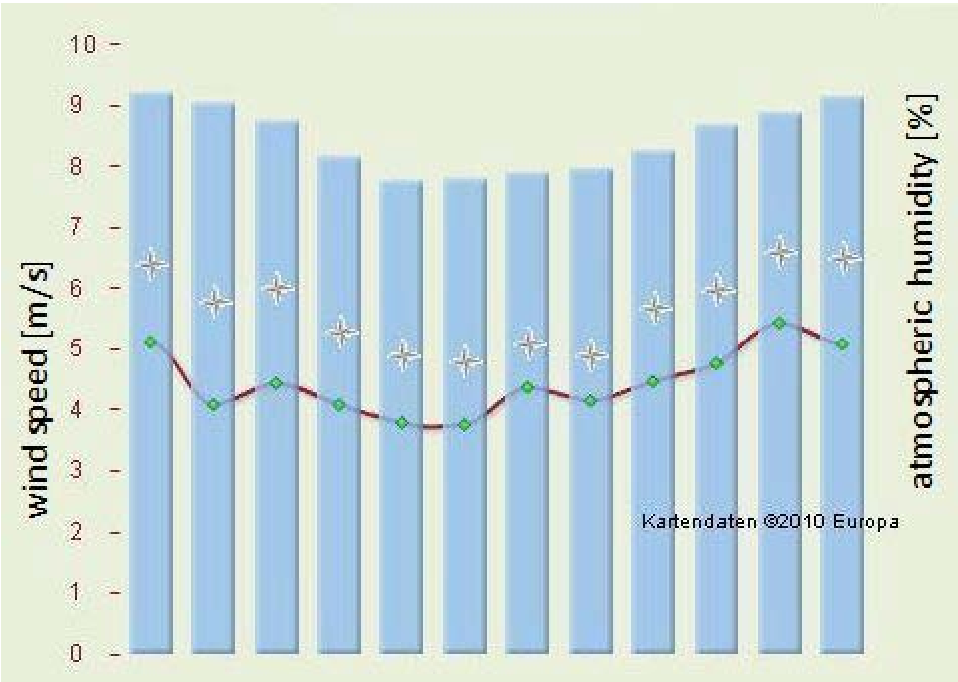
3. Climate and weather in Copenhagen

The local climate and weather is an important data according to our building. Let's introduce some characteristics of Copenhagen's weather.

Copenhagen has a humid continental climate with oceanic influences. The weather is instable, partly windy and grey. The Gulf Stream avoids too low temperatures by heating the water around the country. The precipitation is moderated during the year, with a small peak in summer. It also can snow during the winter. Spring is colder than in the southern countries in Europe, but sunny.

Month	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours of sunshine by day	14,6	22,9	30,9	42,5	49,7	47,1	46,7	49,4	39,7	30,8	22,9	15,3
Rainfall	43,5	27,8	35,5	35,5	42,3	52,3	64,7	61,6	56,4	54,3	56,6	52,4
Daytime temperature	0,2	0	2,2	6	11,1	15	16,4	16,3	13,4	9,8	5,4	2
Temperature profile	3,8	4,1	4,7	6,4	7,5	7,4	6,9	6,9	5,9	4,8	4	4

Figure 28: Climate in Copenhagen 1



Month	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind speed	6,4	5,8	6	5,3	4,9	4,8	5,1	4,9	5,7	6	6,6	6,5
Atmospheric humidity	92,4	90,9	88,2	82,5	78,9	79,3	80,1	80,7	83,6	87,5	89,4	91,8
Rainy days	15,9	12,7	13,8	12,7	11,8	11,7	13,6	12,9	13,9	14,8	16,9	15,8
Ground frost days	18,7	18,5	15,5	8	3,4	0,3	0	0	1,2	3,9	7,8	15

Figure 29: Climate in Copenhagen 2

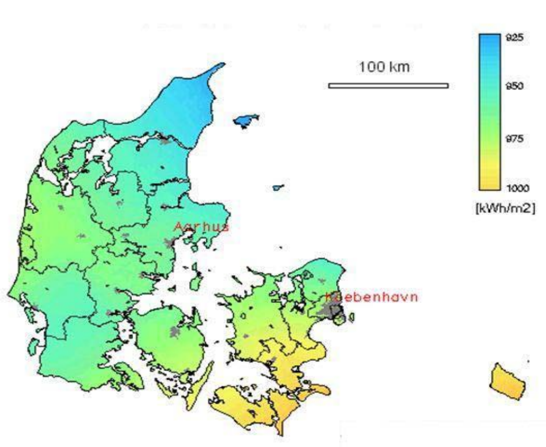


Figure 30: Global irradiation in Denmark

The annual amount of global irradiation is important if we use solar systems. In Copenhagen, it seems that the irradiation is nearly 1000kWh/m².

Part 3: Passive Solutions

1. Insulation

i. Introduction

The insulation is the most important aspect in a building, in order to save energy and to protect the environment by using as less energy as possible. Indeed, it permits to reduce the heating or cooling energy consumption, and so to preserve the energetic resources and to reduce the greenhouse gas emission. Moreover, a well-insulated house needs less entertaining, and offers a better comfort and a better life quality.

In a house, the main heat losses come from the following parts of the construction:

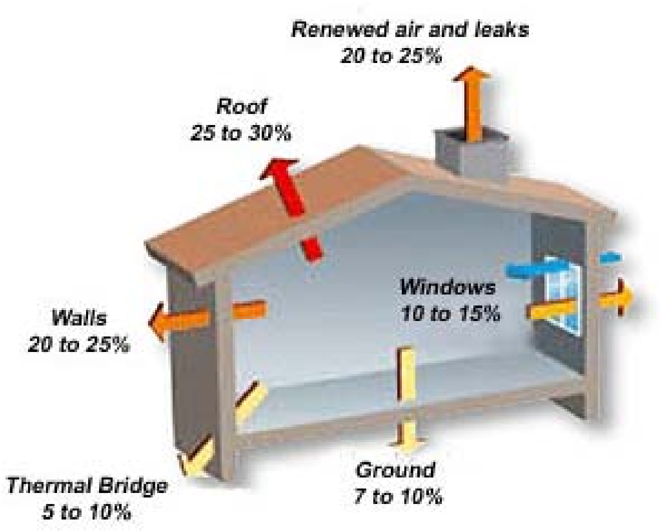


Figure 31: Principal heat losses in a house

Every part has to be insulated, but the most important are the walls, the ground the roof and the windows. The ventilation has to be well thought as well, in order to keep the heat inside while renewing the air every two hours.

So, five main points have to be satisfied:

- Minimizing the heat loss, and placing a good insulating material adapted to each part of the house;
- Creating a continue insulating layer, and avoid thermal points;

- Avoiding water seepage in an insulated wall;
- Avoiding air circulation inside, around and through the wall;
- In case of risk of condensation, slowing down the moving of water into the insulated wall.

ii. Definitions

Heat loss

The *heat loss* defines the energy or the power transmitted out of a system in the form of heat.

One of our main goals is to minimize the heat loss of our building, in order to reduce the heating energy consumption. Usually, it comes either from the transmission, or from the infiltration of cold air. In the first case, a good insulation of the house will avoid the most important of the heat losses. But, even if the insulation is good, they could come from the infiltration. That is why the construction of the building has to be done extremely carefully, in order to avoid water seepage or thermal points.

First, seals will be used in specific points, coatings will be added to the wall insulation, and special insulating layers will be put on the flat roofs to avoid water infiltration into the house.

Then, even if the building is well insulated, some heat losses could appear from the junction between the walls (or the floors and the walls), from the windows and from the doors. Moreover, in a case of a low energy house, good double flow ventilation is required and could be a source of heat loss as well.

These cold points are called *thermal bridges*. It consists in punctual or linear zones, where the thermal resistance is lower than in the rest of the surfaces, and in which moisture can appear. It could come from the zones quoted previously, or in case in defective lagging.

It could be located thanks to the *infrared thermography*. Indeed, by taking pictures of a construction with an infrared camera, the cold and warm points can be highlighted. The well insulated zones are represented in cold colors (blue, green), and the heat losses (thermal points) are represented in warm colors (orange, red). By doing so, it permits to correct those failures in the insulation, and avoid heat losses.

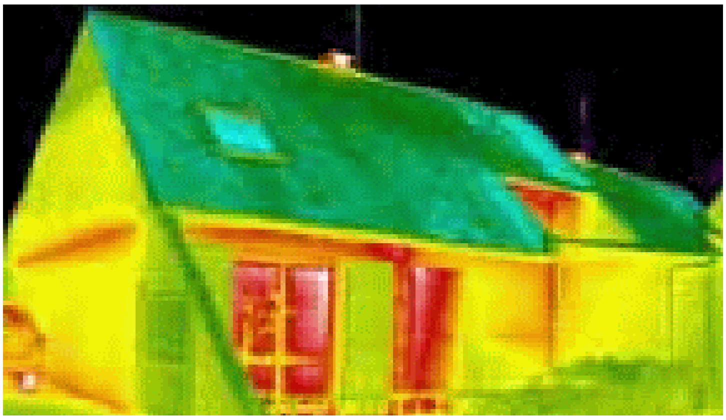


Figure 32: Thermal points around the windows in a house

For example, in this case, the main heat losses come from the windows. A solution could be changing them for a double or triple glazing, and remaking the junction around them.

Finally, another technology is used in order to avoid cold air entering into the house. Indeed, the *Blower Door Test* is used to measure the airproof power of a building, to locate the drafts, and avoid them. The main controlled zones are the following:

- Junction between a wall and a floor
- Junction between a wall and a roof
- Doors and windows
- Electric devices

The test consists in blowing air though these zones, and measuring the air flow. Then, as for the infrared thermography, the heat losses can be avoided by improving the junctions.

Figure 33: Blower door test

Main values

For the following parts of the insulation part, we are going to compare different insulating materials in function of many properties, in order to choose the best of them for each specific part of the building.

So we have to explain each property we are going to deal with.

- The **thermal resistance** corresponds to the ability of a material to resist to the heat conduction. The higher the R-value is, the better the insulating power of the material is. We can consider that a thermal resistance of $5 m^2.K/W$ corresponds to a good insulation.

- The **U-value** is the measure of the rate of heat loss through a material. Indeed, it indicates the amount of heat which moves through 1m² of an insulating material with a temperature difference of 1°K. Its unity is the W/m².K. The lower the U-value is, the better the material is.

- The **coefficient of thermal conductivity** λ acquaints to the ability of a material to conduct the heat. It is measured in W/m².K. In our case, the lower λ is, the better it is.

- The **Phase time difference** ϕ is the ability of the materials which compose the house's envelope to slow down the temperature changes. It is traduced by the time (h) during which the energy stored during the day by the material will be restituted during the night. The higher ϕ is, the better it is.

- The **hygroscopic capacity** is the ability of a material to absorb the excess of water vapor when the air is to wet, and to restitute it when it runs dry**.** A good lagging must be vapor proof, but keep a high hygroscopic capacity.

- The **waterproof power** is the ability of a material to do not let the water and the moisture enter the construction.

- The **reaction to the fire** is the character of a material to be combustible, and the **flameproof power** is the time during which the material limits the fire spread.

- The **thickness** of the laggings is also a criterion. The thinner it is, the cheaper it will cost, and the better it is.

- The **grey energy used for the manufacturing process** measured in kWh/m² for a lagging with a thermal resistance of R=5m².K/W acquaints on the whole energy used to make a given lagging.

- The **greenhouse effect** involved for the manufacturing process measured in kCO_2/m^2 for a lagging with a thermal resistance of R=5m².K/W acquaints on the CO_2 emission level.

- The **price** is always one of the most important problems, and we will try to minimize it.

iii. Insulating techniques

There are two global kinds of insulation: the **intensified** insulation and the **distributed** insulation.

The **intensified** insulation consists in insulating a building by adding lagging layers on its different surfaces.

Indeed, it can be insulated by the following different ways:

- The insulation from the **inside** is interesting when the outside faces are in good conditions. It consists in placing laggings layers inside the house surfaces. It is quite cheap, but involves the reduction of the room's areas, and possible problems for the opening of the windows and the doors.

- The insulation from the **outside** is interesting when the former coatings are defective, because it permits to insulate and to renovate the facades, both at the same time. The outside coatings protect the walls from the weather variation, don't modify the living areas and treat more thermal bridges. But this way is more expensive than the insulation from the inside.

- The insulation in a **hollow wall** is used in Mediterranean countries. The outside part of the wall avoids the rain water to get inside the house, the hollow part is half filled with a lagging for the thermal insulation, whereas the other hollow half will be used as the wall ventilation, and the inside façade consists in the load-bearing wall of the construction.

In each of these cases, the lagging chosen has to be strong enough to not subside with the time.

The **distributed** insulation is used in new buildings. It consists in constructing self-insulated walls, with special bricks. Then adding another lagging layer is not necessary, and so, the walls will be thinner than with an intensified insulation.
Technically, it forces the air from the outside which wants to come into the building to get around all the cavities of the wall. It moves round about three times more than the thickness of the wall, gets calories, and becomes warmer. Then, no cold air enters the house.

Furthermore, the materials used to make these kinds of bricks have a good phase time difference ($\phi \approx 12h$).[11] That is to say that they store the energy got during the day to redistribute it during the night (about12h after).

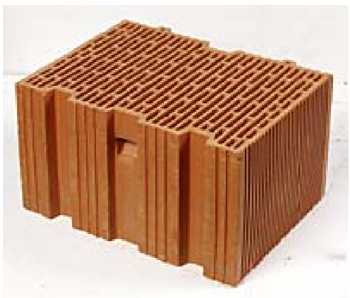
Finally, these materials absorb and store five times less of humidity than the other kinds of walls.

iv. Insulation of the walls

We decided to use the distributed insulation to build and insulate the walls because we are working on a new building, and also because this way seems cheaper, more efficient and more practical.

We compared the three best materials for this kind of insulation:

- Cellular concrete
- Terracotta bricks
- Hollow concrete tiles

		
Figure 34: Cellular Concrete	**Figure 35: Terracotta Brick**	**Figure 36: Hollow concrete tile**

Our benchmarks were the followings:

- The U-values;
- The coefficients of thermal conductivity λ;
- The thermal resistance;
- The phase time difference ϕ;
- The grey energy used to make the bricks;
- The diffusion resistance of water steam;
- The price.

	Terracotta bricks	Cellular concrete	Hollow concrete tiles
U-value (W/m².K)	0.22	0.46	0.49
Coefficient of thermal conductivity λ (W/m.K)	0.11	0.14	0.12
Thermal Resistance (m².K/W)	4.59	4.5	0.50
Phase time difference ϕ (h)	18.3	14.3	12.1
Grey energy needed (kWh/m²)	254	179	135
Diffusion resistance of water steam (m)	5.1	3.5	13.4
Price (dkk/m²)	372	298	74

Figure 37: Benchmarks and values for the walls insulation[12]

We compared the three materials to determine the best of them, and so, the best for our building.

U-value (W/m².K)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		-	-
Cellular concrete	+		-
Hollow concrete tiles	+	+	
Coefficient of thermal conductivity λ (W/m.K)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		-	+
Cellular concrete	-		+
Hollow concrete tiles	+	-	
Thermal Resistance (m².K/W)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		-	-
Cellular concrete	+		+
Hollow concrete tiles	+	-	
Phase time difference ϕ (h)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		-	-
Cellular concrete	+		-
Hollow concrete tiles	+	+	
Grey energy needed (kWh/m²)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		+	+
Cellular concrete	-		+
Hollow concrete tiles	-	-	
Diffusion resistance of water steam (m)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		+	-
Cellular concrete	-		-
Hollow concrete tiles	+	+	
Price (€/m²)	Terracotta bricks	Cellular concrete	Hollow concrete tiles
Terracotta bricks		+	+
Cellular concrete	-		+
Hollow concrete tiles	-	-	
Total of +	8	7	6

Figure 38: Comparison of the three kinds of bricks

Thus, the best way to build self-insulated walls is using terracotta bricks.

Properties of the terracotta bricks:

- It has an excellent phase time difference of 18.3h in average. That means the bricks store the energy given by the sun all the day, and restitute it during the night (after and during around 18h). The inertia of the bricks is in average $202Wh/m^3.K$.[13] Furthermore, it also has a cooling property during the summer time. The house can be 6°C lower than in a normal house with added laggings. Because of the Copenhagen climate, it will avoid us to use any cooling system.
- This material is very environmentally friendly because it doesn't emit any volatile organic compounds, any pollutants, and any fibers. No solvent, no linking products are needed; neither insecticides, nor fungicides because it is not an organic material, and cannot be any animal food.
- It absorbs just a few of humidity, and has no nutritive elements in favor of the mildew development.
- Terracotta has a huge lifespan, as we can see today for the Roman's constructions 4000 years ago. Actually, the performances are conserved during 100 years in average.[14]
- Finally, the bricks are frost resistant, waterproof and noncombustible.

Some Figures:

First, we had to find out which thickness of bricks we needed, and then, the total heat loss by the walls.

The figures we used are the followings:[15]

- The thermal resistance: $R=5m^2.K/W$;
- The coefficient of thermal conductivity: $\lambda=0.11W/m.K$;
- The ***U***-value: $U=0.22W/m^2.K$;
- The area ***A*** of the ground: $A=2948m^2$

In order to calculate the best thickness ***t*** of terracotta bricks we have to use, we used the following mathematic relation with the terracotta's properties:

$$\boldsymbol{R = \frac{1}{U} = \frac{t}{\lambda}}$$

$$\Rightarrow \quad t = R \times \lambda = 4.59 \times 0.11 = 0.5049m$$

$$\underline{\underline{\Rightarrow t = 50cm}}$$

Then, in order to calculate the heat loss $\boldsymbol{H_L}$ by the walls, we will use the following formula:

$$\boldsymbol{HL = U \times A}$$

$$\Rightarrow \quad HL(W) = 0.22 \times 2948$$

$$\underline{\underline{\Rightarrow \quad HL(W) = 642.3\ W/K}}$$

Then, to protect the bricks, and for the aesthetic aspect, inside and outside coatings have to be put on the wall.

For the outside façade, it is better to avoid concrete at the root of the coatings, and prefer more breathable materials like soil, clay or lime which respect much more the terracotta's nature.

For the inside façade, the same benchmarks have to be filled out. So the coatings previously quoted can be used, as well as plaster, with natural paintings (no glycero paintings).

Lime seems to be cheaper than the other materials, and has many good properties:

- It is waterproof, and permeable to water vapor;
- It is not permeable to the air, and so lets the wall breath;
- It is a healthy material, which avoids mildew development;
- It could be put on almost every support, and last a long time;
- It is easy to replace;
- And finally, it is fireproof.

Moreover, it has the same appearance than plaster but is more natural, and avoids thermal bridges.

So we will use it for both internal and external coatings

v. Insulation of the roof and of the roof-terrace

The insulation of the roofs is the most difficult, because we have to take into account how it will be used. In any case, we will use the intensified insulation technology by the outside, because it the only durable en effective way to do. Indeed, this manner permits to make the roof waterproof, and avoid the possible creation of leaks with the time.

Nowadays, flat roofs are aiming at the following points:

- Being flameproof thanks to the chosen insulating material;
- Being waterproof, using the mechanical properties of the chosen lagging;
- Being soundproof, thanks to the density and the thickness of the chosen lagging.

Two technologies are used in the flat roofs insulation:

- The first one, putting the lagging under the waterproof layer, is used when the waterproofness is defective. So it doesn't concern us, because we are working on a new building.
- The second one, which we are going to use, puts the lagging layers over the waterproof layer, on which gravels are added.

They are classified in function of four criterions:

- Their accessibility and their function;
- Their carrier element (material);
- Their slope;
- The region's climate.

But we are going to focus on the first point, which concerns the insulation itself.

Flat roofs can be:

- Inaccessible, except for maintenance;
- Technical areas (roofs to pedestrian traffic for maintenance such as repairing of a lift machinery);
- Accessible to pedestrians;
- Trafficable (for trafficking and parking vehicles).

In our case, we have inaccessible roofs, on which we will place solar panels, and accessible roofs, for the gardens, as we can see on Ole Balslev-Olesen's drawings:

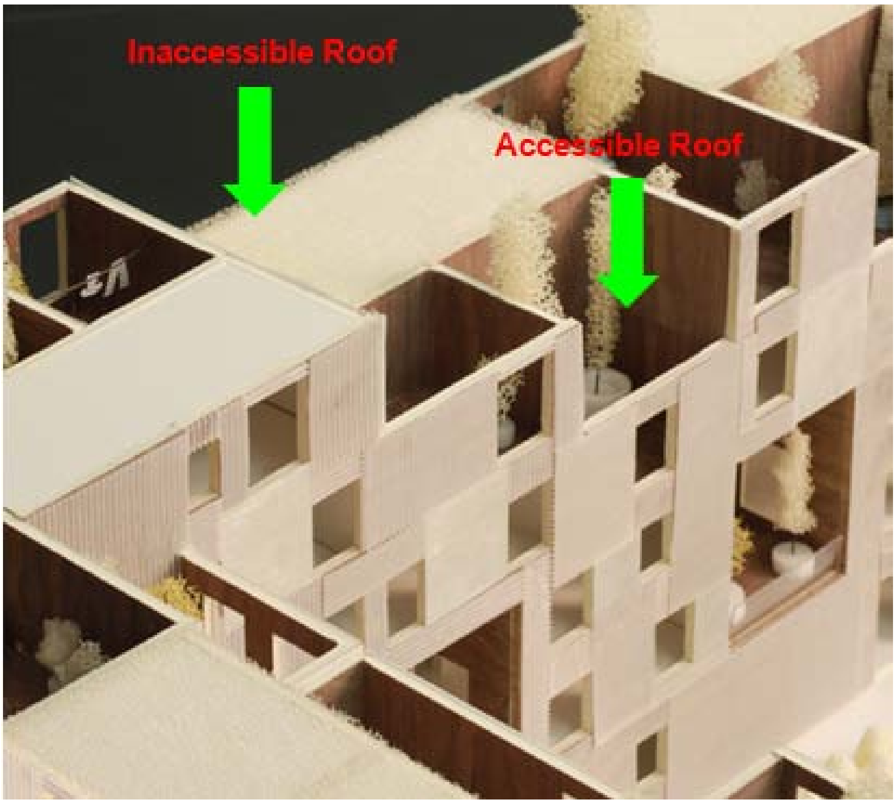


Figure 39: Roof of the building

Structure of a flat roof:

To be perfectly waterproof and insulator, a flat roof is build according to the following structure:

- A carrier element;
- A slope;
- A seal coat;
- The waterproofness;
- A protection;
- A ballasting.

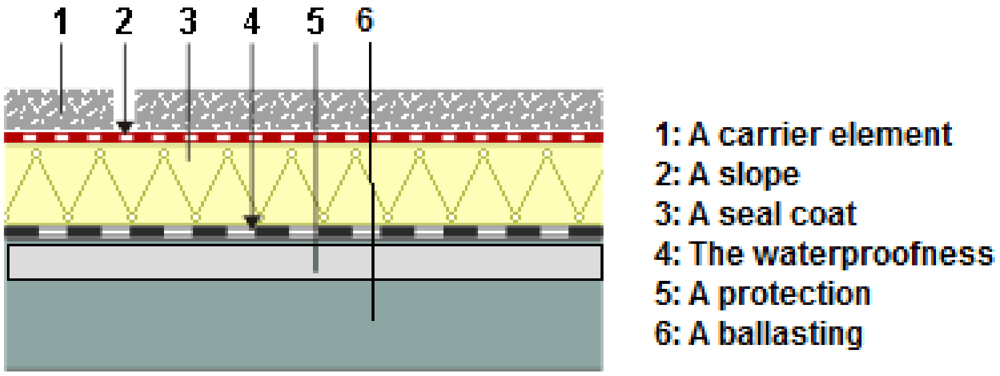


Figure 40: Structure of a flat roof

Insulation:

Thanks to a recapitulative table found in the magazine “La maison écologique n°49” (Cf. Appendix 1), we were able to define the best material for the both parts.

As for the walls’ insulation, we compared each material in function of the following properties:

- The coefficient of thermal conductivity λ;
- The hygroscopic capacity;
- The coefficient of vapor resistance μ;
- The phase time difference ϕ;
- The average thickness needed *t* (cm);
- The primary energy used to produce them (grey energy);
- The greenhouse effect involved during the producing process.
- The average price (dkk/m²);

We consider that all the materials have a thermal resistance of $R=5m^2.K/W$.

Then, we were able to compare each material to the others for all the properties in the table (Cf. Appendix 2) and to imitate it into a diagram:

Materials	Extruded Polystyrene (Boards)	Glass Wool (Rolls)	Rock Wool (Rolls)	Fibre Wood (Flexible Boards)	Fibre Wood Dense Boards)
%	50.00	53.47	59.03	27.08	37.50
Cellulose (Insuflated Bulk)	Cellulose (Dumped Bulk)	Cellulose (Boards)	Cork (Bulk)	Cork (Boards)	Hemp Wool (Rolls)
61.81	47.92	40.28	27.78	36.81	38.19
Hemp Wool (Boards)	Hemp Stalk (Bulk)	Linen Wool (Rolls)	Linen Wool (Boards)	Sheep Wool (Rolls)	Sheep Wool (Boards)
46.53	40.97	49.31	43.75	56.25	68.75

Figure 41: Percentage of good properties

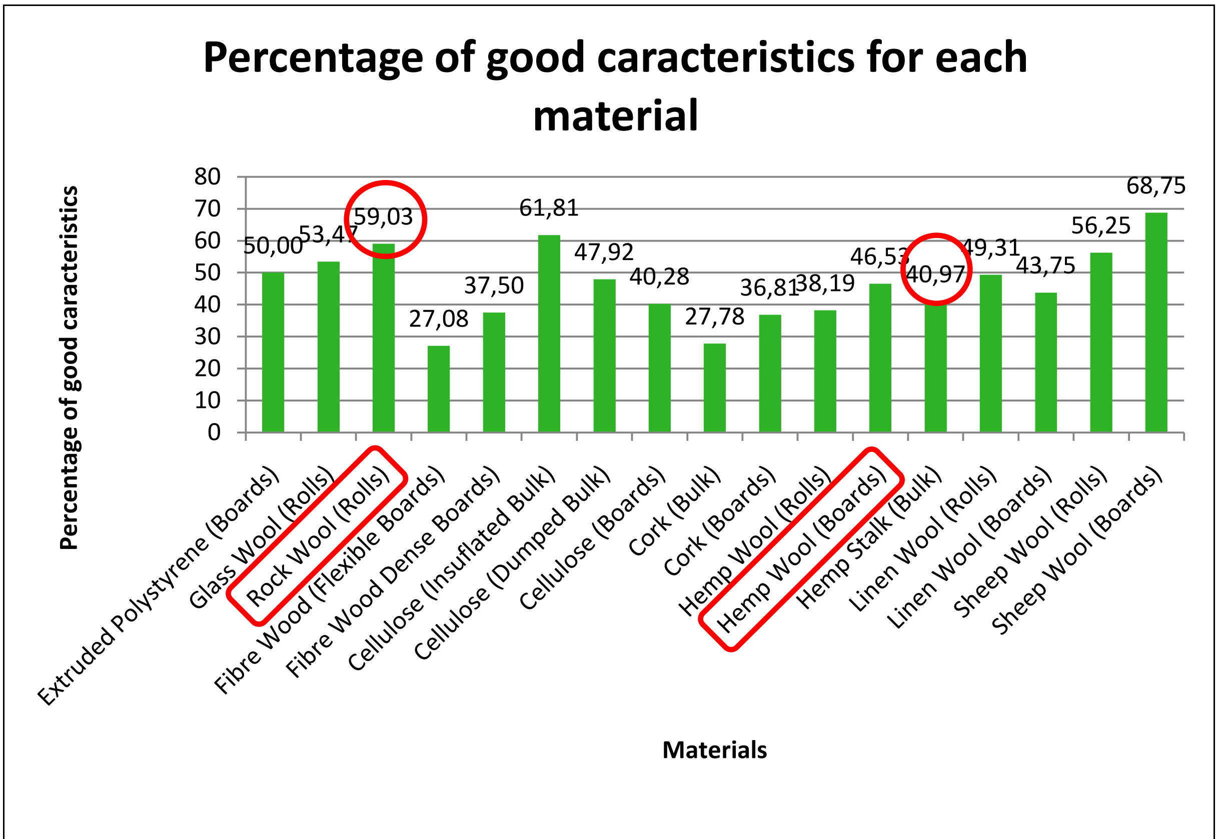


Figure 42: Classification of the laggings in function of their properties

Insulation of the inaccessible roofs (real roofs, with solar panels on the top):

The rock wool turned out to be the best insulating material for the inaccessible roofs' insulation.

In addition of being an excellent insulator thanks to the many air cells inside it, the rock wool is a very good acoustic insulating material as well, and permits to fight against impact and air noises.

It also water-resistant, and protects buildings against fire, because it has the best performance in the European classification (Euroclass A1);

Thanks to its mineral origin, it cannot serve of food to any animal, and avoids termite's development.

Finally, it has very good mechanics properties: durable, inert, stable, and conserves all those qualities during the time.

Some Figures:

As for the walls, we listed the useful figures, in order to find out which thickness of rock wool necessary, along with the heat loss by the flat roofs.

The figures we used are the followings:[16]

- The thermal resistance: R=5m².K/W.
- The coefficient of thermal conductivity: λ=0.04W/m.K.
- The ***U***-value: U=0.2 W/m².K.
- The area ***A*** of the ground: A=2029m².

Calculations:

$$\boldsymbol{R = \frac{1}{U} = \frac{t}{\lambda}}$$

$$\Rightarrow \quad t = R \times \lambda = 5 \times 0.04 = 0.2000m$$

$$\underline{\underline{\Rightarrow t = 20cm}}$$

Then, we were able to calculate the heat loss H_L by the roofs:

$$\boldsymbol{HL = U \times A}$$

$$\Rightarrow \quad HL(R) = 0.2 \times 2029$$

$$\Rightarrow \quad \underline{HL(R) = 405.8\, W/K}$$

Insulation of the accessible roofs (gardens):

The sheep wool turned out to be the best insulating material for the accessible roofs' insulation.

Figure 43: Sheep wool in boards

Sheep wool is a lagging derived from raw materials of variable nature and quality. It can raw or manufactured. In this case we add up to 25% of synthetic fibers to ensure the cohesion of panels.

It also receives complementary antifungal, insecticide and flameproof therapies, even if it catches fire from 560°C, and tends to go out itself. If not, there is a risk of fungal growth or development of insects.

It has an excellent hygroscopic capacity, because it can absorb round about 30% of its mass. But its thermal conductivity depends on the moisture. In this case, the λ is increased of 0.005W/m.K.

Some figures:

As for the other parts, we listed the useful figures, in order to find out which thickness of sheep wool necessary, along with the heat loss by the flat roofs.

The figures we used are the followings:

- The thermal resistance: R=5m².K/W.
- The coefficient of thermal conductivity: λ=0.037W/m.K.
- The ***U***-value: U=0.2 W/m².K.
- The area ***A*** of the ground: A=601m².

Calculations:

$$\boldsymbol{R = \frac{1}{U} = \frac{t}{\lambda}}$$

$$\Rightarrow \quad t = R \times \lambda = 5 \times 0.037 = 0.1875m$$

$$\underline{\underline{\Rightarrow t = 18.75cm}}$$

Then, we were able to calculate the heat loss $\boldsymbol{H_L}$ by the roof-terraces:

$$\boldsymbol{HL = U \times A}$$

$$\Rightarrow \quad HL(RT) = 0.2 \times 601$$

$$\underline{\underline{\Rightarrow \quad HL(RT) = 120.2\ W/K}}$$

vi. Insulation of the floors and the ground

Finally, the last parts to insulate in our building are the floors between the flats, and the ground.

Thanks to the same statistics, we found the appropriated laggings for both parts:

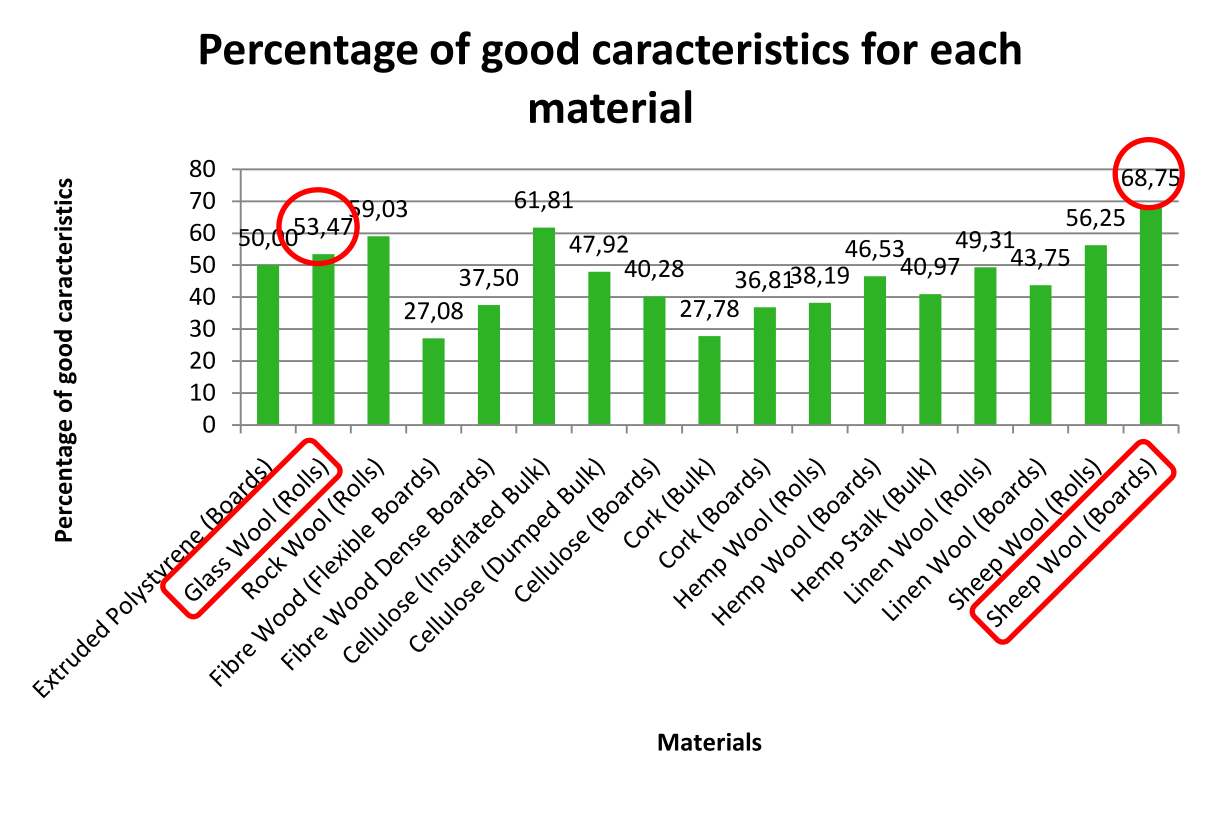


Figure 44: Classification of the laggings in function of their properties

Then, we found, in function of the table and of the diagram, that the best insulating material to insulate the floors was the sheep wool in boards, and the glass wool in rolls to insulate the ground.

<u>Insulation of the floors:</u>

The insulation between each floor is not as important as a surface in relation with the outside because it will not be taken into account for the global heat loss of the construction. But it is still important because it will avoid having any heat transfer between two flats.

Sheep wool was chosen as the best lagging for this part of the building. It is an excellent soundproofing as well, and will permit to insulate phonically the flats between each others.

<u>Some figures:</u>

This material was already described previously. Just as reminder, the figures we used are the followings:

- The thermal resistance: R=5m².K/W.
- The coefficient of thermal conductivity: λ=0.037W/m.K.
- The ***U***-value: U=0.2 W/m².K.

- The area ***A*** of the ground: *A*=601m².

So, we could calculate the thickness needed with the following formula:

$$\boldsymbol{R = \frac{1}{U} = \frac{t}{\lambda}}$$

$$\Rightarrow \quad t = R \times \lambda = 5 \times 0.0375 = 0.1875m$$

$$\underline{\Rightarrow t = 18.75cm}$$

We can calculate the heat loss from the floor, but it is not really necessary since there is no relation with the outside, and then, no relation with the total heat loss of the building.

$$\boldsymbol{HL = U \times A}$$

$$\Rightarrow \quad HL(F) = 0.2 \times 4761.94$$

$$\underline{\Rightarrow \quad HL(F) = 952.4\, W/K}$$

Insulation of the ground:

Finally, the last par to insulate is the ground, or more exactly, the floor between the basement and the living areas.

Thanks to the same table from "La maison écologique n°49", we defined the glass wool as the best material for insulating the ground.

Figure 45: Glass wool in rolls

Glass wool is made with derivates from rock, sand, and recycled glass.

It is a famous material used either for the insulation, or for the acoustics of a building. It is nonflammable, and that is why it is also considered as a protection for the occupants.

Even if many solvents and linking products are part of the glass wool, it is a healthy material, because it is not considered as a carcinogenic.
Lastly, even if the manufacturing of the glass wool uses a lot of grey energy, it is nevertheless taken for granted as an environmentally friendly material because it permits to reduce the CO_2 emissions and the greenhouse effect.

Some Figures:

As for the walls, we listed the useful figures, in order to find out which thickness of glass wool necessary, along with the heat loss by the ground.

The figures we used are the followings:

- The thermal resistance: R=5m².K/W.
- The coefficient of thermal conductivity: λ=0.035W/m.K.
- The ***U***-value: U=0.2 W/m².K.
- The area ***A*** of the ground: A=2630m².

Calculations:

$$\boldsymbol{R = \frac{1}{U} = \frac{t}{\lambda}}$$

$$\Rightarrow \quad t = R \times \lambda = 5 \times 0.035 = 0.1750m$$

$$\underline{\underline{\Rightarrow t = 17.5cm}}$$

Then, we were able to calculate the heat loss $\boldsymbol{H_L}$ by the ground:

$$\boldsymbol{HL = U \times A}$$

$$\Rightarrow \quad HL(G) = 0.2 \times 2630$$

$$\underline{\underline{\Rightarrow \quad HL(G) = 526\, W/K}}$$

vii. Conclusion for our building

To conclude, we had made a study to determinate the best lagging for each part of the building. We are now able to determine the total heat loss of the building, adding all the specific heat losses:

$$HL(TOTAL) = HL(W) + HL(R) + HL(RT) + HK(G)$$

$$HL(TOTAL) = 642.3 + 120 + 405.8 + 526$$

$$\underline{HL(TOTAL) = 1694.3W/K}$$

The floors' heat loss is not taken into account in this calculation, because it doesn't take part into the insulation between the outside and the inside of the construction.

These numbers are theoretical, and they should normally be reached if the work is well done. It also could be interesting to measure the real global heat loss of the house when it will be built.

2. Vegetation

i. Introduction

The vegetation is another way, too much unknown, of insulating a house. Indeed, the principle of the Green Roof consists in making vegetation grow, planted over a waterproofing membrane on a flat roof or on a low slope roof. Beyond, we could discuss about vegetated walls, but not in our case.

Many experiments were made in Europe since the 70s especially in Scandinavian countries, and showed that it was a good way as for the durability of a construction and the protection of the biodiversity, as for giving back a good aesthetic value to the constructions in a city.

More and more companies specialize in complete and efficient systems, like vegetated mats or sprinkler systems. This technology which is well developed is easy to set up, and doesn't damage the building. It brings stability and waterproofness more than classical flat roofs.

Figure 46: Flat green roof

ii. Advantages and disadvantages

Green roofs have many advantages, in which some of them are being of a public interest.

Ecological and sanitary aspects

- Green roofs catch atmospheric dusts and pollens thanks to the dew;
- The substrate catches lead, carbon, and organic matter particles;
- It reduces CO and CO_2 emissions, and increases O_2 emission.
- It creates spare time places, and so relieves over-visited natural sites, while reducing traffic and pollution;
- It has good effects on the climate, microclimates, hygrometry, and so on occupants' health;
- Vegetated roofs reduce global warming effects. A study made in Canada proved that green roofs on only 6% of the houses reduces the temperature of 1.5°C, and cooling costs of 5%[17];
- It has a very good impact on the water, because of the biological filtration and purification;
- It regulates the water flow in pluvial sewer, by absorbing and storing the rainwater in the substrate and by watering the vegetation. Yearly, it is able to absorb round about 50% of the rainwater, and so reduces by 5% to 10% the treating costs[18].

Technical impact

- The waterproofness is protected from the ultraviolet rays by the substrate and the vegetation and lasts longer;
- Vegetated roofs protect the building and its occupants from the heat shocks. Indeed, it reduces temperature variations by round about 40%[19];
- It brings a huge thermal inertia to the building and avoid to cool during the summer;
- It constitutes a good acoustic insulation by absorbing sound waves. It reduces urban noises and impact noises (≈40dB(A) less for 12cm of substrate)[20].

Cost and economical impact

At first, the vegetated roof seems to be more expensive than a normal one, because the waterproofness' and the vegetation's prices depend on the area of the roof, its slope and of the chosen plants. Some strengthening work could also be expected, in order to support the substrate's weight.

But on the long view, this technology turns out to be profitable because of the following points:

- It plays the part of the thermal insulator in which temperatures don't vary so much. It reduces by 20% the energy cost of heating or cooling a building[21];
- It is a capital gain in case of the roof can be used as a garden (selling or renting);
- It contributes secondarily to the reducing of the health costs and of the cleaning costs (maintenance and repairing due to the flood…)

Disadvantages

- This kind of roof requires a very good waterproofness, which cannot be reached for high slope roofs;
- The weight of the substrate can be a problem for weak constructions, that is why we will prefer long and large buildings than high ones;
- The kind of vegetation has to be well chosen, and the sprinkler system well thought for the dry and hot periods;
- Finally, green roofs stay at a high price and are not accessible to everybody. But, "ecological bonuses" for these roofs' construction should be given in few years in order to increase their number.

iii. Structure

A green roof is always composed of five main parts:

Bearing structure

The roof must be flat, or steeped to 35% maximum[1].

The structure must be strong enough to support the substrate's weight, even in case it is full of water. It could be made of concrete, steal, or wood.

Waterproofness

As explained previously, it is an essential part of a flat roof. It must be resistant to the compression (substrate's weight) and to the roots.

The best and most famous way is to put two layers made of asphalt. Indeed, other systems exist like synthetic asphalt, rubber, or PVC, but are less efficient.

Draining and filtering layer

Depending on the slope of the roof, the resistance of the bearing structure and the substrate's thickness, we can put a draining layer in order to help the rainwater to flow until the drainpipes. A filter can be added to avoid any piece of substrate into the pipes.

Growing substrate

The substrate must be light but resistant to the compression, while retaining water.

Its thickness could vary from 10cm to 30cm[2], depending on the type of plants we want to make grow on, and so depending of the climate.

In any case, the construction has to be strong enough to support the substrate's weight, even when it is full of water, or when it is snowing.

Vegetal layer

Normally, all kind of plants could be used. Most of the time, we use grass or shrubs.

But in any case, they have to be chosen in function of the climate, of the sunshine, of the slope, and of the substrate's thickness.

iv. Conclusion for our building

To conclude on the vegetable insulation of the roof, we can say that it seems to be better than all kind of flat roofs.

But in our case, we need to install solar panels on the top of the roof in order to produce electricity to heat the water up, for the heating system, and for the electric devices.

In this case, it is possible but difficult to combine the both technologies for three main reasons:

- The solar panels might be hidden by the plants, and so receive less sunlight and are less efficient;
- They cannot be integrated to the roof (they are put on supports), which means that we do not have any advantageous resale tariff;
- The climate is harsh, and not favourable for the plants development.

3. Glazing

i. Introduction

According to the French Environment and Energy Management Agency (ADEME), heat losses from windows for a house built before 1975 represent 10 to 15%[1] of the total losses.

Nevertheless, windows are the main sources of heat supply in a building. An important choice has to be made: Is it better for heat supply to use double or triple glazing, taking into consideration supply of sun, losses per convection and prices of the windows?

ii. Windows of our building

With a surface of 660 m², windows represent 22% of the total walls surface. According to the drawings, the distribution of them is:

North	235m²
East	205 m²
South	120 m²
West	100 m²

Figure 47: Surface of windows

iii. Conclusion for our building

Because it is very hard to find any study in English about contribution of windows for heat supply, we decided to use data from France. We noticed that the number of hours of sunlight per year is similar: 1603 hours in Copenhagen and 1637 in Strasbourg. Moreover, the climate is the same and the temperatures are very close:

Mois	Jan.	Fév.	Mars	Avr	Mai	Juin	Juil.	Août	Sept.	Oct.	Nov.	Déc.
Températures moyennes (°C)	1,6	2,8	6,7	9,7	14,3	17,3	19,5	19,3	15,5	10,6	5,3	2,8
Précipitations (mm)	30,0	35,0	36,1	42,5	78,2	76,7	66,2	57,9	62,1	52,5	49,8	44,5
Sources des données : Météo France												

mois	jan.	fév.	mar.	avr.	mai	jui.	jui.	aoû.	sep.	oct.	nov.	déc.	année
Température maximale moyenne (°C)	3,1	3,3	5,9	10,7	16,3	19,5	21,5	21,5	17,2	12,5	7,5	4,6	12

Figure 48: Temperature of Strasbourg

The results of the study[2] are below. Negative numbers are obtained when heat is more won than lost:

	Consumption of south glazing (kWh/m²)
South side	
Simple glazing	-47,5
Double glazing with argon	-254,6
Triple glazing with argon	-206
East and West side	
Simple glazing	150,9
Double glazing with argon	-100,3

Triple glazing with argon	-95,7
North side	
Simple glazing	288
Double glazing with argon	7,0
Triple glazing with argon	-19

Figure 49: Temperature of Copenhagen

Considering the high price of triple glazing and the low difference of heat supply, we choose to **use double glazing for the whole building.**

4. Ventilation

i. Our choice: Heat recovery system

As building efficiency is improved with insulation and weather-stripping, buildings are intentionally made more air-tight, and consequently less well ventilated. Since all buildings require a source of fresh air, the need for heat recovery ventilation (HRVs) has become obvious. While opening a window does provide ventilation, the building's heat and humidity will be lost in the winter and gained in the summer. Both of them are undesirable for the indoor climate and for energy efficiency. HRV technology offers an optimal solution: fresh air, better climate control, and energy efficiency.

ii. Conclusion for our building

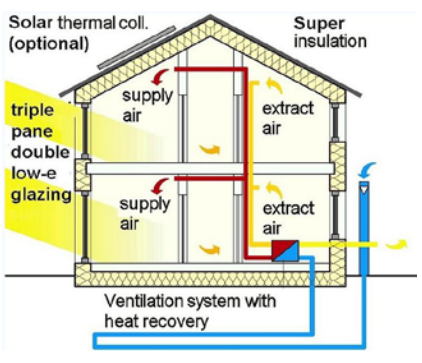


Figure 50: Heat Recovery System and Earth tubes

We propose to combine earth tubes with heat recovery systems Then, the air will be preheated before entering the building:

Different simulations will be obtained in the part 4: Money/Saving.

5. Daylighting

i. Introduction

We can describe *daylighting* as the practice of placing windows or other openings all over the buildings in order to take advantage, as much as possible, of the day natural light hours to provide effective internal lighting.

Daylighting can be distributed to interior space through openings from the side, from the top, or a combination of the two. The building type, height, aspect ratio and massing, dominant climatic conditions, site obstructions, adjacent buildings, and other issues most often drives choice of strategy.

It is a fact that when illuminating a visual task, humans prefer natural light over artificial or electric lighting. Sunlight has a perfect color rendering and provides very proactive elements in the behavior of individuals. Therefore, while designing a new building, it is very important that we pay particular attention to daylighting when the aim is to maximize visual comfort or to reduce energy use.

Good daylighting design can result in energy savings and can shift peak electrical demand during afternoon hours, when daylight availability levels and utility rates are high. Energy savings can be achieved either from the reduced use of electric lighting or from passive solar heating or cooling.

Daylighting has a lot of advantages over artificial or electric light, some of them follow:

- Is provided by a renewable energy source.
- It involves energy savings.
- It can provide higher light levels (during daylight) than those obtained with electric light.
- Direct sunlight introduces less heat per lumen than most of electric light sources.
- Has the distinction of being dynamic.
- Adequate provision of natural light to a house or local may increase their commercial value.

After this brief introduction we will now proceed to mention and describe some daylighting design strategies.[22]

ii. Design strategies using daylight

There are a lot of different ways and different systems to admit daylight into a space, depending on the shape of the building. In this chapter we are going to mention those ways or systems that could fit better in our building to provide daylight.

Windows

Windows are the most common way to admit daylight into a space but still, one of the most efficient. They admit sunlight and diffuse daylight at different times of the day and year. Therefore, we have to take into account the climate and the latitude where the building is going to be constructed and combine windows in different orientations to obtain the right mix of light into our home.

Figure 51: A facade of our future building with random windows.

The sizes and locations of windows should be based on the cardinal directions rather than their effect on the street-side appearance of the house. A generally accepted way of building low energy houses has been to have small windows facing north and large windows to the south. This is to minimize losses on the north side while gaining as much solar heat as possible on the south.

The advantages of placing windows in a building are, obviously, having natural sun light into the house, which derives in having less electricity consumption. Windows are also a great source of passive heating and cooling. During the summer, an open window can help in cooling the house, meanwhile in the winter the heated glass provides a warm atmosphere in the home.

One of the great disadvantages of having windows is the loss of energy. Windows are a big enemy of insulation; we can suffer important heat losses through them if they are not properly insulated.[23]

__Terraces and open spaces__

Figure 52: Courtyards in our future building.

Terraces and *open spaces* are outdoor areas open to the sky, which are partially or totally enclosed by the building. In partly enclosed courtyards, the north orientation should be the open segment to reduce glare and to reduce the need for sun control. Facade and ground materials should reflect daylight and sunlight without increasing glare for building users.

The advantages of having terraces and open spaces are, just like windows, they provide natural sun light into the home and are a natural source of heating and cooling. They are also a leisure area, a transition space between flat and street.

The main problem of open spaces and terraces is also the loss of heat through them.

__Skylights__

Figure 53: A skylight in a bathroom

We could define *skylights* as horizontal windows or domes placed at the roof of a building, where the main aim is to provide daylight into the rooms. Skylights can also be installed on the floor, under our feet, in order to provide light to subterranean areas such as parkings, basements.

The advantages are that they admit more light per unit area than windows, and distribute it more evenly over a space.

The disadvantages, when not correctly installed, are that they may have leaking problems and single-paned skylights may weep with condensation. Thermal gain is an issue in hotter climates.

Light Tubes

A *light tube* or *TDD's* (Tubular Daylighting Devices) use modern technologies to transmit visible light through opaque walls and roofs. The tube itself is a passive component consisting of either a simple reflective interior coating or a light conducting optic fibre bundle. It is frequently capped with a transparent, roof-mounted dome 'light collector' and terminated with a diffuser assembly that admits the daylight into interior spaces and distributes the available light energy evenly (or else efficiently if the use of the lit space is reasonably fixed, and the user desired one or more 'bright-spots').

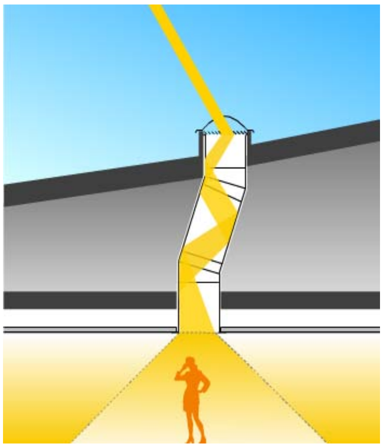


Figure 54: TDD installed in a roof

The advantages of the TDD's are that they are easy to install. They can be located in numerous places. The relation cost-efficiency is very good.

The disadvantages are that they do not allow as much heat transfer as skylights because they have less surface area.[24]

Fiber Optic Solar Lighting

Since we are not only responsible for the search of low energy technologies but also innovative solutions, we think it is worth it to mention this next system, even if we are not going to implement it in our building.

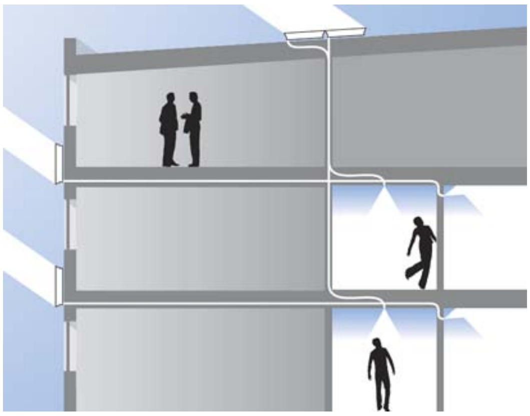


Figure 55: Optic fiber solar lighting

Parans is an indoor lighting system powered by solar energy. Panels are placed outside a building to capture sunlight, which is "transported" via a system of mobile reflectors, to indoor light fixtures that are specially design to fit thin flexible fiber optics. A micro computer, that automatically moves the reflectors throughout the day, guarantees a maximum use of light. The system is thus extremely efficient, because it increases the amount of light that can be transported from a distance, in addition to allowing buildings with few windows to enjoy natural light.

The solar panels

The solar panels are $1m^2$ modules that can be mounted on roofs or facades. Inside the panel, an array of 62 optical lenses move uniformly around their axis tracking and concentrating incoming sunlight. The solar panels employ active tracking, guiding the lenses so that they are always orientated towards the sun. This movement is achieved with three motors, consuming on average under 2W. Thanks to the active tracking, the solar panels can be installed or moved to any location and orientation without pre-programming. On a technical level, the tracking is controlled by a photosensor that continually feeds the internal microcomputer with light level data. At installation, the solar panels immediately scan the sky to detect the direction to the sun. It then learns and remembers the solar path so that it always is ready to collect sunlight.

Figure 56: Parans Solar Panel

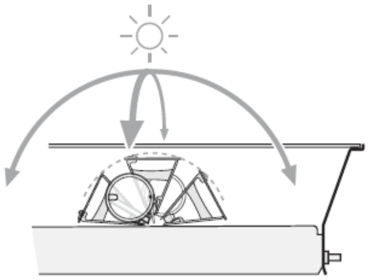


Figure 57: Acting tracking lenses

The solar panels have the capacity of collecting sunlight over large angles as well as delivering high luminous flux. They can collect sunlight with an incident angle of 60 degrees from the direction to the sun, thus forming a 120 degrees active cone. This represents on average 8 hours of sunlight.

They are easily installed and integrate with buildings' surfaces to allow for architectural integrity.

The optical cables

From each solar panel come four optical cables. These are 6mm in diameter, a density of 30 g/m and can be ordered up to 20m long. The bending radius can be as small as 50mm, making light work of tight corners.

The optical cables are sheathed with fire retardant Megolon. Within the cable, the light is transported in 16 of the 0'75 mm High Performance Plastic Optical Fiber made of PMMA (PolyMethylMethAcrylate). The light transmission is 95'6 percent per meter. This gives for example that 64% of the light remains after being transported 10 meters in the optical cable, see graph below.

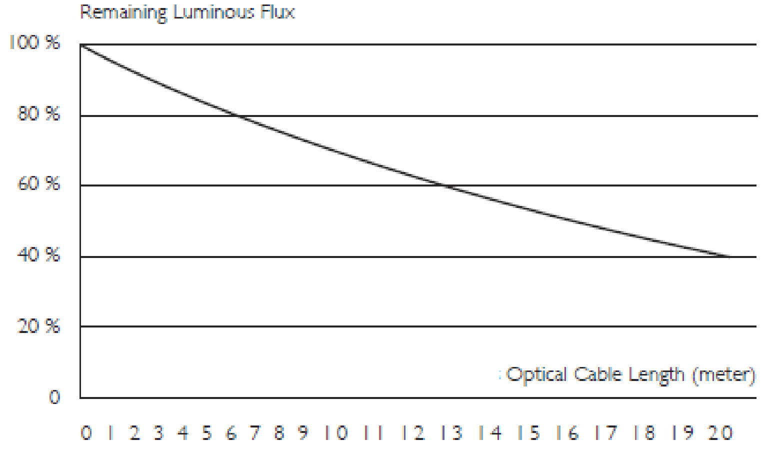


Figure 58: Light transmission in Parans optical cable

The luminaires

Once the light is brought through the fiber optic cables into each room, light flows out through the luminaires. They are made of thin semi-transparent acrylic sheets and they can be mounted directly underneath a ceiling or pending down with wires.[25]

The benefits of this system are is a great system to be installed in areas where the daylight does not reach, such as basements, underground parkings. All materials and components are designed for a life span of 30 years. Exchanging half of a building's electrical lighting for Parans Fiber Optic Solar Lighting can lower the energy costs by 20 – 25 percent and the emission of greenhouse gases by 10 – 15 percent.

Figure 59: Parans Luminaires with 4 fiber optic cables

iii. Conclusion for our building

The shape of our building is a great advantage for daylighting. It is just 10 metres wide, which means, we will have a big amount of light coming from both sides of the building, north and south.

We will provide the building with small windows on the north facade, to avoid heat losses on the side the sun reaches less. On the south facade we will install open spaces and bigger windows to take advantage of the sun day light.

Skylights can be placed at the top, to provide more daylight into the common rooms.

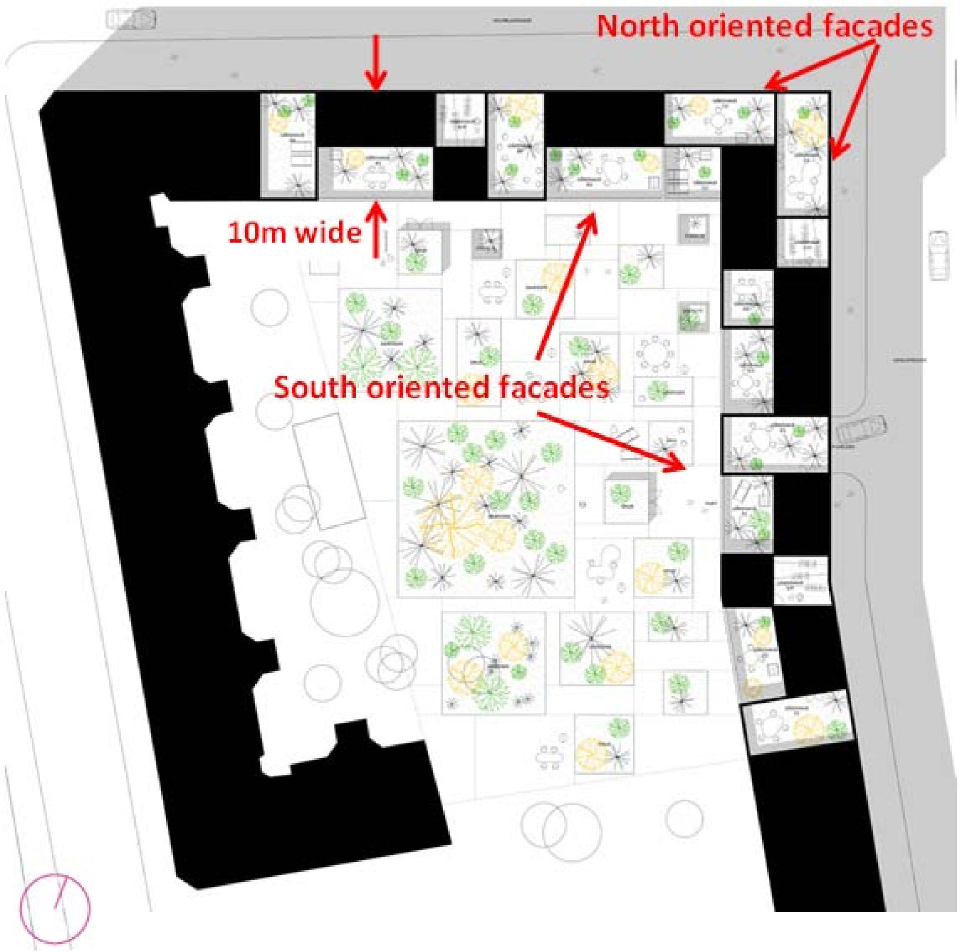


Figure 60: Layout of windows position

Part 4: Active Solutions

1. District heating

i. Introduction

District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating and water heating. District heating is a characteristic of Denmark that we cannot miss.

ii. Energy providing and CO_2 emissions

According to the official Energy Statistics from 2008[1], Heating system provided in 2008 75000 TJ (terajoules), among which 34802 TJ from renewable energy (46,2% including non-renewable waste). At the same time, observed CO_2 emissions for district heating are $2978 \cdot 10^6$ kg. A simple calculation shows that CO_2 emissions are **0,142 kgCO_2 per kWh**. In 2007, the same calculation gives 0,15 kg CO_2 per kWh. Indeed, the percentage of renewable energy was 45 % at that time. According to the environmental declaration[2] of the two main suppliers from district heating in Copenhagen (CTR and VEKS), the CO_2 emissions are only **0,11kg CO_2 per kWh.**

In comparison, the same calculation for **electricity** gives **0,60 kg CO_2 per kWh.**

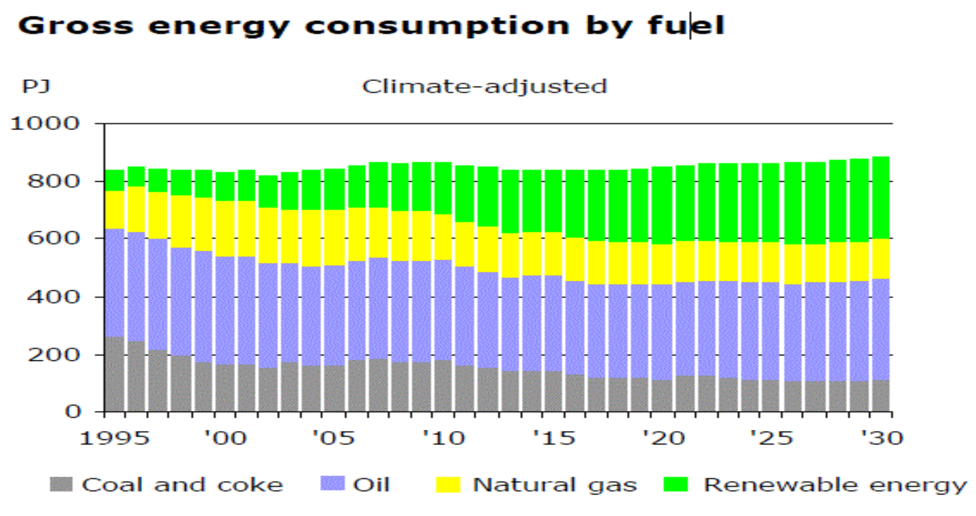


Figure 61: Projections of gross energy consumption by fuel

Furthermore, projections up to 2030 show that the CO_2 emissions will certainly keep on decreasing for the coming years.

iii. Prices in Copenhagen

The prices depend on the location in Copenhagen, because district heating is operated by different companies:

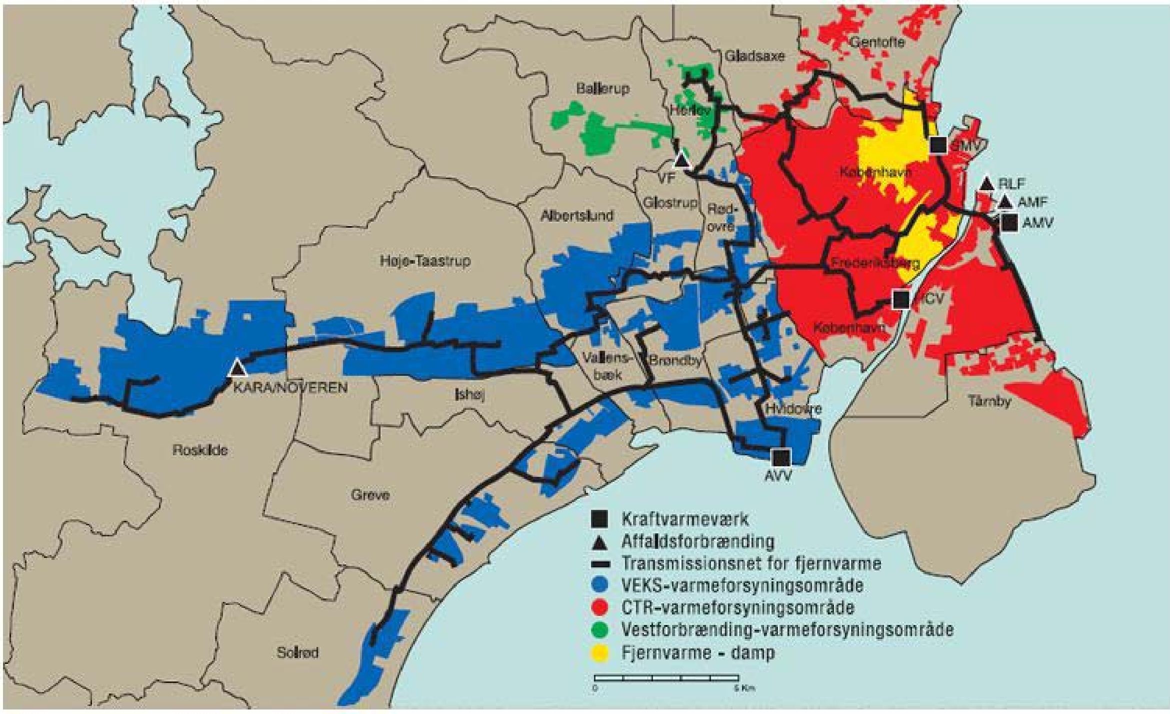


Figure 62: District heating in Copenhagen

As we can see on the picture above, our building is located in the CTR's area. One MWh of warm water costs 646 DKK[3] taxes included (87,3€) on one condition – you can't cool down the water more than 5 °C. Otherwise, extra-price has to be paid.

iv. Conclusion for our building

District heating system seems to be the best solution for heating. The CO_2 emissions are indeed very low (0,11kgCO_2/kWh) and the installation in a new building is not difficult. Only pipes have to be put in. Moreover, prices for use are very low.

2. Solar Systems

i. Introduction

The sun is a glowing gas ball with a diameter of 1.392 million kilometres and an average surface temperature of 5700° Celsius. Matter change to energy and four million tons are radiated into space every second. However, it is only 0.07 percent of its mass in 10 billion years. The solar energy requires approximately eight minutes for reaching the earth.[26] In Copenhagen, one square meter of mother earth receives approximately 800-1.300 kilowatt-hours per year.[27] This is a lot considering that 1.000 kilowatt-hours per square meter is equal to the energy of about 25 gallons of heating oil.[28] In one hour, the soil absorbs as much energy from the sun as the annual world energy consumption.[29]

This irradiation of the earth by the sun can be converted by technical solar systems into another form of energy, with the aim to save fossil energy forces and to provide the converted, free, green and nearly unlimited energy for humanity and nature.

Depending on requested targets and dimension, the operation principle and the produced energy form, several main active solar technologies are differentiated for this project:

- Solar thermal modules
- Solar photovoltaic modules
- Solar power plant modules

It should be mentioned that this chapter basically concentrates on solar thermal modules in order to produce warm water and on solar photovoltaic modules in order to generate electricity for buildings. But it does not concentrate on solar thermal modules which are used for air-heating or ventilation systems. Detailed information about solar power plants are not elaborated during this project, because the focus lies on systems whose application is in private buildings like our block of flats. However, general information and brief examples about solar power plants are included at the end of this chapter and it should be said that solar power plants have a very large potential for future industrial generation of energy as well as wind energy, biomass energy or other new renewable energy sources and therefore it is a good alternative to fossil energy sources and nuclear power plants.

Advantages of solar thermal modules and solar photovoltaic modules for buildings are the reduction of energy from public energy provider and therefore reduction of running costs, because warm water production and electricity generation is possible with such systems. In effect, solar systems do not decrease the energy consumption of a building but it produces green energy without pollution on its own and because of that the running costs are less and buildings become independent from energy generation from dirty power plants. Presently environmental problems like global warming, which depends on the greenhouse effect and therefore also on carbon dioxide emissions, show that we have to change our behaviour concerning energy use and consumption in order to save nature and future human beings. Therefore, as long as it is possible, including solar systems in low energy houses is essential. It is frequently said by critics that a disadvantage of solar systems is their high purchase prices because, depending on the requested targets and dimension, operation principle and produced energy form, they can cause significant additional costs for buildings. But in relation to actual environmental problems, it should not be a matter of costs as long as money is available. Furthermore, solar systems are profitable after a few years and then they save a lot of money on running costs. The time to return on the investment is variable and it also depends on targets, dimension, operation principle and produced energy form but, in general, nowadays solar systems are always profitable because their life expectancy is high enough to recoup the purchase prices. And this is even without considering the rising energy costs, which are a large unknown figure for the future as well. According to *Ingeniør m. IDA Ole Hansen* from *BATEC*, the leading company in Denmark, currently the life expectancy for solar systems average more than 30 years and solar systems often recoup purchase prices in less than 15 years. Some years ago this was not the case but, currently the technology improves very fast. Another point which is often agued by critics is that the return on invested energy for building solar systems, does not recover the gained energy by solar systems. But according to Mr. Hansen and recent science, this is not correct. Possibly, this was in the past but currently, the time to win the same energy as it is needed to build a typical silicon solar cell for photovoltaic panels, amounts in average only two until four years.[30] The same period is expected for thermal solar collectors. Moreover, solar systems are still in development and the future will show what else is possible.

In certain countries private households and industrial companies have the possibility to get subsidies for solar systems. In Germany for example, the government encourages green energy. Depending on the square meters and the kind of solar system the government pays subsidies. Furthermore in Germany, solar photovoltaic systems` owners induct entire solar electricity in public electricity network, because the remuneration is far above the cost of power procurement.[31] On the contrary, Denmark has no general subsidies for solar systems and they only use a net metering system, which contains that the household electricity meter only runs backwards when they generate more electricity than they consume.[32]

ii. Solar thermal module

Solar thermal modules use irradiation of the earth by the sun in order to generate hot water for heating systems and in order to generate hot water for domestic water. Mostly private households use these solar thermal systems as well as industrial companies or public swimming pools. But they are only infrequently used for industrial range of applications.

The general principle of operation for water heating is absorbing direct and diffuse sun light by solar collectors and converting it into heat. Heat passes to a heat transfer fluid and then a pump transfers the fluid through a pipe system to the high temperature water system. There, the heat is transferred to the water with the help of a heat exchanger. After releasing its heat, the heat-transfer fluid flows back to the collectors to be reheated. The closed circuit includes a solar controller which keeps the pump in operation as long as usable heat is available in the collectors. On days, when not enough solar energy is available a heating system provides the missing heat. These solar thermal systems mainly consists of solar thermal collectors with included absorber, interconnecting pipes, heat transfer fluid, safety system and controller, pumping system and water storage tank with included heat exchanger. The heat transfer fluid is typically a glycol and water mixture in regions like Denmark, where seasonal freezing cause concern. Figure 63 shows a simplified principle of operation of solar thermal models for buildings.

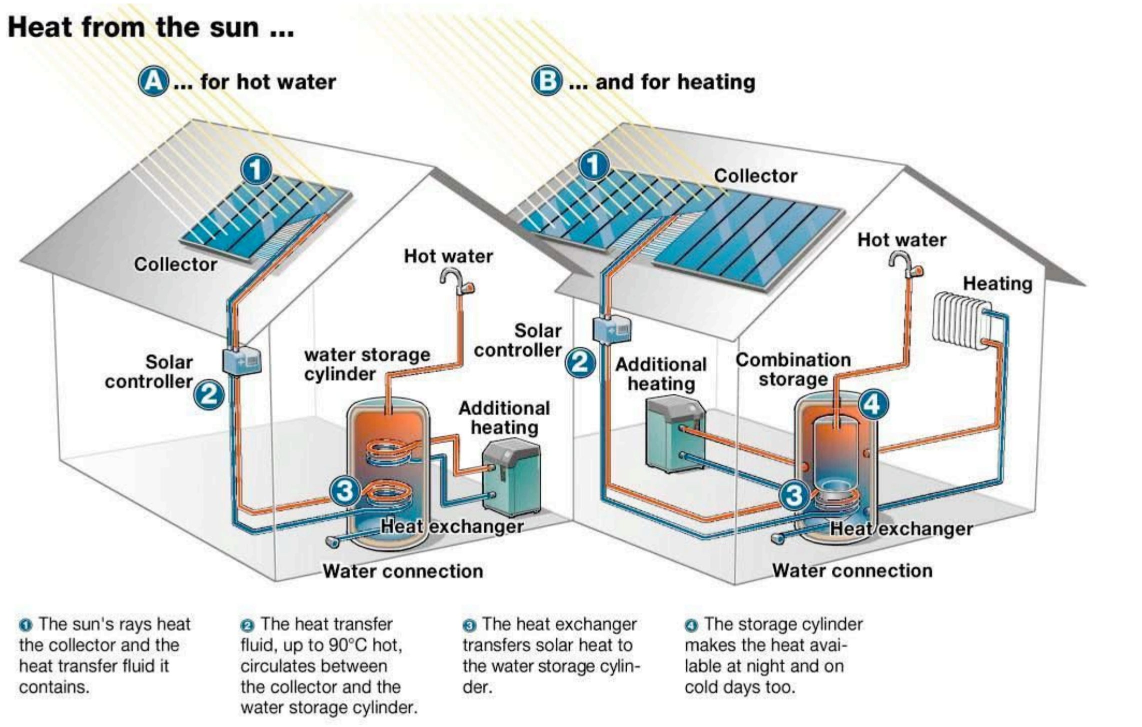


Figure 63: Principle of operation for solar thermal modules

As figure 63 shows, solar collectors are preferably attached on roofs, but also on exterior walls or on the ground with special apparatus. According to Mr. Hansen, highest efficiency is achieved in Denmark by solar thermal collectors if they are aligned southwards with an angle of 45 degrees to 60 degrees. Nevertheless, solar collectors absorb sun light almost evenly from all directions but with a loss on efficiency. Therefore, it is not essential but possible, that solar collectors track the movement of the sun. They also supply certain energy on cloudy days. But depending on the insulation of the absorber inside the collector, two several collectors are mainly differentiated for warm water generation in private buildings:

- Flat plate collectors
- Evacuated (or vacuum) tube collectors

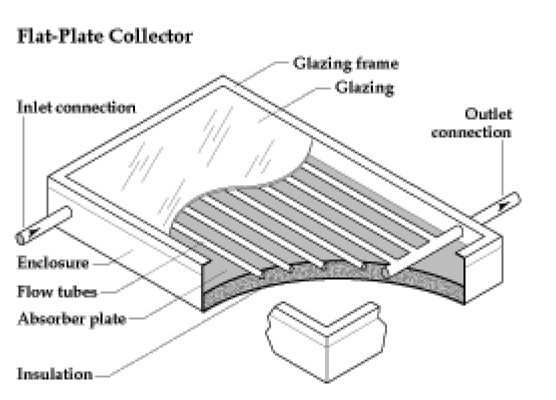


Figure 64: Flat plate collector

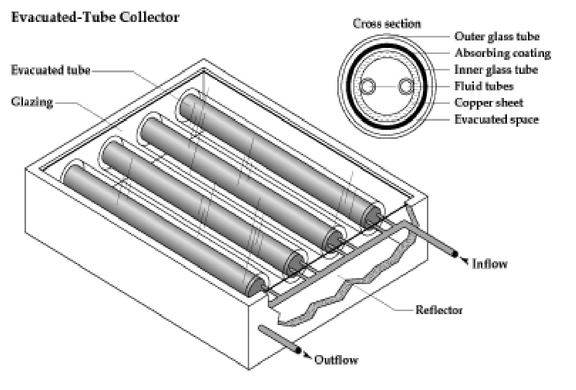


Figure 65: Evacuated tube collector

For both types of collectors, depending on the manufactures, the market offers a large number of different alternatives. Modern evacuated tube collectors for example are no longer constructed as figure 65 shows, but next to each other, the figures show clearly the difference between these collectors and a modern version is discussed below. But in comparison to figure 65, figure 64 is still up to date but different alternatives exist, too. Nevertheless figure 64 shows the most popular version and in general, the principle of operation is similar for all collectors and familiar to anyone who sat in a car, which has been exposed to full sunlight for some minutes.

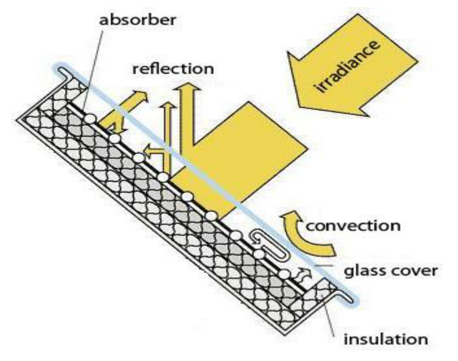


Figure 66: Flat plate collector principle

Figure 66 shows the basic structure and the main components of a flat plate collector. The sun sends energy in the form of radiation on the earth's surface where it rays by a glass plate on a solar absorber. This radiation energy is distributed over a wide range of wavelengths, but it has its maximum on the short-wavelength range. The solar absorber absorbs nearly the entire spectrum of light. The released heat should not be lost, so the collector is insulated on all sides. On all sides insulation's task is, to keep the released heat. The convective heat to the front is reduced by glass cover. In vacuum collectors, the convective heat is completely prevented by a special construction. Heat, which is radiated from the absorber, can be largely retained by the glass cover because glass is not transparent for a higher wavelength. It is called waveband transparency. Therefore, the heat is trapped in the collector. The result is a rising temperature inside the collector, which is similar to the car, which has been exposed to full sunlight for some minutes. This effect conforms to the greenhouse effect. In the case of the flat plate collector, the heated absorber transfers heat to the associated copper or aluminium tubes and because of that the heat transfer fluid becomes warm.

Figure 67: Flat plate collector

The absorber should have selective characteristics. In other words it means that the absorber has to absorb short-wave solar energy, coming from the outside, as much as possible (absorption) and at same time, it also should not release long-wave heat as well as possible (emission). Moreover, it must be long-term heat-resistant and ultraviolet-resistance for a. For these reasons, the sunny side of the absorber is provided with a special coating. One of the first coatings is the black chrome coating. It is applied to the absorber in an electroplating process. Modern coatings for example "eta plus" or "sunselect" have higher efficiencies. Furthermore, they are environmentally friendlier than black chrome coating because of the abdication of galvanic processes and therefore of recycling aspects. Usually, they are bluish shimmering.

Figure 68: Absorber (Flat plate collector)

As mentioned above, in relation to the car, which has been exposed to full sunlight for some minutes, all solar collectors are working with the same principle of operation. But the evacuated tube collectors differ from the flat plate in their insulation principle and in their heat transfer principle. Whereas heat transfer fluid flows through the absorber`s pipes of flat plate collectors, evacuated tube collectors use heat exchangers for heating transfer on top. This

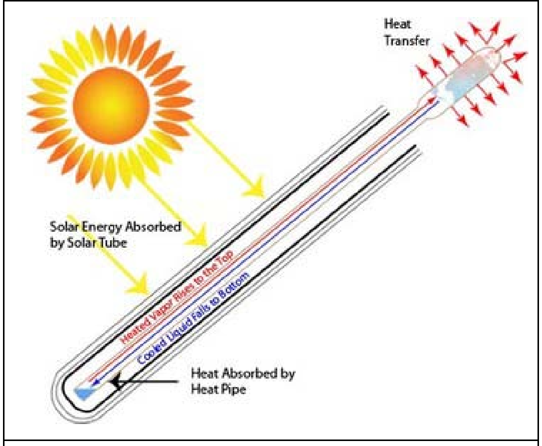


Figure 69: Evacuated tube collector principle

heat exchanger is flowed by the heat transfer fluid. Older versions like figure 64 shows are insulated by only one glass tube. Inside this glass tube a vacuum exist. But the problem is that this vacuum is not stabile for a long time because, stress cracks in the materials caused by different coefficients of expansion often destroy such systems. Modern and innovative systems, such as you can see in Figure 69, have two concentric glass tubes and in-between these a vacuum exists. Because of that, a loss of heat is greatly reduced and the collectors are better protected against ingress of air, because stress cracks by different coefficients of expansion cannot occur in the material. Vacuum tubes are often surrounded by a parabolic mirror. For this reason, especially on less sunny days, this considerably increases the output of evacuated tube collectors.

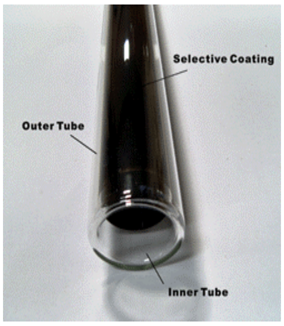


Figure 70: Absorber (Glass tube)

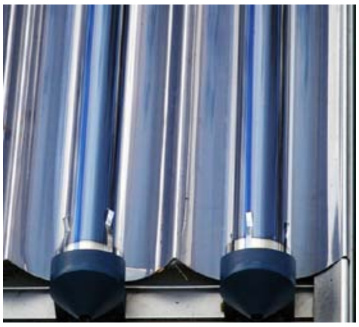


Figure 71: Evacuated tube collector

Also vacuum tube collectors have a darkly coated absorber surface. In older versions it is located on copper stripes or pipes inside the glass tube. But in newer versions, as shown, the selective coating is applied to the surface of the inner of two glass tubes.

A comparison of the flat plate and the evacuated tube collectors shows that flat plate collector`s sole advantage is the purchase price.[33] Prices of flat plate collectors are less than prices for evacuated tube collectors. On the other hand, the efficiency of evacuated tube collectors is 30 percent higher than the efficiency of flat plate collectors.[34] Likewise, the output of evacuated tube collectors is higher at low temperatures, overcast skies and cool breeze or even in the winter. This is because flat plate collectors are influenced by external weather conditions, therefore losses are higher. But for evacuated tube collectors, this is prevented by the vacuum insulation. Depending on using parabolic mirrors, evacuated tube collectors have a better use of diffuse solar radiation, as well. Another point is the repairing and maintaining of vacuum tube collectors. These are simpler because glass tubes can be changed without exhaustion of heat transfer fluid circuit. That way, the currently argument, that life expectancy of the vacuum tube collectors is less than life expectancy of flat plate, is not correct. For example, several manufacturers of evacuated tube collectors provide guarantees for more than 25 years and the average life expectancy of flat plate collectors is not longer than that.[35]

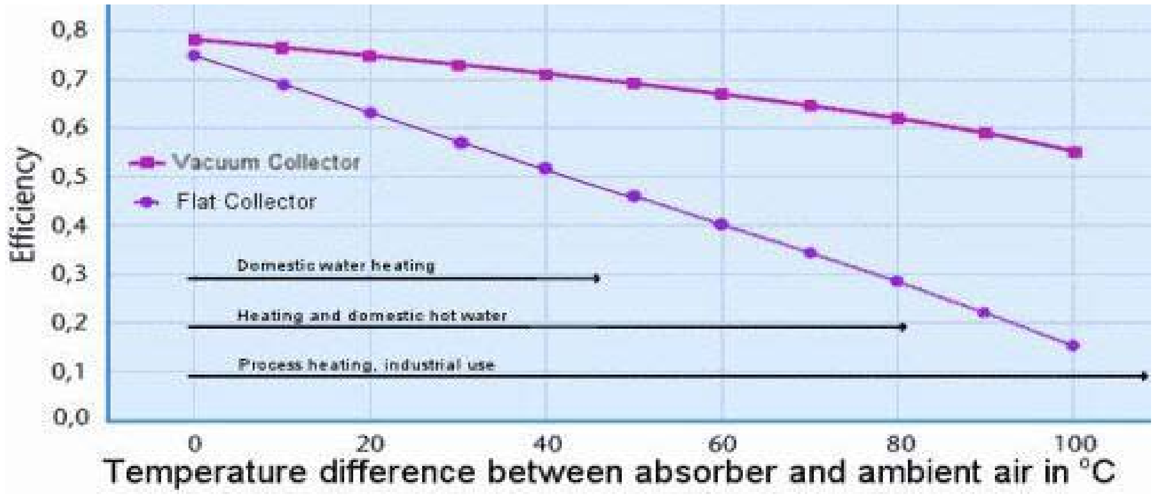


Figure 72: Efficiency of flat plate collectors and evacuated tube collectors

Therefore, the evacuated tube collectors` advantages annually lead to a better covering of warm water use.

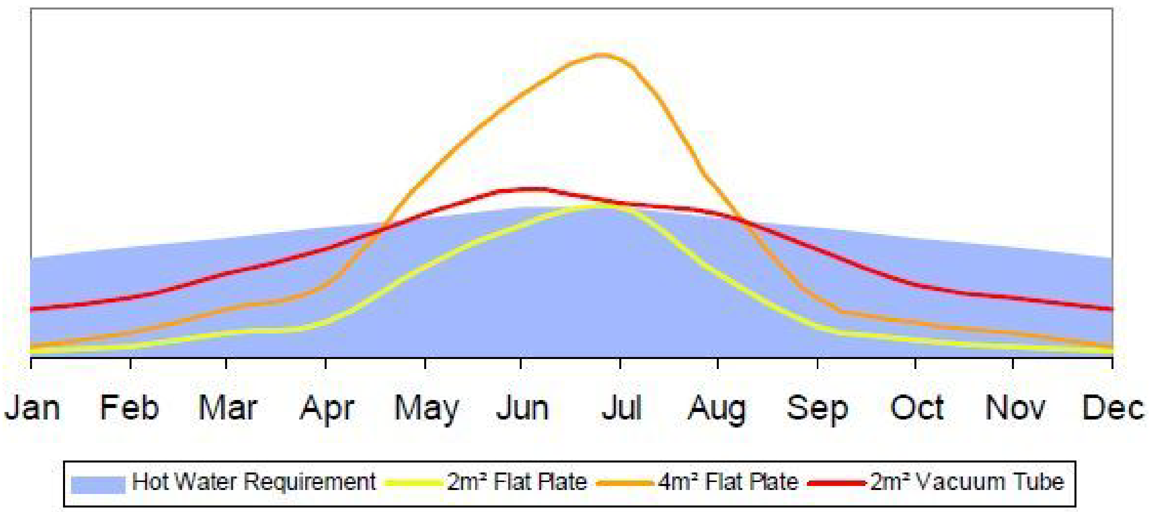


Figure 73: Warm water covering

The efficiency of a solar system does not only depend on the collectors. It consists of a solar system. This means for example, the insulation of the storage water tank is just as important as the pipelines and other components. All components of a solar system significantly contribute to the overall efficiency. For this reason, several components are shortly exemplified on the following pages.

Circulation pump:

There are solar thermal modules, which have their water storage tank above the collectors. Because of the principle of gravity, warm heat transfer fluid automatically flows to the water storage tank to transfer the heat with the help of a heat exchanger. Cold heat transfer fluid automatically flows back into the collector. However, this system does not make sense for our project. Therefore, this report does not inform about these techniques. In general, a water storage tank is among the collectors, for example in the basement. For that reason, a solar thermal system needs a circulation pump, in order to move the heat transfer fluid between collector and water storage tank. But this pump is only in use, if the heat transfer fluid inside the collectors is warmer than the domestic water in the water storage tank. A conventional pump consumes in general 15 percent of the generated energy of the entire solar system. Responsibly is the high electricity consumption of these pumps. For this reason, solar thermal modules should only be designed with new special pumps with permanently excited EC motors. Such circulation pumps reduce the electricity consumption between three percent and four percent of the generated energy of the entire solar system.[36]

Solar Controller:

Solar thermal systems are operated by a controller. The solar controller determines the temperature and is responsible for switching on and off the circulation pump. For example, once the temperature in the collector rises several degrees above the temperature in the storage tank, the solar controller switches on the circulation pump and the heat transfer fluid transports the accumulated heat in the collector to the hot water tank. Therefore, the solar controller takes an important task and should be state-of-the-art.

Safety system:

A frequently asked question is: What happens when the water storage tank is hot enough? But the answer is easy: The heat transfer fluid is no longer pumped through the collectors. This can also happen during an electrical power outage, because the pump would not work. Consequently, the heat transfer fluid begins to boil and evaporate. Now the security system prevents damage. An expansion tank adjusts the volume of steam and later, when the system is cooled again, the expansion tank sets the volume of steam free. The system cools down again, because heat is not transmitted anymore. Therefore, the expansion tank should be properly designed in order to ensure, that the whole vaporized volume can be absorbed – if not, pressure escapes through the safety valve and the result would be, that new heat transfer fluid has to be refilled into the circulation. This is not economically and environmentally friendly because the heat transfer fluid normally includes anti-freeze. But it should be mentioned that the market offers a new environmentally friendly heat transfer fluid. It consists of corn and it is completely renewable and biodegradable. Furthermore, it is more efficient in comparison to traditional glycol.[37]

<u>Interconnecting pipes and other elements:</u>

System's efficiency is always connected to losses. To ensure low loss of the heat transfer fluid, interconnecting pipes have to be adequately insulated. Mostly copper pipes are used because they do not corrode. Heat resistant flexible foams are often used for insulation. The diameter of pipes depends on the flowing heat transfer fluid's speed and cannot be chosen arbitrarily. The speed depends on various factors, like system size or place of location. But in general, the flow velocity should not exceed one meter per second inside the thermal collectors.[38] Furthermore, consumables like valves, pressure gauge, or other connection elements are very important, too. Good quality is always essential.

<u>Water storage tanks:</u>

A solar system can be combined with any heating system and depending on the requests, it can be operated differently as well.[39] However, for bivalent systems, which mean heating systems with varying available energy, a hot water buffer store has to be used because a buffer tank stores excess heat and releases it only when it is needed again. There are two basic kinds of tanks. On the one hand, there are domestic water storage tanks, they are used for heating domestic water and they are equipped with two heat exchangers. One heat exchanger is for the solar system and the other one is for any heating system. That means that tanks for domestic water and heating water are separated. The most suitable water storage tanks are tanks which do not mix cold and warm water. Storage tanks with bad layers need more collectors. A good layer effects up to 5 percent higher efficiency because the rising water affects no energy loss.[40] Currently, the best water heaters are paraffin storages because these achieve the highest efficiency and thereby they need least space. However, presently they are too expensive. On the other hand, there are combination storage tanks, they are used for both domestic water and heating system's water. Often they have two internal tanks, to keep the water separated, but it should be mentioned that these tanks sometimes have the risk of bacterial growth (Legionella). However, for both kinds of buffer tanks and for the whole solar system, the insulation is very important in order to keep the heat.

iii. Solar photovoltaic module

The solar photovoltaic modules' operation of principle is catching diffused sun light by using photovoltaic panels in order to generate electricity directly. Solar photovoltaic panels are made of several solar cells and each cell is comprised of materials which have photovoltaic properties and are called semiconductor. An example for a semiconductor is silicon. Silicon exists in large quantities on earth, because the raw material is sand. The converting of silicon is environmentally friendly and more than 85 percent of the solar cells are made of silicon.[41] Semiconductors are materials which have insulating characteristics at low temperatures, but supplied with light or heat, they have electroconductive characteristics, too. Semiconductors' electrical properties can be influenced by defined inserting of chemical elements. It is called doping. Typical solar cells comprise two semiconductor layers that are equipped with separate metal contacts. A boundary layer is located between both adjoining semiconductor layers. Each layer has been doped. Therefore a collar cell includes an n-layer (negative) with a surplus of electrons and below that, a p-layer (positive) with an electron deficiency. Inside the semiconductor structure, due to the difference in concentration, electrons flow from n into the p area because an electrical field, or a so-called space charge zone, is created. The upper n-layer in a solar cell is so thin that the photons from sunlight can penetrate it and can only discharge their energy to an electron once they are in the space charge zone. The electron that is activated in this manner follows the internal electrical field and thus travels outside of the space charge zone and reaches the metal contacts of the p-layer. When an electrical load is connected, the power circuit is closed and the electrons flow across the electrical load to the solar cell's rear contact and after that they flow back to the space charge zone. This effect is called the photovoltaic effect and it is responsible for the operation of principle for solar photovoltaic models.[42] Based on the photoelectric effect, co-current flow is directly generated and can be transformed, with the help of an inverter, in alternating current.

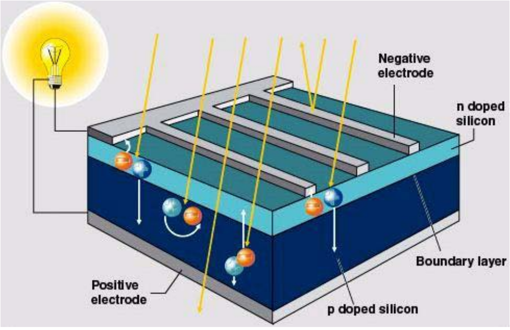


Figure 74: Solar cell 1

There are three different types of solar cells:

- Mono-crystalline solar cells
- Poly-crystalline solar cells
- Amorphous silicon

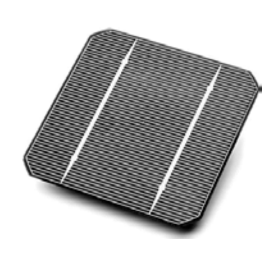


Figure 75: Solar cell 2

Mono-crystalline solar cells and poly-crystalline solar cells are cut from silicon blocks. The material is rigid and not flexible. Amorphous silicon is vapor deposed on a substrate and it is not cut from a silicon block. For evaporating only a little amount of silicon is used. Therefore such cells` efficiency is only 8 percent and it is lower than the efficiency of crystalline cells. Crystalline cells have efficiencies up to 17 percent.[43] Several solar cells are connected in series and the result is the so-called solar photovoltaic panels. Depending on the number of interconnected cells, photovoltaic panels provide electricity between 12 Volt, 24 Volt or 36 Volt. The size of solar panels varies considerably. On the one hand, a calculator needs extremely small cells. On the other hand, there are photovoltaic panels with a size of 2 x 2 meters. But a typical standard photovoltaic panel consists of 72 cells and one cell is 10 x 10 centimeters. Furthermore, there are different types of photovoltaic panels. Most common photovoltaic panels are made of different layers of glass or anti-reflective layers, lamination, cells, and tedlar. Tedlar is fixed on the back of the photovoltaic panels and is visible between the cells on the front. The layers are fused and form a watertight connection. This connection is usually mounted in an aluminum frame and thereby it supports a higher stability. In addition, the aluminum frame framework can be used as a fastening method. Solar modules without frames are called laminates. These are mostly used in integrated roof systems. Is transparent tedlar in use, photovoltaic panels appearing transparent. A typical effect is an aesthetic rectangular shadow. A vapor deposition of amorphous silicon enables the production of flexible photovoltaic panels. Therefore different variants of photovoltaic panels can be made but a disadvantage is the lower efficiency.

Figure 76: Photovoltaic panel

Whether co-current flow or alternating current is generated, both can be used for different applications. On the one hand, solar photovoltaic systems are used in industrial range of applicants, to generate large quantities of electricity generation but on the other hand, they are also used for private households or industrial companies in order to generate their own electricity and therefore to offset their electricity costs. Furthermore, depending on the electricity consumption and connection to a public grid connection, two solar photovoltaic systems are mainly differentiated:

• Off-grid systems

Figure 77: Off-grid system in space

Off-grid systems are able to operate completely independently of traditional public grid connection. They are used in remote areas or buoys at sea, in space, for mobile lanterns but also for sheds, caravans, boats, remote summer residence, closed circuit TV or ticket machines. During the day these off-grid systems produce electricity which is used and stored in batteries. Batteries shall have a high capacity because they should bridge cloudy days and especially dark days in winter. Off-grid systems are not used for generating the maximum electricity production during a year. Their target is electricity basic service for smaller applications than a block of flats. Therefore, these systems are not further discussed during this project.

• Grid-tied systems

Grid-tied systems are connected to the traditional public grid connection. Figure 78 shows a simplified principle of operation of solar photovoltaic models for buildings.

An inverter usually converts co-current flow, which is produced by photovoltaic panels, in alternating current (230 Volt AC). At the time, when the electricity consumption is higher than the generated electricity, actually required electricity is supplied from the public grid

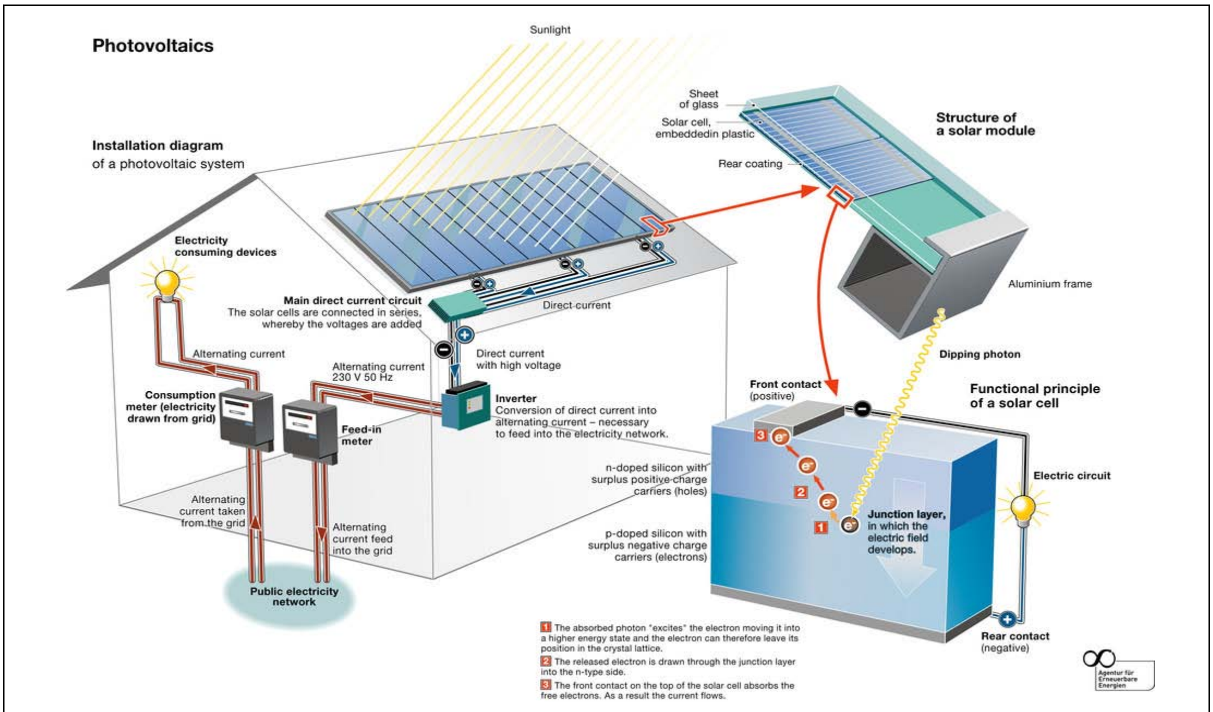


Figure 78: Principle of operation for solar photovoltaic modules

connection. But at the best, or in holidays when electricity is not used, excessive electricity is feed in public grid connection. Such photovoltaic systems mainly consist of several components like solar panels, cables, inverters, batteries if applicable and a system controller.

Photovoltaic panels are preferably attached on roofs as well as solar thermal collectors. Photovoltaic panels can be attached to exterior walls or to the ground with special apparatus, too. In Denmark, according to the irradiation diagram in figure 79, highest efficiency is achieved by photovoltaic panels, if they are aligned to the south and with an angle of 30 degrees. Nevertheless, photovoltaic panels also absorb sun light almost evenly from all directions and they also supply certain energy on cloudy days, but with a loss on efficiency as well as thermal collectors. But also other pieces of photovoltaic systems are important for the efficiency and easy handling.

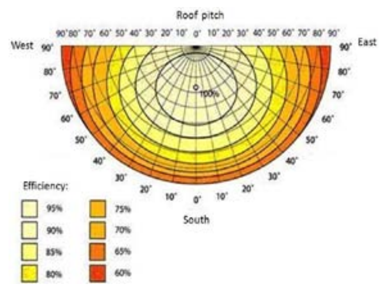


Figure 79: Irradiation diagram

Inverter:

As already mentioned, the type of produced electricity by photovoltaic panels is direct current. For this reason an inverter is included in such solar systems. Inverters are very important components concerning the efficiency of a solar system. There are safety standards that need to be met for any device that is going to be connected directly to the public grid connection. It is important that an inverter is certified for use with the public grid connection. Like photovoltaic panels, inverters also have efficiencies. That efficiency measures their ability to convert the direct current into alternating current. Today, modern inverters have an efficiency of up to 98 percent. The efficiency is critical because it will determine the amount of sunlight that is actually converted and fed to the grid as alternating current power, which in turn, affects the amount of credit that is earned. The inverter is responsible to operate the solar power system so that the maximum energy production possible is achieved. For this reason, high quality for an inverter is very important.

Cables:

High quality is also important for the choice of cables. The diameters for cables depend on size of a photovoltaic system but they should not be chosen too small because this leads to losses and, if it comes to the worst, it can lead to fire.

Solar controller:

A solar controller is normally included in each solar system. It informs about actual electricity production and it operates the whole system. Such controller should be as intelligent as possible and furthermore they should be user-friendly.

iv. Conclusion for our building

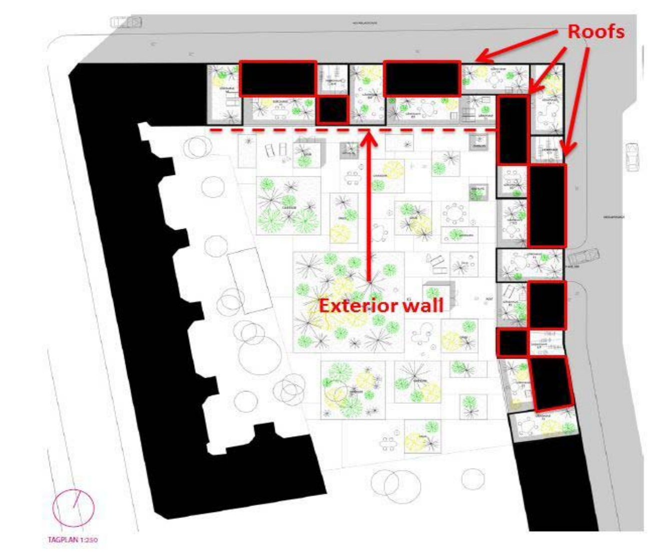


Figure 80: Location for solar models

According to Cenergia's drawings and information, they recommend using both, photovoltaic collectors for electricity generation and thermal collectors for warm water production. Cenergia intends to use thermal collectors in order to use heated water of the solar system for domestic water and heating water. Furthermore, they expect to use a ten square meters available surface for thermal collectors and photovoltaic panels per flat. Combined, there 300 square meters for thermal collectors and photovoltaic collectors. A brief review has shown that this number of actually available surface for solar system is realistic, if roofs and the exterior wall to the backyard are used. On the roofs, collectors and panels can be oriented exactly to the south but on the exterior wall it is not possible. However, the aberration angle to the south is less than 30 angular degrees which is tolerable.

Solar thermal models:

With the help of Mr. Hansen and researched information, we decided to use solar thermal models only for domestic water, because our solar thermal system would not be economically balanced, if we would use solar thermal models for heating and domestic water. That means, in winter we would approximately need three times as many surfaces for producing warm water for heating and domestic water than only for domestic water. But if we would use more surfaces for thermal collectors, we would produce too much warm water in summer. But this warm water would be useless, because we would not be able to consume it. Depending on the field of application and the size of our building, a compromise between summer and winter, which is often found at family houses or smaller projects, would be too uneconomical for our building because we could not use the thermal energy in summer.

Furthermore, district heating is a very good alternative as well as the most economical solution for the heating and nevertheless, we can also use residual surface for photovoltaic panels. Therefore, we would use solar thermal models only for domestic water with two several buffer tanks: One buffer tank for district heating and another buffer tank for domestic water. We also decided to install more expensive evacuated tube collectors, because the comparison shows that they have a higher efficiency and better covering of warm water during a year. These reasons are important for us because we want to cover the heating energy for domestic water as much as possible and this without a large scattering. Furthermore, evacuated tube collectors need fewer surfaces than flat plate collectors to produce the same energy. Therefore, we could use more surfaces for electricity generation and as you can see during this report, prices of electricity in Denmark are the highest one in Europe. In Denmark, according to Mr. Hansen, if evacuated tube collectors are in use, rules of thumb indicate for domestic water one square meter in average per person in a building. The storage capacity per square meter of collectors should be between 50 liters and 70 liters. In our block of flats we design the solar thermal system for approximately 80 occupants and the basement, which includes several unknown shops. According to the water consumption of the building, we assume that the basement consumes approximately 25 percent more domestic water than flats with occupants only. We also take this into account. The result is, to allow 100 square meters for solar thermal collectors and to use a buffer tank with a volume of approximately 6000 liters. Therefore we expect that our solar thermal system, depending on a proper planning, will save nearly 60 percent of energy which would normally be needed for hot water generation.[44]

Solar photovoltaic models:

Assuming, that we are able to use about 300 square meters actually available surface for a solar system and we already use 100 square meters for thermal solar collectors, we can maximally use 200 square meters for photovoltaic collectors. With the help of Mr. Hansen and researched information, we decided that this potential of 200 square meters should be completely exploited for photovoltaic panels, as long as money is available. An advantage of this large solar system is not only the environmental aspect. It is also the economic aspect of this photovoltaic system. A model calculation shows that a photovoltaic system with 200 square meters covers the electricity consumption of approximately two normal floors for occupants. The model calculation is only an example. A truly accurate statement about annual efficiency and output of a photovoltaic system can only be found after one year operating time. The surface for photovoltaic panels is assumed as 200 square meters (A). In Copenhagen solar radiation assumed as by 1000 kilowatt-hours per square meters and year

(S).[45] The Efficiency of the solar system is assumed as 15 percent (η). The result is the gained energy (E).

$$E = A * S * \eta = 200m^2 * 1000\frac{kWh}{m^2 * Year} * 0{,}15 = 30000\frac{kWh}{Year}$$

In relation to the estimated electricity consumption, only for the flats and not for the basement of the building, this photovoltaic system covers approximately 50 percent of the required electricity supply. But according to the overall electricity consumption of the building, the result looks different, because we expect a very high electricity composition for the basement in comparison to all the other flats. For all flats and the basement this photovoltaic system only covers approximately 15 percent of the required electricity supply. However, we decided that the generated energy is primarily used for common electricity consumption and therefore we expect that this solar photovoltaic system covers more than only the common electricity consumption. In other words it means, that this photovoltaic system reduces the running costs for the whole building and therefore for each occupant. The economic benefit would be enormous and each flat would be more attractive for renting or buying.

Costs:

Presently, the costs of solar thermal systems or solar photovoltaic systems are still very high. Unfortunately, it is very difficult to give a statement about expected cost for such large systems. Likewise, it is also difficult, to determine in what amount of time the investment will be recouped. However, after several examples and consultation with Mr. Hansen, costs for this large solar thermal and photovoltaic system are expected to be around 1200000 DKK. This is a tremendous price but normal for solar systems with a large size. Furthermore, the Danish government finances this program and therefore it is achievable. In addition, the ecological aspect of this solar system should be considered and the energy prices will rise. Anyway, we assume that the life time of the solar system and the whole building is very high, depending on attendance and maintenance. And it can be assumed that the investment costs pay off, sooner or later.

3. Heat pumps

i. Introduction

Denmark is located between Sweden and Germany, which are the two biggest users of heat pumps in Europe. As we can see on the next picture, Sweden produces 2909 MW thermal (2008), Germany produces 1653 MW in 2008, while Denmark is only on the twelfth position with 123 MW produced.

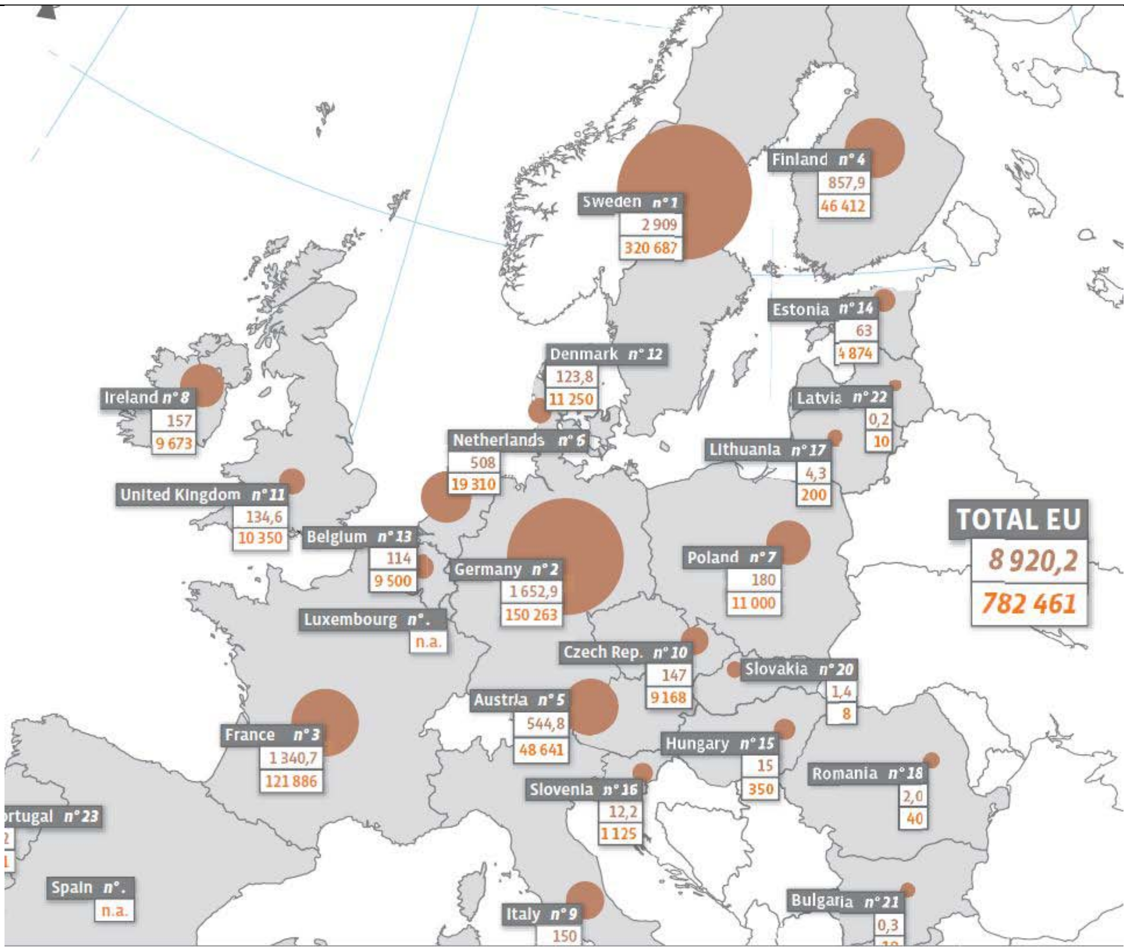


Figure 81: Installed capacity and number of GSHP in European Union (2008)

Because heat pumps use electricity, we can find one explanation to this low number by looking at the figure 82 taken from the Europe’s Energy Portal, showing the price of electricity:

Country	Average amount in euro per one kilowatt-hour of electricity for domestic consumers	For gas
Denmark	0,27	0,12
Germany	0,21	0,09
Sweden	0,19	0,12

Figure 82: Electricity prices

At the sight of this number, we can imagine that it's less profitable to use a heat pump in Denmark than in Sweden. The Danish government is nevertheless launching new advertising campaign promoting them. A new website was opened: **www.varmepumpesiden.dk**, DKK 400 million have been allocated (about €54 million) for scrapping old oil burners and replacing them with heat-pumps[46] . Let's see now why this technology is beginning to expand.

ii. One theory

A **heat pump**'s refrigeration system consists in a compressor and two coils made of copper tubing (one indoors and one outdoors), which are surrounded by aluminum fins to aid heat transfer. In the heating mode, liquid refrigerant in the outside coils extracts heat from the air and evaporates into a gas. The indoor coils release heat from the refrigerant as it condenses back into a liquid. A reversing valve, near the compressor, can change the direction of the refrigerant flow for cooling as well as for defrosting the outdoor coils in winter.

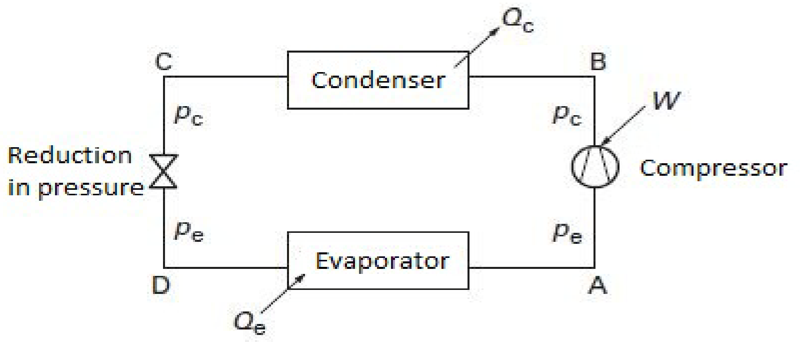


Figure 83: Wiring diagram of heat pump

A refrigerant liquid circulates in the circuit above. The only energy which is brought to the system is electricity through the compressor (power W).

A certain amount of heat (Q_e) is taken from a cold source (ground, outside air or outside water) thanks the evaporator. The liquid is then compressed by the compressor. It is carried to the house which needs to be warmed and then the condenser gives the heat to the inside of the house.

We can visualize these transformations using the Mollier diagram bellow (the pressure being a function of the enthalpy):

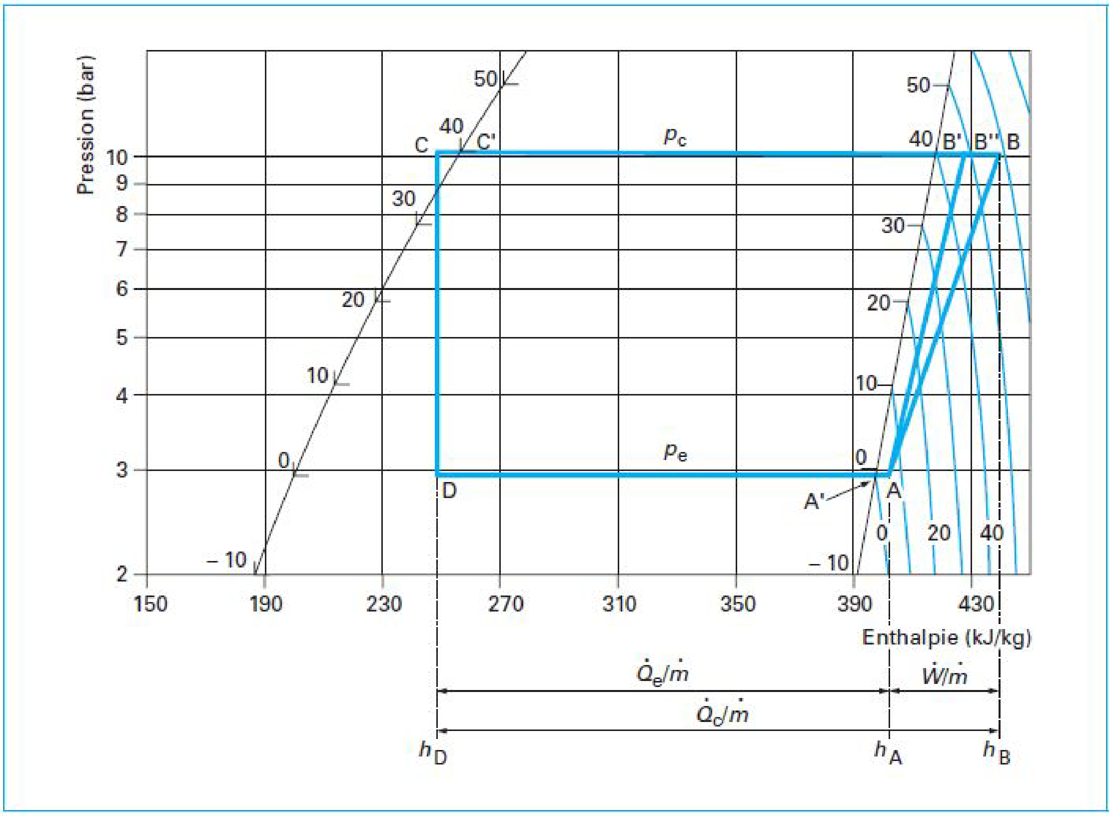


Figure 84: Mollier diagram showing the thermodynamic cycle of the heat pump

Between the points D and A, the heat Q_e is taken from the outside source. Then, some work is brought through the compressor: W (electricity the most of the time but gas can be used too). Thanks to the condenser, heat is given to the inside (Q_c). The reduction in pressure is necessary to close the thermodynamic cycle.

Introduction performances tools (COP)

In order to characterize the efficiency of a heat pump, we use in Europe the Coefficient of Performance (COP).On the Mollier diagram, the COP is given by:

$$COP = \frac{\dot{Q}_C}{\dot{W}}$$

In other words, if we have a COP of 3, it's means that for each kWh from electricity that we bring to the heat pump, we will get 3 kWh thermal of heat in your building.

iii. A lot of technologies

Now let's focus on the different technologies available for our project. We will only focus on the air-to-water heat pumps, because they have more advantages for our project. Nevertheless, we have to keep in mind that air-to-air, water-to-water, and water-to-air heat pumps exist.

HEAT PUMP AIR-TO-WATER:

Advantages:

- In summer, you can use it with a solar panel to get hot water for free and with an excellent COP (more than 4, which means that with 1Wh get from the sun, we can get 4Wh hot water in your home).
- It's easy to install

Inconvenient:

- Fans and compressors make noise. Locate the outdoor unit away from windows and adjacent buildings, and select a heat pump with an outdoor sound rating of 7.6 bells or lower.

iv. Conclusion for our building

Because producing electricity discharges a lot of CO_2, the best solution in order to keep a low CO_2 emission low is to use only district heating system. Heat pumps are more and more used, but they are useful only in order to replace old fuel boilers.

Nevertheless, heat pumps have another advantage: they are able to deliver cold. In our case, because the building is well thought, we don't need extra air conditioning system.

4. Electric Lighting

i. Introduction

The artificial or electric lighting represents around 10% of a household's electricity use. That is why, when designing a new building, it is very important that we pay particular attention to daylighting as, the presence of high amount of windows and openings, can reduce our energy use considerably. Once we have taken maximum advantage of the daylighting options in our building, it is time to choose the right electric lighting so that we have a low consumption.

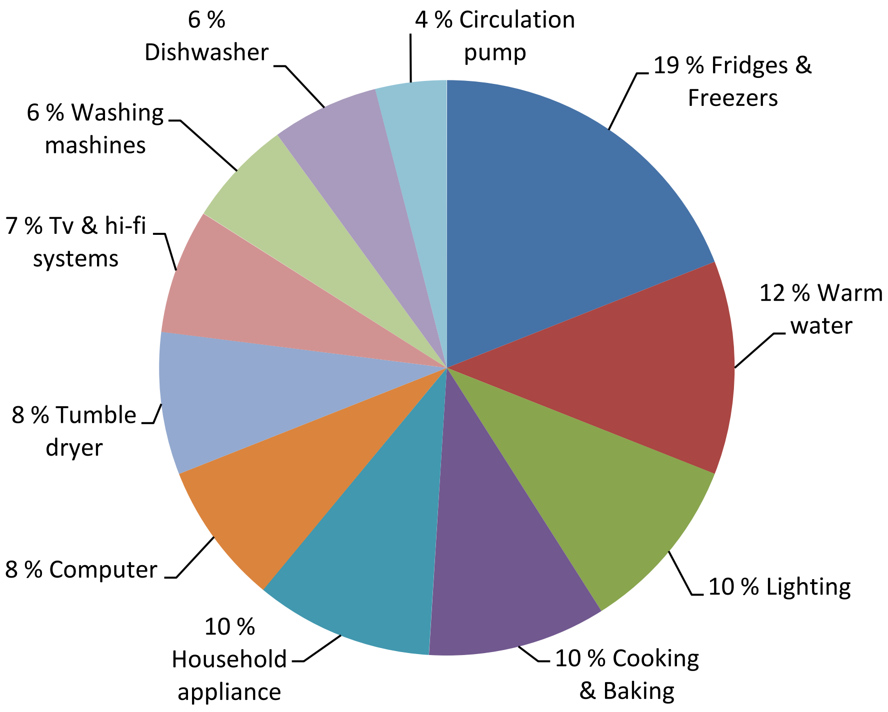


Figure 85: Household electricity consumption

The use of new lighting technologies can reduce lighting energy use in homes by 50% to 75%.[47] Replacing all incandescent bulbs for the latest Compact Fluorescent Lamps (CFL) or LEDs (Light Emitting Diodes) can contribute to reduce money expenses and CO_2 emissions.

Let's introduce and describe the most common types of household lamps used these days:

- Incandescent or General Service Lamp (GSL)
- Halogen Lamps
- Fluorescent Tubes
- Low Energy Bulbs or Compact Fluorescent Lamp (CFL)
- LED (Light Emitting Diode)

ii. Types of lamps Figure

Incandescent or General Service Lamp (GSL)

We call *General Service Lamps (GSL)* to the standard incandescent bulbs, which are the original and most common type of bulbs used in homes, due to their low cost and ease of use. The operation of these lamps is based on the electric current passing by a tungsten filament that reaches very high temperatures, where the radiation emitted is visible to the human eye.

Figure 86: Incandescent bulb

Incandescent bulbs have a low initial cost, have a lifespan of 1,500 hours, are compact and produce a warm colour tone. However, they are not very energy-efficient, as only 10% of the energy that goes into the fixture produces light, while the rest is dissipated as heat.

This type of lamps are about to disappear though. Governments have passed measures to prohibit their sale (the European Union started September last year). The aim is to encourage use of more energy efficient lighting alternatives, such as the CFL and LED lamps.

Halogen

The halogen lamps are based on the same principle as the incandescent lamp, which is electric current passing by a filament only that inside they contain a halogen compound, whose function is to prevent the evaporated tungsten from the filament to be deposited on the bottle. This way, will improve the efficiency and the lifespan of the lamp. The lifetime increases up to 2.000 or 3.000 hours. These lamps provide a high quality light (an excellent colour reproduction, high intensity, etc.) and therefore they are used in areas that require special lighting to highlight paintings, decorative parts, etc.

Figure 87: Halogen Lamp

Nowadays there are dicroique low energy halogen lamps. This type of lamp is the most used halogen. Its efficient version provides the same features of lighting with longer lifespan, 5.000 hours, and 40% less consumption.

Fluorescent Tubes

Tubular fluorescent lamps or *fluorescent tubes* are made of a glass tube containing a small amount of gas. The light is produced by the gas excitation in submission to an electrical discharge between two electrodes. This technology requires an auxiliary equipment to run, although fluorescents with this integrated can be found in the market. The auxiliary equipment can be acquired in one piece with its three components separate:

Figure 88: T5 Fluorescent Tube

1. **Ballasts or stabilizers:** provide energy to the fluorescent tube. There are two types: electromagnetic and electronic stabilizers. Electronic technology provides 25% energy saving compared to the electromagnetic, plus a quick and reliable boot, avoiding the annoying flickering.

2. **Starter:** raise the initial tension needed on the boot to start working.

3. **Capacitor:** is used to correct the power factor, which for fluorescent lamps is very low.

The fluorescents are classified according to diameter: T12 (36mm diameter), T8 (28mm), the most common; T5 (16mm), which is the fluorescent operating with the electronic auxiliary equipment and the most efficient. These lamps consume 80% less than incandescent and have a lifespan between 8 and 10 times longer.

Low Energy Bulb or Compact Fluorescent Lamp (CFL)

The energy-saving lamps are actually *Compact Fluorescent Lamps (CFL)*. With the technology of fluorescent tubes, the size is reduced and the auxiliary equipment is integrated to directly replace incandescent lamps. Compared to general service incandescent lamps giving the same amount of visible light, they use less power and have longer rated life. They are up to four times more efficient (using 80% less energy) and last up to 10 times longer than incandescent bulbs.

Figure 89: Compact Fluorescent Lamp

To optimize the value of CFLs, it is best to use them in areas that are lit for relatively extended periods of time (15 minutes or longer). This could include the outdoor fixtures, the kitchen, family room, and bedroom. Switching a CFL on and off too frequently will shorten its life.

Light Emitting Diode (LED)

A *Light Emitting Diode*, most commonly known as LED, is a semiconductor device (diode) which converts electricity directly into light. As they don't have any filament, their lifetime is very long, up to 50.000 hours and their consumption is 80% less than incandescent.

Figure 90: LED Lamp (18 LED x 1W/LED)

LEDs are about to revolutionize domestic lighting, as they present many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, don't flicker and have greater durability and reliability.

However, they are relatively expensive and require more precise current and heat management than traditional light sources. Current LED products for general lighting are more expensive to buy than fluorescent lamp sources of comparable output.[48]

All these lamps carry an energy label that informs about the energy features. As with all electrical appliances, there are 7 energy efficiency classes that are identified with letters and colours. The letter A and the green colour indicate the highest degree of efficiency and G and the red colour, the lowest. The class A lamps consume 3 times less than those of class G, which is why we should look at the energy class of the lamp when we buy them.

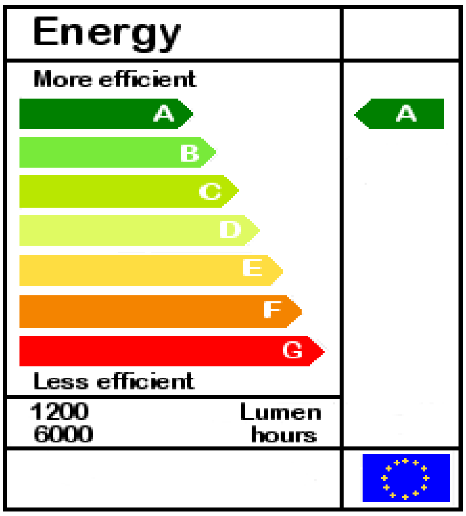


Figure 91 : Label found in lamps where is describe their efficiency

iii. Incandescent vs. CFL vs. LED

Following, we can see a series of charts comparing the three most used light bulbs: incandescent, compact fluorescent lamps (CFL) and LEDs.

Light Output

Light Output (Lumen)	Incandescent (Watts)	CFL (Watts)	LED (Watts)
450	40	8 - 12	4 - 5
300 - 900	60	13 - 18	6 - 8
1100 - 1300	75 - 100	18 - 22	9 - 13
1600 - 1800	100	23 - 30	16 - 20
2600 - 2800	150	30 - 55	25 - 28

Figure 92: Equivalent wattages and light output of incandescent, CFL and LED bulbs

In this first chart one can easily see that, using LEDs instead of CFLs or incandescent bulbs will reduce our energy consumption considerably, since they use less power (watts) per unit of light generated (lumens). LEDs help reduce greenhouse gas emissions from power plants and lower electricity bills.

Important features

	Incandescent	CFL	LED
Lifespan	1.500h	15.000h	50.000h
Frequent on-off cycling	some effect	shorten lifespan	no effect
Turns on instantly	yes	slight delay	yes
Durability	fragile	fragile	durable
Heat emitted	high (85 btu's/hr)	medium (30 btu's/hr)	low (3 btu's/hr)
Hazardous materials	none	5 mg mercury/bulb	none
Replacement frequency (over 50.000 hours)	33,3	3,3	1

Figure 93: Features comparison among incandescent, CFL and LED bulbs.

In this second chart, we can see all the advantages of the LEDs over the CFLs and the incandescent bulbs. To start with, LEDs can have a relatively long useful life. One report estimates 35.000 to 50.000 hours of useful life, though time to complete failure may be longer. Fluorescent tubes typically are rated at about 10,000 to 15,000 hours, depending partly on the conditions of use, and incandescent light bulbs at 1.000–2.000 hours. LEDs last around 3 times more than CFLs, which means we just need to replace one LED instead of the 3,3 CFLs or the 33,3 incandescent, after 50.000 hours of use. Another advantage of LEDs is that, they are ideal for use in applications that are subject to frequent on-off cycling, unlike CFLs that burn out more quickly when cycled frequently. LEDs light up very quickly; a typical red indicator LED will achieve full brightness in microseconds, meanwhile CFL bulbs need some seconds to reach it. LEDs are difficult to damage since they are very robust and they don't use any filament. Unlike CFLs, LEDs don't contain any mercury. And finally LEDs emit cool light, in contrast to most light sources; LEDs radiate very little heat. Wasted energy is dispersed as heat through the base of the LED.

Energy efficiency and energy costs

	Incandescent Light Bulbs	**Compact Fluorescent Lamps (CFL)**	**LED (Light Emitting Diode)**
Life span (in hours)	1.500	15.000	50.000
Wattage (watts)	60	14	6
Cost (of a single bulb)[49]	1,10 €	2,43 €	44,84 €
KWh of electricity used over 50k hours	3.000	700	300
Electricity Cost (0,267€ per KWh)[50]	801 €	186,90 €	80,10 €
Bulbs needed for 50k hours of usage	33,33	3,33	1
Equivalent 50k hour bulb expense	36,67 €	8,10 €	44,84 €
Total 50,000 Hour Lighting Spend	**837,67 €**	**195,00 €**	**124,94 €**

Figure 94: Cost for lighting a bulb for a period of 50.000 hours.

In this third chart, we can see the cost of lighting a single bulb, of each type, for a period of 50.000 hours. The first row indicates the lifespan of each bulb, the second row shows the equivalence wattage and the third row the individual price for each bulb.

On the fourth row it is calculated the KWh of electricity used after 50.000 hours, that results from multiplying the wattage of each bulb by 50.000 hours of use and divided by 1000 to convert it into KW.

On the fifth row it is calculated the electricity cost for lighting each bulb for 50.000 hours. The result comes from multiplying the KWh of electricity used after 50.000 hours by the cost of electricity in Denmark, which is 0,267€ per 1KWh.

On the sixth row it is calculated the number of bulbs we need after 50.000 hours of use. The result comes from dividing the 50.000 hours of use by each bulb lifespan.

On the last row it is calculated the investment cost for each bulb after 50.000 hours of use. The result comes from multiplying the number of bulbs needed by its individual cost.

Finally, the total comes from adding the electricity cost for lighting each bulb for 50.000 hours, plus the investment cost.

We can conclude from this chart, that LEDs have a high investment cost but after some time it is worth it.

Energy savings

	Incandescent Light Bulbs	**Compact Fluorescent Lamps (CFL)**	**LED (Light Emitting Diode)**
# of household light bulbs	24	24	24
Your estimated daily usage (hours)	5	5	5
Days in month	30	30	30
Household savings over 50,000 hours (energy + replacement)			
Household cost	20.104,00€	4.680,00€	2.998,56€
Savings by switching from Incandescent	€ 0,00	15.424,00€	17.105,44€
Monthly household energy savings			
KWh used per month	216KWh	50,4KWh	21,6KWh
Electricity Cost (@ 0,267€ per KWh)	57,67€	13,46€	5,77€
Savings by switching from Incandescent	0,00€	44,22€	51,90€
Annual household energy savings			
KWh used per year	2628KWh	613,2KWh	262,8KWh
Electricity Cost (@ 0,267€ per KWh)	701,68€	163,72€	70,17€
Savings by switching from Incandescent	0,00€	537,95€	631,51€

Figure 95: Energy savings by replacing bulbs

In this chart we can see the energy savings, by replacing bulbs, over 50.000 hours of use, over a month and over a year.

Our flats will have from 6 to 8 rooms; we have estimated that we will put a maximum of 3 points of light in each room, which makes a total of 24 light points in each flat. That is the meaning of the number on the first row of our chart. On the second row we have estimated 5 hours of light daily usage.

On the fourth row it is calculated the household use over 50.000 hours of use in a single flat. The result comes from multiplying the number of bulbs in a flat by the cost of lighting a single bulb over 50.000 hours. And on the fifth row one can appreciate the money saved by switching from incandescent to CFL or LED.

On the sixth row it is calculated the household cost over a month of use in a single flat. The result comes from multiplying the number of light points (24), by the hours of usage (5), by the wattage of the bulb (60, 14 or 6) and by the period (30 days).

The same is done on the last part of the chart, but instead of multiplying by 30 days, we have made the calculations for a whole year, 365 days.

The conclusion we obtain from this chart is that CFLs and LEDs are not that far from each other, but still LEDs are better.

iv. Conclusion for our building

As we have just seen on the charts above, the decision of choosing the right lighting bulbs lies on:

- The individual bulb price
- Their lifespan
- Their wattage
- The electricity cost (how much electricity it takes to light the bulb).

After all the comparisons and calculations among the different types of electric lighting existing for household use, we have come up with the following conclusions:

- Aiming **low energy consumption**, our whole building should be lightened with **LEDs**.

- Aiming **low cost**, we should light the building with **CFLs**. In long term LEDs are more profitable, but if we depend on the initial budget, LEDs are a very big investment.

- Therefore, we have to reach a good compromise between low energy and low cost, with the right mix of both types of bulbs. Thus, the common areas such as stairwells, washing machine rooms, car parking and commercial locals should be lightened with LED. Meanwhile in each flat we can have a mix of both lamps. Note that LEDs should be placed in all toilets, since this is a very used room and LEDs are not subject to the on-off cycling.

5. Automatic regulation

i. Introduction

When speaking about low energy houses it is essential to mention home automation or d*omotics*.

The term *domotics* comes from the contraction between the words *domus* (Latin for *house*) and *informatics* (the science concerned with the collection, transmission, storage, processing and display of information). Domotics is the technology used for the integration of electronic and IT in a building.

Figure 96: Automation systems help saving electricity, water and fuel.

Home automation controls and automates the intelligent management of the house. By incorporating automated systems in your home, you can intelligently manage lighting, air conditioning, hot water, irrigation, domestic appliances, etc., making better use of natural resources, using the hourly rates of lower cost, and thus reduce your energy bills while gaining in comfort and safety.[51]

Home automation services can be grouped under five main areas or aspects:

- **Energy saving**
- Comfort
- Security
- Communication
- Accessibility and remote management

As one of the main goals of this project is to achieve a low consumption, we are going to focus on the energy savings that this system can provide.

ii. Contribution of home automation to savings and energy efficiency

The growing energy consumption and the limitation of energy resources produce negative effects on the environment, and this is reflected in two aspects:

- **Economic:** energy prices tend to rise and therefore the control of the energy consumption increases significantly the user savings.
- **Ecological:** the user can reduce the negative impact on their environment by lowering their energy consumption.

Home automation manages control elements that contribute to saving water, electricity and fuel, noticing its effects both in economic (less cost) and the ecological (less energy consumption).

iii. Elements of an Automation System

In an Automation System we can differentiate three main parts:

- *Sensors:* the sensors are responsible for capturing any physical change in the interior of the home and transmit the information to the control unit, so that it acts accordingly. We find different types of sensors: temperature, humidity, gas, light, motion, presence, etc.

- *Actuators:* the actuators are devices that, using the commands given by the control unit, acts and transforms the data with physical actions (turning on/off lights, turning on/off heat, etc.)

- *Unit control*: the control unit is the most important part of home automation system. It is responsible for managing the information and sending the necessary data to the actuator to solve the problem. Depending on the home automation system used we can find two cases

iv. System architecture

We have three different types for the architecture of the home automation systems:

- *Centralized:* a centralized controller receives information of multiple sensors and, once processed, generates the opportune orders for the actuators.

- *Distributed:* all the intelligence of the system is distributed by all the modules that are sensors or actuators. Usually it is typical of the systems of wiring in bus.

- *Mixed:* systems with decentralized architecture as far as which they have several small devices able to acquire and to process the information of multiple sensors and to transmit them to the rest of devices distributed by the house.

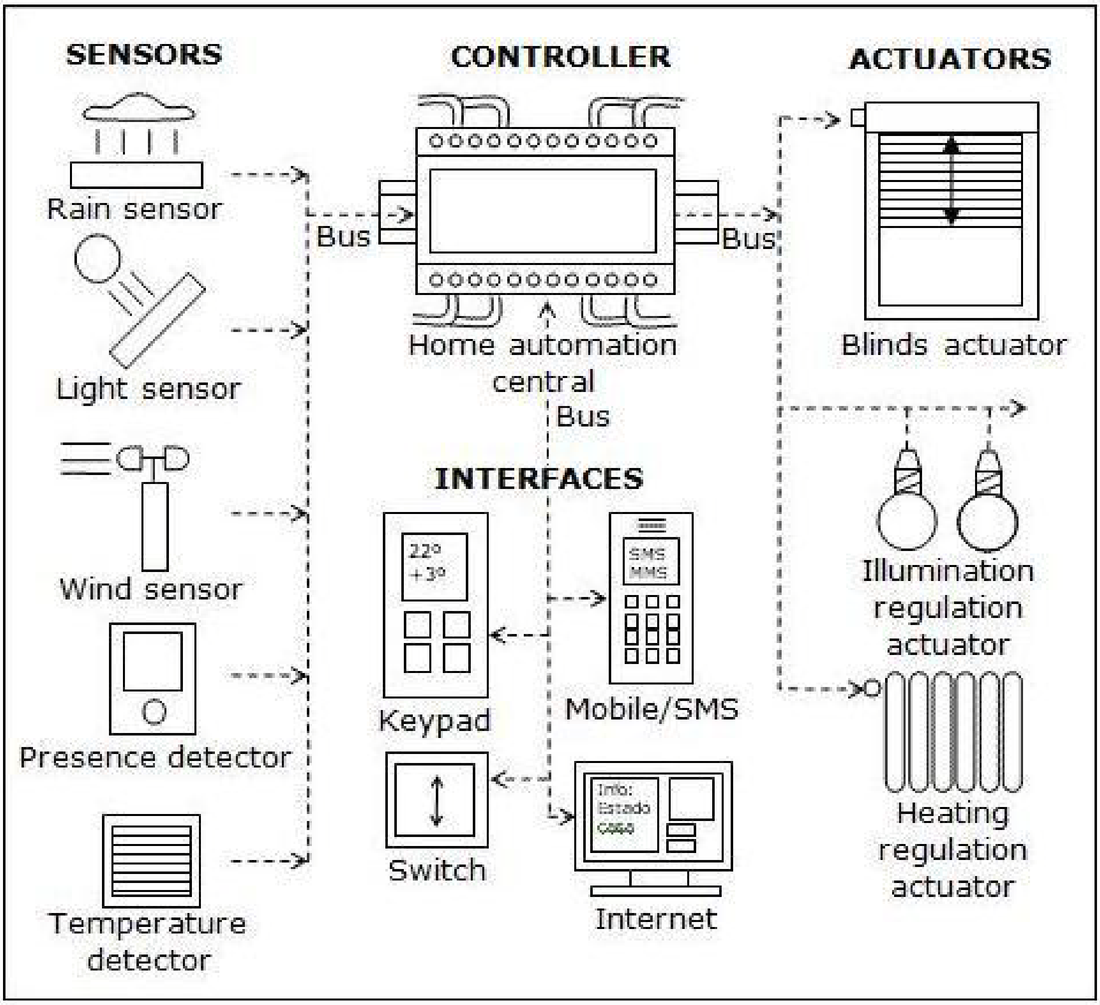


Figure 97: Main elements of an Automation System

v. Automatics in our building

Illumination

We can install a wide range of different automatic systems to reach low energy consumption such as motion systems, programming time, programming light intensity, etc.

- *Efficient illumination systems:* adapting the light level depending on the variation of sunlight, the area of the house or the presence of people, adjusting it to the needs of the moment. For example, detect the presence of people in transit areas such as hallways of the apartment or common areas of a building, and light them up only when necessary.
- *Intelligent automatic control of awnings, blinds and curtains:* allows admitting the most sunlight into the house.
- *Automatic control on the ON/OFF of all lights:* avoid forgetting lights on when leaving the house. We can implement it with motion sensors and timers so that when a person enters a room the light go on and after established minutes they go off again.
- Automatic control of the on and off external lighting depending on the sunlight: we can implement it with light sensors so with a certain level of daylight the lights go off and on the other hand, when it is dark enough they turn on.

Heating and cooling systems

- *Heating and cooling control system:* adapt the house temperature depending on the outdoor temperature, time of day, the area of the house or the presence of people.

Household devices

- *Control or sequencing appliances switching on:* programming their operation to turn them on at times of the day when the energy price is lower.
- *Programming their switching off.*
- *Detection and "on hold" consumption management appliances.*

Water

The simple dripping of a tap in your toilet represents a loss around 100l/month.

- *Intelligent taps:* they regulate the flow and the temperature of the water. An intelligent tap that regulates and eliminates the transitory water lets you save around 25% more water than a common tap.

- *Water leaking:* centralized control and regulation systems. They detect if there is a water leak, give a warning signal and cause an outage. These systems give also information about anomaly operation.
- *Intelligent irrigation control:* through a moisture or rain sensor, soil moisture is detected and independently watered only when necessary.
- *Greywater Recycling:* systems for measuring water quality: they facilitate the management of greywater recycling.

Figure 98: Interactive panel installed in the Energy Flex House Laboratory in Taastrup (Denmark).

vi. Conclusion for our building

We agree with Ole Balselv's drawings that, some automatic systems are needed in our building, in order to reach low energy consumption.

With automated systems in lighting and cooling-heating, we can save 30% of our electricity consumption.

Therefore, we propose to install automated systems with an interactive panel where we can control the house temperature, the water and electricity consumption at any moment. Companies such as Siemens or Schneider Electrics would be our best choice.

Part 5: Guidelines

Guidelines play a very important role in a home when it comes to energy savings. The top of the art technologies installed become useless if we don't use them properly. So, it belongs to the occupants of low energy houses to respect some guidelines so far as possible, to make it efficient. Therefore, we will try to change the occupants' behaviour through them.

Six ranges of guidelines are distinguished, about:

- The electricity;
- The water;
- The electricity and water;
- The heating;
- The wastes;
- The ecological impact.

Electricity consumption

- Use the household devices when the electricity is cheap;
- Don't let the electrical devices in standby. It reduces the electricity consumption by 10%;
- Switch off the lights when they are not necessary;
- Let the daily light entering the rooms as much as possible;
- Use low consumption lamps in appropriated rooms;
- Clean regularly the lamps to optimize their efficiency;
- Avoid too warm washings so far as possible. Heating the water requires electricity, and using a 40°C cycle instead of a 60°C cycle saves round about 25% of electricity[52];
- Use a washing machine using warm water instead of a washing machine heating cold water up;
- Dry the linen outside when possible (use the dryer as less as possible);
- Use induction cookers instead of vitro-ceramic. There is a small difference between the both, but the induction is more economical;
- Use the residual heat of the cookers for the end of the cooking (use the inertia);
- Cover the pans while cooking. It reduces by 30% this energy consumption[53];
- Buy grade A household devices;
- Unfroze the fridges every six months at least, in order to consume three times less of electricity.
- Put the fridges in ventilated rooms to avoid overheat.

Water consumption

- Don't let the water on while washing the hands or brushing the teeth;
- Don't let the water flowing while washing the dishes;
- Install an economical toilet flush (half or entire bucket);
- Use flow limiters for the showers and the taps. It reduces the water consumption by 50% per year[54];
- Prefer showers to baths.

Water and electricity consumption

- Fill the entire washing machines. It reduces at the same time the water and the electricity consumptions.

Heating

- Switch the heating off while airing the rooms;
- Don't air too long;
- Program the heating system in function of the life rhythm (15°C-17°C during the night and 19°C during the day). Reducing the heating of 1°C permits to save 7% of energy[55].

Wastes

- Sort out the wastes (paper/plastic/glass/organic wastes/toxic wastes);
- Treat the grey water (it could be used to warm the water up, by conduction);
- Reduces the amount of wastes, and of packaging bought;

Ecological impact

- Use non polluting detergents (washing powder, soap…) whose are bio-degradable at 99%[56].

To conclude, if people accept to change their behavior by respecting few rules every day, the energy and water consumptions could be noticeably reduced. The waste production will be decreased as well, which will limit the greenhouse gases emission.

Part 6: Money/Savings

1. A first approach: the calculation tool ASCOT

Ole Balslev, the architect from Cenergia, gave us a software called ASCOT in order to help us to do the calculations determining the general energy consumption of our building.

First of all, let’s recapitulate data we will use in our software:

Field	Taken figure
Average floor area per dwellings	110 m²
Number of dwellings	27
Floor height	2,8 meters
Distribution of windows(according to the drawings)	South : 18% - West 15% - North : 36% - East : 31%
Average number of people per housing unit	3 people per housing unit

Figure 99: Recapitulate data

The calculation tool ASCOT - Assessment tool for additional construction cost in sustainable building renovation – was originally developed for dwellings. The purpose of the ASCOT tool is to assist the user in evaluating and thereby optimize the economical costs of a building renovation project in relation to sustainable development issues. The tool is based on earlier development work in various EU- and national (DK) projects.

This tool has been created with the software Excel from Microsoft. It is composed of different sheets:

Nb	Name	Goal
1	Reference	Characteristics of the building are entered in this part
2	Optimizing	Different sustainable concepts can be added
3	Saving	Financial figures are presented
4	Results	Energy consumptions and costs

Figure 100: Different sheets

The first sheet reference looks like below:

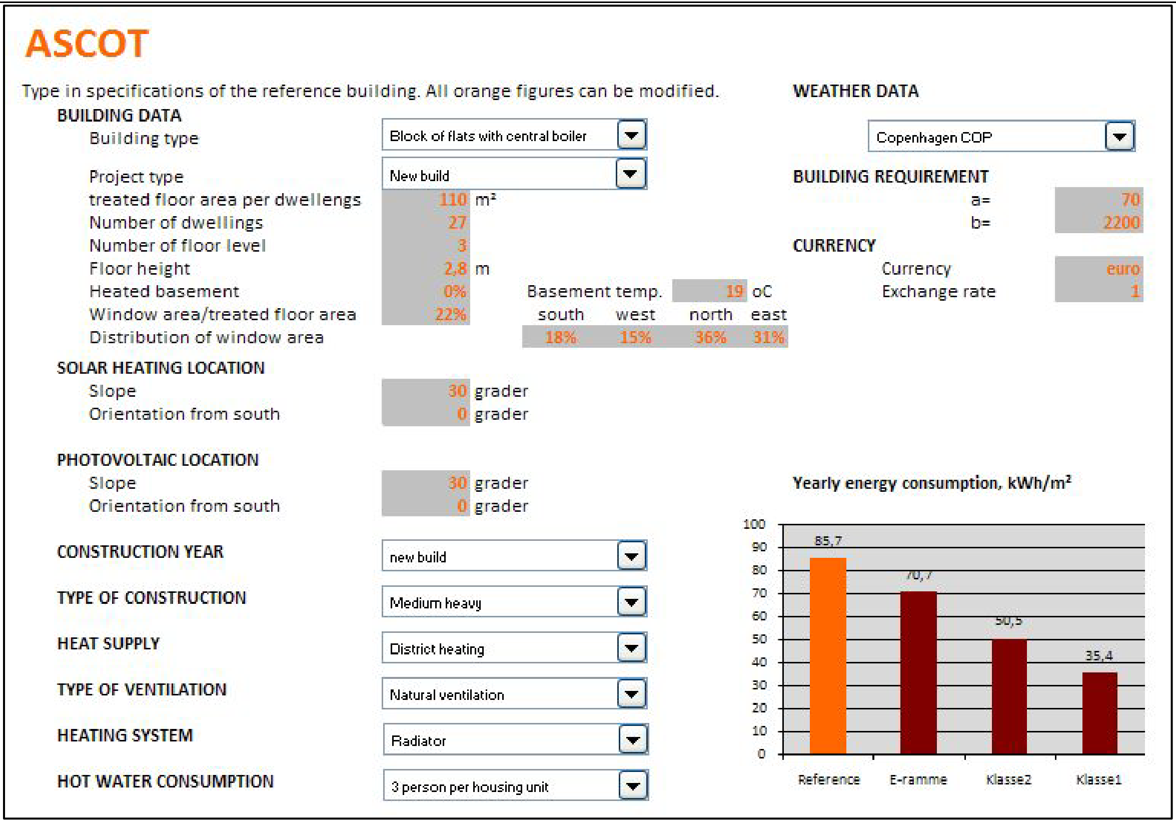


Figure 101: Screenshot ASCOT 1

After entering all data, the yearly consumption of such a building without specific insulation is, according to ASCOT, 85,7 kWh/m². We have a long way to go in order to reach the class 1, and its yearly energy consumption of 35,4 kWh/m²/year.

Let's now add some good insulation (+200 mm for the wall, the roof and the floor), a good heat recovery system for the ventilation, 3 layers energy glasses and a solar DHW as water boiler.

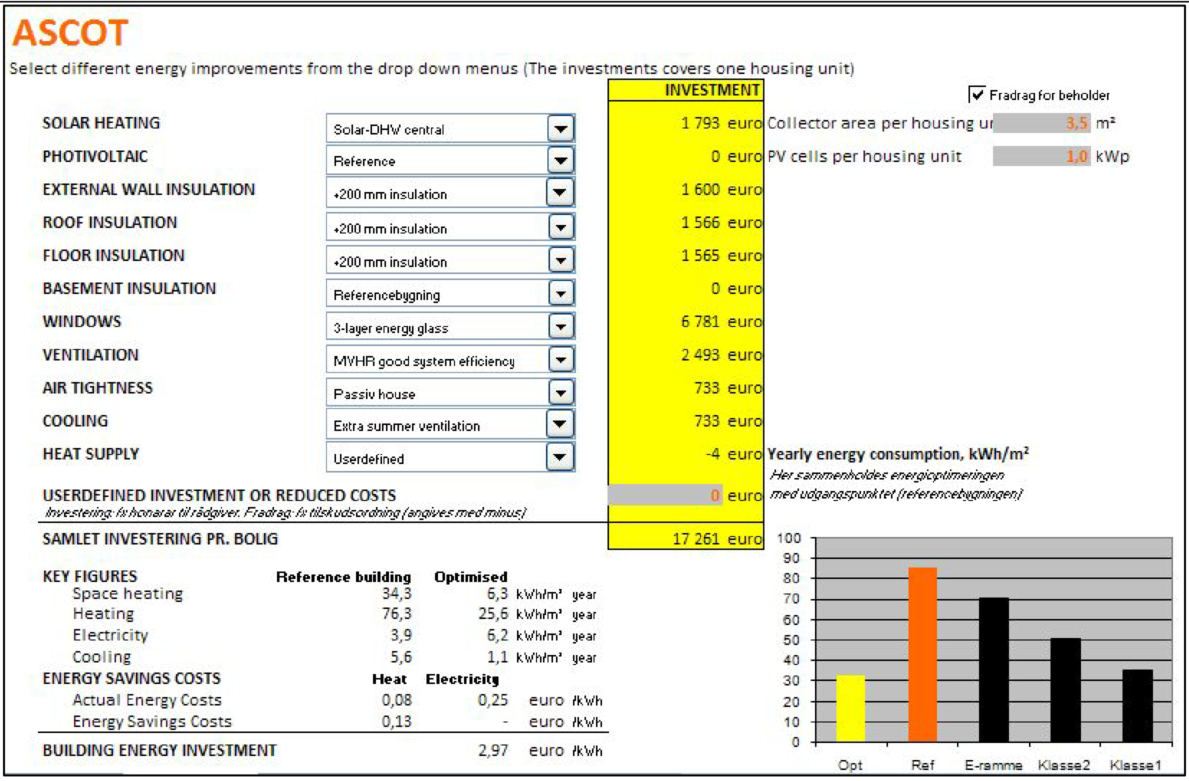


Figure 102: Screenshot ASCOT 2

We see that the yearly consumption is now lower than required. The initial investment is 17000 Euros for the whole building.

ASCOT

The financial figures are listed and the orange figures can be modified.

	Net Present Value, NPV			Heat	El-production
1	Total investment incl. VAT		euro	17 261	0
2	Discount rate	5,0%			
3	Tax of interest income	0,0%			
4	Inflation of energy	4,5%			
5	Inflation of maintenance	3,0%			
6	Expected economic lifetime	25	year		
7	Expected lifetime		year	29	0
8	Factual costing interes, savings	0,005			
9	Factual costing interes, expenses	0,019			
10	NPV factor, saving	23,5			
11	NPV factor, expenses	19,7			
12	Expenses		euro /year	0	0
13	NPV of expenses		euro	0	0
14	Energy savings costs		euro /year	423	0
15	NPV of energy savings costs		euro	9 955	0
16	**NPV of Investement = Bo - Uo - Io**		euro	-7 306	0
17	Energy saving, heat		kWh /year	5572	0
18	Energy savings, fan + pump		kWh /year	-103	0
19	PV production		kWh /year	0	0
20	NPV of the remaining investment		euro	1 437	-
21	Energy saving cost		euro /kWh	0,13	-
22	repay the debt		euro /year	1 225	0

Figure 103: Screenshot ASCOT 3

After a period of 29 years, 60 % of the initial investment is paid off due to the energy savings costs. Nevertheless, this simulation is done with an inflation of energy from 4,5 %, number which could increase in the next years. Moreover, we can admit that some technologies will be useful more than 29 years. The energy savings costs will maybe be lower but still stay sizeable.

		REFERENCE BUILDING		ENERGY OPTIMAIZED	
Space heating		34,3		6,3	
Domestic hot water		22,0		22,8	
Solar heat		0,0		13,4	
Net heating		56,4		15,7	
Losses from installations		19,9		10,0	
Total needs of heating	kWh/m² year		76,3		25,6
Electricity to heat pump		0,00		0,00	
Pumps		1,54		0,76	
Fans		0,00		1,72	
PV production		0,00		0,00	
Net demand		1,54		2,48	
Net demand x 2.5	kWh/m² year		3,9		6,2
Cooling	kWh/m² year	5,6	5,6	1,1	1,1
Energy consumption	**kWh/m² year**		**85,7**		**32,9**
Energy requrement	kWh/m² year		70,7		70,7
Low energy class 2	kWh/m² year		50,5		50,5
Low energy class 1	kWh/m² year		35,4		35,4
DRIFTSUDGIFTER					
Heat	euro /year		638		214
Pump+fans	euro /year		43		69
PV production	euro /year		0		0
SAMLEDE DRIFTSUDGITER	euro /year		**681**		**283**

Figure 104: Screenshot ASCOT 4

In conclusion, ASCOT Software gives us a good general survey about the technologies available for our project. We see that it is possible to reach a class 1 house.

2. Specific analysis of our building

i. Critical analysis of ASCOT tool

Even if ASCOT allowed us to take into account a lot of characteristics of the building (distribution of windows, surface and height of the flats), it stays a simple tool. Some characteristics are indeed forgotten:

- The geometry of the building: It is not a parallelepiped but has contrarily a complex shape. The losses through the walls are higher but the natural ventilation is more effective.
- Shops, cafés and offices are located on the ground floor : these areas are supposed to be loftier (4 meters instead of 2,8 meters), to produce more heat (a lot of costumers are supposed to come here, and more electric devices are going to be used than in a domestic flat)

In order to know if the results of ASCOT are faithful to the reality, we created a software with Microsoft Excel.

First, let's compare the results with ASCOT and our software for a parallelepiped. We consider that the building is a square (60x60 m) with the same height that the real building. For this building, we consider that the insulation is 200 mm for the roof and the walls, that 2-layers energy glasses, District heating and Solar-DHW central is used. 3 people are supposed to live in each flat.

		REFERENCE BUILDING		ENERGY OPTIMAIZED	
Space heating		34,3		24,3	
Domestic hot water		22,0		22,8	
Solar heat		0,0		13,6	
Net heating		56,4		33,5	
Losses from installations		19,9		19,9	
Total needs of heating	kWh/m² year		76,3		53,4
Electricity to heat pump		0,00		0,00	
Pumps		1,54		1,35	
Fans		0,00		0,00	
PV production		0,00		0,00	
Net demand		1,54		1,35	
Net demand x 2.5	kWh/m² year		3,9		3,4
Cooling	kWh/m² year	5,6	5,6	2,9	2,9
Energy consumption	**kWh/m² year**		**85,7**		**59,7**

Figure 105: Screenshot ASCOT 5

ASCOT gives us an energy consumption of 59,7 kWh/m²/year.

Let’s now simulate the same situation with Excel:

inside température at day	19	°C			
inside temperature at night	19	°C			
Recommended air flow		4150 m^3/h	1,153 m3/s		
Sommer air flow	1,153	m3/s			
Number of people living in the building	81	people			
Energy needed to keep inside temperature	151436	kWh	or	151,436083	MWh
Earth tubes give	0	kWh	or	0	MWh
Bodies energy	36223	kWh	or	36,2232	MWh
Contributions of windows	40071	kWh	or	40,07083038	MWh
Or change percentage of windows	*0*	*%*	*or*	*0*	*MWh*
Losses from walls	70271	kWh	or	70,27083308	MWh
Losses from ground	10613	kWh	or	10,61256	MWh
Heat from electric devices	60000	kWh	or	60	MWh
Activate heat from the shops:					
Add need for hot water				*66,194*	*MWh*
District heating needed is :	130	MWh			
per m² :	54	kWh/m²/an			

Figure 106: Screenshot Excel 1

The yearly consumption obtained with our software is 54kWh/m²/year. We see that the results are quite similar. The software we have created uses real data from Copenhagen’s weather.

Let’s now use our software with the real geometry of our building:

inside température at day	19	°C			
inside temperature at night	19	°C			
Recommended air flow		4500 m^3/h	1,25 m3/s		
Sommer air flow	3	m3/s			
Number of people living in the building	75	people			
Energy needed to keep inside temperature	157610	kWh	or	157,6104148	MWh
Earth tubes give	0	kWh	or	0	MWh
Bodies energy	33540	kWh	or	33,54	MWh
Contributions of windows	64898	kWh	or	64,89847	MWh
Or change percentage of windows	*0*	*%*	*or*	*0*	*MWh*
Losses from walls	91964	kWh	or	91,9637604	MWh
Losses from ground	10613	kWh	or	10,61256	MWh
Heat from electric devices	60000	kWh	or	60	MWh
Activate heat from the shops:					
Coefficient heat recovery	*0*	*%*	*or*	*0*	*MWh*
Add need for hot water				*34,536*	*MWh*
District heating needed is :	153	MWh			
per m² :	62	kWh/m²/an			

Figure 107: Screenshot Excel 2

As we expected, the heat losses through the walls raised from 70MWh per year to 92MWh per year. It is the same for the losses from the ground. **The yearly consumption is now 62kWh/m²/year.**

At first sight, the geometry of the building is not profitable. Nevertheless, it allows us to have good natural ventilation in summer and to **avoid using mechanical ventilation**.

Let's now consider that the shops, cafés, and offices produce more heat than domestic flats. A lot of customers are indeed supposed to come in the café, computers will be used in the offices, and gas cooker can be used if a restaurant opens. Let's consider that the heat from electric devices rises from 60MWh to 100MWh, which is a humble scenario:

Heat from electric devices	100000	kWh	or	100	MWh
Activate heat from the shops:					
Coefficient heat recovery	*0*	*%*	*or*	*0*	*MWh*
Add need for hot water				*34,536*	*MWh*
District heating needed is :	135	MWh			
per m² :	56	kWh/m²/an			

Figure 108: Screenshot Excel 3

The yearly consumption is now 56kWh/m². It was 54kWh/m² before taking into account the specification of our building.

Conclusion: We can consider that ASCOT tool gives us results faithful to the reality. The heat needed because of the complex shape is balanced thanks to the heat coming from the shops located on the ground floor. Our building is nevertheless well thought, because its geometry permits good natural ventilation in summer.

ii. Use of earth tubes

GAEA Software from the University of Siegen in Germany gave us a yearly heat supply of 14MWh, using 10 pipes of 30 meters, with a diameter of 20 cm .Thanks to our software, we can take into account that earth tubes don't give useful heat the whole year. Indeed, earth tubes will be useless in summer in order to heat, when the air is warm enough. They permit however to get fresh air in the summer.

Energy needed to keep inside temperature	157610	kWh	or	157,6104148	MWh
Earth tubes give	13996	kWh	or	13,99564812	MWh
Bodies energy	33540	kWh	or	33,54	MWh
Contributions of windows	64898	kWh	or	64,89847	MWh
Or change percentage of windows	*0*	*%*	*or*	*0*	*MWh*
Losses from walls	91964	kWh	or	91,9637604	MWh
Losses from ground	10613	kWh	or	10,61256	MWh
Heat from electric devices	100000	kWh	or	100	MWh
Activate heat from the shops:					
Coefficient heat recovery	*0*	*%*	*or*	*0*	*MWh*
Add need for hot water				*34,536*	*MWh*
District heating needed is :	125	MWh			
per m² :	52	kWh/m²/an			

Figure 109: Screenshot Excel 4

The yearly consumption decreased to 52kWh/m². Because the payback time is only 10 years, **we propose to use earth tubes**.

iii. Conclusion for our building

We propose the following solution:

ASCOT

Select different energy improvements from the drop down menus (The investments covers one ho

		INVESTMENT
SOLAR HEATING	Solar-DHW central	1 793 euro
PHOTIVOLTAIC	Photovoltaic	5 397 euro
EXTERNAL WALL INSULATION	+200 mm insulation	1 600 euro
ROOF INSULATION	+200 mm insulation	1 566 euro
FLOOR INSULATION	+100 mm insulation	918 euro
BASEMENT INSULATION	Referencebygning	0 euro
WINDOWS	2-layer energy glass	255 euro
VENTILATION	MVHR good system efficiency	2 493 euro
AIR TIGHTNESS	Reference	0 euro
COOLING	Reference	0 euro
HEAT SUPPLY	District heating	0 euro
USERDEFINED INVESTMENT OR REDUCED COSTS *Investering: fx honarar til rådgiver. Fradrag: fx tilskudsordning (angives med minus)*		0 euro
SAMLET INVESTERING PR. BOLIG		14 023 euro

Figure 110: Screenshot ASCOT 6

Main heat supply is provided by District Heating, through normal radiator.

We propose to add earth tubes to this solution, which will cost 3200 DKK per flat. The total investment cost will therefore be 107880 DKK.

Let's see now economic aspects:

Net Present Value, NPV				Heat	El-production
1	Total investment incl. VAT		euro	8 626	5 397
2	Discount rate	5,0%			
3	Tax of interest income	0,0%			
4	Inflation of energy	4,5%			
5	Inflation of maintenance	3,0%			
6	Expected economic lifetime	25	year		
7	Expected lifetime		year	29	30
8	Factual costing interes, savings	0,005			
9	Factual costing interes, expenses	0,019			
10	NPV factor, saving	23,5			
11	NPV factor, expenses	19,7			
12	Expenses		euro /year	0	0
13	NPV of expenses		euro	0	0
14	Energy savings costs		euro /year	292	221
15	NPV of energy savings costs		euro	6 867	5 197
16	**NPV of Investement = Bo - Uo - Io**		euro	-1 759	-201

Figure 111: Screenshot ASCOT 7

With an expected lifetime of 30 year, an energy infiltration of 4,5% and without earth tubes, installations would only cost 13087+1495 = 14582 DKK per flat.

If the inflation of energy rises to 6%, the installation will permit to get money:

Net Present Value, NPV				Heat	El-production
1	Total investment incl. VAT		euro	8 626	5 397
2	Discount rate	5,0%			
3	Tax of interest income	0,0%			
4	Inflation of energy	6,0%			
5	Inflation of maintenance	3,0%			
6	Expected economic lifetime	25	year		
7	Expected lifetime		year	29	30
8	Factual costing interes, savings	-0,009			
9	Factual costing interes, expenses	0,019			
10	NPV factor, saving	28,3			
11	NPV factor, expenses	19,7			
12	Expenses		euro /year	0	0
13	NPV of expenses		euro	0	0
14	Energy savings costs		euro /year	292	221
15	NPV of energy savings costs		euro	8 279	6 265
16	**NPV of Investement = Bo - Uo - Io**		euro	-347	868

Figure 112: Screenshot ASCOT 8

The installation would in that case permit to earn 6458-2583 = 3875 DKK per flat.

Now, if we add earth tubes, with the first rate of energy infiltartion, energy savings costs raise to 2306 DKK. **The installation would cost 13392 DKK per flat.** If the inflation of energy rises to 6% the installation will permit to **earn 4018 DKK per flat within 30 years.**

As you can see on the following picture, class 1 is reached if we include the 2kWh/m²/year saved with earth tubes:

		REFERENCE BUILDING		ENERGY OPTIMAIZED	
Space heating		34,3		12,2	
Domestic hot water		22,0		22,8	
Solar heat		0,0		13,6	
Net heating		56,4		21,4	
Losses from installations		19,9		19,9	
Total needs of heating	kWh/m² year		76,3		41,3
Electricity to heat pump		0,00		0,00	
Pumps		1,54		0,97	
Fans		0,00		1,84	
PV production		0,00		7,93	
Net demand		1,54		-5,12	
Net demand x 2.5	kWh/m² year		3,9		-12,8
Cooling	kWh/m² year	5,6	5,6	7,0	7,0
Energy consumption	**kWh/m² year**		**85,7**		**35,5**
Energy requrement	kWh/m² year		70,7		70,7
Low energy class 2	kWh/m² year		50,5		50,5
Low energy class 1	kWh/m² year		35,4		35,4

Figure 113: Screenshot ASCOT 9

The final energy consumption will be 33,5 kWh/m²/year. This theoretical result seem be very close to the reality. More often, low energy buildings consume more than expected because of the bad ventilation in summer.

The presence of vegetation, the thin geometry and earth tubes which will bring fresh air in summer will permit to keep this consumption low. **Automatic regulation and guidelines remain important if we want to keep the consumption low in everyday life.**

Conclusion

As a conclusion for our project, we are going to list all the solutions we decided to implement in our building in order to reach the Class 1, which is 35,4 kWh/m²year. After studying the technical solutions we can differentiate them in two big parts.

The first one deals with **passive solutions**. It includes the following parts:

- Heating system composed of an efficient two layers glazing, 10 earth tubes, and good heat recovery ventilation.
- Insulation of the building, for which we decided the following parameters:
  - 50 cm of terracotta bricks for the walls, with lime coatings;
  - 19 cm of sheep wall for the floors
  - 17,5 cm of glass wool for the ground
  - 19 cm of sheep wool for the roof-terrace
  - 20 cm of rock wool for the roof.
- Daylighting with small windows on the north orientated facades to avoid heat losses, and open areas and bigger windows on the south orientated facades. Also provide some daylighting with skylights.

The second one deals with **active solutions**. It includes the following parts:

- Solar systems composed of 200 m² of photovoltaic panels and 100 m² of thermal collectors in order to produce electricity and to warm the domestic water up.
- District heating involved in the heating system.
- Electric lighting with the right mix of LEDs and CFLs, to reach a good compromise between low energy consumption and low cost.
- Automatic systems, regulating the electricity and heating.

Finally, we reached real low energy consumption (Class 1) by following some guidelines, having common rooms for washing machines, using economical toilet flushes, or washing machines using warm water. But is it such a project economically conceivable?

According to recently released data by the Energy Information Administration, World Energy Use are nevertheless projected to grow by 44% trough 2030. Moreover, peak oil is going to happen soon, and thus demand for coal and its price will rise.

The important use of wind energy in Denmark implies energy demand when wind is not blowing, which can only be satisfied using coal, oil and gas. Prices in Denmark are consequently going to rise in the next decade, even if renewable energies are more and more developed.

According to ASCOT, our project becomes profitable if the inflation of energy rises to 6%. There is a strong chance that occupants will earn money thanks to energy savings in the next 30 years.

Even if economic aspects are important in our project, well-being of occupants has to be taken into account. In a scenario with a low energy inflation of 4,5%, the price of installations will only be 2 € per month per person. This is quite cheap for living in well-being conditions and to have a clear conscience.

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1. List of figures

29	http://www.geo-reisecommunity.de/reisen/kobenhavn/klima	Climate in Copenhagen 2
30	http://re.jrc.ec.europa.eu/pvgis	Global irradiation in Denmark
Part 3: Passive Solutions		
31	http://www.ale-montpellier.org/UserFiles/Image/thermographie/deperditions.jpg	Principal heat losses in a house
32		Thermal points around the windows in a house
33	http://www.espace-energie.com/infiltrometrie.htm	Blower door test
34	http://www.commeunpro.com/dossiers/thermopierre0702/bloc_thermopierre.jpg	Cellular Concrete
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36	http://www.midi-batiment.com/img/fic-tec/materiaux/parpaing.jpg	Hollow concrete tile
37	Made by group 3	Benchmarks and values for the walls insulation2
38	Made by group 3	Comparison of the three kinds of bricks
39	Cenergia's drawing	Roof of the building
40	http://building.do.com/	Structure of a flat roof
41	Made by group 3	Percentage of good properties
42	Made by group 3	Classification of the laggings in function of their properties
43	http://news.editions-des-halles.com/002133.jpg	Sheep wool in boards
44	Made by group 3	Classification of the laggings in function of their properties
45	http://therminsindia.com/images/GlassWool1.jpg	Glass wool in rolls
46	http://www.enviro2b.com/wp-content/uploads/Urbanisme/toit_vert.jpg	Flat green roof
47	Made by group 3	Surface of windows
48	http://fr.wikipedia.org/wiki/Strasbourg#Climat	Temperature of Strasbourg
49	Made by group 3	Temperature of Copenhagen
50	http://en.wikipedia.org/wiki/File:Passivhaus_section_en.jpg	Heat Recovery System and Earth tubes
51	Cenergia's drawing	A facade of our future building with random windows
52	Cenergia's drawing	Courtyards in our future building
53	Google images for Skylights	A skylight in a bathroom
54	http://www.espaciosolar.com/	TDD installed in a roof
55	http://www.parans.com/	Optic fiber solar lighting
56	http://www.parans.com/	Parans Solar Panel

57	http://www.parans.com/	Acting tracking lenses
58	http://www.parans.com/	Light transmission in Parans optical cable
59	http://www.parans.com/	Parans Luminaires with 4 fiber optic cables
60	Cenergia's drawing	Layout for windows position
	Part 4: Active Solutions	
61	http://www.ens.dk/en-US/Info/FactsAndFigures/Energy_statistics_and_indicators/Annual%20Statistics/Documents/Energy%20Statistics%202008.pdf	Projections of gross energy consumption by fuel
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66	http://www.energiesparmobil.de/bilder/erneuerbare_energien/51_01_funktionsprinzip.gif	Flat plate collector principle
67	http://www.solarpanelsplus.com/images/flat-plate-solar-collector.jpg	Flat plate collector
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69	http://www.igensolar.com/images/p027_0_06_01.jpg	Evacuated tube collector principle
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73	http://www.planetenergy.co.uk/Solar%20Vacuum%20v%20Flat%20Collector%20Comparison.pdf	Warm water covering
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80	Cenergia's drawings (Appendix)	Location for solar models
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87	Google images for Halogen Lamps	Halogen Lamp
88	Google images for Fluorescent Tubes	T5 Fluorescent Tube
89	Google images for Compact Fluorescent Lamps	Compact Fluorescent Lamp
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Part 5: Guidelines		
Part 6: Money/Savings		
99	Made by group 3	Recapitulate data
100	Made by group 3	Different sheets
101	Made by group 3	Screenshot ASCOT 1
102	Made by group 3	Screenshot ASCOT 2

103	Made by group 3	Screenshot ASCOT 3
104	Made by group 3	Screenshot ASCOT 4
105	Made by group 3	Screenshot ASCOT 5
106	Made by group 3	Screenshot Excel 1
107	Made by group 3	Screenshot Excel 2
108	Made by group 3	Screenshot Excel 3
109	Made by group 3	Screenshot Excel 4
110	Made by group 3	Screenshot ASCOT 6
111	Made by group 3	Screenshot ASCOT 7
112	Made by group 3	Screenshot ASCOT 8
113	Made by group 3	Screenshot ASCOT 9
Conclusion		

2. List of tables

	america/index.html
29	http://www.solaraccess.de/solarstrom/sonneneinstrahlung-und-ertrag.html
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52	http://www.securikids.fr/parents/famille/droits-de-lenfant/208
53	http://www.letoitangevin.com/-Conseils-pour-economiser-l-energie-
54	http://www.letoitangevin.com/-Conseils-pour-economiser-l-energie-
55	http://www.letoitangevin.com/-Conseils-pour-economiser-l-energie-

56	http://www.pratique.fr/10-gestes-essentiels-economiser-energie.html
Part 6: Money/Savings	
Conclusion	

3. Appendix

➢ Benchmarks and values for lagging comparison

● Recommended Use

○ Possible use with lightweight concrete

1 UF = 1m² of insulant for R=5m².K/W

Lagging Types			Using			Lagging Caracteristics			Technical Caracteristics				Environmental Balance Sheet	
Origin	Insulant	Conditioning	Floor	Roof / Roof terrace	Ground	Coefficient of thermal conductivity λ [W/m.K]	Thickness for R=5 [cm]	Price [DKK]	Hygroscopic Capacity	Vapor Resistance coefficient μ	Flameproofed	Phase Time Diference (in hour for 20 cm)	Primary energy (kWh/m²)	Greenhouse Effect
Synthetic Insulating Materials	Extruded Polystyrene	Boards	●	●	●	0.037 to 0.040	18 to 20	111 to 149	None	30 to 100	B	6	84 🔴	10 🔴
Mineral Wools	Glass Wool	Rolls	●	●	●	0.035	17	45 to 119	None	1	A to B	6	74 🟠	12 🔴
	Rock Wool	Rolls	●	●	●	0.04	20	45 to 75	None	1	A to B	6	168 🔴	43 🔴
Organic Insulants	Fibre Wood	Flexible boards	●			0.038 to 0.040	19 to 20	178 to 283	Low	1 to 2	E	7.5	41 🟠	-4 🟢
		Dense boards	●	●	●	0.037 to 0.046	18 to 23	36 to 75	Low	3 to 8	E	15	195 🔴	-21 🟢 🟢
	Cellulose	Insuflated Bulk	●			0.038 to 0.044	19 to 22	111 to 149	Intermediate	1 to 2	B to E	10	22 🟢	-10 🟢
		Dumped Bulk	●			0.037 to 0.040	18 to 20	111 to 149	Intermediate	1 to 2	B to E	10	22 🟢	-10 🟢
		Boards	●			0.039	20	183 to 312	Intermediate	2	E	12	71 🟠	-5 🟢
	Cork	Bulk	●		○	0.040 to 0.045	20 to 22	208 to 312	Low	5 to 30	E	9	41 🟠	-26 🟢 🟢
		Boards	●	●	●	0.036 to 0.042	18 to 21	335 to 582	Low	5 to 30	E	13	41 🟠	-26 🟢 🟢
	Hemp Wool	Rolls	●			0.038 to 0.042	19 to 21	186 to 268	Intermediate	1 to 2	E	7	52 🟠	-1 🟢
		Boards	●			0.038 to 0.042	19 to 21	149 to 298	Intermediate	1 to 2	E	7	69 🟠	-1 🟢
	Hemp Stalk	Bulk	●		○	0.048	24	127 to 223	Intermediate	1 to 2	E	8.5	16 🟢	-49 🟢 🟢
	Linen Wool	Rolls	●			0.037	19	260 to 298	Intermediate	1 to 2	C to D	6	38 🟠	1 🟢
		Boards	●			0.037 to 0.047	18 to 23	164 to 186	Intermediate	1 to 2	C to D	6	57 🟠	1 🟢
Animal Insulants	Sheep Wool	Rolls	●			0.035 to 0.042	17 to 21	149 to 208	High	1 to 2	C	5	20 🟢	0 🟢
		Boards	●			0.035 to 0.040	17 to 20	208 to 268	High	1 to 2	C	5	20 🟢	0 🟢

Appendix 1: Benchmarks and values for lagging comparison

- Comparison of insulating materials

Coefficient of thermal conductivity		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	+
Glass Wool	Rolls	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Wool	Rolls	-	+		-	-	-	-	-	-	-	-	-	-	+	-	-	+
Fibre Wood	Flexible	+	+	+		-	-	+	-	-	-	-	-	-	+	-	+	+
	Dense	+	+	+	+		+	+	+	-	+	+	+	-	+	-	+	+
Cellulose	Insuflated	+	+	+	+	-		+	+	-	+	+	+	-	+	-	+	+
	Dumped	-	+	+	-	-	-		-	-	-	-	-	-	+	-	-	+
	Boards	+	+	+	-	-	-	+		-	-	-	-	-	+	-	+	+
Cork	Bulk	+	+	+	+	+	+	+	+		+	+	+	-	+	+	+	+
	Boards	+	+	+	-	-	-	+	-	-		-	-	-	+	-	+	+
Hemp Wool	Rolls	+	+	+	+	-	-	+	+	-	+		-	-	+	-	+	+
	Boards	+	+	+	+	-	-	+	+	-	+	-		-	+	-	+	+
Hemp Stalk	Bulk	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
Linen Wool	Rolls	-	+	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Boards	+	+	+	+	+	+	+	+	-	+	+	+	-	+		+	+
Sheep Wool	Rolls	-	+	+	-	-	-	-	-	-	-	-	-	-	+	-		+
	Boards	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	
%		62.5	100	81.25	43.75	18.75	25	62.5	43.75	6.25	43.75	31.25	31.25	0	93.75	12.5	62.5	87.5

Appendix 2: Comparative table of the coefficient of thermal efficiency of the laggings

Thickness		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Glass Wool	Rolls	+		+	-	-	+	-	-	-	-	-	-	-	+	-	+	+
Rock Wool	Rolls	+	-		-	-	-	-	-	-	-	-	-	-	-	-	-	+
Fibre Wood	Flexible	+	+	+		-	+	-	+	-	-	+	+	-	+	-	+	+
	Dense	+	+	+	-		+	-	+	-	-	+	+	-	+	-	+	+
Cellulose	Insuflated	+	+	+	-	-		-	-	-	-	-	-	-	-	-	-	+
	Dumped	+	-	+	-	-	+		+	-	-	+	+	-	+	-	+	+
	Boards	+	+	+	+	+	+	-		-	-	-	-	-	+	-	+	+
Cork	Bulk	+	+	+	-	-	+	+	+		+	+	+	-	+	+	+	+
	Boards	+	-	+	-	-	+	-	+	-		+	+	-	+	-	+	+
Hemp Wool	Rolls	+	-	+	-	-	+	-	-	-	-		-	-	+	-	+	+
	Boards	+	+	+	+	+	+	-	-	-	-	-		-	+	-	+	+
Hemp Stalk	Bulk	+	-	+	-	-	+	+	+	+	+	+	+		+	+	+	+
Linen Wool	Rolls	+	+	+	-	-	-	-	-	-	-	-	-	-		-	-	+
	Boards	+	-	+	-	-	+	-	+	-	-	+	+	-	+		+	+
Sheep Wool	Rolls	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		+
	Boards	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	
%		93.75	43.75	87.5	12.5	12.5	68.75	12.5	43.75	6.25	12.5	43.75	43.75	0	68.75	18.75	68.75	100

Appendix 3: Comparative table of the thickness of the laggings

Price		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		+	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-
Glass Wool	Rolls	-		+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Wool	Rolls	-	-		+	-	-	-	-	-	-	-	-	-	-	-	-	-
Fibre Wood	Flexible	+	+	+		-	+	+	-	+	-	+	+	+	-	+	+	-
	Dense	+	+	+	+		+	+	+	+	-	+	+	+	+	+	+	+
Cellulose	Insuflated	-	+	+	+	-		-	-	-	-	-	-	-	-	-	-	-
	Dumped	-	+	+	+	-	-		-	-	-	-	-	-	-	-	-	-
	Boards	+	+	+	+	-	+	+		+	-	+	+	+	+	+	+	+
Cork	Bulk	+	+	+	+	-	+	+	-		-	-	-	+	-	+	+	-
	Boards	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+
Hemp Wool	Rolls	+	+	+	+	-	+	+	-	+	-		+	+	-	+	+	-
	Boards	+	+	+	+	-	+	+	-	-	-	-		+	-	+	+	-
Hemp Stalk	Bulk	+	+	+	+	-	+	+	-	-	-	-	-		-	-	-	-
Linen Wool	Rolls	+	+	+	+	-	+	+	-	+	-	+	+	+		+	+	+
	Boards	+	+	+	+	-	+	+	-	-	-	-	-	-	-		-	-
Sheep Wool	Rolls	+	+	+	+	-	+	+	-	-	-	-	-	+	-	+		-
	Boards	+	+	+	+	-	+	+	-	+	-	+	+	+	-	+	+	
%		75	93.75	100	100	6.25	81.25	81.25	12.5	43.75	0	37.5	43.75	62.5	18.75	62.5	56.25	25

Appendix 4: Comparative table of the price of the laggings

Hygroscopic Capacity		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glass Wool	Rolls	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Wool	Rolls	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fibre Wood	Flexible	+	+	+		-	-	-	-	-	-	-	-	-	-	-	-	-
	Dense	+	+	+	-		-	-	-	-	-	-	-	-	-	-	-	-
Cellulose	Insuflated	+	+	+	+	+		-	-	+	+	-	-	-	-	-	-	-
	Dumped	+	+	+	+	+	-		-	+	+	-	-	-	-	-	-	-
	Boards	+	+	+	+	+	-	-		+	+	-	-	-	-	-	-	-
Cork	Bulk	+	+	+	-	-	-	-	-		-	-	-	-	-	-	-	-
	Boards	+	+	+	-	-	-	-	-	-		-	-	-	-	-	-	-
Hemp Wool	Rolls	+	+	+	+	+	-	-	-	+	+		-	-	-	-	-	-
	Boards	+	+	+	+	+	-	-	-	+	+	-		-	-	-	-	-
Hemp Stalk	Bulk	+	+	+	+	+	-	-	-	+	+	-	-		-	-	-	-
Linen Wool	Rolls	+	+	+	+	+	-	-	-	+	+	-	-	-		-	-	-
	Boards	+	+	+	+	+	-	-	-	+	+	-	-	-	-		-	-
Sheep Wool	Rolls	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		-
	Boards	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	-	
%		12.5	12.5	12.5	37.5	37.5	87.5	87.5	87.5	37.5	31.25	87.5	87.5	93.75	87.5	87.5	100	100

Appendix 5: Comparative table of the hygroscopic capacity of the laggings

Vapor Resistance		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glass Wool	Rolls	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Wool	Rolls	+	+		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fibre Wood	Flexible	+	+	+		+	+	+	-	-	+	+	+	+	+	+	+	+
	Dense	+	+	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Cellulose	Insuflated	+	+	-	-	-		-	-	-	-	-	-	-	-	-	-	-
	Dumped	+	+	+	-	+	+		-	-	+	+	+	+	+	+	+	+
	Boards	+	+	+	+	+	+	+		-	+	+	+	+	+	+	+	+
Cork	Bulk	+	+	+	+	+	+	+	-		+	+	+	+	+	+	+	+
	Boards	+	+	-	-	-	-	-	-	-		-	-	-	-	-	-	-
Hemp Wool	Rolls	+	+	-	-	-	-	-	-	-	-		-	-	-	-	-	-
	Boards	+	+	-	-	-	-	-	-	-	-	-		-	-	-	-	-
Hemp Stalk	Bulk	+	+	-	-	-	-	-	-	-	-	-	-		-	-	-	-
Linen Wool	Rolls	+	+	-	-	-	-	-	-	-	-	-	-	-		-	-	-
	Boards	+	+	-	-	-	-	-	-	-	-	-	-	-	-		-	-
Sheep Wool	Rolls	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-		-
	Boards	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	
%		93.75	93.75	31.25	12.5	25	25	18.75	0	0	25	25	25	25	25	25	25	25

Appendix 6: Comparative table of the vapour resistance of the laggings

Flameproofed		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glass Wool	Rolls	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Wool	Rolls	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fibre Wood	Flexible	+	+	+		-	+	+	-	-	-	-	-	-	+	+	+	+
	Dense	+	+	+	-		+	+	-	-	-	-	-	-	+	+	+	+
Cellulose	Insuflated	+	+	+	-	-		-	-	-	-	-	-	-	-	-	+	+
	Dumped	+	+	+	-	-	-		-	-	-	-	-	-	-	-	+	+
	Boards	+	+	+	-	-	+	+		-	-	-	-	-	+	+	+	+
Cork	Bulk	+	+	+	-	-	+	+	-		-	-	-	-	+	+	+	+
	Boards	+	+	+	-	-	+	+	-	-		-	-	-	+	+	+	+
Hemp Wool	Rolls	+	+	+	-	-	+	+	-	-	-		-	-	+	+	+	+
	Boards	+	+	+	-	-	+	+	-	-	-	-		-	+	+	+	+
Hemp Stalk	Bulk	+	+	+	-	-	+	+	-	-	-	-	-		+	+	+	+
Linen Wool	Rolls	+	+	+	-	-	-	-	-	-	-	-	-	-		-	+	+
	Boards	+	+	+	-	-	-	-	-	-	-	-	-	-	-		+	+
Sheep Wool	Rolls	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-		-
	Boards	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	
%		87.5	93.75	93.75	0	0	50	50	0	0	0	0	0	0	50	50	75	75

Appendix 7: Comparative table of the flameproof power of the laggings

Phase time difference		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+
Glass Wool	Rolls	+		-	-	-	-	-	-	-	-	-	-	-	-	-	+	+
Rock Wool	Rolls	+	-		-	-	-	-	-	-	-	-	-	-	-	-	+	+
Fibre Wood	Flexible	+	+	+		-	-	-	-	-	-	+	+	-	+	+	+	+
	Dense	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
Cellulose	Insuflated	+	+	+	+	-		-	-	+	-	+	+	+	+	+	+	+
	Dumped	+	+	+	+	-	-		-	+	-	+	+	+	+	+	+	+
	Boards	+	+	+	+	-	+	+		+	-	+	+	+	+	+	+	+
Cork	Bulk	+	+	+	+	-	-	-	-		-	+	+	+	+	+	+	+
	Boards	+	+	+	+	-	+	+	+	+		+	+	+	+	+	+	+
Hemp Wool	Rolls	+	+	+	+	-	-	-	-	-	-		-	-	+	+	+	+
	Boards	+	+	+	+	-	-	-	-	-	-	-		-	+	+	+	+
Hemp Stalk	Bulk	+	+	+	+	-	-	-	-	-	-	+	+		+	+	+	+
Linen Wool	Rolls	+	+	-	+	-	-	-	-	-	-	-	-	-		-	+	+
	Boards	+	-	-	-	-	-	-	-	-	-	-	-	-	-		+	+
Sheep Wool	Rolls	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
	Boards	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
%		0	31.25	37.5	37.5	100	81.25	81.25	87.5	68.75	93.75	50	50	62.5	37.5	37.5	6.25	6.25

Appendix 8: Comparative table of the phase time difference of the laggings

Primary Energy		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		-	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Glass Wool	Rolls	+		+	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Rock Wool	Rolls	-	-		-	+	+	-	-	-	-	-	+	+	-	+	+	+
Fibre Wood	Flexible	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+
	Dense	-	-	-	-		-	-	-	-	-	-	+	-	-	+	+	+
Cellulose	Insuflated	-	-	-	-	-		-	-	-	-	-	+	-	-	+	+	+
	Dumped	-	-	+	-	+	+		+	+	+	+	+	+	+	+	+	+
	Boards	-	-	-	-	+	+	-		-	-	-	+	+	-	+	+	+
Cork	Bulk	-	-	-	-	+	+	-	-		-	-	+	+	-	+	+	+
	Boards	-	-	+	-	+	+	-	+	+		-	+	+	-	+	+	+
Hemp Wool	Rolls	-	-	+	-	+	+	-	+	+	+		+	+	+	+	+	+
	Boards	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	+
Hemp Stalk	Bulk	-	-	-	-	+	+	-	-	-	-	-	+		-	+	+	+
Linen Wool	Rolls	-	-	+	-	+	+	-	+	+	+	-	+	+		+	+	+
	Boards	-	-	-	-	-	-	-	-	-	-	-	+	-	-		-	+
Sheep Wool	Rolls	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-		+
	Boards	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
%		12.5	6.25	43.75	0	68.75	68.75	18.75	43.75	43.75	37.5	25	93.75	62.5	31.25	81.25	81.25	100

Appendix 9: Comparative table of the primary energy used to produce the laggings

Greenhouse Effects		Extruded	Glass Wool	Rock Wool	Fibre Wood		Cellulose			Cork		Hemp Wool		Hemp Stalk	Linen Wool		Sheep Wool	
		Boards	Rolls	Rolls	Flexible boards	Dense boards	Insuflated Bulk	Dumped Bulk	Boards	Bulk	Boards	Rolls	Boards	Bulk	Rolls	Boards	Rolls	Boards
Extruded	Boards		+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Glass Wool	Rolls	+		-	-	+	+	+	+	+	+	+	+	+	+	+	+	+
Rock Wool	Rolls	+	+		-	+	+	+	+	+	+	+	+	+	+	+	+	+
Fibre Wood	Flexible	-	+	-		+	+	+	+	+	+	-	-	+	-	-	-	-
	Dense	-	+	-	-		-	-	-	+	+	-	-	+	-	-	-	-
Cellulose	Insuflated	-	+	-	-	+		-	-	+	+	-	-	+	-	-	-	-
	Dumped	-	+	-	-	+	-		-	+	+	-	-	+	-	-	-	-
	Boards	-	+	-	-	+	+	+		+	+	-	-	+	-	-	-	-
Cork	Bulk	-	+	-	-	-	-	-	-		-	-	-	+	-	-	-	-
	Boards	-	+	-	-	-	-	-	-	-		-	-	+	-	-	-	-
Hemp Wool	Rolls	-	+	-	-	+	+	+	+	+	+		-	+	-	-	-	-
	Boards	-	+	-	-	+	+	+	+	+	+	-		+	-	-	-	-
Hemp Stalk	Bulk	-	+	-	-	-	-	-	-	-	-	-	-		-	-	-	-
Linen Wool	Rolls	-	+	-	-	+	+	+	+	+	+	+	+	+		-	+	+
	Boards	-	+	-	-	+	+	+	+	+	+	+	+	+	-		+	+
Sheep Wool	Rolls	-	+	-	-	+	+	+	+	+	+	+	+	+	-	-		-
	Boards	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	
%		12.5	6.25	43.75	0	68.75	68.75	18.75	43.75	43.75	87.5	43.75	43.75	62.5	31.25	18.75	31.25	100

Appendix 10: Comparative table of the greenhouse effects emitted during the manufacturing process