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Design, Construction, Monitoring and Life Cycle Assessment of Integrated Solar System

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unter der Leitung von

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Undertaken to obtain the academic degree „Doctor of Technical Science“

Under the supervision of

Univ.Doz.Dipl.-Ing.Dr.techn. Andreas Windsperger

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Abstract

This dissertation aims to analyze the environmental effect of the presented innovative energy supply method in households. The research considers the thermal energy demand of different domestic appliances, domestic hot water and space heating within the system. To provide thermal energy services with renewable energies, design, construction, monitoring and life cycle assessment of the integrated solar system have been carried out. The results show the positive effects of the introduced integrated solar thermal system concerning the environmental and financial aspects.

Keywords: Energy analysis, Integrated solar system, Life cycle assessment, Renewable energy. Solar systems

Abstrakt

Ziel dieser Dissertation ist der Erhalt maßgeblicher Informationen über die technischen Möglichkeiten eines solarthermischen Energiekonzeptes als wesentlichen Beitrag zur Reduzierung von CO_2 Emissionen im Zusammenhang mit häuslichem Energiebedarf. Diese Arbeit beschäftigt sich mit den tatsächlichen thermalen Energieverbrauchern durchschnittlicher Einfamilienhaushalte unter Verwendung solarthermischer Energie für verschiedene Haushaltsgeräte, Warmwasserbereitung und Raumheizung. In diesem Zusammenhang wurde eine entsprechende solarthermische Anlage konzipiert, gebaut und im Rahmen von Versuchsreihen Information zur Auswertung gewonnen. Die Bewertung lebenszyklischer Aspekte bildet einen weiteren wesentlichen Bestandteil. Diese Dissertation zeigt die positiven Auswirkungen solarthermischer Anlagen unter ökologischen und ökonomischen Gesichtspunkten.

Schlüsselwörter: Energieanalyse, Erneuerbare Energie, Lebenszyklusanalyse, Solarthermie

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Nomenclature and Abbreviations:

ΔT	thermal differentiate (K)
C_p	Thermal capacity ($\frac{J}{kg.K}$)
CHP	cogeneration or combined heat and power
CEI	Cumulative energy input
DW	Dish washer
DHW	Domestic hot water
Elec.	Electricity
EU	European Union
E_{Aux}	The energy from the wood boiler and electrical energy consumption
E_{Par}	Pump energy consumption
HEX	Heat exchanger
LCA	Life cycle assessment
PV	Photo voltaic
PID	proportional integral derivative controller
Q_{Sol}	Solar heat energy delivered by the solar thermal collectors to the system
$Q_{use\ Building}$	Space heating energy consumption to maintain the building temperature on the set point value
$Q_{use\ WW}$	Domestic hot water energy consumption
Q_{Int}	Thermal energy
WM	Washing machine

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Chapter 1: INTRODUCTION

1.1. Einleitung

Ziel dieser Dissertation ist der Erhalt maßgeblicher Informationen über die technischen Möglichkeiten eines solarthermischen Energiekonzeptes als wesentlichen Beitrag zur Reduzierung von CO_2 Emissionen im Zusammenhang mit häuslichem Energiebedarf.

Diese Arbeit beschäftigt sich mit den tatsächlichen thermalen Energieverbrauchern durchschnittlicher Einfamilienhaushalte unter Verwendung solarthermischer Energie für verschiedene Haushaltsgeräte, Warmwasserbereitung und Raumheizung. In diesem Zusammenhang wurde eine entsprechende solarthermische Anlage konzipiert, gebaut und im Rahmen von Versuchsreihen Information zur Auswertung gewonnen. Die Bewertung lebenszyklischer Aspekte bildet einen weiteren wesentlichen Teil dieser Arbeit.

Die Konzeption dieser solarthermischen Anlage nimmt Bezug auf die verschiedenen Teile einer Solaranlage wie Kollektor- und Speichergrößen. Die angepasste Gestaltung eines entsprechenden regelungstechnischen Konzeptes hat ebenfalls bedeutende Auswirkung auf die optimale Nutzung von solarer und anderer erneuerbarer Energieformen, wie ein im System integrierter Biomassekessel.

Nach dem Bau dieser Anlage in Böheimkirchen, Niederösterreich, wurde diese mit einem entsprechenden Monitoring-System ausgestattet. Dieses liefert die eigentlichen Analysemöglichkeiten und Anlageninformationen über Energiebereitstellung und den Energieverbrauch als Basis für die weiteren Arbeiten. Als eines der Hauptergebnisse dieser Arbeit, zeigt eine Lebenszyklusanalyse die beachtliche Einsparung von CO_2 Emissionen über den Anlagenzeitraum.

1.2. Motivation for study

Consumer activities can be linked to economic activities, because consumption leads to more production. A major part of the consumer activities is determined in households, therefore most of the environmental load in an economy can be allocated to households (Biesiot and Noorman, 1999).

Using energy causes the environmental loads and emissions of greenhouse gases into ecosystem. Sustainable development needs that energy generation and consumption be optimized, in a way that the energy related environmental impacts be minimized and there is no limiting on the energy consumption.

Energy development is increasingly dominated by global concerns of over-population, air pollution, fresh water pollution, coastal pollution deforestation, biodiversity loss, and global climate deterioration. (Lior, 2007). Table below shows the gross energy consumption of the world, EU-27 and some other selected countries. The table shows the gross world energy consumption increased by 30.56% from 1990 to 200, and is therefore three times higher than the increase in gross energy consumption of the EU-27. (Weiss & Biermayr)

Table 1: Gross energy consumption worldwide (TWh) Source: EU 2008 - (Weiss & Biermayr)

Year	World	United State	EU-27	China	Russia	India	Japan
1990	101.852	22.416	19.307	10.163	10.214	3.720	5.169
1991	102.562	22.604	19.350	10.093	9.848	3.867	5.233
1992	102.666	23.051	18.944	10.450	9.020	4.023	5.349
1993	103.836	23.524	18.929	11.066	8.695	4.112	5.382
1994	104.647	23.997	18.863	11.558	7.598	4.269	5.674
1995	107.269	24.307	19.334	12.345	7.308	4.506	5.805
1996	110.277	24.928	19.991	12.797	7.236	4.656	5.967
1997	111.346	25.188	19.814	12.845	6.921	4.838	6.036
1998	111.988	25.418	20.022	12.869	6.761	4.944	5.959
1999	114.248	26.082	19.889	12.931	7.013	5.244	6.044
2000	116.639	26.826	20.037	13.035	7.140	5.345	6.136
2001	117.087	26.280	20.497	13.024	7.226	5.422	6.041
2002	119.717	26.630	20.443	14.092	7.185	5.568	6.046
2003	123.706	26.549	20.967	16.016	7.439	5.707	5.993
2004	129.507	27.081	21.209	18.609	7.461	6.054	6.190
2005	132.976	27.218	21.233	20.181	7.521	6.249	6.169
2006			21.227				

The Fossil energy and renewable sources are the main candidates for energy supply in the entire world. Fossil resources have undergone transformations over periods of millions of years. Fossil fuels are burned in conventional Carnot cycle, oil in vehicles, natural gas in furnaces and turbines for heat and electricity, and coal in Rankine cycle. The aim of all energy planning systems is to reach the higher conversion efficiency. Coal, oil and natural gas are polluting and unsustainable resources to generate energy. They have the ratio of resources to production (R/P) as: R/P (oil) ≈40 years, for R/P (gas) ≈60 years, for R/P (coal) =200+ years and it is mostly rising. There will probably be sufficient oil and gas for this century and coal for 2 or more (Lior, 2007).

Using fossil resources cause a huge amount of environmental loads, although there are some technologies that they claim to reduce the amount of CO_2 emission and provide clean fossil for example using membrane techniques, catalyst process that convert CO_2 to methanol, and cryogenic processes that provide solid CO_2. These techniques absorb CO_2 after conventional combustion and are quite helpful but they need considerable energy input.

There is an increasing demand for economically and environmentally efficient energy generation and consumption. Nonetheless many of alternative energy solutions are expensive and cannot compete with fossil energy, natural gas, oil and coal.

Renewable energies decrease the emission compare to fossil resources. But it should be considered that it may increase the demand using renewable energies. The lack of a global price on carbon is also significant barrier to the competitiveness of renewables. The main renewable energy sources for energy extraction are direct sun, wind, hydro and biomass. Low temperature district heating by use of average outflows of heat from the interior of the earth could also be option for small cities. Solar panels produce heat and power but the areas in the earth that need high space heating demand have little solar radiation. (Sörensen, 2011)

Energy security and diversification of the energy mix is a major policy driver for renewables. The renewable energy sector is demonstrating its capacity to deliver cost reductions. Costs have been decreasing and a portfolio of renewable energy technologies is becoming cost competitive. Non-hydro renewables, such as wind and solar photovoltaic, are increasing at double-digit annual growth rates[2]. Wind and solar photovoltaic (PV) power generation are experiencing a costs decrease, and are becoming commercially competitive. Established technologies such as hydro and geothermal are often fully competitive and wind is also depending to the geographical situation competitive. However, economic barriers remain important in many cases.

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[2] http://www.iea.org

The provision of energy services in the EU-27 depends on the availability of fossil energy carriers. The major fossil types providing energy in the EU-27 are oil (36.9%), natural gas (24%), solid fuels (17.8%), nuclear (14%) and renewables (7.1%). (Weiss & Biermayr)

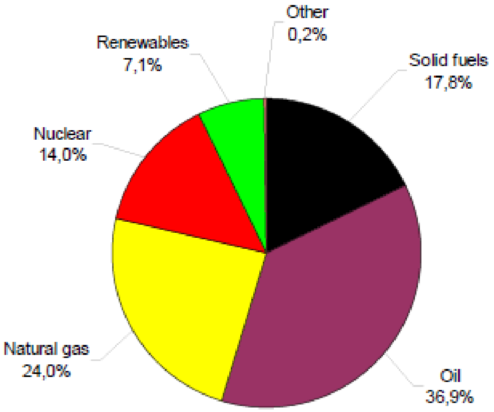

Figure 1: Gross inland energy consumption in EU-27 by fuel type in 2006, source: EU 2008- (Weiss & Biermayr)

To reduce dependency on fossil energy carriers, the member countries of the European Union have committed themselves to the European energy target "20-20-20". This means to increase the percentage of renewables used in final energy consumption, to reduce the primary energy use, and to decrease CO_2 emission below 1990 level, by 20% until 2020. [3]To achieve this goal a major contribution must be made in the field of heat generation from renewable energy since the heat and cooling production account for 49% of total energy demand in Europe (Weiss & Biermayr)

The EU needs to save energy, invest in low carbon alternatives, build intelligent and diversified energy networks and to integrate growing amounts of renewable energy. And specially focus on providing the thermal energy from renewable energies. Sine there are only three renewable energy sources used for heat production; biomass, geothermal and solar thermal; it is important to clarify how these technologies can contribute to achieve the target of renewable energy consumption.

Solar energy seems to be an environmental friendly option to produce energy. Although when solar collectors are manufactured the environmental issues again arise, as the toxic materials are using in the solar collectors. Solar thermal systems and Biomass are mainly

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[3] http://www.european-council.europa.eu/

required for the generation of low-temperature heat. The use of geothermal energy is only accessible in a few places. In the following figure, Figure 2, the solar energy technology potential has been compared with wind, biomass, geothermal and ocean. The figure represents that solar energy has the largest potential supply respect to other forms of renewable energies.

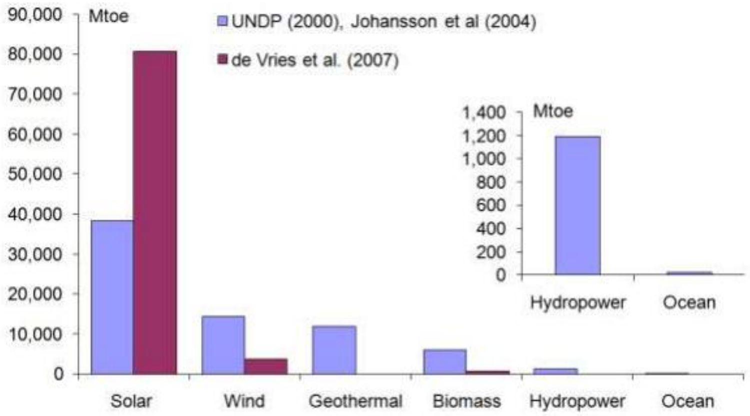

Figure 2: Technical Potential of Different Renewable Technologies. Ref: (J. Byrne, 2010)

Globally, building energy uses nearly 30%-40% of total primary energy demand, and the building sector is expected to play a major role in reducing CO2 emission to mitigate climate change (UNEP, 2007). In recent years the concern has raised about energy use in buildings and specially to reduce energy for space heating and thermal energy demand, to reduce transmission lost and to optimize the solar gains. (Verbeeck & Hens, 2007). Low energy buildings and efficient housing become more common in the world, and it seems to need more innovative approaches to design a system that can provide energy from the renewable resources in an efficient way for housing. *Zero energy building* is now one of the interesting topics for researchers as a solution to minimize the primary energy consumption. Zero energy building is defined as zero net emission building. It is a residential or commercial building with reduced energy needs and energy supplied with renewable energy forms during the life cycle of the building. The operational energy demand also should be supplied in site.

Energy is used during the life cycle of buildings for material products, transport, construction, operation, maintenance and demolition, but the most share of energy usage belongs to operation. This dissertation concentrates on operational energy usage of the buildings.

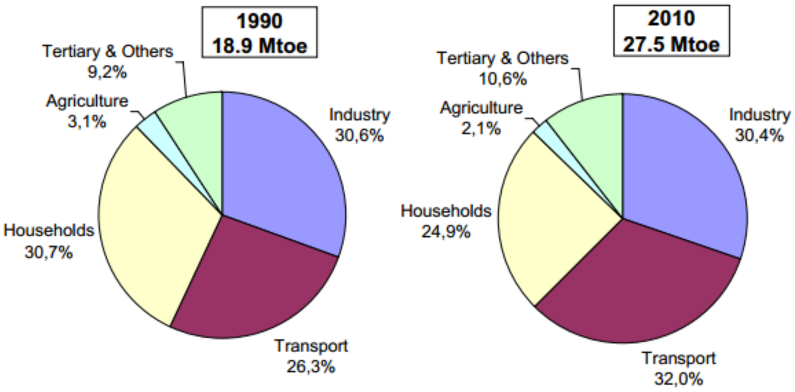

Figure 3: Final energy consumption by sector in Austria –Ref: (Jellinek, 2012)

1.3. Objective and scope of the study

The suggested energy supply system, *integrated solar system*, designed to help to significantly reduce CO_2 emissions and other environmental loads by targeting actual household energy demands without additional constraint on consumer spending energy.

An integrated solar production regime shall ensure the provision of thermal energy services. The design of this production regime, which covers such aspects as the sizing of the different parts of the solar system including collector area and storage tank, is aimed at optimizing the solar and biomass back-up supply in the system. Programming a control system has also a crucial and important role for optimized use of the solar and other renewable energy provider in the system.

The corresponding energy system has been constructed and monitored with a view to observe and analyse the definitive information of the demand – supply data of the system. In particular, this information has served as an input for the life cycle assessment of the total energy service. The construction of the prototype system has been done with the centre of appropriate technology[4]-Technical university Vienna, in one of the cities in lower Austria-Böheimkirchen.

The suggested energy supply system, integrated *solar system,* is a combination of hot fill dishwasher, washing machine and dryer with solar system and biomass back-up.

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[4] GrAT-Gruppe Angepasste Technologie

Solar energy can be a popular renewable resource to provide energy for the households due to: direct and easy usability, renewable and continuity, being safe, being cheap, being environmentally friendly and as it cannot be on the monopoly of any institution and it is available for all places in the world, but this may result in an increased use of materials and more environmental pressure on the ecosystem. Considering that solar cells manufacturing is very energy intensive and toxic materials are used to provide the solar collectors; the question that needs to be answered is weather the introduced strategy is more environmentally friendly than conventional ways of providing energy for domestic units. Then the ultimate step of the research consists of conciliating the collected information from the prototype integrated solar system to gear it towards the life cycle assessment of the total energy system and economical assessment.

In this work the primary energy use and CO_2 emission for the operation of conventional and two other suggested scenarios to provide energy for residential buildings have been analyzed.

The main focuses would be:

- Accurate designing of a prototype solar thermal system; sizing the different parts of solar layout, i.e., Collector area and Storage volume
- Elaborating the control System
- Monitoring, data acquisition, simulating and analyzing the energy demand and energy performance of the different endpoints in the system
- Life cycle assessment of the hot-fill appliances and comparison with the conventional energy supply methods in the households appliances
- Economical assessment and sensitivity analysis
- Thermal simulation and analyzing the system performance under different weather conditions

Chapter 2: LITERATURE REVIEW

In recent years many researches have been conducted to analyze energy and environmental impacts of residential units with different energy services and different constructions. The studies differ in *methodology*, and different *level of a building energy life cycle*, like operation, construction and material productions. In most of the studies the environmental loads are measured in energy use figures and mainly energy related greenhouse gas emissions.

A proper analysis (an evaluation) of the environmental load of consumption is important in the context of sustainable development. For example (Gustavsson & Joelsson, 2010) showed that it is essential to consider primary energy use when analyzing building operation energy, instead of focusing final energy. They presented that although a passive house that uses electricity for space heating has lower final energy consumption than a normal building that uses district heating, but the primary energy consumption of the normal conventional building is less than passive house.

The task of calculating the environmental load and primary energy can be methodologically approached from two different directions:

- Bottom-up, based on process analysis (PA)
- Top-down based on environmental input-output (EIO)

Both methodologies need to capture a full life cycle assessment (LCA). Bottom-up process analysis has been developed to understand the environmental impacts of individual products from candle to grave (Wiedmann & Minx, 2008). The bottom-up nature of life cycle assessment in this methods means that this process analysis suffers from a system boundary problem (Lenzen, 2001). The other challenge of this analysis is consistency. As the process analysis procedure usually needs the use of information from different databases, which are usually not consistent (Tukker & Jansen, 2006).

The second method, top-down based on environmental input–output, consists a table that describes the relations between sectors and final demand. With the symmetric input–output table it is possible to calculate the indirect impacts of consumption of goods and services. An input–output table combined with data on energy use results in the energy intensity of each sector. In combination with consistent environmental account data they can be used to establish carbon footprint estimates in a comprehensive and robust way taking into account all higher order impacts and setting the whole economic system as boundary. The suitability of this method to assess micro systems is limited, as it assumes homogeneity of prices, outputs and their carbon emissions at the sector level. (Wiedmann & Minx, 2008).

(Kok, Benders, & Moll, 2006) in their paper reviewed the main methods used in households energy consumption studies based on top-down method and environmental input-output analysis. They distinguished three main different types of approached in this method. All these methods are primarily based on top-down input–output analysis.

- Input-output energy analysis, based on national accounts
- Input-output energy analysis combined with household expenditure data
- Hybrid energy analysis, input–output analysis combined with process analysis

The following table provides an overview of the literature existing about energy analysis to investigate the environmental loads of households (Kok, Benders, & Moll, 2006)

Table 2: Overview of studies investigating the environmental load of households

Description	Conclusion
(Feist, 1997), Life-cycle Energy Analysis: Comparison of Low-energy house, Passive House, Self-sufficient.	Used cumulative energy input method to compare different building construction standards. The paper shows the cumulative energy input as a function of insulation. And presents that cumulative energy input drops greatly through thicker insulation. In a way that good insulation can cut the cumulative energy input by a factor of four.
(Lenzen, 1998), Primary energy and green gases embodied in Australian final consumption: an input-output analysis	The paper proves a large share of indirect energy and greenhouse gas requirements of households (65%), and the importance of indirect energy and greenhouse gas requirements for change.
(Wilting, Biesiot, & Moll, 1999), Analyzing potentials for reducing the energy requirement of households in the Netherlands	The main result of the paper is that technological and demand-side energy conservation options may lead to a reasonable reduction in the household energy requirements.
(Alfredsson, 2004), "Green" consumption—no solution for climate change	Green consumption patterns with the same level of consumption have only small effects on the energy and CO_2 requirements of households.

(Tsilingiridis, Martinopoulos, & Kyriakis, 2004), Life cycle environmental impact of a thermosyphonic domestic solar hot water system in comparison with electrical and gas water heating	The paper shows an adapted version of. “Eco-indicator ’99” Life Cycle Impact Assessment method used for evaluating the environmental impact over the life span of a thermosyphonic domestic solar hot water system.
(Bin & Dowlatabadi, 2005), Consumer life style approach to US energy use and the related CO2 emissions	The main results of the paper are: -Large share of indirect energy and CO_2 requirements of households. -Importance of direct and indirect requirements for policies on energy conservation and CO_2 mitigation
(Dodoo, Gustavsson, & Sathre, 2011)Building energy-efficiency standards in a life cycle primary energy perspective	Analyzed the life cycle primary energy use of a wood-frame apartment building designed to meet the current Swedish building code and showed the significance of a life cycle primary energy perspective and the choice of heating system in reducing energy use in the built environment.
(Thiers & Peuportier, 2012), Energy and environmental assessment of two high energy performance residential buildings	The focus of the paper is modeling and simulation to evaluate the heating load, thermal comfort level, and the impact indicators. A building with high energy performance tends to present a higher environmental performance than a standard building. But the choice of the construction materials and the equipment can strongly impact the environment either on a positive or negative way.

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Chapter3: RESEARCH HYPOTHESIS AND METHODOLOGY

In this chapter the innovative autonomous thermal energy system, *integrated solar system*, has been described. And the three suggested scenarios to provide building energy services have been explained. At the end the methodology to compare the three defined scenarios has been expounded.

3.1. *Integrated solar system*, the layout and assumptions

Households require energy for space heating and cooling. They need domestic hot water and also energy for cooking, washing, and other electrical devices. For the reduction of greenhouse gas emissions and the promotion of independence from fossil resources, on one hand, the energy consumption can be reduced with better construction standards like better insulation; on the other hand, autonomous energy system based on renewable energy sources and innovative energy supply systems can be practiced.

The strategy raised in this dissertation is shifting a part of household`s electrical energy supply to thermal energy, aiming to provide more sustainable and efficient energy system, to save the primary energy and to reduce the environmental pollution. Figure 4 exemplifies the part of residential electricity demand that can be provided with thermal energy instead.

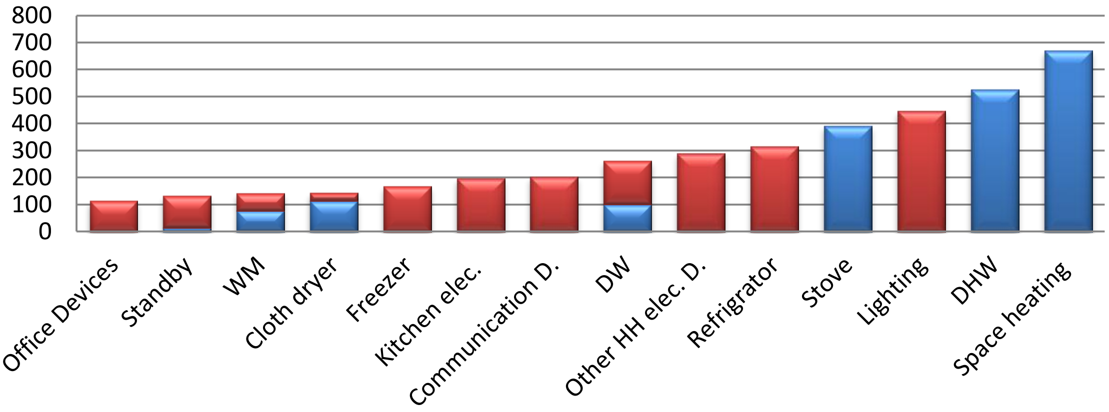

Figure 4: The electrical households energy consumption in Austria(The blue parts are the share of electrical energy that can be shifted to thermal energy supply)

Shifting the electrical energy demand to thermal energy demand can involve the individual consumers in renewable energy production and provide higher energy efficiency systems, especially if the thermal demand of the households be provided with green energies like thermal solar.

In the suggested *solar integrated system*, the space heating plus the domestic hot/warm water for the entire house are provided with the solar heating and an appropriate energy back up. Besides that, the dishwasher, washing-machines, and cloth dryer have direct hot water feed to save the electricity consumption.

As the schematic layout of the energy unit in shows, the energy from solar collectors and the biomass boiler supply the demanded warm/hot water for wall heating system (space heating), cloth dryer, water taps, washing machine and dishwasher. To do the monitoring and energy analysis this system has been constructed in Böheimkirchen, lower Austria. In the next chapter the installation and monitoring of the system have been discussed in detail.

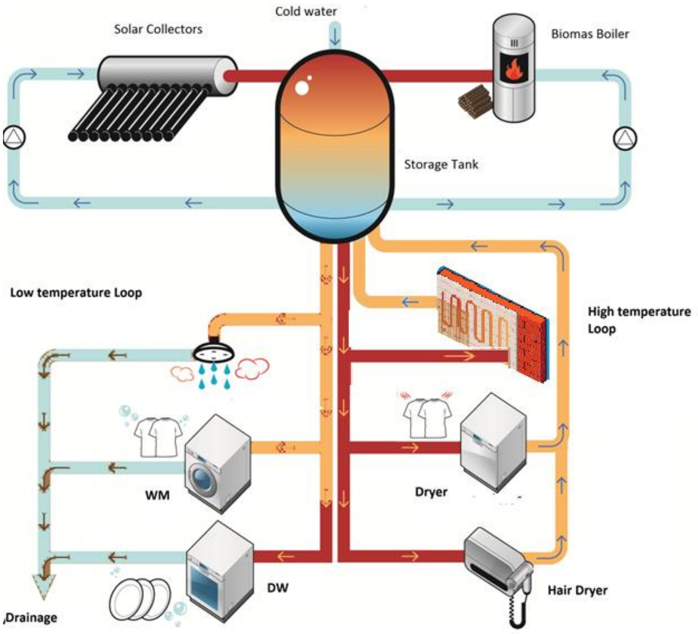

Figure 5: Thermal energy System Layout- Prototype in Böheimkirchen –Lower Austria (GrAT)

3.2. Research hypothesis

Sustainable developments needs that energy demand and supplied be matched in a way that there is no constraints on consumer and environmental impacts be minimized. Then a proper analysis and evaluation of the environmental load of consumption is important in the context of sustainable energy supply service. In this research analysis three different scenarios have been considered. Considering the different thermal and electrical energy in each scenario and also environmental impacts of producing different constituents, that can change the results.

Three different scenarios are:

- Scenario one: Conventional way producing energy for the households(reference system)
- Scenario two: Practice of integrated solar energy in a normal insulated energy building
- Scenario three: Practice of integrated solar energy in low energy building category

Here it is claimed that using the integrated solar energy system in one hand cause preventing the transformation of electrical to thermal energy in the appliances that consequent increasing the performance of the individual systems and leads to lower energy costs for consumers. On the other hand, as the energy is provided in site, it prevents the transportation loss, and reduces the total energy consumption and carbon footprint.

The hypothesis aiming to be answered is weather scenario two and three can show better environmental impact regarding primary energy consumption and CO_2 emissions in their energy life cycle relative to conventional way of producing energy for the households.

3.3. Research methodology

Although solar energy and biomass are regarded as a clean energy forms, both manufacture and final disposal of these technologies are connected with significant environmental transactions.

It is necessary therefore to evaluate each introduced scenarios accounting for the direct and indirect environmental impacts over their life cycle, called carbon footprint and primary energy.

A large number of methods and tools for describing environmental aspects have been developed for using in different types of decision context. Due to comprehensive approach life cycle assessment method employed in this research, to compare different technologies providing the thermal energy for households, and to distinguish the best scenario with the lowest impact on the environment.

3.3.1. Introduction of life cycle assessment (LCA)

Before describing the meaning of life cycle assessment, it is important to clear the meaning of two different terms about energy requirements in site:

- *Direct energy requirement*: The energy requirement that is literally consumed in or via households, e.g. electricity, natural gas and motor fuel
- *Indirect energy requirement*: The energy requirement of the production, distribution and disposal of all goods and services consumed by households

Life cycle assessment is an important environmentally oriented tool to evaluate a process or system regarding direct and indirect energy requirements of the system. LCA has been used in literature from 1980 with different terminologies like: integrated impact assessment, full cycle analysis, and cradle to grave method.

LCA in energy field normally is used to analyze different solutions. It helps to identify, classify and rank the environmental impacts of a product or a process and it provides the possibility for determining ways of minimization of the most opposing impacts.

This method uses an extended view to follow the inputs and outputs associated with the production, processes, and disposal of the system. By following the material and energy streams, LCA can give a good approximation of the environmental impacts that the system may present over the whole lifetime of a product or process, starting from potential global warming impact, human health risk, total global warming potential, extraction of raw material, environmental impact production, transportation, distribution, usage and waste. Further interpretation of an LCA will target the areas of high environmental impacts assist in choosing more environmentally friendly alternatives. (Bukowski M., 2012)

3.3.2. LCA main steps

LCA is composed of four main stages: (i) goal, which refers to the purpose of the analysis and the application of the results, and scope definition which includes boundaries, time period of the study, technology, and types of impacts to consider; (ii) setting up data inventory, that consists in analyzing the processes flow, collecting data (inputs), defining system boundaries and processing the data (outputs); (iii) impact assessment, that in this study is related to the energy consumption and CO_2emissions, and (iv) interpretation of the results. (A.F.Ferreira, 2011)

The methodology used in LCA will take into account the whole life cycle of products .The impacts output will be firstly presented in physical terms (e.g. kg of CO_2), divided into parts of different life cycle phases (assembling, use, distribution, end of life, ...). Then the physical parameters will be summed up by damage category (e.g.: global warming, as weighted addition of greenhouse gases), as follow:

- *global warming*
- *acid rain*
- *ozone depletion*
- *resource consumption*
- *energy consumption*

These calculations related to the natural environment characteristics impose a need of carrying out a complete life cycle assessment of a product, including production, usage and waste utilization phases (PN-EN ISO 1404- 2009).

3.3.3. LCA computer program – SimaPro

Because of the increasing complexity of such analysis in life cycle analysis, computer-aided tools play a key role to enable a complete assessment of a process's or product's impact on the environment. One of the most popular software is SimaPro, created by a Dutch company Pré Consultants[5].

SimaPro allows to model products and systems from a life cycle perspective and contains a number of impact assessment methods, which are used to calculate environmental impact results.

The SimaPro software in its version 7 provides a few pre-set environmental impact assessment methods, including CML (invented by the Centre of Environmental Science at the University of Leiden) versions 2000 and 2001, Ecopoints 97 (Swiss Agency for Environment, Forest and Landscape), Eco-indicator 95 and Eco-indicator 99 versions E (Egalitarian), H (Hierarchist), I (Individual) (PRé Consultants, sponsored by the Dutch government), EPS 2003 (Environmental Priority Strategies in Project Design, mainly by Centre for Environmental Assessment of Products and Material Systems, Chalmers University of Technology), IMPACT 2000 (combination of other databases by Pré Consultants), Ecological Scarcity 2006 (an extension to Ecopoints 97), EDIP 2003 (Institute for Product Development, Technical University of Denmark), EDP 2007 (Environmental Product Declarations, composed by Swedish Environmental Management Council).

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[5] http://www.pre-sustainability.com/

LCA contains graphs, tables and results that express impact assessment, characterization, damage assessment, normalization, and weighting. The following definitions are posed to ensure understanding of concepts presented:

Characterization:

Substances that involved in the impact category have a characterization factor. This factor expresses the relative contribution, for example: If the characterization factor of methane is 21 and characterization factor of CO_2 is one that means that 1 kg methane causes the same amount of climate change as 21 kg CO_2.

Damage assessment

Damage assessment combines a number of impact category indicators into a damage category. In the damage assessment step, impact category indicators with a common unit can be added.

Normalization:

Many methods allow the impact category indicator results to be compared by a reference value. This means, the impact category like human health is divided by the reference. A commonly used reference is the average yearly environmental load in a country or continent, divided by the number of inhabitants.

Weighting:

Some methods allow weighting across impact categories. This means the impact (or damage) category indicator results are multiplied by weighting factors, and are added to create a total or single score.

3.3.4. IMPACT method6

For the present study IMPCT method recommended by the software producer was applied. IMPACT method is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology - Lausanne (EPFL), with current developments carried out by the same team of researchers now under the name of ecointesys-life cycle systems. The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other

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[6] **(Ref: SimaPro user manual)**

interventions) via 14 midpoint categories to four damage categories. The overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories has been shown in following figure, Jolliet et al. (2003a)

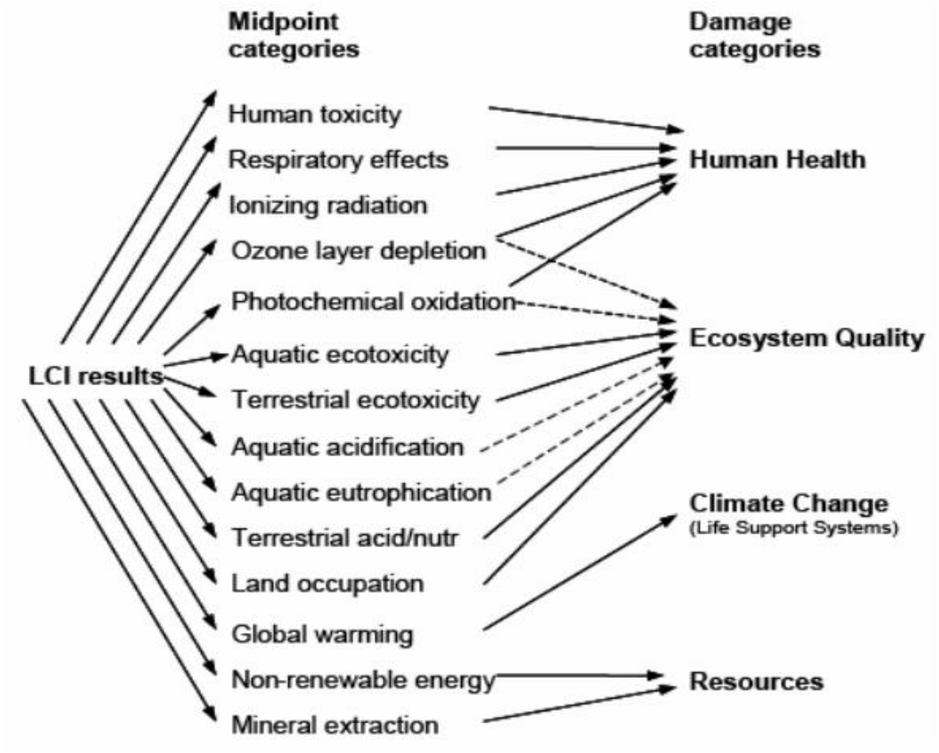

Figure 6 : Overall schema of IMPACT method (SimaPro Maual

3.3.5. Boundary conditions considered in this study

The boundaries determine which unit processes should be included in the LCA study and is a key element of the LCA that should clearly be defined. In this research the target is to use the energy life cycle with the focus of energy efficiency for comparing different alternatives. We accounted for the primary energy and green gas emissions by including the energy system chains from natural resources to different energy services. The functional unit of the analyses was 100 square meters of produced and operated building area. This enables comparisons to be made between different energy systems for domestic units. In comparison analysis it has been assumed that there is minor difference of the life cycle energy and the variations between different house construction practices and materials.

LCA method here has been utilized to evaluate the environmental impact of the different sources of energy within the whole system life cycle. The LCA has involved two direct energy consumptions: the energy used for the production, installation and transportation during every life cycle phase of the energy service, and energy quantities consumed by final user.

However, the energy quantities are end-energy quantities, meaning the energy quantities consumed by final users. All these quantities have to be valued as primary, defined as the energy embodied in natural resources (e.g. coal, crude oil, sunlight, and uranium). The secondary sources can be transformed into primary quantities by means of specific conversion factors. They represent the effective amounts of energy that are necessary to deliver one kWh of energy to users, including all the energy losses occurring during the energy source life cycle.

It is important to mention that different assumptions give very different results, especially in normal household analysis. In this research any facilities needed for handling the energy suppliers, like the storage tank considered for solar energy have been included in life-cycle study. Analyses will be limited to the environmental impact assessment of using different energy carriers for thermal and electrical energy production. Processes related to the production of household appliances, dishwasher, cloth dryer and WM, were not included, assuming that those impacts were similar for different appliances. But the influence of infrastructure needed for the supply of individual energy carriers, the process for production of boiler and other equipment used for energy production was accounted for as far as it had been included in the SimaPro databases.

It should be pointed out, that the electricity mix influence the environmental performance of the different scenarios. In fact the Austrian carbon content of electricity mix of Austria is lower than many countries in EU. Then choosing energy to provide the energy demand of the households will be more critical in this case.

Chapter 4:

RESEARCH MATERIALS: PROTOTYPE HOUSE IN BÖHEIMKIRCHEN-LOWER AUSTRIA

For the realization of providing the thermal energy demand for the households an *integrated solar system*, a prototype system in Böheimkirchen - lower Austria, has been planned, constructed and monitored.

The following section describes the actual design and technology details of this prototype house, located in Böheimkirchen. It will be shown how the combination of active and passive solar energy systems have been used to supply the thermal energy demand of the appliances in the house. The control and monitoring system of the energy supply unit will also be discussed in detail.

4.1. Solar system layout- Böheimkirchen

The solar system in Böheimkirchen contains two main parts, the thermal energy supply and the thermal energy demand section. The supply futures are mainly thermal solar collectors, hot water stratified storage tank, heat exchanger, buffer tank, system controller, sensors, piping system, pumps, cold water input, expansion tank, and etc.

4.1.1. Thermal solar collectors

Solar collector is the engine of any hot water system for harnessing the solar energy. Solar thermal collectors absorb solar radiation from the sun and transfer this heat to a fluid which passes through collectors. This fluid is then sent to the system where it contributes its heat to the hot water that is being sent to the appliances. The amount of supplied hot water depends on the demand and is regulated with the control system.

Solar thermal collectors are classified as low-, medium-, or high-temperature collectors. Medium-temperature collectors that have been installed in Böheimkirchen are Vacuum solar collectors from company Aschoff Solar[7] with 14 m^2 aperture area. Solar tubes have always been the most efficient solar power production systems but are more expensive than flat panel system. However the growing demand of solar and modern manufacturing techniques

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[7] http://www.aschoff-solar.com/

have driven down the costs such that solar tube technology provides the greatest return on investment versus any other solar system.

The principle behind solar tubes is simple. The outer layer of the solar tube is from special glass which is very low in iron and allows 98% of light energy to pass through. The second inner layer has a very special coating applied to it. The absorbed solar radiation is transferred to a heat transfer fluid within the tube. In an open tube system the water is heated directly within the tube. Thermo siphon causes the hot water to rise and be replaced by colder water. The hot water is then collected in the top collection chamber and pumped though the system. The advantage of this type of heat system is, that there is no costly copper piping involved therefor these open tubes are the most cost effective. The disadvantage is that they can only be used in an open loop system that is controlled by the atmospheric pressure. They can withstand small amounts of pressure but should not be used in pressure systems.

Evacuated tube collectors have essentially a vacuum between the absorber and the glazing tube. This eliminates most of the heat loss by conduction and convection. Therefore, these collectors give a very high efficiency at higher temperatures. High water content of the collectors avoids stagnation problems and ensures long lifetime of the systems. Evacuated tube collectors are typically used in the temperature range of 80 to 140°C.[8]

Figure 7: Vacuum tube collector

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[8] D.YogiGaoswami, Book:Energy conversion, chapter 8.10 , 8-117,

Figure 8: Installed vacuum tube collectors in Böheimkirchen prototype house – GrAT

Collector's side includes: tubes, collector manifold with insulation, tube supporter profiles, and aluminum frame. The collectors oriented at an optimum angle taking into account solar irradiation, as well as shades projected by surrounding buildings and landscapes to maximize integrated system efficiency.

Table 3: Technical data of the solar collectors from company- Aschoff

Type	Specification
Max. operating pressure [mPa]	0.05
Evacuated tubes	Boron-silicate
Manifold outside	galvanized steel
Manifold	stainless steel SUS 316
Orientation of manifold	vertical
Insulation of manifold	PU-foam 40 mm
Collector frame	Aluminum profiles 40/40, 30/30
Sealing rings	Silicon
Aperture-/gross-area [m²]	4.88/5.96
Number of tubes in each	50
Size l x h x t	3.100x2.000x210[mm]
Weight without/with water	100/180
Collector Efficiency Data [9]	0,756
U	2,33 W/m²K

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[9] acc. to DIN EN 12975:

4.1.2. Storage tanks

For the periods of year which hot water consumption and supply don’t coincide, thermal energy is temporarily stored in storage tanks. The thermal tank is sized in a way that allows the satisfaction of hot water energy demand for 2-4 days. Then it is possible to easily make it through even at less sunny summer periods. In the winter season it is necessary in many cases to employ additional energy sources, such as oil, gas, or wood. If the system elements are well designed, storage tank allows for proper functioning with the least possible use of additional energy.

As shown in layout, Figure 10, two storage tanks have been considered in the energy system. The smaller storage tank, that in this study will be named (SP1) , has 200 liters capacity .The bigger storage tank has 1500 liters capacity and will be named (SP2). Both storage tanks have foam insulation on the sides, top and bottom being 400mm, 800mm and 200mm respectively.

Two storage tanks have been considered for the system, because actually there are two different demand cycles in the system: closed system-smaller storage tank (SP1) and open system –the storage tank (SP2). Thermal cloth dryer needs hot water input more than 70°C and the water from the dryer comes back to the storage tank (closed system). Washing machine and dish washer need less input temperature, and warm water will not come back to the system (open system). When there is not enough radiation, backup system can warm the water in the smaller tank with less energy and in shorter time.

4.1.3. Piping system

The piping dimensions varied between 22mm and 28mmdiameter.The material for the high temperature is plastic and the other pipes are from cooper and steel with foam insulations.

Table 4 : Piping dimensions

Piping category	Pipe diameter/insulation thickness (mm)	Pipe/Insulation Material	Length
Solar Loop	28	copper	12 m
Storage tank loop	28/7	Steel/ plastic foam	6m
Network loop	28/7	Steel/ plastic foam	6m

4.1.4. Biomass Boiler

Autonomy combined with fluctuating production of solar energy leads to a need of back up energy. The fire wood boiler has 15 kW capacity and uses a woodchip boiler. The performance of the boiler is nearly 85%. This boiler has been chosen as it has high reliability, low wood consumption, easy operation, and long service life. It allows burning pieces of wood up to 1 m in length. To protect the boiler, an integrated cooling circuit has been considered which make the boiler cold in case of overheating and when it is necessary.

4.2. Demand side of the energy system

In demand side of the system the heat demand, annual and daily load distribution in each appliance have the major importance for system dimensions.

4.2.1. Hot water fill washing machine (WM)

The installed washing machine is from Elektra Bregenz, provided specially for this project. Two water hoses, cold and warm , are connecting the washing machine to the energy supply system. The hoses can tolerate 6 bar pressure.

The user selects a washing program and the WM combines the warm and cold water from the inlets via valves to reach the suitable temperature for the selected washing program. If the temperature during the main wash cycle drops inside the WM, the electrical heater inside, supplies the intent temperature. Mechanical main power of the WM is provided with electricity. The WM has safety valves to protect against water damages and linkages.

4.2.2. Hot water fill dish washer (DW)

The specification of the DW is somehow like the WM. The DW is also from Elektra Bregenz company, provided specially for this project. It has warm water and the fresh water input. DW combines the hot and cold water via a magnetic valve to reach the selected temperature. At the end of the washing program the drying phase is done by storing fresh cold water in a tank and using that cold water to condense the wet air inside to speed up the drying phase.

4.2.3. Thermal cloth dryer

The interface connectors from building to cloth dryer are: hot water input from the high temperature storage tank (SP1) capable to tolerate till 3 bar pressure, and a warm water output from the dryer to the storage tank.

In the solar dryer there is a heat exchanger (HEX). The input hot water and output water from the HEX has the 10°K difference in temperature, and the flow rate inside is 0.2 m^3/h, this means nearly 3 kW performance for the HEX.

The user selects a program and dryer start heating up via the HEX to the desired temperature. When the desired temperature is reached the valve of the heat circuit become closed and heat demand signal also be switched off. Condensing is also done via another air HEX inside the machine

4.2.4. Space heating

Wall heating system has been used in the prototype house to produce the appropriate living temperature. Wall heating systems operate on the same principle as floor heating system, with very low water temperature and shorter response time. The main advantageous of wall heating systems are: They emit the heat rapidly, they need low supply temperature, they are suitable for solar energy boilers

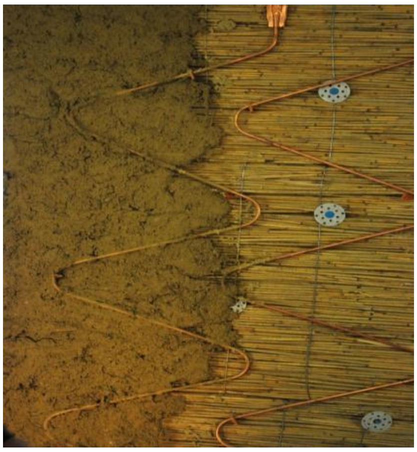

Figure 9: Wall heating system which has been installed in the prototype house- Böheimkirchen

4.3. Control system

The following subsection describes how the different parts of the integrated solar system operate together. Figure10 shows the hydraulic layout, that referencing the installed equipment's, and sensors. The sensors with labeling(S and CAN) indicate temperature sensors, (M and B) indicate the valve, (P) indicates a pump, and (VOL) indicates digital flow meter.

The whole control system has been designed based on a universally programmable controller , TAPPS[10], specific for heating and solar purposes from the Austrian company “Technische Alternative”, model UVR1611. The UVR1611 can handle 16 inputs, and up to15 outputs and can be fitted with additional external input-outputs modules. Several UVR1611devices can be connected to a network and can communicate with each other if one UVR1611 is not enough. For better system visualization a 10" touch screen of system state also has been provided.

Table 5: List of all input/output to/of the UV1611 device

Sensor or port number	Measures
M1 (ports A3/A4)	mixing valve for biomass circuit
M2 (port A8/A9)	mixing valve high temperature circuits
M3 (port A10/A11)	mixing valve space heating circuit
N1 (can-network port)	switching valve storage tank SP1/SP2
N2 (can-network port)	switching valve biomass circuit storage tank SP1/SP2
P1 (port A7)	Solar pump
P2 (port A6)	Solar pump - storage tank circuit
P3 (port A2)	biomass pump
P4 (port 12)	pump in high temperature circuit
P5 (port 13)	space heating
S1	Solar radiation
S2	Ambient Temperature
S3	Hot water temperature in the collectors
S4	Hot water temperature, output of heat exchanger to storage tanks
S5	Upper layer temperature in the small storage tank SP1
S6	Lower layer temperature in the 200 Lit. storage tank SP1
S7,S9,S10,S11	Different layer temperature in 1500 Lit. storage tank SP2
S8	Temperature of the output gas from the biomass boiler
S12	Input water temperature to the heating room elements
S13	Flow temperature in high temperature circuit
S14	Tap water temperature SP2
S15	Output temperature from the biomass boiler
S16	Input temperature to the biomass boiler

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[10] “A - Technische Alternative" Austria Model UVR1611 with accessories.http://www.ta.co.at/frei-programmierbare-mehrkreisregler/

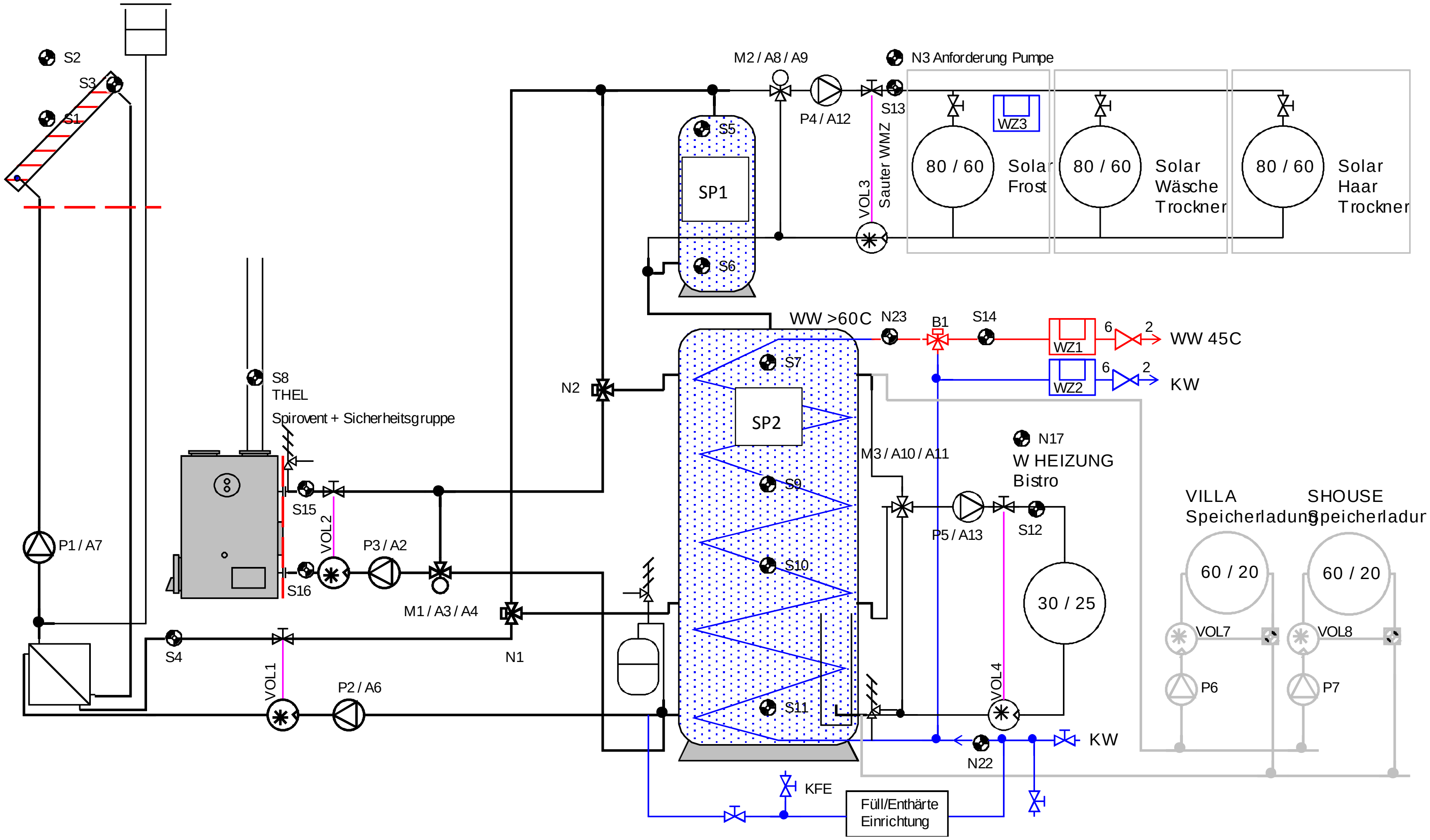

Figure 10: Hydraulic Layout of the integrated solar system in Böheimkirchen- Designe from GrAT

4.3.1. Control system of solar loop

There exist two temperature sensors at the collectors (S1) and (S3).(S1) which measure the solar radiation and (S3) that measures the water temperature in the collectors.

In the control program, two main modes have been distinguished, SOLAR1 and SOLAR2. Mode SOLAR1 is responsible for heating up storage tank SP1 with a volume of 200l. The solar pump1 and pump2 are switched on, if the temperature in the collector (S3) is higher by a difference of 8K than the temperature (S6) in the storage tank SP1. In addition (S6) must not have reached its upper limit of 80°C. The speed of solar pump2 is controlled by a PID function. The PID control function is being used to change the flow rate to maintain a collector temperature (S3) at 90°C. If solar radiation decreases and (S3) goes down, the control unit reduces the speed of solar pump (P2). This leads to a longer time for the heat transfer medium in the heat exchanger and let the collector temperature be constant.

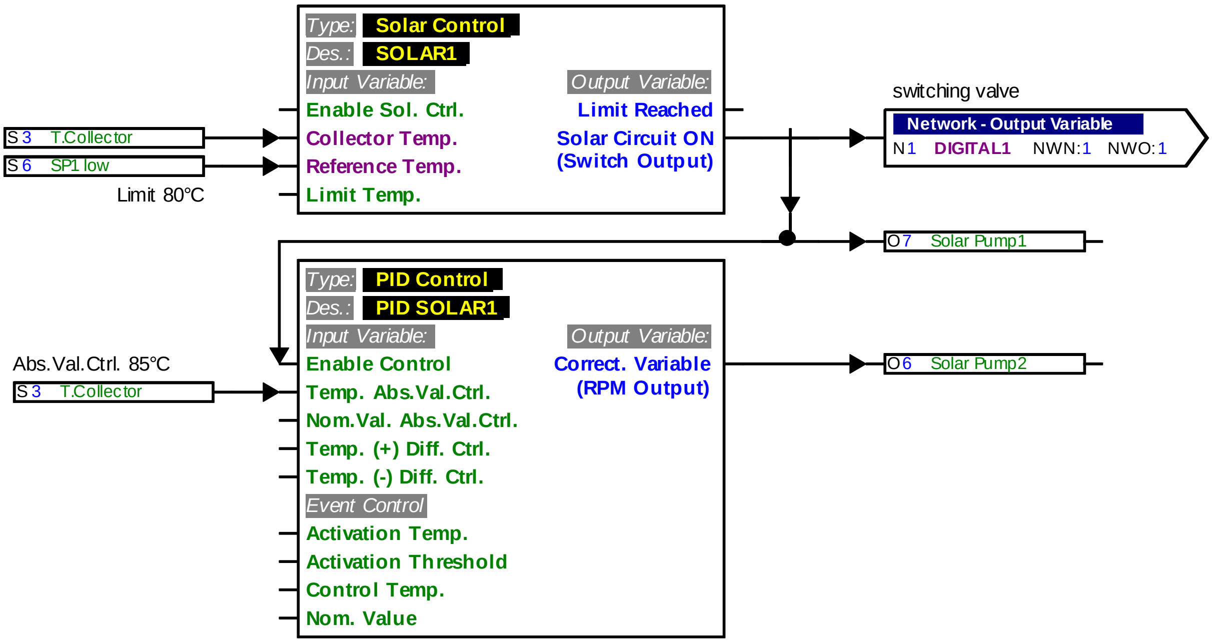

Figure 11: Solar and PID control function (mode SOLAR1) - Software TAPPS

During the whole time the control function SOLAR1 is watching the solar temperature (S3). If its value goes above 130°C the control unit assumes that the heat exchange fluid will soon turn into steam. This will not harm the solar collectors, but to prevent damage on the solar pumps or other hydraulic parts of the system, the solar pumps will be blocked. As soon as the temperature goes below 130°C the solar pumps are enabled again.

Mode SOLAR2 is working just like SOLAR1 but this mode is responsible for the storage tank SP2. The reference temperature of SP2 is (S11) located in the lower layer of the tank.

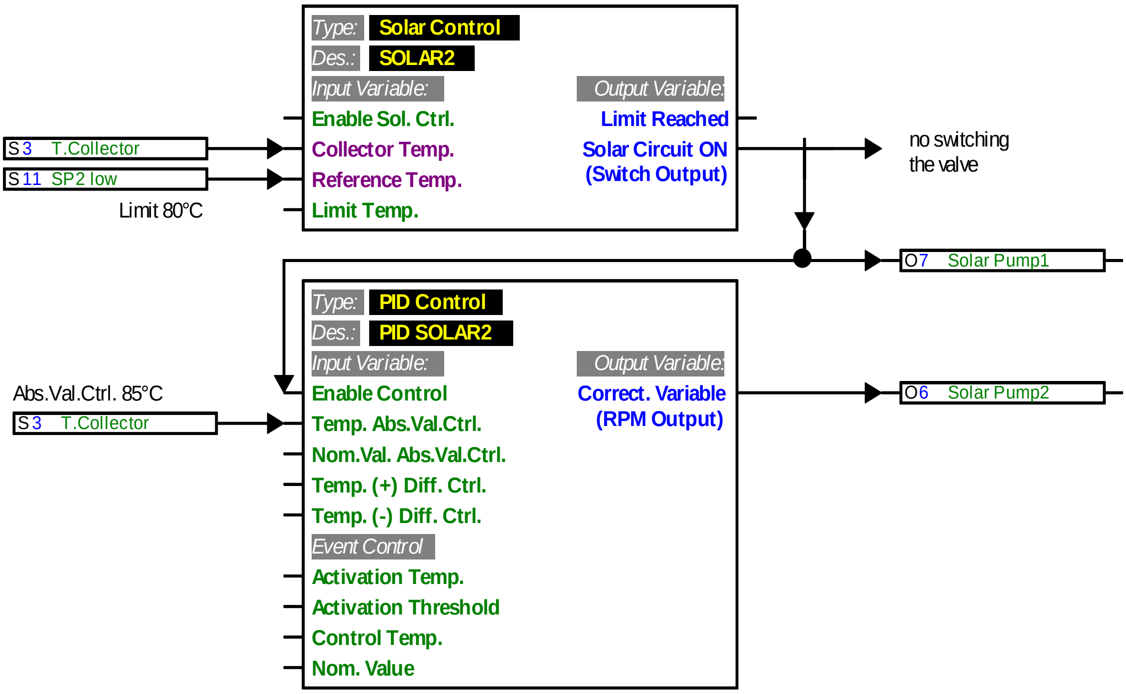

Figure 12: Solar and PID control function (mode SOLAR2) - Software TAPPS

It is important that storage tank SP1 has always enough energy to provide enough hot water for the cloth dryer. As solar dryer needs more energy than other appliances, the control system has set the loading priority on storage tank SP1. Since storage tank SP1 needs higher temperature SOLAR1 mode is set to run when solar radiation is higher than 600w/m^2.

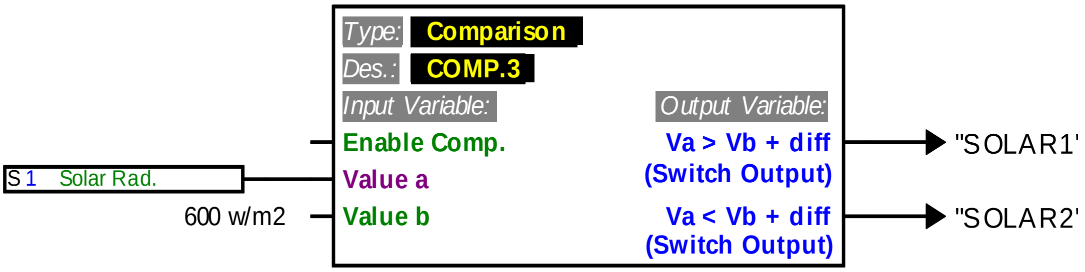

Figure 13: Comparison mode SOLAR1 or mode SOLAR2-difference=100 w/m^2- Software TAPPS

The function COMP3 decides which solar mode should be activated. If the solar radiation (S1), shown as ”value a”, is higher than the ”value b”= 600W/m², then the SOLAR1 mode will be chosen. As soon as the temperature of (S6), the lower layer of storage tank SP1, reaches 80°C the remaining energy from the solar collectors will be stored in tank SP2.

4.3.2. Control system for biomass boiler

For the time that solar irradiation is not enough a firewood boiler with 15kWoperating load is used. The biomass boiler needs to be filled with wood and turned on manually. The control device UVR1611 is responsible for energy supply/demand and for the storage tank loading management. As soon as the sensor (S15) measures the output hot water temperature of the biomass, be more than 55°C the mixer control and the pump control are being enabled. To prevent corrosion caused by flue gas condensate, the input water (S16) to the biomass boiler must have at least a temperature of 55°C.The mixer control takes back some of the hot water to the biomass boiler by opening the mixing valve (M1). If the temperature (S16) goes up again, the valve will close. This mechanism ensures that the temperature (S16) remains between the ranges of 55 -60°C.

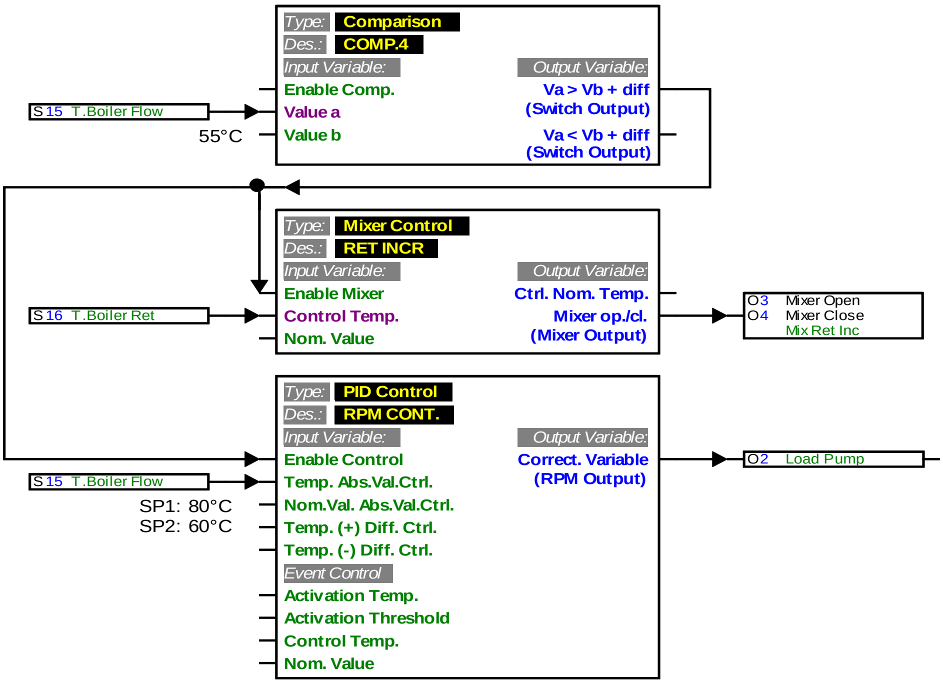

Figure 14: Wood boiler control - Software TAPPS

The flow temperature control is done via PID, regulating the rotation speed of (P3) to keep (S15) on a temperature level of 80°C or 60°C depending on whether storage tanks SP1 or SP2 are being loaded.

Like in the solar loop, the biomass loop also controls a switching valve (N2) to load either storage tank SP1 or SP2.As has been mentioned before, loading priority goes to storage tank SP1 with a temperature (S15) of 80°C. When switching the valve (N2) loading SP2, the PID control of biomass boiler pump (P3) will change the regulated value of (S15) from 80°C to 60°C.

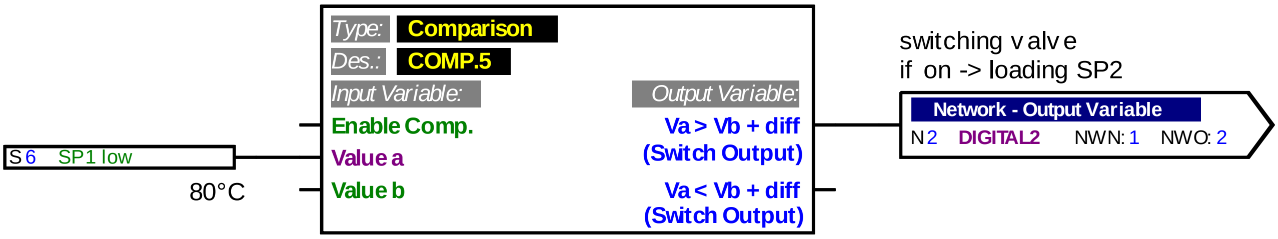

Figure 15: Switching valve N2 for loading either SP1 or SP2 - Software TAPPS

4.3.3. High temperature circuit energy management

The domestic appliances in high temperature circuit need a supply temperature around 80°C. To keep this supply temperature (S13) on its level, two control circuits are responsible for operating: the heat pump (P4) and the mixer (M2). As soon as the switch (N3) is turned on and as long as SP1 can provide enough energy, the pump (P4) and the mixer (M2) assure that the value of (S13) stays around 80°C.

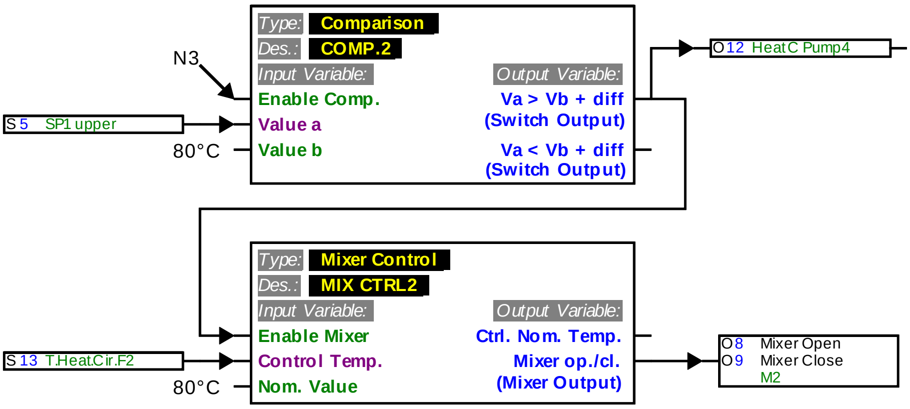

Figure 16: Supply temperature control of domestic appliances – Software TAPPS

4.3.4. Wall heating control

In the domestic appliances circuit, there is also a circuit for a space heating. Space heating is supplied with energy of storage tank SP2 and loaded either by solar or biomass energy. This mechanism is controlled by a heating circuit function as shown in Figure 17.

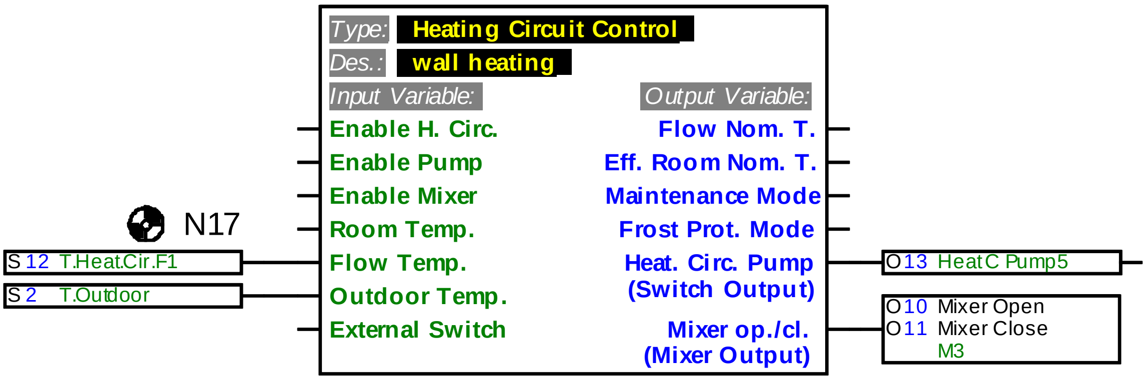

Figure 17: Heating circuit function for wall heating – Software TAPPS

A mixer controller heats the medium based on outdoor temperature (S2), and with consideration of room variable temperature (N17). The heating pump can be activated based on various parameters such as outdoor temperature and preset running times. The water flow temperature (S12) is dependent on the outdoor temperature and the heat curve.

The heat curve is calculated based on an indoor nominal temperature (+20°C). Indoor temperature and the factor of the building define the forward temperature of water (S12). For example if the factor of the building be 0.5 (good isolated building) and the outdoor temperature be -5°C then the forward temperature should be about 30°C. Depending on the characteristic of the isolation of the building (building energy category), the heat curve is higher for higher flow temperatures or lower.

Some important operations have been considered in the space heating control circuit:

1. NORMAL: The controller is switched to normal heating mode. This means that according to the outdoor temperature the flow temperature will be kept on a certain level and it will only stop if the preset room temperature for example 22°C for normal mode is reached.

2. LOWERED: This mode is used for example during the night when the room does not need to be on higher temperature level. Therefore a lower room temperature for example 18°C is defined and the controller prevents the room temperature to become below this level.

3. STANDBY: This switches the controller to a standby mode and only a frost protection remains active. If this mode is activated, and the temperature outside goes below +5°C, the controller will keep the room temperature above 5°C.

4. TIME/AUTO: The control circuits operating according to the preset times. For example NORMAL mode can be set from 7:00-19:00. Within this time frame the

room temperature will be kept on the level which is defined in NORMAL thermostat settings. Between 19:00-7:00 the control circuit will automatically work as set in LOWERED mode and keep the room temperature according to the definition of this mode.

4.4. Data logging and monitoring

The measured data from the controllerUVR1611 are exported into a monitoring system. This system is capable of logging the following components:

- 4 heating energy meters
- 2 water meters
- 4 electrical energy meters
- All temperature values and output status in the UVR1611 system

Two different softwares have been chosen for visualizing the data and monitoring the energy consumption of the system. “Winsol” is a program that monitors the outputs of the UVR1611 controller. In addition the program “Volkszähler” is being employed to have a unified monitoring and logging system that allows including external devices such as electricity meters to give energy consumption outlook of the whole integrated solar system.

4.4.1. Winsol

Winsol program is used for acquisition and evaluation of measured values recorded, and is able to capture and save the data from several data loggers. Winsol shows a window like the one shown in Figure 18, which presents the recorded data (log files) over each day. The program in prototype house – Böheimkirchen, can monitor and save these data in excel format:

- Status of the pumps (on/off)
- status of the valves (open/closed)
- temperature of different layers of the storage tanks
- solar circuit temperature variations that include the forward and return temperature and the solar irradiation
- temperature of biomass circuit
- ambient temperature
- solar radiation

Winsol visualizes several graphs in real time. The measured values can be specified for all devices, for example: the status of the pumps, the input water temperature to the appliances, solar irradiation, the temperature of different level of the storage tank, and input-output water temperature to/from the solar collector. The window can show the description in analogue or digital values.

As shown in figure 18, on a sunny day in July at Böheimkirchen the solar radiation can reaches up to 115W/m^2 and the water temperature in the collector ranged reached to 59°C. The sample window shows the change of output water temperature from collectors, ambient temperature, solar irradiation during the day, and the on-off status of the solar pumps.

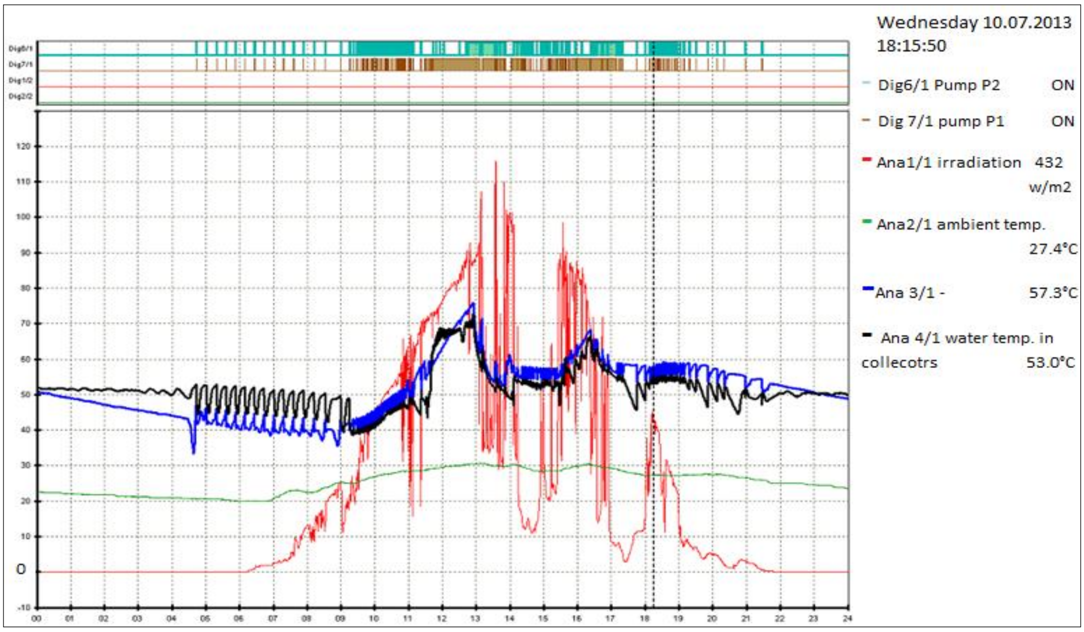

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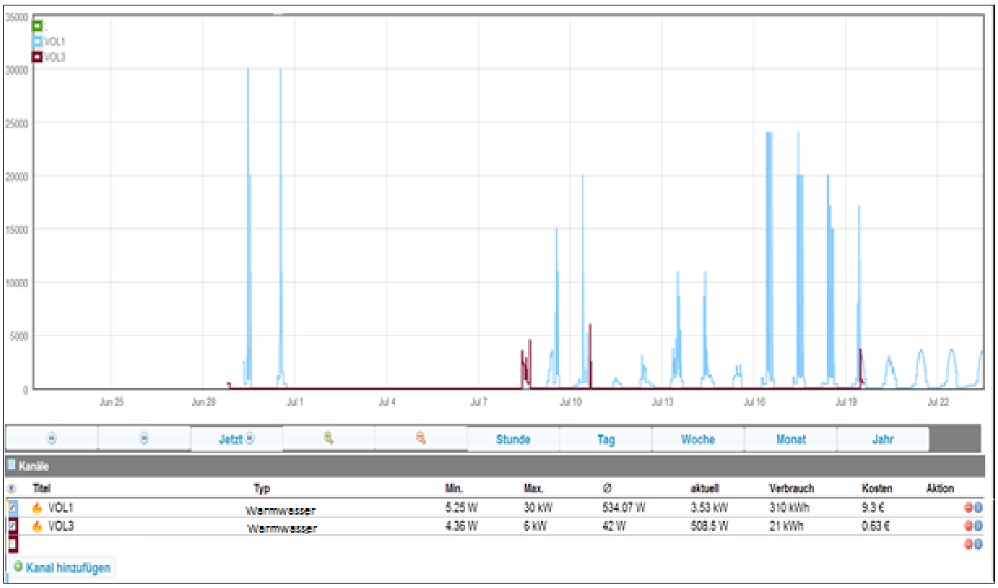
Figure 18: Sample window of Winsol program

4.4.2. Volkszähler

This energy visualization program can display an over view of the energy consumption from different appliances in the system. It gives information about the total solar energy consumption, the auxiliary electrical energy consumption of the pumps and valves. Volkszähler program in this research has been programmed to save and show the following data:

- hot water energy demand for the water consumption in the house
- hot water energy demand and electricity consumption of the thermal hairdryer
- electricity and thermal demand of the solar dryer
- electricity and hot water consumption of the dishwasher and washing machine
- possibility for monitoring the absorption fridge that may be installed in future

Figure 19 shows the energy to provide warm in the prototype house, between 1st and 22nd of July. For each appliance the minimum, maximum, current and total values are shown.



Titel	Typ	Min.	Max.	Ø	aktuell	Verbrauch	Kosten	Aktion
VOL1	Warmwasser	5.25 W	30 kW	534.07 W	3.53 kW	310 kWh	9.3 €	
VOL3	Warmwasser	4.36 W	6 kW	42 W	508.5 W	21 kWh	0.63 €	

Figure 19: Sample window of Volkszähler

The next figure shows the amount of solar energy that has been produced with solar collectors on 22nd of July. The graph also explains at which time of the day the energy production has started, then reached to its highest point and decreased in the late afternoon.

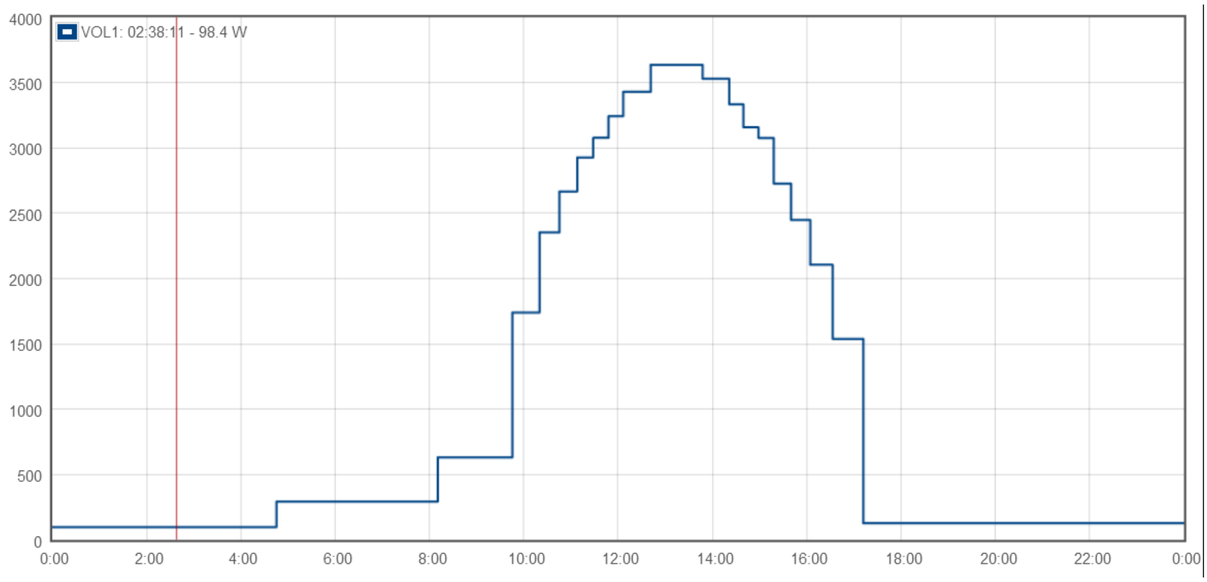


Figure 20: Sample window of Volkszaehler-the unit in vertical axes is W and in horizontal axes is time- The graph belongs to Monday 22 July 2013

Chapter5: MONITORING RESULTS

A proper analysis (an evaluation) of the environmental load of consumption for different presented scenarios is important in the context of sustainable development. And to have a proper analysis, correct estimation of consumption figures in necessary.

Normally the energy statistics are the best available environmental data and provide the possibility to calculate energy requirements in relation to consumption. In this research for measuring the environmental data of the first scenario (conventional energy provision for households) the average energy demands of Austrian households have been considered.

To estimate the energy consumption of the "*integrated solar system*" some tests based on the consumer behavior data have been designed. These experiments and monitoring of the installed prototype system in Böheimkirchen comforted the access to real energy demand of the presented system.

5.1. Energy demand of the hot-fill dishwasher (DW)

In the following part of the study, the consumer's energy demand of dishwasher with thermal and electrical resources of energy has been measured. The source of the energy for the warm water supply should come from a reasonable source such as solar thermal or gas to keep CO_2 emissions low. To do the experiments for measuring the energy consumptions a DW from Elektra Bregenz[11] Green brand model has been used.

5.1.1. Defining the user behavior of DW

A lot of consumer don´t believe that dishwasher is a necessary appliance at home. They think that washing the dishes with hand is more ecological and less expensive. To know more about the consumer behavior and to analyze the interaction between different appliances and the energy system, an extensive consumer survey has been developed with (R. Satmminger, 2007). In this survey almost 2,500 households from ten European countries have been interviewed to identify the "real life" consumer behavior when using household appliances.

Based on this report consumer behavior and energy consumption of each appliance varies with the country. Other factors that affect energy consumption of dish washer are:

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[11] http://www.elektrabregenz.at

- Ambient conditions
- Frequency of operation
- Selected program and its consumption
- Program temperature
- Machine efficiency
- Load size

The number of loaded items and their heat capacity may influence the amount of the energy used, since the load has to be heated to the selected washing cycle temperature. The frequency of DW operation depends mainly on the household size. Here in this study the energy consumption has been calculated for an Austrian average family, 2.26 persons.

Assuming three meals per day and the use of one place setting per meal (each place setting consisting of 11 items), 1 095 place settings per person per year will have to be cleaned. Since meals are also taken outside of the house (e.g. at a canteen or a restaurant) the real place settings number will be considerably lower. The following graphs, Figure 21&22, show the average cycles per week in the considered EU countries, is nearly 4.1 cycles per household and 1.3 cycles per persons. (A.K.Weber, 2009) claims for three person's family the average use of DW is 170 times per year with the average temperature of 59.3°C. In each times of the run, dishwasher needs nearly 13 liters water.

The other important aspect affecting the energy consumption of a dishwasher is the temperature and the selected washing program. (R. Satmminger, 2007) reports that program at 50/55 °C (36.3 %) are as common as program at 60/65 °C (35.6 %); the program at higher temperature (70°C) are used on average in 14.2 % of the cases, while lower temperature program (40/45 °C) is used in 13.9 % of the cases.

The average DW temperature is 59.3 °C and the most frequently used programs are eco and automatic program. The type of selected DW program shows a dominance of the "normal/regular" program. About 40% of the consumers use "normal/regular" program always and 25%, often. The second most used program is "automatic". The less frequently used program is the "rinse and hold". This program is intended to be used mainly to rinse off heavy residues from dishes with cold water if they cannot be immediately washed due to the time needed to fill the dish washer.

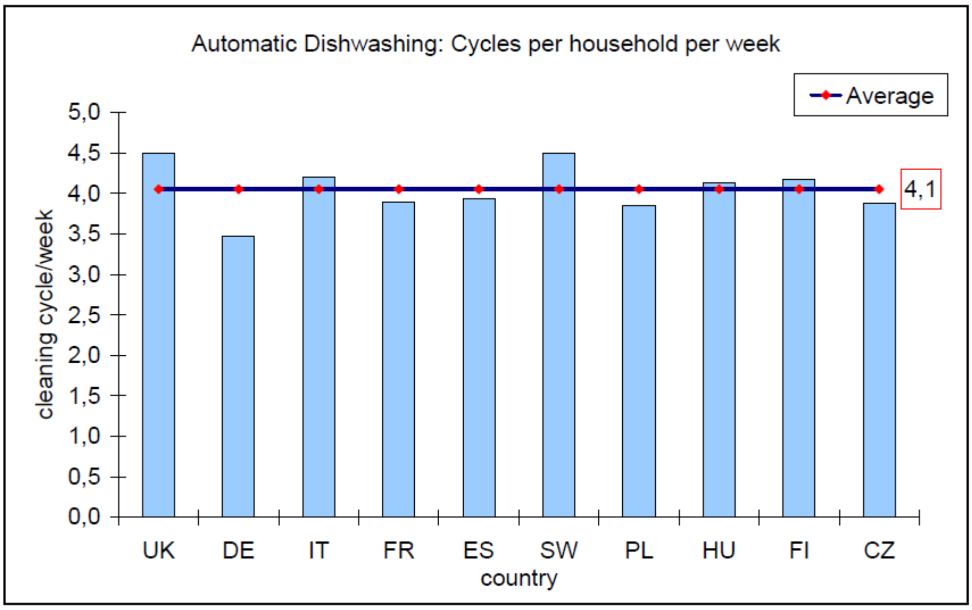

Figure 21: Average number of dishwasher cycles per household per week – EU Ref: (R. Satmminger, 2007)

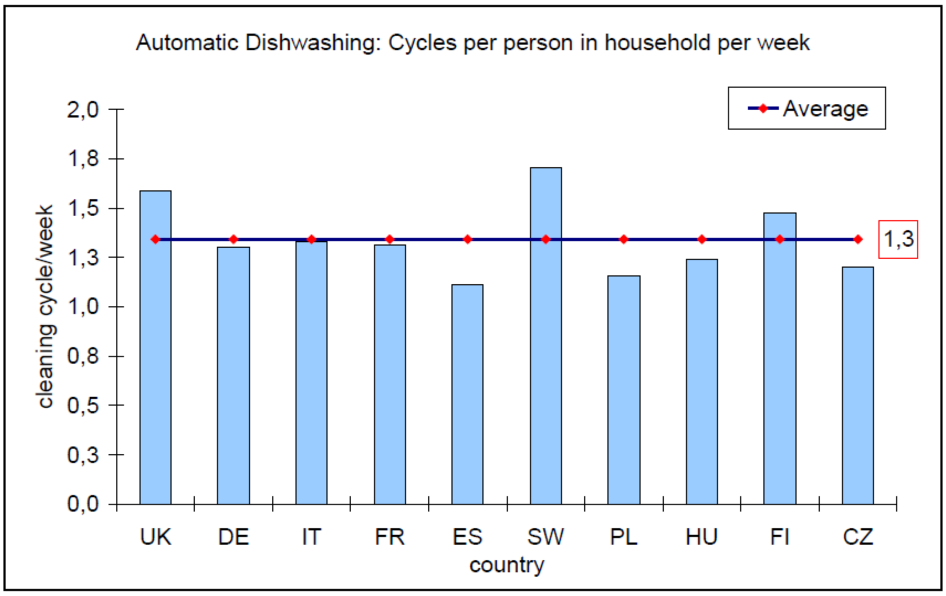

Figure 22: Number of dishwasher cycles per person per week Ref: (R. Satmminger, 2007)

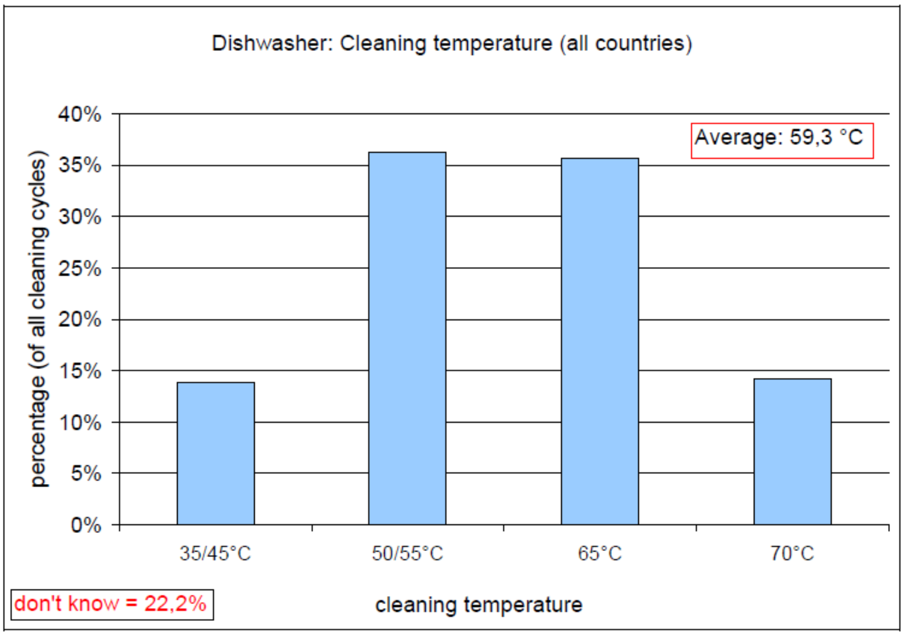

Figure 23: Relative occurrence of dishwasher temperatures (average of 10 EU countries)- (R. Satmminger, 2007)

In summary, the consumer behavior for dishwasher used to do the energy analysis in this research is characterized by:

- average 1.34 dishwashing cycles are done per week per person.
- Programs at 50/55 °C (36.3 %) are used as common as programs at 60/65 °C (35,6 %), program at 70°C is used on average in 14.2 %, lower temperature program is used in 13.9 % of the cases.
- Consumers claim to load the dishwasher almost always at the full capacity or even more.

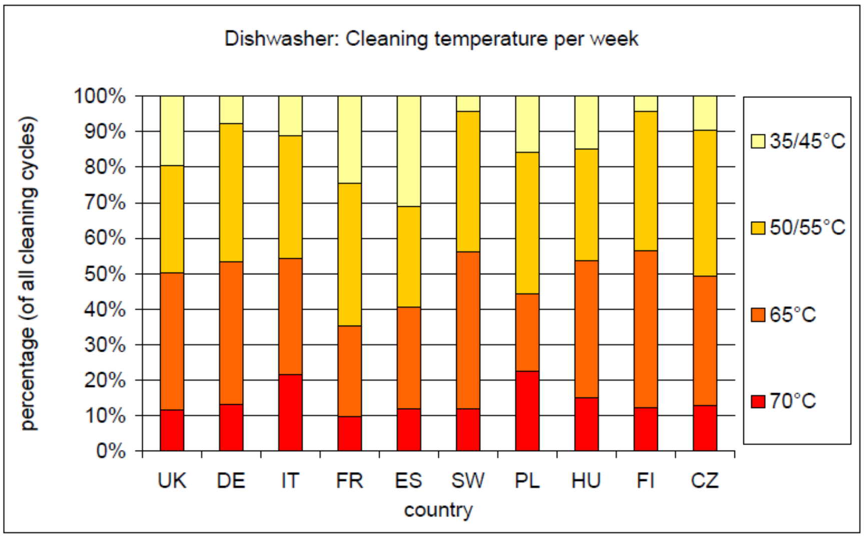

Figure 24: Temperature distribution of dishwasher programs in various countries (R. Satmminger, 2007)

5.1.2. Results of the experiments (DW)

The mentioned using behavior conditions have been incorporated to do the experiments with the installed hot fill dish washer in the prototype system and to calculate saving potential through the use of direct hot water input to the DW.

The more detailed boundary conditions for the mentioned scenarios for life cycle analysis will be regarded in the next chapter of the study. And the subsequent calculated savings in (primary) energy and environmental impact will be displayed and discussed. In the following table, results of the energy demand tests have been mentioned.

Table6 : Energy consumption –monitoring of the Elektra Bregenz DW GrAT –Böheimkirchen prototype system

	Electrical energy demand (kWh)	Hot water demand (kWh)	Total Energy (kWh)
Cold water	320	-	320
Hot fill operation	206.5	120	326.5

5.2. Energy demand of the hot-fill Washing machine (WM)

The washing machine introduced and experimented in this study has inlet for the hot water. Washing machine needs electricity to run the machine. The needed energy for heating water can come from a variety of sources, e.g. electricity, natural gas, biomass, oil or solar energy.

The hypothesis is: If rendering another source of energy except electricity to provide warm water for the WM will save the primary energy, and will reduce the environmental impact.

For answering this question, it is necessary to determine the energy consumption and water usage per consumption.

5.2.1. Washing Behavior of Households

Washing behavior of households is very diverse. To calculate the potential savings through the hot water use for an average household, the following parameters must be specified:

- washing frequency (number of wash cycles per household per year)
- Wash program (cotton, wool, synthetics, etc.)
- washing temperature
- Actual load

Unfortunately, answering all these questions simultaneously and consistently is difficult. In a study of (Gensch C., 2008), they calculated the potential savings through a simplified user behavior. Their results have been summarized in the table below, Table 7.

The table shows that the use of wash machine is nearly 163.8 times per year for a household with three persons. It is obvious that washing devices have different programs, which would be distinguished by water temperature during the wash cycle.

Another study (Berkholz P., 2007)also shows the most frequently used program is cotton 60°C and the most temperature used is 40°C. The total number of wash cycles for wash machine per household ranged from 1 to 11cycles per week .The number of the wash cycles for washing machine is almost the same in summer and winter.

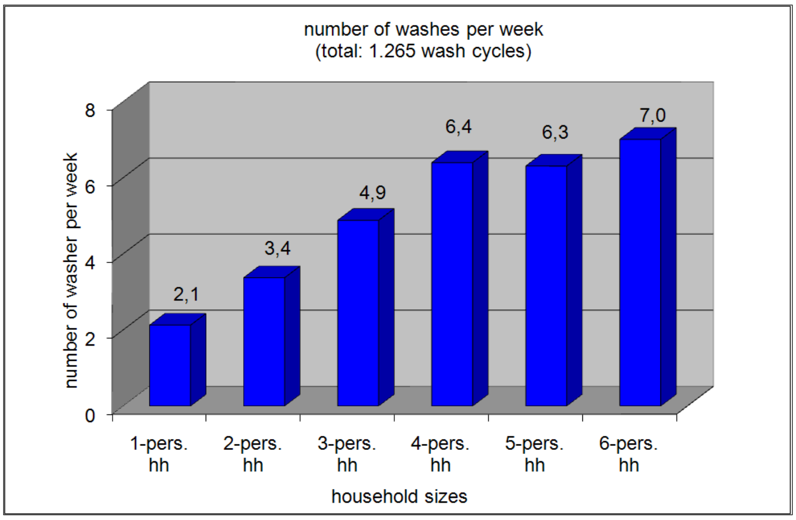

Figure 25: Number of washed per week for different household size (Ref: Berkholz P. , et al)

Table 7: Specification of the average annual household WM behavior Ref ((Gensch C., 2008))

Program	Temperature	Degree of dirtiness	Loading	Usage per year	Percentage
Cotton	90 °C	Intense	6 Kg	8.2	5.01%
Cotton	90 °C	Normal	4.5 Kg	4.9	2.99%
Cotton	60 °C	Normal	4.4 Kg	38.3	23.38%
Cotton	40 °C	Normal	3.25 Kg	21.3	13.00%
Cotton	40 °C	Light	3.25 Kg	3.8	2.32%
Cotton	40 °C	Light	1.5 Kg	16.9	10.32%
Cotton	30 °C	Light	1.5 Kg	13.9	8.49%
Easy care	60 °C	Normal	3 Kg	9.3	5.68%
Easy care	40 °C	Light	3 Kg	9.3	5.68%
Easy care	30 °C	Light	1.4 Kg	15.1	9.22%
Easy care	40 °C	Light	2.36 Kg	9.3	5.68%
Easy care	30 °C	Light	2.36 Kg	9.3	5.68%
Wool	30 °C	Light	2.46 Kg	4.3	2.63%
Total				163.8	100%

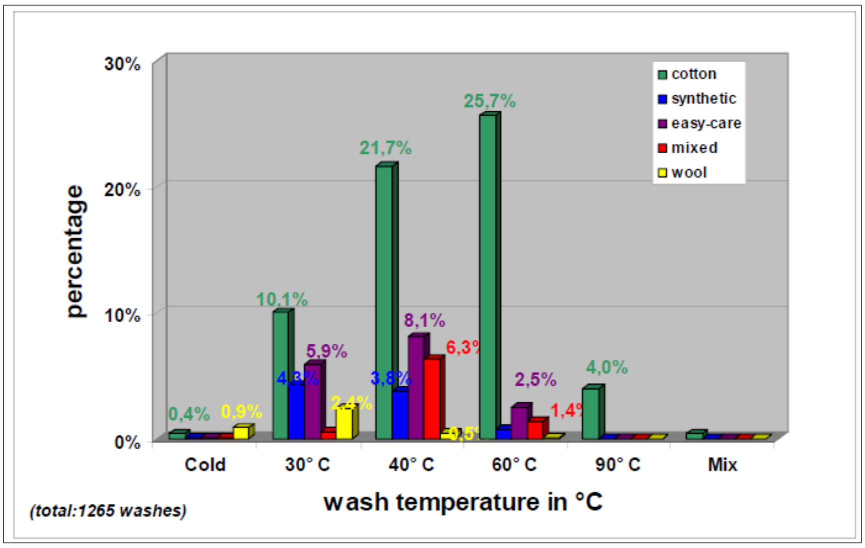

Figure 26: Wash program and temperature (Ref: Berkholz P. , et al)

The following figure show how the size of the household and the family type affect using the WM. Wash cycles in wash machine are highly dependent to the family type and mostly on the number of the people per household.

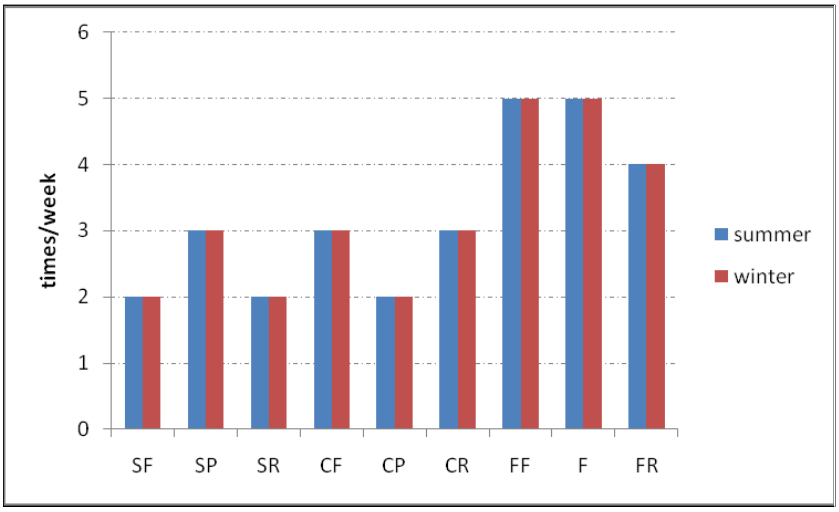

Figure 27: Number of washing cycles of WM regarding defined family types Ref: (Ghaemi S., 2011)

(SF Single fulltime family, CF Couple fulltime family, SR Single retired family, CR Couple retired family .FF Family fulltime, F Family with one parent at home, FR Family with retired member)

5.2.2. Results of the experiments (WM)

Based on the above literature review concerning the consumer behavior the energy consumptions and the results of the experiments with the hot-fill WM have been summed up in the following table

Table 8: Energy consumption–monitoring of the Elektra Bregenz WM

	Electrical energy demand (kWh)	Hot water demand (kWh)	Total Energy (kWh)
Cold water	206	-	206
Hot fill operation	122	88.9	211

5.3. Energy demand of the thermal cloth dryer

Calculating the energy consumption for the solar dryer based on report (I.Stadler & S.Tapanlis, 2008) is 0.7 till 1 kWh per usage. This is equals to nearly 175-250 kWh energy per year for 250 usages per year.

In the experiments it has been considered that the users after each time of using WM use the cloth dryer.

Table 9: Energy consumption–monitoring of cloth dryer

	Electrical energy demand (kWh)	Hot water demand (kWh)	Total Energy (kWh)
Cold water	200	-	
Hot fill operation	141	260	401

Chapter 6: LIFE CYCLE ASSESSMENT RESULTS

In this chapter, to quantify the environmental impact life cycle assessment (LCA) method has been applied. Life cycle assessment here measures the viability of using hot fill appliances and the entire solar integrated energy layout considering the global warming and primary energy factors. The objective of the assessments is to determine the results against the benefits of each considered scenario.

6.1. Life cycle assessment of conventional energy service for the households (Scenario one)

The LCA carried out in this research is conformed to the ISO standard on LCA. And the main greenhouse gas taken into account is carbon dioxide (CO_2).

6.1.1. Household electrical energy consumption in Austria-

Table 10 shows different family sizes of Austrian households and their electricity demand. In Figure 28 the electricity consumption has been ordered based on consumption values of end users. The most electrical energy consumption in residential sectors in Austria belongs to the space heating in winter 16% (although just small portion of families use mainly electricity for space heating), and the next group is domestic hot water demand[12] 13% . The electricity used for the pumps also has been considered in the total amount of electricity consumption for space heating and domestic hot water. The office devices have the least share, 2%, in total electricity consumption. 13% of total consumption belongs to washing machine, dishwasher and cloth dryer. Austrian households consume 33% more electricity in winter than summer, Figure 29.

Statistic Austria has linked the data records for the period 2003 to 2010 to a forecast he electricity demand consumption for each category for the year 2012 .

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[12] Hot water for shower and other types of hot/warm water demand at home

Table 10: Average consumption of Electricity demand in Austria per year for households Ref: (Statistik Austria 2012)

	1 Person (kWh)	2 Persons (kWh)	3 Persons (kWh)	Households in Average (kWh)
Total	2,402	3,955	5,198	4,187
Refrigerator	276	277	263	316
Freezer	204	273	249	167
Cooking Devices	173	458	554	391
Washing Machine(WM)	134	259	383	142
Cloth Dryer	16	124	214	143
Dish Washer (DW)	164	237	329	262
Kitchen Electrical Devices	132	185	274	**197**
Office Equipment	95	117	127	**113**
Entertainment Equipment	148	154	231	178
Communication Devices	17	32	28	25
Other HH electricity Devices.[13]	17	430	244	361
Standby office Devices	11	7	18	10
Standby Communication Devices	79	79	120	93
Standby cooking equipment	10	14	19	14
Standby Kitchen Equipment	12	17	15	15
	239	380	654	446
Domestic Hot Water(DHW)	502	521	557	527
Space Heating	173	391	919	670

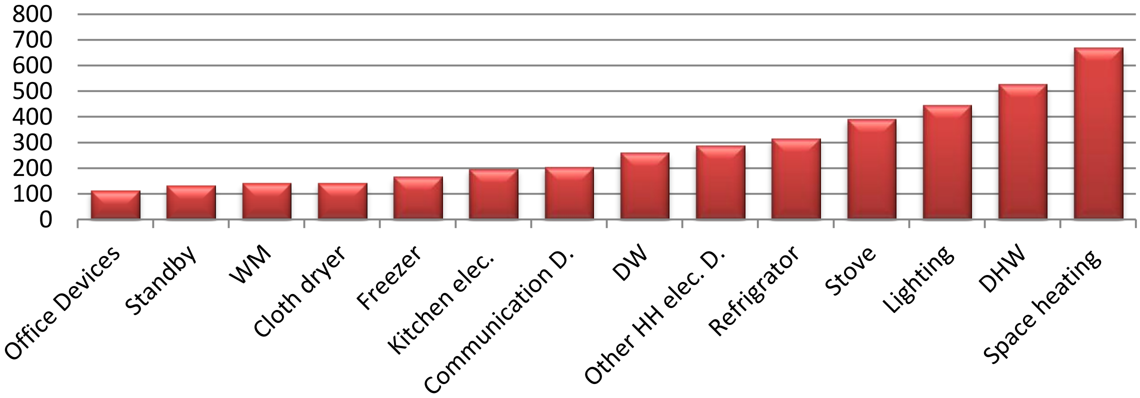

Figure 28: Average electricity demand (kWh) of Households in Austria per year -2012 Ref: (Statistik Austria)

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[13] Like lawn mower, battery recharger and etc.,

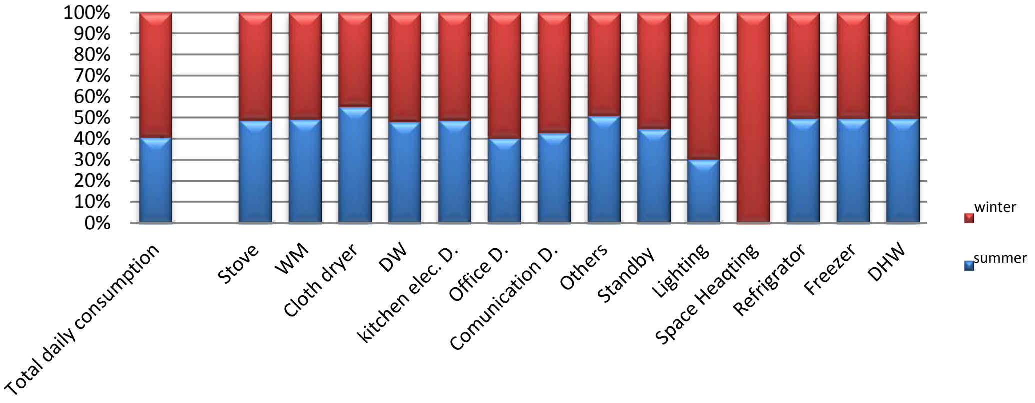

Figure 29: Share of electricity demand in winter and summer- Average Austrian HH-Ref : (Statistik Austria 2012)

6.1.2. Environmental load of providing electricity for an average Austrian HH

Figure 30 illustrate the shares of domestic electricity production considering imports from neighboring countries (production mixes). [14] Based on this figure 3% of the supplied electricity in Austria comes from oil as primary energy, 17% produced with gas power plans, 51% from hydro power plans, the remaining comes from coal power plans, pumped storage of hydropower and also renewable energies. 11.7% of Austrian electrical energy mix importing is from Germany, 8% from Czech Republic, 0.26% from Switzerland, 3% from Slovenia, and 0.95% from Hungary, the remaining 80% is produced in the country[15]. Table 11 shows the environmental load to provide 4,187 kWh electrical energy for Austrian households considering energy transmission and transformation losses form medium voltage to low voltage. This calculation has been done with the software SimaPro considering the real mix energy carriers to provide the electricity in Austria. As the table shows in order to provide 4,187 kWh at socket, nearly 7,000 kWh energy should be supplied in the power plans[16]. This corresponds to nearly 1,500 kg CO_2 emissions for each household just for electricity consumption.

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[14] It does not include transformation, transport nor distribution losses.

[15] : IEA database, and energy strategy for Europe and http://ec.europa.eu/energy/energy_policy/doc/factsheets/country/at/mix_at_de.pdf

[16] SimaPro analysis , Input parameter as processes considered Electricity, Low Voltage, at grid /AT U

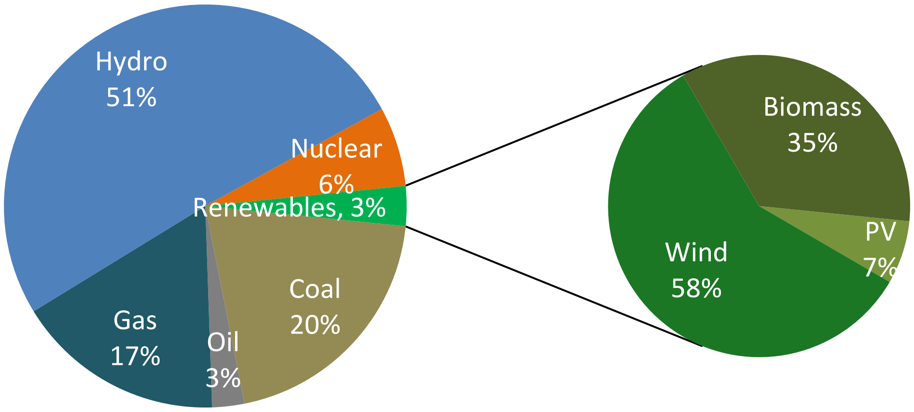

Figure 30: Share of domestic electricity production by technology and imports as medium voltage in Austria[17]

Table 11: Environmental load of providing electricity for an average Austrian HH in year-(Database:SimaPro7-IMPACT method)

Impact category	Unit	Conventional Method
Carcinogens	kg C2H3Cl eq	8.77
Non-carcinogens	kg C2H3Cl eq	3.95
Respiratory inorganics	kg PM2.5 eq	0.589
Ionizing radiation	Bq C-14 eq	3.26E4
Ozone layer depletion	kg CFC-11 eq	0.000159
Respiratory organics	kg C2H4 eq	0.376
Aquatic ecotoxicity	kg TEG water	3.51E4
Terrestrial ecotoxicity	kg TEG soil	7.86E3
Terrestrial acid/nutri	kg SO2 eq	11.8
Land occupation	m2org.arable	4.7
Aquatic acidification	kg SO2 eq	3.01
Aquatic eutrophication	kg PO4 P-lim	0.0142
Global warming	kg CO_2 eq	1.54E3
Non-renewable energy	MJ primary	2.5E4
Mineral extraction	MJ surplus	3.14

6.1.3. Household thermal demand in Austria

The first step to estimate the saving trend in household energy consumption would be focusing on heating requirement details such as heating requirement for thermal appliances

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[17] This figure has been adapted with the writer from different references like: IEA database, and energy strategy for Europe and http://ec.europa.eu/energy/energy_policy/doc/factsheets/country/at/mix_at_de.pdf

in household. This is also necessary to design the characteristics and dimensions of the different parts of the solar system.

6.1.3.1. Domestic hot water consumption (DHW)

Based on Statistic Austria the share of renewable energy to provide the domestic hot water and space heating has increased during recent years, Figure 31. Table 12 shows the energy sources to provide DHW. The average energy consumption to provide hot water for each Austrian household is nearly 2000 KWh per year. This is nearly equal to 110 liters water per day with the temperature of 50°C.

In a report from (defra, 2008) the DHW consumption for UK households has been reported 122 liters per day with 95% confidence interval of ±18 lit/day. And the average temperature has been reported 51.9 °C with a confidence interval of ±2°C. In this study the simulation analysis and calculations for domestic hot water, presented in the next chapter, has be done with the assumption of 110 liters (50°C) with the daily run off profile shown in Figure 33.

Table 12: Annual fraction of different energy sources providing the domestic warm water for Austrian households- Ref: Statistik Austria-Adapted

Energy Source	kWh	Percentage
Black coal	0.857	0.04%
Brown coal	0.503	0.02%
Coke	2.337	0.11%
Wood	166.067	7.94%
Wood pellets	27.025	1.29%
Wood briquette	3.814	0.18%
Wood chips	29.279	1.40%
Heating oil	275.348	13.16%
Liquefied petroleum gas	14.018	0.67%
Natural gas	461.071	22.04%
District heating	311.555	14.89%
Electricity	538.428[18]	25.73%
Solar energy	186.312	8.90%
Heat Pump	75.778	3.62%
Total	2,092.392	100%

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[18] This amount is little bit different form table 10 (average electricity consumption). Because this table has been adopted for each family with the writer of this dissertation based on Statistik Austria data given for total Austrian households. The population of Austria considered 8,443,018 and number of people in each household assumed 2.26.

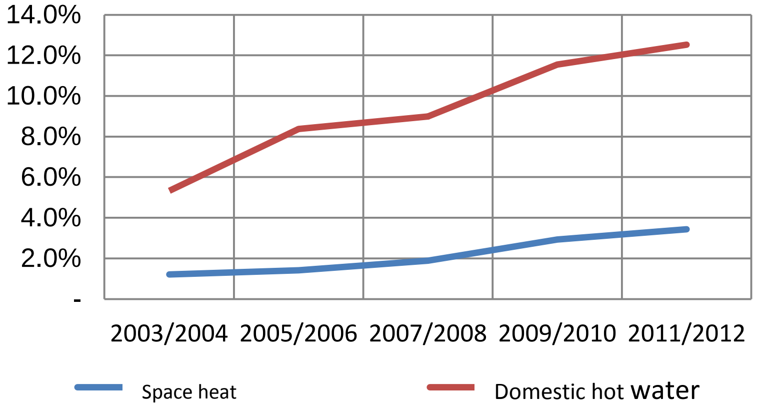

Figure 31: Percent of sharing the renewable energy providing heat demand and DHW –Rfe: Statistic Austria 2012

6.1.3.2. Thermal demand of space heating

The average floor space in families has been addressed with Statistic Austria, 99.5 m^2in 2011 and 102.3 m^2 in 2010. The same reference also shows that in 2003 just 1.2% of energy for space heating was from renewable energies and in 2012 the share of renewable energies to produce space heating has increased to 3.4%.

In this research the average floor space has been considered 100 m^2, with the heat demand of 14,483 kWh as space heating. As following table shows the most energy source share of space heating belongs to wood, and then to natural gas. And electricity has just a share of 4%., although in electricity demand of households 14% of total consumption belongs to space heating.

6.1.4. Environmental analysis of Thermal demand for an average Austrian HH

For the environmental assessment of current energy providing situation for the households in Austria, LCA has been adapted. To do the LCA it is important to know the different energy carriers that provide electrical and thermal energy for the households. Table 14 shows the energy carriers that deliver DHW[19] and space heating for Austrian households. LC energy analyzing of the above mentioned average household thermal energy production shows that the highest environmental impact is noticed as a result of combustion of hard coal (39.7 kg CO_2). The wood combustion and heat pump are the technologies with lowest environmental impact. For natural gas the contribution to the total score in Global warming is 44% and for heat oil, it is 47%, table 14.

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[19] DHW has been calculated for a 100m^2 living space.

Table 13: Annual fraction of all energy sources providing space heating per square meter for each family– Ref : Statistik Austria 2012-Adapted [20]

Energy sources	GJ total	kWh/m^2	Percentage
Black coal	261,518.43	0.20	0.13%
Brown coal	25,301.78	0.02	0.01%
Brown coal briquette	277,190.27	0.21	0.14%
Coke	804,663.41	0.60	0.41%
Wood	50,867,578.57	37.97	26.22%
Wood pellets	4,689,387.31	3.50	2.42%
Wood briquette	2,084,998.10	1.56	1.07%
Wood chips	5,960,277.75	4.45	3.07%
Heating oil	43,692,135.18	32.61	22.52%
Liquefied petroleum gas	978,830.82	0.73	0.50%
Natural gas	45,959,273.26	34.30	23.69%
District heating	24,158,052.26	18.03	12.45%
Electricity	7,628,630.83	5.69	3.93%
Solar energy	2,478,280.07	1.85	1.28%
Heat Pump	4,172,977.39	3.11	2.15%
Total	**194,039,095.42**	**144.83**	100.00%

Table 14: Energy source of thermal energy for households in Austria for DHW and space heating[21] – Adapted from Statistik Austria 2012

Energy Source	Thermal energy(kWh)	Percent
Black coal	21.02	0.13%
Brown coal	23.6	0.15%
Coke	62.79	0.4%
Wood	3995.41	25%
Wood pellets	382.29	2.4%
Wood briquette	160.56	1%
Wood chips	479.98	3%
Heating oil	3589.97	23%
Liquefied petroleum gas	89.75	0.7%
Natural gas	3980.86	25%
District heating	2175.23	14%
Solar energy	407.59	2.6%
Heat Pump	401.53	2.5%
Total	15770.58	100%

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[20] This table has been calculated based on the data from Statistik Austria. The data from Statistik Austria has been based on total space heating energy demand for Austria. Steinkohle translated to Black coal, Braunkohle to Brown coal, Braunkohlenbriketts to Brown coal briquette, Koks to coke, Holz to wood, Pellets to wood pellets, Holzbriketts to Wood briquette, Hackschnitzel to wood chips, Heizöl to Heating oil, Flüssiggas to Liquefied petroleum gas, Naturgas to natural gas, Fernwärme to District heating, Strom to electricity, Solarwärme to solar energy, Wärmepumpe to heat pump.

21 The amount of electrical energy has not been mentioned in this table, it will be added in the next part to the electricity demand of the households.

6.1.5. Environmental analysis of total energy demand of an average Austrian HH

Table 15, shows the LCA of thermal and electrical energy demand of Austrian HH. An analysis of an inventory table allows it to determine which energy carrier contributes most importantly to each impact category. The total primary energy demand of each family for energy consumption is equal to 66,387 MJ(18,441 kWh) primary energy. Figure 33 and 32 shows relative strength of unwanted environmental impact providing energy for the households. IMPACT method groups the inflows and outflows of providing energy in 15 impact categories and single score, Figure 33, shows their contribution to each environmental problem.

Table 15 :LCA energy analyze of average Austrian households -IMPACT method-SimaPro7

		total	Electricity	Heat(Coal and coke)	Heat (Wood logs, Pellet, and chips)	Heat(oil)	Heat(Liquid gas)	Heat(Natural gas)	Heat(District heating)	Heat(Solar)	Heat(Heat pump)
Carcinogens	kg C2H3Cl eq	17.10	8.77	0.04	2.61	3.57	0.00	1.05	0.64	0.13	0.01
Non-carcinogens	kg C2H3Cl eq	30.9	3.95	0.54	16.40	3.11	0.00	1.88	2.74	0.33	0.02
Respiratory inorganics	kg PM2.5 eq	3.06	0.59	0.01	1.58	0.35	0.01	0.22	0.26	0.02	0.00
Ionizing radiation	Bq C-14 eq	64940.77	32590.21	103.69	14519.35	6485.45	0.00	10016.72	1024.80	1437.09	4.51
Ozone layer depletion	kg CFC-11 eq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Respiratory organics	kg C2H4eq	3.06	0.38	0.00	1.73	0.40	0.03	0.42	0.08	0.01	0.00
Aquatic ecotoxicity	kg TEG water	390E3	350E2	55E3	10E4	42E3	21.52	11E4	8E3	32E3	38.05
Terrestrial ecotoxicity	kg TEG soil	62476.73	7865.4	242.87	32480.95	9822.56	54.27	10236.87	1143.52	283.66	14.34
Terrestrial acid/nutri	kg SO2eq	51.72	11.83	0.30	20.04	8.04	0.23	7.71	2.88	0.30	0.00
Land occupation	m2org.arable	51.10	4.71	0.08	30.25	1.40	0.00	6.25	3.35	1.34	0.00
Aquatic acidification	kg SO2eq	11.14	3.01	0.13	3.15	2.55	0.05	1.47	0.44	0.18	0.00
Aquatic eutrophication	kg PO4 P-lim	0.13	0.01	0.00	0.03	0.08	0.00	0.00	0.00	0.00	0.00
Global warming	**kg CO2eq**	4063.71	1538.82	16.13	115.05	1200.89	22.20	1109.75	26.70	11.54	0.41
Non-renewable energy	MJ primary	66386.51	24984.89	182.28	2232.71	18239.37	318.19	19680.49	363.43	254.43	2.41
Mineral extraction	MJ surplus	26.04	3.14	0.01	4.60	4.93	0.00	6.27	0.44	6.75	0.02

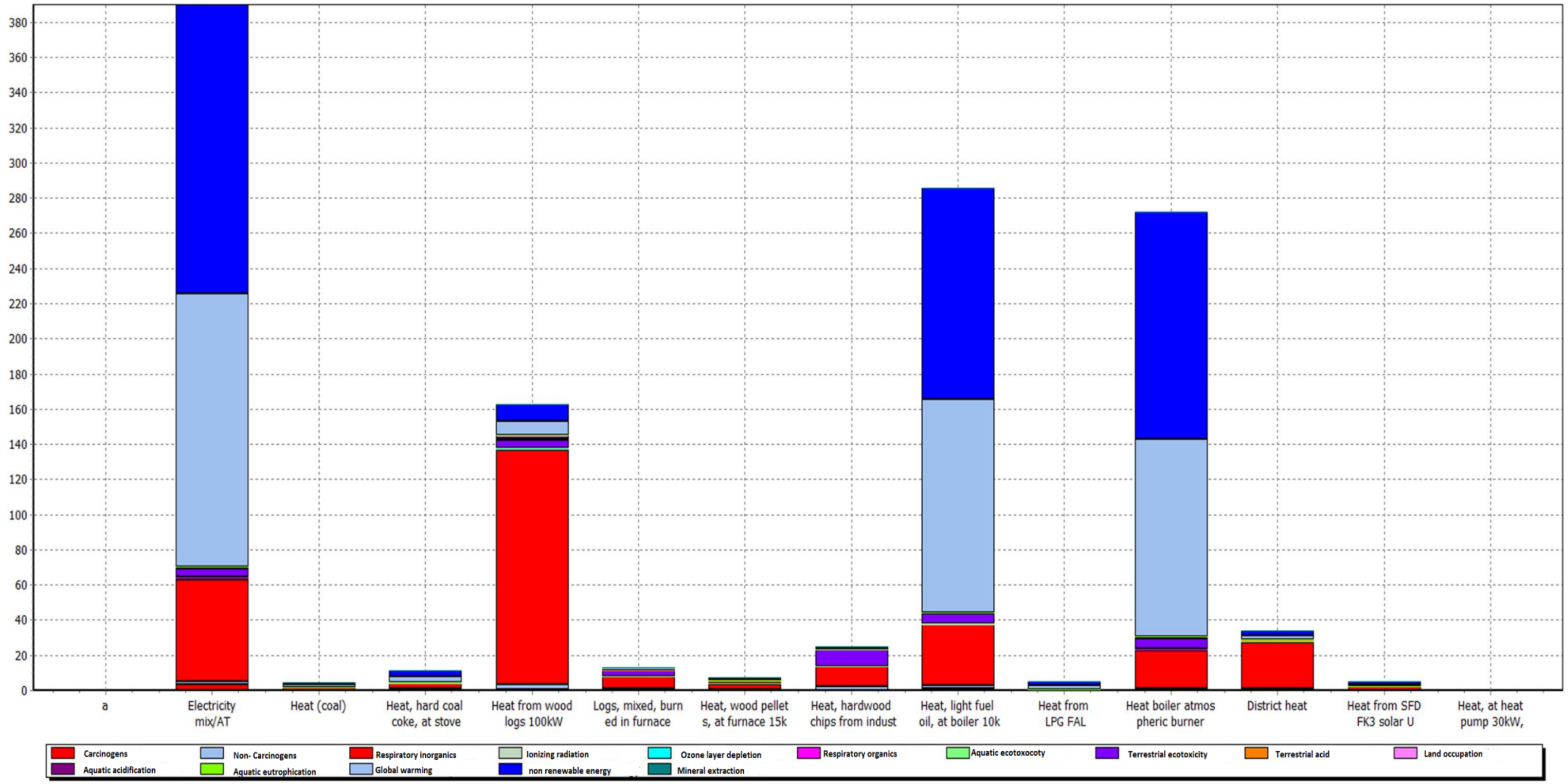

Figure 32: Single score evaluation of per impact category of energy providers for Austrian Households - IMPACT method – SimaPro7

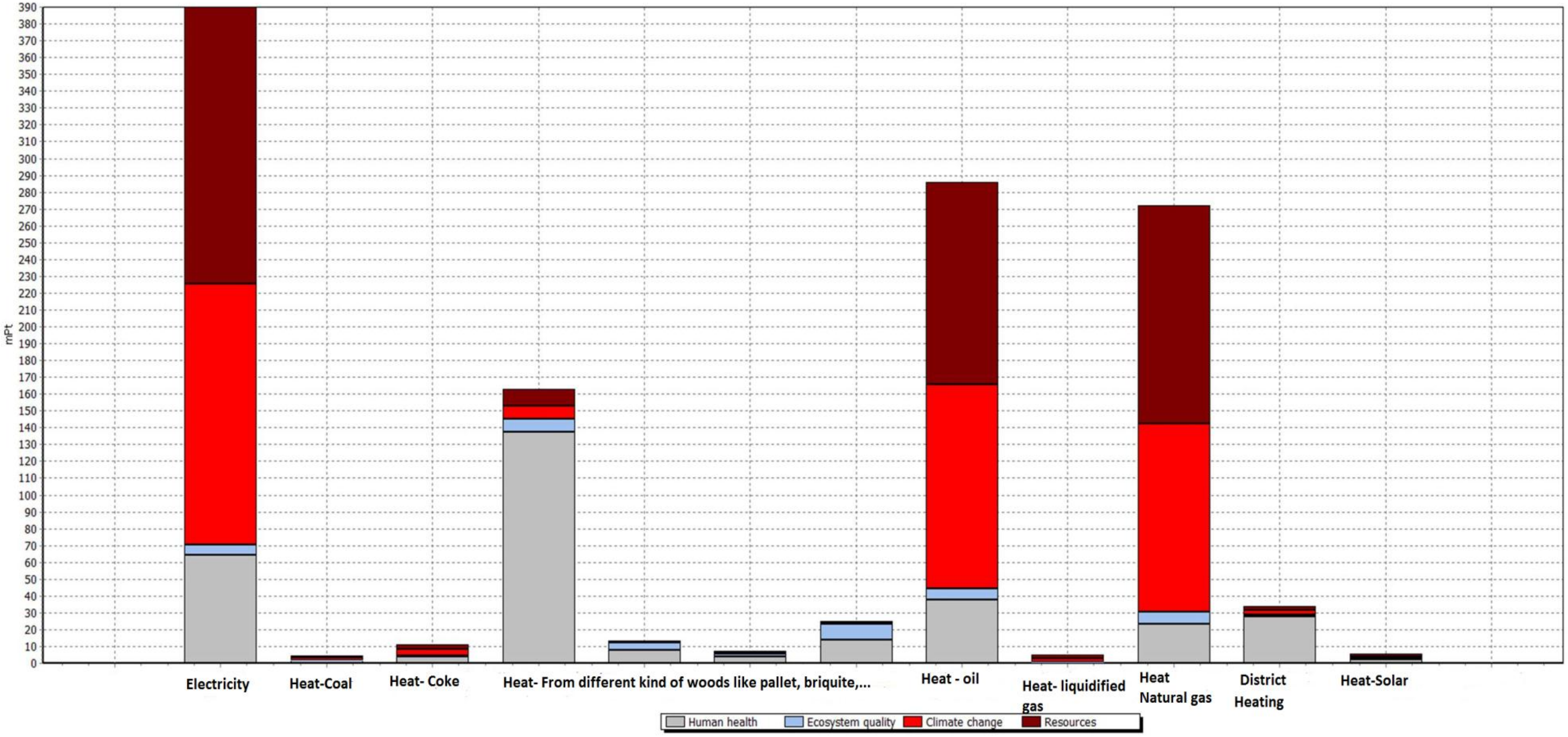

Figure 33: Single score evaluation of per impact category of energy providers for Austrian Households - IMPACT method – SimaPro7

6.2. LCA of the different strategies to provide energy for the hot-fill appliances

In the following part of the study, the consumer saving primary energy consumptions, and environmental impacts of using hot fill dishwasher and washing machine with alternative sources of energy than electricity have been measured.

The undertaken reports of LCA are based upon the average consumer behavior, calculated on the basis of the most frequently used programs and temperature that mentioned in previous chapter. All of the consumption data (electricity, water) for the various strategies have been calculated based on the monitoring and usage of the DW and WM Elektra Bregenz with hot water feeding model. The environmental impacts for all strategies have been incorporated with the software Simapro7. Simapro calculates for all processes and defined scenarios, so-called life cycles, primary energy and raw materials to produce the energy.

The method used for the environmental comparison analysis is IMPACT method. The main factor in this method is given to the damage on human health, ecosystem quality, and energy resources. The reader is cautioned that as the aim of LCA is to compare different sources of energies for the WM and DW, it has been assumed that the amount of water consumption and the materials for constructing the appliances are the same.

6.2.1. Life cycle energy assessment of implementing hot-fill Dishwasher

The behavior of the consumer with household appliances influences the environmental impact because of the usage of resources like water, energy, and chemicals.

The assumption for the experiments and energy measurements area average 2.26-person household basis; in which the DW is used an average of 3.02 times per week and 49 weeks of usage per year. The mentioned using behavior conditions have been incorporated to do the experiments with the installed hot fill dish washer in the prototype system and to calculate saving potential through the use of direct hot water input to the DW.

Regarded Alternatives:

The Hypothesis wanted to be answered is:

- Weather providing the direct warm water with renewable energy sources for the DW would be more environmentally friendly, than providing the warm water with the electricity.

The different scenarios to provide the warm water for DW are:

- Scenario 1: Cold water operation (conventional DW)
- Scenario 2:Warm water supply operation via solar thermal and gas boiler as back up
- Scenario 3:Warm supply operation via solar thermal and biomass boiler as back up
- Scenario 4: Warm water supply via the condensing gas boiler

LCA results of the different strategies to provide energy for the DW:

LCA investigates the subsequent savings of primary energy, environmental impact of using different sources of energy to provide the hot water for the DW. In all alternatives it is examined to what extent the environmental impacts will be considerable. In practice, the cold water input DW is compared with the alternatives “warm water supply through gas condensing boiler” or “solar thermal system with additional gas heating / Biomass heating back up”.

Table 16 show the results of IMPACT method for the competition of greenhouse gas emissions, CO_2 emission and other environmental impacts. Global warming potential (GWP) is the potential contribution of a substance to greenhouse effect. This value has been calculated for a number of substances over 100 years. Table 17, summarized the scenario comparison, shows hot fill compared to cold water mode is clearly beneficial concerning the environmental variables.The provision of hot water for DW has nearly total maximum CO_2 emission saving up to 33% [22] for the environment.

Figure 34 & 35 describe in detail the effect of using different energy sources on global warming, human health, climate change, resources, ozone depletion and mineral extraction. The impact assessment proves that the most harmful scenario for the environment is the first scenario (conventional DW). Among renewable technologies, the solar energy with the biomass back up have the smallest environmental load. The damage assessment in this study has been done without considering the circulation pumps, because in the prototype system - Böheimkirchen the energy providers are near to the appliances then circulation pumps have not been installed. Extending the analysis considering the pump might change the results.

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[22] [Co_2 emission of solar +Biomass Policy /Co_2 emission conventional DW)-1]=33%

Table 16: Comparison of the four strategy to provide the warm water for DW- LCA Method: IMPACT;Simapro7

Impact category	Unit	DW solar&Gas	DW Solar&Biomass	DW Gas condensing Boiler	DW Cold water
Carcinogens	kg C2H3Cl eq	0.642	0.555	0.782	0.67
Non-carcinogens	kg C2H3Cl eq	0.335	1.19	0.233	0.302
Respiratory inorganics	kg PM2.5 eq	0.0337	0.0506	0.0332	0.045
Ionizing radiation	Bq C-14 eq	1.97E3	1.87E3	1.68E3	2.49E3
Ozone layer depletion	kg CFC-11 eq	1E-5	8.13E-6	1.31E-5	1.22E-5
Respiratory organics	kg C2H4eq	0.0223	0.0221	0.0262	0.0287
Aquatic ecotoxicity	kg TEG water	2.33E3	9.25E3	2.07E3	2.68E3
Terrestrial ecotoxicity	kg TEG soil	600	3.13E3	478	601
Terrestrial acid/nutri	kg SO2eq	0.669	0.883	0.697	0.904
Land occupation	m2org.arable	0.274	2.07	0.242	0.36
Aquatic acidification	kg SO2eq	0.172	0.193	0.178	0.23
Aquatic eutrophication	kg PO4 P-lim	0.000	0.00403	0.000	0.001
Global warming	**kg CO2eq**	**89.6**	**78.6**	**107**	**118**
Non-renewable energy	MJ primary	1.52E3	1.29E3	1.83E3	1.91E3
Mineral extraction	MJ surplus	1.28	0.722	0.23	0.24

Table17: CO_2 emission comparison for different strategy providing hot water for DW

	DW solar&Gas	DW Solar&Biomass	DW Gas condensing Boiler	DW Cold water
Global warming kg	89.6	78.6	107	118
Relative percent	76%	67%	91%	100%
saving co_2 emission	24%	33%	9%	-
Primary energy MJ	1520	1290	1830	1910
saving primary energy	20%	32%	4.1%	-

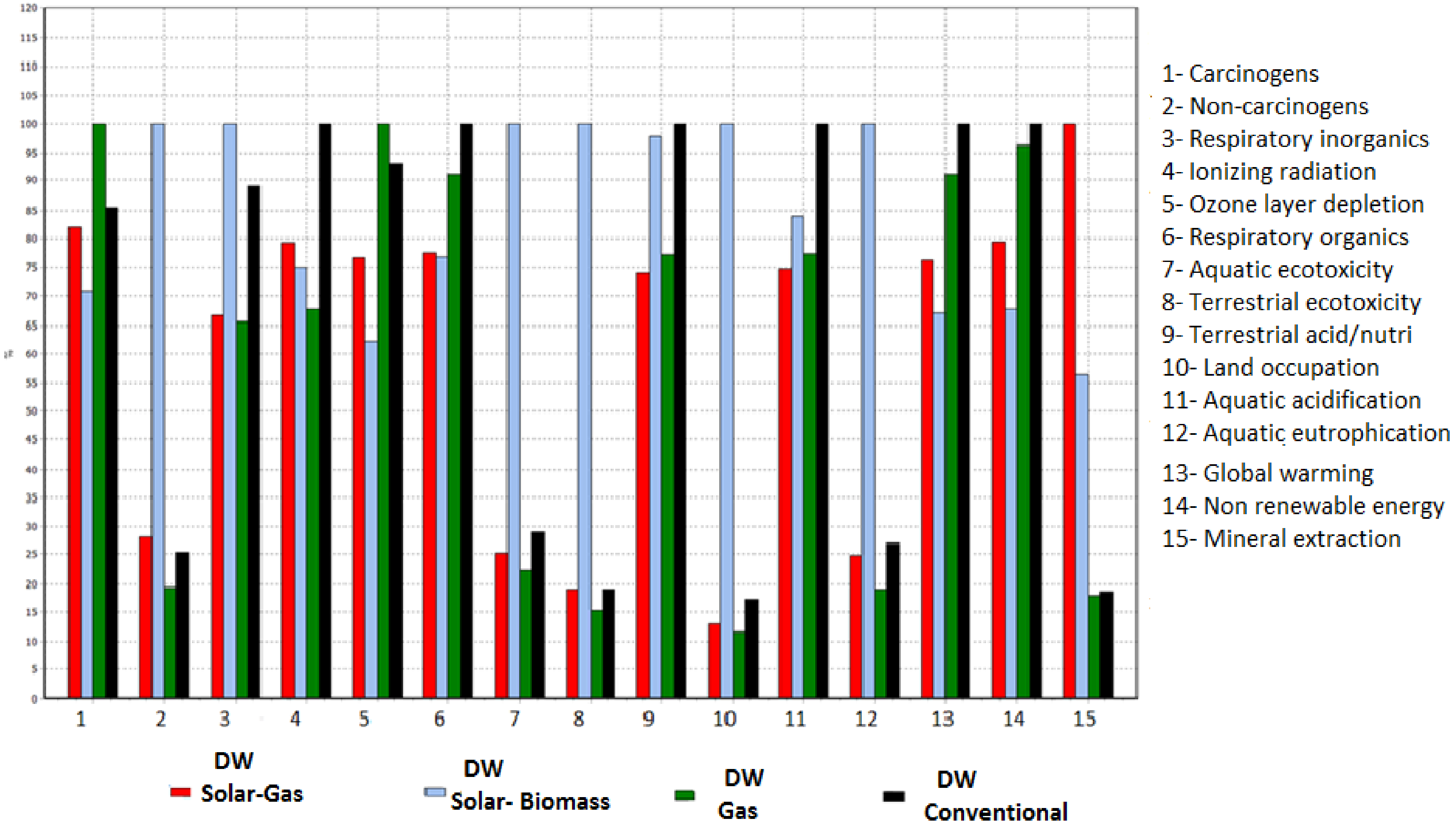

Figure 34: Characterization comparison of different strategies to provide hot water for DW –IMPACT method,Simapro7.1

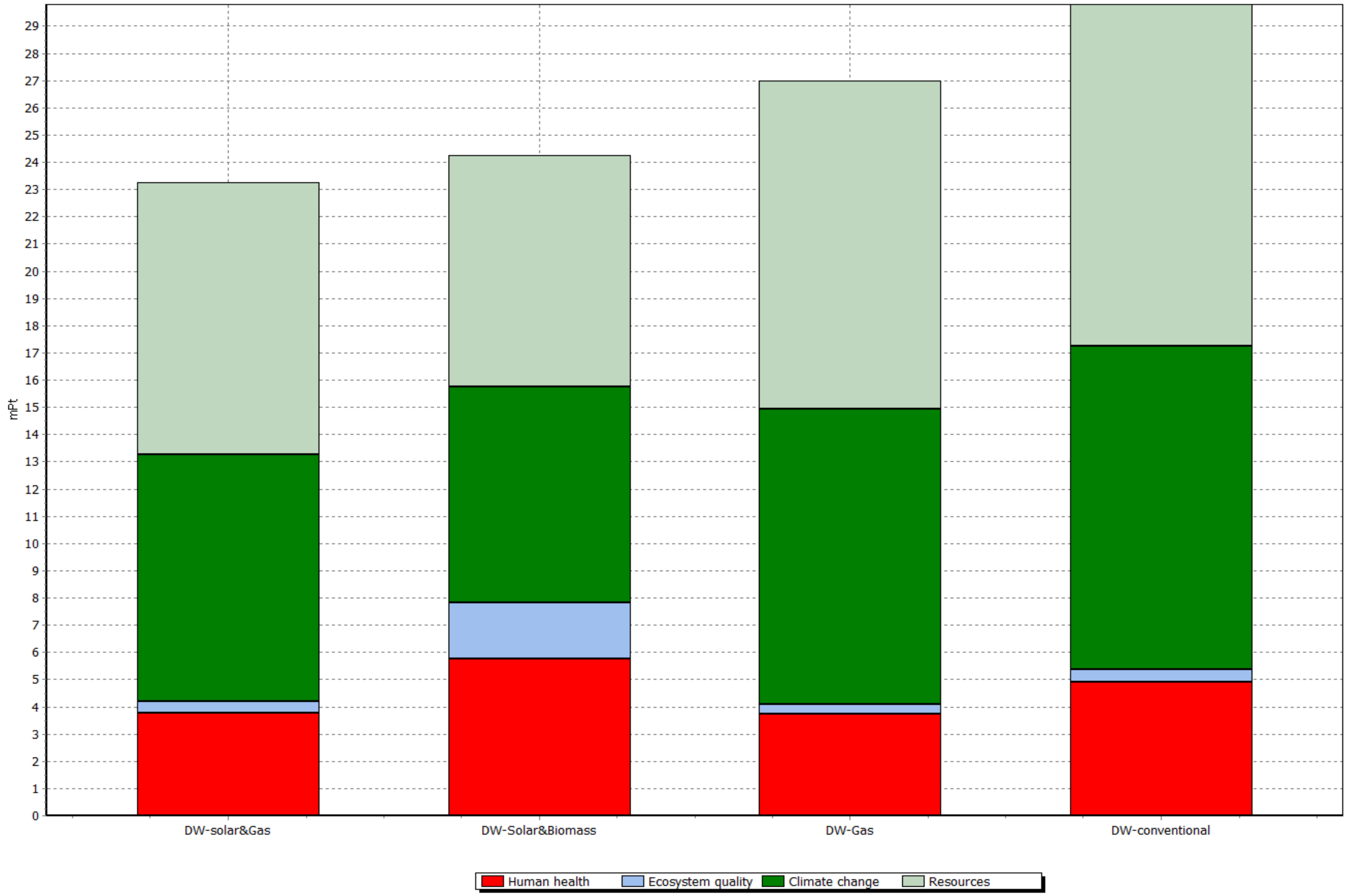

Figure 35: Single score comparison of different strategies to provide hot water for DW –IMPACT method, Simapro7.1

6.2.2. Life cycle energy assessment of implementing hot-fill Washing machine

For the energy LCA the following alternatives have been considered.

- Scenario one: Cold water operation
- Scenario two: Warm water supply operation via solar thermal and gas boiler as back up
- Scenario three: Warm supply operation via solar thermal and biomass boiler as back up
- Scenario four: Warm water supply via the gas condensing boiler

Results of LCA-WM

In this part the primary energy demand, and greenhouse gas emissions have been calculated for different scenarios. The LCA results show that from the environmental view, providing the hot water filling for the WM is rewarding. By connecting the WM to the hot water input, the demand for electrical energy can be nearly half. And the provision of hot water offers more efficient system to supply thermal energy for the WM.

The different environmental variables in the LCA indicate that the hot water use has significant advantages compared to the cold water mode. With the primary energy consumption as well as with the emissions of greenhouse gases significant savings can be proved. The results show significant reduction in emissions of CO_2 equivalents that can be achieved by providing the hot water for the WM from other source of energy than electricity. Approximately 10% of greenhouse gas emissions can be decreased with the alternative energy supply by gas condensing boilers. By using a solar thermal system with gas heating as a back-up, greenhouse gas emissions will be decreased to nearly 27% compared to the operating of the washing machine just with electricity. And using solar thermal system with biomass back-up saves 35% CO_2 emissions each year. Almost similar results have been asserted for the non-renewable primary energy.

Alternative of using the solar energy with the back-up of gas or biomass is the most favorable nearly in all environmental impact categories. In these calculations the waste related to circulation pump has not been considered.

Table18: Comparison of the four strategy to provide the warm water for WM- LCA Method:IMPACT;Simapro7

Impact category	Unit	WM solar&Gas	WM Solar&Biomass	WM Gas condensing Boiler	WM Cold water
Carcinogens	kg C2H3Cl eq	0.411	0.346	0.515	0.431
Non-carcinogens	kg C2H3Cl eq	0.219	0.855	0.143	0.194
Respiratory inorganics	kg PM2.5 eq	0.020	0.033	0.020	0.029
Ionizing radiation	Bq C-14 eq	1.22E3	1.14E3	1.01E3	1.6E3
Ozone layer depletion	kg CFC-11 eq	0.00	0.00	0.00	0.00
Respiratory organics	kg C2H4eq	0.0137	0.014	0.016	0.018
Aquatic ecotoxicity	kg TEG water	1.47E3	6.6E3	1.28E3	1.73E3
Terrestrial ecotoxicity	kg TEG soil	387	2.26E3	296	387
Terrestrial acid/nutri	kg SO2eq	0.408	0.567	0.429	0.582
Land occupation	m2org.arable	0.168	1.5	0.145	0.231
Aquatic acidification	kg SO2eq	0.105	0.121	0.11	0.148
Aquatic eutrophication	kg PO4 P-lim	0.00	0.00	0.00	0.00
Global warming	**kg CO2eq**	**55**	**49.6**	**68**	**75.7**
Non-renewable energy	MJ primary	939	771	1.17E3	1.23E3
Mineral extraction	MJ surplus	0.925	0.512	0.147	0.155

Table 19: CO_2 emission comparison for different strategy providing hot water for WM

	WM solar&Gas	WM Solar&Biomass	WM Gas condensing Boiler	WM Cold water
Global warming kg	55	49.6	68	75.7
Relative percent	73%	65%	90%	100
saving co_2 emission	27%	35%	10%	-
Primary energy MJ (none renewable)	939	771	1.17E3	1.23E3
saving primary energy	24%	37%	4.8%	-

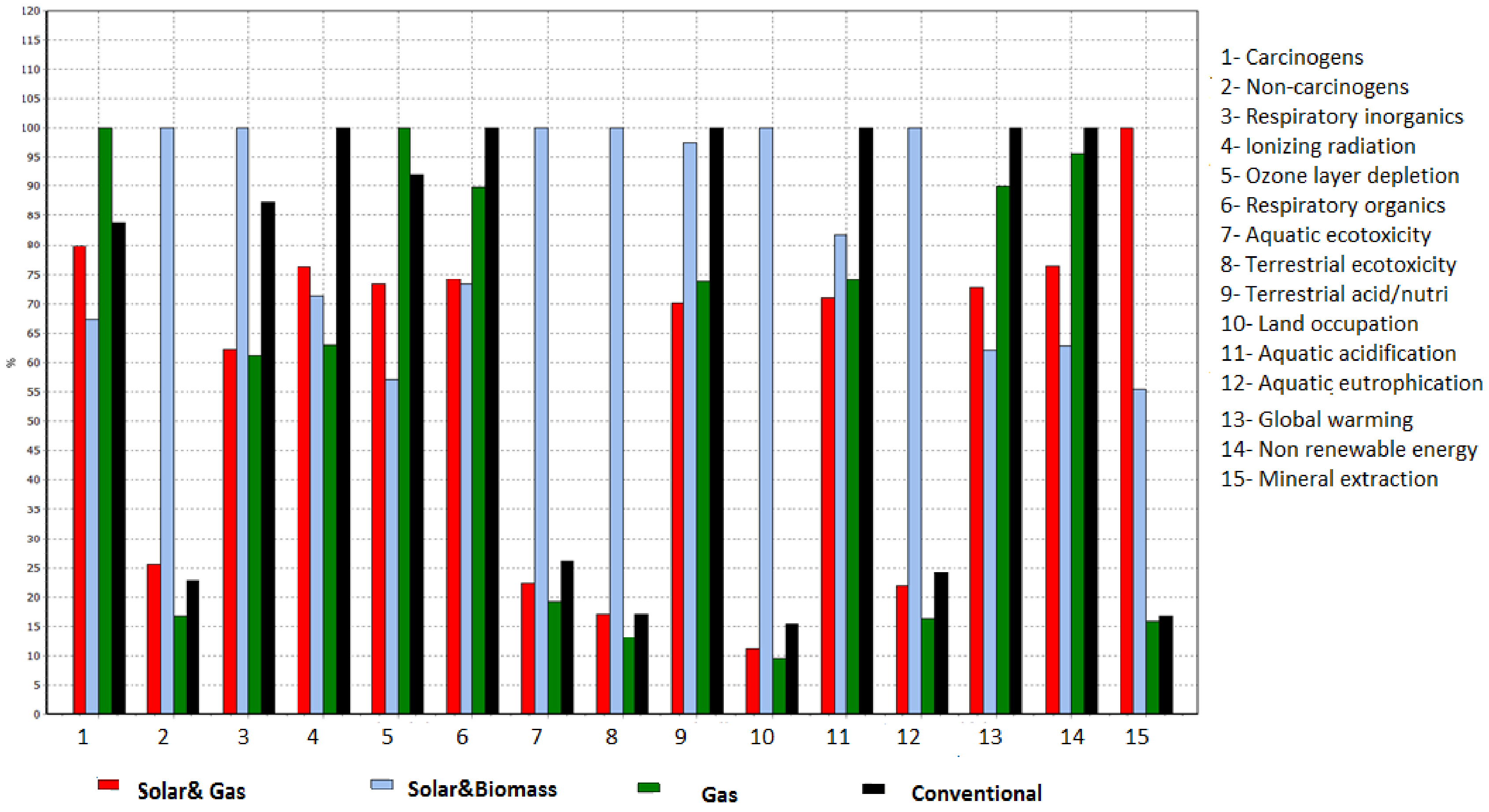

Figure 36: Characterization compare between the four strategies to provide the warm water for the WM - IMPACT method , SimaPro7

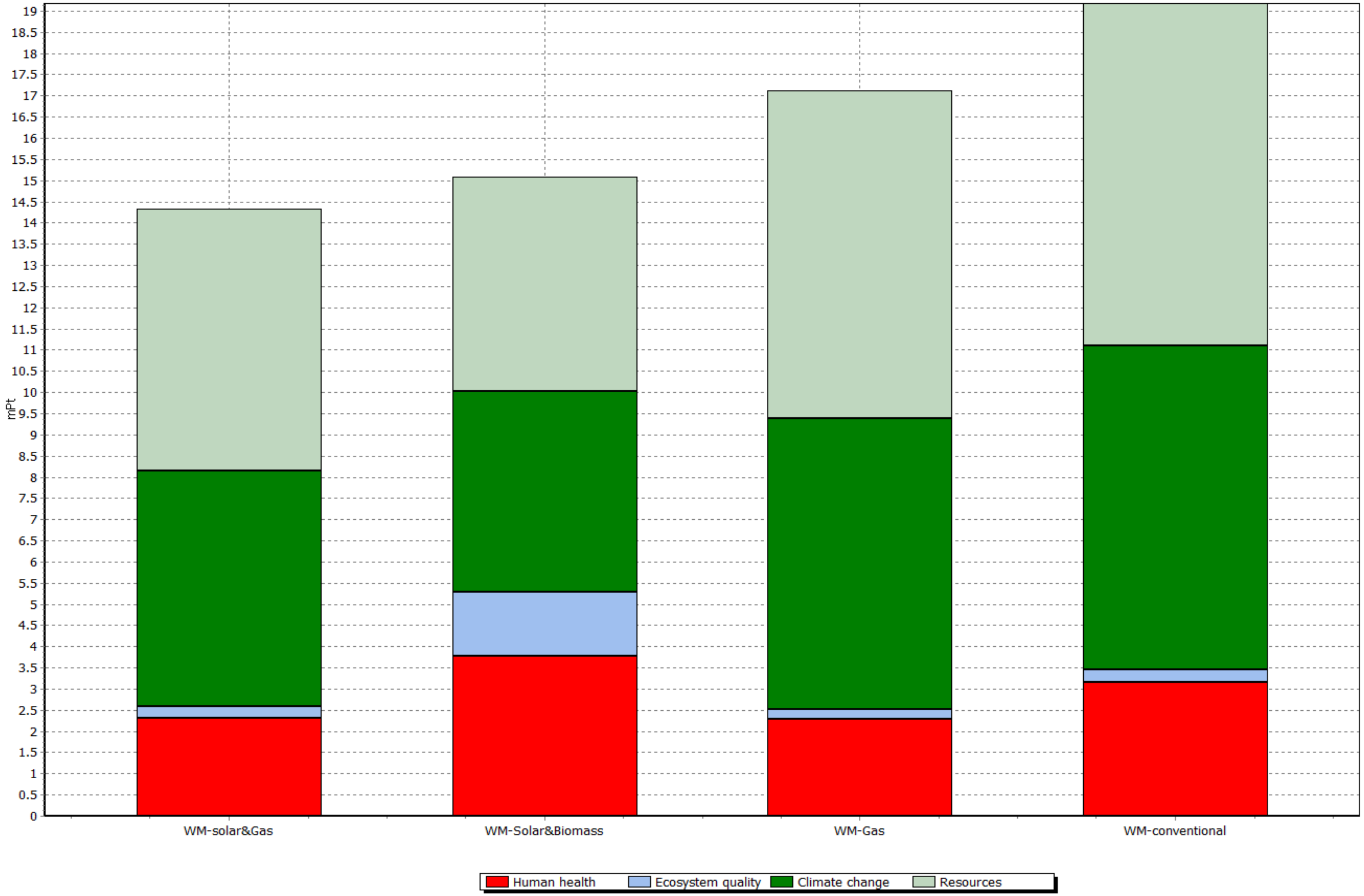

Figure 37: Single core comparison between four strategies to provide the warm water for the WM-IMPACT method, SimaPro7

6.3. LCA result of comparing different scenarios providing energy for households

In this part of the chapter environmental impacts of implementing *integrated solar energy* to provide the energy demand in an Austrian family with 100 m^2 floor surface living area have been conducted.

To describe the environmental impacts and compare it with conventional energy services, three different scenarios have been introduced. And the necessary amount of energy or fuel needed for all year of a house has been determined to do the LCA for all strategies. Table 21 shows comprehensively thethermal and electrical energy consumption of each of these scenarios. The conventional household energy service has been considerd as based scenario.

Strategy A (second scenario):

This strategy considers a “normal energy category” house. In this house the thermal energy is provided with *integrated solar system*. The implementing of the new innovative energy supply system will reduce the electricity consumption to 2,487$kWh_{Electrical}$ (40% reduction compared to average Austrian HH).

Strategy B (third scenario):

This strategy considers a “low energy category” house that the thermal energy is provided with integrated solar system. It is important to reference the practice of low energy building because the households can save more energy compare to normal energy buildings. The low energy category of building benefits from better sun light and heat insolation, then the energy for the space heating, and also lighting decrease (R. Wimmer, 2008).

- Lighting: With better deign the buildings can benefit more sun light; this reduces the electricity needed for lighting. Based on research (R. Wimmer, 2008) the lighting electricity demand with better design can reduce to 80%.
- Space heating and cooling: It is clear that better insulation reduces the space heating energy demand.

In the following table some of the assumed specifications of two different energy category buildings have been mentioned, Table 20.

Table 20: Building characteristics for different building energy category

	U Value($W/m^2.K$)	Heating demand(kWh/m^2)	Heat capacity($kJ/ m^2.K$)
Normal building	0.5	150	500
Low energy building	0.35	30	750

Table 21: Households Energy consumption calculated for three different scenarios

	Average HH (kWh)		Strategy A (kWh)		Strategy B (kWh)	
	Electrical	Thermal	Electrical	Thermal	Electrical	Thermal
Total	4189	15,771	2487	16,288	2,412	8,374
Refrigerator	316	-	316	-	316	-
Freezer	167	-	167	-	167	-
Cooking Devices	391	-	391	-	391	-
WM	142	-	64	104	64	104
Cloth Dryer	143	-	95	175	95	175
DW	262	-	160	238	159.82	238
Kitchen Electrical	197	-	197	-	197	-
Cooling air conditioning	149	-	149	-	74.5	-
Office Equipment	113	-	113	-	113	-
Entertainment Devices	178	-	178	-	178	-
Communication Devices	25	-	25	-	25	-
Other kind of HH	361	-	361	-	361	-
Standby office D.	10	-	10	-	10	-
Standby communication	93	-	93	-	93	-
Standby cooker	14	-	14	-	14	-
Standby kitchen Devices	15	-	15	-	15	-
	446	-	446	-	90	-
DHW+ Pumps	576	1,857	49	1,857	49	1,857
Space Heating+ Pumps	591	13,914	90	13,914	90	6000

The existence of different strategies to supply household energy requirements raises questions about the comparability of these different policies. LCA makes it possible to better understanding of the strength and weakness of each method and insight in the validity of the strategies. For environmental calculation with Simapro7, all the members of the energy system like construction material of solar collectors and storage tank have been considered to calculate the primary energy consumption. It has been considered that the electrical demand of all other appliances than DW, WM and cloth dryer remain the same for all three scenarios. The LCA has been done with the calculation of fuel input at each stage in the energy system chain, and takes into account the energy-efficiency of each process.

The results of comparison are presented in table 22. This table shows the impact assessment of each of scenarios, grouped in 15 categories. Calculation of primary energy and CO2 emission results pointed out that in case of thermal energy production in normal Austrian household global warming is 3,723.98 (kg CO2), this is nearly three times more than "Strategy A" that shows 1,323.8 (kg CO2), per year, and 3.4 times more than "Strategy B"; 1096.54 (kg CO2). Primary energy equivalent in "strategy A" is 23,300 MJ(6,472 kWh) and in "strategy B" is 18,700 MJ(5,194 kWh).Then the primary energy equivalent in "strategy A" shows 45% reduction relative to conventional energy service and "strategy B" shows 71% primary energy reduction.

In damage categories like carcinogens, land occupation, and mineral extraction "Strategy A" has the highest values. And in all other categories like global warming and ozone depletion conventional household energy service has the worst situation. "Scenario B" shows significant different result compared to first two scenarios, this is also due to better insolation and architectural changes in the buildings.

Overall environmental impacts are presented in the Figure 38. The figure presents the result of the most important impact categories with the detail of their origin. Scenario A and B have better impact reduction potential than existing traditional energy supply system, but they occupy more land and need more mineral extraction to construct the solar collectors.

Figure 39 compares all scenarios among all impact categories and presents the result of calculations, aggregated into a synthetic indicator denoted as single score. The single score diagram can give better view of different scenarios providing energy for a household. The highest relative impact is observed on categories Global warming, non-carcinogens and non-renewable energies. The figure shows that the first strategy has the highest environmental load for nearly all impact categories. It is clear that the impact is considerably lower when the other form of energy like solar be used to make the thermal demand instead of electricity.

The results prove that actually the most harmful environmental energy strategy is producing the electricity in power plans and convert it to thermal energy at home. The introduced new strategies significantly reduce CO_2 emissions, mitigate climate change and contain a minimum of grey energy over their entire life cycle.

Table 22: The comparison result of three different scenarios providing the energy for HH-IMPACT method-SimaPro

Impact category	Unit	Normal HH	Strategy A	Strategy B
Carcinogens	kg C2H3Cl eq	17.1	23.20	14.30
Non-carcinogens	kg C2H3Cl eq	30.09	149.37	77.85
Respiratory inorganics	kg PM2.5 eq	3.06	3.53	1.97
Ionizing radiation	Bq C-14 eq	6.49E4	5.76E4	3.84E4
Ozone layer depletion	kg CFC-11 eq	0.00	0.00	0.00
Respiratory organics	kg C2H4eq	3.06	0.74	0.48
Aquatic ecotoxicity	kg TEG water	395,334.41	1,128,210.61	589,452.85
Terrestrial ecotoxicity	kg TEG soil	62,533.32	408,473.62	212,106.16
Terrestrial acid/nutri	kg SO2eq	51.70	51.14	29.49
Land occupation	m2org.arable	51.58	273.11	141.67
Aquatic acidification	kg SO2eq	11.1	8.38	5.12
Aquatic eutrophication	kg PO4 P-lim	0.13	0.50	0.26
Global warming	kg CO2eq	4.06E3	1.32E3	1.1E3
Non-renewable energy	MJ primary	6.64E4	2.33E4	1.87E4
Mineral extraction	MJ surplus	26.05	85.39	44.75

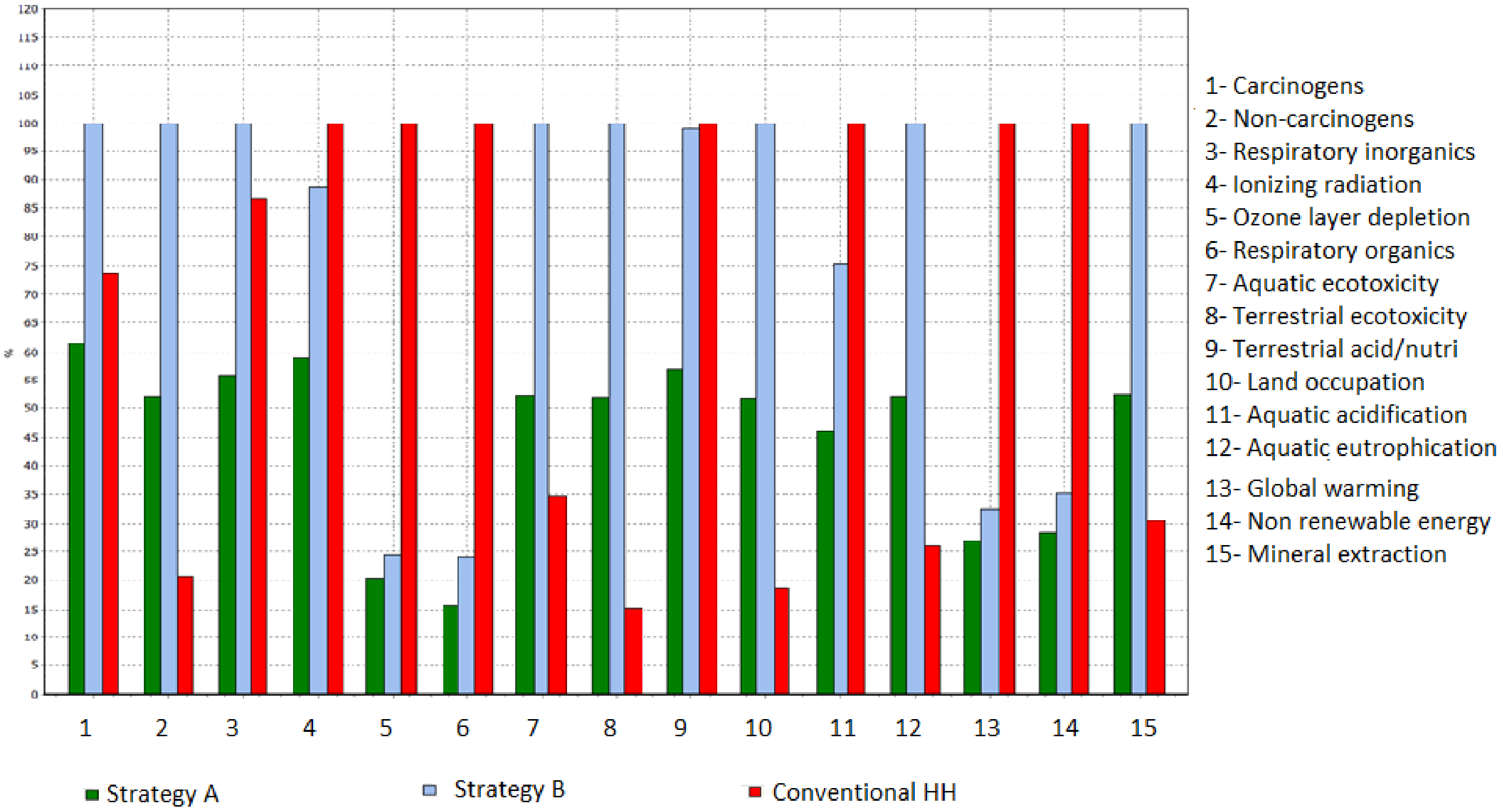

Figure 38: Characterization result of comparing different strategy providing energy for the HH, IMPACT method- SimaPro 7

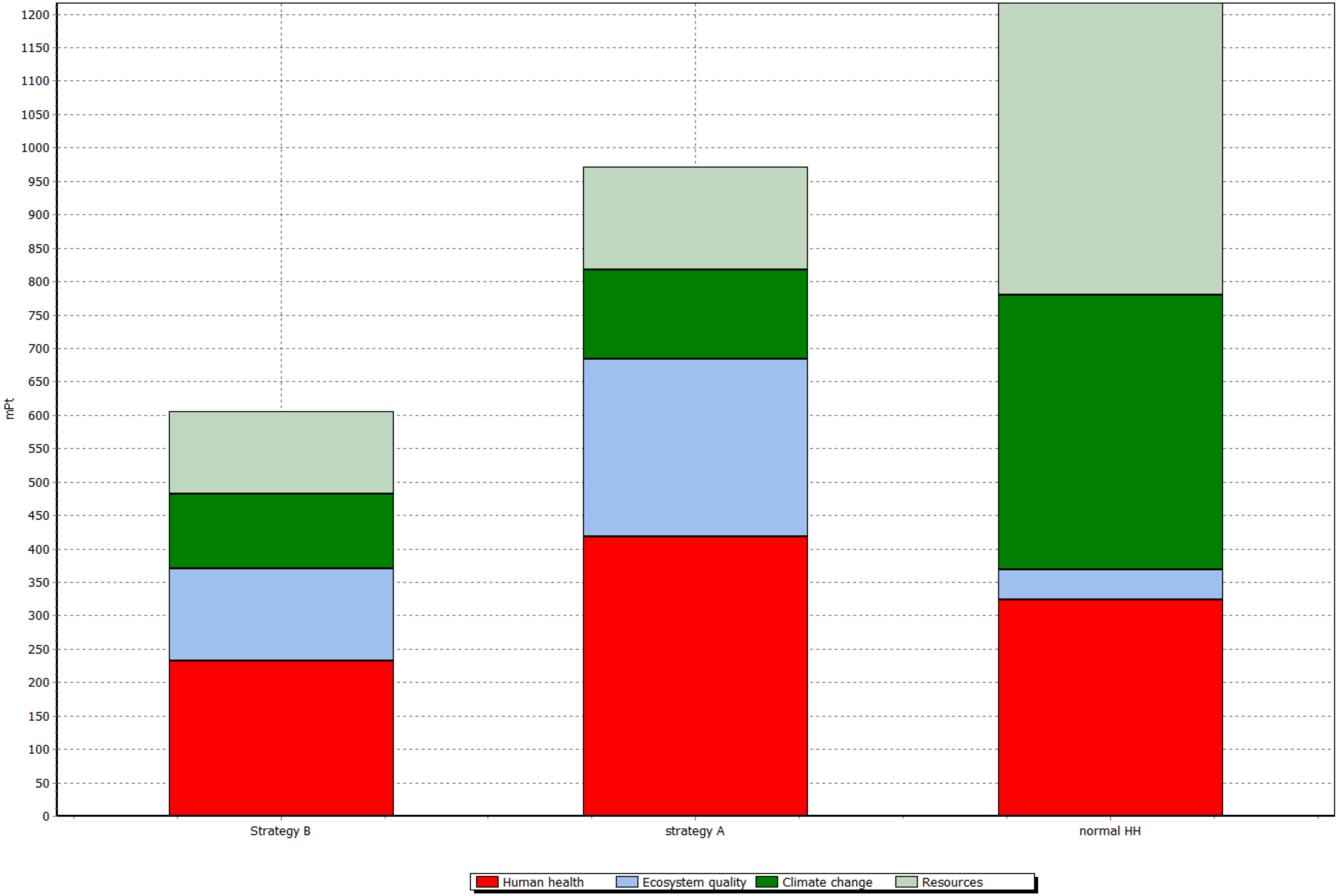

Figure 39: Single Score comparison between three different strategies providing energy for HH- IMPACT method-SimaPro7:

Chapter 7: DISCUSSION OF RESULTS - SYSTEM PERFORMANCE AND SIMULATION

In this part simulation and performance evaluation of the considered *solar integrated system* has been carried out. The system is evaluated, with parameters like: solar factor, solar thermal energy to the system, total performance, and heat generation. The simulation also makes sure that the specified thermal demand in the system can be satisfied. At the end electricity saving and the economical evaluation of the system and sensitivity analysis of the different financial and technical variables have been implemented.

7.1. Model development

7.1.1. Model system layout and parameters

The current system needed to be simplified to its basic operation before modeling. The model in Figure 40 shows, the simplifications that have been done to simulate the real *solar integrated system* in Böheimkirchen.

The chosen program in this research to model and to simulate the real energy system is PolySun that makes the hourly system simulation possible. This software provides a different range of boilers, storage tanks, external or internal heat exchangers, and various types of heat pumps. PolySun also provides the tools for controller settings of different parts of the system

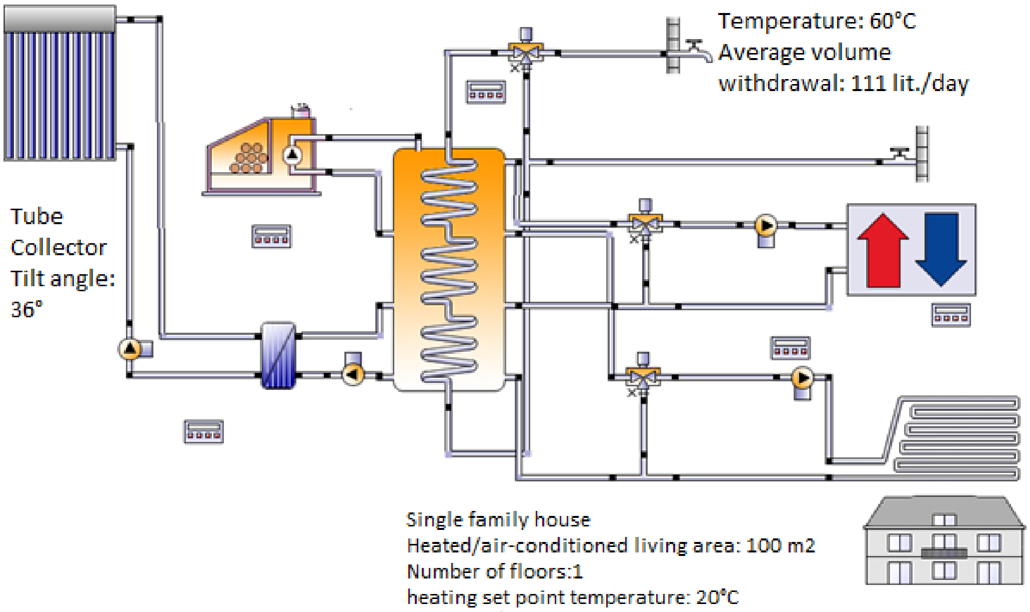

Figure 40: Modeling the integrated solar system with PolySun

7.1.2. Weather and location information

Böheimkirchen has elevation of 247 m, Longitude: 15.767°, and Latitude: 48.200°. To be more precise Meteonorm hourly weather data of Böheimkirchen has been incorporated to the simulation analysis. As the following table shows the horizontal beam radiation in the city, has a yearly total value of 522kWh/m^2 is nearly equal to 1,073 kWh/m^2/year direct normal radiation.

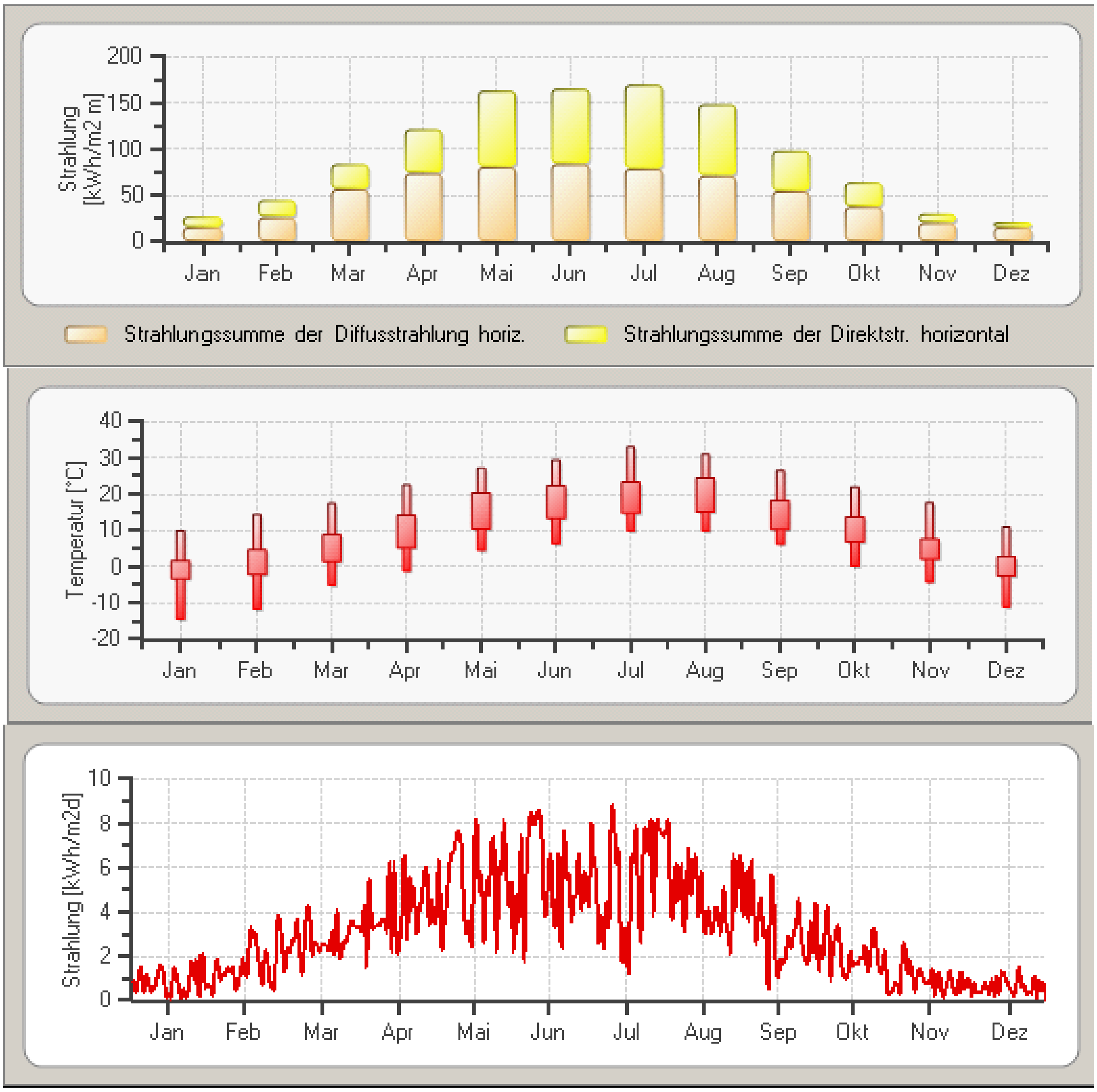

Figure 41: Monthly solar irradiation, ambient temperature in Böheimkirchen –Meteonorm data base

Table 23: Meteorological data overview of Böheimkirchen Austria –Ref: Meteonorm data base

Month	Temperature	Irr. Global horizontal	Irr. Beam horizontal	Irr. Diffuse horizontal	Wind speed
	[C]	kWh/m^2	kWh/m^2	kWh/m^2	m/s
January	-0.8	27	12	15	2.6
February	1.4	45	19	26	3.1
March	4.9	84	27	56	3
April	10	121	47	74	2.8
May	15.5	164	82	81	2.6
June	18.3	166	81	84	2.6
July	19.3	169	90	79	2.8
August	19.8	148	77	71	2.3
September	14.5	98	44	54	2.4
October	10	64	27	37	2.4
November	4.8	29	10	20	2.5
December	-0.1	20	6	15	2.6
Year	9.8	1131	522	612	2.6

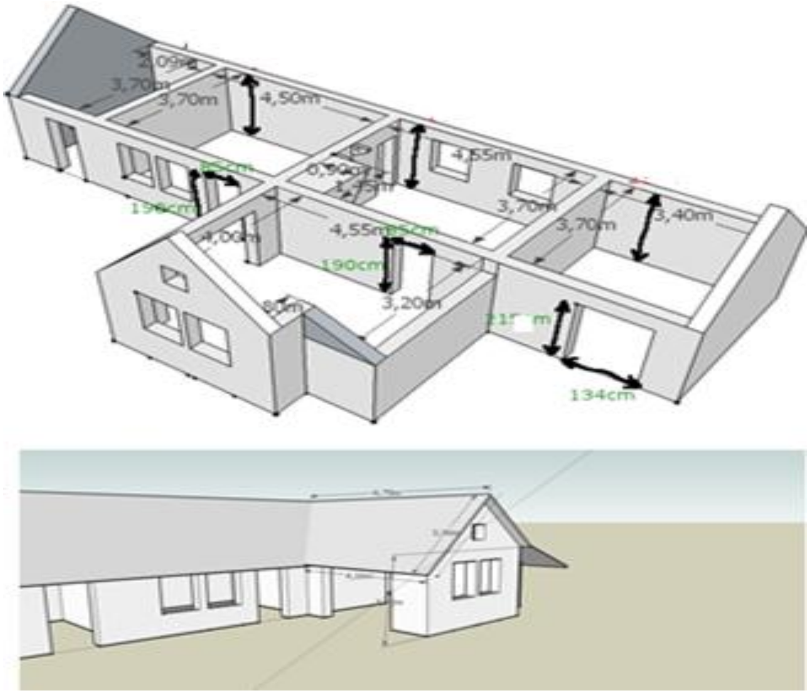

Figure 42: AutoCAD layout of the prototype house in Böheimkirchen

7.2. Simulation Results

The simulation has been done with PolySun for the prototype house located in Lower Austria, Böheimkirchen. The collectors have been installed to the south direction to gain the maximum possible solar radiation. The “auxiliary energy”, that has been mentioned in the simulation results, is the heat output from the auxiliary energy system, thus including the thermal demands like heat for DHW heating, space heating and also heat losses from the piping and the tank. The performance of solar system strongly depends on the correct design and sizing of system components.

7.2.1. Tilt angle

The success of a solar energy system depends on the availability of the solar radiation. The meteorological condition of each place on the earth imposes the inclination of the solar radiations. The best tilt angle of the collectors corresponds to the meteorological condition for each region. As a tree causes shading on the collector in this prototype prototype house, to find the optimum tilt angle the simulation with PolySun can be helpful, as PolySun considers also shading. Based on the following graph resulted from the simulation for different tilt angle, the optimum tilt angle for the vacuum collectors considered to be 33° to 34°. At this tilt angle the solar gain will be nearly 4,500 kWh per year.

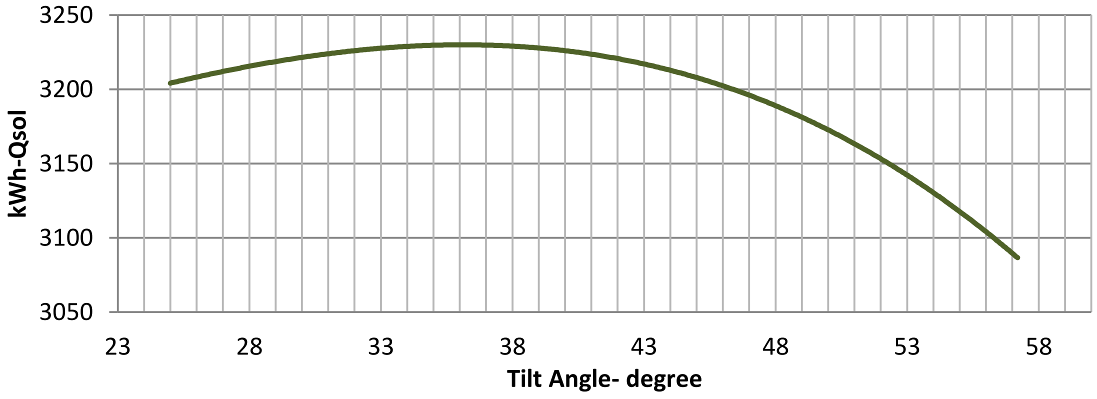

Figure 43: PolySun simulation of solar gain versus solar collectors tilt angle

7.2.2. Storage tank volume

It is important to consider the right storage tank volume because the economic reasons and also heat losses. A larger tank affects the auxiliary energy use and is more expensive. The tank preferably be designed based on the daily energy demand. On the other hand the tank should not be too small because of lowered storage capacity and in view of the risk of overheating. A high insulation is important and it becomes more important for the bigger tanks. The flowing figure, Figure 44, shows the influence of the tank capacity on the axially energy demand from the biomass boiler. Table 24 also shows the simulation results for different storage tank capacity on different system parameters. These results show that the storage tank capacity has a much larger influence on the auxiliary energy use than solar factor and energy lost. The suggested system with 14 m² collector area is then a storage volume of 1.5 m³ that would entail neither overheating nor excessive tank losses, according to the simulation results. For simulating the variation of the auxiliary energy with the size of storage tank, the insulation material and thickness is the same.

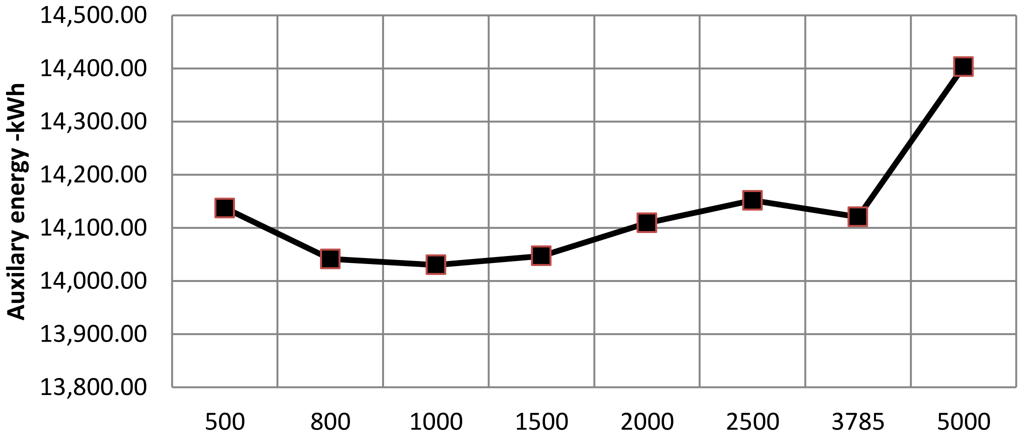

Figure 44: The auxiliary energy demand (kWh) for different tank volumes (lit.)

Table 24: Influence of storage tank capacity on different system parameters

Storage tank capacity (Lit.)	Aux. Energy (kWh)	Heat loss of the storage tank (kWh)	solar factor
500	14,137.20	589.8	18.20%
800	14,041.40	740.4	19.20%
1000	14,030.40	850.7	19.70%
1500	14,047.30	1026.8	20.30%
2000	14,109.10	1175.5	20.70%
2500	14,151.60	1297.5	20.90%
3785	14,120.70	1370.1	21.30%
5000	14,403.00	1782.7	21.30%

7.2.3. Different energy buildings categories

The object of energy conservation is to use the optimum amount of energy necessary for thermal comfort and health in a safe and efficient manner. The amount of energy consumption of a building depends on different factors like size, location, and the type of building (residential, office, hospital), orientation, window orientation, HVAC system, and any number of design parameter selections such as building and envelope performance, ventilation rate, and thermostat set point.

In the recent years more efficient installations, better insulation, and local production of sustainable energy have strongly improved the energy performance of buildings. In this part of the study two different types of houses, Normal energy house and low energy house have been considered. The different design specifications of these two energy house categories have been shown in Table 26.

Simulation results in table 25 and Figure 45 show modern house construction and good insolation play an important role in the solar fraction. The solar fraction of normal energy building increases from 28% to 39% for low energy building. And better insulated house need 34% less total thermal energy consumption compared to normal insulated house. Figure 45 shows that efficient construction of the house save considerable auxiliary energy needed to provide space heating energy in winter time.

Table 25: Compared solar fraction for normal and low energy building types

	Normal single family House U value 0.5 (W/m^2K)	Low Energy single family House U value 0.35 (W/m^2K)
Solar fraction	28%	39.2%
Solar fraction of hot water	56.2%	50%
Solar fraction of the Building	14.5%	5%
Solar thermal energy to the system(Qsol) kWh	4,604	4,442
Total energy used with Biomass back up including the electrical energy of the pumps (Qaux) - kWh	12,001	7,039

Table 26: The design parameter specification of the considered “normal” and “low energy” single family house considered in this study

	Normal Single family house	Low Energy single family house
U value W/K/m^2 (overall heat loss coefficient)	0.5	0.35
Specific heating power demand W/m^2	80	55
Specific cooling power demand W/m^2	100	50
Specific heating/ cooling energy demand kWh/m^2	150	30
Window to wall area ratio South/North/East/West	25/13/25/6	25/13/25/6
Fresh air change 1/hr	0.3	0.3
Air infiltration 1/hr (undesired air changes through cracks andopenings)	0.6	0.3
Internal heat gain Electrical equipment/People W	240/2	240/2
Heat capacity of the building kJ/K/m^2	500	750
g-Value[23](solar energy transmittance coefficient of the windows)	0.8	0.7

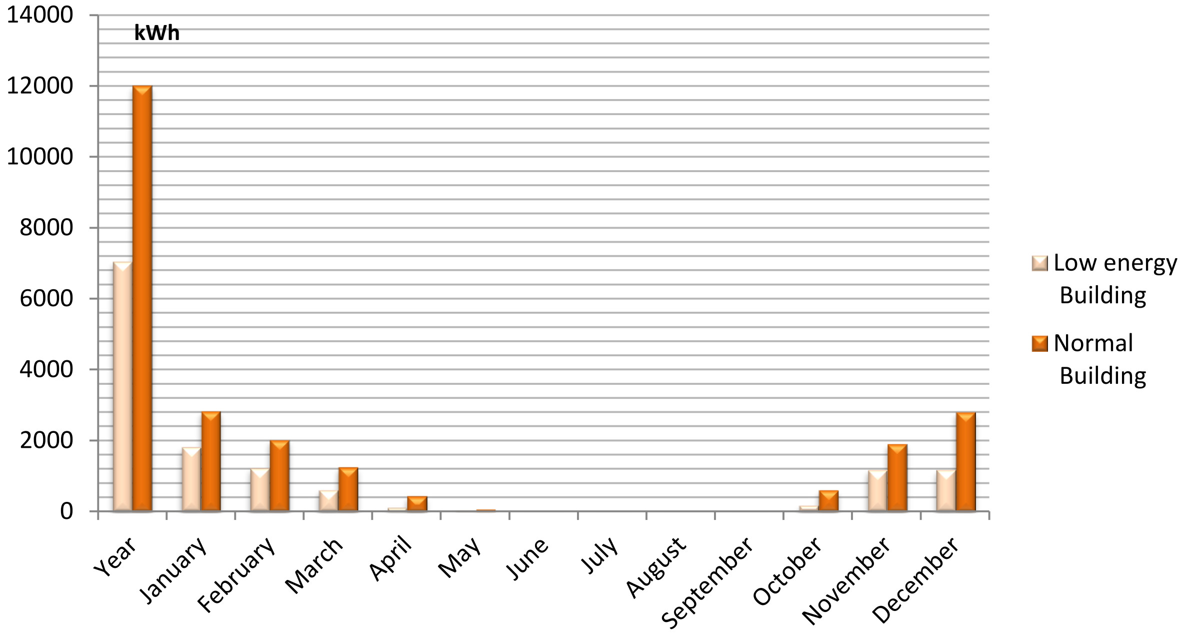

Figure 45: The comparison of the Q_{aux}(auxiliary energy) between normal house and low energy hose.

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[23] This factor describes how much sun lights inters the building through the windows , normally ít is between 0.3 for triple glazing and 0.9 for single glazing

7.2.4. The effect of heating set point on thermal energy demand of households

It goes without saying that the buildings occupants have an enormous influence on the energy performance of the building. Thermal comfort and health criteria of the building occupants mostly involve the temperature and humidity conditions in the building. Without sacrificing comfort or convenience the bandwidth in heating demand is mainly determined by set point heating temperature.

Table 27 shows the comparison of energy consumption for different heating set points in the buildings. The results in this table shows that by increasing the heat set point of just one degree the solar fraction decreases nearly 6%, the energy consumption of the building increases nearly 9% and in following the total fuel consumption of the system increases also nearly 9% per year for one household. This is equal to nearly 1200 kWh energy per year and 60 kg CO_2 emissions from the fuel of biomass boiler.

Table 27: The comparison of the system energy consumption for thermostat setting (Normal building single family house)

	Heat set point Temperature			
	19°C	21°C	22°C	24°C
Solar fraction	29.7%	26.4%	24.9%	20.6%
Solar fraction of hot water	58%	53.9%	52%	44%
Solar fraction of the Building	14.7%	14.6%	14.6%	13%
Solar thermal energy to the system(Qsol) -kWh	4,584	4,675	4,704	4631
Total energy consumption of the building (Quse-Building)	10,823	13,230	14,428	17,502
Total energy used with Biomass back up including the electrical energy of the pumps (Qaux) - kWh	11,943	13,188	14,345	18,144

7.2.5. Detailed simulation results of the basic prototype model

Here the results of simulation analysis have been pointed out (annual values). It should be mentioned that demand side of system has the main factor for system dimension and system performance.

System overview (Assumptions: Normal house, thermostat setting point 20°C.)

Total fuel and electrical consumption of the backup boiler (Auxiliary heating devices - pumps included) [Qaux]: 12,001kWh

Total energy consumption (Quse): 14,500kWh

Solar thermal energy (Collector area: 14 m2, Tilt angle: 36°, Orientation: E=+90°, S=0°, W=-90°)

Solar fraction total: 28%

Global irradiation on aperture area: 10,927 kWh

Solar thermal energy: 4,600 kWh

Bioler [24]**(Power: 15kw)**

Energy to the system: 11,900 kWh

Fuel consumption of the backup biomass: 2380.6 kg

Number of switch on times: 1,420

Operational time: 793 h

Fuel saving because of solar thermal to the system: 921 kg

Building - heated area: 100 m^2 and heating set point temperature: 20°C (single family house, normal building)

Heat demand excluding DHW: 11,851 kWh

Specific heat demand excluding DHW: 118.5 kWh/m^2

Solar gain through windows: 10,023 kWh

Total energy loss: 24,715 kWh

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[24] Assumption: each kg fuel for biomass system emits 0.25 kg CO_2 and contains 5 kWh heat energy.

Heating element

Nominal inlet temperature: 40°C

Nominal return temperature: 25°C

Net energy to heat elements: 11,817 kWh

Hot water demand: (Daily consumption: 310 l/day)

Maximum Temperature: 70.6°C

Minimum Temperature: 33°C

Energy supplied: 2,220 kWh

Energy consumed: 1,925 kWh

External heat exchanger (Transfer capacity: 5000 W/K)

U value of the housing: 1 $W/m^2.K$

Number of heat exchanger plates: 20

Heat loss: 85.5 kWh

Pumps:

Electricity consumption: 85 kWh

Storage tank (1500 Lit. Buffer)

Average bottom layer temperature: 40°C

Average top layer temperature: 74°C

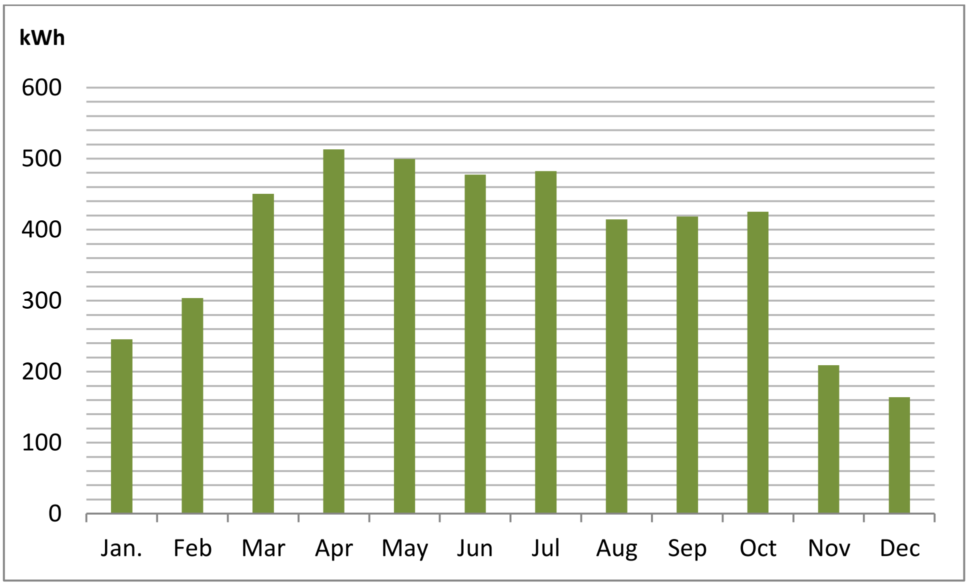

Figure 46: Solar thermal energy to the system (Qsol)-PolySun simulation result

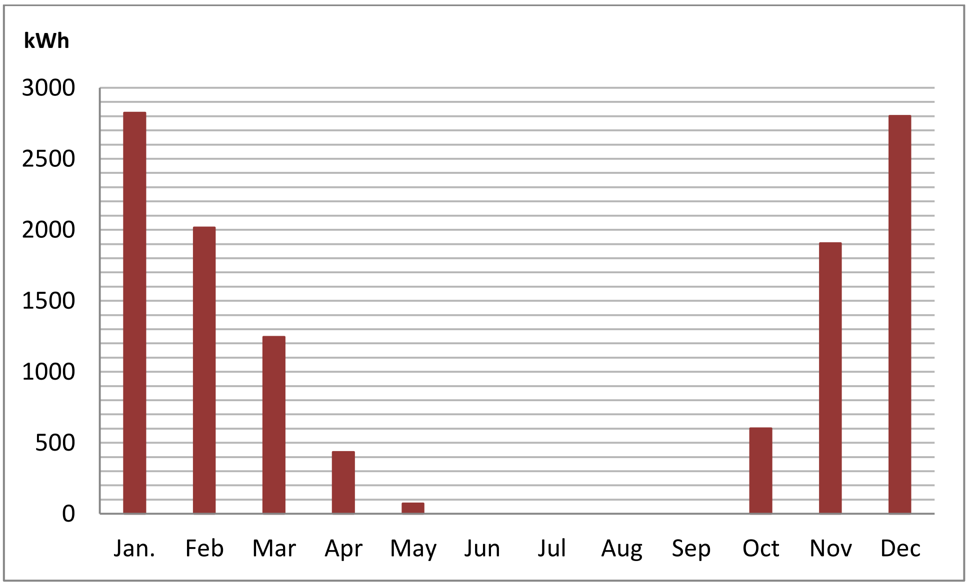

Figure 47: Total fuel and electrical energy consumption of the backup boiler- PolySun simulation

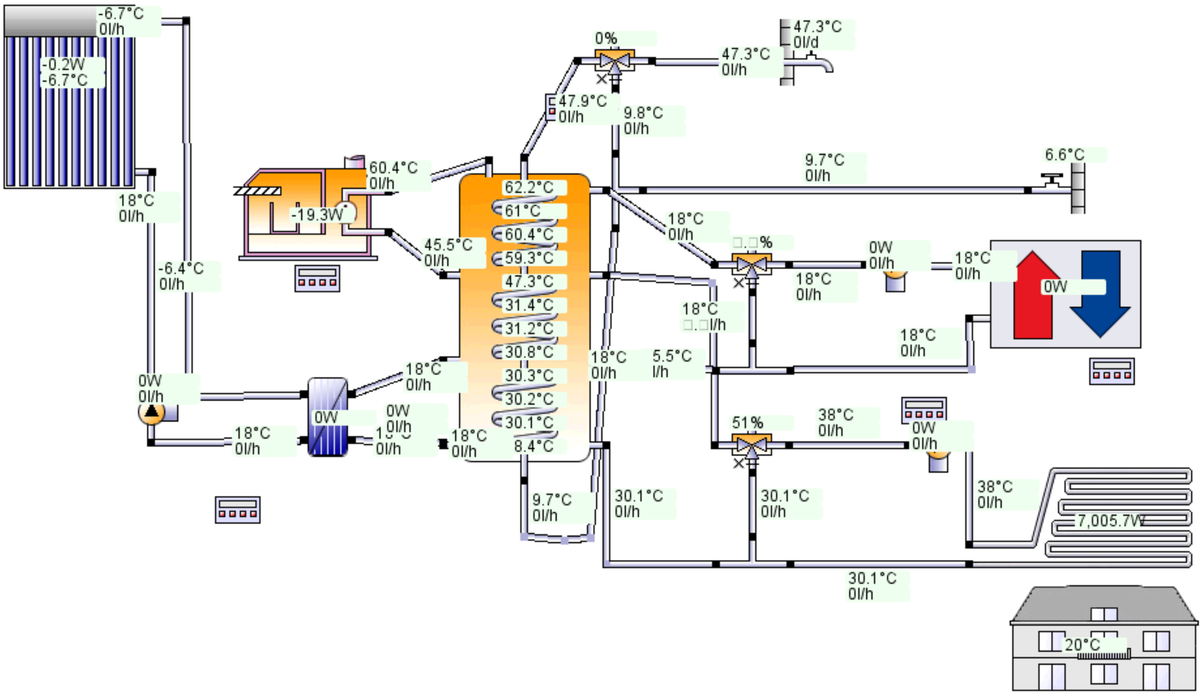

Figure 48: System simulation of a cold day in January at 7:00 AM

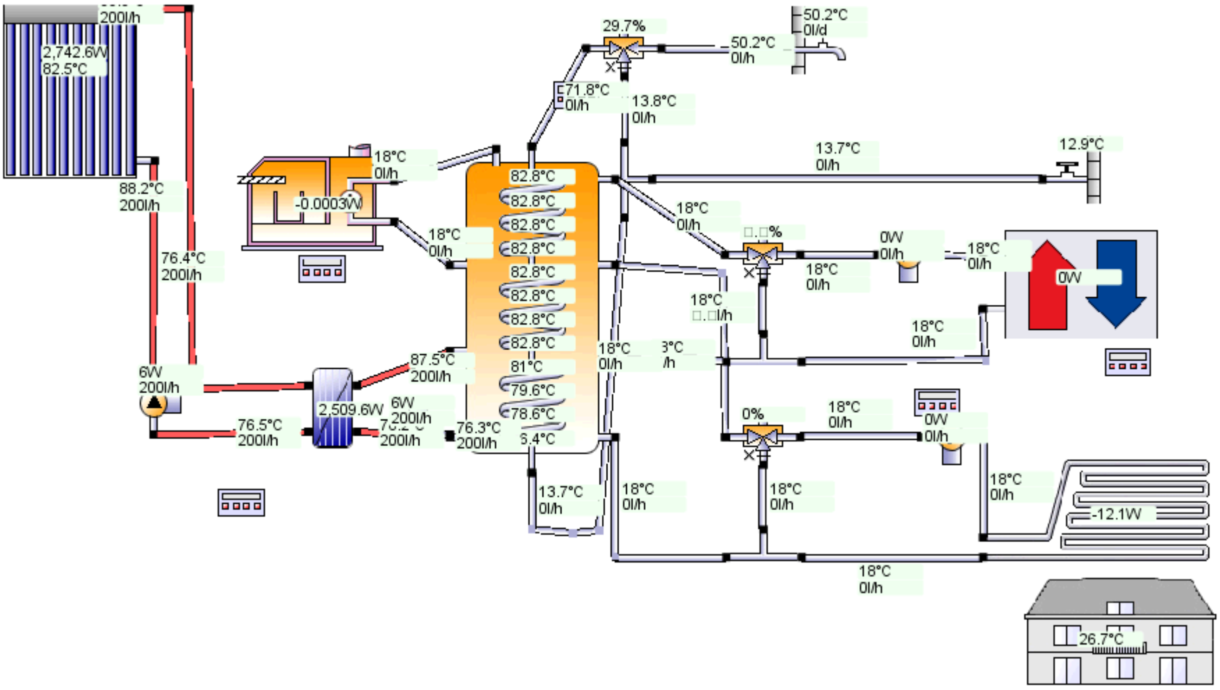

Figure 49: System simulation of a warm day in July at 2:00P M

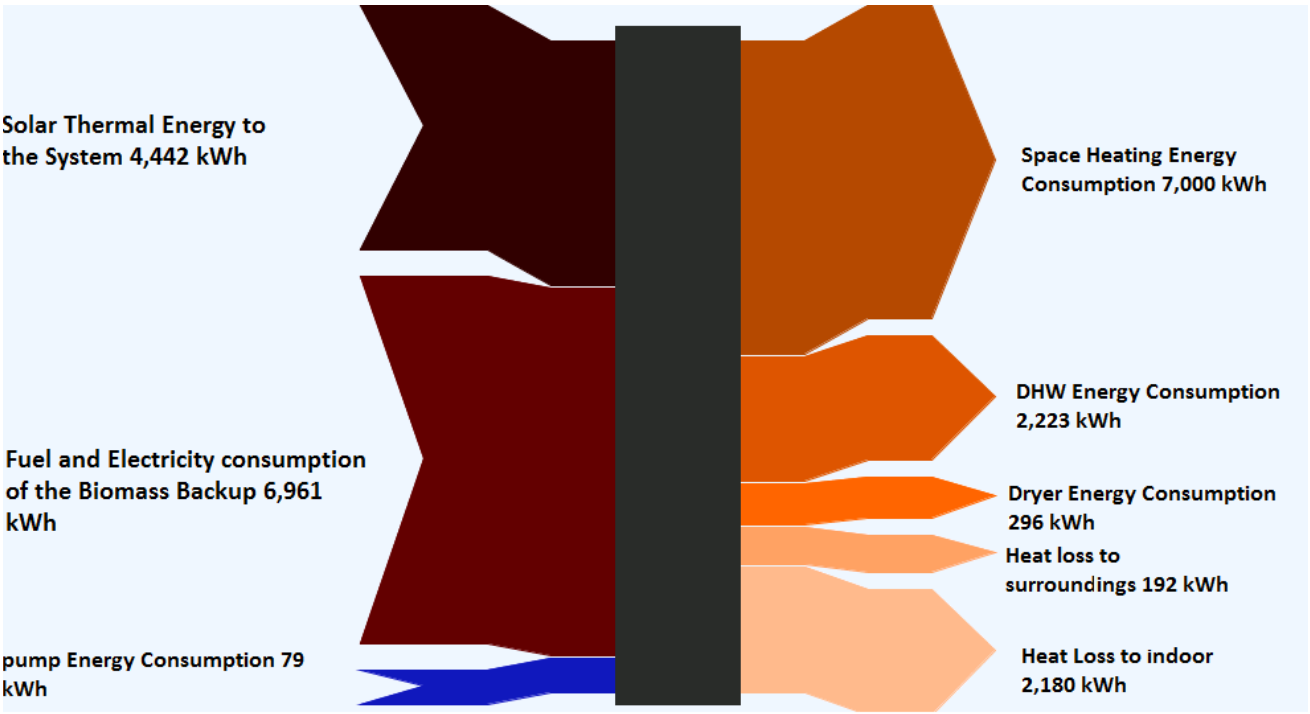

Figure 50: Energy flow diagram – low energy building

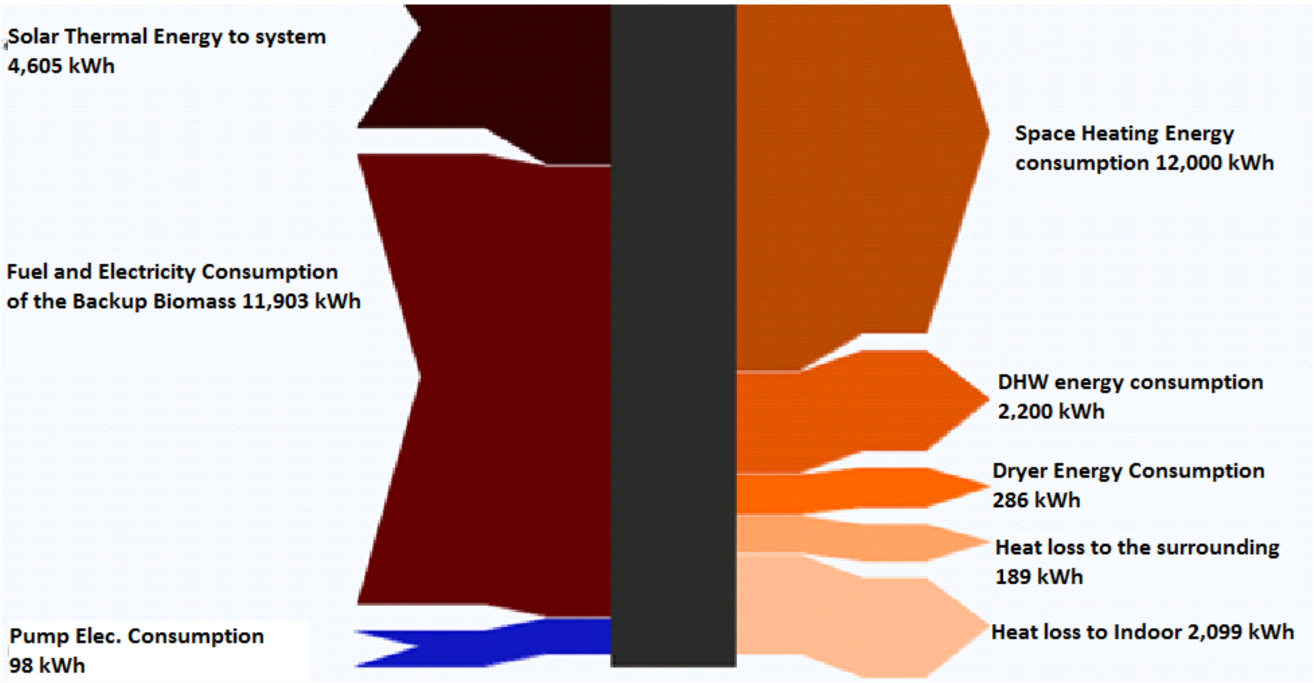

Figure 51: Energy flow diagram- normal building

7.3. Financial analysis

The design characteristics and system performance of the solar energy system have been presented in the previous parts. This gives assistance to know if the new alternative plan can improve the energy system of the households.

This part investigates the financial feasibility on the presented solar system. The selected economic indicators are; thermal generation cost, net present value, solar energy cost, and payback period.

The economic viability calculation here is based on standard values and assumptions. The calculation basis assumptions have been introduced in the following table.

Table 28: Input parameters for the financial analysis

Purchasing cost [C_{CI}]	EUR	30,000
Incentive : fixed amount on purchasing cost [C_{CS}]	EUR	1000
Incentive: fixed amount on collector area [C_{CF}]	EUR/m^2	70
Incentive: percentage on purchasing cost [f_{CS}]	EUR	0
Incentive: heat production tariff per kWh [b_{GT}]	EUR	0
Incentive: feed in tariff per Kwh [B_{FI}]	EUR	0
Energy Price per kWh [P_F]	EUR	0.2
Energy cost increase per year [E]	%	0.03
Interest rate [r]	%	0.03
Inflation rate [I]	%	0.02
Scrap vale [S]	EUR	100
Fixed annual maintenance cost [C_{FV}]	EUR	80
Annual maintenance cost percentage of purchasing cost [C_{FI}]	EUR	0
Life spam [n]	years	20
Collector Area [A_{coll}]	m^2	14
Fire wood cost per kg	EUR/kg	0.05
Generated energy with solar Q_{sol}	kWh	4100
Generated energy with Biomass	kWh	10300

The purchasing costs after financial incentives [C_0], present value [P_0], net present value of the system [NPV], and solar energy price for the thermal system [P_{SE}] can be calculated based on the following equations[25]:

Purchasing costs after financial incentives: $C_0 = C_{CI}(1 - f_{CS}) - C_{cs} - C_{CF} .\ A_{coll}$

Annual repair and maintenance costs: $C = CFV + CFI$

Cash Value: $d = \frac{r-I}{I+1}$

Present value of the sytem: $P_0 = \frac{B_{Fs}}{E-d} \cdot \left[\left(\frac{1+E}{1+d}\right)^n - 1\right] - C \cdot \left[\frac{(1+d)^n-1}{d\cdot(1+d)^n}\right] + \frac{S}{(1+d)^n}$

Net present value: $NPV = \frac{B_{Fs}}{E-d} \cdot \left[\left(\frac{1+E}{1+d}\right)^n - 1\right] - C \cdot \left[\frac{(1+d)^n-1}{d\cdot(1+d)^n}\right] + \cdot \frac{S}{(1+d)^n} - C_0$

The cash value serves as the basis for the decision to invest in a system as benchmark to to compare the system with others. As the above equations show the system´s net cash value results from the future discounted fuel savings through solar system, the discounted costs and the scrap value of the system. The present value is important parameter as it involves the lifespan of the system, future trends of prices, and interest rates. As the equation shows high annual fuel saving and long lifespan result in high present value.

The following equation is used to calculate the solar energy price:

$$P_{SE} = \frac{\text{Total\_annual\_cost}}{\text{Total\_energy\_generated\_per\_year\_(kWh)}} = \frac{A + C}{\text{Energy produced with the system}} - b_{GT}$$

$$A = C_0 \cdot \left[\frac{d \cdot (1+d)^{\ n}}{(1+d)^n - 1}\right]$$

Referring the assumptions in Table 28, the results of the financial analysis are listed in Table 29.

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[25] The equation has been adapted from PolySun user manual

Table 29: The financial analysis results of the solar system

Effective purchase cost after intensives [C_0]	28,020 EUR
Annual profit through fuel saving [B_{Fs}]	2,365 EUR
Annual repair and maintenance cost [C]	80 EUR
Present value of the system [P_0]	55,541 EUR
Net present value [NPV]	27,521 EUR
System energy price per kWh [P_{SE}]	0 11 EUR

The amortization period is another important factor for system investment decision. It corresponds to the period (n) with the net present value equal to zero. And means the total length of the time, it will take to pay off the total initial investments. The following graph, Figure 52, shows the net present value of the system during its total lifespan. Based on the definition, the amortization period of this solar system will be nearly 14 years. The financial analysis shows that production of thermal energy with considering system and assumptions has practically 0.12 EUR/kWh cost for consumer that can provide long-thermal feasible solution even in Austria.

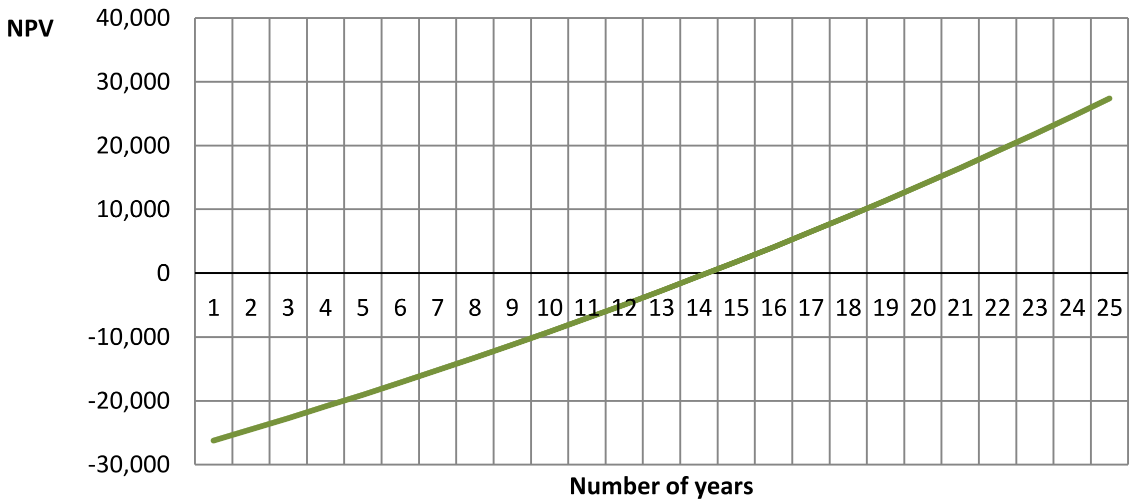

Figure 52: Net present value of the system during the lifespan

In order to investigate the magnitude of the effect of the parameter´s variation on cost, on net present value and on amortization time, a series of sensitivity analyses are undertaken. In these analyses the variations of these important parameters have been considered:

- Purchasing cost [C_{CI}]
- Life spam [n]
- Annual solar radiation that affects the generated energy with solar [B_E]

The sensitivity analysis results show that, the considered plan offers a viable solution under the following conditions:

- Purchasing cost [CCI] < 45,000 EUR
- Life spam [n] > 17 years

The sensitivity analysis shows that even if there is no incentive from government (fixed amount on purchasing cot and fixed amount on collector) still the solar energy price will be cheaper than considered thermal energy cost, 0.2 EUR/kWh. In this case the amortization time will be 15 years and the system energy price will be 0.12 EUR/kWh. And if the incentives: fixed amount on purchasing cot be 7,000 EUR, the amortization time will be just 11 years and the system energy price will be 0.098 EUR/kWh.

Table 30: Sensitivity analysis: variation of system purchase cost

Purchasing cost [C_{CI}] - EUR	30,000	35,000	40,000	45,000
Effective purchase cost after intensives [C_0] - EUR	28,020	33,020	38,020	43,020
System energy price [P_{SE}] - EUR/kWh	0.12	0.14	0.16	0.18
Amortization time -years	14	16	18	20

Table 31: Sensitivity analysis: variation of lifetime

Lifetime -years	10	15	20	25
System purchase cost [C_{CI}] - EUR	30,000	30,000	30,000	30,000
Annual repair and maintenance cost [C] - EUR	80	80	80	80
system energy price- EUR/kWh	0.22	0.22	0.12	0.096
Amortization time -years	14	14	14	14

Table 32: Sensitivity analysis: variation of annual maintenance cost

Annual repair and maintenance cost [C] - EUR	80	100	200	300
System purchase cost [C_{CI}] - EUR	30,000	30,000	30,000	30,000
Net present value [NPV] - EUR	13,926	13,564	11,756	10,000
System energy value - EUR/kWh	0.12	0.11	0.13	0.13
Amortization time -years	14	14	15	15

Table 33: Sensitivity analysis: variation of generated energy with solar Q_{sol}

Generated energy with solar Q_{sol} - kWh/m^2	1000	2000	3000	4000
System purchase cost [C_{CI}] - EUR	30,000	30,000	30,000	30,000
Annual repair and maintenance cost [C] - EUR	80	80	80	80
System energy value- EUR/kWh	0.15	0.14	0.13	0.12
Amortization time -years	20	17.5	15.5	14

Chapter 8: DISCUSSION OF RESULTS - PERFORMANCE OF THE SYSTEM SUBJECTED TO VARIOUS WEATHER CONDITIONS (DEVELOPMENT OF THE FRAMEWORK)

The performance of the solar energy system and system design parameters are strongly affected by the solar radiation. The system has been described in previous part of this study has been simulated based on Austrian weather data that has cold climate specifications. And the analysis showed the solar energy in this weather condition can cover more than 20% of the heat demand in the considered house. Now the question is if the same system be considered in different climate situation, how the solar factors change. To answer this question the simulation of the system has been done for different climate conditions. Unless otherwise stated, the parameters of the simulated systems are the same as for the system solution described before.

In this chapter in order not to limit the research to just one location, the specific system configurations and performance have been studied in different cities: Puerto princesa-Philippines, Yazd-Iran, Kathmandu-Nepal.

8.1. The chosen different climates conditions

In the following table, Table 34, the monthly weather condition of Yazd has been mentioned. This city that has been located in the middle of Iran, has a cold semi desert weather condition with average 20.3°C and annual global irradiation of 2,101 kWh/m^2.

Table 34: Monthly analysis of weather data Yazd-Iran-coordinates: 31.89° N, 54.36° E, PolySun data

Month	T_{amb}	Irr. Global horizontal	Irr. Beam normal	Irr. Diffuse horizontal	Wind speed	Relative Humidity
	[C]	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[m/s]	%
Jan	6.4	106.4	180.7	29.9	2.4	48.8
Feb	9.5	119.4	176.6	31.7	2.8	36.1
Mar	14.5	174.1	208.5	51	3	28.3
Apr	20.5	196.5	201.8	63.3	3.1	23.6
Mai	26.2	238.1	252.7	62.9	3.2	14.8
Jun	30.9	239	256.1	60.3	3.1	10.9
Jul	33.5	249.9	280.1	52.5	3.4	11.3
Aug	31.8	229.8	274.4	47.9	3	11.7
Sep	27.5	191.5	275.5	38.3	2.7	15.3
Oct.	21.1	156.2	235.9	34.6	2.6	21.6
Nov	12.7	110.2	171.2	31.7	2.3	35.2
Dec.	8.3	90	141.8	31.6	2.3	43.4
Year	20.3	2101.1	2637.3	535.5	2.8	25

The next city is Puerto Princesa that is located in the western provincial island of Philippines with a tropical wet and dry climate. The city is usually wet from June to December and with very little rain from February to May. Average temperature is 29° C and annual global irradiation is 1,972 kWh/m^2.

Table 35: Solar irradiation and ambient temperature in Puerto Princesa- Philippine, Metenonorm data

Coordinates: 9.73° N, 118.73° E

Month	T_{amb}	Irr. Global $_{horizontal}$	Irr. Beam $_{normal}$	Irr. Diffuse $_{horizontal}$
	°C	kWh/m2	kWh/m2	kWh/m2
Jan	26.3	167	159	64
Feb	26.1	171	178	52
Mar	26.5	205	207	58
Apr	27	201	199	58
May	27.3	182	161	70
Jun	27.3	152	107	77
Jul	27	150	113	73
Aug	27.2	151	107	77
Sep	27	149	110	72
Oct	26.8	150	110	75
Nov	26.9	143	116	66
Dec	26.7	151	150	55
Average	26.8	164	143	66
Year	29	1,972	1,717	797

The third city is Kathmandu in Nepal with the latitude of 27.7°N and longitude 85.33°E. In Kathmandu valley the average summer temperature varies from 28-30 °C and the average winter temperature is nearly 10°C.The annual global irradiation as Table 36 shows is nearly 1,952 kWh/m^2. As the Meteonorm data shows the city has the average yearly humidity of 63% and the average wind speed of 1.8 m/s.

Figure 53 demonstrates the variation of diffuse and direct monthly irradiation in these four different climate conditions. In January, April, November and December Kathmandu has the best direct irradiation than all other considered cities. In February, and March Puerto Princesa has the best direct solar irradiation and in May, June, July, September, October, and August Yazd has the best direct solar irradiation.

Puerto Princesa has the least solar direct irradiation in June and July. And Kathmandu has the least direct solar irradiation in August. In other months of the year Böheimkirchen has the least direct solar irradiation.

If we consider the Böheimkirchen as the benchmark, Yazd has 2.9 times, Kathmandu has 2.5 times and Puerto Princesa has 3.2 times more yearly direct solar radiation than Böheimkirchen.

Table 36: Solar irradiation and ambient temperature in Kathmandu-Napal; Meteonorm data

Month	T_{amb}	Irr. Global horizontal	Irr. Beam horizontal	Irr. Diffuse horizontal	Wind speed	Relative Humidity
	[C]	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]	[m/s]	%
Jan	7.9	140	118	22	1.2	73
Feb	12.3	145	115	30	1.7	61
Mar	17.9	186	135	51	2	47
Apr	24	204	148	56	2.2	35
Mai	26.8	213	143	70	2.6	41
Jun	26.3	175	99	76	2.6	57
Jul	24.1	149	58	91	2.2	78
Aug	23.5	147	65	82	2.1	82
Sep	22.6	146	82	64	1.8	81
Oct.	19.8	163	118	45	1.1	72
Nov	14.9	142	112	30	0.8	63
Dec.	9.9	140	117	23	0.9	69
Year	19.2	195,2	130,9	643	1.8	63

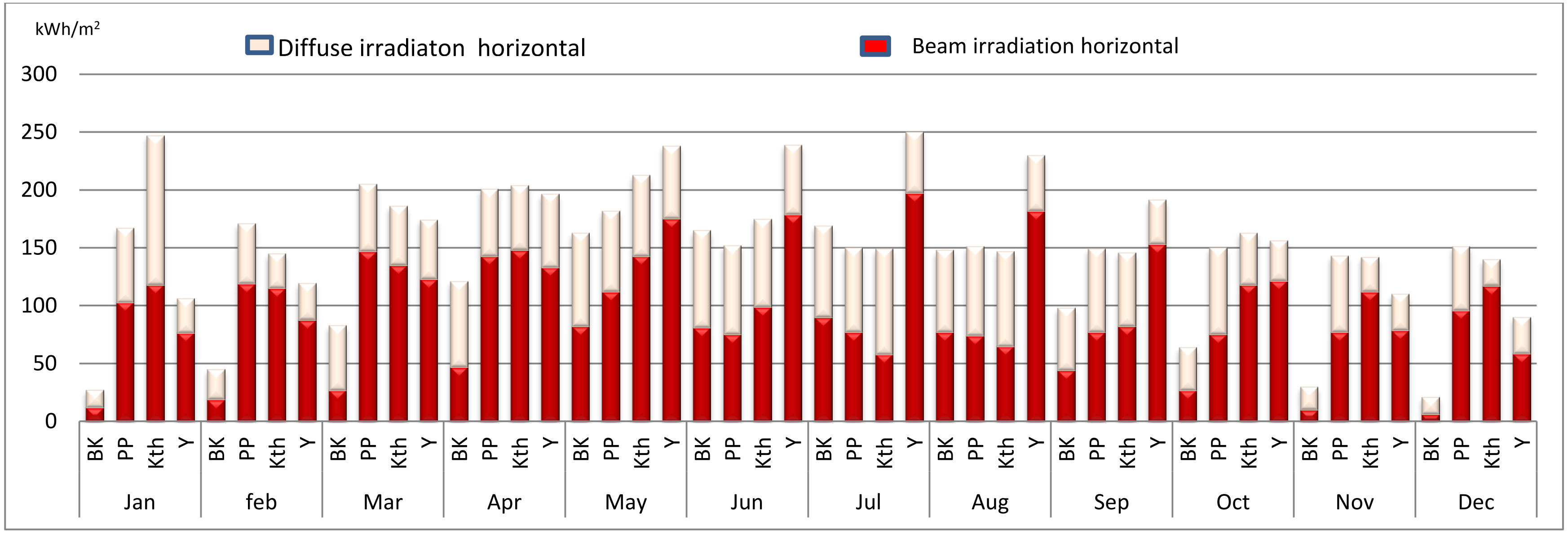

Figure 53: Monthly diffuse and beam solar irradiation (kWh/m^2) for BK: Böheimkirchen-Austria, PP: Puerto Princesa- Philippines, Kth: Kathmandu-Nepal, Y: Yazd- Iran

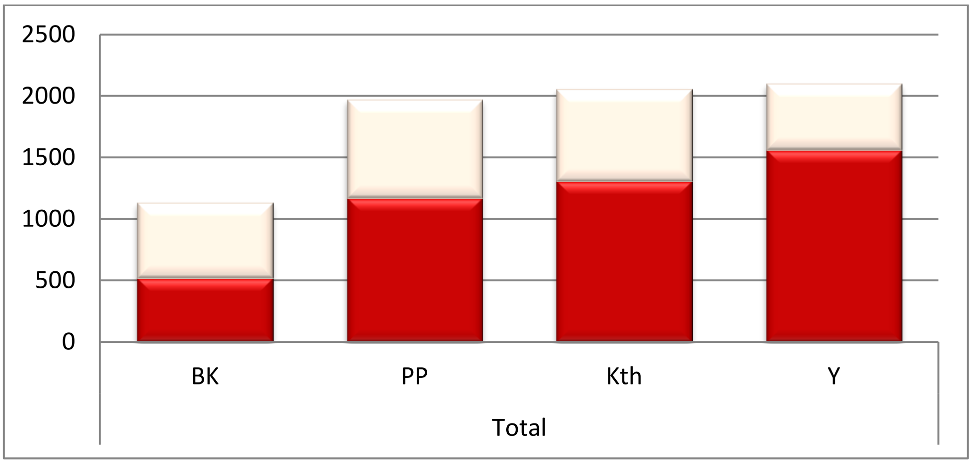

Figure 54: Yearly diffuse and beam solar irradiation (kWh/m^2) for BK: Böheimkirchen-Austria, PP: Puerto Princesa- Philippines, Kth: Kathmandu-Nepal, Y: Yazd- Iran

8.2. Results and discussions

Table 37 shows the solar factor of the integrated solar energy unit in different considered cities. It is clear that as Austria benefits less than other considered four countries from solar radiation then in Böheimkirchen-Austria the solar fraction of the system is less than other presumed cities. The solar factor and the performance of the solar system is not just a function of direct solar radiation but also depend to other factors like the ambient temperature. As the following results show, Yazd has the best direct solar radiations between the assumed countries, but the system in Yazd has not the highest average solar factor.

Appendix A tries to research more in detail how changing the climate condition, changes the different factors to design an energy autarky house.

Table 37: Comparison of simulation results for four different climate conditions

BK: Böheimkirchen-Austria, PP: Puerto Princesa- Philippines, Kth: Kathmandu-Nepal, Y: Yazd- Iran

	Unit	BK	PP	Kth	Y
Solar fraction [SFn]	%	29%	98	96	73.9
Solar thermal energy to the system [Qsol]	kWh	4,600	5,445	6,125	6,031
Fuel and electricity consumption [Eaux]	kWh	11,900	220	552	3,782
Pump energy consumption [Epar]	kWh	98	23.6	25	27
Total energy consumption [Quse]	kWh	10,800	1,396	2,253	4,131

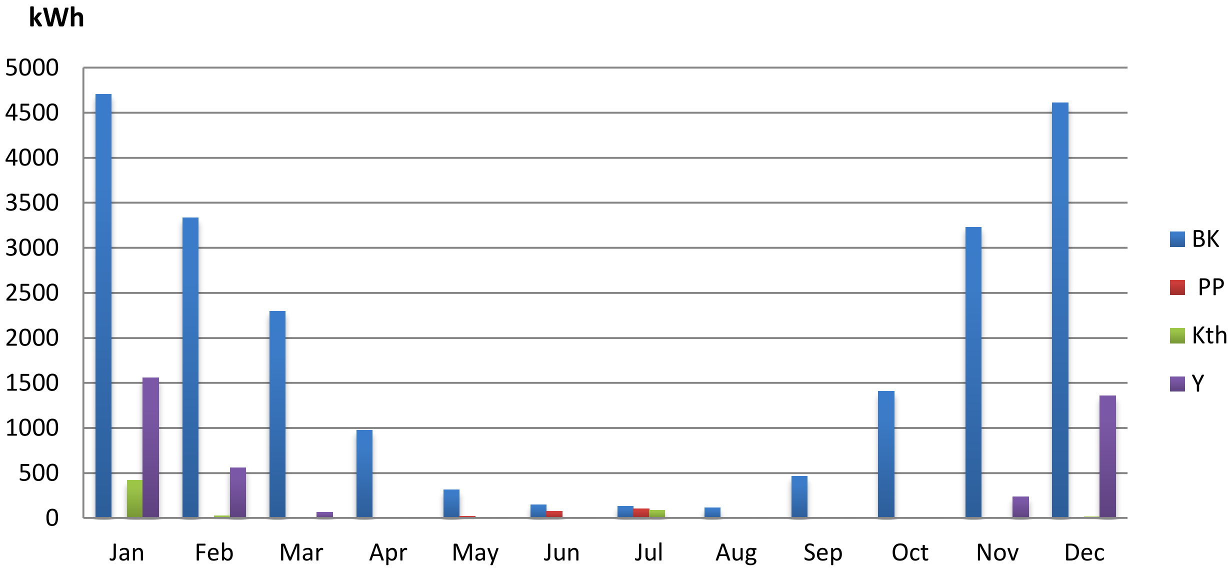

Figure 55: Fuel and electricity consumption [Eaux] of the integrated solar system in different months

BK: Böheimkirchen, PP: Puerto Princesa, Kth: Kathmandu, Y:Yazd

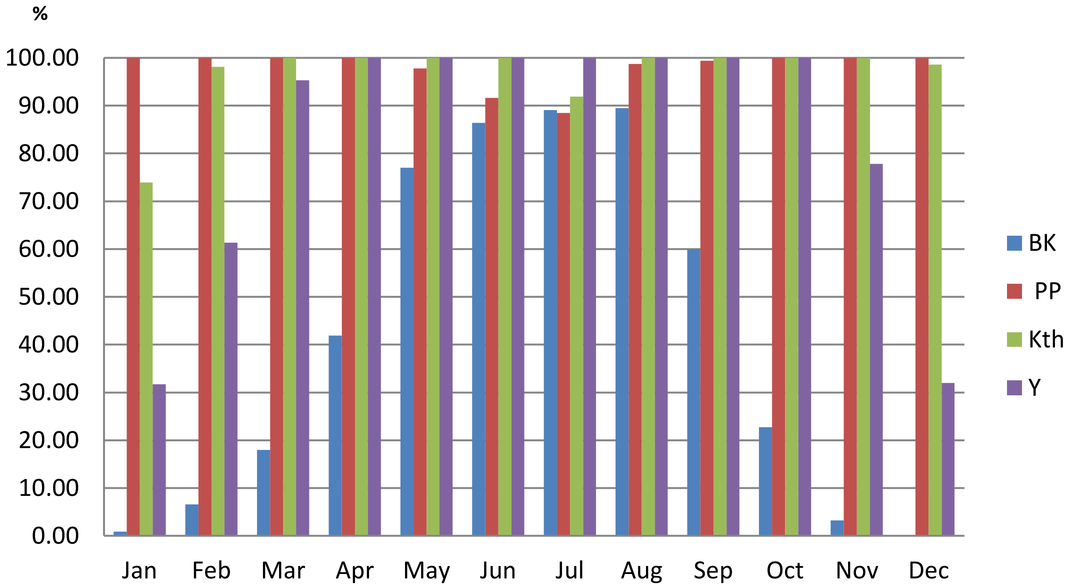

Figure 56: The solar fraction of the integrated solar system at different months and different climate conditions

BK: Böheimkirchen, PP: Puerto Princesa, Kth: Kathmandu, Y:Yazd

Chapter 9: SUMMERY AND CONCLUSION

During the mid-20th century, most countries experienced a move towards a higher degree of centralization in the energy systems with small district heating systems being replaced by big power plans (Sörensen, 2011). In different researches it is intensively being discussed how to design a centralized energy system for the households in the best way, in which the combustion of fossil fuels be reduced or completely avoided. For an optimum selection of the energy sources there should be some mixed technologies so that energy lost during distribution and consequently load on environment can be reduced.

This study points out new *integrated solar system* that provides thermal energy autarky for the households with the further discussions about carbon emission of the considered solar system.

This approach could be considered as a starting point for global transition to renewable energy and more energy efficient cities. As an example of contributing the results of this dissertation a zero carbon cottage system in Philippines has been developed. This cottage explores the possible socially and technologically innovative *solar integrated system* for sustainable living. The results of the zero carbon cottage in Philippines have been mentioned in appendix A.

9.1. Goals and contribution of this thesis

The innovative energy supply system, *integrated solar system*, concentrates on the separation of the electrical and thermal energy demand/ supply in domestic units, aiming to reduce as possible the energy conversion from electricity to thermal energy in the total system to avoid conversion losses and to maintain the efficiency of the system. To reach this goal the thermal demand of the system be provided with solar energy and biomass back-up.

It is commonly assumed that solar hot water system save energy and reduces greenhouse emissions relative to conventional systems. To find out the emissions by the introduced integrated solar system and compare it with the conventional energy supply system in households a life cycle assessment has to be undertaken.

The objective of this study is spreading information about the energy effective housing design. Using efficient appliances at home and efficient renewable energy supply system that covers the energy demand is sustainable way to particularly lower the use of energy from fossil fuels.

To reach this goal, the main focuses are:

- Introducing a new strategy to provide the electrical and thermal demand of the households
- Estimation of thermal and electrical energy demand of the household with the new strategy considering the user behavior
- Design of the renewable supply system
- Programming the control system optimizing the better meet of energy supply-demand
- Monitoring the energy demand-supply in the system to extract the real saving potentials
- Life cycle assessment of hot fill appliances and the total energy supply system and estimating the primary energy saving potential
- Contributing the results for construction of zero carbon cottage in Philippine.

9.2. Conclusion

According to the result derived in the chapter 7, the technical and economic evaluation shows that the considered plan offers a technical feasible and economical viable solution. Simulation of thermal and electrical energy demand of the households shows that the suggested integrated solar system covers 28% of total heat demand of a 100m^{2}building, 56% solar fraction for DHW and 14% for the space heating. If the insolation of the building be improved and the building considered to be low energy building the solar fraction increases to 39%.

As the solar factor especially for the space heating in Austria with the existing solar technologies cannot reach 100%, the utilization of back –up system is necessary. Because, the availability of wood in Austria, here the biomass backup system has been suggested. With the proposed *solar integrated system* thermal energy autarky for the households can be achieved.

To know system performance subjected to various climate conditions, system simulation has been done considering the same consumer behavior in three different cities: puerto princesa (Philippines), Kathmandu (Nepal) and Yazd (Iran). The simulation results show that the solar factor can increase to 98% for Puerto Pricesa, to 96% for Kathmandu and to 73.9% for Yazd, which is very promising.

The economic assessment of the integrated system in Austria shows that even with the measured 28% solar factor the system is economically feasible. With the incentive of 70 EUR/m^2 collector areas the amortization time will be nearly 14 - 15 years and without incentives the amortization time will be between 15 - 16 years.

The sensitivity analysis of financial analysis results show the considered system layout offers a valuable solution when the total purchasing cost plus cost of installation be less than 45,000 EUR. The sensitivity analyses also show that if the generated energy with solar be more than 1,500 kWh per year the system is financially feasible. And this is possible when yearly direct solar irradiation be more than 799kWh/m^2. It is good to mention that even the Kiruna city as the northernmost town of Sweden has nearly 1,090 kWh/m^2 annual direct solar irradiation.

A general tendency in the results for the above studied energy service is clearly in favor of renewable energy technologies. Comparing for the strategies providing energy for the households, it is observed that solar thermal system and biomass backup has the least environmental load. For example the calculations show that cold water fill washing machines (conventional WM) in households use nearly 1.23E3 MJ primary energy each year for each family. Using hot fill WM and providing the thermal demand with thermal solar and biomass back up reduces the primary energy to 771MJ primary none-renewable energy and gas condensing boiler uses 1.17E3 MJ primary none-renewable energy. If the thermal energy demand of washing machine be provided with solar and biomass back up the CO_2 emotions will reduce 34% in relation to conventional washing machines and using gas condensing boiler reduces the CO_2 emotions to 10% in relation to cold water fill WM.

Impact assessment results highlight that in conventional way of producing thermal energy for the households, oil and natural gas are the major factors on environmental load factors. And decentralize way of providing energy for the households cause enormous waste in primary energy. The results show that each Austrian family emits 4.06E3kg CO_2 each year (15,181,405,609kg CO_2 for all families in Austria) required to provide heat and electricity. And this is equal to 6.64E4 MJ primary energy for each family (2.48E11 MJ primary energy for all families in Austria).

As a main result, the life cycle analysis shows that CO_2 emissions are greatly reduced over the entire lifespan of the system using the hot fill appliances, strategy A, and using the hot fill appliances plus low energy building category, Strategy B. LCA of Strategy A shows 67% reduction of CO_2 emissions (means 10,236,225,363 kg less CO_2 emission each year for all families in Austria) and LCA of strategy B shows 73% reduction of CO_2 emissions(means 11,058,112,071kg less CO_2 emission each year for all families in Austria).

It can be concluded that the practice of the separate generation of electrical energy in electric supply stations and transform it to thermal energy at home, which is still regular today, is a waste of primary energy, and contributes considerably to global warming and environmental pollution due to emissions. If energy transmission and transformation losses form medium voltage to low voltage are counted, the LCA results show that total Austrian households cause to emit 6,537,735,177 kg CO_2 just for providing energy for electrical appliances at home.[26]

As ultimate conclusion, the suggested new energy supply system proposes synergy of sustainability and efficiency. This is possible by avoiding energy transmission lost, precise control system, and accurate design of different parts of the integrated energy system that leads to the highest efficiency with a high proportion of renewable energy sources. The study clearly shows that small decentralized power and heat generation system increase the security of supply and reduce greenhouse gases. This has been proved with LCA techniques in micro (appliances) and macro (total energy system) level.

9.3. Future work

This study cannot be ended with a clear cut as the question of the environmental impact for different energy providing scenarios for zero carbon villages/cities as larger integrated system is still open. One of the main targets of constructing the prototype system in Böheimkirchen is assessing the actual thermal and electrical demand, and monitoring the new innovative strategy to provide energy for the households. This will help to design, and plan the policies, providing the energy for the autonomy districts.

The ultimate goal of zero carbon villages is to make carbon-neutral and life-cycle-oriented residential buildings and energy-efficient settlements in line with the EU 2020 objectives.

Extending the result of this dissertation can determine that technical improvement related to appliances and other system components, better building construction, and combining

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[26] Considering that Austria has a population of 8,443,016 (Statistik Austria in 2012). And each family has 2.26 persons based on the same reference, then there are nearly 3,735,849 households in Austria.

centralized electricity supply system like PV or CHP can be realized to lower environmental impact compared to conventional way of providing energy for the households. As an example in Appendix A , the practical contribution of the results of this research has been demonstrated by designing a zero carbon cottage in Puerto Princesa, Philippines.

Bibliography

Chwieduk, D. (2002). Towards sustainable-energy buildings. *Jurnal of applied energy*.

Dodoo, A., Gustavsson, L., & Sathre, R. (2011). Building energy-efficiency standards in a life cycle primary energy perspective. *Energy and Buildings*, pp. 1589-1597.

A.F.Ferreira, J. C. (2011). Energy consumption and CO2 emissions of potato peel and sugarcane biohydrogen production pathways, applied to Portuguese road transportation. *International Jurnal of Hydrogen Energy*, 13547–13558.

A.K.Weber, A. (2009). *Ökologische und ökonomische Einsparpotenzialenutzung beim Geschirrspülen am Beispiel der Spülmaschine 'Miele G1022 Sci.* Öko-Institut.

Alfredsson, E. (2004). Green" consumption—no solution for climate change. *Energy*.

B. J. HUANG†, T. H. (2001). PERFORMANCE EVALUATION OF SOLAR PHOTOVOLTAIC/THERMAL. *Solar Energy*.

B.J., H. (n.d.). PERFORMANCE RATING METHOD OF THERMOSYPHON .

Berkholz P., B. A. (2007). *Verbraucherverhalten und verhaltensabhängige Einsparpotentiale beim Betrieb von Waschmachinen.* Shaker- Verlag.

Bin, S., & Dowlatabadi, H. (2005). Consumer lifestyle approach to US energy use and the related CO2 emissions. *Energy policy*, 197-208.

Braun, J., P.K Bansal, P., & Groll, E. (2002). Energy efficiency analysis of air cycle heat pump dryers. *international Jurnal of refrigration*, 954-965.

Bukowski M., S. H. (2012). Environmenta Impact Of Using Different Energy Sources For Family House Heating . *Journal of Energy and Power Engineering*, 1408-1415 .

Cole, R. (1998). Energy and greenhouse gas emissions associated with the Energy and greenhouse gas emissions associated with the. *Building and Eenvironment*, 335-348.

Coventry J.S., L. K. (2003). Development of an approach to compare the 'value' of electrical and thermal output from a domestic PV/thermal system. *Solar Energy*, 63-72.

defra. (2008). *Measurement of Domestic Hot Water consumption in Dwellings .* Crown Copyright.

Dodoo, A., Gustavsson, L., & Sathre, R. (2011). Building energy-efficiency standards in a life cycle primary energy perspective. *Energ and building*.

Essaoui. (2001). *Présentation du sèche-linge, Fagor-Brandt internal documentation.*

Feist, W. (1997). *Comparision of low energy house, passive house and self sufficient house*. Retrieved from http://www.passivhaustagung.de/Passivhaus_D/Primary_Energy_Input_comm2007.pdf.

Fulvio Ardente, G. B. (2005). Life cycle assessment of a solar thermal collector. *renewable energy*.

Gensch c. (n.d.).

Gensch C., R. I. (2008). *Ökologische und ökonomische Einsparpotenziale durch Warmwassernutzung beim Wäschewaschen Miele W 3841 Allwater* . Studie im Auftrag der Miele & Cie. KG, Öko-Institut e.V.

Ghaemi S. (2011). *Efficiency potential in private sector in ADRES.*

Gustavsson, L., & Joelsson, A. (2010). Life cycle primary energy analysis of residential buildings . *Energy and Buildings*, pp. 210-220.

http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE99_ENV_D_000452_LAYMAN.pdf. (n.d.). *Layman Report, Mini CHP with longlife Stirling engine .*

Huang , B. (1993). PERFORMANCE RATING METHOD OF THERMOSYPHON SOLAR WATER HEATERS. *Solar energy*, 435-440.

I.Stadler, & S.Tapanlis. (2008). Power grid balancing of energy system with high renewable nergy penetration by demand response . *Utilities policy*, 90-98.

ISIS Faberi S., p. M. (2007). *Preparatory Studies for Eco-design Requirements of EuPs , Lot 14 task 3-5:Domestic Washing Machines & Dishwashers.*

ISIS Faberi S., p. M. (Dec. 2007). *Domestic washing machines and dishwashers, task 1-2-Lot14:Domestic washing machines and dishwashers.*

J. Byrne, L. V. (2010). *World solar energy review : Technology, Markets and Policies .*

J.E. Braun, P. B. (2002). Energy efficiency analysis of air cycle heat pump dryers. *Internal Journal of Refrigeration*, 954-965.

Jellinek, R. (2012). *Energy efficiency policies and measures in Austria.* Austrian Energy Agency .

Kemna R., K. V. (n.d.). *Energy consumption of domestic appliances in European Households.*

Kok, R., Benders, R., & Moll, H. (2006). Measuring the environmental load of household consumption using somemethods based on Input-output nergy analysis : A comparision of methods and a discussion of results. *Energy policy*, 2744-2761.

Layman Report, M. &. (n.d.). *Micro CHP holds the future.*

Lefèvre, C. (2009). *Ecodesign of Laundry Dryers Preparatory studies for Ecodesign requirements of energy using products (EuP)- Lot 16.* Price waterhouse coopers Advisory.

Lenzen, M. (1998). Energy and greenhouse gases embodied in Australian final consumption: an input-output analysis. *Energy policy*.

Lenzen, M. (1998). Primary energy and greenhouse gases embodied in Australian final consumption: an input–output analysis. *Energy Policy*, 495-506.

Lenzen, M. (2001). Errors in Conventional and Input-Output—based Life—Cycle Inventories. *Industrial ecology*.

Lior, N. (2007). Energy resources and use: The present situation and possible paths for the future. *Energy*.

Loga T., I.-B. U. (1997). *Energiepaß Heizung/Warmwasser .* Darmstadt: Institut Wohnen und Umwelt GmbH.

R. Satmminger, A. S. (2007). *Preparatory studies for Eco-design requirements of EuPs;Lot 14:Domestic Washing machines and dishwashers;Task 3.* Bonn.

R. Wimmer, H. H. (2008). Wireless house, self sufficient and sustainable building solutions. Wien.

Siepmann (Miele), S.; Schimke(Miele), P.; Jäger(Solvis), H.; Herde (Solvis), G.;. (kein Datum). *Solartrockner reduziert durch direkte Nutzung der Sonnenenergie Energiekosten und Primärenergieverbrauch.*

Sörensen, B. (2011). *Life cycle Analysis of Energy System , From methodoly to applications.* RSCPublishing.

Technische ALternative. (n.d.). UVR 1611 Freely programmable universal controller ,www.ta.co.at.

Thiers, S., & Peuportier, P. (2012). Energy and environmental assessment of two high energy performance residential buildings. *Jurnal of building and environment*.

Tsilingiridis, G., Martinopoulos, G., & Kyriakis, N. (2004). Life cycle environmental impact of a thermosyphonic domestic solar hot water system in comparison with electrical and gas water heating. *renewable enrgy*.

Tukker, A., & Jansen, B. (2006). Environmental Impacts of Products: A Detailed Review of Studies. *Jurnal of Industrial ecology*.

UNEP, U. (2007). *Building and climate change status, challenges and oppotunities.*

Vela Solaris, w. (2011). *Polysun simulation Software user manual .*

Verbeeck, G., & Hens, H. (2007). Life cycle optimization of extremely low energy dwellings. *Journal of building phyics*, pp. 143-177.

Weiss, W., & Biermayr, P. (n.d.). *The solar thermal potential in Europe, Studie zum Potenzial der Solarthermie in Europa,http://www.aee-intec.at/0uploads/dateien709.pdf.* AEE-Institut für Nachhaltige Technologien,Technische Universität Wien(Energy Economics Group).

Wiedmann, T., & Minx, J. (2008). *Pertsova, Ecological Economics Research Trends: Chapter1.* Hauppauge NY, USA.: Nova Sceience Publishers, .

Wilting, H., Biesiot, W., & Moll, H. (1999). Analyzing potentials for reducing the energy requirement of households in the Netherlands. *Economic systems research*, 233-243.

Appendix A