NTNU

Solar Decathlon

Integrated Energy Design

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Preface

This report is made by engineering and architecture students from NTNU.

The project is a part of the course “Building Environmental Design and Engineering” and “Integrated Energy Design”.

This report is discussing different building concepts for a ZE+building which can be used in both Oslo and Madrid. The cause of the project is to participate in the competition “Solar Decathlon Europe 2012” in Madrid.

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1. Summary

The basis for this project was to build a flexible hytte less than 75 m^2 which can be used both in Madrid and Oslo. The goal was to construct a hytte which would be a passive house in Norway and a ZE+hytte in Madrid. The hytte should cover its energy demand by renewable energy sources, mainly solar power. Passive house standards for Norway and requirements from TEK2010 have set the requirements for the building. The hytte should also meet the requirements for a decathlon competition in Madrid for a week in June.

From the initial building concept made for the competition, different building concepts have been evaluated and developed. Important focus areas have been the climate, building form, lighting, structure and materials as well as solutions for ventilation, heating and cooling. The initial concept only uses PV's as energy source. The revised concept includes heat pump and solar collector as well as the PV's. This will cover the energy demands for space heating, electricity and hot tap water, respectively. The window area was also reduced to reduce the space heating.

The simulation program SIMIEN and Ecotect have been used to perform a thermal analysis, an analysis of the lighting conditions and to simulate the energy demand for the building concepts. The initial building concept in Oslo did not meet the requirements for passive houses due to a large space heating demand. The PV's did not manage to cover the total energy demand with solar cells only on the southern and southeastern wall, but placing the PV's on the roof it is possible. In the second building concept in Oslo the space heating demand was decreased due to a smaller window area and less heat loss. The heat pump and the efficient solar collector reduced the required PV area so it would be possible to meet the demand. This solution fulfills the passive house standard in every way.

2. Boundary conditions, limitations and requirements

Our challenges for the hytte are to follow the passive house standard and meet requirements for energy demand in both Madrid and Oslo. To cover the energy demand the climate will be important; solar radiation, shading, solar angle, outdoor temperature and so on. Our priorities are to make a hytte that produces more energy than it consumes during a year, this means that we have to meet the requirements for passive houses in Norway. Another requirement is to use renewable energy sources, mainly solar energy, and to achieve a good indoor climate.

2.1 Passive houses

The standard for passive houses in Norway is NS 3700. This standard will be used to evaluate concepts for the building. See table 1.

Table 1: Demands in NS 3700

Demands	**NS 3700**
Total glass-, window- and door area (BRA)*	< 20 % of heated area
U-value walls [W/m^{2}K]*	< 0,15
U-value roof [W/m^{2}K]*	< 0,13
U-value floor to ground and to open space [W/m^{2}K]*	< 0,15
U-value glass/windows/doors [W/m^{2}K]*	< 0,80
Specific cold bridge value [W/m^{2}K]*	< 0,03
Air tightness [1/h]*	< 0,6
Heat recovery system [%]*	> 80
Specific fan power in ventilation system, SFP-factor [kW/(m^{3}s)]*	< 1,5
Ventilation air flow rate [m^3/hm^2]**	> 1,2
Maximum heat loss number [W/(m^{2}K)]***	0,6
*Table 5 in NS 3700 **Table A.1 in NS 3700 *** Table 2 in NS 3700	

One other target is to make sure the energy demand for heating is less than 15 kWh/m^2, and given from TEK10 that the total energy demand is less than 120 kWh/m^2.

2.2 Climate challenges

In Oslo the angle of solar radiation is low and has a south-east position. In Madrid the solar angle is much higher and is perpendicular to the surface.

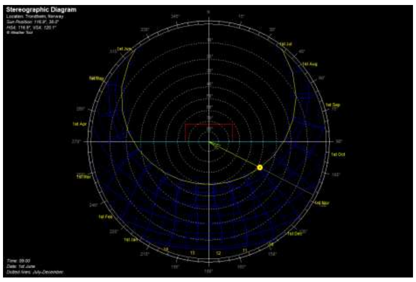


Figure 1: Oslo solar radiation angle

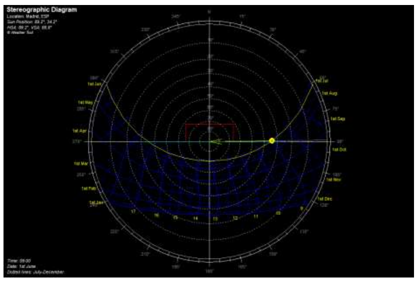


Figure 2: Madrid solar radiation angle

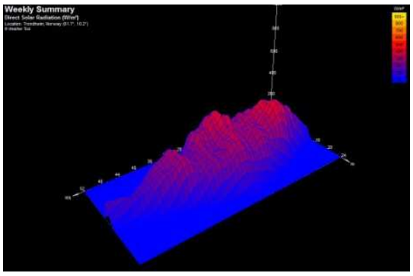


Figure 3: Oslo direct solar radiation

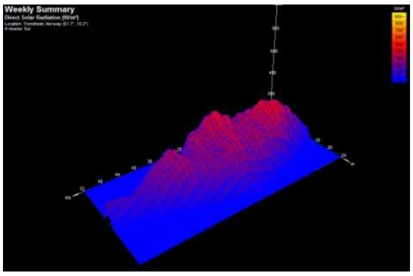


Figure 4: Madrid direct solar radiation

The direct solar radiation is higher in Madrid than in Oslo. For this reason the PV panels are expected to produce more electrical energy in Spain (3,60 kWh/ym^2) than in Norway (2,06 kWh/ym^2)[5].

Table 2: Comparison of Madrid and Oslo

	Oslo	Madrid
Best orientation	172.5 °	180 °
Temperature in winter	-20—0 ° C	-1—15 ° C
Temperature in summer	0—26 ° C	8—32 ° C
Humidity(Day)	70%	30%
Humidity(Night)	80%	50%
Summer solstice	50 °	70 °
Winter solstice	5 °	30 °

From table 2, we could see that the climate in Oslo is cold and humid, but in Madrid, it is hot and dry. Since the Solar Decathlon is held in June, we just consider summer in Madrid and a whole year for Oslo in our simulations.

2.3 Development of building concepts

After a group discussion on schematic options relative to performance targets, it turned out that several issues need to be considered. The most important is to build a house which can be used in both Norway and in Spain. This means that the building should be insulated in a proper way. The thickness of the thermal insulation should be dimensioned to optimize the performance of the envelope and the indoor conditions in cold and warm climate.

Before choosing the best solution a brainstorming of different systems and strategies for both climates has been done.

Figure 5: Maintain heat

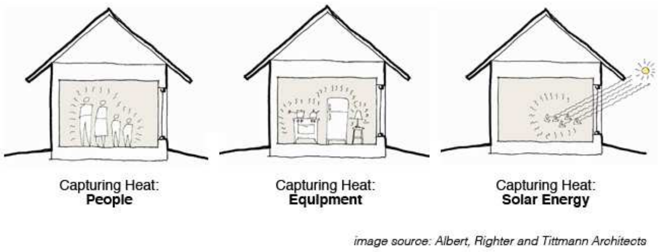


Figure 6: Gain heat

See Appendix 1 for further brainstorming.

3. Building concepts

The main energy source to be used for all concepts is solar power, both in Oslo and Madrid. The solar radiation has a lower angle in Oslo than in Madrid and the weather conditions are different. The use of PV's on the roof in Oslo might not be enough to cover the energy demand. This will be simulated and evaluated.

3.1 Building concept 1

The initial ideas for the development of the energy concept were based on the strategies described in the Technical Proposal to the Solar Decathlon Europe 2012 and the Norwegian Standard for Passive Houses 3700:2010.

The concept described in the Technical Proposal is based on three main ideas:

- Flexibility (satisfy different functional requirements varying its spatial configuration).
- Easy assembly and disassembly (modularity of the construction to solve the problem of the transport).
- Energy positive (reduction of the thermal demand through the use of passive strategies).

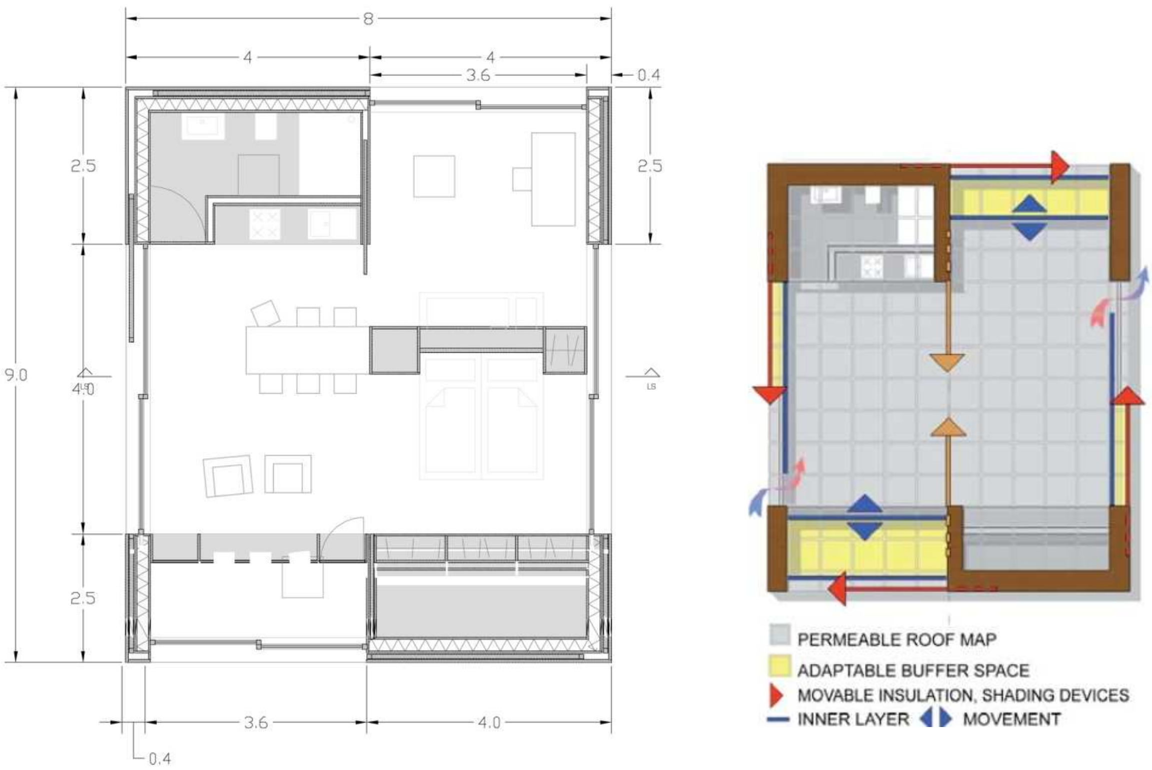


Figure 7: Project plan

The idea of an energy positive house is based on using the roof of the building as a "solar power plant" able to maximize the PV energy production, but also using it as a permeable skin able to filter and diffuse the solar radiation for thermal comfort and luminous comfort. The inner layer of the roof is highly insulated and able to minimize the summer heat gains and to prevent the heat island effect. According to the plan the building openings are very big. They represent 68% of the heated area. This means that it could provide overheating in warm climate and heat loss in cold climate.

In contrast to this, the Norwegian Standard for Passive Houses 3700:2010 is based on the idea of avoiding general heat losses and optimizing free heat gains. Through the optimally insulated, hermetical building envelope the heat remains in the house, thus reducing the amount of required heating (winter) or cooling energy (summer). Passive heat gains through windows, from people and technical equipment contribute to further energy savings. The idea is to combine the advantages of both these approaches in order to be able to develop a plus-energy house.

3.2 Building concept 2 (in Oslo)

In this building concept the window areas have been reduced to reduce the heat losses. The windows have a much higher U- value than the walls and it will therefore be profitable for the energy demand to reduce the total window area. In the east- and west direction the sun in Norway is very low. This makes shading difficult and can give uncomfortable lighting conditions in the hytte. This is another reason to reduce the window height and width. In Madrid the reduction of windows has been neglected, but not in Oslo.

Changes in energy sources in Oslo have been made from the initial concept. Instead of using PV's to cover all of the energy demand we have chosen to use three different energy sources to cover different energy demands. For heating of tap water it is more efficient to use solar collectors. Solar collectors can utilize a maximum of 80% of the energy from the sun for heating of tap water while the PV's are only able to convert 10-15 % of the energy in the sunlight to electricity[1][3]. The water can also be heated directly instead of using the electricity, which is high quality energy, for the heating. The collector is to be placed on the roof in a southern position with at least a 30 degrees angle. For the space heating we have decided to use an air to air heat pump. This is a flexible system since the heat pump can also be used for cooling during the summer. The PV's will still cover the electricity demand. Some electricity is needed for running the heat pump, which will be delivered from the PV's.

The window sizes compared to the initial building concept can be seen in table 3. Distribution of energy sources for the different types of demand is to be found in table 4.

Table 3: Window sizes for the two concepts

	Concept	**Concept 2**
Windows North & South		
Width [m]	3,6	3
Height [m]	2,35	2
Windows East & West		
Width [m]	4	2
Height [m]	2,35	2

Table 3: Energy source distribution for the concepts

	Concept 1	Concept 2
Electricity	PV	PV
Heating and cooling	PV	heat pump
Tap water	PV	solar collector

3.3 Building concept 3

To reduce the energy requirements, not only highly heat-insulating, airtight components will be used for the thermal envelope, but also a regulated ventilation system will be deployed. An air to air heat pump is planned for heating and cooling the building. An optimal balance of the room temperature and the relative humidity is guaranteed by the natural – cross ventilation, which constitutes a basic requirement. Highly-efficient monocrystalline PV cells will be used on the roof and will be also implemented on the movable shading devices for generating the required energy. To stabilize the temperature fluctuations inside the living space, a prefabricated floor concrete slab and a thin layer of PCM (phase change material) is used. It provides the necessary storage mass to avoid extreme peaks of loads for comfort. Shading is also an important part in the concept. It facilitates a maximal reduction of solar loads combined with an ideal supply of the room with daylight.

The aim is to use several passive measures: insulation, BIPV movable shading devices, natural ventilation and thermal mass, to carry the loads, which are occurring in summer (especially in Madrid), and also to cover the thermal heat requirements occurring in the winter months (Norway - Oslo) through solar gains mainly from the windows.

4. Simulations and results

4.1 Daylight analysis for concept 2

4.1.1 Madrid summer and winter

- For the 1st week of June, in overcast sky with design sky illuminance of 6500 lux.

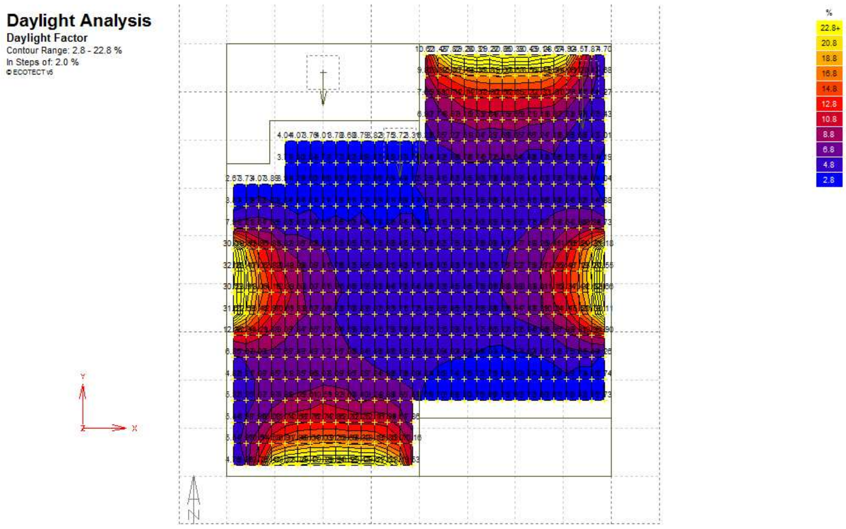


Figure 8: Madrid summer

Minimum daylight factor at the centre of the room on the working table is 5.4% and at corners with no windows, the minimum daylight factor is 3.15%.

- For the 1st week of December, in overcast sky with design sky illuminance of 5000 lux.

Minimum daylight factor at the centre of the room on the working table is 5.4% and at corners with no windows, the minimum daylight factor is 3.15%.

4.1.2 Oslo summer and winter

- For the 1st week of June, in overcast sky with design sky illuminance of 2000 lux.

Minimum daylight factor at the centre of the room on the working table is 5.3% and at corners with no windows, the minimum daylight factor is 3.05%

- For the 1st week of December, in overcast sky with design sky illuminance of 1500 lux.

Minimum daylight factor at the centre of the room on the working table is 5.04% and at corners with no windows, the minimum daylight factor is 3.05%.

Even though the daylight factors are almost similar, the daylight levels for the two places vary greatly. For eg: the daylight levels in June for Madrid on the working table is 583.09 lux while in Norway is only 179.41 lux. For winter it is 446 lux and 134 lux respectively.

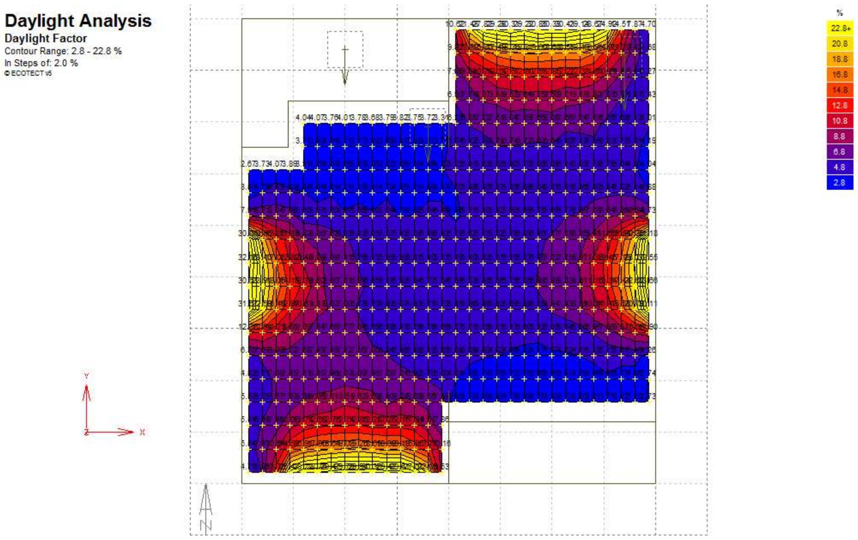


Figure 9: Oslo winter

We also see that the daylight near the windows is much higher. So, we need to shade these windows. However, if we use the conventional shadings, the required daylight factor on the working table at the centre of the room is reduced below 5%. So, sliding shading to control the sunlight as suggested in the proposal would be the best option.

4.2 Assumptions made in SIMIEN simulations

To simulate the energy demand for the hytte the program SIMIEN was used. When constructing the building some assumptions were made:

- Look at the hytte as one room.
- Areas used are in table 5.
- Set the U-values instead of choosing insulation and other materials in the walls, roof and floor.
- Set the U-value for the total window construction.
- The floor is against open air.
- Use balanced ventilation with variable air supply temperature.
- Use a heat exchanger.
- Use standard loads for lighting, technical equipment, tap water and persons. See table 6.
- The ventilation and person are apparent 24 hours per day.
- Lighting and technical equipment only 16 hours per day.
- Simulate for a year with 24 hour use of hytte every day.
- Awning with reflecting glass as an approximation to the horizontal shading in the proposal.

When using the standards we use the numbers for small houses. In table 4 and 5 values used in the simulation are listed.

Table 4: Areas and measures for the hytte

Hytte areas	
Heated floor area [m^2]	59
Heated air volume [m^3]	156
Area wall north & south[m^2]*	25,2
Area wall east & west[m^2]*	28,4
Area roof [m^2]	72
Area floor [m^2]	59
*Included window area	

Table 5: Values used in simulation compared to NS 3700

Values	**Values from simulation**	**NS 3700**
Total glass-, window- and door area (BRA)*	33,9	< 20 % of heated area
U-value walls [W/m^{2}K]	0,1	< 0,15
U-value roof [W/m^{2}K]	0,1	< 0,13
U-value floor to ground and to open space [W/m^{2}K]	0,1	< 0,15
U-value glass/windows/doors [W/m^{2}K]	0,7	< 0,80
Specific cold bridge value [W/m^{2}K]	0,03	< 0,03
Air tightness [1/h]	0,5	< 0,6
Heat recovery system [%]	85	> 80
Specific fan power in ventilation system, SFP-factor [kW/(m^{3}s)]	1,5	< 1,5
Ventilation air flow rate [m^3/hm^2]	1,2	> 1,2
* The area can be larger than 20 %, if the u-value for windows is better than the standard NS 3700.		

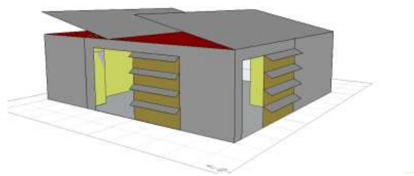
4.3 Building concept 1 in Oslo

From the simulation we found that the energy demand of the hytte is 5 576 kWh/year, which is supposed to be covered by the electricity production from the PV's. Energy demand for hot tap water is 1757 kWh, for space heating and cooling 1183 kWh and the electricity demand is 2635 kWh.

4.4 Building concept 2 in Oslo

From the simulation we found that the energy demand of the hytte is 5469 kWh/year. Energy demand for hot tap water is 1757 kWh, so it is the same as for concept 1 but will be covered by a solar collector. Combined space heating and cooling demand is 1077 kWh and electricity demand is 2635 kWh.

4.5 Building concept 3



4.5.1 Madrid

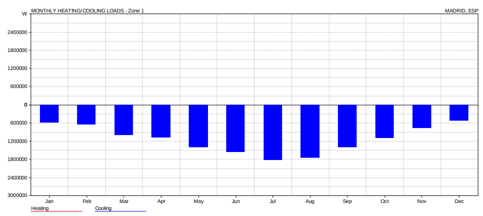


Figure 10: Monthly load of the house under cooling only

Figure 10 shows that when we choose the movable shading and cooling only as the energy strategies of the house, the cooling load of the house increase a lot, but we still could use cross ventilation as the passive concept (Infiltration rate=50). It works well in the summer in Madrid.

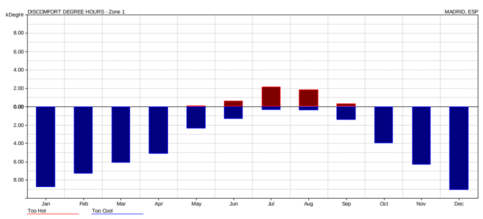


Figure 11: Discomfort degree hours of the house under cross ventilation in Madrid

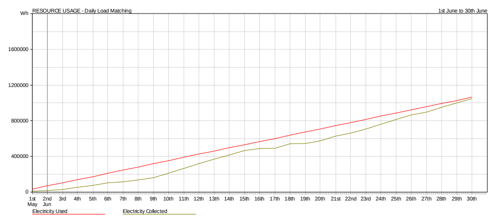


Figure 12: Energy production of PV in June

Figure 11 shows that the heating and cooling demand are not too high in June in Madrid.

Figure 12 shows that the electricity collected by PV in June in Madrid could almost meet the electricity demand of the house.

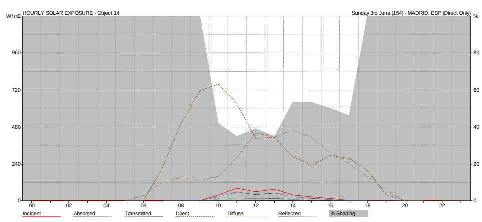


Figure 13: Shading of the southern window

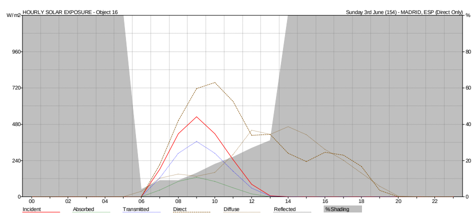


Figure 14: Shading of the eastern window

Figure 13 shows the shading situation of the southern window on 3rd June, it works almost well.

Figure 14 shows the shading situation of the southern window on 3rd June, it works almost well. Since we are using movable shading system, we could close the movable shading if needed. This works well.

Oslo

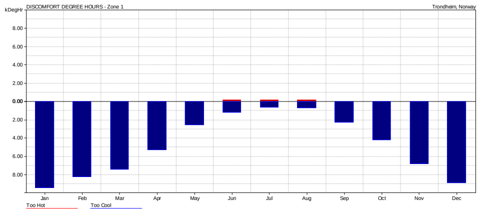


Figure 15: Discomfort degree hours under natural ventilation in Oslo

Figure 15 shows we could choose natural ventilation in the summer in Oslo.

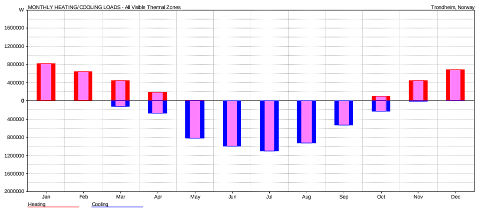


Figure 16: Monthly heating/cooling load under full air conditioning in Oslo

Figure 16 show that we can choose the full air conditioning strategy in winter in Oslo. However, it's still not enough. Heat pump should be a good supplement strategy.

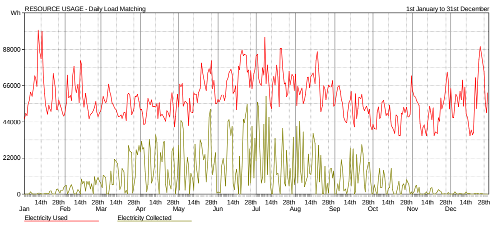


Figure 17: Energy production of PV in Oslo

Figure 17 illustrates that the electricity collected by PV is not enough in Oslo. So we decide to choose some energy efficient strategies for the house, which are heat pump and solar collectors. Besides, in Oslo, we should consider about the other heating strategy. For example, district heating.

5. Evaluation

5.1 Concept 1 in Oslo

The PV's are able to convert 10-15 % of the energy in the sunlight to electricity [1]. The area demand for the PV's was calculated from values for the average irradiation in Norway [2]. Irradiation for 90 degrees has been used, since the PV's will be on the outer wall, even though the angle of the PV will be lower than this value. The result is listed in table 7. The area of PV's which is necessary to cover the energy demand is 49,9 m^2. This is small enough to be placed on the roof of the hytte.

The energy demand for space heating is 16,6 kWh/ m^2, which is higher than the requirement from the passive house standard. Building concept 1 fulfills the requirements for the total energy demand with a demand of 94,5 kWh/ m^2.

Table 6: Calculations for concept 1

	PV's
Irradiation (90deg) [kWh/m^2*year]	744,6
% absorbed	0,15
Energy demand [kWh/year]	5576,0
Hot tap water	x
Space heating	x
Electricity	x
Area demand [m^2]	49,9

5.2 Concept 2 in Oslo

The total energy demand for the hytte is now 5 469 kWh/year. Assumptions for the PV's are the same as for building concept 1, except that it is only covering the electricity demand. A heat pump covers the space heating while a solar collector will cover the demand for heating of the tap water. For the solar collector we have used a value of 60% for the utilization of solar energy into heating. The result is listed in table 8. It is sufficient with a 3,5 m^2 solar collector to manage to heat the tap water. The area demand for the PV's are 23,6 m^2 and is sufficiently small to be placed on the roof. The energy demand for space heating will be covered by the heat pump placed on one of the walls.

The energy demand for space heating is 14,8 kWh/ m^2, which is less than the requirements from the passive house standard. The total energy demand also meets the requirements.

Table 7: Calculations for concept 2

	PV's	Solar panels	Heat pump	Total
Irradiation (90 deg) [kWh/m^2*year]	744,6	-	-	
Irradiation (0 deg) [kWh/m^2*year]	-	843,2	-	
% absorbed	0,15	0,6	-	
Energy demand [kWh/year]	2635,0	1757	1077	5469,0
Hot tap water	-	X	-	
Space heating	-	-	x	
Electricity	x	-	-	
Area demand [m^2]	23,6	3,5	-	27,1

Table 8: Comparison of the concepts for Oslo with the requirements

Specific energy demand [kWh/m^2]	Concept 1	Concept 2	Requirement
Space heating	16,6	14,8	15
Total	94,5	92,7	120

6 Conclusion

6.1 Chosen solution

Based on the PV on the roof, the concept 3 adds the movable BIPV shading on the southern, eastern and western window, which meets the electricity demand in June for Madrid. Since the direct solar radiation is much lower in Norway, the use of PV panels, as an energy source in Norway is not enough. Purchasing the electricity which produced by hydropower is also a good choice. We choose the different strategy for Madrid and Norway, respectively. In Madrid cross ventilation as cooling strategy in June will be sufficient. For the rest of the summer a more efficient cooling system is needed. During winter we also need heat recovery to meet the passive house requirements. In Norway, natural ventilation will be enough in summer. However, in winter, a heating system is needed to meet the heating demand of the house, so heat pump could be an energy-efficient option.

For Oslo the initial concept with large windows and only PV's as energy source will not meet the passive house standard in Norway. The PV's on the wall are not sufficient to cover the energy demand of the hytte. By reducing the area of the windows the energy demand for space heating is lowered to a lower value than the requirement for passive houses. When using a solar collector and a heat pump in addition to the PV's, the required area of PV's is reduced so it will be possible to meet the demand by placing PV's n the southern and southeastern wall. The hytte will then have a total energy demand of 92,7 kWh/ m^2, and matches the definition of a passive house. This energy simulation does not take into account that the hytte has a horizontal window shading. This would probably make the problems with the large window areas in the initial concept less important.

The solution with smaller windows may not be a good solution because of the limitation with SIMIEN concerning shading. We think with the movable shading devices it will be sufficient with the window sizes already given.

6.2 Limitations using Ecotect

1. We could not find the real material we used.
2. Solar collector in Ecotect just stands for PV, not solar collector.
3. Have not put lighting in the model. But it should be contained in simulation process.
4. Ecotect puts the ventilation and infiltration together

6.3 Limitations using SIMIEN

1. No real materials have been defined using this program, only U-values.
2. The correct shading of the windows could not be simulated.
3. There have been used only standard values for all internal loads given in NS 3031.

6.4 Follow-up plan

In this part of the project planning, investment and operation costs have not been taken into consideration. It will probably not be profitable to install a solar collector and heat pump together with the PV's since the investment and operation costs are high for all the systems. It also requires energy and materials to construct the PV's, the heat pump and the solar collector. Even though the solar collectors can utilize up to five times more of the solar energy for heating than the PV's, it will probably be a more energy efficient solution to use PV's for heating tap water. Another possibility is to look at a new technology with a combined panel for electricity production and heating of tap water.

7 Sources

[1]http://enova.no/sitepageview.aspx?articleID=526

[2] Survey of Available Technologies for Renewable Energy Supply to Buildings, ZEB

[3] http://www.zero.no/bygg/solfanger

[4] www.byggemiljo.no

[5] ZE+Hytte Technical proposal, Norwegian Wood Team

[6] Team IKAROS - BAVARIA, Solar Decathlon Europe 2010 (2010). *Project Manual as Built*. Rosenheim: Hochschule Rosenheim, University of Applied Sciences.

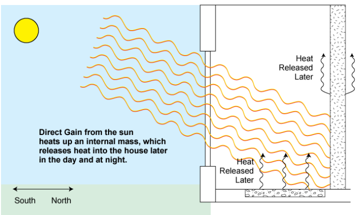
[7] NS 3700

[8] TEK 2010

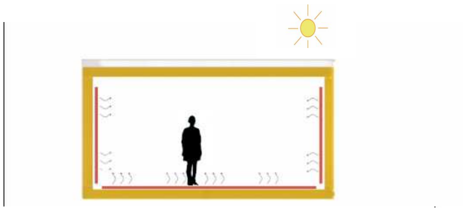
[9] NS 3031

Appendix 1: Ideas for different energy strategies

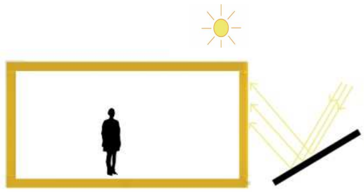
Passive and active solar strategies



Thermal mass wall



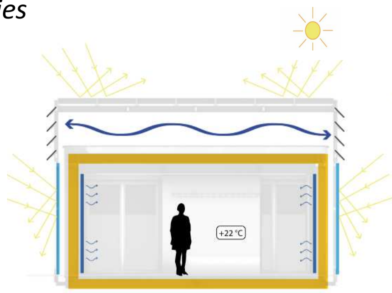
Heat pump/solar collector



Mirrors

Passive and active cooling strategies

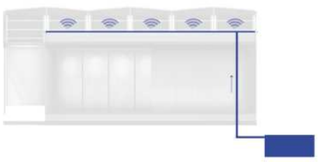
Heat pump



Double ceiling

Vegetation

Water (ceiling, walls)



Appendix 2: Energy demand and delivered energy in SIMIEN

- Energy budget concept 1

Energy budget	**[kWh]**	**[kWh/m^2]**
Ventilation heating	978	16,6
Tap water	1757	29,8
Fans	258	4,4
Pumps	0	0
Lighting	999	16,9
Technical equipment	1378	23,4
Ventilation cooling	205	3,5
Total net energy demand	5576	94,5

- Energy budget concept 2

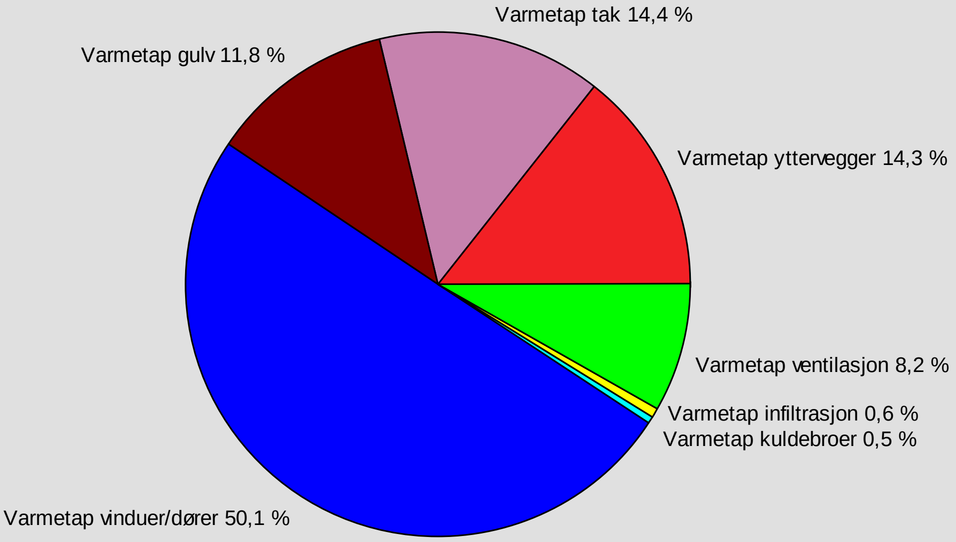
Energy budget	**[kWh]**	**[kWh/m^2]**
Ventilation heating	873	14,8
Tap water	1757	29,8
Fans	258	4,4
Pumps	0	0
Lighting	999	16,9
Technical equipment	1378	23,4
Ventilation cooling	204	3,5
Total net energy demand	5469	92,7

- Delivered energy, both concepts

Delivered energy [kWh]	**Concept 1**	**Concept 2**
Electricity, PV's	136	26
Electricity, heat pump	0	478
Solar collector	0	176
Total	**136**	**680**

- Concept 1: Heat loss coefficient

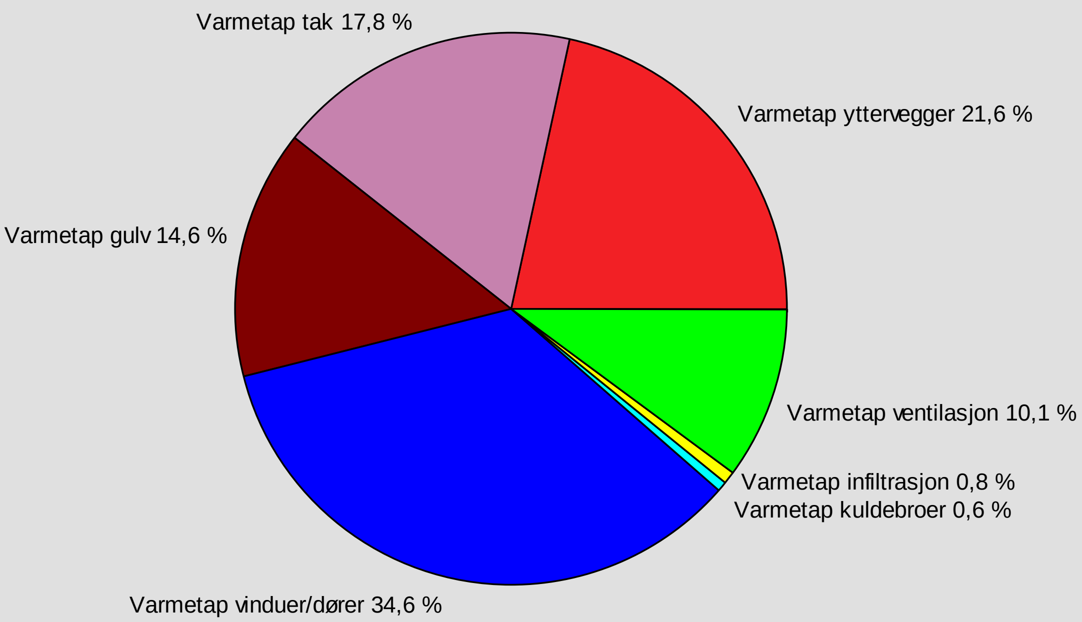
Varmetapsbudsjett (varmetapstall)



Varmetapstall yttervegger	0,12 W/m²K
Varmetapstall tak	0,12 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,10 W/m²K
Varmetapstall glass/vinduer/dører	0,42 W/m²K
Varmetapstall kuldebroer	0,00 W/m²K
Varmetapstall infiltrasjon	0,01 W/m²K
Varmetapstall ventilasjon	0,07 W/m²K
Totalt varmetapstall	0,85 W/m²K

- Concept 2: Heat loss coefficient

Varmetapsbudsjett (varmetapstall)



Varmetapstall yttervegger	0,15 W/m²K
Varmetapstall tak	0,12 W/m²K
Varmetapstall gulv på grunn/mot det fri	0,10 W/m²K
Varmetapstall glass/vinduer/dører	0,24 W/m²K
Varmetapstall kuldebroer	0,00 W/m²K
Varmetapstall infiltrasjon	0,01 W/m²K
Varmetapstall ventilasjon	0,07 W/m²K
Totalt varmetapstall	0,69 W/m²K