MSc Program
Renewable Energy in Central & Eastern Europe

Realisation of an energy independent building
Integration and combination of available energy efficient building components and renewable energy technologies

A Master Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, November 2008

Affidavit

I, **MICHAELA VEZMAR**, hereby declare

1. that I am the sole author of the present Master Thesis, "Realisation of an energy independent Building – Integration and combination of available energy efficient building components and renewable energy technologies",
   53 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, 26. November 2008 ______________________________

Date Signature

Abstract

Energy efficiency and renewable energy technology represent a team for solving energy and living questions more convenient and successful in future. Being able of affording enough energy services seems to become more and more luxury, which is tried to overcome by the development of the so called “energy independent building” or even the realisation of the “zero-energy-cost” House.

State of the art building typology and the integration of energy efficient building technology in cooperation with renewable energy defines the framework of this Master thesis. It is evaluated on the technical and economical side, if it is possible to realise the aspired “zero-energy-cost” House, by using a ground source heat pump and a photovoltaic system. The results show the clear tendency that from the technical point of view the combination of heat pump and photovoltaic is possible but energetically not feasible, if the heat pump is only used for heating. Whereas the economical results, with the applied calculation method of leaving out the investment costs, are very positive and verify the possibility of the “zero-energy-cost” House.

In summary it can be said that the “zero-energy-cost” house or “energy independent building” are a realistic solution for the actual energy discussion going on worldwide. The open question to be answered in the following years is a strategy for the successful and fast market introduction of these ideas.

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1. Introduction

Energy efficiency measures the amount of energy needed for providing a specified amount of energy service, meaning electric and electronic appliances, like energy saving lamps or AAA refrigerators, or heating applications like solar thermal systems, used for having light, fresh food or hot water.

Focusing more on the energy efficient building typology, the criteria of a passive / energy efficient house are defined as follows:

- Airtight construction requires integrating a mechanical ventilation system to meat the requirements of healthy living conditions, fresh air and high comfort.
- The used ventilation units are designed at a high energy efficient scale, reduce the energy costs and even allow an economic operation.
- Apart from the fresh air and comfort supply the ventilation system is used for the covering of the remaining heating loads via a so called controlled heat recovery system.
- All above mentioned criteria can only be realised by building a superior thermal insulation resulting in a maximum heat load of the building lower that 10 W/m².
- Concerning construction it is very important to avoid thermal bridges, e.g. decoupling of outer wall and balcony, which are responsible for heat losses.
- High quality windows with optimized U-values of 1 W/m²K and achieving high passive solar gains for the support of the heating system.
- Building technology not only for ventilation but also for heating and hot water preparation meet latest efficiency parameters as for instance the integration of heat pumps and solar thermal systems.
- Reducing thermal losses at different levels of the building by integrating high efficient building technologies result in a higher electricity demand for pumps, regulation and ventilation. To overcome this fact it is necessary to plan the used components very precisely and to optimise the cooperation in between and including a possible use of photovoltaic.

Working in the field of energy efficient houses and building technologies another interesting factor, the so called heating degree days, must be also a part of the dimensioning and planning of the integrated heating and power system.

The heating degree day is a value for the intensity of the heating period and is a result of the difference between room temperature of 20℃ and the daily mean outside temperature below 12℃. Therefore in literature it is often written a s heating degree days 12/20 (HDD 12/20).

For Vienna the long time average of the HDD 12/20 is 3.233[2], Figure 1 shows the cumulated monthly mean of the HDD 12/20.

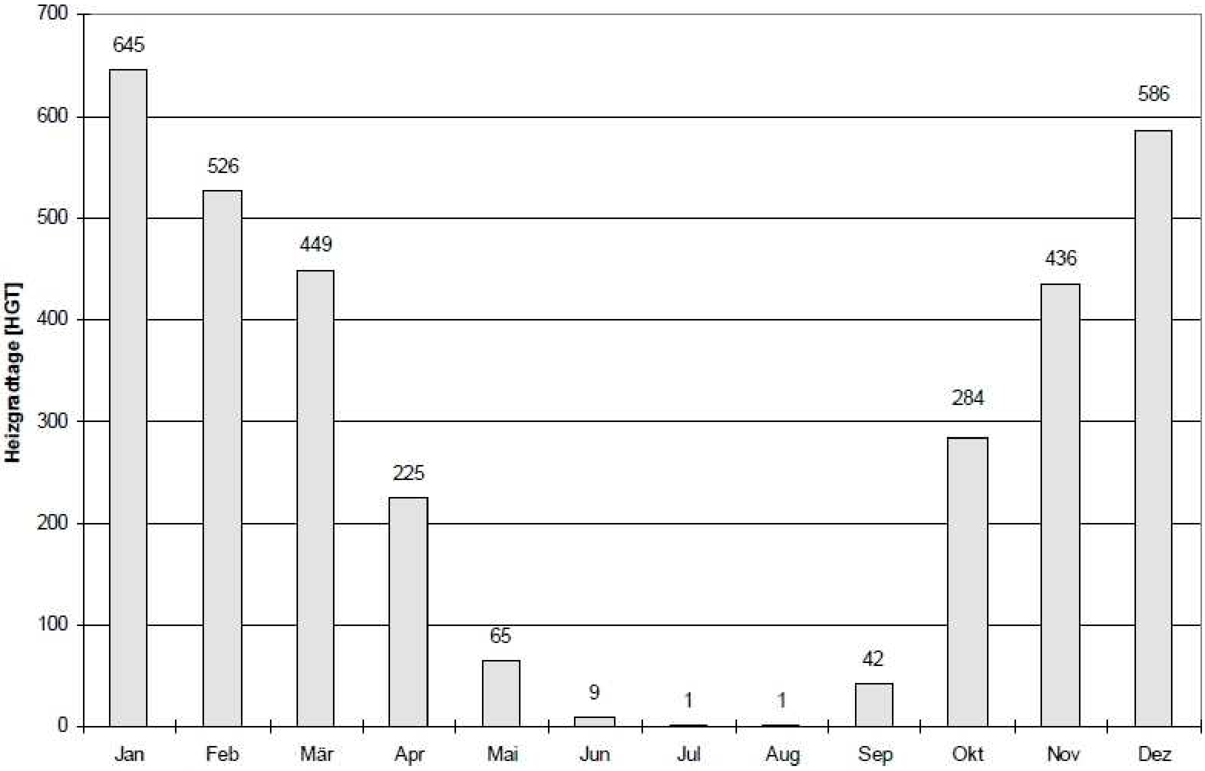

Figure 1 monthly mean of heating degree days for Vienna, long time average[3]

Besides the value of the heating degree days it is also very interesting to know the sunshine hours and the solar irradiation, for instance when calculating solar passive gains of the building.

[2] MA 22, KliP Working Paper Nr. 2 – Basisdaten, 3. aktualisierte Auflage, September 1997, p.5
[3] Idem, p.7

1.1 Motivation

In the framework of the REHAU BAU HAUS© it was decided to implement solar energy technologies to round up the product portfolio, starting with high efficiency windows and ending with heat pump systems.
Renewable energy technology at REHAU© means solar thermal systems, heat pump, geothermal energy and biomass. These products are assembled to packages for standard applications for single and two family houses. In regard to biomass it is to mention that the REHAU© branded products in this special field are only used in biogas power plants as fermentation heating system and for heat transport. Therefore biomass is not a part in the development of the energy independent house.
Photovoltaic was part of REHAU© renewable energy systems completing the REHAU BAU HAUS©, because of strategic decision it will not be continued after the year 2008.

For this master thesis only the building technology and components are applied which are part of REHAU's© current product portfolio, meaning solar thermal, photovoltaic, heat pump and geothermal energy. Another important aspect is to combine and manage all components working together in a user friendly and energy efficient way.

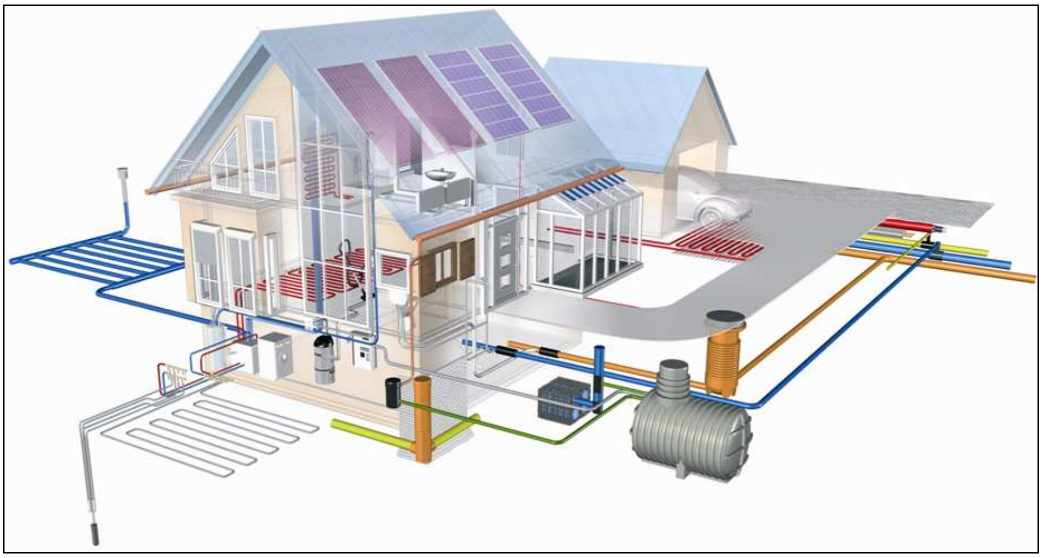

Figure 2 REHAU BAU HAUS©

1.2 Core objective

The core objective of this master thesis is the evaluation and development of the so called „Zero-energy-cost" House and summarizing the essential questions as the basis for further work to be done.

The term „zero-energy-cost" House is the definition of a building by its amount of needed energy costs for heating and electricity. This type of house produces the whole energy demand by the integration of various technologies, e.g. heat pump plus photovoltaic, and covers that way the resulting energy and energy costs balanced over a whole year. In this perception investment costs are not considered, the topic of amortisation is not the driving force behind this special method. The main message to the costumer is that there will not be future expenses for the running costs of the heat and electricity supply system, no payments for energy to the local energy suppliers.

1.3 Structure of work

This Master thesis has three main focuses, first the technical, second the economical and third the social discussion of energy efficiency measures and renewable energy technology. In the course of the introduction important definitions and explanations are given concerning energy efficiency and the appropriated building concept.

Chapter 2 "Methodology" deals with the description of the Master-House[4], the climatic conditions and the results of the heat load calculation presenting the key parameters for the further technical and economical analysis in chapter 3. Divided into the main parts, heat pump and photovoltaics, energy flows, demand and supply are calculated for the Master-House. The results are taken for the further economic analysis of the applied energy efficiency and renewable energy technologies, respectively assessed for two variants, stand alone back up and grid connected system. Third part of chapter 3 outlines the social component of energy efficiency measures and tries to find answers, why there is a lack of market penetration.

In chapter 4 "Recommendations" the further work to be done is summarized in the subchapters named environment, technique, economics and social. The gained results and solutions are discussed in chapter 5 "Conclusion".

[4] House representing state of the art building standard, which is taken as a prototype for the done calculations and system design

2 Methodology

A standardized building with state of the art energy figures is described. This thesis only takes into account heating and hot water demand as well as electricity demand for electric appliances and for powering a heat pump. No energy demand for an eventual cooling is considered here. The building is assumed to be exposed to a climate representative for large areas of the inhabited parts of Central and Eastern Europe. This is expressed in the assumed heating degree days and the values for solar irradiation see table 1.
Heat is provided via a heat pump, the electricity demand of the heat pump, domestic appliances and lighting is supplied by a photovoltaic system. Two different versions of energy supply systems will be calculated:

1. a stand-alone system with a battery back
2. a grid connected version.

Because of the broadness and complexity of the topic the system is simplified. This means the low temperature heating distribution system and a solar thermal system, both of which are part of the REHAU© product portfolio and realised in the described building, are not taken into consideration. Resulting questions and crucial parameters are summarized in chapter 4, which shall present the base for further work to be done in the following years.

2.1 Description of the Master-House

The Master-House, situated in the surroundings of Vienna, is an already existing building of a private person, who has consented to taking this object as a practical example. That way it is possible to have data on real energy consumption and associated costs.

2.1.1 Boundary conditions

The choice of an adequate building structure according to the local climate is a crucial part in the design of a house and determines the energy needs and efficiency as well. In this work the Master-House represents a broad spectrum of new building structures mainly in Central Europe, in contrast to the actual building standard in Eastern and South Eastern Europe. For the Master-House located in the Vienna region it is feasible to apply the generalized humid continental climate as shown in Figure 4. Thus, for making more precise calculations it is necessary to have all detailed information regarding temperatures, heating degree days, solar irradiation and building typology for the defined site.

Figure 3 Climate in Europe[5]

This work deals with the construction site of the Master-house only, whereas the related personal energy service mobility and micro-grids are not considered in this paper.. Moreover it is important to point out that the real conditions of the Master-House' area and roof are not crucial for evaluation of the performed calculations.

[5] European Climate Picture of Europe Climate Map World Book Encyclopedia.htm

2.1.2 Key parameters

The key parameters for the Master-House are taken from the results of the nominal heat load calculation by REHAU RAUWIN© Version 3.60[6], which bases on the standard ÖNORM H 7500 / EN 12831:

Building type	Single family house
Inhabitants	2 adults, 2 children
Norm outside temperature[7]	- 13℃
Average annual temperature	9,6℃
Geometry of building	Width: 12,90 m Length: 13,00 m Base area: 167,70 m² Number of floors: 3 Height: 11,50 m
Heat load	Heat load -transmission part: 7.306 W Heat load -ventilation part: 7.254 W
Total heat load $Q_{HL, Geb}$	14.561 W
Heated effective building area	347,77 m²
Specific heat load factor	41,87 W/m²
Total heat loss coefficient H_{Geb}	395,49 W/K
Heating degree days[8] HDD 12/20 of Vienna	3233 Kd
Solar irradiation[9]	South: 315 kWh/m² a East / West: 211 kWh/m² a North: 144 kWh/m² a Horizontal: 357 kWh/m² a

Table 1 Key Parameters of Master-House

According to Formula 1 and inserting the key parameters of the house the yearly heat energy losses can be calculated.

[6] According to ÖNORM H 7500 / EN 12831 "Heating systems in buildings – Method for calculation of the design heat load"
[7] OIB-382-011/99 Ausgabe März 1999, Klimadaten Wien, p. 35
[8] MA 22, KliP Working Paper Nr. 2 – Basisdaten, 3. aktualisierte Auflage, September 1997, p.5
[9] OIB-382-011/99 Ausgabe März 1999, Klimadaten Wien, p. 35

Formula 1 Calculation of total yearly space heating demand Q_T

$$Q_T[kWh/a] = H_{Geb}[W/K] \cdot HDD[Kd] \cdot 0{,}024[kh/d]$$
$$Q_T = 395{,}49 \cdot 3233 \cdot 0{,}024 = 30.686{,}8 kWh/a$$

The Master-House has annual heat energy losses Q_T of 30.686,8 kWh/a, resulting in a specific yearly heat energy demand q_T of 88,2 kWh/m²a.

In contrary to the calculation in the framework of the energy performance certificate the factors for internal and solar passive gains are not part of the underlying standard ÖNORM H 7500 / EN 12831 and is therefore not considered in this paper.

2.1.3 Sketches and plans

The Master-House is a two storey building with a cellar and a fully developed top floor. In the following some sketches and views are presented.
In the cellar the heat pump and the buffer tank are located, the solar thermal system is mounted on the west roof.

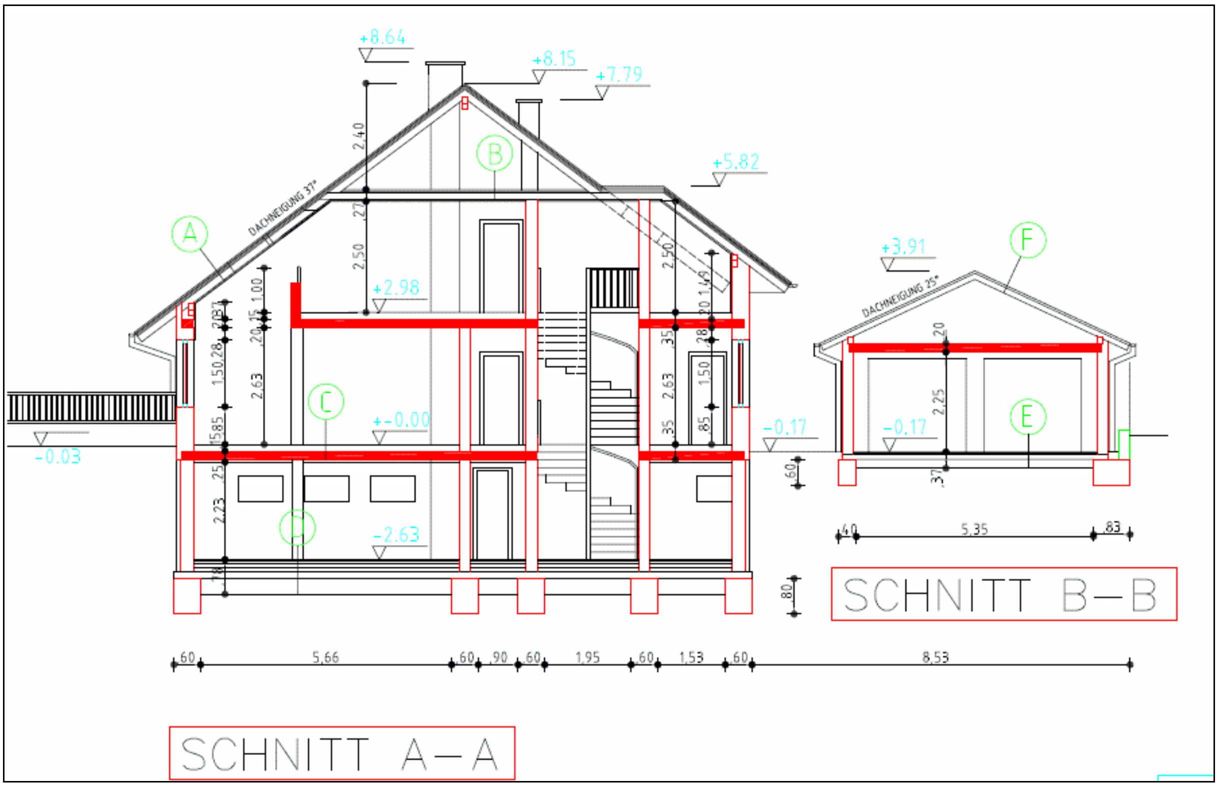

Figure 4 Sectional view of Master-House

Looking at Figure 6, which shows the view from the south, the main building area was designed with a low window amount, and therefore it was chosen to erect a part of the living room with the connection to the terrace with a constant window area.

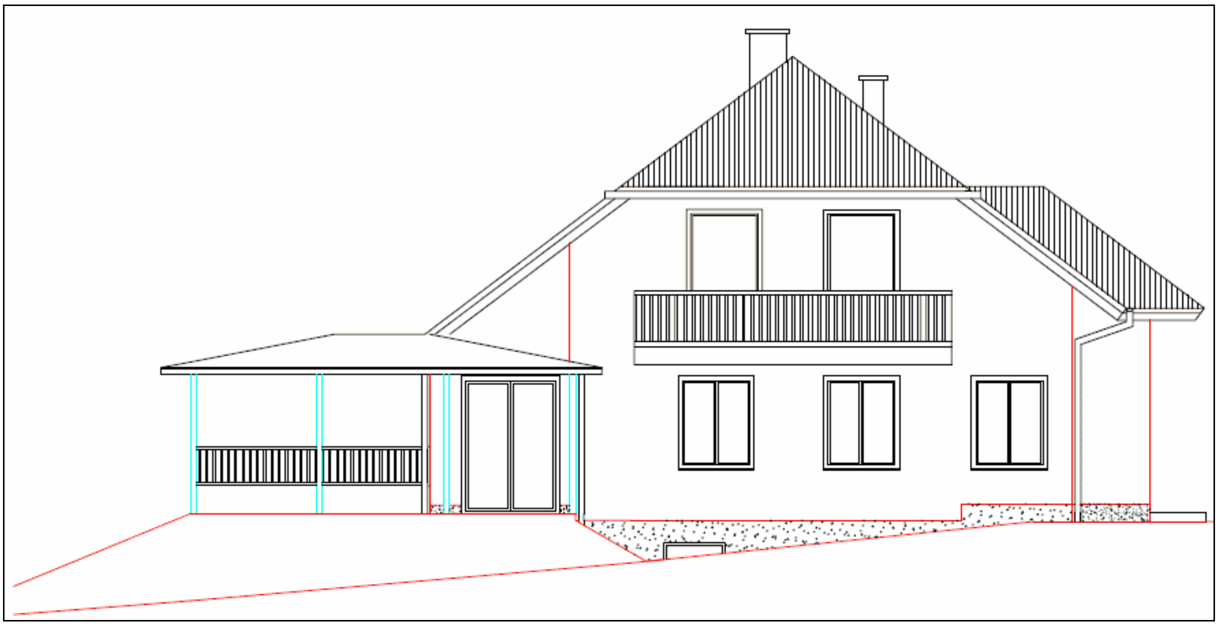

Figure 5 South view of Master-House

The west view of the Master-House indicates the optimum position of the solar energy system, both thermal and electrical, at the west roof, see Figure 7.

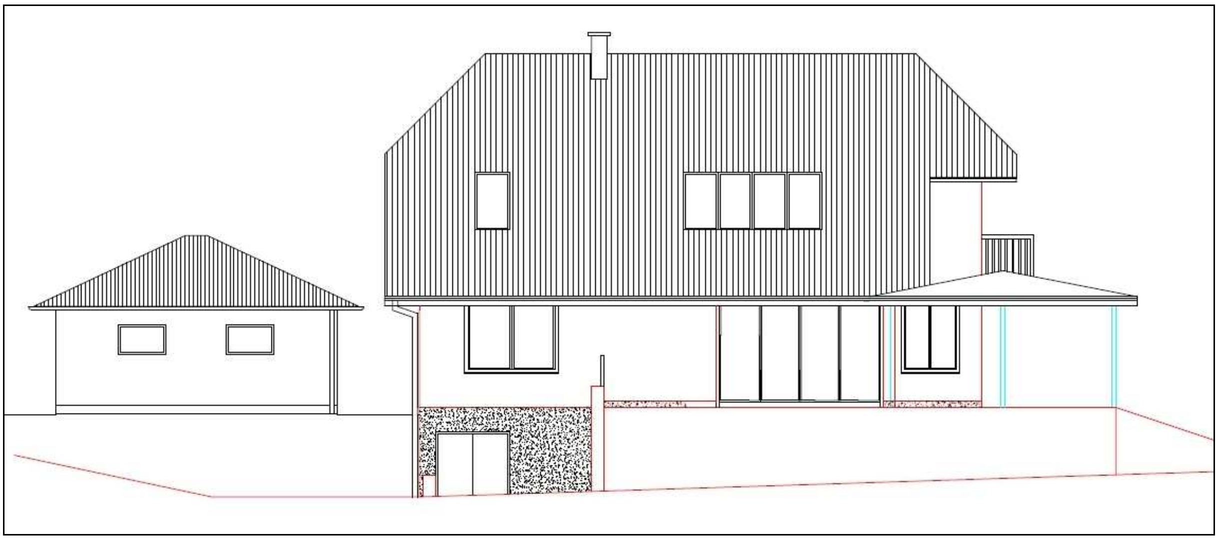

Figure 6 West view of the Master-House

The ground plan illustrated in Figure 8 gives a detailed impression of the integrated energy efficient building technology floor heating system, which is installed in every room at the ground and the first floor.

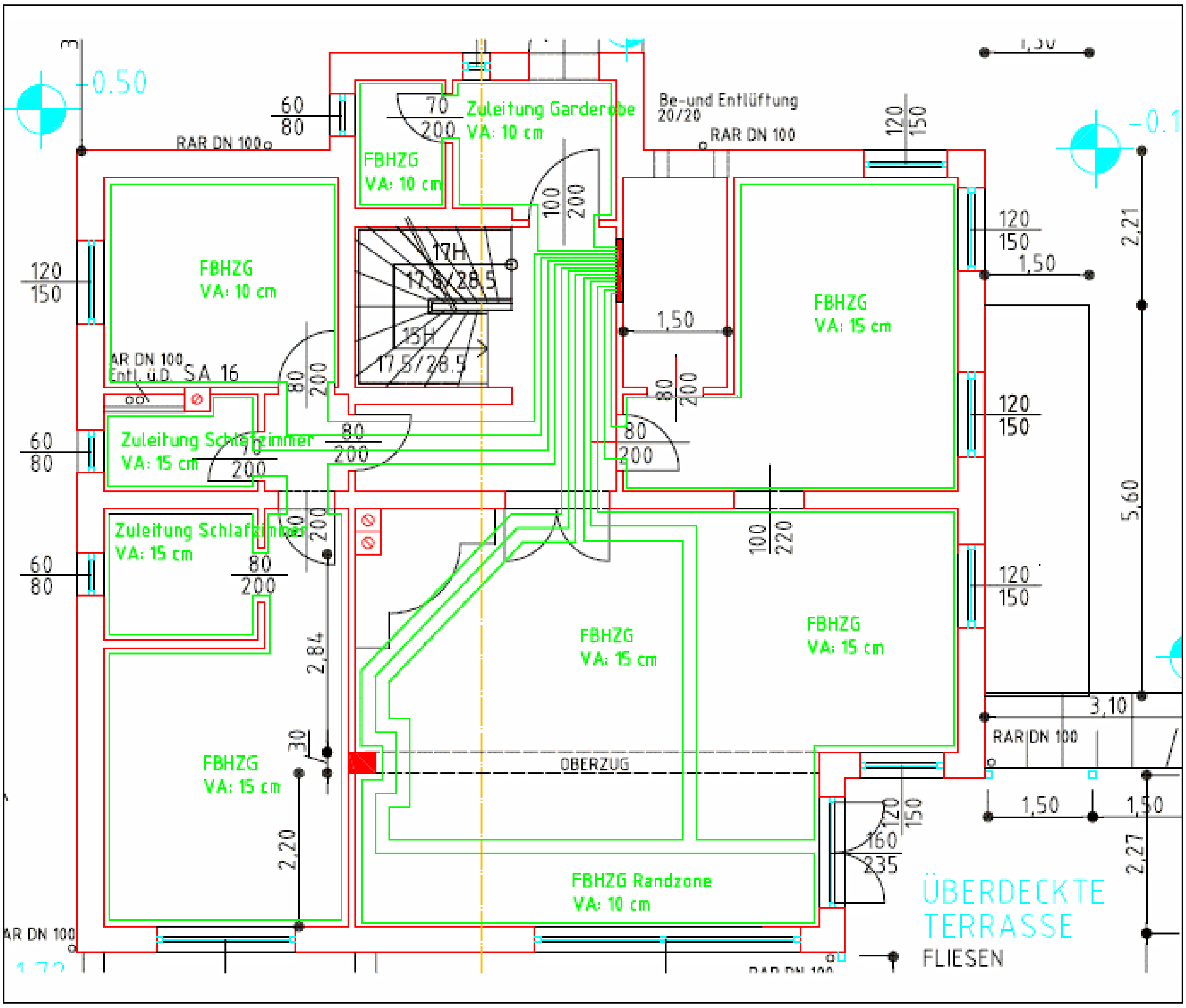

Figure 7 Ground plan Master-House

The owner of the Master-House provided also a picture taken from a plane, showing the house from the bird's view and moreover gives an impression of the environment, see Figure 9.

Figure 8 Bird's eye view of the Master-House

2.1.4 Hypothesis

This paper hypothesises that the integration and combination of energy efficient building components and renewable energy technology facilitates the realisation of an energy independent house. As characteristic the house produces the total needed heat and electricity demand by for instance using a heat pump and photovoltaic system, which guarantees over the whole year enough electricity for household appliances and the heating independent from the public grid. The extension of this idea is presented in this master thesis as the so called "Zero-energy-cost" House, namely not only being autonomous from the energy point of view but also from the energy cost side.

3 Technical and economic analysis

This chapter deals with the technical and economic design of the chosen energy supply system and analyses possibilities for a better market introduction.

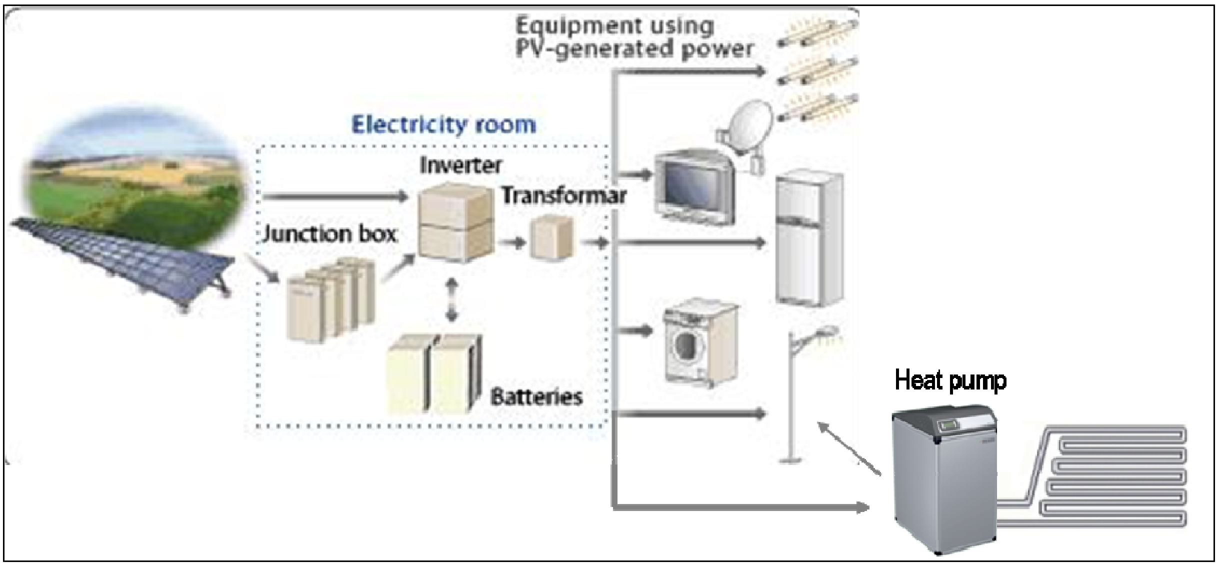

Figure 9 Schematic of „Zero-energy-cost“ Master-House

As presented in Figure 9 the “Zero-energy-cost” House consists of a photovoltaic system both for the electricity supply for household appliances and the covering of the electricity demand of the installed heat pump.

3.1 Technical calculation of energy supply systems

In the following the main energy supply systems, ground source heat pump and photovoltaic, are calculated.

3.1.1 Heat pump

The dimensioning of the heating capacity Q_{WP} of a heat pump system depends on four main parameters[11]:

- heating load of the building Q_H
- heating load for the hot water preparation Q_{TW}

[11] REHAU WÄRMEPUMPENPROGRAMM, PREISLISTE 2008 952.001/1 A, p.6

- heating load of special applications (e.g. swimming pool) Q_S
- Off-period of energy supplier

Formula 2 Calculation of energy demand of a heat pump system

$$Q_{WP} = (Q_H + Q_{TW} + Q_S) \cdot off - period$$

Energy suppliers are authorized to shut down specified grid levels for a defined period of time because of peak load handling in the grid. In regard of heat pumps this means that the storage volume must be planned with this factor for securing the supply of the heating system with enough energy.

The following table shows typical off-period factors[12] of Austrian energy suppliers:

Off-period	Factor
1 x 2 hours	1,1
2 x 2 hours	1,2
3 x 2 hours	1,33

Table 2 typical off-period factors

Taking the data of the Master-House into consideration the exact heating capacity Q_{WP} of the heat pump can be calculated. The value for the 1.000 litre buffer tank is assumed with 0,25 kW per person, resulting in this case with 1 kW.

Heat load Q_H	14,5 kW
Buffer tank 1000 litre	1 kW
Off-period (Energy supplier EVN)	1,2

Table 3 Data of the Master-House

Calculation of Q_{WP} by using Formula 2:

$$Q_{WP} = (14{,}5 + 1) \cdot 1{,}2$$

$$Q_{WP} = 18{,}6 kW$$

As a general rule it can be said that the chosen type of heat pump is always smaller than the calculated heating load Q_{WP} due to recommendations of the heat pump producers, resulting in this case to take the heat pump with 17,1 kW[13].

12 Idem, p.7

13 Technische Information Wärmepumpenprogramm 952002A, p. 33

According to the REHAU© Technical Information the chosen heat pump GEO 17 has a coefficient of performance (COP) at defined conditions of 4,4 and an electric load of 3,89 kW_{el}[14].

Table 4 illustrates the energy demand in form of electricity and energy supply in form of heat for the Master-House at the specific environmental conditions, described by the heating degree days HDD 12/20 of Vienna. The monthly values are calculated by applying the percentages of the HDD to the heating demand of the heat pump, with the same factor the results of the electricity demand is received.

The amount of energy needed for the hot water preparation is assumed to be 15% based on practical experience, which is the reason for the energy demand on the heat pump even during summer period.

			Heat pump	
	HDD12/20 Vienna	HDD %	kWhth	kWhel
January	645	20	6.057	1.377
February	526	16	4.939	1.123
March	449	14	4.216	958
April	225	7	2.113	480
May	65	2	610	139
June	9	0	85	19
July	1	0	9	2
August	1	0	9	2
September	42	1	394	90
October	284	9	2.667	606
November	436	13	4.094	931
December	586	18	5.503	1.251
SUM	**3.233**		**30.360**	**6.900**

Table 4 Energy flows of heat pump according to HDD 12/20

The calculated annual electricity demand of the heat pump is 6.900 kWh_{el}, resulting in a heat supply of 30.360 kWh_{th} per year, which covers almost the whole calculated heat demand Q_T of 30.686,8 kWh/a of the Master-House.

In Figure 10 the load curve of the heat pump, the thermal and electrical parts, is shown at a monthly base.

[14] COP Brine 0°C/Water 35°C according to EN 14511 „Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling“

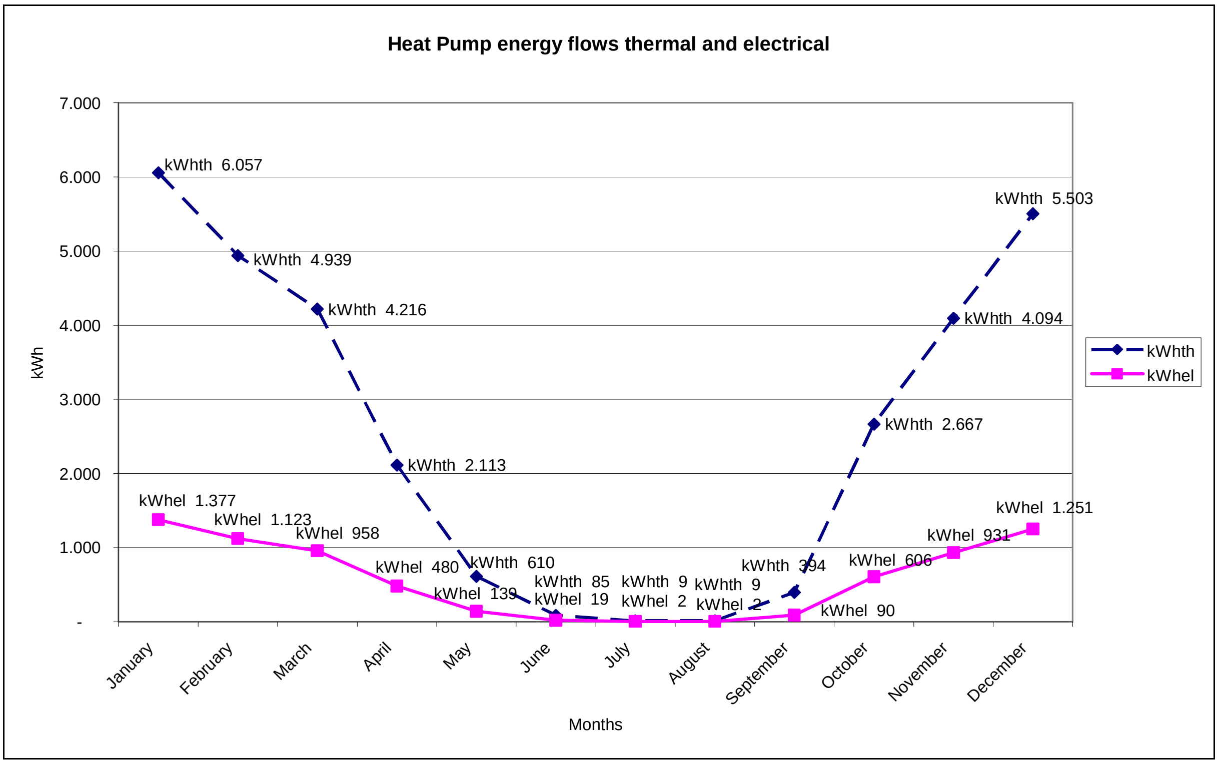

Figure 10 Profile of the energy flows of the heat pump GEO 17

Concerning the dimensioning of the earth collector and the piping the information is given by the owner, stating that the earth collector has an area of 660m², twice the heated space area, resulting in 900 metres of 25x2,3 piping, with an inlet pipe of dimension 50 for the heat pump.

The schematic shown in Figure 11 illustrates the hydraulic of the heat pump in combination with the 1.000 litre buffer tank and the floor heating system.

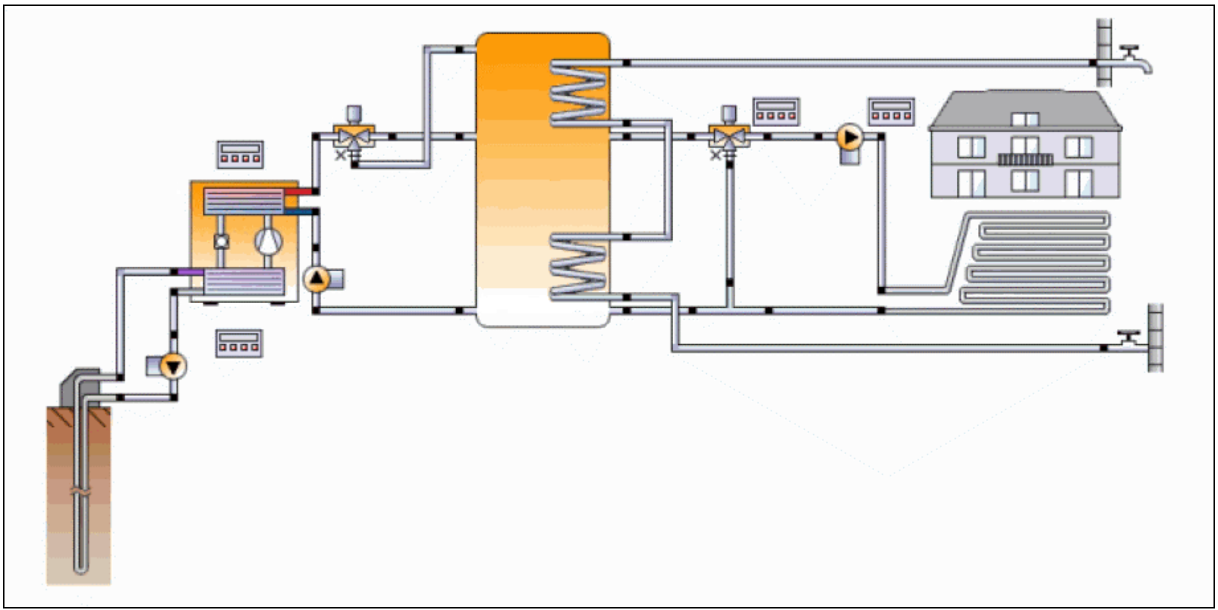

Figure 11 Schematic of a heat pump system in Polysun 4

Because of the fact that in the used software Polysun 4[15] it is not possible to simulate a ground source earth collector, the tube variant is taken.

3.1.2 Photovoltaics

For household appliances and lighting a demand of further 4.000 kWh_{el} per year are assumed. Because it is very crucial to know the seasonal variation of the electricity demand of the building for the dimensioning of the photovoltaic system a load profile of a typical Austrian household is applied for the following calculations, see Figure 12.

[15] Polysun 4 Version 4.3.0.1, Institut für Solartechnik SPF, Schweiz, www.solarenergy.ch

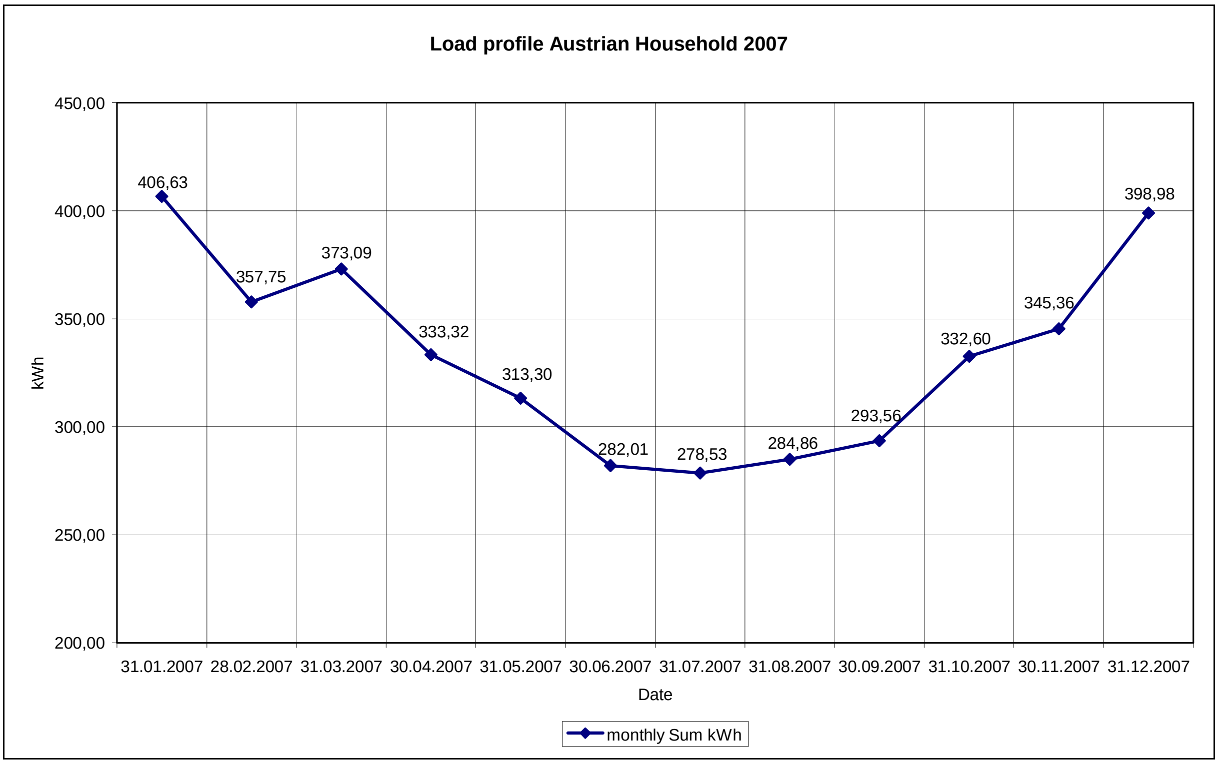

Figure 12 Load profile for electricity demand of Austrian household 2007[16]

The data is taken from the organisation APCS, which is responsible for the calculation of the balancing energy values for the Austrian electricity market based on the planned volumes of electricity fed into the grid and received from the grid.

Summarizing the electricity demand of the heat pump and the household appliances the photovoltaic system should cover the following:

[16] APCS Power Clearing and Settlement AG, www.apcs.at

	Heat pump kWhel	Load profile Austrian Household 2007 kWhel	Sum kWhel
January	1.361,43	406,63	1.768,06
February	1.110,25	357,75	1.468,00
March	947,72	373,09	1.320,82
April	474,92	333,32	808,23
May	137,20	313,30	450,50
June	19,00	282,01	301,00
July	2,11	278,53	280,64
August	2,11	284,86	286,97
September	88,65	293,56	382,21
October	599,45	332,60	932,05
November	920,28	345,36	1.265,64
December	1.236,89	398,98	1.635,88
SUM	**6.900,00**	**4.000,00**	**10.900,00**

Table 5 Summary of the monthly electricity demand of the Master-House

Next step in the design of the needed photovoltaic system is to investigate the solar irradiation potential of the Master-House's area. The parameters of the PV modules are determined with 45° inclination and direct orientat ion to the south, representing an average with respect to the seasonal output.

	Sum kWhel	needed kWh per day	PV generation kWh/kWp per day	PV generation kWh/kWp per month	needed installed PV capacity kWp	needed installed PV capacity kWp per day
January	1.768,06	57	1,40	45	39	40,74
February	1.468,00	52	2,10	59	25	24,97
March	1.320,82	43	2,90	89	15	14,69
April	808,23	27	3,50	105	8	7,70
May	450,50	15	3,70	116	4	3,93
June	301,00	10	3,80	114	3	2,64
July	280,64	9	4,10	126	2	2,21
August	286,97	9	3,80	116	2	2,44
September	382,21	13	3,30	100	4	3,86
October	932,05	30	2,60	80	12	11,56
November	1.265,64	42	1,50	46	28	28,13
December	1.635,88	53	1,00	32	51	52,77
SUM	**10.900,00**					

Table 6 PV generation kWh/kWp at the site of the Master-House and the resulting needed installed PV capacity at a daily and monthly base

The results presented in Table 6 for the daily and monthly photovoltaic generation kWh/kWp, column 3 and 4, are taken from the website of the European Commission Joint research centre “Photovoltaic Geographical Information System” PVGIS[17], where it is possible to simulate for a specific site the PV generation per day and per month.

3.1.2.1 Version 1: stand alone system with battery back up

With regard to the dimensioning of a photovoltaic island system with battery back up there are two crucial parameters to bear in mind. First the solar capacity of the site, which results in the number of needed PV modules for generating the demanded electricity. Second the amount of battery capacity for overcoming bad weather conditions.

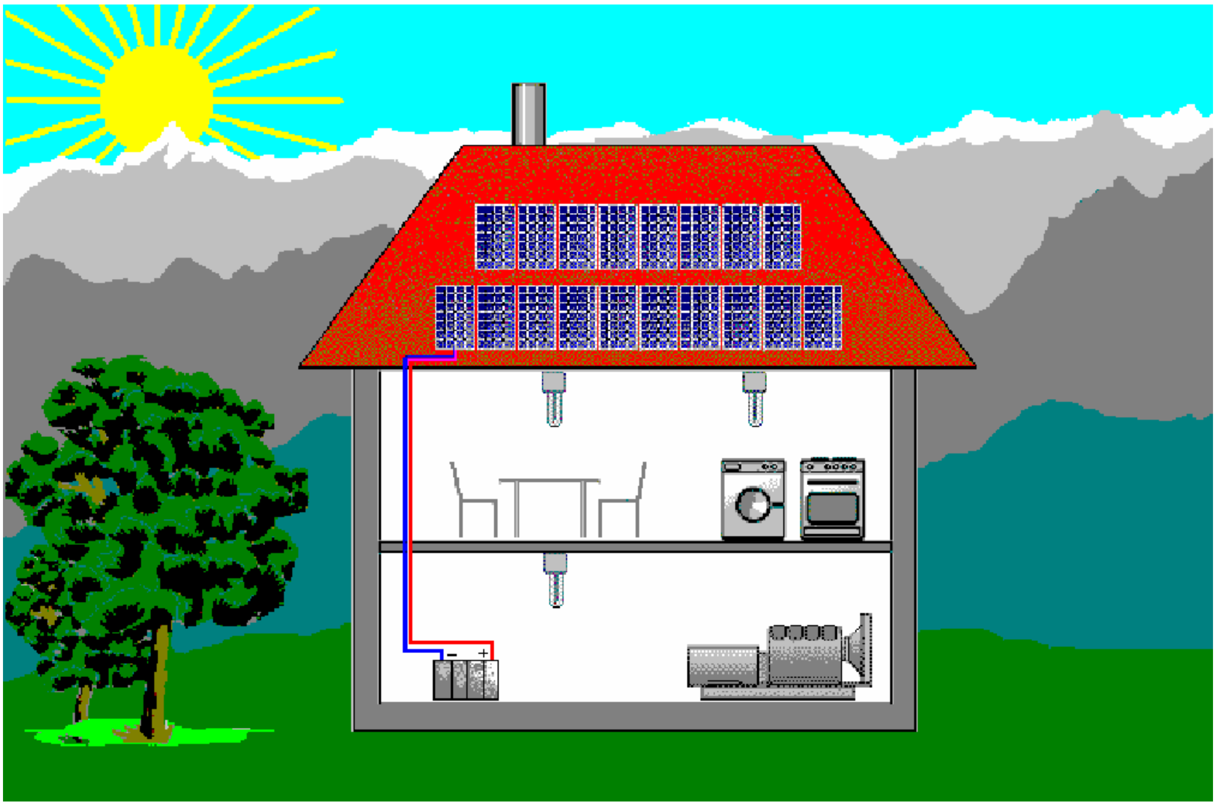

Figure 13 Schematic of photovoltaic island system, simulated with software PV*SOL[18]

a) Calculation by hand

PV Modules

As seen in Table 6, the column 5 “needed installed PV capacity kWp” and column 6 “needed installed PV capacity kWp per day” show just a slight difference in results on a daily and monthly base. To cover the total electricity demand the worst case is taken, meaning

[17] re.jrc.ec.europe.eu
[18] PV*SOL 2.6 PRO Version R9, Dr. Valentin EnergieSoftware GmbH, Germany, www.valentin.de

December with a demand of 1.635,88 kWh, or 53 kWh per day, resulting in a needed installed photovoltaic capacity of 52 kWp.

Formula 3 Calculation of PV generator for December

$$PVgenerator[kWp] = \frac{demand[kWh]}{specificyield[kWh/kWp]} = \frac{1635{,}88kWh}{32kWh/kWp} = 52kWp$$

Taking the polycrystalline PV module of the type “Solon P220/6+” with 200 Wp the number of modules is calculated:

Formula 4 Calculation of needed pieces of PV modules

$$Modulpieces = \frac{systemcapacity}{\mathrm{mod}\,ulcapacity} = \frac{52000Wp}{200Wp} = 260Modules$$

Battery

The right calculation of the battery back up is essential for the efficient and reliable electricity supply.

According to the handbook “Photovoltaische Anlagen[19]” the capacity of the battery is calculated using the following formula:

- Daily demand D in VAh
- Reserve days F 4 days are chosen, factor 4
- System voltage U_n
- Load factor of battery assumed with 50%, factor 2

Formula 5 Calculation of battery capacity C_n

$$C_n = \frac{2 \cdot D \cdot F}{U_n}$$

$$C_n = \frac{2 \cdot 53000VAh \cdot 4}{48V} = 8833Ah$$

For the coverage of the daily 53 kWh of electricity demand for the heat pump and the household appliances in December a battery capacity of 8833Ah per day must be installed, which means that the total demand can be supplied for four more days in case of bad weather conditions.

[19] Photovoltaische Anlagen, Leitfaden für Elektriker, Dachdecker, Fachplaner, Architekten und Bauherren, Deutsche Gesellschaft für Sonnenenergie e.V. 2. Auflage, DGS Berlin, 2002, p. 6-15

The system voltage U_n of 48 V was chosen to reduce the energy losses in the installation to the minimum and to optimise the battery back up.

For this thesis the battery type OPzV2900 with 2 V nominal voltage and a capacity of 2900 Ah is chosen, resulting according to Formula 6 in 144 units at a system voltage of 48 V.

Formula 6 Calculation of needed battery pieces for 48 V

$$battery\_units = \frac{needed\_capacity}{battery\_capacity} = \frac{8833Ah}{2900Ah} = 3{,}04 units$$

$$48V battery\_units = 2V \cdot 24 \cdot 3 = 144 units$$

Peripheral components of the system like island inverter, charge controller and cabling are not subject of the calculations in this section.

b) PV SOL simulation

The system is simulated with the software PV*SOL 2.6.

Peculiarities

The results are calculated using a mathematical model. The actual PV System yields can vary due to variations in climate conditions, module and inverter efficiency and other factors. Moreover the load curves of the heat pump and the household entered into the software are tried to be as realistic as possible. Therefore it is pointed out at this stage that the energy demand, in the simulation program called “Energy requirement” is 10.161 kWh /a in contrary to the real calculated load of 10.900 kWh/a.

The schematic in Figure 14 shows the parameter entered for the simulation, table 7 below presents the simulation results.

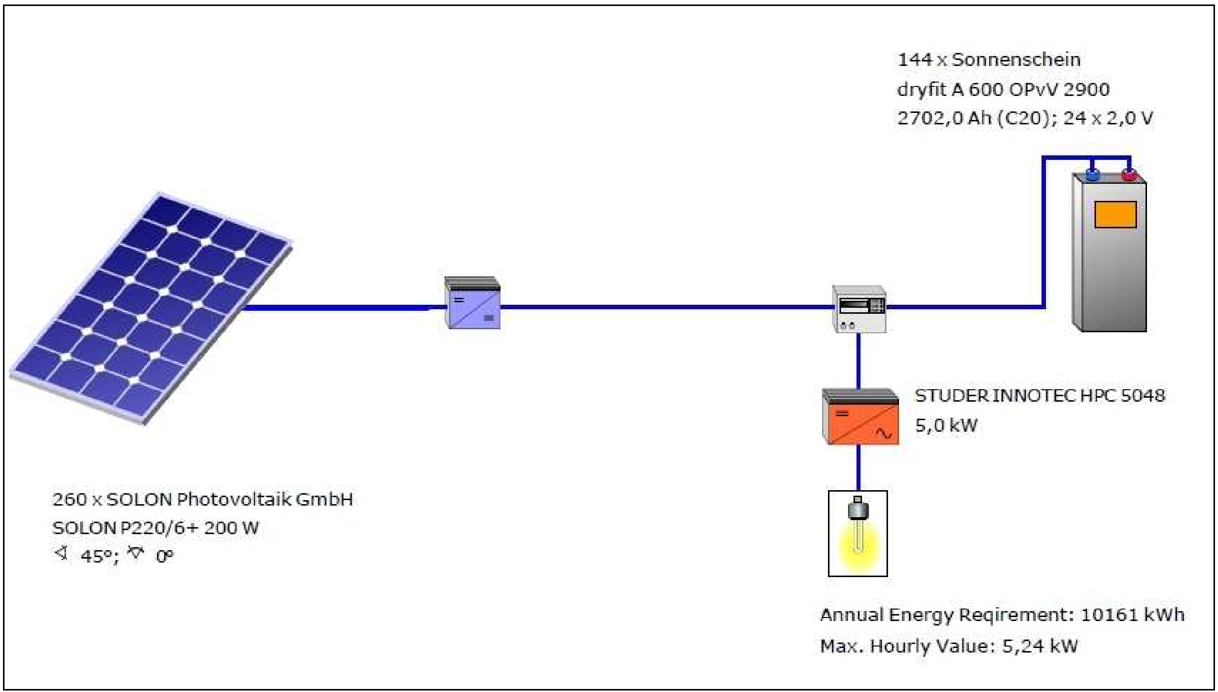

Figure 14 schematic of PV island system

Location:	**Wiener Neustadt**	
Climate Data Record:	Wiener Neustadt	
PV Output:	52,11	kWp
Gross/Active Solar PV Surface Area:	427,28 / 423,69	m²
PV Array Irradiation:	503.217	kWh
Energy Produced by PV Array:	50.632	kWh
Converter Energy:	39.317	kWh
Consumption Requirement:	10.161	kWh
Consumption Covered by Solar Energy:	9.679,7	kWh
Consumption Not Covered by System:	481,2	kWh
Solar Fraction:	95,3	%
Performance Ratio:	15,6	%
Specific Annual Yield:	185,7	kWh/kWp
CO2 Emissions Avoided:	5.946	kg/a
System Efficieny:	1,9	%
PV Array Efficiency:	10,1	%

Table 7 simulation results of PV island system 52 kWp

The simulation results confirm that the planned PV generator of 52 kWp and the battery capacity of 8.700 Ah almost enable the total energy supply for the needed energy demand of the Master-House independent from the grid, described by the “Solar Fraction” of 95,3%.

Regarding the energy flows the seasonal dependency of the photovoltaic generation is obvious and illustrated in Figure 15.

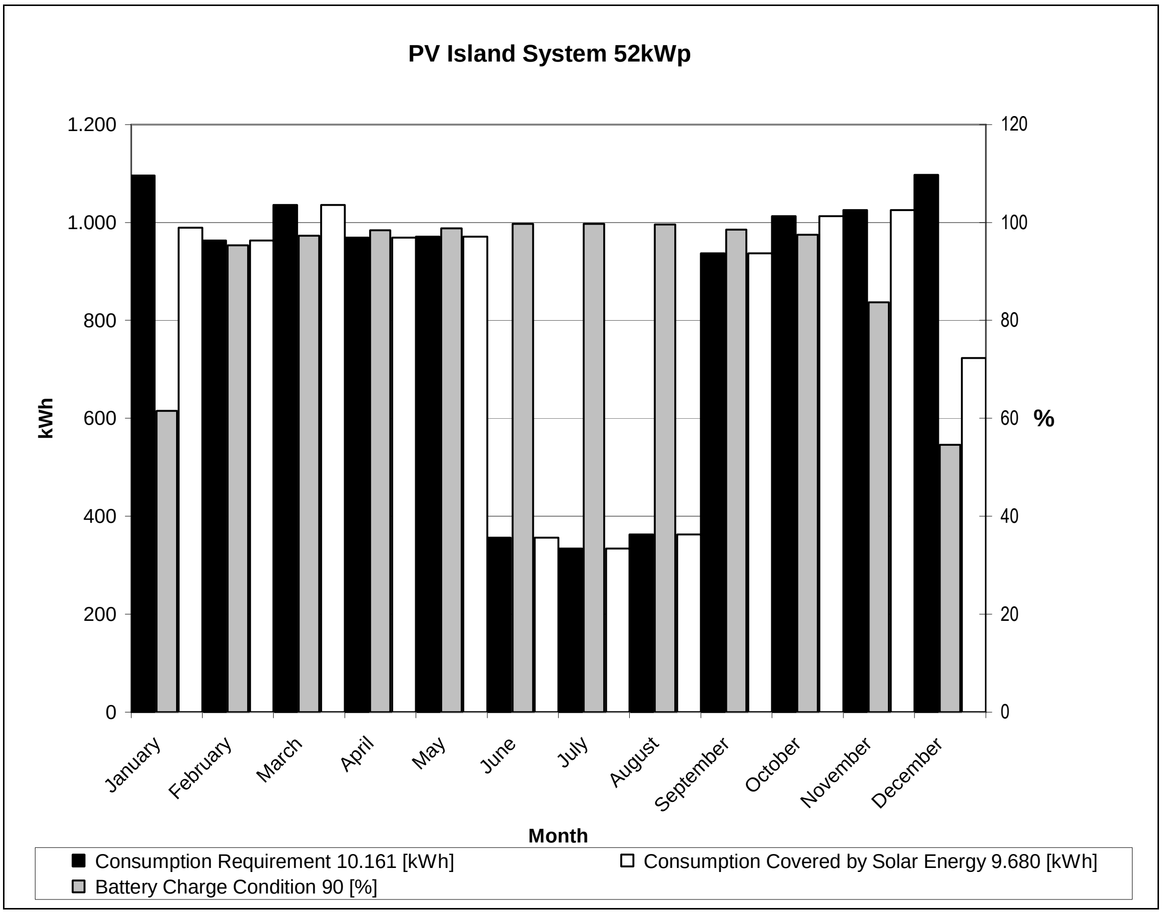

Figure 15 Energy balance between requirement and solar covering in comparison with battery charge condition at a yearly base

The values for the battery charge condition are indicated in percent, meaning that in the summer season the battery is fully load, see 100%, whereas in December the battery is charged approximately to 50%. The displayed 90% in the legend is the result over the whole year.

c) Discussion of results

The realisation of an independent energy supply system by using photovoltaic is, as demonstrated in the simulation, technical possible but not feasible, because of the big difference between demand and supply side, showing very effectively the limitation of photovoltaic back up systems. In winter time there is the problem of high energy demand for heating but low energy supply and therefore a low battery capacity. Whereas in summer time

the demand for electricity is only a third of the annual demand but the photovoltaic system yields the best output.
The only possibility to achieve even in summer a useful mode of operation would be the supply of a cooling system, for instance a reversible heat pump, which can heat and cool.

3.1.2.2 Version 2: grid connected system

The design of the grid connected system is easier than the one with battery back up, because in the case of grid connection the grid acts like the back up. Thus it is necessary to calculate the needed photovoltaic capacity covering the yearly electricity demand. Figure 16 illustrates the system with the connection to the public electricity grid.

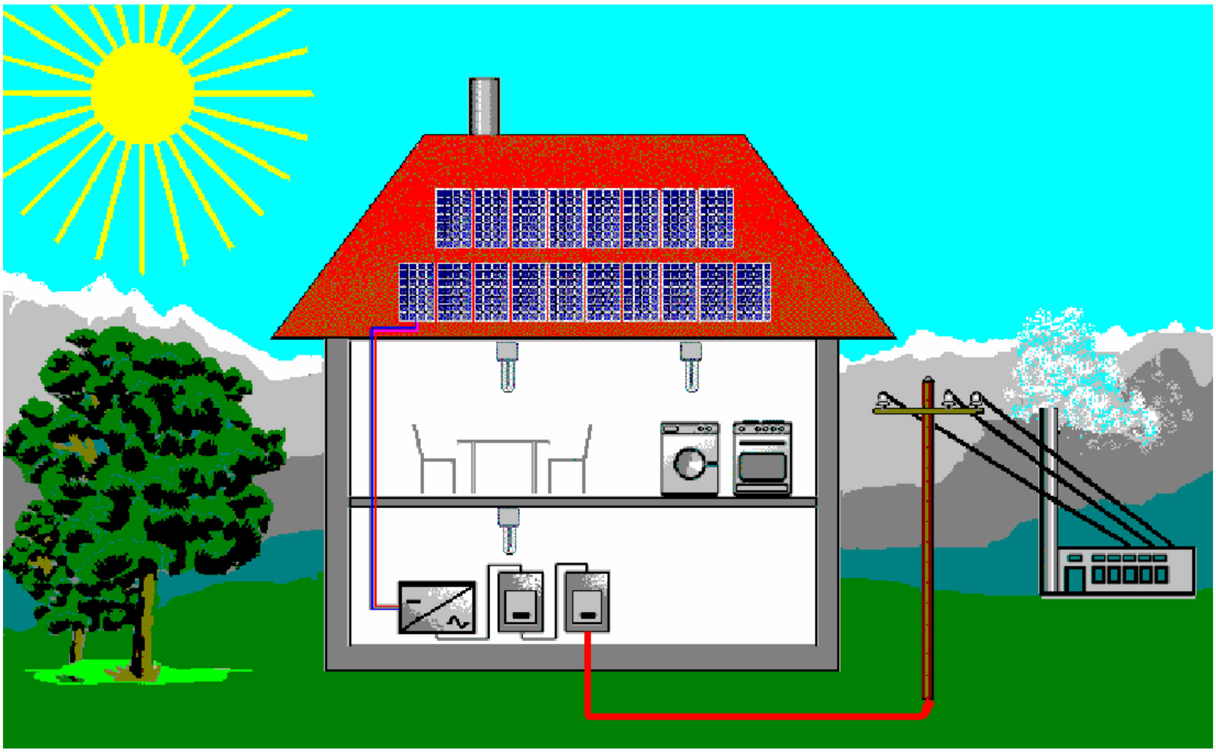

Figure 16 schematic photovoltaic grid connected system, PV*SOL 2.6

a) Calculation by hand

PV Generator

The yearly electricity demand of the Master-House is 10.900 kWh. Assuming that the specific annual yield at the construction site is 900 kWh/kWp, see Table 8, the needed PV generator can be calculated as follows:

Formula 7 Calculation of PV generator

$$PVgenerator[kWp] = \frac{demand[kWh/a]}{specificyield[kWh/kWpa]} = \frac{10977kWh/a}{900kWh/kWpa} = 12{,}2kWp$$

Taking the same module type, Solon P220/6+ 200W, as for the calculation of the island system and applying Formula 4, the number of modules adds up to 61. Because it is necessary to have an even number of modules for the string design of the inverter, 60 modules are taken for this work, meaning a PV system with a capacity of 12 kWp.

Inverter

The design of the inverter is done by checking the datasheets of the possible inverter types. For this project the inverter type KACO Powador 5000xi is chosen, with a peak output power of 5,7 kW, thus using 2 units for the simulation.

b) PV SOL simulation

The by hand calculated parameters are entered into the simulation program. The schematic in Figure 17 shows the system design, Table 8 the resulting energy output.

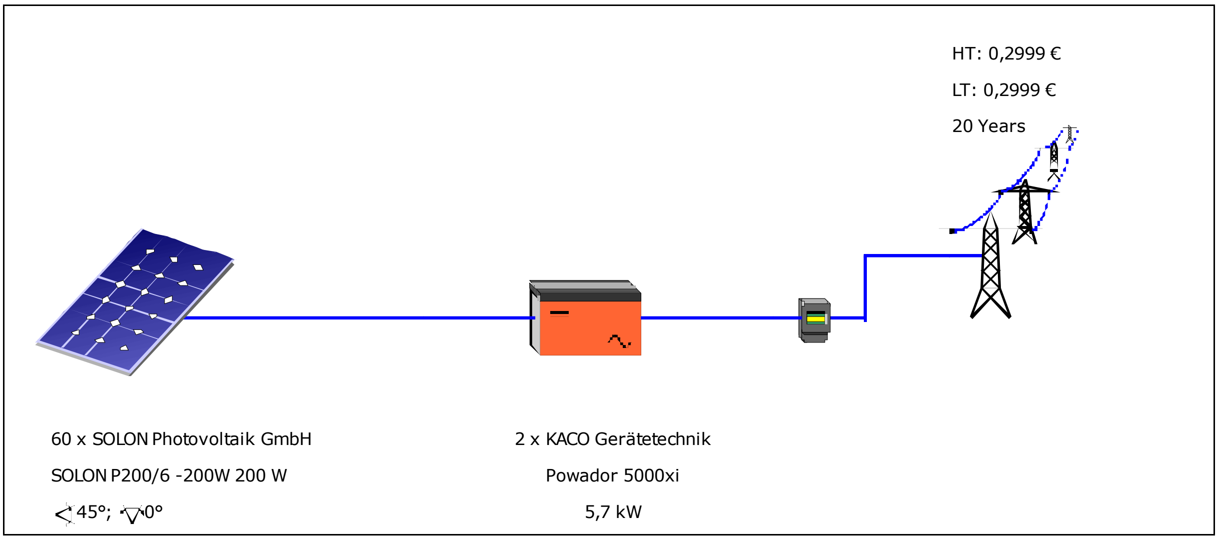

Figure 17 Schematic of PV grid connected System 12 kWp

Location:	**Wiener Neustadt**	
Climate Data Record:	Wiener Neustadt	
PV Output:	12,00	kWp
Gross/Active Solar PV Surface Area:	91,20 / 90,87	m²
PV Array Irradiation:	107.929	kWh

Energy Produced by PV Array (AC):	10.871	kWh
Grid Feed-in:	10.871	kWh
System Efficieny:	10,0	%
Performance Ratio:	76,1	%
Inverter Efficiency:	93,3	%
PV Array Efficiency:	10,8	%
Specific Annual Yield:	903,9	kWh/kWp
CO2 Emissions Avoided:	9.603	kg/a

Table 8 simulation results PV grid connected system 12 kWp

c) Discussion of results

Looking at a yearly base the photovoltaic system generates as much electricity as needed for the Master-House. Again Figure 18 shows the high yields in summer in comparison to the high demand in winter. Due to the fact that the public grid operates as the back up the system can be planned approximately 4 times smaller than the island system.

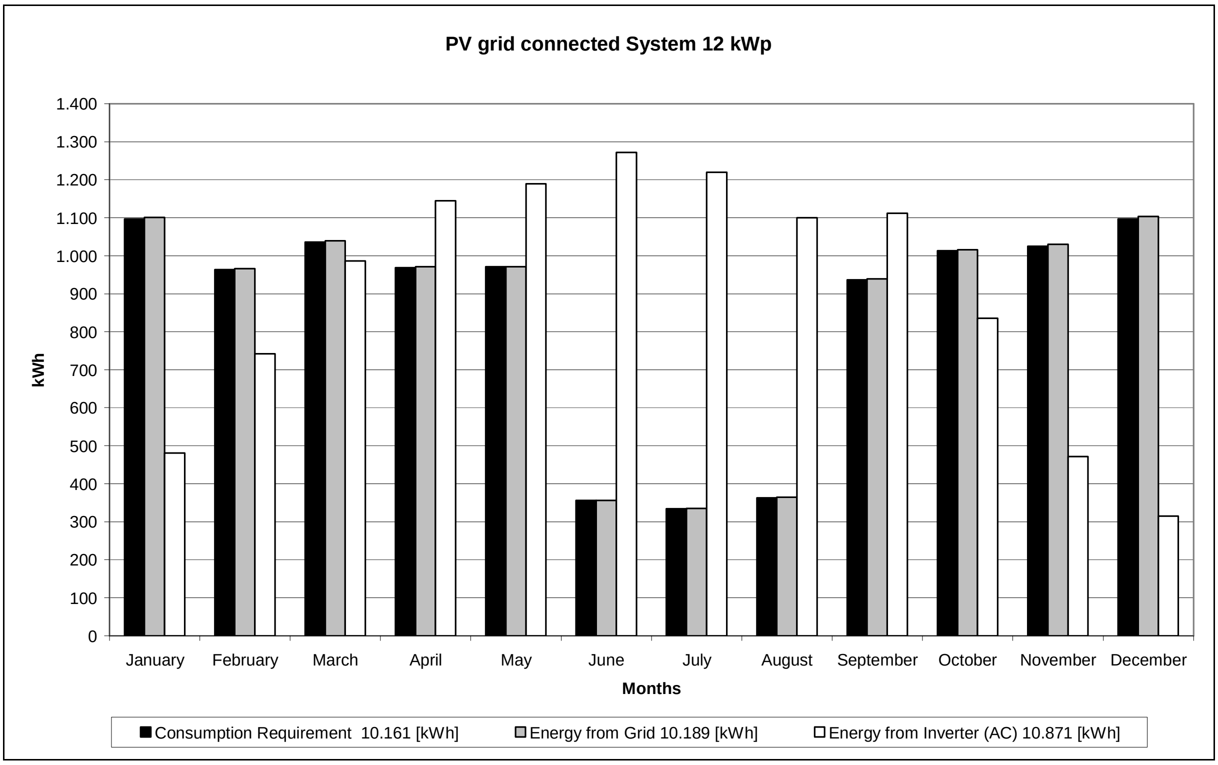

Figure 18 Comparison of requirement, grid supply and PV generation at a yearly base

3.2 Economic calculation

In this part of the Master thesis the possibility of the "Zero energy cost" House is evaluated for the two different variants.

3.2.1 Variant 1: island system with battery back up

In the case of the system with battery back up only material costs play a role in the economic calculation. Concerning the percentage of the total costs of the components it is communicated inside the branch that the breakdown between modules and battery almost equalised at around 45%, because costs of the raw material of batteries, mainly lead, increase the last years tremendously.

The following costs are investigated[20]:

Units	Component	Specific price	Price excl. VAT
260	Photovoltaic module type Solon P220/6+ 200W	Euro 3.200,-/kWp	Euro 166.400,-
144	Battery type OPzV2900	Euro 1,269/kWh	Euro 230.400,-
1	Cabling, island inverter, charge controller	Euro 384,6 /kWp	Euro 20.000,-
	SUM		**Euro 416.000,-**

Table 9 Costs of the PV island system with battery back up

The Master-House can be supplied with electricity the whole year and without paying the prices of the local electricity supplier. Under this perception, and without taking the investment costs into consideration, it would verify the possibility of the "Zero-energy-cost" House.

3.2.2 Variant 2: grid connected system

Photovoltaic grid connected systems can be economically calculated in two different ways, always considering the investment costs and getting the so called amortisation calculation. One possibility in the case of no subsidies given by the state is the calculation of the saved

[20] recommended retail prices according to company Siblik GmbH, Austria

energy delivered by the PV system. Under this circumstance the amortisation would take quite a long time, probably more than the life span of the modules, because savings in electricity cost which otherwise would have been paid to the supplier are too low, e.g. about Euro 0,16 per kWh.
If there is a subsidy system in the state and the electricity can be fed into the public grid, the so called feed-in tariff often enables an economical operation of the system and achieving an amortisation time of ten to fifteen years, depending on the height of the feed-in tariff.

In this Master thesis the above explained calculation methods are applied with only one big difference, which is the fact that the investment costs are not considered. The period under review is one complete calendar year, starting from the 1.1. and ending with the 31.12.. The aim is not the amortisation, the aim is to realise the “Zero-energy-cost” House.

3.2.2.1 NO subsidy

To calculate the saved electricity costs by the photovoltaic system it is necessary to know the current average prices, which are for the end costumer Eurocent 16,3 / kWh and the market price Euro 81,78 / MWh[21]. Both data are published regularly on the website of the E-Control, which is the national regulatory body for the Austrian electricity and natural gas markets.

[21] E-control October 2008, www.e-control.at

					NO SUBSIDY	
	Consumption Requirement	Energy from Grid	Energy from Inverter (AC)	Delta consumption and PV in kWh	Buy from the grid in Euro	Sell to the grid in Euro
	10.161 [kWh]	10.189 [kWh]	10.871 [kWh]		0,163	0,082
					Euro/kWh	Euro/kWh
January	1.096	1.101	481	615	100,25	
February	963	966	742	221	36,02	
March	1.036	1.039	986	50	8,15	
April	969	971	1.145	176		14,393
May	971	971	1.189	218		17,828
June	356	356	1.272	916		74,910
July	334	335	1.220	886		72,457
August	363	365	1.100	737		60,272
September	937	939	1.112	175		14,312
October	1.013	1.016	836	177	28,85	
November	1.025	1.030	472	553	90,14	
December	1.097	1.103	315	782	127,47	
EURO					**390,87**	**254,172**

Table 10 Comparison of electricity costs and delivered PV generation

For this calculation it is first necessary to know the variation of kilowatt-hours generated by the photovoltaic system over the year. The results of this variation are shown in Table 10 column 4.

Formula 8 Example for January

$$Delta\_January = Energy\_from\_inverter - Consumption\_requirement$$

$$Delta\_January = 481kWh - 1096kWh = -615kWh$$

To make an example this means for March that 50 kWh are generated less than required by the Master-House. These 50 kWh must be bought from the energy supplier for a certain price, the final customer price. Whereas in April the system produces 176 kWh more than needed, which is fed into the public grid getting back a certain revenue, the kilowatthours multiplied by the specific market price (€/kWh).

With this sort of calculation the aimed at “Zero-energy-cost” House is almost presentable, the net difference between the cost for bought electricity from the grid and the revenues from electricity sold to the grid is Euro 136,7. This must be paid to the local energy supplier based on the annual bill.

3.2.2.2 With subsidy

The situation in regard of subsidies for photovoltaic power plants in Austria is not that clear and structured like for instance in Germany, where the so called Renewable Energy Sources Act[22] (EEG) is in operation and permits customers to receive preferential tariffs for solar generated electricity homogeneously on a national scope. With this support mechanism Germany is leader in the photovoltaic world market in installing and producing systems and components since more than four years.

There is of course an equivalent law in force in Austria, the Green Electricity Act from the year 2003. Since then there were a lot of changes in the law and the associated ordinances[23]. Moreover some federal countries have their own subsidy system for photovoltaic, mostly investment based benefits.

For the calculation in this paper the actual feed-in tariff of Eurocent 29,99 / kWh[24] is applied, although it must be assumed that the results are only theoretically achievable.

WITH SUBSIDY

	Consumption Requirement	Energy from Grid	Energy from Inverter (AC)	Feed in tariff Euro	Electricity price Euro
	10.161 [kWh]	10.189 [kWh]	10.871 [kWh]	**0,2999**	**0,163**
				Euro/kWh	Euro/kWh
January	1.096	1.101	481	144,2519	179,463
February	963	966	742	222,5258	157,458
March	1.036	1.039	986	295,7014	169,357
April	969	971	1.145	343,3855	158,273
May	971	971	1.189	356,5811	158,273
June	356	356	1.272	381,4728	58,028
July	334	335	1.220	365,878	54,605
August	363	365	1.100	329,89	59,495
September	937	939	1.112	333,4888	153,057
October	1.013	1.016	836	250,7164	165,608
November	1.025	1.030	472	141,5528	167,89
December	1.097	1.103	315	94,4685	179,789
EURO				**3.259,91**	**1.661,30**

Table 11 comparison of results for the „Zero-energy-cost“ House

[22] Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act) from March 29th, 2000

[23] 114. Bundesgesetz, mit dem das Ökostromgesetz geändert wird (2. Ökostromgesetz-Novelle 2008)

[24] 59. Verordnung: Ökostromverordnung 2008, published 14. February 2008, § 5

As presented in Table 11 the photovoltaic system of the Master-House almost earns twice as much as the yearly electricity costs are. This means that the PV system can be half that big, so only 6 kWp, or a 1:1 feed-in tariff can be negotiated with the local electricity supplier.

3.3 Energy efficient market and investor profile

In the framework of the Austrian Program on Technologies for Sustainable Development the project “"Energy saving" - the best PR strategy for sustainable housing?”[25] aimed at finding an answer to this difficult question, which determines marketing and communication strategies of companies working in the sector energy efficiency and renewable energy. Some key results will be discussed in this thesis on behalf of getting a better understanding for market situations and how consumers behave.

The economical meaningfulness of energy saving depends on different parameters, as for instance the energy price, which is a degree of a shortage of feedstock. Because energy prices are very volatile some countries introduced special tools for a better market development, e.g. subsidies or environmental taxes. These activities are not always working out the way it was intended because of other factors concerning consumer behaviour, like price elasticity. Many consumers associate energy saving with lack of usage and comfort and accept higher energy costs as long as the level of comfort is kept up.
In case the energy saving measure creates an additional benefit the higher investment is made, this is often a result of awareness raising campaigns of cities or countries.

Concerning companies two different strategies can be seen; the first one is to react to the market demands and then start with the marketing of energy saving products. That way the competiveness of the company is better on behalf of cost leadership and differentiation. The other possibility is to organise an offensive Eco-marketing for awareness rising and benefits and that way justify higher product prices.

There are three levels of realising the market success of energy efficiency measures[26]:

[25] Psychologie und Energie-PR - Energiesparen als optimale Vermittlung nachhaltigen Bauens und Wohnens? Alexander G. Keul, Berichte aus Energie- und Umweltforschung 14/2002
[26] Idem, p. 69

Emotional relations

Energy solutions should have brand qualities and encourage long-term relations. Quality certificates and modular solutions go into the right direction, but in an emotionally indifferent way, offering no identification.

Everyday reality

Energy solutions and products must touch down from the universe of physics and technology into the everyday environment of their users and be of relevance there. Advantages and problems should be explained in plain, everyday language.

Social grounding

Energy solutions do not happen individually, exclusively, but exist in social contexts. These are to be taken into account. What will our neighbours say? What kind of opinions are to be expected in a group discussion with friends? Communicable, socially meaningful messages spread even without expensive advertising. And: not all social emotions are noble and constructive.

In the framework of the Master program the topic was presented in module 5 "Efficient Energy Use and Thermal Building Optimisation", which content is taken for the further discussion[27].

3.3.1 Market barriers

Energy efficiency in services and components, energy optimised building standards and the integration of renewable energy technologies represent state of the art know how and the successful integration and operation of the above mentioned is already proven more than thousand times all over the world. Nevertheless seems the idea of building for instance a passive house something new, innovative and just for top earners.
There are a variety of market barriers defined, which is discussed in the following.
.

- Non-competitive market price: economies of scale and learning benefits have not been realised yet, thus additional technical development and more investments in commercialization are required.

[27] MSc Script Module 5 „Efficient Energy Use and Thermal Building Optimisation", lecture "Market transformation instruments", September 2007, DI Herbert Ritter, Austrian Energy Agency

- Price distortion: the costs associated with the used technology are not included in its price; sometimes a subsidy is in use. The “external” costs should be included, subsidies removed and offsetting done by taxes or rebates.
- Lack of information: availability, performance and benefits of the product must be understood at the time of investment. With the integration of standardization and labelling reliable information sources can develop.
- High transaction costs: costs preparing the purchase decision. It is important to have convenient and transparent calculation methods, fulfilling standardization and labelling criteria for decision making.
- Higher buyers risk: difficulty in forecasting product performance over a certain time frame. Via demonstration learning on the product and routines for understandable life-cycle costs.
- Higher financial risk: initial costs may be a boundary; only limited access to funds. Special funding and alternative funding options, third party financing options
- Inefficient market organisation in relation to new technologies: different incentives of market players, traditional business boundaries may be inappropriate, established companies may have power to guard their position. With the implementation of market liberalization and reconstructing markets new solutions and services are offered.
- Excessive / inefficient regulation: traditional regulation, standards and codes, which are not up to date any more must be reformed and adopted.
- Technology-specific barriers: often related to existing infrastructures concerning hardware and institutional skills o handle. The focus must be set on the system requirements in the context of the used technology and if possible link it to other business issues as productivity or environment.

3.3.2 Investor profile

When talking about investors it is an advantage knowing the driving forces behind buying decision and how that can be supported. In market theory there is a distinction between different investor types, who represent a typical behaviour, see Figure19.

Adopter type	Characteristic	Role and size
Innovators • enthusiast	Venturesome; Enjoys the risk of being on the cutting edge; Demands technology	Market drivers. Want more technology, better performance. (16%)
Early adopters • visionaries	Well connected; Integrated in the main-stream of social system; Project oriented; Risk takers; Willing to experiment; Self-sufficient; Horizontally connected and acts as their peers	
THE CHASM (where marketing and distribution must radically change)		
Early majority • pragmatists	Deliberate; Process oriented; Risk Averse; Want proven applications; May need significant support; Vertically connected and acts as their superiors	Followers on the market. Want solutions and convenience. (68%)
Late majority • conservatives	Sceptical; Does not like change in general. Changes under 'pressure' from the majority.	
Laggards • sceptics	Traditional; Point of reference is 'the good old days'; Actively resists innovations	Economic/ power interest different from status quo?

Figure 19 „Who will buy and why“[28]

4 Recommendations

Working in the field of renewable energy and energy efficiency it is very obvious that it must be dealt with many different topics and issues to find a good and appropriate solution. In the following these crucial parts are distinguished into environmental, technical, economic and social ones.

4.1 Environmental recommendations

Environmental and climate conditions seem to be very obvious but often not taken into consideration when dealing with energy efficiency and renewable energy technologies. Planning a low energy or even “zero-energy-cost” house requires the consideration of site specific temperatures, heating degree days, solar irradiation, and geographical parameters.

[28] Idem

4.2 Technical recommendations

In the framework of this Master thesis some parts of the technical design and planning of a so called "zero-energy-cost" House are discussed. At the same time it became very clear that crucial parts are not thought through in detail and must be developed in the following work to do.

The most crucial parts are:

- Building structure: first of all the building standard must be optimised and only the impossibly covered energy demand is to be delivered by the integration of renewable energy technologies.
- Optimisation of heating system: floor heating system always favoured because of the low temperature operation mode
- Integration of solar thermal: when dealing with energy efficient building standards it has to be evaluated, if the use of heat pump in combination with heat pump is feasible and economically interesting.
- Optimisation of energy system, solar thermal, heat pump and photovoltaic: this thesis deals with one version of the possible energy supply system for the "zero-energy-cost" House. Other possibilities are to be evaluated for the optimisation for specific applications and conditions.
- Energy management: for an energy efficient operation of all involved system components of a "zero-energy-cost" House it is feasible to integrate a energy management system for the control and regulation of energy flows of the building.
- Cooling system: in some regions of South Europe the heating demand of a building is negligible but the cooling demand plays an important role in the design of energy supply systems.

4.3 Economical recommendation

The applied calculation method for achieving the "zero-energy-cost" Master-House gives a first impression of the market potential of the presented solution. For the successful market development a marketing and communication concept must be generated, which deals with country specific issues, as energy prices, infrastructure and energy markets.

When introducing solar thermal the calculation must be enlarged and changed for indicating correctly the benefits of this system to the whole system. Moreover the version with cooling demand has to be developed and evaluated.

4.4 Social recommendation

Products and ideas of everyday relevance help to position the energy and sustainability discussion, where the political and economic decisions happen - into the mainstream, into bulk consumption. A diffusion of innovations is successful when it offers clear steps to follow and understandable examples.

5 Conclusion

The core objective of this Master thesis, realising the “zero-energy-cost” house or “energy independent building” and the hypothesis of verifying the realistic solution for the actual energy discussion are both positively fulfilled. With state of the art building standard and the clever combination of energy efficient building components and renewable energy technology it is possible to live in a house, which satisfies the needed energy demand by its own without causing environmental damage and being independent of future energy price increases.
The open questions to be answered in the following years are a strategy for the successful and fast market introduction of these ideas, which will be a market benefit for innovative companies.

6 Acknowledgements

First I would like to thank the Company REHAU© in general, in special my boss Mr. Ing. Mag (FH) Nico Maierhofer and the business unit leader of the Building technology department Mr DI. Jörg Eberhardt for the support and the possibility of attending the MSc Program and writing the Master Thesis.
Thank you for the input, ideas and discussion.
Furthermore I am deeply grateful for being granted the permission for using the data of the real existing building by the owner.
I also want to thank my supervisor Mr. DI Thomas Lewis for his efforts, ideas and interest in the topic and that it was possible to have a flexible and open communication.

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8 Annex

Nominal heat load calculation of Master-House REHAU RAUWIN© Version 3.60

Datasheet Photovoltaic Module SOLON P220/6+

Datasheet Photovoltaic inverter KACO Powador 5000xi

Datasheet Solar battery OPzV 2900

"Photovoltaic Geographical Information System" PVGIS
http://re.jrc.ec.europa.eu/pvgis/index.htm

Norm-Heizlast

ÖNORM H 7500/ EN 12831

Gebäudedaten

Formblatt G1

Kenngrößen

Gebäudetyp

Einfamilienhaus

Gebäudelage

- ☐ gute Abschirmung
- ☒ moderate Abschirmung
- ☐ keine Abschirmung

Gebäudemassen

- ☒ leicht
- ☐ mittelschwer
- ☐ schwer

c_{wirk} = Wh/m³K
(optionale Angabe aus DIN V 4108-6)

Luftdichtheit der Gebäudehülle

- ☒ sehr dicht
- ☐ dicht
- ☐ wenig dicht

Temperaturen

Norm-Außentemperatur	θ_e	=	-16 °C
Jahresmittel der Außentemperatur	$\theta_{m,e}$	=	8.0 °C

Innentemperaturen gemäß
☐ Norm ☒ Vereinbarung s. Formblatt V

Geometrie

Breite	b_{Geb}	=	12.90 m	Anzahl Geschosse	n	=	3 -
Länge	l_{Geb}	=	13.00 m	Gebäudehöhe	h_{Geb}	=	11.50 m
Grundfläche	A_{Geb}	=	167.70 m²	Gebäudevolumen	$V_{e, Geb}$	=	1023.00 m³

Erdreich

Tiefe der Bodenplatte*	z	=	2.80 m	Grundwassertiefe	T	=	5.00 m
Erdreich berührt.Umfang*	P	=	51.80 m	Faktor period. Schwankung	f_{g1}	=	1.45 -
Parameter*	B'	=	6.47 m	Faktor Einfluss Grundwasser	G_W	=	1.00 -

*) Werte können raumweise abweichen

Lüftung

Luftwechselrate bei 50 Pa Druckdifferenz	n_{50}	=	3.00 h⁻¹
Gleichzeitig wirksamer Lüftungswärmeanteil Infiltration	ζ_{inf}	=	0.50 -
Gleichzeitig wirksamer Lüftungswärmeanteil minimaler Luftwechsel	ζ_{min}	=	1.00 -
Gleichzeitig wirksamer Lüftungswärmeanteil maschinelle Lüftung	ζ_{su}	=	1.00 -
Gleichzeitig wirksamer Lüftungswärmeanteil mechanische Infiltration	$\zeta_{mech, inf}$	=	1.00 -
Wirkungsgrad des verwendeten Wärmerückgewinnungssystems (Herstellerangabe)	η_V	=	0.00 -

Zusatz- Aufheizleistung (durch unterbrochenen Heizbetrieb)

Berechnung

- ☒ keine
- ☐ raumweise
- ☐ global

beheiztes Volumen $V_{N, Geb}$ = 923.57 m³
Wärmeverlustkoeffizient $\Sigma H_{T, Geb}$ = 198.52 W/K

Absenkphase

Absenkdauer	t_{Abs}	=	7.00 h
Luftwechsel	n_{Abs}	=	0.10 h⁻¹

Temperaturabfall ☒ berechnet ☐ angenommen

$\Delta\theta_{RH}$ = 3.95 K

Aufheizphase

Wiederaufheizzeit	t_{RH}	=	2.00 h
Luftwechsel	n_{RH}	=	0.10 h⁻¹

Wiederaufheizfaktor f_{RH} = **19.74 W/m²**

Norm-Heizlast

ÖNORM H 7500/ EN 12831

Gebäudezusammenstellung

Formblatt G3

Wärmeverlust-Koeffizienten

Transmissionswärmeverlust-Koeffizient	$\Sigma H_{T, e}$	=	198.52	W/K
Lüftungswärmeverlust-Koeffizient	ΣH_V	=	196.97	W/K
Gesamtwärmeverlust-Koeffizient	H_{Geb}	**=**	**395.49**	**W/K**

Wärmeverluste

Transmissionswärmeverluste (nur nach außen)	$\Phi_{T, Geb}$		**=**	**7306**	**W**
Mindest-Luftwechsel	$\Phi_{V, min, Geb}$	$= \zeta_{min} * \Sigma\Phi_{V, min}$	=	7254	W
natürliche Infiltration ohne RLT	$\Phi_{V, inf, Geb}$	$= \zeta_{inf} * \Sigma\Phi_{V, inf}$	=	719	W
mech. belüftete Räume					
- natürliche Infiltration mit RLT	$\Phi_{V, inf, Geb}$	$= \zeta_{inf} * \Sigma\Phi_{V, inf}$	=	0	W
- mechanischer Zuluftvolumenstrom	$\Phi_{V, su, Geb}$	$= \zeta_{su} * (1-\eta_V) * \Sigma\Phi_{V, su}$	=	0	W
- Abluftvolumenüberschuss	$\Phi_{V, mech, inf, Geb}$	$= \zeta_{mech, inf} * \Sigma\Phi_{V, mech, inf, Geb}$	=	0	W
Lüftungswärmeverluste	$\Phi_{V, Geb}$		**=**	**7254**	**W**

Lüftung

Luftwechselrate bei 50 Pa Druckdifferenz	n_{50}	=	3.00	h^{-1}
Gleichzeitig wirksamer Lüftungswärmeanteil Infiltration	ζ_{inf}	=	0.50	-
Gleichzeitig wirksamer Lüftungswärmeanteil minimaler Luftwechsel	ζ_{min}	=	1.00	-
Gleichzeitig wirksamer Lüftungswärmeanteil maschinelle Lüftung	ζ_{su}	=	1.00	-
Gleichzeitig wirksamer Lüftungswärmeanteil mechanische Infiltration	$\zeta_{mech, inf}$	=	1.00	-
Wirkungsgrad des verwendeten Wärmerückgewinnungssystems (Herstellerangabe)	η_V	=	0.00	-

Gebäudeheizlast

Netto-Heizlast	$\Phi_{N, Geb}$	**=**	**14561**	**W**
Zusatz-Heizlast (für selten oder unterbrochen beheizte Räume)	$\Phi_{RH, Geb}$	**=**	**0**	**W**
Norm-Gebäudeheizlast	$\Phi_{HL, Geb}$	**=**	**14561**	**W**

Spezifische Werte

Beheizte Gebäudenutzfläche	$A_{N, Geb}$	=	347.77 m^2	$\Phi_{HL, Geb}$	=	41.87 W/m^2
Beheiztes Netto-Gebäudevolumen	$V_{N, Geb}$	=	923.57 m^3	$\Phi_{HL, Geb}$	=	15.77 W/m^3
wärmeübertragende Umfassungsfläche	A	=	646.49 m^2			
Spezifischer Transmissionswärmeverlust				H'_T	=	**0.31 W/m^2K**

SOLON P220/6+

Mechanical specifications

Length:	1,660 mm
Width:	990 mm
Height:	42 mm
Weight:	26 kg
Junction box:	A SOLON junction box with bypass diodes
Cable:	Solar cable, length 1,100 mm, 4 mm^2, prefabricated with MC plug
Front glass:	White toughened safety glass, 4 mm
Cells:	60 pc. polycrystalline Si 6.2˝ (156 x 156 mm)
Cell encapsulation:	EVA (Ethylene-Vinyl-Acetate)
Back:	Tedlar composite film
Frame:	Anodised aluminium profile
Dimensions of the frameless module:	1,653 x 983 x 5 mm (L x W x H)

Electrical specifications (typical)

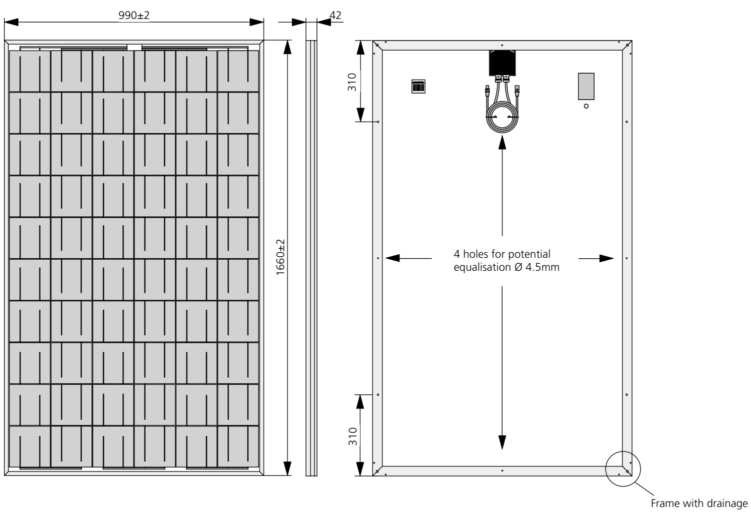
Module class/peak power Pmax (± 3 %):	235 W_p	230 W_p	225 W_p	220 W_p	215 W_p	210 W_p	205 W_p	200 W_p
Rated voltage Umpp:	29,0 V	28,9 V	28,8 V	28,7 V	28,5 V	28,2 V	28,0 V	27,75 V
Rated current Impp:	8,1 A	7,95 A	7,8 A	7,65 A	7,55 A	7,45 A	7,3 A	7,2 A
Open circuit voltage Uoc:	36,9 V	36,8 V	36,5 V	36,4 V	36,3 V	36,1 V	35,9 V	35,5 V
Short circuit current Isc:	8,7 A	8,6 A	8,5 A	8,3 A	8,2 A	8,1 A	8,05 A	7,8 A
Maximum system voltage:	860 V	860 V	860 V	860 V	860 V	860 V	860 V	860 V
Module efficiency:	14,3 %	14,0 %	13,7 %	13,4 %	13,1 %	12,8 %	12,5 %	12,2 %

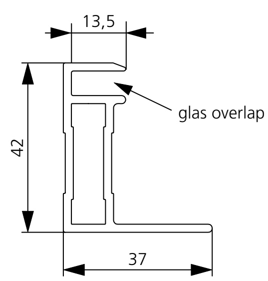
Temperature coefficient of open circuit voltage: -0.35 %/K
Temperature coefficient of short circuit current: 0.05 %/K
Temperature coefficient of power: -0.44 %/K

These values are effective for irradiation of 1,000 W/m^2, AM 1.5, and a cell temperature of 25 °C (standard test conditions). The modules can be delivered with their respective data sheets upon request.

Operating conditions

Temperature range:	-40 °C to +85 °C
Hail:	maximum diameter of 28 mm with impact speed of 86 km/h
Maximum surface load capacity:	tested up to 5,400 Pa according to IEC 61215 (advanced test)





Detailed information please take from our assembly notes issued on our homepage www.solon-pv.com.
Last revised: 11/2006. Subject to change, no claims made for accuracy of electrical data

Input – Electrical data

Type	Powador 4000xi	Powador 4500xi	Powador 5000xi
Max. PV generator power	5250W$_p$	6000W$_p$	6800W$_p$
MPP range	350 - 600V$_{DC}$		
No-load voltage	up to 800V$_{DC}$		
Monitoring - input voltage	Stand-by from U_e>300V$_{DC}$ Night shutdown from U_e<250V$_{DC}$		

Output – Electrical data

Continuous rated power	4400 W$_{AC}$	4600 W$_{AC}$	5500 W$_{AC}$
Max. power	4800 W$_{AC}$	5060 W$_{AC}$	6000 W$_{AC}$
Grid voltage	190 ... 254V (according to EN50160) Safety shut-down: 190 - 264V within 0,2s		
Max. current	20,9 A	22,0 A	26,0 A
Frequency	47,5 - 50,2 Hz		

Solar inverter - Electrical data

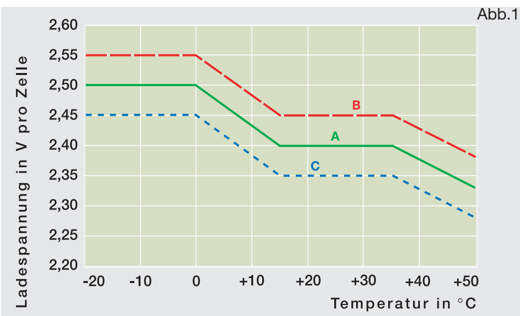
Max. degree of efficiency	96,3%	96,3%	96,3%
European degree of efficiency	94,4%	95,5%	94,5%
Internal power consumption	Night shutdown: 0W Operation: 6W		
Min. grid-feeding capacity	30W	40W	40W
Temperature monitoring	>75°C temperature-dependent adjustment of capacity >85°C disconnection from grid		
Circuit concept	Grid-tied, transformerless		
Clock frequency	18kHz		
Principle	Single-phase full bridge in IGBT technology		
Grid monitoring	Redundant 3-phase monitoring according to VDE 0126-1-1:2006-02		

Solar inverter – Mechanical and technical data

Optical displays	PV generator (green) Grid-feeding (green) Disturbance (red) Illuminated LC display (2 x 16 characters)		
Operating elements	2 keys for display operation		
Connections	PCB terminals inside the inverter (max.cross section 10mm²) Cable connections via PG-type fittings (DC-connection M16, AC-connection M32)		
Ambiente temperature	-20°C ... +40°C		
Temperature monitoring	>75°C temperature-dependent adjustment of capacity >85°C disconnection from grid		
Cooling	Free convection (no fan or blower)		
Protection	IP54 according to EN 60529:1991+A1:2000		
Noise emission	< 35dB (noiseless)		
Enclosure	Aluminum – wall enclosure		
Dimensions W x D x H	340 x 220 x 550	340 x 220 x 600	340 x 200 x 600
Weight	26 kg	28 kg	29,4 kg

Typ	Nenn-spannung V	Nenn-kapazität C_{100} 1,85 V/Z Ah	Ent-ladestrom I_{100} A	Länge (l) max. mm	Breite (b/w) max. mm	Höhe bis Deckel-oberkante (h1) max. mm	Höhe inkl. Verbinder (h2) max. mm	Bau-länge (B/L) mm	Gewicht ca. kg	An-schluss	Pol-paare
*6 OPzV 360	2	360	3,6	147	208	360	398	155	28,0	F-M8	1
*5 OPzV 400	2	400	4,0	126	208	475	513	135	31,0	F-M8	1
*6 OPzV 500	2	500	5,0	147	208	475	513	155	36,5	F-M8	1
*7 OPzV 600	2	600	6,0	168	208	475	513	175	42,0	F-M8	1
*6 OPzV 720	2	720	7,2	147	208	650	688	155	50,0	F-M8	1
*8 OPzV 960	2	960	9,6	215	193	650	688	220	68,0	F-M8	2
*10 OPzV 1200	2	1200	12,0	215	235	650	688	220	82,0	F-M8	2
*12 OPzV 1400	2	1400	14,0	215	277	650	688	220	97,0	F-M8	2
*12 OPzV 1700	2	1700	17,0	215	277	800	838	220	120,0	F-M8	2
*16 OPzV 2300	2	2300	23,0	215	400	775	815	220	160,0	F-M8	3
*20 OPzV 2900	2	2900	29,0	215	490	775	815	220	200,0	F-M8	4
*24 OPzV 3500	2	3500	35,0	215	580	775	815	220	240,0	F-M8	4

* Nicht Lagernd (2-8 Wochen)



Ladeverfahren (zu Abb.1):

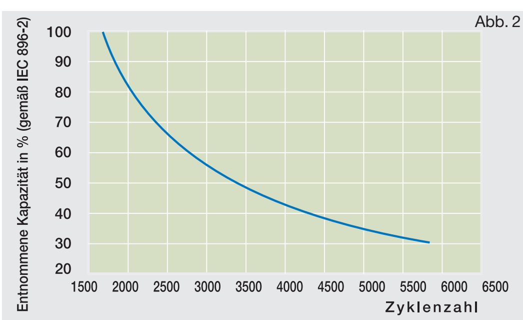
1.) mit Umschalter (2-Punkt Regler)
 - Laden an Kurve **B** (max. Ladespannung) für max. 2h/Tag dann Umschaltung auf Dauerladen - Kurve **C**

2.) Standardladung (ohne Umschaltung) - Kurve **A**

3.) Starkladung (Ausgleichsladung mit externem Generator)
 - Laden an Kurve **B** für max. 5h/Monat, dann Umschaltung auf Kurve **C**

Kapazitäten C_1 – C_{100} (20°C)

Typ	C_1 1,67 V/Z	C_3 1,75 V/Z	C_5 1,77 V/Z	C_{10} 1,80 V/Z	C_{100} 1,85 V/Z
6 OPzV 360	162	227	263	300	360
5 OPzV 400	180	252	292	350	400
6 OPzV 500	225	315	365	420	500
7 OPzV 600	270	378	438	490	600
6 OPzV 720	324	454	526	600	720
8 OPzV 960	432	605	701	800	960
10 OPzV 1200	540	756	876	1000	1200
12 OPzV 1400	630	882	1022	1200	1400
12 OPzV 1700	765	1071	1241	1500	1700
16 OPzV 2300	1035	1449	1679	2000	2300
20 OPzV 2900	1305	1827	2117	2500	2900
24 OPzV 3500	1575	2205	2555	3000	3500



(zu Abb. 2)
Haltbarkeit in Zyklen nach IEC 896-2

Estimation of PV electricity generation for the chosen location

Modify the parameters of your PV installation and click the "Submit" button. [help]

PV technology: Crystalline silicon

Enter installed peak PV power 1 kWp

Estimated system losses (%) [0.0:100.0] 14.0

Module inclination [0,90] 45 deg.

Module orientation [-180;180] (E:-90 S:0) 0 deg.

- (•) Use given inclination and orientation
- ( ) Find optimal inclination for given orientation
- ( ) Find optimal inclination and orientation

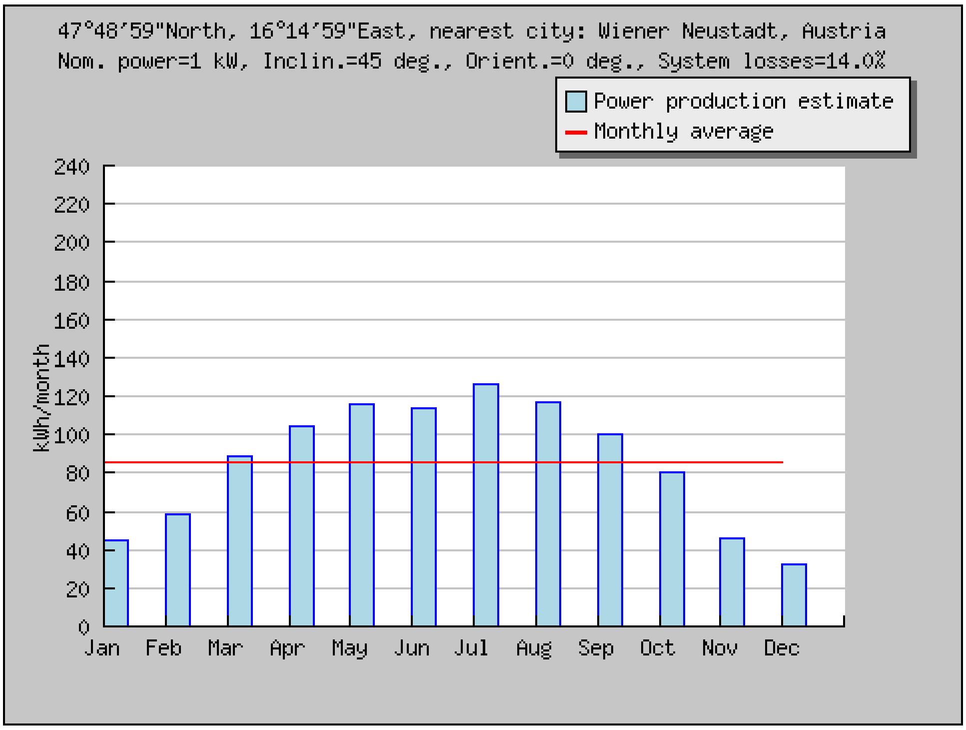
- [ ] Show performance for 2-axis tracking system
- [ ] Show horizon outline graph
- [ ] Show also the in-plane irradiation

Click to confirm your choice Submit

Location: 47°48'59" North, 16°14'59" East, Elevation: 262 m a.s.l,
Nearest city: Wiener Neustadt, Austria (1414108 km away)

Nominal power of the PV system: 1.0 kW (crystalline silicon)
Inclination of modules: 45.0°
Orientation (azimuth) of modules: 0.0°
Estimated losses due to temperature: 7.0% (using local ambient temperature data)
Estimated loss due to angular reflectance effects: 2.8%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 23.8%

This graph and table show the (estimated) amount of electric power you can expect each month from a PV system with the properties you entered (using optimal inclination and orientation, if you requested so). It also shows the expected average daily and yearly production.



PV electricity generation for: Nominal power=1.0 kW, System losses=14.0%		
	Inclin.=45 deg., Orient.=0 deg.	
Month	**Production per month (kWh)**	**Production per day (kWh)**
Jan	45	1.4
Feb	59	2.1
Mar	89	2.9
Apr	105	3.5
May	116	3.7
Jun	114	3.8
Jul	126	4.1
Aug	116	3.8
Sep	100	3.3
Oct	80	2.6
Nov	46	1.5
Dec	32	1.0
Yearly average	**86**	**2.8**
Total yearly production (kWh)	**1027**	