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MSc Program
Renewable Energy in Central & Eastern Europe

Pellet fired stirling engine – CHP system Feasibility study for a multiple-family house in Styria/Austria

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

supervised by
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Graz, 2008

Affidavit

I, **Mag. Dr. Ralf Hasler**, hereby declare

1. that I am the sole author of the present Master Thesis, "Pellet fired stirling engine CHP – system Feasibility study for a multiple-family house in Styria/Austria", 72 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.

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Abstract

This master thesis describes a CHP – system with the labelling Sunmachine Pellet as an example of a pellet fired stirling engine. In addition a feasibility study of the pellet fired stirling engine – CHP is worked out analysing the technical, economical and legal boundary conditions of the Sunmachine Pellet system for a multiple-family house in Styria/Austria.

The feasibility study demonstrates that the Sunmachine Pellet can cover the annual energy demand for space heating and for hot water preparation for the multiple-family house and would produce up to 10302 kWh/a electricity out of the annual heat demand of the building of 36060 kWh/a. Also it is shown in this study that the annual costs and cumulated costs of the CHP – system are strongly influenced by the annual costs of service and maintenance and the market price for electricity whereas higher market prices for electricity lead to higher cost reductions if the generated electrical power is consumed fully within the multi-storey residential building and lower annual service and maintenance costs would reduce the annual and cumulated costs of the CHP – system.

As the Sunmachine Pellet is a very young product there are no figures available about costs for maintenance and service and lifetime of this engine which causes a serious risk for the whole investment. Another element of uncertainty is the price development of wood pellet which doubled e.g. in Austria in 2006 caused by a strong demand. Due to the fact that the statutory single or general approval for being allowed to install the pellet fired stirling engine – CHP in the Province of Styria is still not available it is not possible to install and run a Sunmachine Pellet unit for buildings of private use or commercial facilities within the area of the Province of Styria up to now.

Pellet fired stirling engine – CHP system Feasibility study for a multiple-family house in Styria/Austria

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1. Introduction

Currently more than 80 % of the total world energy demand is covered by fossil fuels like natural gas, crude oil or coal. Beside the fact that fossil fuels are limited resources on earth and will run out during the next decades the usage of fossil fuels is also responsible for negative environmental impacts. The most popular negative environmental impact is the green house effect which is made responsible for the world wide increase of temperatures and climate changes.

Nuclear energy, which covers more than 5 % of world energy requirement, can not be an alternative to cover the world wide growing demand of energy as long as the risks involved with this technology and questions of disposal are not solved satisfactorily.

As a consequence of these considerations a long term alternative might be the increased usage of renewable energies like hydropower, wind energy, biomass, solar energy or geothermal energy.

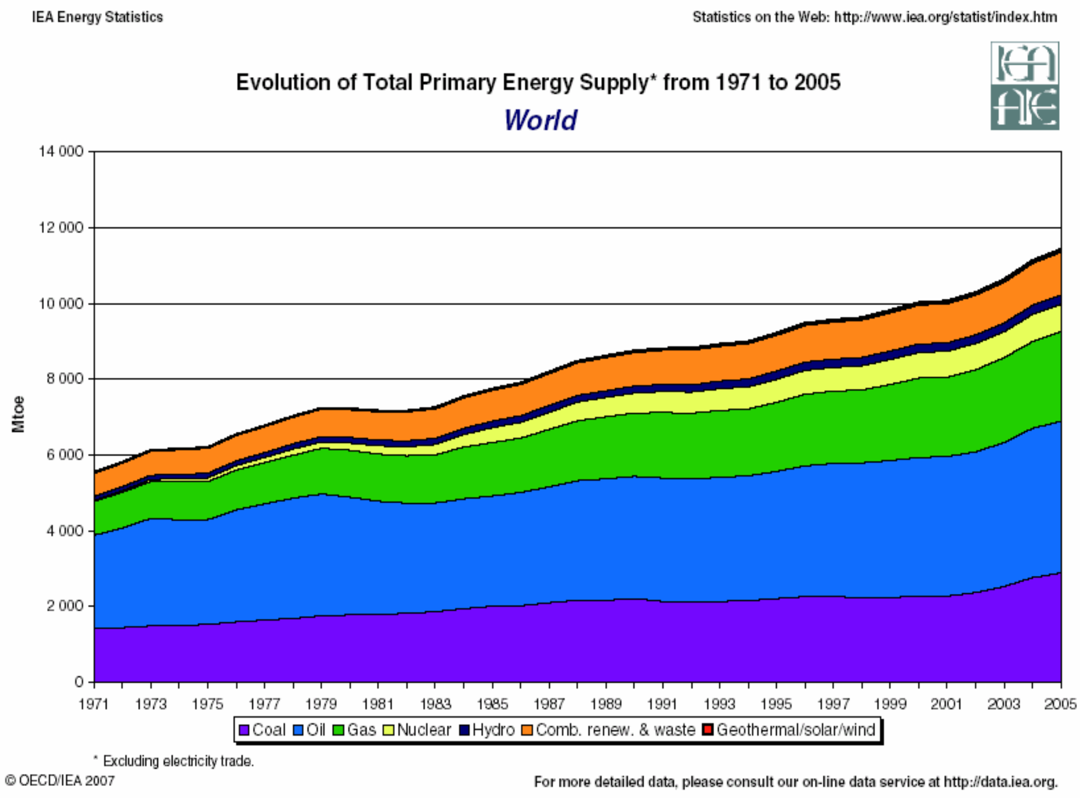

Figure 1[1]: Evolution of Total Primary Energy Supply from 1971 to 2005

[1] http://www.iea.org/statist/index.htm, accessed June 15th, 2008.

In Austria the share of renewable energies of the total primary energy supply is consequently increasing since 1970. In 2001 renewables represented 22.65 % of the total primary energy supply in Austria. Figure 2 illustrates the final energy supply in Austria in the year 2006 considering different energy sources.

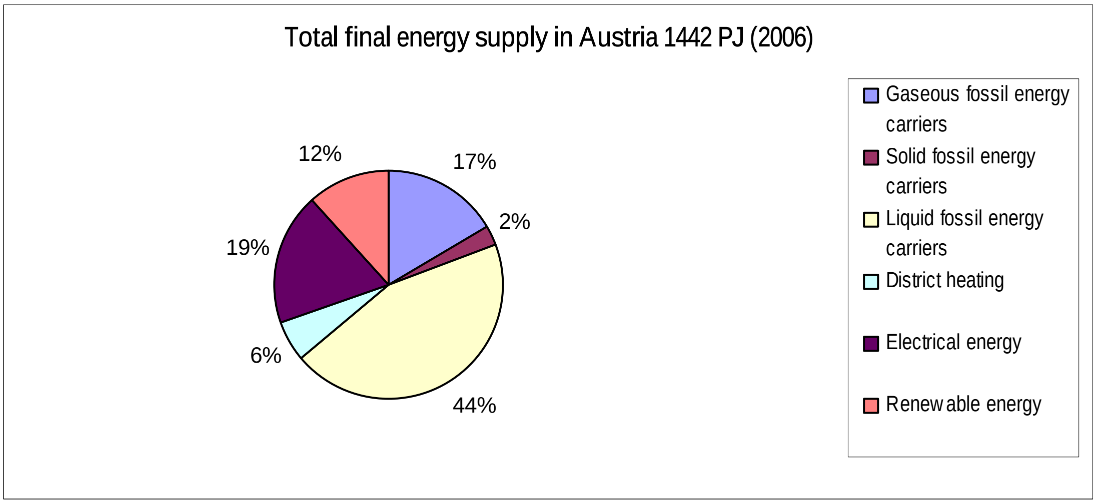

Figure 2[2]**:** Total final energy supply in Austria (2006).

As figure 3 points out hydropower by 11.6 % is the most significant renewable energy source in Austria followed by biomass which has among the remaining 11 % the second highest market share.

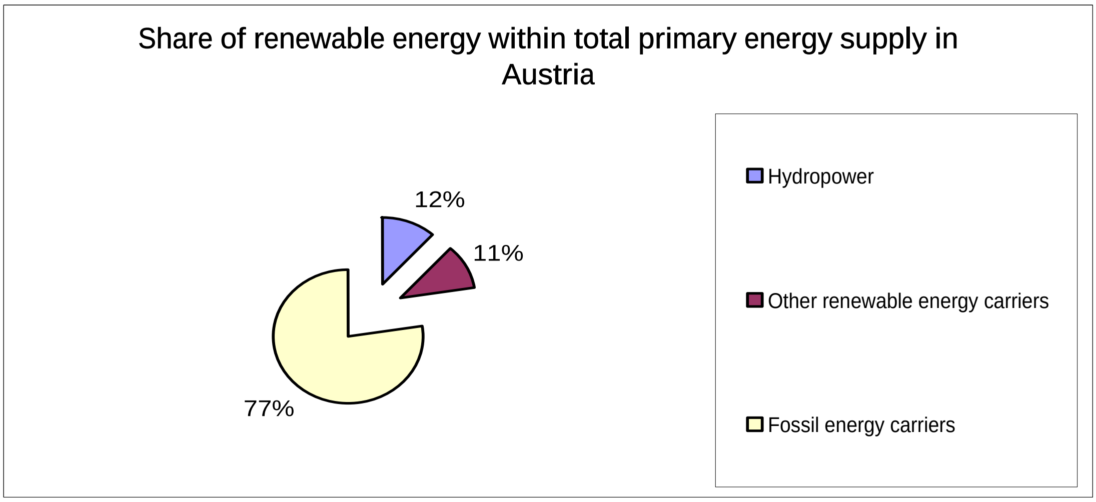

Figure 3[3]**:** Share of renewable energy within total primary energy supply in Austria.

[2] http://www.umweltbundesamt.at/umweltschutz/energie/energie_austria/accessed June 15th, 2008.
[3] http://www.energyagency.at/ accessed June 15th, 2008.

Considering the fact that the increased use of wood pellets can contribute to expand the share of renewable energies on the total primary energy supply in Austria this master thesis focuses on a new, innovative technology which allows the production of electrical power from pellets in addition to heat using a stirling engine in combination with a pellet fired heating system.

Therefore the aim of this master thesis is to outline the ecological and economical advantages of small scale pellet fired central heating systems and small scale stirling engines on one hand and to analyse a CHP-system combining these two technologies on the other hand.

2. Pellet fired central heating systems:

2.1. Ecological and economical advantage of the use of pellets as fuel

Wood pellets are a type of wood fuel which are produced as a byproduct of sawmilling and other wood transformation activities under high pressure. As binding material organic additives like rye flour are used. Therefore pellets are extremely dense and have a high calorific value of about 4.9 kWh/kg[4] which corresponds approximately to the calorific value of half a litre of heating oil. As one result of the high density wood pellets can be transported easily over long distances and can be blown from a tanker to a storage bunker or silo by using a flexible tube. Once placed in the storage bunker or silo wood pellets can be transported to a burner by auger feeding or by pneumatic conveying.

Due to the fact that wood pellets consist of nearby 100% of wood the usage of this fuel is almost CO_2 neutral. During the combustion process of wood pellets only that amount of CO_2 is produced which was bound by the growing trees during their lifetime and will be absorbed by plants again[5].

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[4] Fachagentur Nachwachsende Rohstoffe (2006), p. 22.
[5] Fachagentur Nachwachsende Rohstoffe (2006), p. 8.

The combustion of wood pellets emits much less carbon monoxide with modern heating systems especially during the part-load operational range and dust than the combustion of wood chips or split logs[6].

In comparison to other heating fuels like natural gas or heating oil wood pellets have a minimum risk of transport and storage. For example environmental damages caused by leakage in oilpipelines or oil tanks are not possible. Further more there is no risk of explosion or contamination of ground water caused by storing wood pellets[7].

Beside these above mentioned ecological benefits there are also some important economical advantages caused by the usage of wood pellets.

Due to the fact that wood pellets are a byproduct of sawmilling and other wood transformation activities wood pellets can be produced within the local region using regional raw material[8].

The high energy density of wood pellets makes it possible to store wood pellets cheaper than some other types of biomass like e.g. wood chips or split logs.

The usage of wood pellets as product of regional raw material creates new jobs in forestry, business, industry and trade within a region.

The price for wood pellets does not correspond to the price of oil and gas because wood is a renewable raw material whereas oil and gas as fossil fuels are limited rescources which will run out during the coming decades[9].

2.2. Technical design of pellet fired heating systems

Modern pellet fired heating systems are an interesting and environmental friendly alternative to oil or gas fired central heating systems. They can be installed in new buildings or within old buildings using already existing hydraulic components.

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[6] Fachagentur Nachwachsende Rohstoffe (2006), p. 13.
[7] Fachagentur Nachwachsende Rohstoffe (2006), p. 8.
[8] Fachagentur Nachwachsende Rohstoffe (2006), p. 11.
[9] Fachagentur Nachwachsende Rohstoffe (2006), pp. 11,12.

The heart of a pellet fired central heating system is the pellet boiler which is installed in the central heating room. Also other hydraulic installations are normally placed in this room like buffer tank, expansions vessel, electronically steering or circulation pumps.

A buffer tank helps to reduce the number of starts of the pellets boiler and allows the boiler to run longer under full load which reduces emissions and increases the efficiency and the life time of the heating system[10].

The fuel for the wood pellet fired heating system is transported to the boiler from a storage room, underground tank or a textile silo by using an auger or a vacuum suction in combination with a siphon pipe.

The advantage of using vacuum siphon pipe is that the storage room for wood pellets can be situated up to 20 m beside the central heating room inside or outside the building. The disadvantage of this kind of transportation is that it is much noisier than the usage of an auger.

An optimized storage tank should be able to store wood pellets for one year of heating demand so that the tank would be needed to be filled up only once a year. 0.9 m^3 storage room is needed for one kW heat load by rule of thumb[11].

3. Stirling engines

3.1. Ecological and economical advantage of stirling engines

A stirling engine is a piston engine which is driven by external heat supply whereas an encased working gas is heated up indirectly from outside through a heat transfer area[12]. The encased working gas is permanently heated up and cooled down whereby mechanical energy is produced at a balance wheel. Waste heat and mechanical energy are usable in many ways whereas e.g. mechanical energy can be transferred to eletricity by using an alternator[13].

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[10] Fachagentur Nachwachsende Rohstoffe (2002), p. 57.
[11] Fachagentur Nachwachsende Rohstoffe (2006), p. 11.
[12] Zahoransky (2007), p. 159.
[13] Fachagentur Nachwachsende Rohstoffe (2002), p. 67.

Herein already lies an important ecological advantage of stirling engines because any fuel for heating up stirling engines is eligible. Therefore also renewable fuels like solar energy or biomass can be used for driving a stirling engine[14].

Also regarding economical aspects stirling engines have some specific benefits as e.g. stirling engines can reach higher efficiency during partial load in comparison with other combustion engines[15].

Another economical advantage of stirling engines also might be that the technology is suitable for multiple applications like for CHPs, for engines of boats and submarines or for cooling[16].

Caused by the fact that stirling engines have a sealed off crankcase, work with few vibrations and oil-free maintenance requirements are low in comparison with other combustion engines.

Due to the sealed off crankcase also pressure peaks within the combustion chamber do not exist which increases the lifetime of stirling engines, allows lightweight construction of the gearboxes and reduces vibrations of the engine[17].

Beside these above mentioned advantages stirling engines have some typical disadvantages like the high weight of most of the engines, the need of a large heat exchanger, a high operating pressure and problems with gas leakage and tightness[18].

3.2. Technical design of stirling engines

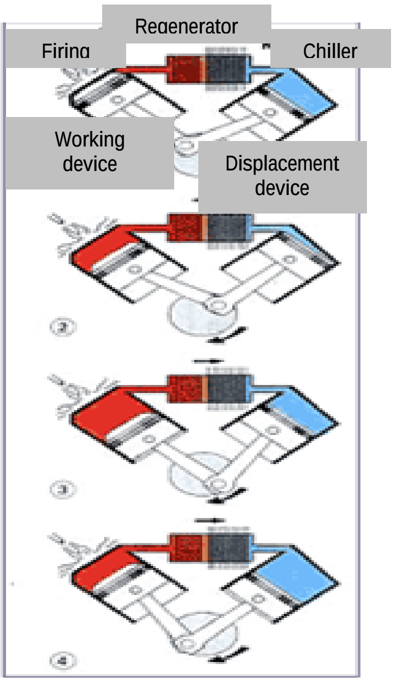
As it was already described above a stirling engine is a piston engine which is driven by external heat supply. An encased gas called the "working fluid" which is most commonly air, hydrogen or helium is permanently heated up and cooled down the

[14] Zahoransky (2007), p. 159; Werdich/Kübler (2005), p. 37.
[15] Werdich/Kübler (2005), p. 37.
[16] Werdich/Kübler (2005), pp. 94.
[17] Werdich/Kübler (2005), p. 37.
[18] Werdich/Kübler (2005), p. 144.

expansion and contraction of which produces mechanical energy which can be transferred to electricity by using an altanator[19].

The stirling engine working cycle consists of four main processes: Heating and expansion on one side and cooling and compression on the other side. These processes happen by moving the working fluid back and forth between hot and cold areas of the engine. Thereby the stirling engine uses the temperature difference between its hot end and cold end to establish a continuous working cycle transforming thereby thermal energy into mechanical energy. The greater the difference of temperature between the hot and cold areas of the stirling engine is the greater is the thermal efficiency[20].

There exists a multitude of different designs of stirling engines on the market and it would go beyond the scope of this master thesis to discuss all these different designs[21]. Picture 1 below shows a stirling engine operation of simple design.



Picture 1[22]: Working schematic of a stirling engine

Phase 1:
The displacement device (right) moves upwards and presses the encased cold gas (blue marked area) into the hot working device.

Phase 2:
The encased gas called „working fluid“ is heated up within the working device (red marked area) and expands whereas the working device is pressed downwards.

Phase 3:
The hot gas flows to the displacement device passing the regenerator and the cooling device whereas the gas is cooled down.

Phase 4:
The working device moves upwards whereas the gas is pressed from the working device to the displacement device. The cycle of four working phases is closed when the working device has reached its upper dead centre.

The working device and the displacement device are linked by a balance wheel and piston rods to guarantee a perfect interaction of these components.

19 Fachagentur Nachwachsende Rohstoffe (2002), p. 67.
20 Zahoransky (2007), pp. 159, 160.
21 Werdich/Kübler (2005), p. 17.
22 http://www.sunmachine.com/funktionsweise.htm, accessed June 15th, 2008.

When the displacement device moves to the right the hot working fluid needs to pass through the internal regenerator into the cold area of the engine. Thereby the working fluid is cooled down by heating up the regenerator and loosing temperature within the cold area of the engine. As a consequence the pressure drops and the working piston moves to the right. In the next step the displacement device with the regenerator is moved to the left side into the cold area of the engine. Now the cold working fluid needs to pass through the hot internal regenerator into the warm area of the engine being heated up by the regeneration and the warm area. As a consequence the pressure increases and the working piston moves to the left[23].

If the displacement device with the regenerator and the working device are connected via a gearbox and a balance wheel in the right power factor the system can be used to produce mechanical power[24].

4. Pellet fired stirling engine – CHP system

4.1. Ecological and economical advantage of a pellet fired stirling engine

The numerous ecological and economical advantages of the use of pellets on the one hand and of the stirling engines on the other hand were already pointed out in the chapters before. Of course these positive effects will occur also if a pellet fired heating system is used in combination with a stirling engine.

The very special and additional ecological advantage of this system is the environmental friendly combined production of heat and electricity. This is e.g. proven by a study of the Institute of Regional Planning and Habitation of Salzburg (SIR) which documents that pellet fired central heating systems provide the highest potential to reduce CO_2 emissions because these systems are CO_2 neutral[25]. For instance due to the fact that burning 1 l heating oil which corresponds to an energy content of 10 kWh produces 2.8 kg CO_2[26] the switch from an existing oil fired

[23] Werdich/Kübler (2005), p. 19.
[24] Werdich/Kübler (2005), p. 19.
[25] Brandl/Strasser (2007), p. 7.
[26] Bundesministerium für Wirtschaft und Arbeit (2004), p. 191.

heating system to a pellet fired central heating systems can reduce the CO_2 emissions for a single household by approximately 5 tons a year[27].

Nearby one third of the Austrian electricity production comes from non renewable sources like coal or gas power stations and the consumption of electricity in Austria still increases from year to year[28]. So a further reduction of CO_2 emissions can be reached by using waste heat of pellet fired central heating systems for producing CO_2-neutral electricity.

Considering the fact that a technical optimized combined production of heat and electricity increases the degree of efficiency of the whole system there are also multiple economical advantages.

As it was already mentioned before prices for fossil fuels increase steadily and the price gap between natural gas and heating oil on one side and pellets e.g. on the other side seems to become bigger and bigger as figure 4 below shows.

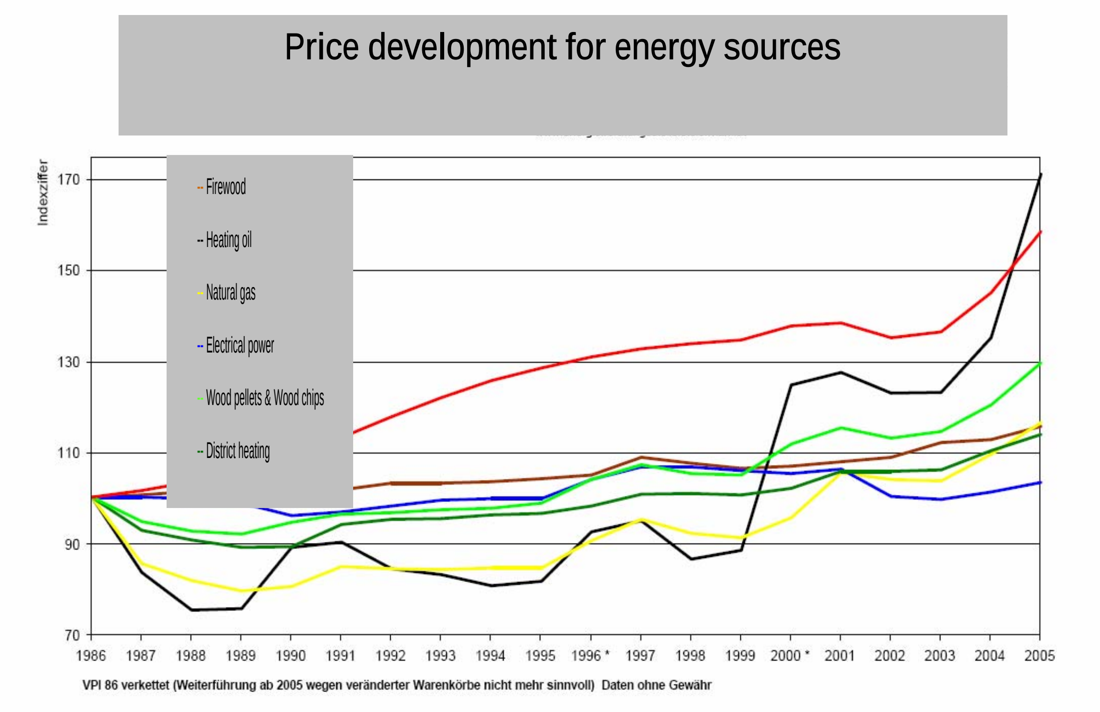


Figure 4[29]: Development of heating fuel market prices

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[27] Fachagentur Nachwachsende Rohstoffe (2006), p. 10.
[28] http://www.bmlfuw.gv.at/article/articleview/60336/1/1457, accessed October 17th, 2008.
[29] http://www.verwaltung.steiermark.at/cms/dokumente/10098710_2628249/23e1ddcf/I_Index%202000%20VPI%2076.pdf, accessed June 20th, 2008.

But market situations can change rapidly as it happened in Austria in 2006 when the price for wood pellets nearby doubled within a year. Meanwhile the price for wood pellets is approximately on the same level as it was before the enormous price increase in 2006 as it is indicated in figure 5.

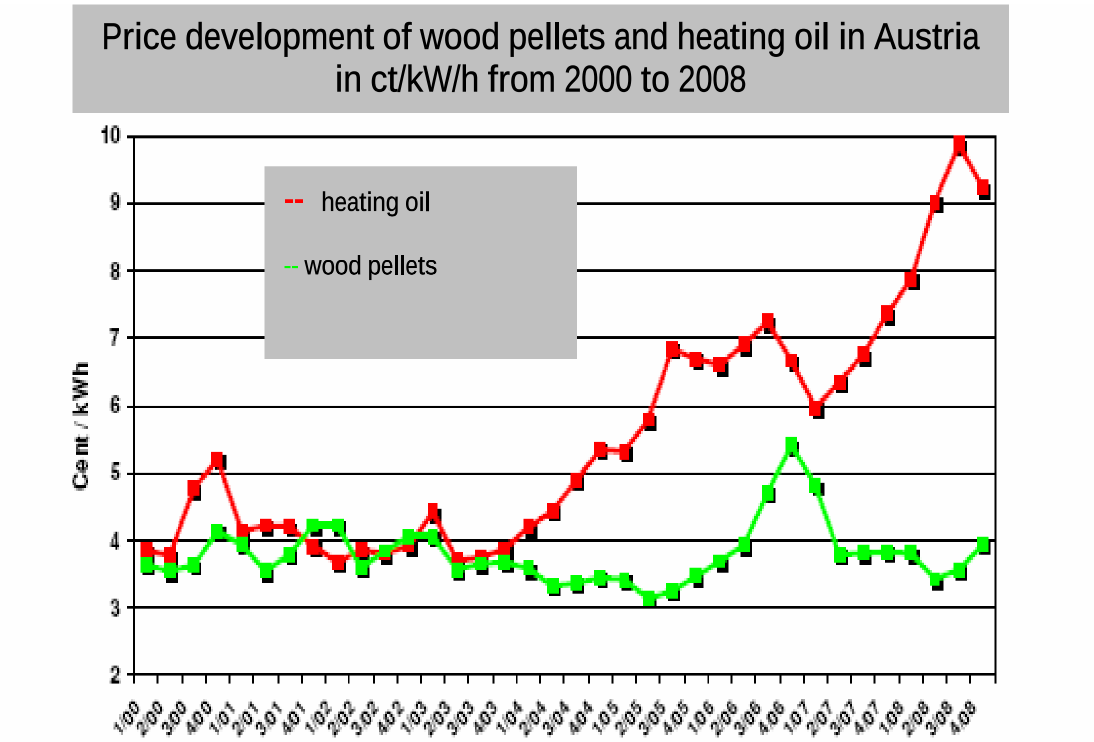

Figure 5[30]: Development of heating fuel market prices

As a result of the increasing energy prices heating becomes more and more expensive especially for heating systems based on fossil fuels.

Figure 6 shows via an example of an Austrian single family household that the operational heating costs per kWh (costs of investment and costs of service and additional operating costs are not included) would be approximately decreased by 40 % using a modern pellet fired boiler compared to a modern heating oil fired boiler. This would lead to savings of about Euro 552 per year.

30 http://www.propellets.at/images/content/pdfs/200810_quartalspreise_hel-p.pdf, accessed October 17th, 2008.

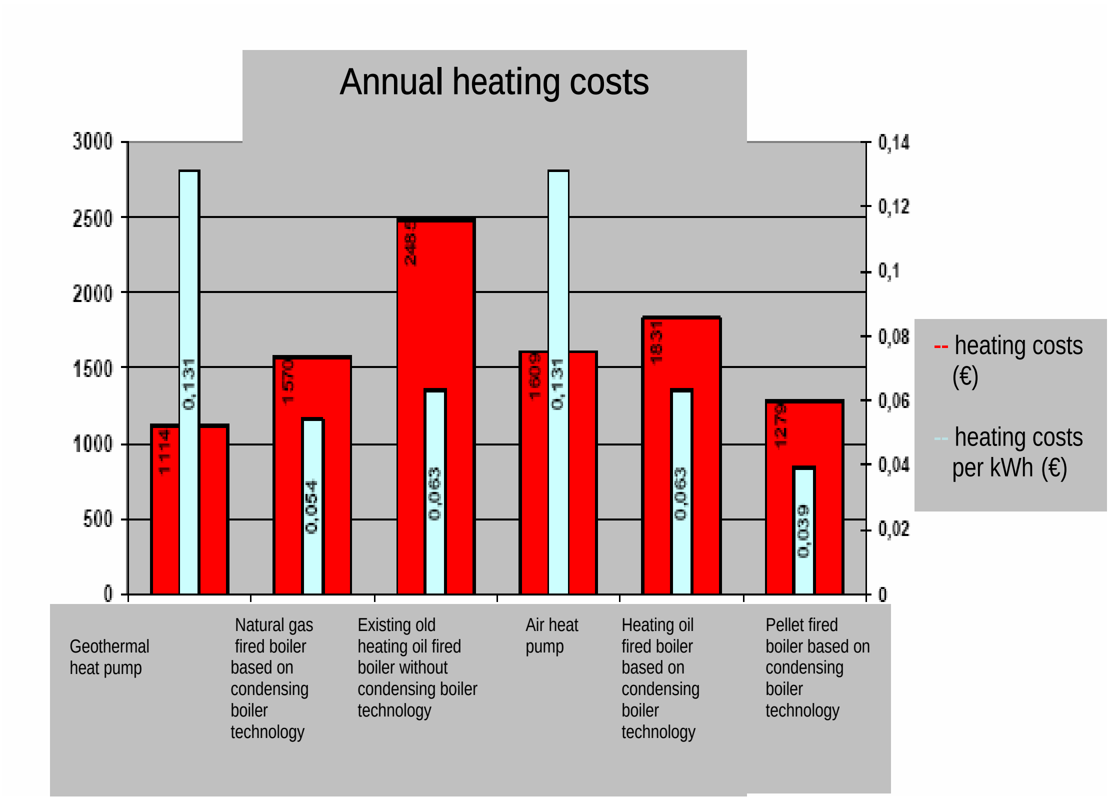

Figure 6[31]: Comparison of annual heating costs for different heating systems (costs of investment and costs of service and additional operating costs are not included)

But not only prices for fossil fuels increase - also prices for electricity go up on the international market as shown in figure 7.

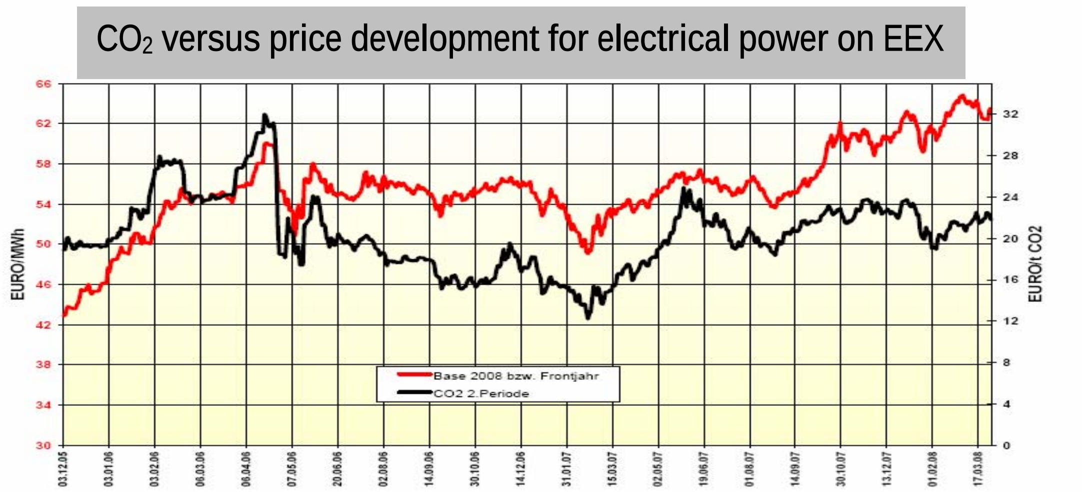

Figure 7[32]: Price development of electricity on the international market

31 Brandl/Strasser (2007), p. 18.
32 http://www.oekv-energy.at/website/output.php?3plus=1053&printable=1, accessed June 20th, 2008.

If less electricity is needed than produced by the CHP the surplus can be fed into the local grid at a special feed in tariff.

As pellet fired central heating systems for producing electricity are considered as environmentally friendly technologies there are also public subsidies available for the installation of these systems which help to reduce the costs of investment considerably.

Another advantage of the CHP - system is that it can help households to face power failures of the grid.

4.2. Technical design of pellet fired stirling engine – CHP system

The technical design of wood pellet fired heating systems and stirling engines was already basically described in the chapters before.

In this master thesis a CHP – system will be described as an example of a pellet fired stirling engine which is already available on the market. This special CHP model with the labelling Sunmachine Pellet is already mass-produced by Sunmachine GmbH based in Wildpoldsried in Germany.

In contrast to common decentralized CHP`s which work with internal combustion engines the Sunmachine Pellet works with an external combustion engine, a sophisticated stirling engine which is driven by heat coming from a specially designed pellet fired boiler based on condensing boiler technology with a capacity of fuel input from 7.5 to 14.9 kW and an overall efficiency of 90%[33]. 70 % of the heat produced by the pellet fired boiler can be used for space heating and warm water processing covering a demand of up to 10.5 kW. 20 % of the heat produced by the pellet fired boiler is used to warm up a heat exchanger which drives the stirling engine which generates up to 3 kW electricity in combination with an alternator[34].

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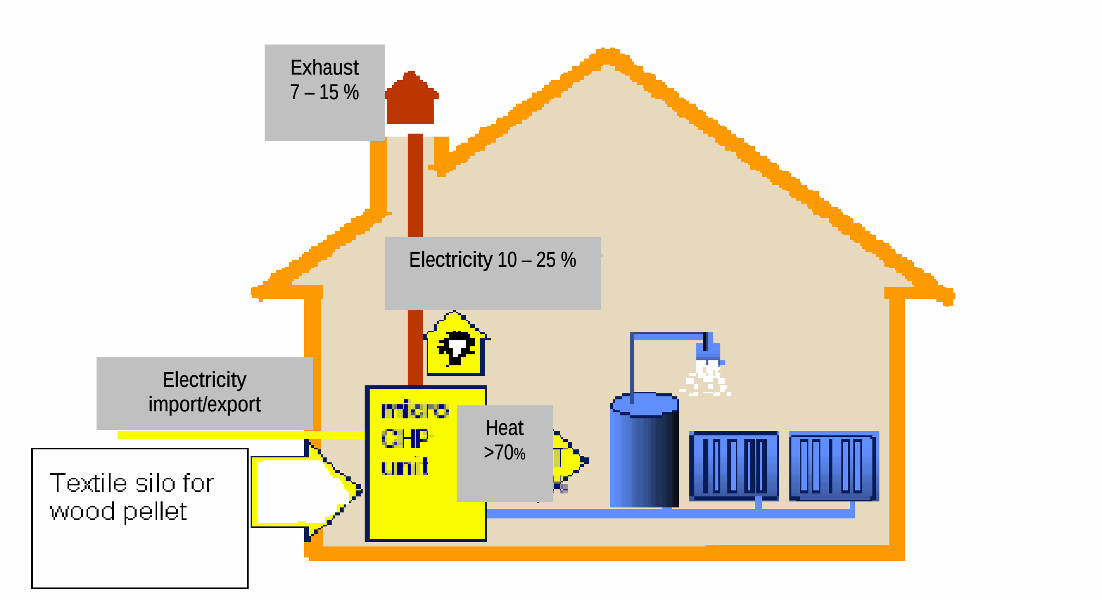
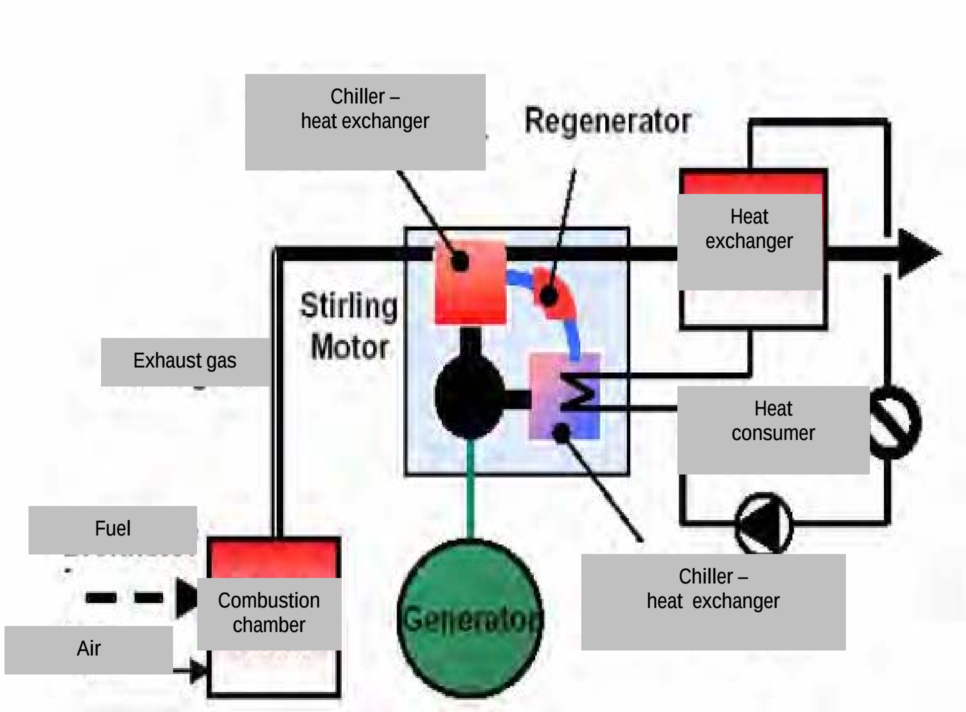
33 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 15th, 2008.
34 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 15th, 2008.

Picture 2 and picture 3 show an example of the installation of such a CHP - system within a building.

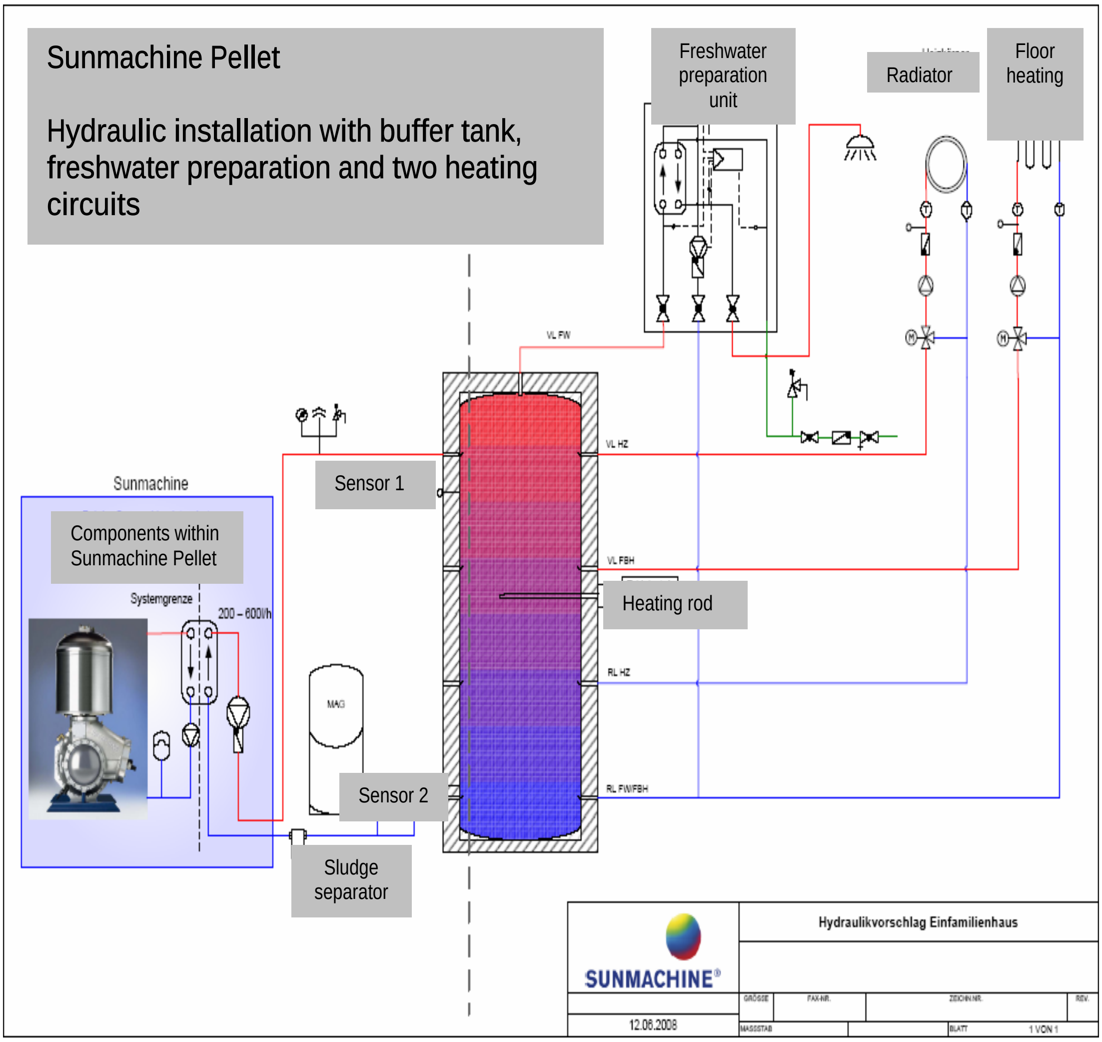


Picture 2[35]: Scheme of a hydraulic installation of a CHP - system within a single family house



Picture 3[36]: Main components of the hydraulic installation of a CHP - system

35 Simader, et. al. (2004), p. 3.
36 Simader, et. al. (2004), p. 29.



Picture 4[37]: Example of hydraulic installation of Sunmachine Pellets for a single family house

The boiler is designed to be driven by standardized wood pellets which are automatically transported by a vacuum suction system from the storage room or a textile silo to the Sunmachine. Initially this boiler converts the wood pellets into wood gas which is afterwards burned within a separated chamber with a very low level of pollutants compared to other wood-fired stoves.

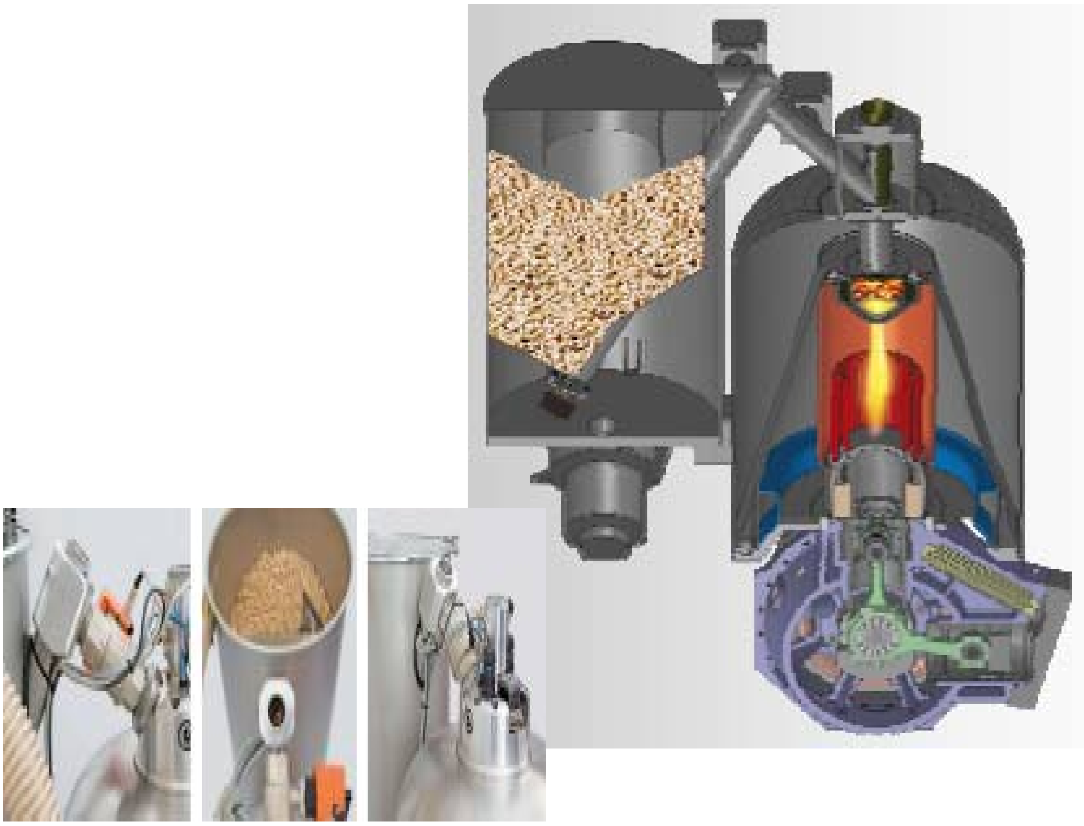
The remaining ashes are removed together with the condensate coming from condensing boiler technology into the wastewater disposal line[38].

[37] Sunmachine GmbH (2008): Example of hydraulic installation of Sunmachine Pellets for a single family house
[38] http://www.sunmachine.com/download/prospekte/ImageBroschuere.pdf accessed June 15th, 2008.

For keeping the heating system separated from the internal components the Sunmachine Pellet is equipped with an integrated circulation pump and an integrated heat exchanger. A second integrated circulation pump transports the heat to the heating system. Connections for flow and return, vacuum suction system, electrical in- and output and exhaust condensate are mounted on the rear side of the CHP.

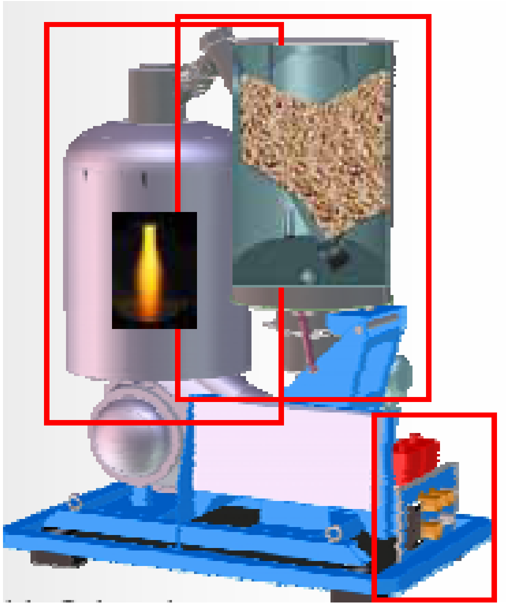
Due to the fact that the unit`s dimensions are 1160 mm x 760 mm x 1590 mm it can be transported through doors of a standard width of 800 mm (LxBxH).

The combination of using heat coming from a pellet fired boiler for electricity production and heating leads to a system efficiency in total of about 90 %. The maintenance rate of the pellet fired boiler is scheduled once a year. The first service for the stirling engine is necessary after 80000 operating hours which corresponds to a time period of 9 years of permanent operation[39].

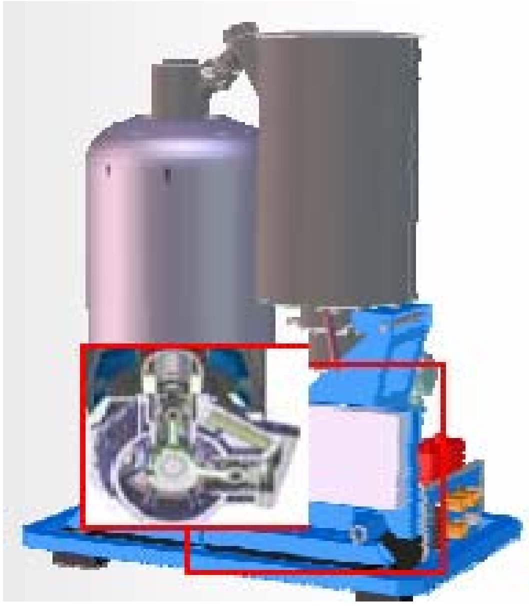


Picture 5[40]: Components of Sunmachine Pellet

39 http://www.sunmachine.com/download/prospekte/ImageBroschuere.pdf, accessed June 15th, 2008.
40 http://www.sunmachine.com/download/prospekte/ImageBroschuere.pdf accessed June 15th, 2008.



Picture 6[41]: Sunmachine Pellet with pellet boiler, pellet storage tank and hydraulic connections



Picture 7[42]: Sunmachine Pellet with stirling engine and control unit

Picture 8[43]: Sunmachine Pellet with puffer tank

Picture 9[44]: Textile silo for Sunmachine Pellet

41 http://www.energyagency.at/(de)/publ/pdf/070116_beilschmidt.pdf accessed October 31th, 2008.
42 http://www.energyagency.at/(de)/publ/pdf/070116_beilschmidt.pdf accessed October 31th 2008.
43 Hasler, (2008).
44 Hasler, (2008).

Table 1[45]: Datasheet Sunmachine Pellet

1.0 Boiler unit SUNMACHINE®	6.0 Alternating-current converter
Heating fuel: wood pellet, minimum requirement DIN plus	Feed-in: single phase 230 Volt 50 Hz
Capacity of fuel input kW: 7.5 – 14.9	Input voltage : 350-600 Volt
Service: once a year	Efficiency max.: 95.7 %
Cleaning: on demand	Grid monitoring : 3 phases
2.0 Control unit	**7.0 CHP**
Operation system: graphical touchscreen	Feed-in: 1.5 – 3 kW
Interface RS 232: for PC	Thermal output: 4.5 – 10.5 kW
Optional: controlling of 3 heating circuits and 1 hot water generator	Electrical efficiency: 20 – 25 %
Loading option for additional buffer tank,	Overall efficiency: ca. 90 %
Interface for peak load demand	Flow temperature: 50 - 75° C
3.0 Fuel transportation system	Return temperature max.: 60° C
Pellet – storage tank	Optimal return temperature: 30° C
Volumetric capacity of pellet – storage directly at the boiler: 80 liters	Acoustic emission: ca. 49 dB
Pellet transportation: vacuum suction system from storage tank (textile silo or underground tank) incl. day/night - control unit	Colour of housing: RAL 5001 (cyan)
	Weight: (without housing) 410 kg
	Dimensions LXBXH in mm: 1160x760x1590
4.0 Exhaust gas	**8.0 Recommended buffer tank**
Exhaust gas evacuation on demand of boiler unit	Stratified storage tank min. 1.000 l
Condensate <1l/h	
5.0 Stirling motor	
Number of cylinders: 1	Included in delivery
Cylinder capacity: 520 ccm	Control of heating circuit
Range of speeds : 500-1000 rpm	Inverter
Working gas: Nitrogen	Vacuum suction system
Working pressure: 33 bar	

[45] http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.

5. Feasibility Study of a pellet fired stirling engine – CHP system for a multiple-family house in Styria / Austria

5.1. Description of the building

Before the installation of a new heating system it is necessary to evaluate the heating and hot water demand of a building. In addition to that it is also important to evaluate the electricity demand of the building within a calendar year to achieve a correct and economically dimensioning of a CHP. In general it can be stated that for an economically operation of a CHP also there should be some heat demand during the summer month[46].

Figure 8 shows the heating demand of a single household within a calendar year of an average quality of the thermal hull of the building.

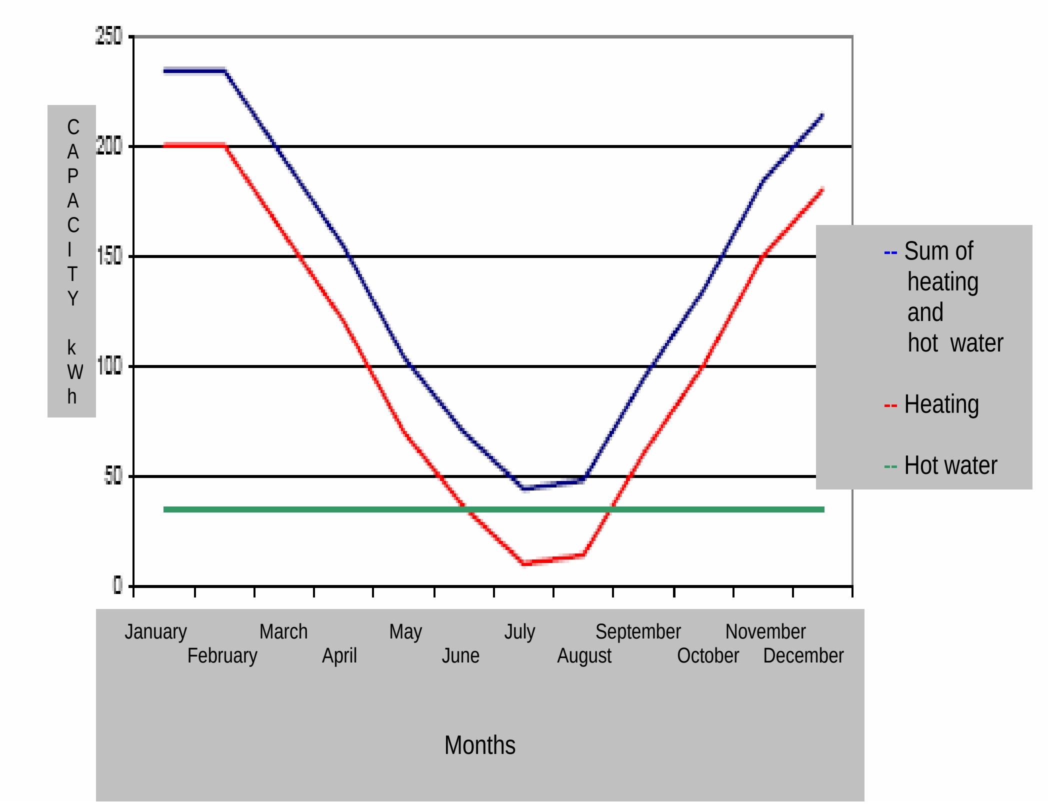


Figure 8[47]: Heating demand of a single household within a calendar year

[46] Simader, et. al. (2004), p. 47.
[47] Simader, et. al. (2004), p. 47.

The present case study is about a multi-storey residential building situated in the municipality of Graz in the Austrian province of Styria. The building has 3 storeys where each storey forms a flat. Two flats are three-room apartments with 70 m^2 and 80 m^2 living space and one flat is a four-room apartment with 100 m^2 living space. It is planned to reconstruct the loft of the building to another flat with a living space of about 30 m^2. In total the gross building area of this house is 350 m^2 already including the adaptation of the loft as a flat. Therefore this building offers living space for approximately 10 persons.

The considered multi-storey residential building was renovated in 2006. Now it is upgraded with an insulation of 16 cm thickness in the two upper stories and 8 cm thickness in the ground floor. Furtherly, the two upper stories are equipped with new high insulating windows with triple glazing.

The floor of the loft is insulated with mineral wool of 20 cm thickness and the floor of the ground floor is insulated with xps - insulation boards of 6 cm thickness.

Furtherly, the building is fitted with a central heating system which consists of a gas boiler with a maximum load of 35 kW based on condensing boiler technology which is equipped with a sophisticated control for regulating individually up to four heating circuits within the building. The same gas boiler is also used to heat up the 800 litre domestic hot water storage tank.

The heat load of the building was analysed in 2006.

Picture 10[48]: Multi-family house in Graz before renovation

[48] Hasler (1994).

Table 2[49]: Heat load calculation of multi-family house in Graz, Austria before renovation

Data of building before renovation

Storage mass of building (Speichermasse)	325	kg/m²
Specific thermal capacity of building components (Wärmekapazität der Baustoffe)	1.04	kj/m³K
Common temperature for internal rooms (Ti) (Raumtemperatur)	20	C
Sea level of building (Seehöhe)	415	m
Heating degree days (HGT) (Heizgradtage)	3515	Kd
Number of heating days during heating period (HT12) (Heiztage in der Heizperiode)	211	d
Lowest temperature (Tne) (Norm-Außentemperatur)	-12	C
Global irradiation (Globalstrahlung)	1147	kWh/m²a
Gross volume of building (Brutto-Rauminhalt der beheizten Gebäudeteile)	949.13	m3
Gross floor area (Bruttogeschoßfläche)	301.03	m²
Net floor area (Nettogeschoßfläche)	255.88	m²
Heated surface area of building (beheizte Oberfläche)	597.3	m²
Losses resulting from airing (Lüftungsverluste)	0,1	W/m³K
Thermal bridges (Wärmebrücken)	18.19	W/K

Calculation of building before renovation

Medium thermal transmission coefficient (mittlerer Wärmedurchgangskoeffizient)	1.14	W/m²K
Specific losses resulting from heat transmission (spezifischer Transmissionswärmeverlust)	0.72	W/m³K
Specific heat loss in total (spezifischer Gesamtwärmeverlust)	0.82	W/m³K
Heat coming from solar radiation (Solarwärmeangebot)	13988	kWh/a
Internal heat supply (internes Wärmeangebot)	6387	kWh/a
Heat losses in total (Gesamtwärmeverlust)	65371	kWh/a
Heat benefits in total (Gesamtwärmegewinn)	13940	kWh/a
Heat insulation of building (LEK-Wert / Wärmeschutz der Gebäudehülle)	95.56	LEK-Wert
Heating load of building (Gebäudeheizlast)	24797	W
Energy index (Energiekennzahl)	171	kWh/m²/a
Heating demand of building (Heizwärmebedarf)	51428	kWh/a

[49] TB Haybach (2006).

Heating load: 24.79 kW

Full load hours per annum: 2073 hours

Annual natural gas demand: 5368 m^3

Based on these figures an energy index of 171 kWh/m^2a was evaluated which means for the building before the reconstruction and with a gross building area of 300 m^2 an annually head demand of 51428 kWh/a.

For this heat demand it was further evaluated that a boiler would fit best with a maximum head load of 24 kW[50].

This energy index is better than the Austrian average of about 220 kWh/m^2a but is still far away form the value of modern low energy houses of about 50 kWh/m^2a[51].

In a second step the house was evaluated with the building components after the reconstruction and including a fourth flat with a living space of about 40 m^2 in the area of the former loft.

Picture 11[52]: Multi-family house in Graz after renovation

[50] TB Haybach (2006).
[51] Simader, et. al. (2004), p. 3.
[52] Ralf Hasler (2007).

Table 3[53]: Heat load calculation of multi-family house in Graz, Austria after renovation

Data of building after renovation

Storage mass of building (Speichermasse)	325	kg/m²
Specific thermal capacity of building components (Wärmekapazität der Baustoffe)	1.04	kJ/m³K
Common temperature for internal rooms (Ti) (Raumtemperatur)	20	C
Sea level of building (Seehöhe)	415	m
Heating degree days (HGT) (Heizgradtage)	3515	Kd
Number of heating days during heating period (HT12) (Heiztage in der Heizperiode)	211	d
Lowest temperature (Tne) (Norm-Außentemperatur)	-12	C
Global irradiation (Globalstrahlung)	1147	kWh/m²a
Gross volume of building (Brutto-Rauminhalt der beheizten Gebäudeteile)	1048.11	m³
Gross floor area (Bruttogeschoßfläche)	350.03	m²
Net floor area (Nettogeschoßfläche)	297.53	m²
Heated surface area of building (beheizte Oberfläche)	643,67	m²
Losses resulting from airing (Lüftungsverluste)	0.1	W/m³K
Thermal bridges (Wärmebrücken)	15.35	W/K

Calculation of building after renovation

Medium thermal transmission coefficient (mittlerer Wärmedurchgangskoeffizient)	0.39	W/m²K
Specific losses resulting from heat transmission (spezifischer Transmissionswärmeverlust)	0.24	W/m³K
Specific heat loss in total (spezifischer Gesamtwärmeverlust)	0.34	W/m³K
Heat coming from solar radiation (Solarwärmeangebot)	12693	kWh/a
Internal heat supply (internes Wärmeangebot)	7426	kWh/a
Heat losses in total (Gesamtwärmeverlust)	29900	kWh/a
Heat benefits in total (Gesamtwärmegewinn)	12089	kWh/a
Heat insulation of building (LEK-Wert / Wärmeschutz der Gebäudehülle)	32.47	LEK-Value
Heating load of building (Gebäudeheizlast)	11342	W
Energy index (Energiekennzahl)	51	kWh/m²/a
Heating demand of building (Heizwärmebedarf)	17810	kWh/a

[53] TB Haybach (2006).

Heating load: 11.34 kW

Full load hours per annum: 1570 hours

Annual natural gas demand: 1859 m^3

Based on these figures an energy index of 51 kWh/m^2a was calculated which means an annual heat demand of 17810 kWh/a for the building after the reconstruction with a gross building area of 350 m^2. For this heat demand it was further evaluated that a boiler would fit best with a maximum heat load of 11 kW[54].

These heat load calculations show that reconstruction measures especially regarding a good insulation of the outer walls and the roof and a change of windows reduce the annual heat demand of the whole building by almost two thirds.

But these calculations also bring up that the installed gas boiler is drastically oversized after reconstruction of the whole building. Due to the fact that the installed gas boiler is based on modern condensing boiler technology and can modulate its heat output from 8 kW up to 35 kW this still means that the boiler produces too much heat during most time of the heating period under lowest load.

As it was already mentioned, the existing system is equipped with an 800 litre hot water storage tank. Considering that the hot water demand in residential buildings is about 50 litres per person and day at a temperature level of 50 degree Celsius and that at maximum 10 persons will live in this building[55] the 800 litre hot water storage tank is well designed. The annual demand for 10 persons would be 365 times 500 litres which are 182500 litres. For heating up this amount of water to a temperature of 50°C 8468 kWh are needed based on the formula hot water demand (l = 10 persons times 50 l times 365 days) times specific heat capacity of water (Wh/lK = 1.16)[56] times temperature difference (K = 40°C)[57].

Due to the fact that the existing system is equipped with an 800 litre hot water storage tank heat losses for storing the hot water have to be considered too. One

54 TB Haybach (2006).
55 Weiss (2007), p. 80.
56 http://www.envisys.de/forum/viewtopic.php?t=86, accessed June 30th, 2008.
57 http://www.envisys.de/forum/viewtopic.php?t=86, accessed June 30th 2008.

possibility to calculate the fuel demand for hot water preparation is regarding article 9 of german heat cost ordinance[58] :

$$\frac{(2.5 \times V \times (tw - 10))}{Hu}$$

V = hot water demand in m^3

tw = medium temperature of the water in °C

Hu = calorific value of used heating fuel in kWh (natural gas 10.5 kWh/m^3, wood pellets 4.9 kWh/kg)

2.5 = absolute term standing for the efficiency of the hot water preparation (based on an efficiency of 46.5 %; 53.5 % are energy losses caused by boiler, chimney, storage tank and distribution)

Regarding this formula[59] and based on the medium hot water demand of 10 persons of about 50 liters per day and a hot water temperature of 50 °C[60] the energy demand for hot water preparation is 18250 kWh/a.

Calculation of energy demand for hot water preparation:

2.5 x 182.5 m^3 x 40 °C = 18250 kWh/a

Due to the fact that the calorific value of wood pellet is about 4.9 kWh/kg and considering 20 % less system efficiency of overall efficiency of 90%[61] for hot water preparation caused by heat converted to electricity 5.32 t of wood pellet are needed to cover this annually hot water demand.

Calculation of fuel demand (wood pellet) for hot water preparation:

18250 kWh/a / (4.9 kWh/kg x 0.7) = 5.32 t

58 http://www.heizkostenverordnung.de/par9.html, accessed June 30th, 2008.
59 http://www.heizkostenverordnung.de/par9.html, accessed June 30th, 2008.
60 Weiss (2007), p. 80.
61 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 15th, 2008.

5.2. Description of pellet fired stirling engine CHP – system

It was already mentioned that the pellet fired boiler has a capacity of fuel input from 7.5 to 14.9 kW and an overall efficiency of 90%[62]. Due to the fact that the heat demand of a building varies with seasonal, daily but also hourly fluctuations the CHP must be switched off as soon as the heat demand sinks under the technical possible heat production of the CHP. If the pellet fired stirling engine CHP - system should be started again, the stirling engine needs to be preheated. Therefore the number of shutdowns should be kept as low as possible. This can be achieved by the usage of a buffer tank in combination with the CHP – system. As it was pointed out already in chapter 2 a reduced number of starts of the pellet boiler and operation under full load increases the efficiency as well as the lifetime of the heating system. Further more the electricity produced by the CHP system is a by-product of the heat production which reaches its peak at full load.

As a consequence out of these circumstances the CHP works most cost-effective if it has high operation loads and only few shutdowns.

In many cases CHP – systems are installed additionally to existing heating boilers. Under these circumstances a CHP - unit should be operated as base load boiler to reach as many operating hours as possible. An additional boiler should support the CHP – unit only during peak load[63].

In general two scenarios are conceivable for a hydraulic integration of a pellet fired stirling engine CHP – system into an existing central heating system:

The simpler solution would be a serial connection between the pellet fired stirling engine CHP – system and the back-up boiler.

This system has high operational reliability and the CHP reaches high running times. The CHP is installed in parallel to the main return. The example below shows a CHP – unit with a boiler as back up system.

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[62] http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 15th, 2008.
[63] Simader, et. al. (2004), p. 21

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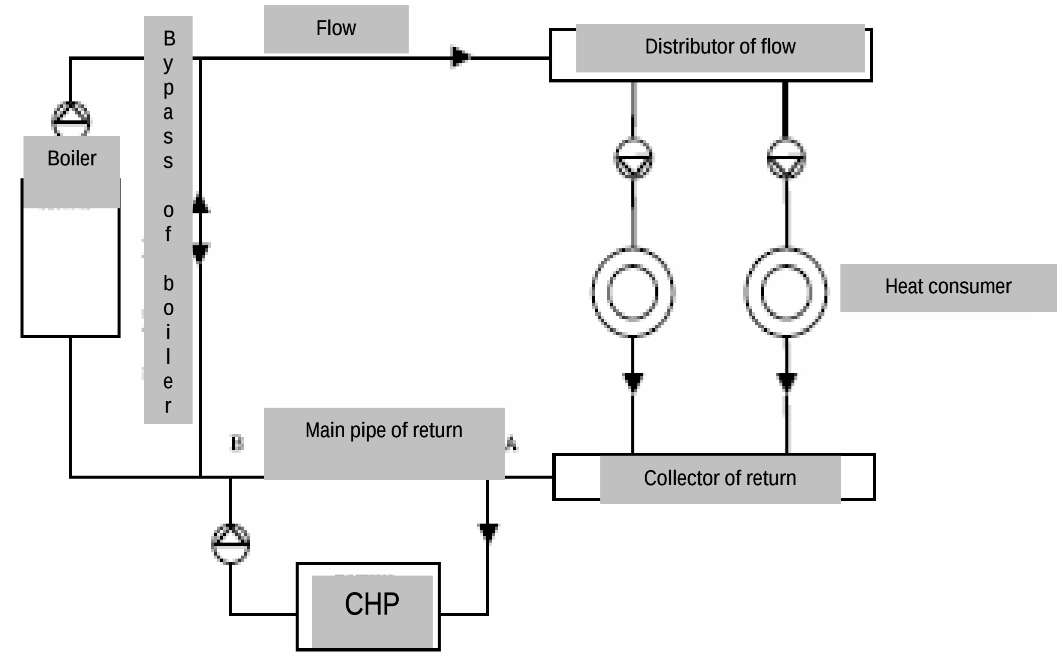

Picture 12[64]: CHP – unit with a boiler as back up system

The more complex solution for a hydraulic integration of a pellet fired stirling engine CHP – system into an existing central heating system would be a parallel connection of the pellet fired stirling engine CHP – system and a buffer tank.

This design is mainly used for heating systems with low return temperatures in combination with boilers based on condensing boiler technology and more complex heating systems.

The puffer storage tank is installed in parallel to the CHP – unit to increase the operating hours of the CHP and to support it in cases of higher heat demand[65]. Also operation cycles of the CHP – unit are decreased by the usage of an additional puffer storage tank[66].

The example below shows a CHP – unit with a boiler as back up system with the CHP parallelly connected to an additional puffer storage tank.

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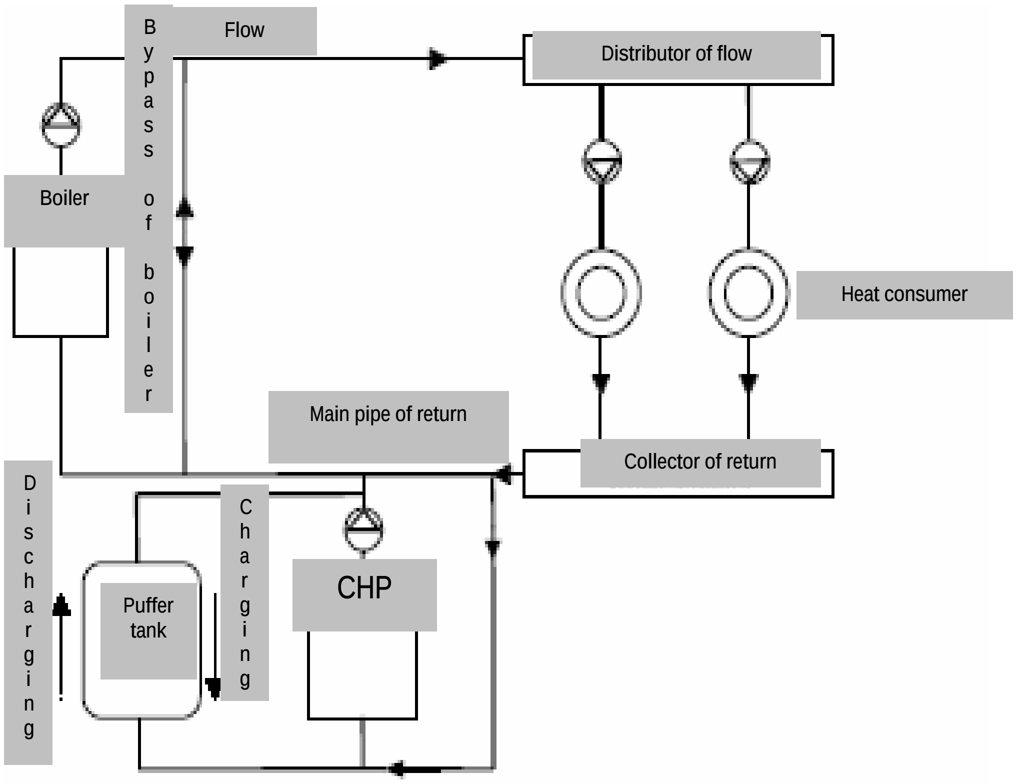
[64] Simader, et. al. (2004), p. 22.
[65] Simader, et. al. (2004), p. 22.
[66] Simader, et. al. (2004), p. 22.



Picture 13[67]: Parallel connection of a CHP – unit with an additional puffer tank

Regarding to the data sheet of Sunmachine Pellet[68] the pellet fired stirling engine CHP – system has a thermal output of 10.5 kW. As it was described in the chapter before the maximum head load for the renovated building is 11 kW[69]. This means that nearby during the whole year the head load for the building will be below the above mentioned 11 kW so that it can be covered by the thermal output of 10.5 kW of the CHP – system.

There is also no requirement of a higher thermal output of the boiler caused by the additional energy demand for hot water. Due to the fact that the hydraulic system is equipped already with an 800 l hot water storage tank which covers the average hot water demand for 10 persons for about 1 ½ days the boiler can heat up the hot water during the time of a night setback where a minimum temperature in the heating circuit is maintained.

[67] Simader, et. al. (2004), p. 22.
[68] http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.
[69] TB Haybach (2006).

So the pellet fired stirling engine CHP – system layout is optimized for circumstances which exist during most time of a heating period, because in the summer month the heat demand is lower than during the winter month[70]. But it has to be mentioned that caused by the optimized system layout exceptional circumstances like extreme low outer temperatures for a period of several days during winter can lead to a temporary shortage of hot water or reduced room temperature.

As it was already mentioned the heating demand of the building is 17810 kWh/a after renovation. Considering that the efficiency of the Sunmachine Pellet[71] is in total up to 90% whereas about 20 % is electrical efficiency and the remaining 70 % are thermal efficiency and taking into account that the calorific value of wood pellet is 4.9 kWh/kg 5.19 t of wood pellet are needed annually to cover the heating demand of the multi-family house.

As the electrical efficiency is about 20 % 5088 kWh/a electricity are produced by the Sunmachine Pellet out of 5.19 t of wood pellet.

The additional energy demand of 18250 kWh/a for hot water preparation is already calculated with energy losses caused by boiler, chimney, storage tank and distribution. Considering that the thermal efficiency of the CHP – system with up to 70 % is lower than the efficiency of modern heating boilers with about 90 % efficiency the energy demand for hot water preparation also increases. However, during hot water preparation also electricity is produced (see below).

Based on the above mentioned additional energy demand of 18250 kWh/a for hot water preparation and 20 % less system efficiency compared to modern heating boilers 5.32 t of wood pellet are needed annually and up to 5213 kWh/a electricity are produced out of this additional energy consumption.

To sum up it can be stated that based on the heat load calculation regarding the house after renovation and a calculated hot water demand for 10 persons the energy demand in total would be 36060 kWh/a.

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70 Simader, et. al. (2004), p. 47.
71 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.

Table 4: Energy demand, fuel demand and electricity production of CHP-System

Space heating heat demand, fuel demand, produced electricity of CHP			Hot water preparation heat demand, fuel demand, produced electricity of CHP			Heat demand, fuel demand, produced electricity of CHP in total		
energy demand for space heating of multi-family house	electricity produced as by-product	demand of wood pellet for space heating of multi-family house	energy demand for hot water preparation of multi-family house	electricity produced as by-product	demand of wood pellet for hot water preparation of multi-family house	energy demand of multi-family house in total	electricity produced as by-product in total	demand of wood pellet of multi-family house in total
17810 (kWh/a)	5088 (kWh/a)	5190 (kg)	18250 (kWh/a)	5214 (kWh/a)	5320 (kg)	36060 (kWh/a)	10302 (kWh/a)	10510 (kg)

To cover the annual energy demand of 36060 kWh/a 10.5 t of wood pellet are needed and the Sunmachine Pellet would produce up to 10302 kWh/a electricity out of this 10.5 t of wood pellet as it is shown in table 4.

Considering the fact that in Austria one person consumes on the average 1.100 kWh[72] electricity per year the *Sunmachine Pellet would cover up to 90 % of this statistical electricity demand per inhabitant of the building in the present case study*.

Based on the fact that the Sunmachine Pellet[73] has a maximum heat output of 10.5 kW the pellet fired stirling engine *CHP – system needs 3434 full load hours to cover the annual heat demand of 36060 kWh/a*.

Based on this figures for the present case studie a textile silo would fit best because there is no floor space left within the building for a wood pellet storage room. Regarding the caculated annual demand of wood pellet and the available space of the planed installation of the storage facility e.g. the external installation of a textile silo of the Austrian Company Oekofen at a size of 197x287x195 (LxBxH in cm) and

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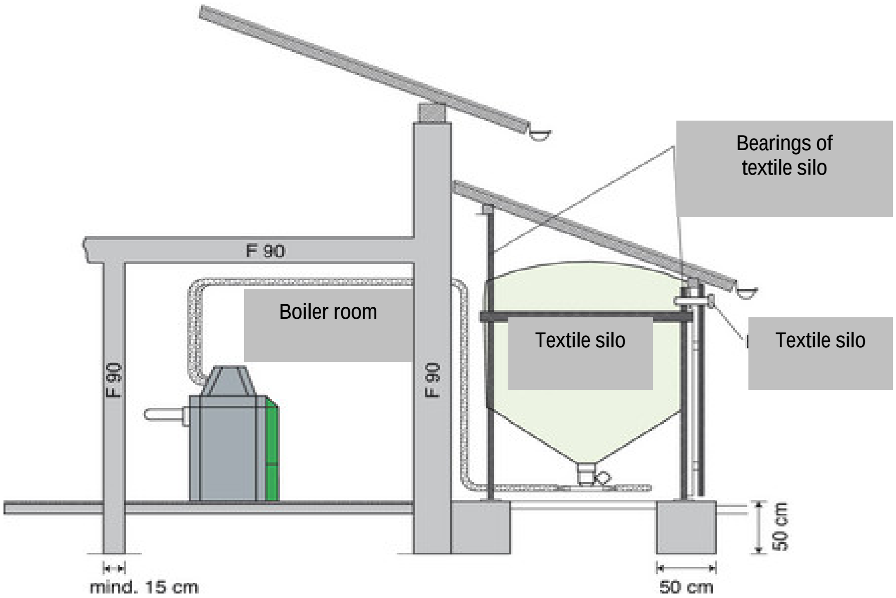
72 ELEKTROGERÄTE IM HAUSHALT, O.Ö. Energiesparverband, http://www.wsed.at/wsed/fileadmin/esv_files/Info_und_Service, accessed June 30th, 2008.

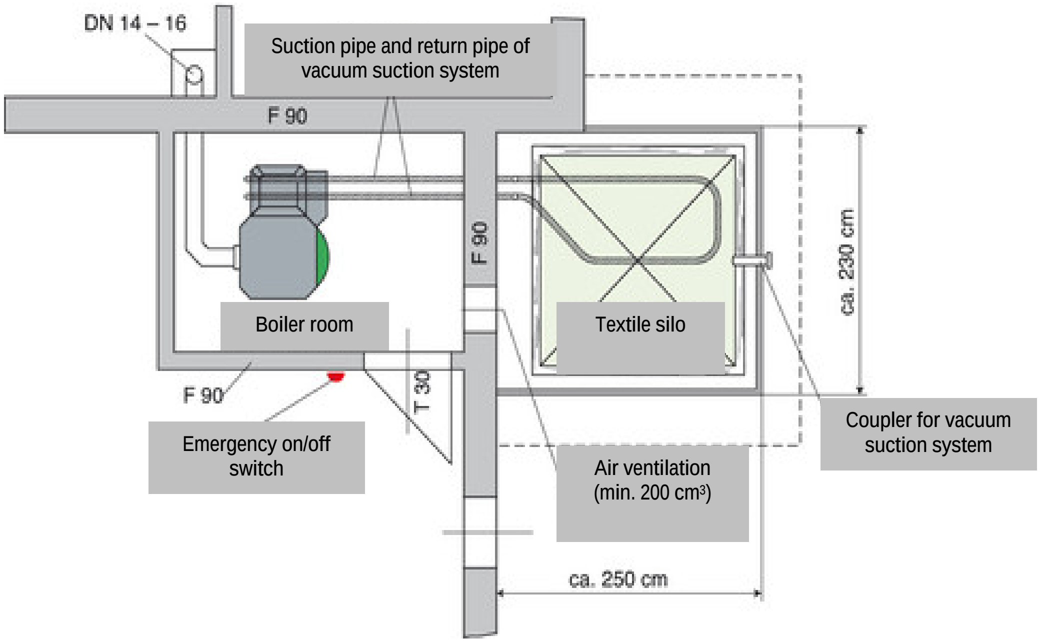
73 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.

a volume up to 5 t in combination with a vacuum suction system would fit well[74]. The storage tank would have enough volume for half of a heating period.

A sample of a textile silo with outdoor installation and vacuum suction system is shown in picture 14 and picture 15 below.



Picture 14[75]: Vertical section of textile silo



Picture 15[76]: Horizontal projection of textile silo

74 http://www.pelletsheizung.at/de/planung/gewebetank.html, accessed June 30th, 2008.
75 http://www.pelletsheizung.at/de/produkte/lager-foerdersysteme/gewebetank/aussenaufstellung.html, accessed June 30th, 2008.
76 http://www.pelletsheizung.at/de/produkte/lager-foerdersysteme/gewebetank/aussenaufstellung.html, accessed June 30th, 2008.

The Sunmachine Pellet itself is sized 116 cm x 76 cm x 159 cm (L x B x H). It could be installed in the small cellar room placed in the northwest corner of the ground floor. In the same room also the stratified storage tank with a volume of 1.000 litres at a size of 80 cm x 200 cm (D x H) could be placed.

Next to this room the electricity meter cabinet for the building is situated. This is important for feeding in the produced electricity into the regional grid and into the local grid of the multi-storey residential building.

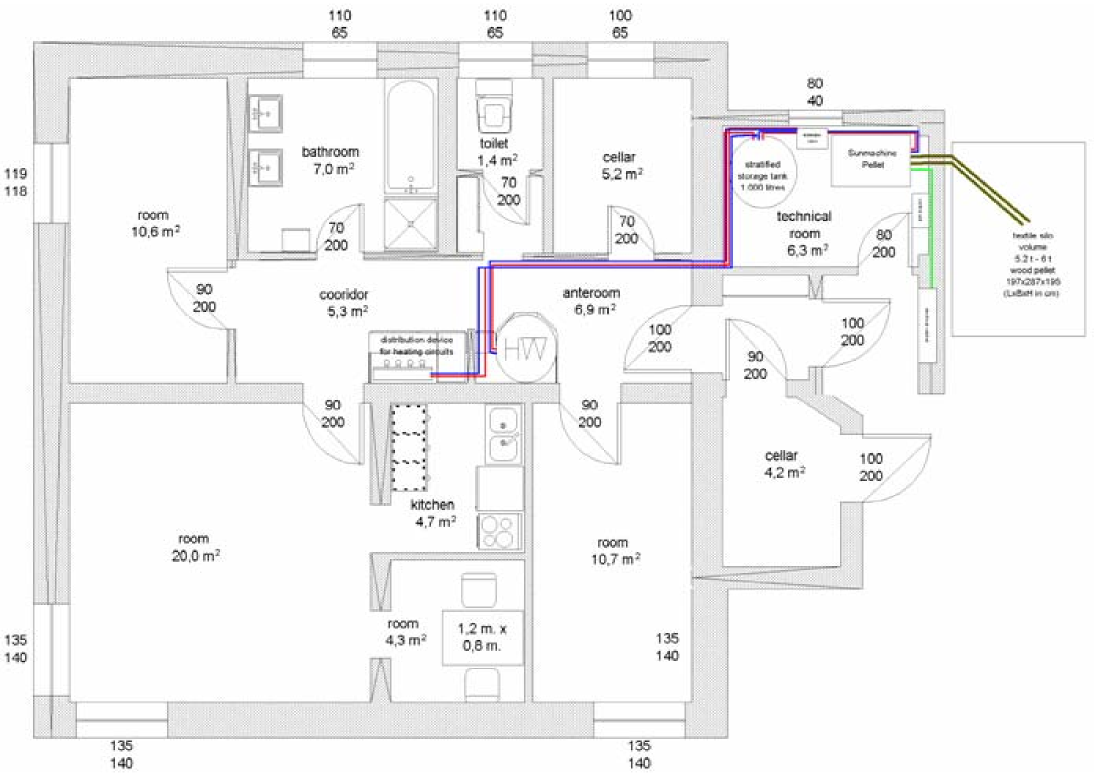
Due to the fact that the existing gas boiler is over dimensioned this boiler should be replaced by the Sunmachine Pellet.

The existing four circulation pumps as well as the 800 litre hot water storage tank should remain in the building whereas the control of these heating circuits and of the hot water preparation will be handled by the control unit of the Sunmachine Pellet.

Hydraulic pipes for flow and return have to be installed leading from Sunmachine Pellet placed in the above described cellar to the distribution device of the four existing heating circuits in the corridor of the ground floor.

Due to the fact that the Sunmachine Pellet is equipped with an internal circulation pump for driving the external heating circuit no additional pump needs to be installed for the heating circuit and for the hot water preparation in combination with the 800 litre hot water storage tank.

The Sunmachine Pellet control unit should be placed next to the CHP and needs to be linked to the Sunmachine as well as to the heating pumps and the hot water tank situated in the corridor of the ground floor including additional sensors and controls inside and outside of the building.



Picture 16[77]**:** Plan of ground floor with adoptions for CHP and textile silo

In general micro CHP`s are operated parallel to the public electrical grid whereas technical guidelines regarding the parallel operation to low voltage grid have to be fulfilled[78].

5.3. Concept of operation

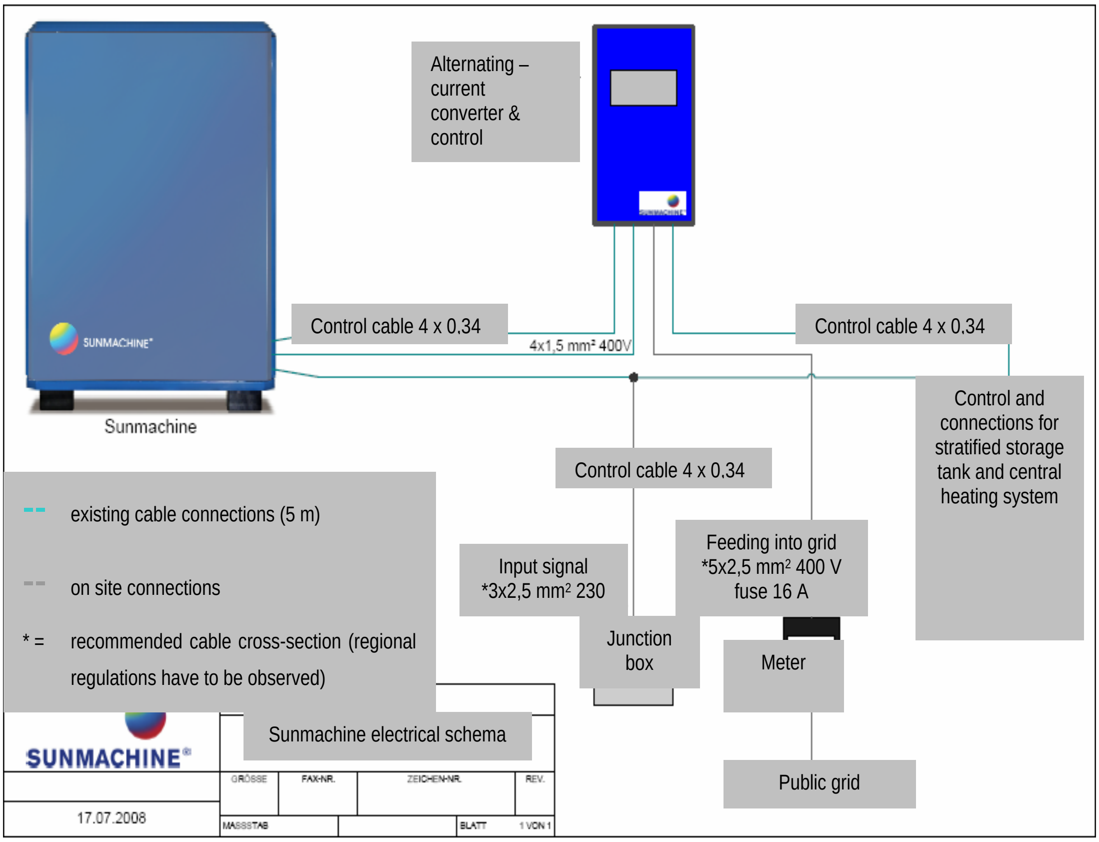
There exist several possibilities to make use of the electricity production of the CHP-unit.

1. One possibility is that the *generated electrical power is consumed in total within the multi-storey residential building by its dwellers*. The annual electricity bill would be reduced by the electricity amount produced by the CHP multiplied by the current price for electrical energy of the electricity provider.
2. A second possibility to calculate the financial contribution of the electricity production of the CHP-system is that the *generated electrical power is sold to OEKOSTROM AG based on an individually negotiated basis*.

[77] Hasler (2008).
[78] Simader, et. al. (2004), p. 24.

3. A third possibility to calculate the financial contribution of the electricity production of the CHP is to *make use of the feed in tariff based on the Green Electricity Code (Oekostromgesetz)*[79] supplemented by the Ordinance of Green Electricity 2008.

Anyway the feed in of the produced electricity has to correspond to the regulations oft the regional electricity company[80]. The Sunmachine Pellet is already equipped with an alternator for transferring the produced continuous current into single-phase alternating current of 230 V at 50 Hz.



Picture 17[81]: Electrical schematic of Sunmachine Pellet for grid connection

5.4. Applicable legal framework

Generally spoken a heating system is an important component of a building. As heating systems can cause risks regulations exist for the installation and change of

[79] http://www.e-control.at/portal/page/portal/ECONTROL_HOME/ OKO/EINSPEISETARIFE, accessed June 30th, 2008.

[80] Simader, et. al. (2004), p. 24.

[81] Sunmachine GmbH (2008), Electrical schema of Sunmachine Pellet for grid connection.

heating systems in a variety of national and provincial laws which have to be observed.

Based on the fact that heating systems are installed in a building the applicable law is the national or provincial building code (Baugesetz bzw. Bauordnung). In Austria each province has its one Provincial Building Code which have sometimes considerable differences regarding the same legal matter.

Depending on the specific use of a heating system additional laws are applicable. If the heating system is installed for a company also the Commerce and Industry Regulation Act (Gewerbeordnung) has to be taken into consideration.

In the present case the installed heating system produces also electricity which should be fed into the grid. Regarding this fact furtherly the Electricity Industry and Organisation Act (ElWOG) needs to be taken into account. In Austria each province has its one Provincial Electricity Industry and Organisation Act (ElWOG). Table 5 gives an overview regarding possible applicable laws for the installation of a CHP - system.

Table 5[82]: List of potential applicable laws for the installation of heating systems

Type of usage	Applicable law	Provisions regarding exhaust fumes of engines
Commercial facilities	Commerce and Industry Regulation Act (Gewerbeordnung GEWO 1994)	article 77 GEWO paragraph 1 and paragraph 3
	Building Code of the Province concerned	indirectly by observing laws concerning the respective interests of neighbours
	Air Monitoring Code (Luftreinhaltegesetz LRG-Kessel)	only regarding waste heat boiler
	Electricity Industry and Organisation Act of the Province concerned (ElWOG)	subsidiary to Commerce and Industry Regulation Act; indirect by observing laws concerning the respective interests of neighbours

82 Simader, et. al. (2004), p. 38.

Type of usage	Applicable law	Provisions regarding exhaust fumes of engines
Public buildings, residential buildings	Building Code of the Province concerned	indirectly by observing laws concerning the respective interests of neighbours
Energy supply companys	Commerce and Industry Regulation Act (Gewerbeordnung GEWO 1994)	article 77 GEWO paragraph 1 and 3
	Building Code of the Province concerned	indirect by observing laws concerning the respective interests of neighbours
	Air Monitoring Code (Luftreinhaltegesetz LRG-Kessel)	only regarding waste heat boiler
	Electricity Industry and Organisation Act of the Province concerned (ElWOG)	subsidiary to Commerce and Industry Regulation Act; indirect by observing laws concerning the respective interests of neighbours
Hospital, nursing homes	Hospital Act (Krankenanstaltengesetz (KAG)	no provisions
	Building Code of the Province concerned	indirect by observing laws concerning the respective interests of neighbours
Landfill Site	Commerce and Industry Regulation Act (Gewerbeordnung GEWO 1994)	article 77 GEWO paragraph 1 and 3
	Waste Management Act (AWG)	article 77 GEWO paragraph 1 and 3; Ordinance of Waste Management
	Ordinance of Waste Management	Ordinance of Waste Management
	Water Rights (WRG)	WRG - regulates only emissions concerning water
Sewage treatment plant	Water Rights (WRG)	WRG - regulates only emissions concerning water
Farms	Building Code of the Province concerned	indirect by observing laws concerning the respective interests of neighbours

In the present case study the concerned project of a three-storey residential building is in private use and placed in the capital city of the province of Styria. Therefore the *Building Code of the Province of Styria is applicable for the installation of the pellet fired stirling engine CHP – system.* As the system is not dedicated for a commercial use *the Commerce and Industry Regulation Act (Gewerbeordnung) is not affected.* Due to the fact that electricity is produced by the system and should be fed into the grid *the Electricity Industry and Organisation Act of the Province of Styria (Steiermärkische ElWOG) has to be taken into account.*

Regarding the application process for a building permit according to article 20 and article 22 respectively of the Building Code of the Province of Styria (Stmk BauG) the project needs to be planned by an government-approved architect or an government-approved master builder.

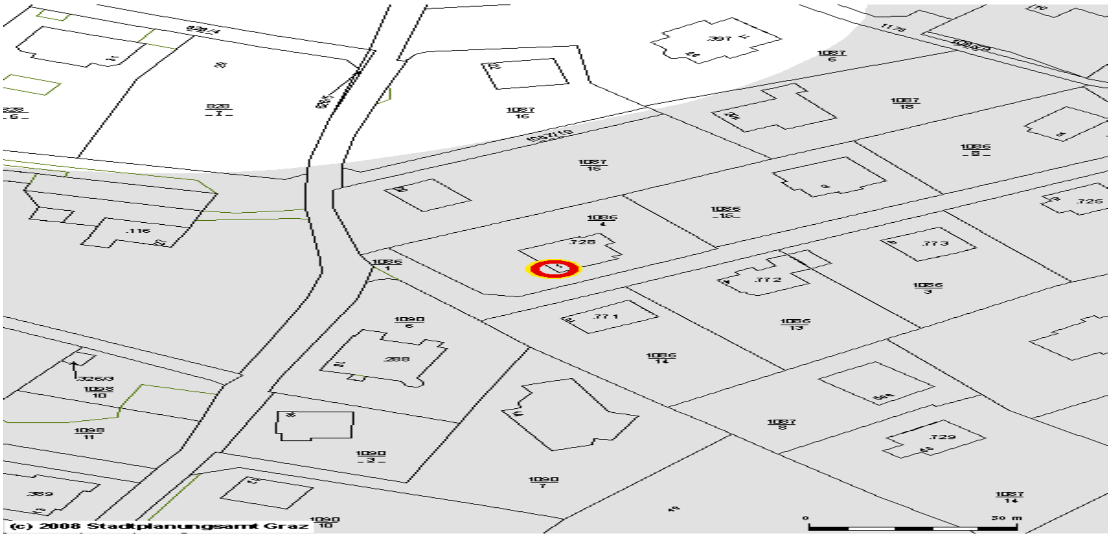
The facilitation regarding article 21 Stmk BauG which would just require to inform the authority in charge about the planed heating system is not applicable because the heating system has a capacity of more than 8 kW nominal head load.

Regarding article 59 Stmk BauG central heating systems of a nominal load less than 18 kW need no separate room for installation. According to article 62 Stmk BauG a storage room has to be considered for storing the essential heating fuel for the heating system. In article 61 Stmk BauG it is prescribed that exhaust fumes produced by the heating system need to be led off by a chimney which has to be higher than the roof of the building.

Article 60 Stmk BauG appoints that a boiler is not allowed to be put into operation without having a valid single approval or general approval issued by the Government of the Province of Styria.

If all these legal requirements are fulfilled the builder-owner can apply for the building permit. After having received this permission, the builder-owner has five years time to start with the building measures otherwise the allowance expires. Therefore the authority in charge has to be informed about the beginning of the civil works. After having finished the building measures the builder-owner has to apply in another step for the use of the building regarding article 38 Stmk BauG. This application has to include a written confirmation of the government-approved architect in charge or the government-approved master builder in charge confirming that the project was constructed according to the building permit and the Building Code of the Province of Styria. Further written confirmations of the electrical engineering technician in charge and the chimney sweeper in charge are necessary confirming that the installed electrical equipment, the installed chimney and the fire-fighting equipment fulfil the legal requirements. Due to the fact that a new heating system is installed also a written confirmation of an expert or plumber is necessary declaring that the prescriptive limits during the trial operation were fulfilled.

Regarding Regional Planning Act of the Province of Styria municipalities have to define the land use within their sphere of action based on ordinances which are called land utilisation plans. Therefore the City of Graz mapped a land utilisation plan. Based on article 23 paragraph 16 of the Regional Planning Act of the Province of Styria and on article 11 paragraph 2 of the Ordinance of Land Utilisation Plan of the City of Graz, chapter 2, version 3.0 defines restrictions for space heatings for some areas within the municipality. Regarding this map it is forbidden to install or change heating systems driven by solid fuels at a capacity of more than 8 kW in certain areas of the municipality (grey marked areas of picture 18[83]). Exceptions from this prohibition are possible, if the particle emissions of the heating system do not exceed the value of 4 g per m^2 of gross storey area a year. Regarding the above mentioned regulations the present case study is situated in such a protected area.



Picture 18[84]: Restricted areas for space heatings - extract from Ordinance of Land Utilisation Plan of the City of Graz

[83] http://geodaten1.graz.at/WC41/FrontController?project=flaewi_3, accessed June 30th, 2008.
[84] http://geodaten1.graz.at/WC41/FrontController?project=flaewi_3, accessed June 30th, 2008.

It is a fact that a boiler is only allowed to be put into operation with a valid single approval or general approval issued by the Government of the Province of Styria. In this approval also the emissions should be stated.

Regarding the obligation to obtain a permit according to the Electricity Industry and Organisation Act of the Province of Styria (Stmk. ElWOG) article 5 Stmk ElWOG appoints that the installation, modification and operation of an electricity producing unit with a maximum capacity of more than 200 kW needs to be approved by the provincial government.

Due to the fact that the Sunmachine Pellet unit has a maximum capacity of 3 kW electrical output no approval is necessary by the government of the province of Styria regarding the Stmk. ElWOG.

Regarding article 7 Green Electricity Code (Ökostromgesetz) the governor of a province is obliged to declare a unit, which produces electricity out of renewable energy by official notification as a green electricity unit.

All necessary permissions and official notifications regarding the planed CHP – system are important for the next step which should be asking authorities for additional subsidies which can help to reduce the cost of investment considerably.

5.5. Applicable system of subsidies

In Austria a plurality of financial aids exists granted by public authorities to encourage new environmental friendly technologies. In general it can be stated that in most cases public authorities are not legally obligated to grant financial aids even if the corresponding guidelines are fulfilled by the applicant. Another basic rule regarding subsidies is that financial aid can only be granted for one time to a specific investment. But it is possible, that financial aid for an investment is shared between different public authorities like e.g. municipality and province or province and federal state. As a consequence it can be important in which municipality or province in Austria an investment is planned. Also it is important to differ strictly between private and professional investment because for both types of investment different systems and forms of financial aid exist.

Due to the fact that in general only costs are subsidised which are within the approved period for the financial aid it is strictly recommended to discuss the planned project with the involved authorities at a very early stage.

As the concerned project of a three-storey residential building is used for private living and placed in the capital city of the province of Styria the following grants might be possible for the pellet fired boiler:

Funding authority: Province of Styria[85]
Name of grant: Förderung moderner Holzheizungen

Address:
Amt der Steiermärkischen Landesregierung
Geschäftsstelle des Steiermärkischen
Umweltlandesfonds
Fachabteilung 13A
Burggasse 9/I
A-8010 Graz

Type of grant:
Capital investment grant for a pellet fired central heating system up to € 1400 and for a multi-storey residential building multiplied by the figure of storeys. The amount of the grant is limited by 25 % of the net investment. Additional grants are allowed. Maximum capital investment grant in total: € 1400 * 3 = € 4200

Funding authority: Province of Styria[86]
Name of grant: Förderungen im Zusammenhang mit der Stromerzeugung aus erneuerbaren Energieträgern (Ökofonds)

Address:
Amt der Steiermärkischen Landesregierung
Geschäftsstelle des Steiermärkischen
Umweltlandesfonds
Fachabteilung 13A

[85] http://www.verwaltung.steiermark.at/cms/beitrag/10098158/2627997/, accessed June 30th, 2008.
[86] http://www.energyagency.at/esf/st05a.de.htm, accessed June 30th, 2008.

Burggasse 9/I
A-8010 Graz

Type of grant:
Capital investment grant up to 100 % of the regarding additional project costs after positive evaluation of the project by a jury of experts according to the annual call for tenders.

Funding authority: OeMAG – settlement centre for Green Electricity in Austria
Name of grant: Feed - in rate based on the Green Electricity Code
(Oekostromgesetz) [87] supplemented by the Ordinance of Green Electricity 2008 (Ökostromverordnung 2008; BGBl II Nr 59/2008)

Address:
OeMAG Abwicklungsstelle für Ökostrom AG Alserbachstrasse 14-16
A-1090 Vienna

Type of grant:
Feed – in rate regarding to the applicable Ordinance of Green Electricity for green electricity produced out of solid biomass for 12 years. The applicable feed – in rate for 2008 is 15.64 ct/kWh whereas the tariff is reduced in the 11th year by 25 % and another 25 % in the 12th year. Regarding article 2 paragraph 1 of the Ordinance of Green Electricity 2008 the share of solid biomass or liquid fired biomass in the fuel mix has to be at least 60 %.

Funding authority: Climate and Energy Fund of the Federal Government of Austria
Name of grant: Climate and Energy Fund – campaign – wood fired heating systems

Adress:
Kommunalkredit Public Consulting GmbH[88]
Türkenstraße 9
A-1092 Vienna

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[87] http://www.e-control.at/portal/page/portal/ECONTROL_HOME/ OKO/EINSPEISETARIFE, accessed June 30th, 2008.
[88] http://www.public-consulting.at/de/portal/umweltfrderungen/klimaundenergiefonds/frderaktionholzheizungen/, accessed June 30th, 2008.

Type of grant:

Capital investment grant for a pellet fired central heating system with a maximum capacity of 50 kW up to € 800; campaign ends with end of October 2008; heated floor area must be used for private purposes and emissions of heating system have to be under defined values.

If the concerned project of a three-storey building is owned by a municipality or a association or if it is owned by a physical person or an enterprise and is used for commercial activities (e.g. as a guest house or as a hotel) the following grants might be possible for the pellet fired boiler:

Funding authority: Federal Government of Austria

Name of grant: Biomass CHP-Systems

Adress:

Kommunalkredit Public Consulting GmbH[89]

Türkenstraße 9

A-1092 Vienna

Type of grant:

Capital investment grant up to 30 % environmental concerned costs of investment for solid biomass or liquid biomass fired systems dedicated to the combined heat and power production. CHP must be used for commercial purposes for self supply and/or grid – coupled.

Funding authority: OeMAG – settlement centre for Green Electricity in Austria

Name of grant: Feed - in rate based on the Green Electricity Code

(Oekostromgesetz) [90] supplemented by the Ordinance of Green Electricity 2008 (Ökostromverordnung 2008; BGBl II Nr 59/2008)

Address:

OeMAG Abwicklungsstelle für Ökostrom AG Alserbachstrasse 14-16

A-1090 Vienna

Type of grant:

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89 http://www.public-consulting.at/de/portal/umweltfrderungen/klimaundenergiefonds/frderaktionholzheizungen/, accessed June 30th, 2008.

90 http://www.e-control.at/portal/page/portal/ECONTROL_HOME/ OKO/EINSPEISETARIFE, accessed June 30th, 2008.

Feed – in rate regarding to the applicable Ordinance of Green Electricity for green electricity produced from solid biomass. The applicable feed – in rate for 2008 is 15.64 ct/kWh limited for 12 years whereas the tariff is reduced in the 11th year by 25 % and another 25 % in the 12th year. Regarding article 2 paragraph 1 of the Ordinance of Green Electricity 2008 the share of solid biomass or liquid fired biomass in the fuel mix has to be at least 60 %.
Additional grants are possible but each case has to be evaluated separately.

Funding authority: Federal Government of Austria
Name of grant: Biomass CHP-Systems

Adress:
Kommunalkredit Public Consulting GmbH[91]
Türkenstraße 9
A-1092 Vienna

Type of grant:
Capital investment grant up to 30 % of the environmental concerned costs for "Sunmachine Pellet" excluding additional subsidies like feed – in tariff. If the feed – in tariff is additionally accessed the capital investment grant of Kommunalkredit Public Consulting GmbH would be up to 40 % of the environmental concerned costs but limited to the heating part of "Sunmachine Pellet" which is about 60 % of the price per unit. Regarding the specific guidelines of Kommunalkredit Public Consulting GmbH the environmental concerned costs for biomass boilers with a capacity up to 50 kW are limited with € 500 per kW.

5.6. Cost analysis of system implementation of the pellet fired CHP-system "Sunmachine Pellet"

In the chapters before the energy demand for space heating and hot water preparation of a multi-family house in Graz are described.

Furthermore it is illustrated that the pellet fired CHP-system "Sunmachine Pellet" can cover the energy demand for space heating and hot water preparation for this

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91 http://www.public-consulting.at/de/portal/umweltfrderungen/klimaundenergiefonds/frderaktionholzheizungen/, accessed June 30th, 2008.

multi-family house and it is also shown how the pellet fired CHP-system "Sunmachine Pellet" can be installed within the building.

Furthermore the applicable legal framework and the available subsidies are explained for the hydraulic installation of the pellet fired CHP-system in the chapters before.

Based on these data this chapter points out the capital fixed costs, the consumption fixed costs, the operation fixed costs, the applicable subsidies and potential revenues which have to be considered by an installation and operation of a Sunmachine Pellet under the circumstances of the present case study of a multi-family house in Graz.

Prices listed in the following tables are estimations based on information from the distributor of the Sunmachine in Austria, based on available market prices and available comparable offers of similar components.

Table 6: Costs of investment - fixed costs by capital for the present case study (expected lifetime of Sunmachine Pellet: 15 years)

Costs of investment	Costs in €
Sunmachine Pellet 14.5 kW	€ 24.990,00 VAT excluded
Textile silo 5 t, 197x287x195 (LxBxH in cm)	€ 1.500,00 VAT excluded
Tube, gate, gatevalve, hose clip, frame for tube	€ 1000,00 VAT excluded
Shed roof for textile silo	€ 2.000,00 VAT excluded
Foundation for textile silo	€ 1.500,00 VAT excluded
Removal of entrance door to technical room, new entrance door, mounting of new entrance door 80 cm x 200 cm (BxH)	€ 1000,00 VAT excluded
Stratified storage tank 1000 litres volume, storage tank insulation and stratified-charge module	€ 2.000,00 VAT excluded
Stainless steel chimney, 9 m high, 20 cm diameter	€ 2.000,00 VAT excluded
Pipes for heating system and hot water system, 20 m, insulation, switching valve, heat meter and hot water meter	€ 1.500,00 VAT excluded
Electric installation material, electric meter	€ 500,00 VAT excluded
Costs for building permission, commissioning, certificates	€ 1.000,00 VAT excluded
Mounting of all components, hydraulic installation, electrical installation, masonry works, integration of existing hydraulic and electric installations	€ 3.000,00 VAT excluded
Costs of investment in total	€ 41.990,00 VAT excluded

Table 7: Running expenses for the present case study

Costs fixed by consumption	Costs in €
Heating fuel (wood pellet); current market price: € 175/t VAT excluded [92] Calculation of costs of heating fuel considering an annual demand of wood pellet for the multi-family house of 10.5 t: € 175/t x 10.5 t	€ 1.837,5 VAT excluded
Total costs fixed by consumption per year	€ 1.837,5 VAT excluded

Costs fixed by operation	Costs in €
Service and maintenance of pellet boiler per year (costs of investment x 0,02)	€ 1000
Service and maintenance of stirling unit (after 80.000 running hours)	unknown
Additional costs per year e.g. for insurance (costs of investment x 0,01)	€ 500,00
Total costs fixed by operation per year	€ 1500,00

5.7. Feasibility study of system implementation

The economic feasibility study of the present case study is based on a capital expenditure budgeting according to the annuity method. This method is a dynamic procedure evaluating annual costs consisting of interest payments and operating costs[93].

The inflation is considered by calculating a real interest rate whereas it is assumed that the increase of these payments complies with the inflation rate[94].

The real interest rate therefore is calculated by the following formula[95]:

$$i_N \text{ (mixed interest rate)} = i_{equity} \text{ (interest of equity)} \times a_{equity} \text{ (share of equity)} + i_{debt} \text{ (interest of debt)} \times a_{debt} \text{ (share of debt)}$$

[92] http://www.propellets.at/images/content/pdfs/200810_pelletpreis_to.pdf, accessed October 30th, 2008.
[93] Fachagentur Nachwachsende Rohstoffe (2005), p. 285.
[94] Fachagentur Nachwachsende Rohstoffe (2005), p. 285.
[95] Fachagentur Nachwachsende Rohstoffe (2005), p. 232.

$$i \text{ (=real interest rate)} = i_N \text{ (mixed interest rate)} - \text{rate of price increase}$$

Bench marks already exist e.g. for costs for service and maintenance, operating expenses and additional costs which can be used for the economic feasibility study. Regarding existing experiences operating costs like electricity are valued with 0.1 % to 0.5 % of the total investment. Costs for insurances and taxes are valued with 0.5 % to 1 % and costs for service and maintenance with 1 % to 2 % of the costs of investment[96].

In a further step the specific heat generation costs can be determined by dividing the annual costs by the annual produced energy amount.

Based on the model of an economic feasibility study regarding VDI 6025 with adoptions for a CHP – systems[97] the present case study was evaluated as shown in the figures and tables below.

As it was pointed already out before there are different models of subsidies available for the CHP – systems.

5.7.1 System of subsidies for a multi-storey residential building with private usage

According to the explanations in chapter 5.5 *a capital investment grant of Euro 4200 from the Province of Styria and an additional grant of Euro 800 from Kommunalkredit Public Consulting GmbH are available for the evaluated multi-storey residential building with three storeys and private usage*.

As the loft is not adopted as flat up to now it is not considered for the calculation of the subsidies.

As a consequence out of the existing schema of subsidies there exist *three possibilities to evaluate the financial contribution of the electricity production of the CHP – system*:

[96] Fachagentur Nachwachsende Rohstoffe (2005), p. 205.
[97] Fachagentur Nachwachsende Rohstoffe (2005), p. 285.

1. ***Electrical power is consumed in total within the multi-storey residential building by its dwellers:***

One possibility to calculate the financial contribution of the electricity production is that the generated electrical power is consumed in total within the multi-storey residential building by its dwellers. The annual electricity bill would be reduced by the electricity amount produced by the CHP multiplied by the current price for electrical energy of the electricity provider.

As it was mentioned already before *in the city of Graz the price for electricity for private consumers depends on the electricity supplier and is currently between 14.2 ct/kWh and 19.6 ct/kWh*[98] and it can be expected that this price will increase in the coming years.

Taking into account 3434 full load hours per year which would lead to an electrical energy production of 10302 kWh the annual savings would be € 1463 per year considering a price for electricity of 14.2 ct/kWh and € 2024 per year considering a price for electricity of 19.65 ct/kWh.

2. ***Electrical power is sold to OEKOSTROM AG:***

A second possibility to calculate the financial contribution of the electricity production of the CHP-system is that the generated electrical power is sold to OEKOSTROM AG based on an individually negotiated base.

3. ***Electrical power is sold based on the feed in tariff according to the Green Electricity Code (Oekostromgesetz):***

A third possibility to calculate the financial contribution of the electricity production of the CHP is to make use of the feed in tariff based on the Green Electricity Code (Oekostromgesetz) [99] supplemented by the Ordinance of Green Electricity 2008. The applicable feed – in rate for a pellet fired CHP in 2008 is 15.64 ct/kWh whereas the tariff is reduced in the 11th year by 25 % and another 25 % in the 12th year. The disadvantage of this special feed in tariff is that the price is fixed over a long period of 10 years to a certain amount which is already very close to the market price for

[98] http://tarifkalkulator.e-control.at/tarifkalkulator/TKStart.do, accessed October 10th, 2008.
[99] http://www.e-control.at/portal/page/portal/ECONTROL_HOME/ OKO/EINSPEISETARIFE, accessed June 30th, 2008.

consumers and is reduced drastically in the 11th year by 25 % and another 25 % in the 12th year.

Table 8: Subsidies and revenues for the present case

Typ of subsidy, feed in tariff or amount of savings	Subsidies, feed in tariff, savings in €
Subsidy for pellet boiler / Province of Styria € 1400 times 3 for a three-storey house (25% of netto investment at maximum)	€ 4200
Subsidy for pellet boiler / Federal Government of Austria € 800	€ 800
Feed in tariff regarding Green Energy Code of 15.64 ct/kWh (GreenEnergy Ordinance 2008) expected up to 3434 full load hours and guaranteed for 10 years, reduced in the 11th year by 25 % and another 25 % in the 12th year or savings by internal consumption of generated electricity (between 14.2 ct/kWh and 19.65 ct/kWh depending on the price of the electricity supplier[100]) Calculation of cost reduction by feed in tariff regarding Green Energy Code: 15.64 ct/kWh x 3434 full load hours x 3 kW electrical output of CHP (11th year of operation: 11.73 ct/kWh x 3434 full load hours x 3 kW electrical output of CHP; 12th year of operation: 7.82 ct/kWh x 3434 full load hours x 3 kW electrical output of CHP) Calculation of cost reduction by internal consumption of generated electricity considering a price of 14.2 ct/kWh of local electricity supplier: 14.2 ct/kWh x 3434 full load hours x 3 kW electrical output of CHP Calculation of cost reduction by internal consumption of generated electricity considering a price of 19.65 ct/kWh of an electricity supplier: 19.65 ct/kWh x 3434 full load hours x 3 kW electrical output of CHP	€ 1611 per year for 15.64 ct/kWh for 10302 kWh produced electricity of the CHP (11th year of operation: € 1208; 12th year of operation: € 805) € 1462 per year for 14.2 ct/kWh for 10302 kWh produced electricity of the CHP € 2024 per year for 19.65 ct/kWh for 10302 kWh produced electricity of the CHP

As it was already figured out in chapter 5.2. the hydraulic system is equipped with a 800 l hot water storage tank which covers the average hot water demand for 10 persons for about 1 ½ days so that the boiler can heat up the hot water during the time of a night setback. The energy demand for hot water preparation is calculated with 18250 kWh/a.

[100] http://tarifkalkulator.e-control.at/tarifkalkulator/TKStart.do, accessed October 10th, 2008.

So even outside the annual heating period from September to April there is still a high daily heat demand which has to be covered by the CHP whereas electrical power is produced as a by-product.

Figure 9 illustrates the consumer behaviour of single households in Austria regarding electricity.

It is shown that the daily demand of a single household is at a minimum of 1 kW of electricity between 4.00 am and 12.00 pm.

As a result out of this it can be assumed that for the multi-storey residential building with three stories and up to 10 inhabitants a minimum amount of electric power of 3 kW is needed between 4.00 am and 12.00 pm.

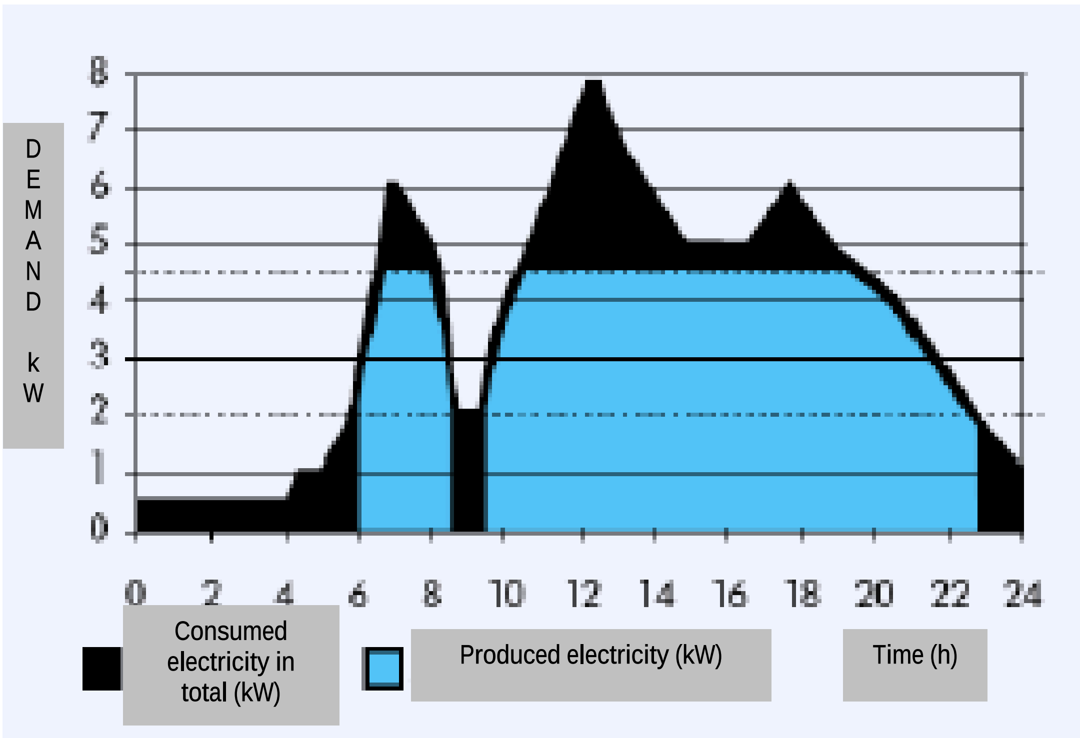

Figure 9[101]: Consumer behaviour of single households regarding electricity per day

If the CHP is switched on only in the period between 4.00 am and 12.00 pm all the produced electricity will be consumed by the inhabitants of the building.

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101 http://www.ifz.tugraz.at/index.php/filemanager/download/602/Mürzl-Ausarbeitung.pdf, accessed June 20th, 2008.

Based on the considerations above *in the present feasibility study it is assumed that the generated electrical power is consumed fully within the multi-storey residential building*.

5.7.2 Cumulated annual costs of CHP – system over a period of 15 years considering different boundary conditions

1. ***Cumulated annual costs of CHP – system over a period of 15 years***

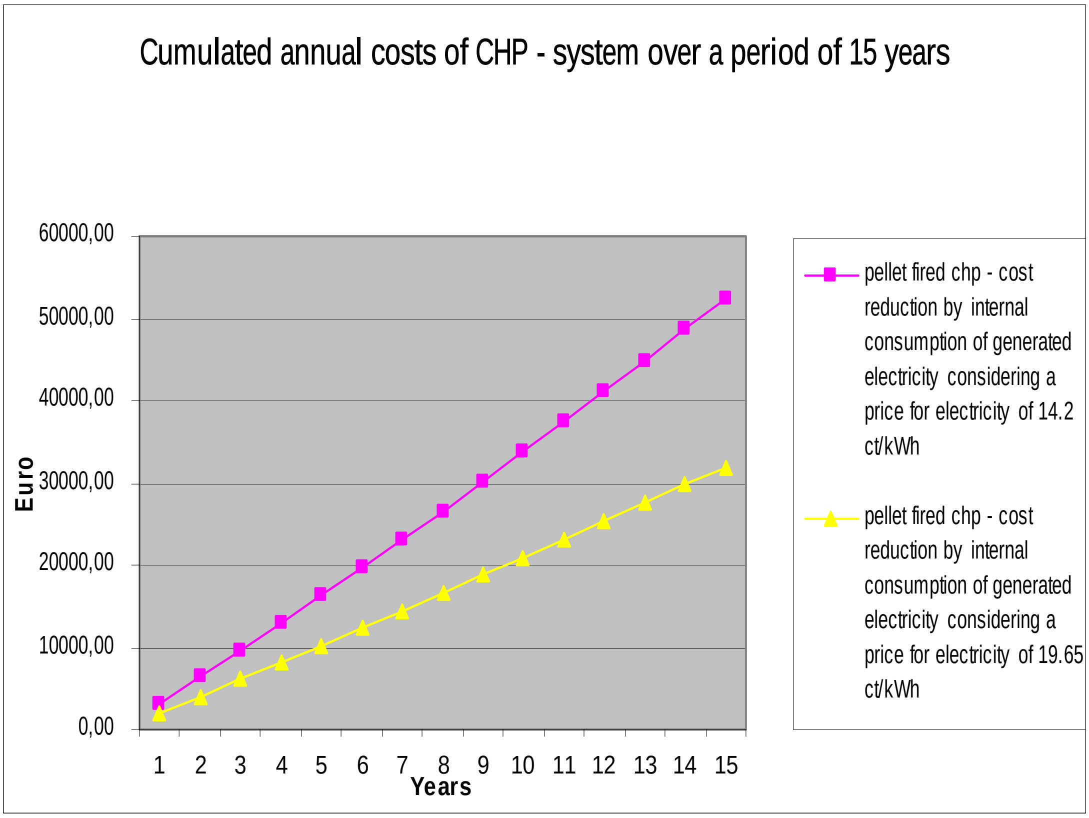

Figure 10: Cumulated annual costs of CHP - system over a period of 15 years

The annual costs for pellet fired stirling engine CHP – system are calculated based on the current price for electricity for private consumers in the city of Graz. The lowest offered price for electricity is currently 14.2 ct/kWh and the highest offered price is 19.65 ct/kWh[102].

[102] http://tarifkalkulator.e-control.at/tarifkalkulator/TKStart.do, accessed October 10th, 2008.

Figure 10 shows the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a low market price for electricity of 14.2 ct/kWh (pink curve) on one hand and considering a high market price for electricity of 19.65 ct/kWh (yellow curve) on the other hand.

The annual mean inflation rate is calculated with 3 %.

Figure 10 illustrates that the cumulated annual costs of the CHP - system after a period of 15 years would be € 52448 taking into account a cost reduction by internal consumption of generated electricity and considering a low market price for electricity of 14.2 ct/kWh. The cumulated annual costs of the CHP - system after a period of 15 years would be € 31957 taking into account a cost reduction by internal consumption of generated electricity and considering a high market price for electricity of 19.65 ct/kWh.

As a consequence out of this it can be stated that the *annual costs and cumulated costs of the CHP – system are strongly influenced by the cost reduction caused by internal consumption of generated electricity and in addition by the market price for electricity*.

The higher the market price for electricity is the higher is the annual cost reduction and the lower are the annual and cumulated costs of the CHP – system.

2. Cumulated annual costs of CHP - system over a period of 15 years considering reduced service and maintenance costs

Considering 80000 operating hours of the stirling engine without service costs and 3434 full load hours per year which are needed to cover the annual heat demand for space heating and hot water preparation of 36060 kWh/a *the first service of the stirling engine would be necessary after 23 years*.

Based on these facts it can be assumed that the annual service and maintenance costs of the pellet fired stirling CHP – system would be during a calculated lifetime of 15 years as high as the service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input.

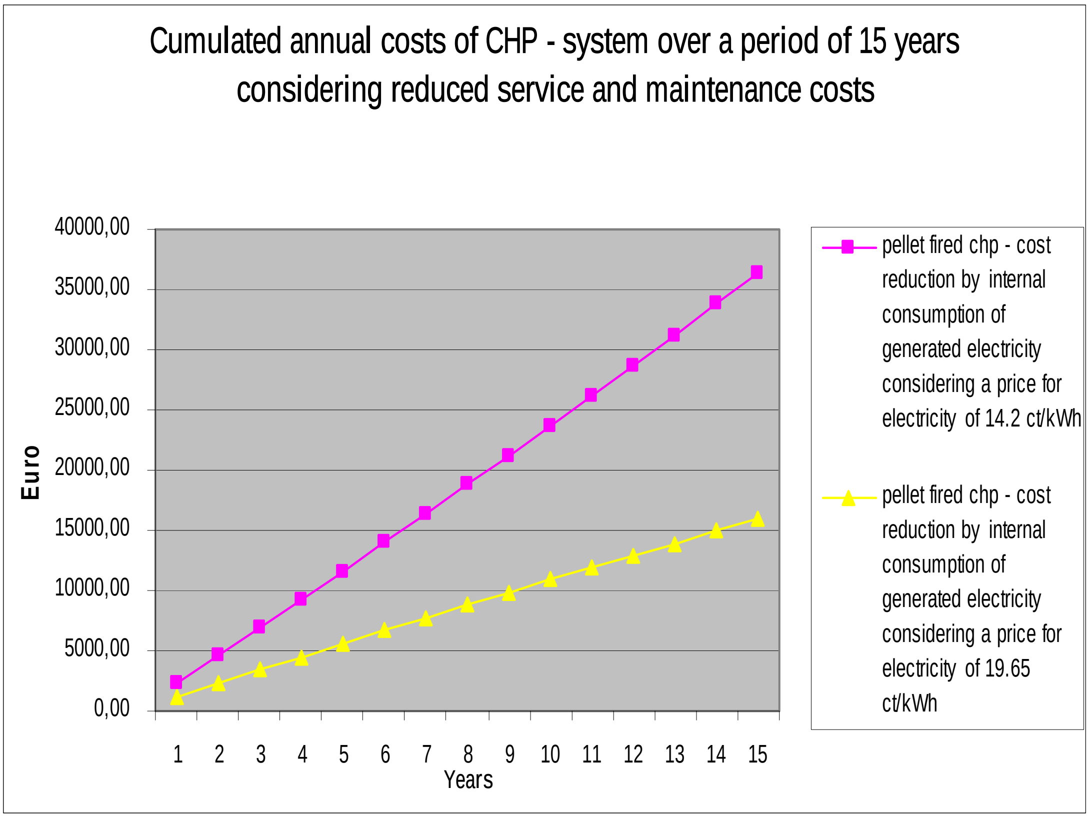

Figure 11: Cumulated annual costs of CHP - system over a period of 15 years and reduced service and maintenance costs

Figure 11 illustrates the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a low market price for electricity of 14.2 ct/kWh (pink curve) as well as equal service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input. In this case the cumulated annual costs of the CHP - system would be € 36385 after a period of 15 years.

The yellow curve in figure 11 shows the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a high market price for electricity of 19.65 ct/kWh (yellow curve) as well as equal service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input. In this case the cumulated annual costs of the CHP - system would be € 15894 after a period of 15 years.

In both cases the mean annual inflation rate is calculated with 3 %.

Figure 11 shows that the annual costs and cumulated costs of the CHP – system are strongly influenced by the annual service and maintenance costs. *The lower the annual service and maintenance costs are the lower are the annual and cumulated costs of the CHP – system*.

But it has to be remarked that the Sunmachine Pellet is a very young product and that there are *no figures available about costs for maintenance and service and lifetime* of this engine which causes a serious risk for the whole investment.

3. *Cumulated annual costs of CHP - system over a period of 15 years considering 4 % price increase for electricity*

Considering the annually growing demand of electrical energy it can be expected that the price for electricity will increase more rapidly than the annual mean inflation rate.

A market study[103] regarding price development for electricity for private households between 2000 and 2008 evaluated an increase of prices for electricity on average of about 35 % within these eight years which would correspond to an annual increase of about 4 %.

Assuming a current price for electricity for private consumers in the city of Graz of about 14.2 ct/kWh respectively 19.65 ct/kWh and taking a potential annual price increase for electrical energy of 4 % into account the annual cost evaluation for the pellet fired stirling engine CHP – system would change as demonstrated in figure 12.

[103] http://www.verivox.de/Power/strompreis.asp, accessed June 30th, 2008.

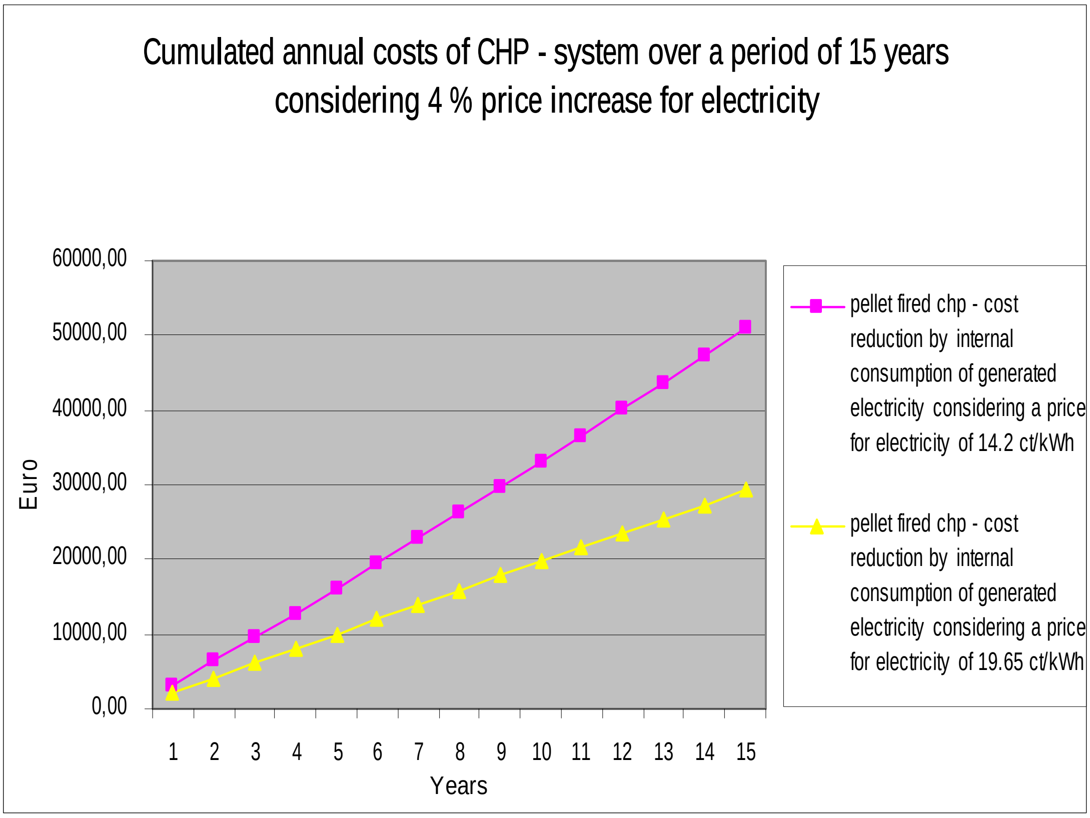

Figure 12: Cumulated annual costs of CHP - system over a period of 15 years and 4 % annual price increase for electricity

The pink curve in figure 12 shows the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a low market price for electricity of 14.2 ct/kWh as well as a potential annual price increase of 4 % for electricity. In this case the cumulated annual costs of the CHP - system would be € 50912 after a period of 15 years.

The yellow curve in figure 12 shows the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a high market price for electricity of 19.65 ct/kWh as well as a potential annual price increase of 4 % for electricity. In this case the cumulated annual costs of the CHP - system would be € 29235 after a period of 15 years. In both cases the mean annual inflation rate is calculated with 3 %.

Figure 12 shows that the annual costs and cumulated costs of the CHP – system are also influenced by a potential annual price increase of 4 % for electricity. *The higher the price increase for electricity is the lower are the annual and cumulated costs of the CHP – system*.

4. Cumulated annual costs of CHP - system over a period of 15 years considering 4 % price increase for electricity and reduced service and maintenance costs

Taking a potential annual price increase of 4 % for electricity into account and assuming that the annual service and maintenance costs of the pellet fired stirling CHP – system would be during a calculated lifetime of 15 years as high as the service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input the cumulated annual costs of CHP – system would be as high as shown in figure 13.

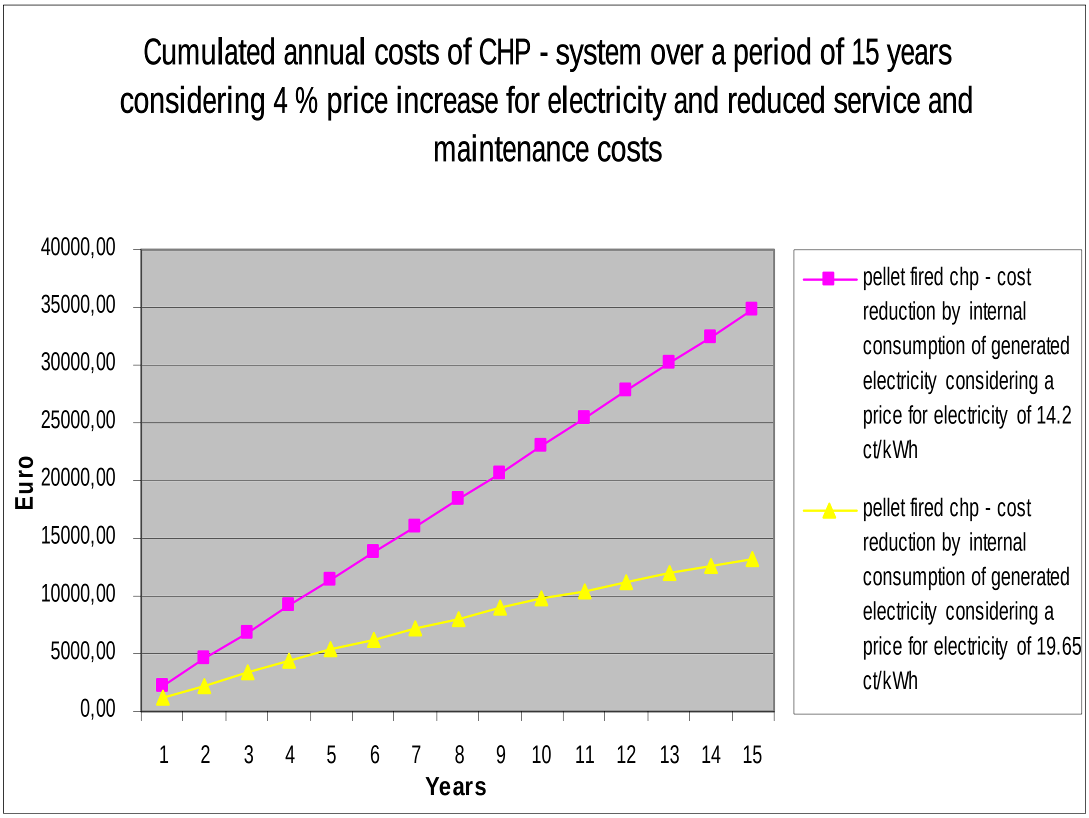

Figure 13: Cumulated annual costs of CHP - system over a period of 15 years and 4 % annual price increase for electricity and reduced service and maintenance costs

Figure 13 demonstrates the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a low market price for electricity of 14.2 ct/kWh (pink curve) and equal service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input as well as a potential annual price increase of 4 % for electricity. In this case the cumulated annual costs of the CHP - system would be € 34849 after a period of 15 years.

The yellow curve in figure 13 shows the cumulated annual costs of the CHP - system over a period of 15 years taking into account a cost reduction by internal consumption of generated electricity and considering a high market price for electricity of 19.65 ct/kWh and equal service and maintenance costs of a wood pellet fired – system of the same capacity of fuel input as well as a potential annual price increase of 4 % for electricity. In this case the cumulated annual costs of the CHP - system would be € 13172 after a period of 15 years.

In both cases the mean annual inflation rate is calculated with 3 %.

Comparing figure 13 to figure 10, 11 and 12 it can be said that the *annual costs and cumulated costs of the CHP – system would be the lowest assuming a cost reduction by internal consumption of generated electricity considering a price for electricity of 19.65 ct/kWh as well as equal service and maintenance costs of the CHP – system and of a wood pellet fired – system of the same capacity of fuel input and a higher inflation rate of 4 % for electricity.*

Table 9 gives an overview of the cumulated annual costs of the CHP - system considering the available subsidies, different cost reductions by internal consumption of the produced electricity and an annual mean inflation rate of 3 % as well as a higher inflation rate of 4 % for electricity.

Table 9: Cumulated annual costs of the CHP - system considering different boundary conditions regarding figure 10, 11, 12, and 13

Cumulated annual costs of the chp – system regarding figure 10, 11, 12, and 13							
Figure 10	Figure 10	Figure 11	Figure 11	Figure 12	Figure 12	Figure 13	Figure 13
Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building	Assuming own consumption of produced electricity within building
capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)	capital investment grant of Euro 4200 (Province of Styria) additional grant of Euro 800 (Kommunalkredit Public Consulting GmbH)
		assuming equal service and maintenance costs of chp – system and wood pellet fired boiler	assuming equal service and maintenance costs of chp – system and wood pellet fired boiler			assuming equal service and maintenance costs of chp – system and wood pellet fired boiler	assuming equal service and maintenance costs of chp – system and wood pellet fired boiler
considering a price for electricity of 14.2 ct/kWh	considering a price for electricity of 19.65 ct/kWh	considering a price for electricity of 14.2 ct/kWh	considering a price for electricity of 19.65 ct/kWh	considering a price for electricity of 14.2 ct/kWh and 4 % annual price increase for electricity	considering a price for electricity of 19.65 ct/kWh and 4 % annual price increase for electricity	considering a price for electricity of 14.2 ct/kWh and 4 % annual price increase for electricity	considering a price for electricity of 19.65 ct/kWh and 4 % annual price increase for electricity
€ 52448,40	€ 31957,05	€ 36385,65	€ 15894,3	€ 50912,25	€ 29235,45	€ 34849,50	€ 13172,7

The comparison points out that the *annual costs and cumulated costs of the CHP – system are strongly influenced by the annual costs of service and maintenance and the market price for electricity.*

Higher market prices for electricity lead to higher cost reductions if the generated electrical power is consumed fully within the multi-storey residential building. As a consequence out of this the annual and cumulated costs of the CHP – system are reduced.

Also lower annual service and maintenance costs reduce the annual and cumulated costs of the CHP – system.

The cumulated annual costs of the CHP - system would be € 52448 after a period of 15 years assuming a cost reduction by internal consumption of generated electricity and considering a price for electricity of 14.2 ct/kWh (worst boundary conditions illustrated in figure 10).

The cumulated annual costs of the CHP – system would be € 13172 after a period of 15 years assuming a cost reduction by internal consumption of generated electricity and considering a price for electricity of 19.65 ct/kWh as well as equal service and maintenance costs of the CHP – system and of a wood pellet fired – system of the same capacity of fuel input and a higher inflation rate of 4 % for electricity (best boundary conditions illustrated in figure 13).

So the difference regarding the cumulated costs of the CHP – system after a period of 15 years between the above described best case and the worst case is € 39276 which is illustrated in figure 14.

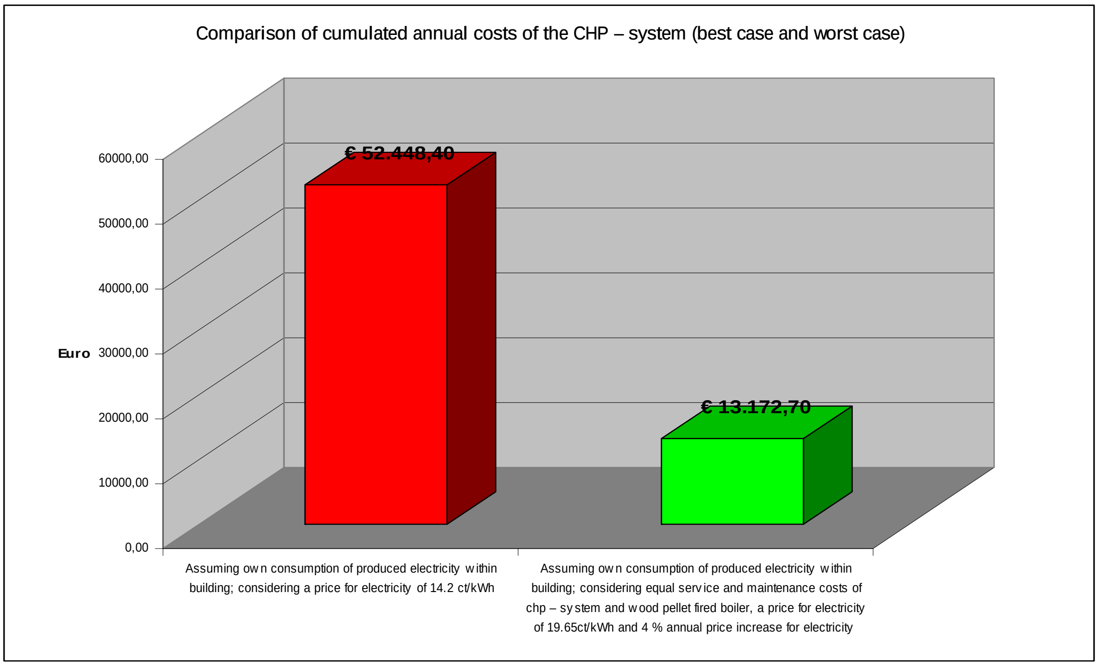

Figure 14: Comparison of cumulated annual costs of the CHP – system after a period of 15 years (best case and worst case)

In Table 9 the capital expenditure budgeting based on the annuity method for the private used multi-family house is illustrated.

Table 10[104]: Capital expenditure budgeting based on the annuity method

Capital Expenditure Budgeting	unit	short term	formula	pellet fired CHP; 70 % thermal efficiency; cost reduction by internal consumption of generated electricity considering a price for electricity of 14.2 ct/kWh	pellet fired CHP; 70 % thermal efficiency; cost reduction by internal consumption of generated electricity considering a price for electricity of 19.65 ct/kWh	pellet fired CHP; 70 % thermal efficiency; cost reduction by internal consumption of generated electricity considering a price for electricity of 14.2 ct/kWh; assuming equal service costs of a wood pellet fired boiler of the same capacity	pellet fired CHP; 70 % thermal efficiency; cost reduction by internal consumption of generated electricity considering a price for electricity of 19.65 ct/kWh; assuming equal service costs of a wood pellet fired boiler of the same capacity
heating fuel costs (ct per kWh)				3,42	3,42	3,42	3,42
real interest rate i eq = 5%; i de = 8%; 3 % inflation; equity = 30% of invest.; debt 70%of invest.	%	i	in = i of eq x % of eq + i of de x % of de; i = in - rate of price increase	4,1	4,1	4,1	4,1
period of observation (15 years lifetime expected)	years	T	15	15	15	15	15
annuity factor		a	(i x (1 + i)T) / ((1 + i)T - 1)	4,1	4,1	4,1	4,1
Basic data							
calorific value of heating fuel (kWh)	kg			4,9	4,9	4,9	4,9
annually produced heat amount	MWh/a	E		36,06	36,06	36,06	36,06
annual fuel demand	t	m1		10,51	10,51	10,51	10,51
specific fuel costs	€/t	b1		€ 175	€ 175	€ 175	€ 175
fuel demand for peak load	MWj/a	m2	no additional boiler installed				
specific fuel costs für peak load	€/MWh	b2	no additional boiler installed				
manpower requirements	mp/a	p		0	0	0	0
Costs of capital							
net investment costs	P	I		41990	41990	41990	41990
subsidies	P	F		5000	5000	5000	5000
remaining costs of capital	P	K	I - F	36990	36990	36990	36990
Annual costs							
interest payments	€/a	AN	K x a	€ 1.517	€ 1.517	€ 1.517	€ 1.517
annual costs of fuel demand	€/a	B1	b1 x m1	€ 1.839	€ 1.839	€ 1.839	€ 1.839
annual costs of maximum head load	€/a	B2	b2 x m2	€ 0	€ 0	€ 0	€ 0
costs of manpower requirements	€/a	P	p x 75	€ 0	€ 0	€ 0	€ 0
costs for service and maintenance	€/a	W	I x 0,02	€ 840	€ 840	€ 250	€ 250
additional costs	€/a	S	I x 0,01	€ 420	€ 420	€ 125	€ 420
operating expenses in total	€/a	G	B1 + B2 + P + W +S	€ 3.099	€ 3.099	€ 2.214	€ 2.509
cost reduction by sold electricity	€/a	El	EL	€ 1.463	€ 2.024	€ 1.463	€ 2.024
annual charges in total	€/a	Z	G - EL + AN	€ 3.153	€ 2.592	€ 2.268	€ 2.002
Specific costs							
specific heat generation costs	€/kWh	z	Z/E	€ 0,0867	€ 0,0713	€ 0,0624	€ 0,0551

104 http://www.lsi.at/news, accessed June 30th, 2008; http://www.holzenergie.net, accessed June 30th, 2008; Brandl/Strasser (2007), p. 7; Fachagentur Nachwachsende Rohstoffe (2005), p. 286; http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.

6. Conclusion

Due to the fact that the pellet fired stirling engine CHP – system has a thermal output of 10.5 kW and the maximum head load for the renovated building is 11 kW and considering the fact that the head load for the building will be below the above mentioned 11 kW nearby during the whole year the *"Sunmachine Pellet" can cover the energy demand for space heating of 17810 kWh/a of the analysed multi-family house* in Graz.

Also the calculated energy demand for hot water preparation for the multi-family house in Graz of 18250 kWh/a can be covered by the "Sunmachine Pellet". The existing hydraulic system is equipped with an 800 l hot water storage tank which covers the average hot water demand for 10 persons for about 1 ½ days so that the pellet fired stirling engine CHP – system can heat up the hot water during the time of a night setback.

Based on the heat load calculation regarding the building after renovation and a calculated hot water demand for 10 persons the *annual heat demand in total would be 36060 kWh/a for the multi-family house.*

Based on the fact that the Sunmachine Pellet[105] has a maximum heat output of 10.5 kW the pellet fired stirling engine *CHP – system needs 3434 full load hours to cover the annual heat demand of 36060 kWh/a.*

To cover this annual heat demand 10.5 t of wood pellet are needed. *The Sunmachine Pellet would produce up to 10302 kWh/a electricity out of this 10.5 t of wood pellet.*

Considering the fact that in Austria one person consumes on the average 1.100 kWh[106] electricity per year the *Sunmachine Pellet would cover up to 90 % of this statistical electricity demand per inhabitant of the analysed building.*

Due to the fact that even outside the annual heating period from September to April there is still a high daily heat demand which has to be covered by the CHP whereas

105 http://www.sunmachine.com/download/datenblatt/datenblatt_sm.pdf, accessed June 25th, 2008.
106 ELEKTROGERÄTE IM HAUSHALT, O.Ö. Energiesparverband, http://www.wsed.at/wsed/fileadmin/esv_files/Info_und_Service, accessed June 30th, 2008.

electrical power is produced as a by-product it can be assumed *that the generated electrical power is consumed fully within the multi-storey residential building by its dwellers.*

As a consequence out of this the financial contribution of the CHP-system is that the *generated electrical power reduces the annual electricity bill by the electricity amount produced by the CHP multiplied by the current price for electrical energy of the electricity provider.*

As it was mentioned already before *in the city of Graz the price for electricity for private consumers depends on the electricity supplier and is currently between 14.2 ct/kWh and 19.6 ct/kWh*[107] and it can be expected that this price will increase in the coming years.

Considering 3434 full load hours per year which would lead to an electrical energy production of the CHP of 10302 kWh the annual savings would be € 1463 per year considering a market price for electricity of 14.2 ct/kWh and € 2024 per year considering a market price for electricity of 19.65 ct/kWh.

In the present case study the *total costs of investment for the installation of the CHP-system are estimated with € 41.990 VAT excluded.*

The total costs per year fixed by consumption of € 1.837 VAT excluded are calculated considering an annual demand of wood pellet of 10.5 t for the multi-family house and a current price for wood pellet of € 175/t VAT excluded.

The total costs fixed by operation per year like costs for service and maintenance of the pellet fired CHP-system are estimated with € 1500 VAT excluded.

As the Sunmachine Pellet is a very young product *there are no figures available about costs for maintenance and service over the whole lifetime of this engine which causes some risks for the whole investment.*

[107] http://tarifkalkulator.e-control.at/tarifkalkulator/TKStart.do, accessed October 10th, 2008.

Regarding these circumstances and based on the figures and tables shown in chapter 5 table 11 gives an overview of the evaluated most favourable and most unfavourable boundary conditions of “Sunmachine Pellet” in the present feasibility study.

Table 11: Comparison of cumulated annual costs of the CHP – system (best case and worst case)

Cumulated annual costs of the chp - system after a period of 15 years	
Assuming own consumption of produced electricity within building; considering a price for electricity of 14.2 ct/kWh	Assuming own consumption of produced electricity within building; considering equal service and maintenance costs of CHP – system and wood pellet fired boiler, a price for electricity of 19.65 ct/kWh and 4 % annual price increase for electricity
€ 52448,40	€ 13172,7

Table 11 illustrates that the cumulated savings after a period of 15 years would be € 39276 considering the most favourable boundary conditions assuming own consumption of produced electricity within the building, considering equal service and maintenance costs of the CHP – system and a wood pellet fired boiler as well as a price for electricity of 19.65 ct/kWh and 4 % annual price increase for electricity.

Under consideration of the results of figure 10, 11, 12 and 13 it can be said that the annual costs and cumulated costs of the CHP – system always depends on the special conditions of the single case.

As it was already mentioned above the Sunmachine Pellet is a very young product and there are *no figures available about costs for maintenance and service and lifetime* of this engine which causes a serious risk for the whole investment.

Another *element of uncertainty is the price development of wood pellet* which doubled e.g. in Austria in 2006 caused by a strong demand.

Based on the legal framework of the Province of Styria the installation of a Sunmachine Pellet is currently not possible under the circumstances of the present feasibility study.

As it was pointed out it chapter 5 of this master thesis a single or general approval for specific heating systems is needed to allow the installation of these systems in the Province of Styria.

Regarding the available information from the Austrian distributor of the Sunmachine Pellet this approval is not available up to now for the Province of Styria.

Finally it can be pointed out that *it is not allowed to install and run a Sunmachine Pellet unit for buildings of private use or commercial facilities within the area of the Province of Styria up to now.*

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